ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

INVESTIGATION OF STORMWATER COLLECTION SYSTEM PROBLEMS IN ISTANBUL

M.Sc. THESIS

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Department of Civil Engineering

Hydraulics and Water Resources Engineering Program

NOVEMBER 2019

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ISTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

İSTANBUL'DA YAĞMUR SUYU TOPLAMA SİSTEMLERİNDEKİ SORUNLARIN İNCELENMESİ

YÜKSEK LİSANS TEZİ

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Zeynep Beril UYGUN, a M.Sc. student of ITU Graduate School of Science Engineering and Technology student ID 501161525, successfully defended the thesis/dissertation entitled “INVESTIGATION OF STORMWATER COLLECTION SYSTEM PROBLEMS IN ISTANBUL”, which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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FOREWORD

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November 2019 | Zeynep Beril UYGUN
(Environmental Engineer)

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ABBREVIATIONS

EPA **:** Environmental Protection Agency
SWMM **:** Stormwater Management Model
ISKI **:** Istanbul Water and Sewerage Administration
BC **:** Before Christ
mm **:** milimeter
LPS **:** Liter Per Second
DMI **:** State Meteorological Works

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INVESTIGATION OF STORMWATER COLLECTION SYSTEM PROBLEMS IN ISTANBUL

SUMMARY

Recently, the rapid rise of the human population, the increase in construction and industrialization put pressure on the environment. Unplanned and unsustainable settlements, improper land use disrupt the natural flow of the environment and create increasingly difficult problems. This deterioration in the environment causes global warming and also flood disasters. This has a negative impact on people's standard of living and may even lead to casualties.

With this approach, three regions (Uskudar, Kadikoy and Umraniye) where frequent floodings occur in Istanbul and a region in Dresden (Lockwitz) where big flooding disasters occurred in the past were identified and the existing rainwater collection systems of these regions were modeled on SWMM. In order to make modeling on SWMM, the data obtained in Microstation format were converted to SWMM format by using Civil 3D and Urbano programs. Because it was not possible to convert the data in .dgn format to .inp format. The corruption in the data during these transformations as well as the deficiencies and inaccuracies in the raw data were corrected manually. As a result of simulating the models, it was aimed to investigate at which points especially the overflows occurred in these systems and what the reasons are. In the simulations, besides the infrastructural data, the rainfall data in 1-Hour, 10-Minutes and 1-Minute resolutions has been used and it was observed how the models react to different resolutions of rainfall data and also the responses of the models in the regions of Istanbul and Germany were compared. 1-Hour resolution data covers 4 years period between 01.01.2014 and 31.12.2017, 10-Minutes resolution data covers 9 months period between 01.01.2018 and 20.09.2018 and 1-Minute resolution data covers 1 month period between 01.12.2018 and 31.12.2018. After seeing the present situation, some rainfall scenarios have been applied to the models. The first scenario was applying the rainfall data of Germany to the regions in Turkey and applying the rainfall data of Turkey to the region in Germany. In Turkey, the rainfall amount is higher than in Germany, however, the number of rainy days is higher in Germany than in Turkey. In this wise, it was aimed to see how to react the regions to the peak amount of rainfalls and cumulative rainfalls. On the next step, numbers in each minute in 1-Minute resolution data were summed up in tens and sixties, thus it was obtained 10-Minutes and 1-Hour resolution data in the same time period. In this wise, it was aimed to see how the models react at the same time range. Finally, after all the meteorological scenarios, some physical modifications were made on the networks. With Urbano software, some of the pipes' diameters, elevations or slopes have been changed and some optimizations could be possible.

As a result of the study, it was observed that 1-Hour resolution rainfall data was insufficient for flooding modeling, and 1-Minute resolution is a very small resolution to investigate the results clearly. The most optimistic results could be obtained by 10-

Minutes resolution data and it was determined that this resolution type is the most proper one for the regions that have these sizes.

On the other hand, when the rainfall data of Dresden was applied in the regions in Istanbul, it was seen that the networks in these regions could respond better to cumulative rainfall. Between the simulation results in the original case and in scenario case, there was a big difference. Besides that, when the rainfall data of Istanbul was applied in the region in Dresden, there was not a that big difference between these cases. The region in Dresden could respond well to the peak rainfall amounts of Istanbul even though the network was planned for less amount of rainfall. After these results, it could be considered how important the green area is. With more permeable grounds, it is more possible to respond to more amount of rainfall.

When the 1-Minute resolution data was expanded as 10-Minutes and 1-Hour resolution data and applied to the models, it was seen that regardlessly of the time period, the most optimistic results can be obtained with 10-Minutes resolution data again. It is not important how the time range is or the dates.

At last, after the physical modifications by Urbano software, it was demonstrated that even in the current situation, it is possible to optimize the systems. To make life in the city more qualified and comfortable, municipalities can carry some works on the infrastructural systems.

The most important of these issues is the accuracy of the data used. Especially, inaccuracies and deficiencies in infrastructure data directly affect the reliability of the study, at the same time the results may be different from what supposed to be. Administrations should keep all the data accurate, consummate and also actual.

İSTANBUL'DA YAĞMUR SUYU TOPLAMA SİSTEMLERİNDEKİ SORUNLARIN İNCELENMESİ

ÖZET

İstanbul, yaklaşık 3 bin yıldır insanların yerleşimde bulunduğu bir şehirdir. İstanbul ilk olarak milattan önce 13. yüzyıl civarında Trakyalıların kurduğu, sonrasında Yunan kolonilerinin yerleştiği, sırasıyla Bizans, Roma ve Osmanlı İmparatorluklarının eline geçen ve sonuçta Türkiye Cumhuriyeti'nin bir parçası haline gelen bir şehirdir. O tarihlerden itibaren İstanbul, tarihte bir başkent ve şimdilerde de bir metropol olarak hep önemli bir yere sahip olmuştur. Bilinen en eski yerleşimlerden biri olan bu şehirde nüfus günden güne artmış ve yapılaşma da gittikçe hızlanmıştır.

İstanbul'da yerleşimle birlikte altyapı sistemleri de oldukça eskiye dayanmaktadır. Endüstri gelişene dek el yapımı toprak künklerle su iletimi sağlanırken, sanayileşmeyle birlikte beton borular ve sonrasında diğer boru tipleri gelişerek su iletimi gerçekleştirilmiştir.

Özellikle son zamanlarda insan nüfusunun hızla yükselmesi, yapılaşma ve sanayileşmedeki artış çevre üzerinde bir baskı oluşturmaktadır. Plansız ve sürdürülebilir olmayan yerleşimler, yanlış arazi kullanımı çevredeki doğal akışı bozmakta ve çözümü gittikçe zorlaşan sorunlar doğurmaktadır. Çevredeki bu bozulmalar, küresel ısınma ve beraberinde sel felaketlerinde de çoğalmaya sebep olmaktadır. Bu da insanların yaşam standardını olumsuz etkilemekte ve hatta can kayıplarına sebep olabilmektedir.

Bu yaklaşımla İstanbul'da sıklıkla sel olaylarının yaşandığı 3 farklı özelliklere sahip bölge (Üsküdar, Kadıköy ve Ümraniye) ve geçmişte büyük sel felaketlerinin yaşandığı Dresden'de bir bölge (Lockwitz) belirlenerek, bu bölgelerin mevcut yağmur suyu toplama sistemleri SWMM üzerinde modellenmiştir. Modeller için ihtiyaç duyulan meteorolojik veriler İstanbul için Meteoroloji 1. Bölge Müdürlüğü'nden ve Dresden için Alman Hava Servisi'nin resmi internet sitesinden; altyapı verileri İstanbul için İSKİ'den ve Almanya için de enstitüden elde edilmiştir. SWMM üzerinde modelleme yapılabilmesi için İSKİ'den Microstation formatında alınan veriler, Civil 3D ve Urbano programları kullanılarak SWMM formatına dönüştürülmüştür. Çünkü .dgn formatındaki bir verinin doğrudan .inp formatına dönüşümü mümkün değildir. Bu dönüşümler esnasında verilerde meydana gelen bozulmalar ve aynı şekilde ham veride yer alan eksiklik ve yanlışlıklar (bazı kotlar, eğimler ve çaplardaki belirsizlikler, herhangi bir hatta veya çıkış noktasına bağlantısı olmayan borular vb.) çevrimiçi haritalardan da yararlanılarak manuel olarak düzeltilmiştir. Modellerin simüle edilmesi sonucu bu sistemlerde hangi bacalarda taşma gerçekleştiği, taşan bacaların yüzdesi, taşma miktarları ve bunların sebepleri araştırılmıştır.

Simülasyonlarda, altyapı verilerinin yanı sıra, 1-Saat, 10-Dakika ve 1-Dakika çözünürlüklü yağış verisi kullanılarak modellerin farklı çözünürlüklere nasıl tepki verdiği gözlemlenmiş, ayrıca İstanbul ve Almanya'daki bölgelerin bu farklı çözünürlüklere nasıl yanıt verdiği karşılaştırılmıştır. 1-Saat çözünürlüklü veri 01.01.2014 ile 31.12.2017 tarih aralığındaki 4 yıllık zaman periyodunu, 10-Dakika

çözünürlüklü veri 01.01.2018 ile 20.09.2018 tarih aralığındaki 9 aylık zaman periyodunu ve 1-Dakika çözünürlüklü veri 01.12.2018 ile 31.12.2018 aralığındaki 1 aylık zaman periyodunu kapsamaktadır. Bu çalışma kapsamında meteorolojik veri olarak yalnızca direkt yüzeysel akışa geçen yağmur yağışı verileri kullanılmış olup kar erimesi, buharlaşma, yer altı suyu gibi parametreler göz ardı edilmiştir. Bölgelerin mevcut yağış verileri ile durumlarının gözlemlenmesinin ardından modellere bazı yağış senaryoları uygulanmıştır. İlk senaryoda, Türkiye'deki bölgelere Almanya'nın yağış verisi ve Almanya'daki bölgeye de Türkiye'nin yağış verisi uygulanmıştır. Türkiye'de yağış miktarı Almanya'dakinden daha fazladır ancak Almanya'da da yağışlı gün sayısı, yani yağış yoğunluğu Türkiye'dekinden daha fazladır. Bu yolla bölgelerin pik yağışlara ve kümülatif yağışlara nasıl tepki verdikleri incelenmiştir. Bir sonraki adımda, bölgelerin 1-Dakika çözünürlüklü verileri onar onar ve altmışar altmışar toplanarak aynı zaman aralığında 10-Dakika ve 1-Saat'lik yeni yağış verileri elde edilmiştir. Bu yolla da bölgelerin, yağış verilerine aynı zaman diliminde nasıl yanıt verdiği gözlemlenmiştir. Son olarak, tüm meteorolojik senaryoların ardından, bölgelerin altyapı ağlarında bazı fiziksel modifikasyonlar uygulanmıştır. Urbano programının yardımıyla bazı boruların çaplarında, kotlarında veya eğimlerinde bazı değişiklikler yapılarak sistemlerde iyileştirmenin mümkün olduğu gözlemlenmiştir.
Çalışmanın sonucunda, 1-Saat çözünürlüklü verinin taşma modellemesinde yetersiz kaldığı ve 1-Dakika çözünürlüklü verinin de sonuçları net bir şekilde inceleyebilmek için çok küçük bir çözünürlük olduğu gözlemlenmiştir. Söz konusu boyutlardaki bölgeler için en doğru sonuçların 10-Dakika çözünürlüklü veriyle elde edilebileceğine karar verilmiştir. Simülasyonlar sonucu elde edilen grafiklerle reelde gerçekleşen taşma olaylarının uyumlu bir tutum sergilediği görülmüş ve böylelikle bu karar doğrulanmıştır. Böylelikle projelendirme esnasında seçilen meteorolojik verinin çözünürlüğünün bu hususta oldukça önemli bir yeri olduğu, kullanılacak verinin seçiminde çok dikkatli olunması gerektiği görülmüştür.
Diğer taraftan, İstanbul'daki bölgelere Dresden'in yağış verisi uygulandığında, bu bölgelerin kümülatif yağışları daha iyi karşılayabildiği görülmüştür. Orijinal durum ve senaryo verisi ile yapılan simülasyonların sonuçları arasındaki fark oldukça büyüktür. Bununla birlikte, Dresden'deki bölgeye İstanbul'un yağış verisi uygulandığında, orijinal durum ve senaryo verisi ile yapılan simülasyon sonuçları arasındaki fark, o kadar da büyük olmamıştır. Daha az yağış miktarına göre projelendirilmesine rağmen Dresden'deki bölge, İstanbul'un pik yağışlarını da iyi bir şekilde karşılayabilmiştir. Bu sonuçlara bakılarak yeşil alanın sebep olduğu geçirimlilik düzeyinin ne kadar önemli olduğu anlaşılabilmektedir. Şehirleşmede akış katsayısı dikkate alınarak projelendirme yapılması gerekmektedir. Yerleşim kapasitesi, çevresel etki, yeşil alan vb. dikkate alınarak bir katsayı limiti belirlenip, bu limitin aşılmaması sağlanmalıdır, zira zemin geçirgenliğinin yüksek olması, havzanın daha yüksek miktardaki yağışlara bile karşılık verebilmesini sağlamaktadır. Diğer taraftan, projelendirmede debi hesabı yapılırken yalnızca kümülatif yağışlar değil, pik yağışlar da dikkate alınarak daha dayanıklı bir yağmur suyu toplamı sisteminin oluşturulabileceği sonucuna varılabilir.
1-Dakika çözünürlüklü verilerin 10-Dakika ve 1-Saat çözünürlüğe genişletilmesi ile elde edilen yeni yağış verilerinin modellere uygulanmasıyla, zaman periyodundan bağımsız olarak, en iyi sonuçların yine 10-Dakika çözünürlüklü veri ile elde edilebileceği görülmüştür. Bu durumda, zaman aralığının veya simülasyon yapılan tarihin bu kapsamda bir etkisinin olmadığı sonucuna varılmıştır.
Son olarak, Urbano programı ile yapılan modifikasyonlar sonucunda, mevcut durumda bile sistemlerin iyileştirilmesinin mümkün olduğu gösterilmiştir. Sistemdeki zayıf kısımlar, örneğin ağırlıklı olarak hangi bacalarda taşma oluştuğu, taşmaların

miktarları, hangi şiddette yağışlarda meydana geldikleri, hangi boruların iletimde yetersiz kaldığı gibi bilgiler bu tür programlarla tespit edilerek gerekli düzeltmeler sağlanabilmektedir. Belediyeler, bu programlar yardımıyla altyapı sistemlerinde iyileştirici bazı çalışmalar yürüterek şehirdeki hayatı daha kaliteli ve konforlu hale getirmelidir.

Bunların dışında, kullanılan verilerin doğruluğu, en önemli husus olarak belirtilebilir. Özellikle altyapı verilerindeki yanlışlıklar ve eksiklikler çalışmanın güvenilirliğini doğrudan etkilemekle birlikte, sonuçların olması gerekenden farklı çıkmasına yol açabilir. İlgili birimler tüm verileri doğru, eksiksiz ve de güncel olarak bulundurmak zorundadır.

Yapılan çalışma sonucunda, şehirde artan nüfus ve yapılaşmayla birlikte altyapı sistemlerine yapılan eklemelerin, geçici olarak bir çözüm sağlamış olsalar da, daha geniş bir perspektiften bakıldığında sistemleri daha da karmaşıklaştırarak kalıcı sorunlara yol açtıkları görülmüştür. Karmaşıklaşan sistemler, gün geçtikçe düzeltilemeyecek boyutlara ulaşmakta ve daha büyük problemlerin oluşmasına sebep olmaktadır. Bunun yanı sıra yeşil alanların tahrip edilerek geçirimli yüzeylerin yok edilmesi, bu sistemlere binen yükü arttırmakta ve yağış rejiminde oluşabilecek herhangi bir değişikliğe karşı toleransı azaltmaktadır. Şehrin geleceği için planlamaların daha ileri görüşlü, çevre korumacı ve sürdürülebilir bir yaklaşımla ele alınması gerekmektedir.

1. INTRODUCTION

1.1 Motivation

Flooding can occur almost everywhere in the world, including the driest (desert) and most humid (tropical) areas. Although defined in many different ways, the flood is the uncontrolled flow and spread of large bodies of water caused by various reasons on river beds, valley slopes and bottoms, hollow areas and coasts. The vast majority of floods are actually the result of events that develop within the self-preservation mechanism of nature (Özcan, 2006).

In Turkey, we face with flooding events frequently. As seen in Figure 1.1, even at the ordinary rainy weather, flooding events can happen. Therefore, too much traffic occurs, daily life is getting harder, even there can be loss of life. Besides that, when compared to European countries, we don’t see flooding events that much frequent.

Figure 1.1 : Flooding event in Istanbul (http://www.ulasimonline.com/cevre/63271/son-dakika-istanbulda-yogun-sis-ve-yagmur-felaketi.html)

In addition to the impact of nature, the technological, socio-economic and cultural activities of human beings play a crucial role in transforming floods into disasters and making them vulnerable (Özcan, 2006).

In today's world where population, industrialization and construction are rapidly increasing, the destruction of green areas and then decrease in permeable surfaces have increased the importance of infrastructure planning. Nevertheless, the truth is, infrastructure systems are bad engineering products in Turkey. Unpredictable population growth, wrong calculations or unsuitable projects due to politics are some of the causes of that situation.

1.2 Aim of this Study

It was aimed in this study to understand better what can be the causes of that much flooding events and how this situation can be fixed.

1.3 Limitations

In this study, the aim is to reveal the causes of flood events by simulating on SWMM. The primary requirements for simulation in SWMM are infrastructure and meteorological information. The data is received from the Istanbul Water and Sewerage Administration (ISKI).

However, the data obtained from the Istanbul Water and Sewerage Administration (ISKI) contain some wrong and missing parts since the data is transferred to the administration from the metropolitan municipality some time ago. Some pipes and junctions were missing on the network, some slopes and elevations were wrong, and outlets were not certain on data. Elevations and location of missing junctions were determined and missing parts were completed with the help of online maps, discharge points were determined by following slopes, and all other problems were fixed manually.

Another issue was the data was kept in a licensed program and also the other programs which used for making the data available for SWMM were licensed. Some of those programs were downloaded with edu-released and for the others, temporary licenses were used because they are very expensive programs.

Also while obtaining meteorological data from Turkey, the directorate of State Meteorological Works (DMI) does not share the data easily. Each time for each data, it is necessary to give an official letter from a university, institute or company and there should be a valid reason to take the data. However, the meteorological data in Germany can be easily obtained from web site of German Weather Service.

2. STATE OF ART

Human beings have been threatened with floods since their existence. But in order to control this disaster, they have continued their research and struggle. Floods, including our country, are effective all over the world and can cause serious loss of life and property. Besides that, it is not possible to express flood disasters due to only meteorological occurrences (Burgan, 2013).

In particular, in the countries which economic development activities continued intensively, such as Turkey, urbanization activity brought by industrialization and industrial diversity, increase diversity and intensity of human activities in various parts of the river basin dramatically. This situation disrupts the hydrological balance in the basin as a whole, resulting in flood disasters that result in the loss of life and property. With the settlements growing in the river basins, new roads opened and new facilities established; the land structure is changing, unfavorable agricultural methods are being used more extensively, the forests and pastures are being destroyed, and in all these conditions, flood disasters are seen more and more frequently (Burgan, 2013).

Besides that, as a result of the excessive increase of impermeable hard surfaces in urban areas and the decrease of light-green areas in proportion to this increase, stormwater after rainfall does not penetrate the soil sufficiently. On the other hand, the amount of evapotranspiration (sweating + evaporation) decreases and the amount of stormwater flowing to the surface flow increases significantly. The excess stormwater that is generated passes to the surface flow along hard surfaces and is collected in low elevated areas. Over-collected stormwater in low-altitude areas causes serious problems (flooding, overflow, etc.) caused by stormwater (Müftüoğlu and Perçin, 2015). Flood risks can not be entirely avoided, thus they have to be managed (Tingsanchali, 2012). In this manner, with the prediction of possible floods, it is possible to take precautions against possible damages (Burgan,2013).

In the natural cycle, the systematic use of water by people in the most economic, social and environmental terms is defined as water resource management. The problems arising from the insufficient quantity and quality of water resources and the excessive use of water resources as a result of the population increasing, industrial developing and agricultural activities reveal that water resources should be managed in the best way. In this context, the protection and development of water resources, the sustainability of the system should be done in the best way to manage the watershed and watershed efficiency should be evaluated (Gülbaz and Kazezyılmaz-Alhan, 2011). The traditional engineering approach to manage urban drainage is by combined (sewage water and stormwater in the same pipe) or separate pipe systems. In semi-urban catchments, urban drainage systems may be combined with dams, levees, and other types of storage and detention facilities to cope with floods. However, during recent decades alternative ways to manage floods have evolved since traditional methods often harm the riverine ecosystems in urban as well as rural areas and increase the long-term flood risk. Alternative methods relate to resilience theory and address the city’s capacity to mitigate flooding in particularly sensitive urban areas, tolerate controlled flooding on assigned areas, and to re-organize in case of damage. This means that adaptive, multifunctional infrastructure in combination with water sensitive urban design is seen as a means to reinforce resilience against climate change (Sörensen et al., 2016).

Together with watershed management, it is necessary to prevent erosion, floods and overflows, to produce water of sufficient quantity and quality to meet the needs of the society and to carry out various studies to plan natural resources in the watershed. These studies include observing the events affecting the hydrological system, performing the necessary hydrological measurements systematically and creating a simulation model using the appropriate computer software. Especially with the rapidly developing information technology, the use of mathematical models has become widespread in water resources and watershed management (Gülbaz and Kazezyılmaz-Alhan, 2011).

Overland flow is highly affected by increasing urbanization variations in land use and climatic variables, especially in the last few decades (Akdoğan and Güven, 2016). Therefore, modeling flood inundation has become increasingly significant, especially for the urban setting. Information on flood characteristics and accurate flow paths are significant for stormwater management, hydrological modeling, hydrological data analysis, and vulnerability assessment (Liwanag et al., 2018).

In the literature, hydrodynamic and water quality model samples can be found using the Storm Water Management Model (EPA SWMM). The models created in the studies are calibrated by using various methods or trial and error method and then the models are verified using observed data. In this context, EPA SWMM is a widely accepted program used in water quantity and water quality modeling given in the literature (Gülbaz and Kazezyılmaz-Alhan, 2011).

The SWMM requires first to establish the schematic plan of the drainage area. The major parameters required by the model are the subcatchments, canal network, the junction details, channel and conduit details, the rain gauge and outfall locations (Wanniarachchi and Wijesekera, 2012).

The EPA SWMM computer software calculates the quantity, quality of surface flow coming from subcatchments or velocity and depth of flow through the pipe or channel. The EPA SWMM software takes account of system elements such as subcatchments, open channels or pipes, junctions, outlet points, precipitation meters, pumps, regulators, storage tanks. Area, slope, width of the subcatchments; lengths and cross-sectional areas of the channels; elevations of entry and exit points; long or short-term precipitation values are entered as input on EPA SWMM computer software and the hydrodynamic variables of the catchments such as flow rate, velocity, water height in channels are obtained as output. Surface flow and flow calculations in EPA SWMM are based on the principles of mass, momentum and energy conservation, which are the basic principles of fluid dynamics. On the calculations the surface runoff, precipitation and water resources of the catchment are considered inputs to the system; seepage, evaporation and surface runoff are the outputs from the system. Kinematic, diffusion and dynamic wave shifting options are available in order to shift the current occurring in pipes or open channels (Gülbaz and Alhan, 2011).

Rainfall data drive the model and produce runoff, which means that an accurate estimation of rainfall data determines the success of the modeling effort (Liwanag et al., 2018).

Besides modeling, measures of urban planning are increasingly recognized as the central means to prevent urban flood disasters because it can lead in the long run to more effective and economically more efficient solutions than the traditional means of developing exposed areas. By combining flood models with scenario modeling, it is possible to delineate the zones which have the probability of flooding and minimize flood damages (Tingsanchali, 2012).

Urban resilience should be viewed as an adaptive process where society continuously learns how to cope with changing socioeconomic conditions and urban land use as well as a changing climate. Besides that, sustainable and resilient water management needs to involve water supply access and security, public health protection, as well as flood protection in densely built urban areas with many types of important urban infrastructure. In view of these, it is clear that urban water management systems need to become integrated elements in a multifunctional urban environment. Increasingly urgent and complex problems have to be solved by the city, where the water sector management systems should be developed in close collaboration with regional and municipal planning authorities (Sörensen et al., 2016).

3. DATA AND METHOD

3.1 Data

3.1.1. Infrastructure data

Stormwater infrastructure network data of Uskudar, Kadikoy and Umraniye were obtained from ISKI. In Istanbul, 95 percent of wastewater and stormwater infrastructures are separated systems. So, we can say that all stormwater data of these regions are separated from the wastewater network. Most of the pipes are Bellmouth Concrete and also seen that Reinforced Concrete and High-Density Polyethylene pipes are used. Stormwater reaches to discharge points moving by gravity from high to low levels. The length of pipes are approximately between 30 meters and 70 meters in most part of the areas.

However, when the data was obtained from the administration, there were some missing and wrong parts on the data. There was some missing information about diameters, ground levels, slopes and also some of them were wrong. Besides that, there were some missing parts on the network. Missing parts on the network were completed using online maps so that they can reach the outlets logically and according to beginning and endpoints, slopes, ground levels and diameters were decided.

3.1.2. Meteorological data

Meteorological data of the regions in Istanbul were obtained from First Regional Directorate of DMI. The data measured at Kadikoy Rihtim, Uskudar and Umraniye raingage stations were used for those regions.

Meteorological data of the region in Dresden was obtained from German Weather Service web site. The data received from Dresden-Hosterwitz raingage station was used for that region.

Three types of precipitation data were used in this study; one-minute, ten-minutes and one-hour resolution data from the stations mentioned above. One-minute data covers one month (01.12.2018-31.12.2018), ten-minute data covers nine months (01.01.2018-20.09.2018) and one-hour data covers 4 years (01.01.2014-31.12.2017) period.

Meteorological data were arranged on Microsoft Excel. They were converted to text files and directly put on SWMM as the rain gage data file.

3.2. Method

In this study, models and simulations were run on SWMM (Storm Water Management Model). However, stormwater infrastructure network data of Uskudar, Kadikoy and Umraniye were obtained from ISKI and these infrastructure networks data are kept on Microstation format at the administration. That’s why all network data should have been converted from .dgn format to .inp format required as the input format to the software.

The conversion of data format has ben carried out in two steps. The first step was the conversion of .dgn to .dwg. Because direct conversion from .dgn to .inp was not possible. Therefore, stormwater data were exported from Microstation to Civil 3D and data were obtained with .dwg format. After that, .dwg format was exported to SWMM with Canalis option of Urbano software.

3.2.1. Microstation

MicroStation is a CAD software platform used in the engineering and architectural industries. It has ability for two and three-dimensional design and drafting. First Microstation version was 1.0 and it was .dgn format read-only and plot program developed in 1985. The first Microstation version which can create dgn files was 2.0 developed in February 1987 by Bentley Systems. By the time, other versions and their under versions were developed and more properties were added on the program. The version of Microstation which used in this study is version 8.11 (V8.1i) developed in November 2008. The last version of Microstation is v10.0 developed in September 2015. An interface example screen of Microstation can be seen in Figure 3.1.

Microstation was used in this study only to open and view the data. Data were converted to .dwg format with the export option on Microstation.

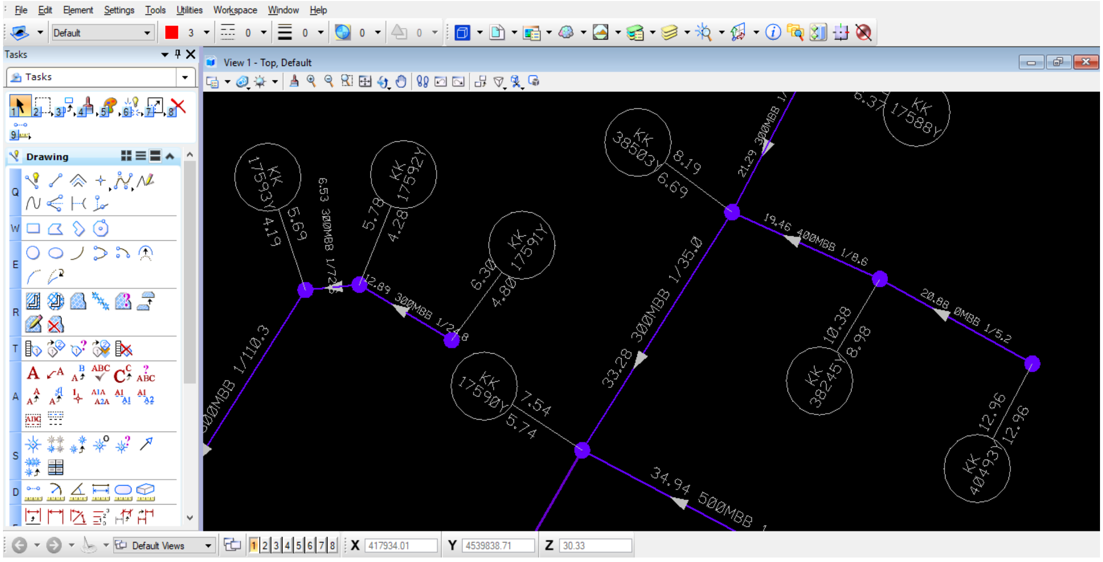


Figure 3.1 : Interface of Microstation

3.2.2. Civil 3D

Civil 3D is Autodesk's based CAD software for 3D terrain and civil engineering design software. This program was developed in 2004 to use for planning, designing and managing infrastructure, development and civil engineering projects. It helps to complete projects faster and more precisely with a dynamic design model. In addition to road, rail and canal plans and designs, it offers powerful and efficient tools for leveling, excavation and parceling. The biggest difference from Civil 3D software from others is, it creates intelligent relationships between objects. Objects are dynamically updated as soon as there is a change in design. In this study, the 2018 version of Civil 3D was used. An interface of example screen Civil 3D can be seen in Figure 3.2.

Civil 3D was used in this study only to open the data as .dwg format. Also, Urbano software is working based on Civil 3D formatting and it was the use of Urbano.

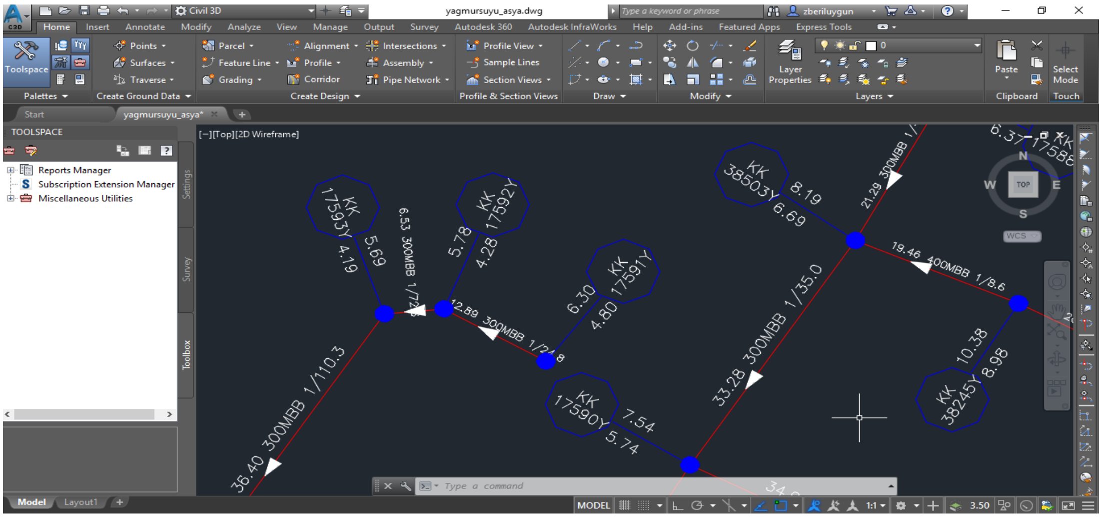


Figure 3.2 : Interface of Civil 3D

3.2.3. Urbano

Urbano is a modern and flexible software developed by Studio Ars and used for more than 15 years by European engineers. It was prepared according to European design methods and it offers several tools for pipe design and analysis. Urbano is based on Autocad and Civil 3D is one of the most commonly used programs in connection with Urbano. Version 9.2 of Urbano developed in 2018 has been used in this study. The interface of Urbano can be seen in Figure 3.3.

In this study, Urbano was used for converting the data format from .dwg to .inp. Data was opened as .dwg format with Civil 3D and all CAD drawings were converted to Urbano system format. Therefore, Urbano could export the system to .inp format with Canalis tool. Also, Urbano could create a table to include properties of the pipes and junctions. Thus, all information of network could be copied from that table and pasted to models' text files.

Also, after modeling, to see the problems on the network, Urbano software has been used. The program makes the hydraulic calculations and within the framework of regulations, suggests some optimizations like enlargement/reduction of the diameters or lifting/lowering the slopes, etc. to make the system better. In this study, after some modifications of this software, flooding problems could be prevented highly.

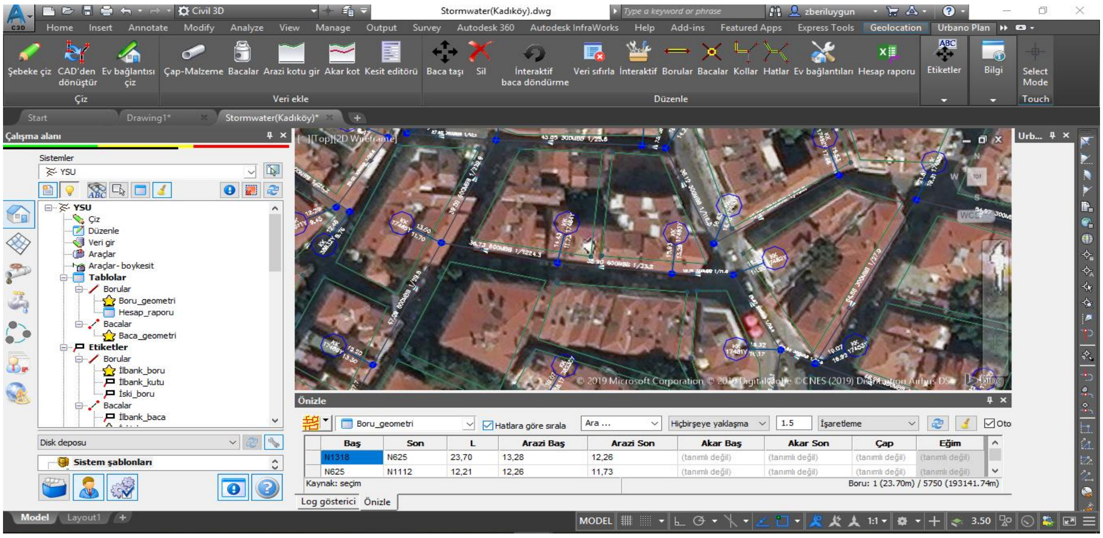


Figure 3.3 : Interface of Urbano

3.2.4. Storm Water Management Model (SWMM)

SWMM is, the EPA Storm Water Management Model and primarily used for urban rainfall runoff modeling. This comprehensive hydrological model is able to make both single or long-term dynamic simulation of rainfall-runoff event in urban areas. On the basis, study area must be divided into subcatchments on SWMM and average precipitation data on these subcatchments must be determined. Each subcatchment must be connected with a junction for the transport of the surface runoff. At the end, runoff reaches to an outlet (urban drainage system) by following the pipeline system. SWMM was first developed in 1971 and version 5.1 of SWMM was used in this study. An interface example screen of SWMM can be seen in Figure 3.4.

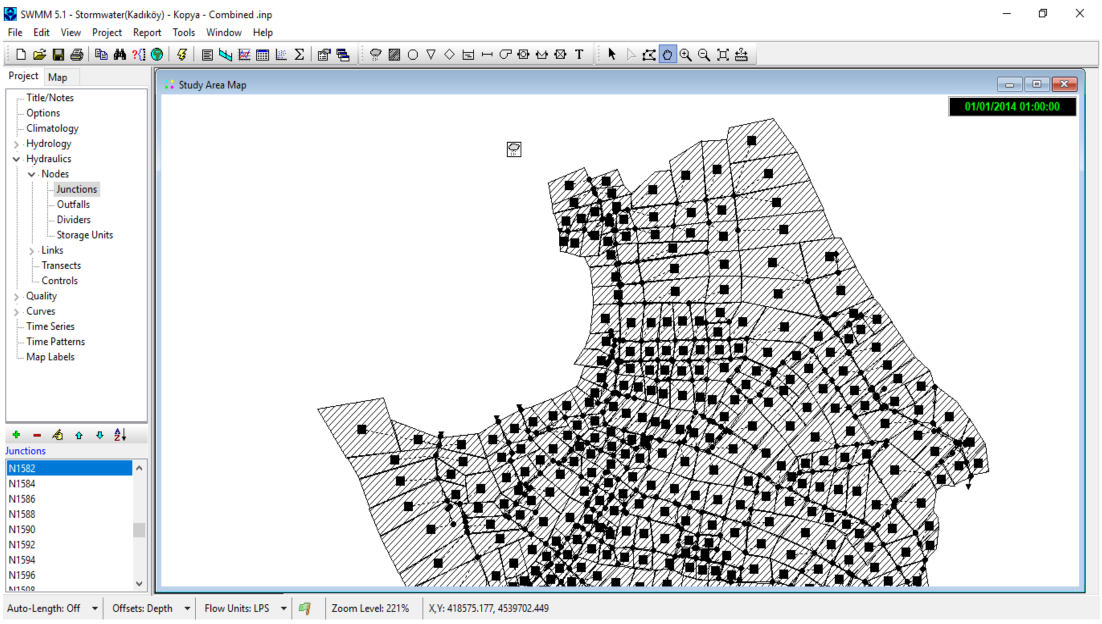


Figure 3.4 : Interface of SWMM

3.2.4.1.Reasons of working on SWMM

- ✓ SWMM is a user-friendly, free downloadable and easily understandable software program.
- ✓ It can be used for both pre- and post-development conditions to overcome the shortcomings.
- ✓ This is an open sourcesoftware thus the user is able to read the code and see exactly how the software simulates a certain process.
- ✓ Models' sensitivity on SWMM can be improved with various parameters like conduit roughness, percent imperviousness, etc.
- ✓ It is suitable for hydrological modeling procedure in urban areas and convenient to operate with a spatial interface.
- ✓ It is a powerful tool which can create a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality.
- ✓ It produces runoff coefficients and applies the well-known Rational Method (Q=CiA) for each subcatchment to establish a relationship between time-series precipitation and surface runoff.
- ✓ After the model's running, SWMM produces the system precipitation and runoff graphs to see whether the model captures the relationship between rainfall and runoff in a reasonable attitude.
- ✓ SWMM also shows the capability to model several outfalls simultaneously, leads to a significant advantage of modeling a land extent of any shape.

3.2.4.2.Simulation options

Routing Model

In SWMM, there are three options that can be used for determining the flowing route through the system. These options are Steady Flow, Kinematic Wave and Dynamic Wave.

Steady Flow routing is the simplest choice for routing possible (actually no routing). It assumes that flow is uniform and steady within each computational time step. In this option, inflow hydrographs at the upstream end of the conduit is simply translated to the downstream end with no delay or change in the shape. The normal flow equation is used for associating the flow rate to the flow area (or depth). At this option, channel storage, backwater effects, entrance/exit losses, reversal flow or pressurized flow can not been taken account. It can only be used with dendritic conveyance networks, where each node has only a single outflow link (unless the node is a divider in which case two outflow links are required). This routing option is not sensitive to the time step and is only suitable for preliminary analysis using long-term continuous simulations.

Kinematic Wave routing solves the continuity equation with a simplified form of the momentum equation in all conduits. The assumption of this option is that the slope of the water surface is equal to the slope of the conduit. The maximum flow that can be carried through a conduit is the full normal flow value. The excess flow of the entrance of the inlet node is either lost from the system or can make pond atop the inlet node and enter into the conduit as capacity becomes available. This routing allows flow and area to change both spatially and temporally in a conduit. This can result in attenuated and delayed outflow hydrographs as inflow is routed through the channel. Nevertheless, this routing form cannot take account entrance/exit losses, backwater effects, reversal flow, or pressurized flow, and is also restricted to dendritic network layouts. Numerical stability can usually be sustained with moderately large time steps between 1 and 5 minutes. This option can be an accurate and efficient routing method, especially for long-term simulations unless these effects are very significant.

Dynamic Wave routing produces theoretically the most accurate results due to solving the complete one-dimensional Saint Venant flow equations. Those equations contain continuity and momentum equations for conduits and volume continuity equation at nodes. With this routing form, it is possible to demonstrate pressurized flow when a closed conduit becomes full, thus flows can exceed the value of full normal flow. When the water depth at a node exceeds the maximum available depth, flooding occurs and the excess flow is either lost from the system or can make pond atop the node and re-introduced in the drainage system. This method can take into account the backwater, entrance/exit losses, channel storage, reversal flow and pressurized flow. Because of its gathering the solution for both flows in conduits and water levels at nodes, it is applicable in any general network layout, even for those contain multiple downstream diversions and loops. For systems which subjected to remarkable backwater effects because of downstream flow restrictions and with flow regulation via weirs and orifices, this method can be chosen. This is because of having to use much smaller time steps like thirty seconds or less (the user-defined maximum time step can automatically be reduced by SWMM to sustain the numerical stability).

With such backwater accounting, can increase storage utilized within the conveyance system

With the ability of backwater accounting and increasing storage utilized within the conveyance system it can be obtained more evident effects. This is why as the routing model, the Dynamic Wave method has been chosen in this study.

Infiltration Model

There are three different methods, named Horton, Green-Ampt and Curve Number models available, in SWMM for computing infiltration loss on the pervious areas of a subcatchment. There is no general agreement in the literature on which model is the best.

Horton Method is based on empirical observations that demonstrate infiltration decreases exponentially from an initial maximum rate to some minimum rate over during a long rainfall event. The maximum and minimum infiltration rates, a decay coefficient that describes how fast the rate decreases over time, and the time it takes a fully saturated soil to completely dry (used to compute the recovery of infiltration rate during dry periods) are input parameters of this method.

Also, there is a modified version of the Horton Method in SWMM that uses the cumulative infiltration in excess of the minimum rate as its state variable (instead of time along the Horton curve), providing a more accurate infiltration estimate when low rainfall intensities occur. Input parameters are the same as the classical Horton Method.

Green-Ampt Method assumes that a sharp wetting front exists in the soil column, separating soil with some initial moisture content below from saturated soil above. Required input parameters are the initial moisture deficit of the soil, the soil's hydraulic conductivity, and the suction head at the wetting front. The recovery rate of moisture deficit during dry periods is empirically related to the hydraulic conductivity. In this study, Green-Ampt Method was used as the infiltration model.

In SWMM, there is a modified version of also Green-Ampt Method. This method doesn't deplete moisture deficit in the top surface layer of soil during initial periods of low rainfall as was done in the original method. This change can produce more realistic infiltration behavior for storms with long initial periods where the rainfall intensity is below the soil's saturated hydraulic conductivity.

Curve Number Method is adopted from the NRCS (SCS) Curve Number method for estimating runoff. It assumes that a soil's total infiltration capacity can be found by using the soil's tabulated Curve Number. This capacity is consumed as a function of cumulative rainfall and remaining capacity during a rain event. The input parameters of this method are the curve number and the time for a fully saturated soil to completely dry (used to calculate the recovery of infiltration capacity during dry periods).

Dynamic Wave Simulation Options

Inertial Terms: This option is about how the inertial terms in the St. Venant momentum equation will be approached.

- KEEP takes the full value of those terms at their in all conditions.
- DAMPEN reduces the terms when the flow gets critical and ignores them when the flow is supercritical. This option has been chosen in this study.
- IGNORE reduces the terms completely from the momentum equation, producing what is fundamentally a Diffusion Wave solution.

Normal Flow Criterion: This option is used to determine when supercritical flow occurs in a conduit.

- water surface slope only (i.e., water surface slope > conduit slope)
- Froude number only (i.e., Froude number > 1.0)
- both water surface slope and Froude number

The third choice which checks both conditions is the recommended one and it has been used in this study.

Force Main Equation: This option determines which equation will be used to calculate friction losses during pressurized flow for conduits which have Circular Force Main cross-section.

- Darcy-Weisbach
- Hazen-Williams (this equation has been used in this study)

Surcharge Method: This option determines which method will be used to handle surcharge conditions.

- EXTRAN uses a diversification of the Surcharge Algorithm from previous versions of SWMM to update nodal heads when all connecting links become full. This option has been used in this study.

- SLOT uses a Preissmann Slot to add a small amount of virtual top surface width to full flowing pipes thus SWMM's normal procedure can continue to be used for updating nodal heads.

The screen of simulation options selection is shown in Figure 3.5.

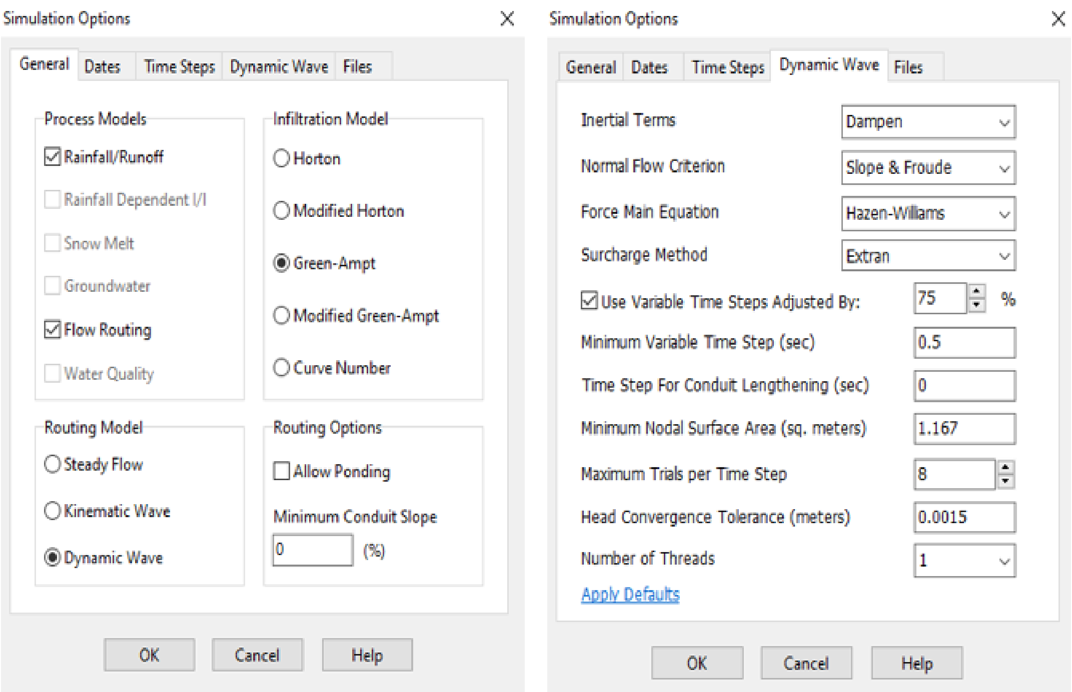


Figure 3.5 : The screen of simulation options selection

4. REGIONS

In this study, three regions from the city of Istanbul in Turkey and one region from the city of Dresden in Germany, where the study is mainly accomplished, were chosen. The location of the cities can be seen in Figure 4.1 and Figure 4.2. The first region is located in the district of Uskudar and the second region is located in the district of Kadikoy. Both two regions are located in the coastline, both of them are residential, commercial and highly populated areas, have relatively old infrastructure systems and frequent flood events. The third region is located in the district of Umraniye. This region is mostly industrial area, board on automobile repairing. This region is relatively remote to the sea and the discharge point is a river. On the other hand, the fourth region is located in the district of Lockwitz, Germany. This region is semi-industrial, board on mill flourishing, fruit growing and wine making. Stream of Lockwitzbach passes through the middle of the district and discharge point of stormwater network is this stream.

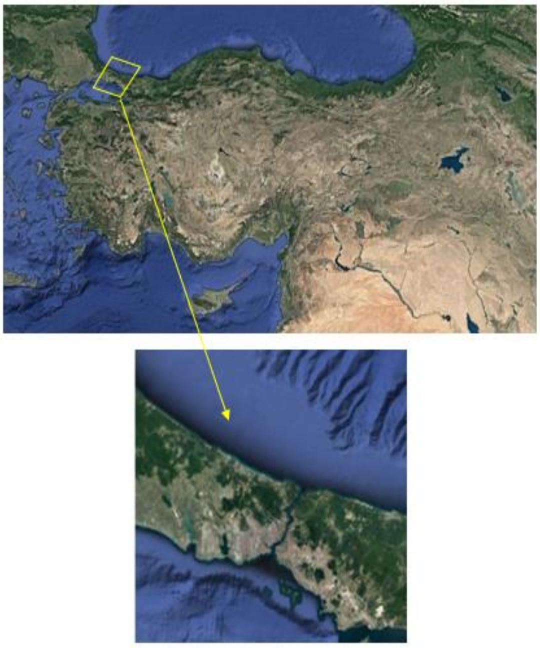


Figure 4.1 : Location of Istanbul

Figure 4.2 : Location of Dresden

4.1. Uskudar

4.1.1. History

History of Uskudar is dating back to BC 1000s. During the domination of some big civilizations like Persia, Athenian and Roman Empire, Uskudar was an important for trade and accommodation.

In 609 Iran, in 710 Arabs, in 782 Abbasid Caliph Harun Rashid, in 1102 Crusaders, in 1147 King of France VII. Louis and the German Emperor Konrad, in 1203, when the Crusaders on the door of Istanbul, they always passed through the Uskudar. XI. Century, the Crusades period was the most spectacular looting time for Uskudar.

After Crusades, Latin sovereignty continued from 574 to 1261 for 57 years in Uskudar. It's written in old sources that Sayyid Battal Gazi, who is mentioned in the legends, was a pioneer and guard for Islamic armies in Uskudar. The presence of permanent Turkish traces in Uskudar corresponds to the aftermath of the Malazgirt Victory. Following the conquest of Iznik, the early Turkish settlements began in approximately 1078 in Uskudar. However, the settlements in these dates were completely civil and individual.

After the conquest of Istanbul on May 29, 1453, Uskudar had developed rapidly. While Uskudar was previously seen as a small Anatolian town, the first signs to form a city texture after the conquest of Istanbul began to manifest themselves.

During the reign of Fatih, Uskudar was almost rebuilt. Fatih placed some of the Turks whom they were displaced from Anatolia in this region and built a bazaar to the current İskele Square, thus enabling the rapid development of trade.

The first postal route from Uskudar to Kartal was opened at II. Mahmud period with his participation. Also, the first car ferry in Istanbul sea transport was opened to service in Uskudar. At III. Selim period opening of Uskudar Printing Office and the founding of Painters' Community which is important for Turkish art in Uskudar, make Uskudar more valuable.

Uskudar, where is known and settled since BC 1000s, with Maiden's Tower from Byzantine, with watersides, wooden houses with bay windows from Ottoman, groves, pavilions, mosques, churches and synagogues, is a golden city. An old photo of Uskudar can be seen in Figure 4.3.

Figure 4.3 : Photo of old Uskudar
(https://www.uskudar.bel.tr/tr/main/pages/tarihce/25)

4.1.2. Geography

Uskudar is located in Anatolian side of Istanbul and it has 41.032234 latitude and 29.031939 longitude coordinates. Location of the region can be seen in Figure 4.4 and Figure 4.5. The chosen region includes some part of Aziz Mahmud Hudayi, Ahmediye and Salacak neighborhoods. The area of the region is approximately 180 hectare. The population of the area is approximately 23000 and population growth rate varies from year to year.

Figure 4.4 : Uskudar region’s location in Istanbul

Figure 4.5 : Uskudar Region

4.1.3. Information about infrastructure

There are totally 300 pipes with several lengths, slopes and diameters in Uskudar region, 262 of them are Bellmouth Concrete, 34 of them are Reinforced Concrete and 4 of them are High-Density Polyethylene. Discharge point of the stormwater network is the Marmara Sea.

4.1.4. Climate

Uskudar shows characteristic of Marmara Region in terms of climate. This region is under the influence of the temperate air of Marmara and the cold air from the Balkans as well. Summers are hot and dry, spring, autumn and winter are usually rainy. The average annual temperature is 14.0 degrees Celcius. The average annual rainfall is 787 mm.

4.1.5. Current situation

From the 1960s onwards, Uskudar has been subjected to rapid population growth. With the migrants from outside of the region, there has been an intense construction in the existing settlement areas and the rural areas have been opened to new settlements and new neighborhoods have been formed. It is a popular area with the richness of the historical heritage and the hills with spectacular views. The dominant economic activity in this region is trade. In general, in this region where conservative people live, the level of income of the people is medium and the workers, civil servants and tradesmen make up most of the population. Current view of this region can be seen in Figure 4.6.

Figure 4.6 : Photo of current Uskudar (https://istanbeautiful.com/uskudar-istanbul/)

4.2. Kadikoy

4.2.1. History

Kadikoy's history is dating back to very old years. Founded in BC 675 years is accepted. First trade colony called Harhadon in various sources was created in Fikirtepe by Phoenicians around BC 1000s is known. Opposite the first settlement in Fikirtepe, there was a second settlement between Moda Foreland and Yogurtcu, called Halkedon (Copper Country). Halkedon (Chalcedon) was famous for its Temple of Apollo at that term and Haydarpaşa Meadow was used by the Halkedonis for horse races.

During the 18th century, especially during the Tulip Period, the environment of Kadikoy was popular as a promenade. Haydarpasa, Yogurtcu, Moda ve Kusdili meadows and Uzuncayir were demanded places for stroll. In the 18th century, the Armenians began to settle near Turks and Greeks in Kadikoy.

Kadikoy and its surroundings began to develop steadily in the second half of the 19th century. With the construction of important buildings such as Selimiye Barracks and Hardarpasa Military Hospital, the main developments began. Two other important events that follow these developments are The opening of the Haydarpasa-Izmit railway and the operation of the inner city ferries.

By the end of the 19th century, it was seen that the leading state officials and wealthy non-Muslims built pavilions in Kadikoy. Air-gas came to the city in 1892 with the construction of the Hasanpaşa Gasworks, urban water came in 1894 and electricity came in 1928. Kadikoy, which was connected to Uskudar for a long time, became a district on September 1, 1930.

Between 1938-1949, Bagdat Avenue was tarmacked up to Kartal, Kadikoy Community Center was built, a reservoir built in Kozyatagi and upward 1947 bus operation started beside trams at public transportation. After 1950, the building of Haydarpasa Harbor, construction of double lane road between Kadikoy and Pendik, also the construction of interurban new roads were important developments for Kadikoy. After the 1960s, trade and service sectors improved and Kadikoy became a central place.

At the present time, Kadikoy is one of the most important districts of Istanbul in terms of population size, economic activity and public improvements. An old photo of Kadikoy can be seen in Figure 4.7.

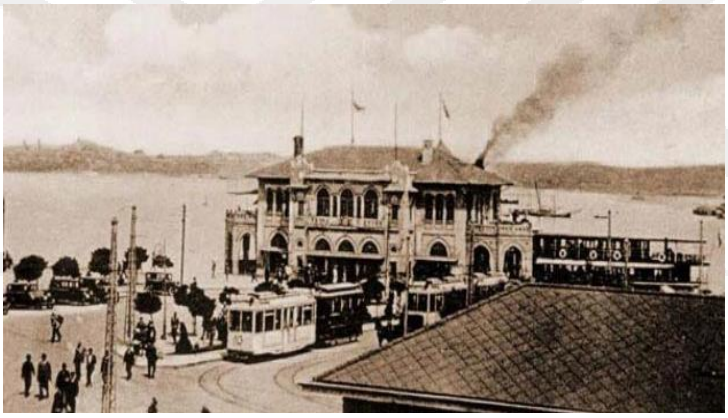


Figure 4.7 : Photo of old Kadikoy
(http://www.kadikoy.bel.tr/Kadikoy/Fotograflarla-Kadikoy)

4.2.2. Geography

Kadikoy is located in Anatolian side of Istanbul and it has 40.980141 latitude and 29.082270 longitude coordinates. Location of the region can be seen in Figure 4.8 and Figure 4.9. The chosen region includes Fenerbahce neighborhood. The area of the region is approximately 300 hectare. The population of the area is approximately 18000 and population growth rate varies from year to year.

Figure 4.8 : Kadikoy region's location in Istanbul

Figure 4.9 : Kadikoy Region

4.2.3. Information about infrastructure

There are totally 493 pipes with several lengths, slopes and diameters in Kadikoy region, 433 of them Bellmouth Concrete, 57 of them Reinforced Concrete and 3 of them High-Density Polyethylene. Discharge points of the stormwater network are the Marmara Sea and Kurbagalidere.

4.2.4. Climate

The climate is generally mild in Kadikoy. Black Sea climate from the north and slightly degraded Mediterranean climate from south influence this region. Winters have much more rainfall than summers. The average annual rainfall is 586 mm. The average annual temperature is 12.9 degrees Celcius.

4.2.5. Current situation

Kadikoy became a settlement area in the 19th century and became a district in 1930. Some of the major transport routes linking various districts of Istanbul pass through the district of Kadikoy. That's why Kadikoy has an important position in terms of city transportation. The dominant economic activity in this region is trade. The population density of this region has continuously increased until 2009 when it reached its present borders. However after that time, maybe because of the negative effects of rapidly increasing urban transformation activities in the environment, population density started to decrease. Current view of this region can be seen in Figure 4.10.

Figure 4.10 : Photo of current Kadikoy (https://www.emlaklobisi.com/bilgi-bankasi/istanbulun-bu-ilcelerinden-konut-alan-yasadi-89056)

4.3. Umraniye

4.3.1. History

According to historical sources, the first settlers to Umraniye are Phrygians. In the following years, the places where Umraniye was located were dominated by the Romans and the Byzantines. Umraniye had changed hands from time to time among the Byzantines and Muslim armies. The first state that made Anatolia as a Muslim and Turkized was the State of Danishmends. During the Ottoman Empire, the sultan, Orhan Gazi, added this district to the Ottoman lands.

The first settlers in Umraniye came from Batumi and then from Yugoslavia and Bulgaria after the Balkan Wars. For a while, there was well known as "Refugee Village". Umraniye, which remained as a village until 1960, was exposed to intense migration after it was declared as an Organized Industrial Zone. The municipality was established in 1963 for the first time. Umraniye is one of the fastest urbanizing and rapidly growing districts of Istanbul. An old photo of Umraniye can be seen in Figure 4.11.

Figure 4.11 : Photo of old Umraniye (https://www.umraniye.bel.tr/tr/main/pages/umraniye-tarihi/18)

4.3.2. Geography

Umraniye is located in Anatolian side of Istanbul and it has 39.933363 latitude and 32.859741 longitude coordinates. Location of the region can be seen in Figure 4.12 and Figure 4.13. The chosen region includes some part of Saray neighborhood. The area of the region is approximately 40 hectare. The population of the area is approximately 2500 and population is increasing year by year.

Figure 4.12 : Umraniye region's location in Istanbul

Figure 4.13 : Umraniye Region

4.3.3. Information about infrastructure

There are totally 128 pipes with several lengths, slopes and diameters in Umraniye region, 64 of them are Bellmouth Concrete and 64 of them are Reinforced Concrete. Discharge point of the stormwater network is Ayazma Hekimbasi Stream and the network reaches at the discharge point with closed box sections.

4.3.4. Climate

Both the Black Sea and Mediterranean climate characteristics are seen in Umraniye region. In winters, this region remains under the influence of frontal rainfall because of Mediterranean climate properties while in summers, there is not dry like a Mediterranean region because of Blacksea climate influence. The average annual rainfall is 817 mm. The average annual temperature is 13.8 degrees Celcius.

4.3.5. Current situation

Umraniye, which is one of the fastest urbanized and population growth areas of Istanbul, became the district in 1987. This region, where the village and local traditions are mostly preserved, is rich in terms of economic diversity. Some of the various economic activities in this region are small manufacturing industry, apparel, spare parts and production of wood products. Current view of this region can be seen in Figure 4.14.

Figure 4.14 Photo of current Umraniye
(https://www.aksam.com.tr/yasam/umraniyede-8-yilda-115-bin-konut/haber-181965)

4.4. Lockwitz

4.4.1. History

Lockwitz was first mentioned as Lucawicz in 1288. The place is originally divided into maiori Lucawicz (later Großlockwitz and Niederlockwitz) and parvo Lucawicz (Kleinlockwitz, Oberlockwitz). Due to stream of Lockwitzbach and the surrounding agriculture, several mills and bakers settled in Lockwitz.

In the 18th century, Lockwitz was a village in Dresden authority, one and a half hours from the city towards Dohna, whose inhabitants feed on woodworking and straw hat making with all kind of business. The mills emerged especially in 19th century, including Otto Rüger's chocolate factory. Emil and Albert Donath, both from Laubegast, founded Lockwitzgrund, the first fruit caster in Saxony, and later the Lockwitzgrund winery.

In 1923, the neighboring and for many years the manor of Lockwitz belonging Nickern was incorporated into Lockwitz. The resulting large community Lockwitz was incorporated to Dresden in 1930, but kept their village, secluded from the city character. An old photo of Lockwitz can be seen in Figure 4.15.

Figure 4.15 : Photo of old Lockwitz (https://www.alamy.com/stock-photo/lockwitz.html)

4.4.2. Geography

Lockwitz is located in the extreme southeast of Dresden and it has 50.983 latitude and 13.800 longitude coordinates. Location of the region can be seen in Figure 4.16 and Figure 4.17. The area of the region is approximately 995 hectare. The population of the area is approximately 1600.

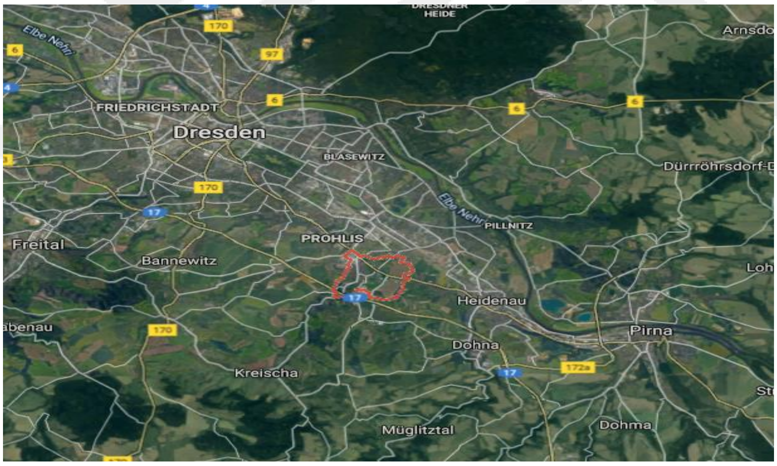


Figure 4.16 : Lockwitz region’s location in Dresden

Figure 4.17 : Lockwitz Region

4.4.3. Information about infrastructure

There are totally 747 pipes with several lengths, slopes, diameters and shapes in Lockwitz region. Most of them are concrete, stoneware, polyvinyl chloride and the others are reinforced concrete, asbestos cement, ductile cast iron, polypropylene and polyethylene. The discharge points of the network are mostly Lockwitzbach and Elbe Streams.

4.4.4. Climate

This region is assigned to the climate zone of the humid climate of the middle latitudes. It is characterized by the constant change of maritime and continental weather influences. The average annual rainfall is 665 mm. The average annual temperature is 8.9 degrees Celcius.

4.4.5. Current situation

Lockwitz is characterized by loose and green buildings. The center of the district is located around the plan, which is also close to the Lockwitz Castle and the church. Its exposed location on the outskirts overlooking the Saxon Switzerland makes Lockwitz popular as a place of residence. It has ideal living conditions with solid infrastructure for families with children. Current view of this region can be seen in Figure 4.18.

Figure 4.18 : Photo of current Lockwitz (https://www.dresdenausflug.de/ferienwohnung-in-dresden-lockwitz/)

5. RESULTS

5.1. Running Models with the Regions’ Own Data

In this part of the study, all the models of the regions were simulated with the meteorological data obtained from the closest meteorological stations to each region. Three types of data were used for the simulation: 1-Hour, 10-Minutes and 1-Minute resolution data. Thus, it was observed how the current situation of the regions is against the amount of rainfall they have and which resolution gives the best results.

5.1.1. Uskudar region

Uskudar is one of the most flooded regions in Istanbul. Some examples of those flooding events can be seen in Figure 5.1 and Figure 5.2. For this region, meteorological data from Uskudar meteorological station was used.

Figure 5.1 : Flooding event in Uskudar on 02.06.2014 (https://www.haberturk.com/gundem/haber/953980-Istanbulu-dolu-vurdu)

Figure 5.2 : Flooding event in Uskudar on 18.07.2017 (https://www.haberler.com/Istanbul-da-saganak-2-9843337-haberi/)

When the model was simulated with 1-Hour resolution data, it was observed that there is not any flooding event in that time period as can be seen in Figure 5.3. Also, the hyetograph in Figure 5.4 shows that there is no flooding event even though all those amounts of rainfall. However, there are already some examples of flooding events in that time period. So, this result can not be considered.

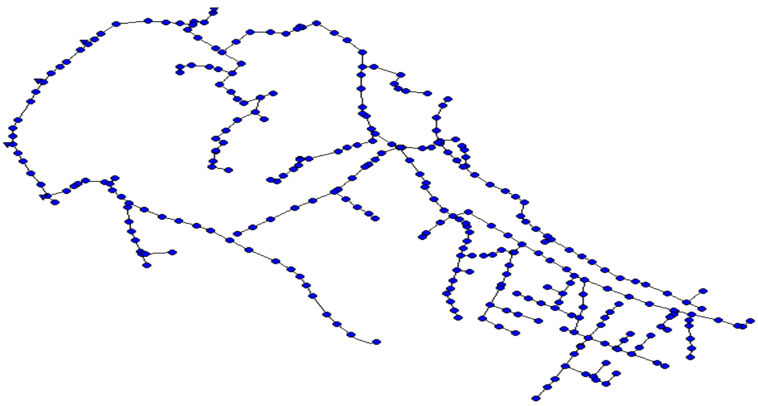


Figure 5.3 : Flooded nodes in Uskudar region with 1-Hour resolution data

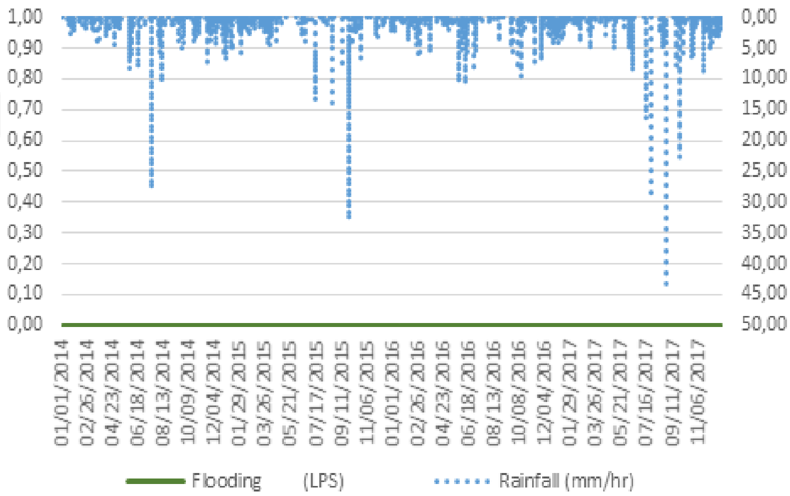


Figure 5.4 : Flooding-Rainfall hyetograph with 1-Hour resolution data for Uskudar region

The other results that belong to simulation with 1-Hour resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.
After that, when the model was simulated with 10-Minutes resolution data, very opposite to the first situation, as can be seen in Figure 5.5 and Figure 5.6 that 57% of 300 nodes can be flooded at the peak rainfall amounts. Because with 1-Hour resolution data the peak amount of rainfall

is 43 mm/hr, besides that with 10-Minutes resolution data the peak amount of rainfall is 148 mm/hr.

The main cause of this difference is that the measurement in one hour includes six times 10-Minutes and it can not be known in which 10-Minutes range the peak rainfalls are happening. So, the peak rainfalls are distributed in one hour. However, the measurement in ten minutes demonstrates us exactly in which 10-Minutes range the peak rainfalls are happening. That is why 10-Minutes resolution data shows better results.

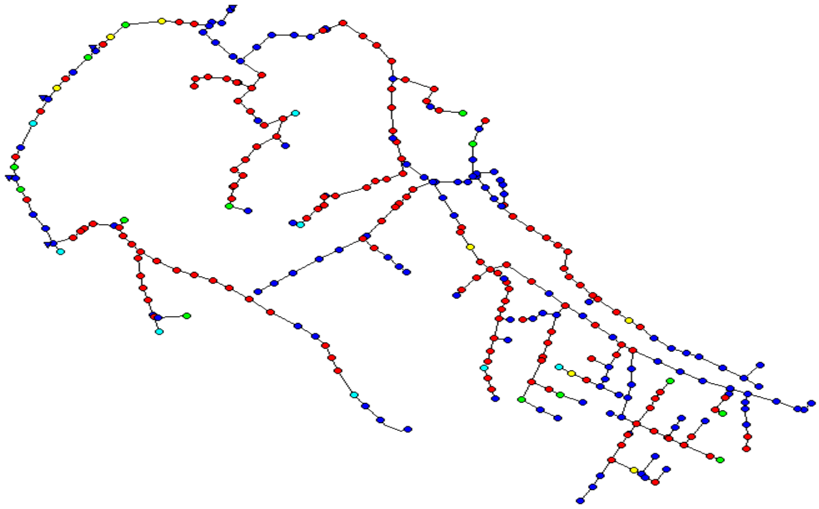


Figure 5.5 : Flooded nodes in Uskudar region with 10-Minutes resolution data

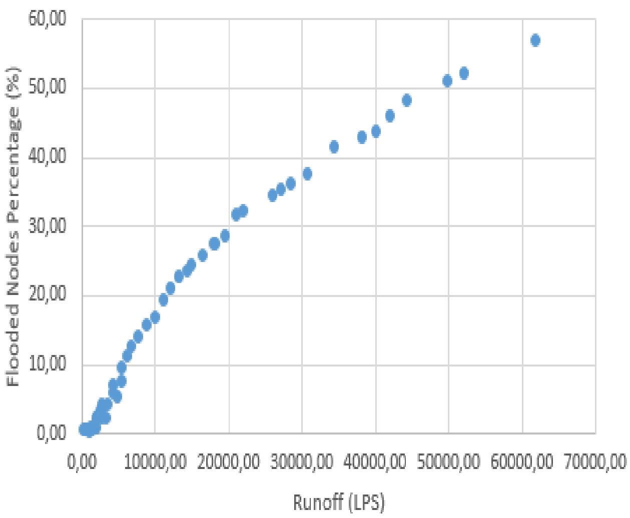


Figure 5.6 : Relationship between Flooded Nodes Percentage and Runoff in Uskudar region with 10-Minutes resolution data

Also, as can be seen in Figure 5.7, the relationship between flooding and rainfall obtained with 10-Minutes resolution data is more sensible than the first case. This means 10-Minutes resolution data give us more realistic results.

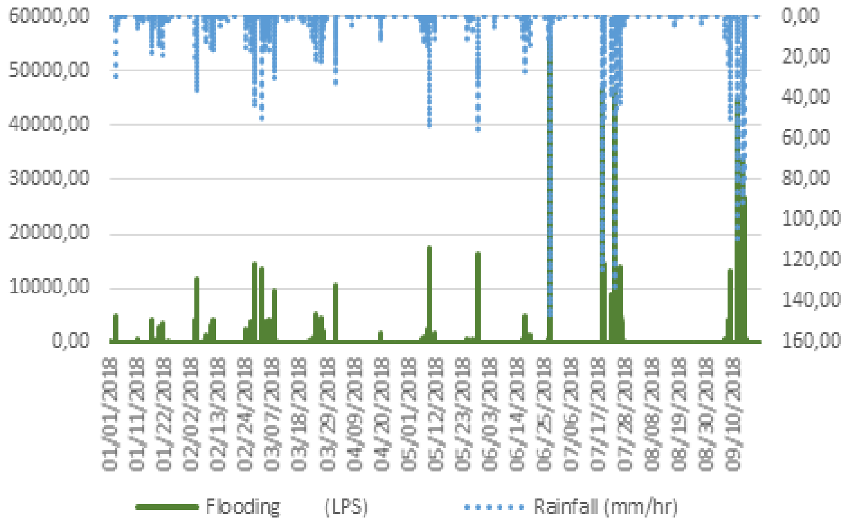


Figure 5.7 : Flooding-Rainfall hyetograph with 10-Minutes resolution data for Uskudar region

The other results that belong to simulation with 10-Minutes resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

Finally, when the model was simulated with 1-Minute resolution data, as can be seen in Figure 5.8, only 5 of 300 nodes can be flooded at the peak rainfall amounts. With 1-Minute resolution data, the peak amount of rainfall is 21 mm/hr.

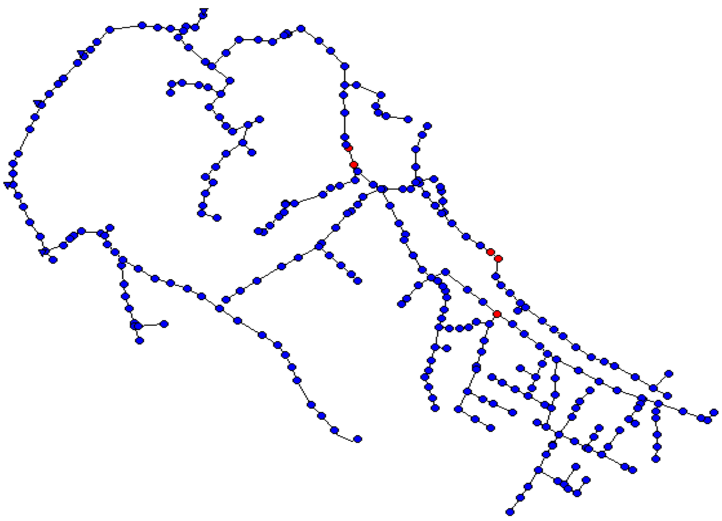


Figure 5.8 : Flooded nodes in Uskudar region with 1-Minute resolution data

Besides that, when the relationship between flooding and rainfall obtained with 1-Minute resolution data was examined in Figure 5.9, flooding events and rainfalls do not look coherent. So, it can be told that 1-Minute resolution data doesn't give results as good as 10-Minutes resolution data.

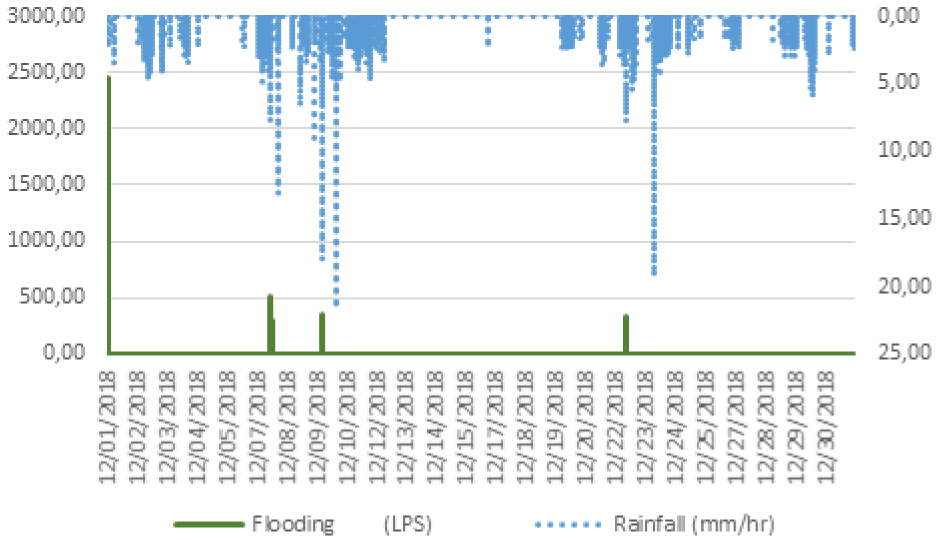


Figure 5.9 : Flooding-Rainfall hyetograph with 1-Minute resolution data for Uskudar region

The other results that belong to simulation with 1-Minute resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

5.1.2. Kadikoy region

Kadikoy is a region where strong flooding incidents like in Figure 5.10 and Figure 5.11 are very common. For this region, meteorological data from Kadikoy Rihtim meteorological station was used.

Figure 5.10 : Flooding event in Kadikoy on 14.07.2014
(https://emlakkulisi.com/Istanbuldaki-saganak-yagis-su-birikintilerine-neden-oldu/270719)

Figure 5.11 : Flooding event in Kadikoy on 27.07.2017
(https://www.youtube.com/watch?v=miTAe627_Us)

When the model was simulated with 1-Hour resolution data, it was observed that there is not any flooding event in that time period like the first region as can be seen in Figure 5.12. Also, the hyetograph in Figure 5.13 shows that there is no flooding event similarly to the first region. However, there are already some examples of flooding events in that time period. So, the results obtained from 1-Hour resolution data were not realistic for this region as well. Again, it was confirmed that 1-Hour resolution is not enough measurement for flooding modeling for these regions.

Figure 5.12 : Flooded nodes in Kadikoy region with 1-Hour resolution data

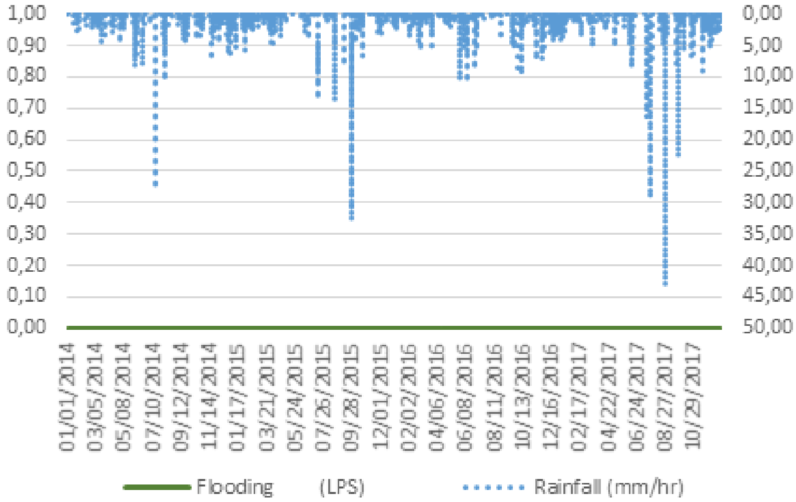


Figure 5.13 : Flooding-Rainfall hyetograph with 1-Hour resolution data for Kadikoy region

The other results that belong to simulation with 1-Hour resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

After that, when the model was simulated with 10-Minutes resolution data, very opposite to the first situation, as can be seen in Figure 5.14 and Figure 5.15 that 62% of 511 nodes can be flooded at the peak rainfall amounts. With 1-Hour resolution data the peak amount of rainfall is 43 mm/hr, besides that with 10-Minutes resolution data the peak amount of rainfall is 156 mm/hr.

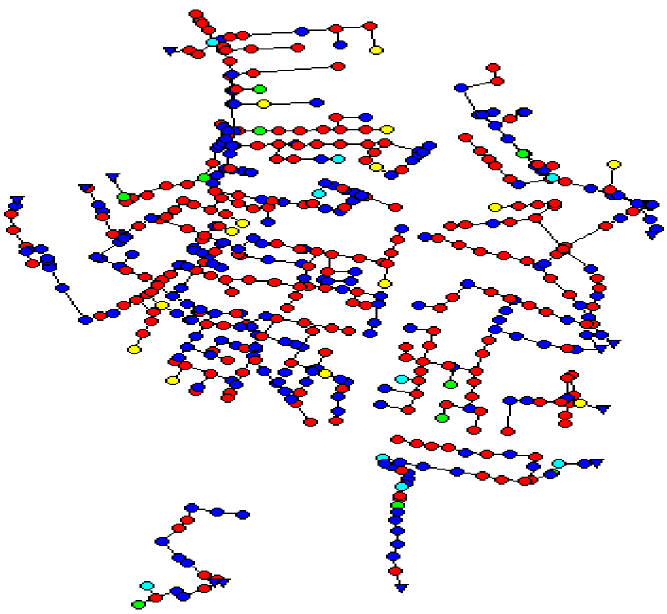


Figure 5.14 : Flooded nodes in Kadikoy region with 10-Minutes resolution data

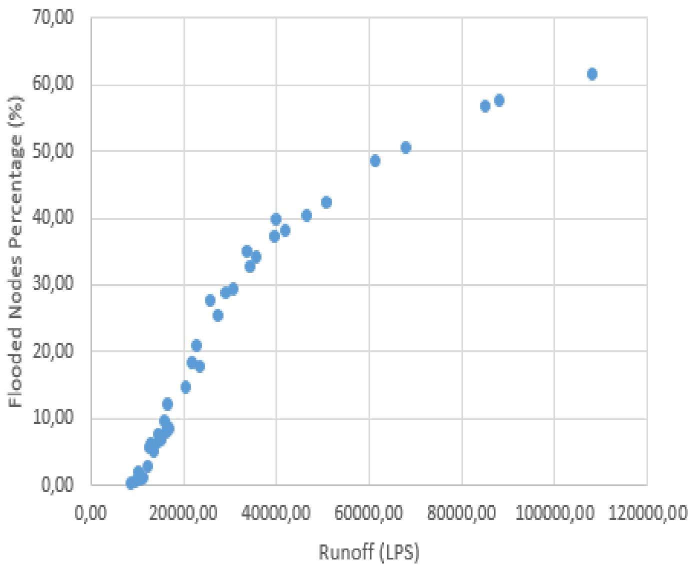


Figure 5.15 : Relationship between Flooded Nodes Percentage and Runoff in Kadikoy region with 10-Minutes resolution data

The other results that belong to simulation with 10-Minutes resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices. Also, when the relationship between flooding and rainfall obtained with 1-Minute resolution data was examined in Figure 5.16, flooding events look coherent with rainfall. So, it can be told 10-Minutes resolution data give more consistent results.

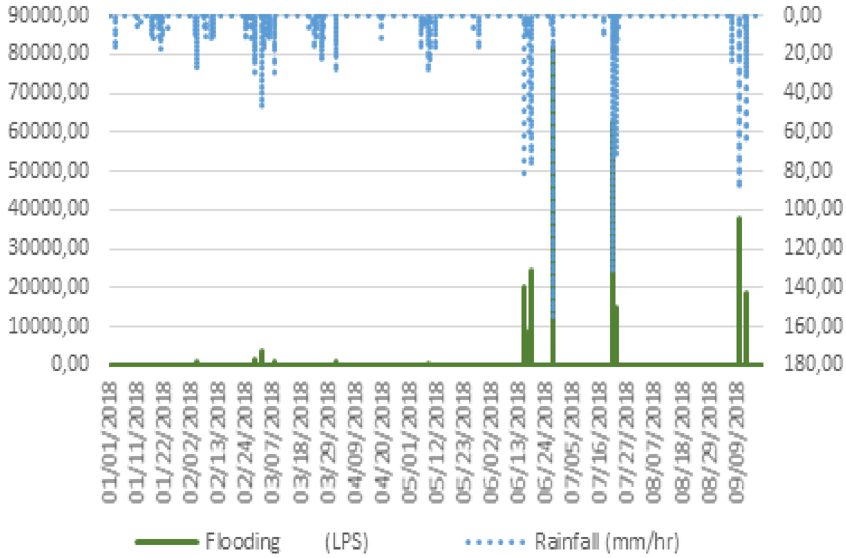


Figure 5.16 : Flooding-Rainfall hyetograph with 10-Minutes resolution data for Kadikoy region

Finally, when the model was simulated with 1-Minute resolution data, as can be seen in Figure 5.17 and Figure 5.18 that 6% of 511 nodes can be flooded at the peak rainfall amounts. With 1-Minute resolution data, the peak amount of rainfall is around 40 mm/hr.

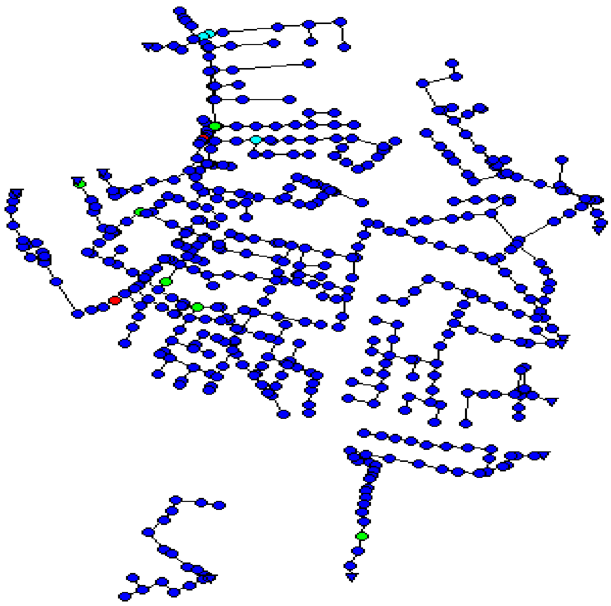


Figure 5.17 : Flooded nodes in Kadikoy region with 1-Minute resolution data

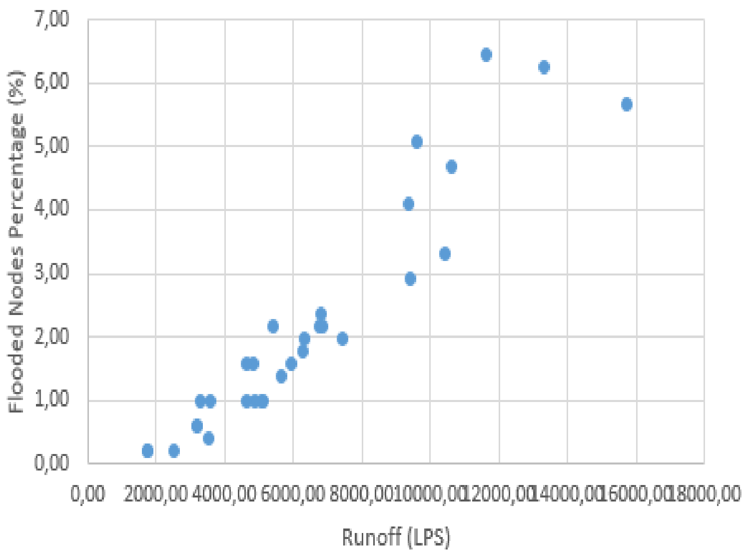


Figure 5.18 : Relationship between Flooded Nodes Percentage and Runoff in Kadikoy region with 1-Minute resolution data

However, when the relationship between flooding and rainfall obtained with 1-Minute resolution data was examined in Figure 5.19, 1-Minute resolution data gives better results than 1-Hour resolution data but not as good as 10-Minutes resolution data for Kadikoy region.

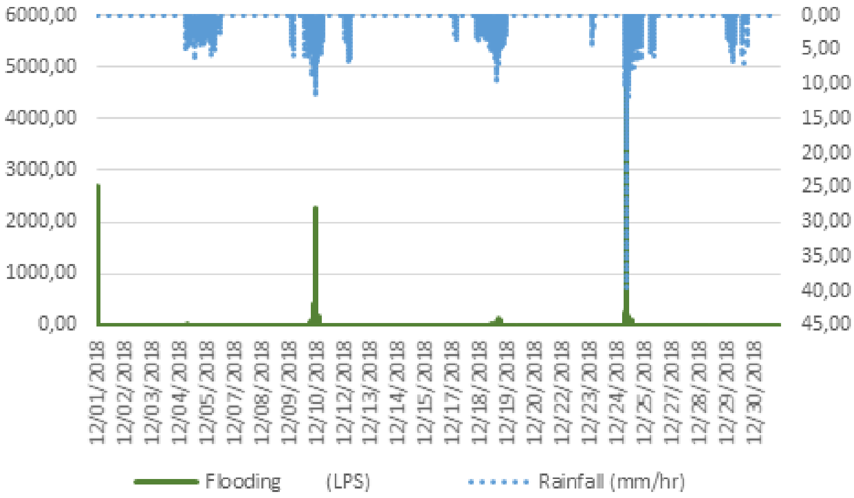


Figure 5.19 : Flooding-Rainfall hyetograph with 1-Minute resolution data for Kadikoy region

The other results that belong to simulation with 1-Minute resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

5.1.3. Umraniye region

Umraniye is another region where strong flooding incidents like in Figure 5.20 and Figure 5.21 are very common. For this region, meteorological data from Umraniye meteorological station was used.

Figure 5.20 : Flooding event in Umraniye on 18.07.2017 (https://www.haberler.com/umraniye-sel-sulari-boyle-goruntulendi-9843710-haberi/)

Figure 5.21 : Flooding event in Umraniye on 12.09.2015 (https://www.facebook.com/cekmekoyhabergazetesi/photos/a.1584703668458831/1605829969679534/?type=3&theater)

However, when the model was simulated with 1-Hour resolution data, as seen in Figure 5.22 and Figure 5.23, there isn't any flooding event in this region in the 4-year period. These results can not be correct due to there are already some strong flooding events in that 4 years period similar to the other two regions. 1-Hour resolution data did not work well in this region as well.

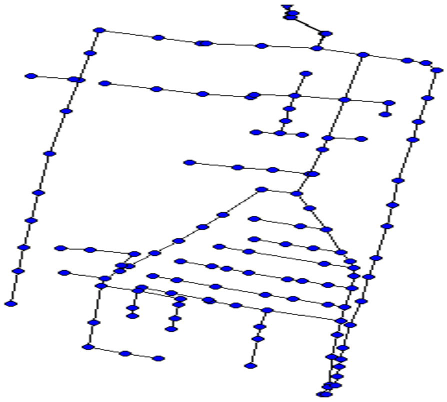


Figure 5.22 : Flooding situation in Umraniye region with 1-Hour resolution data

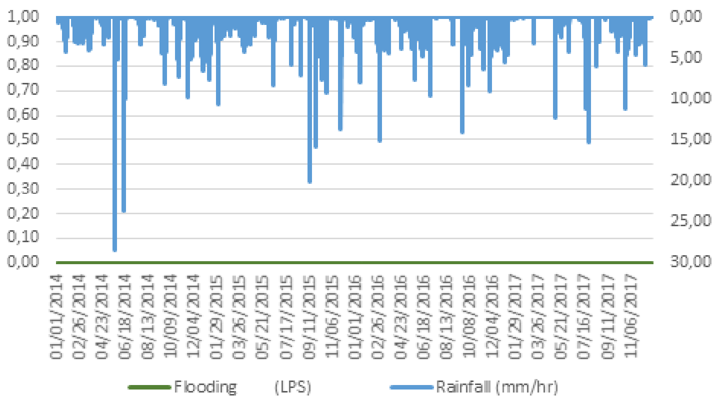


Figure 5.23 : Flooding-Rainfall hyetograph with 1-Hour resolution data for Umraniye region

The other results that belong to simulation with 1-Hour resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.
After that, when the model was simulated with 10-Minutes resolution data, opposite to the first situation, as can be seen in Figure 5.24 and Figure 5.25 that in 9 months period, a maximum of 49% of 137 nodes was flooded at the peak rainfalls. With 1-Hour resolution data the peak amount of rainfall is 28 mm/hr, besides that with 10-Minutes resolution data the peak amount of rainfall is 135 mm/hr.

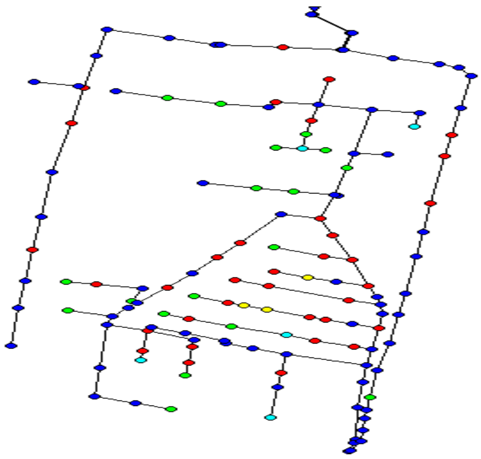


Figure 5.24 : Flooded nodes in Umraniye region with 10-Minutes resolution data

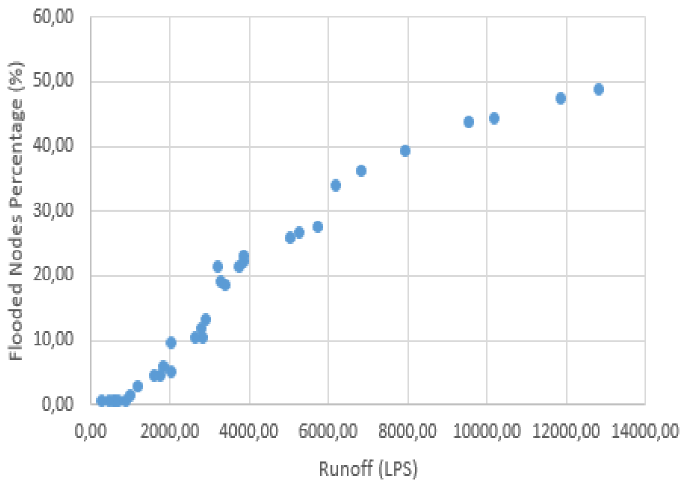


Figure 5.25 : Relationship between Flooded Nodes Percentage and Rainfall in Umraniye region with 10-Minutes resolution data

Besides that, when the relationship between rainfall and flooding events were examined in Figure 5.26, they look reasonable. There is not any flooding event regardless of rainfall. So, it can be told again that 10-Minutes resolution data give more consistent results.

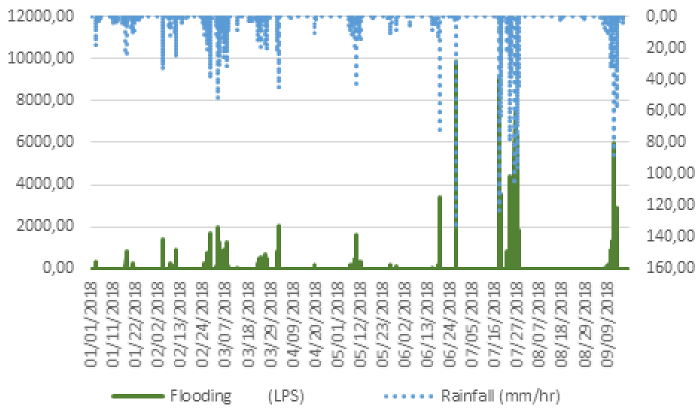


Figure 2.26 : Flooding-Rainfall hyetograph with 10-Minutes resolution data for Umraniye region

The other results that belong to simulation with 10-Minutes resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices. Finally, when the model was simulated with 1-Minute resolution data, as can be seen in Figure 5.27 and Figure 5.28 that there is no flooding event, even though there is a strong rainfall in this time range. With 1-Minute resolution data, the peak amount of rainfall is around 28 mm/hr.

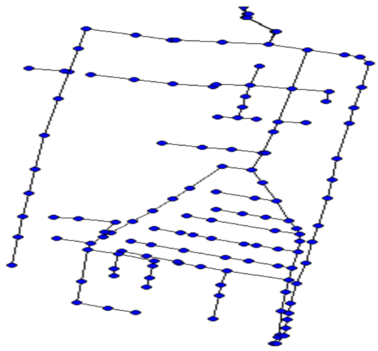


Figure 3.27 : Flooded nodes in Umraniye region with 1-Minute resolution data

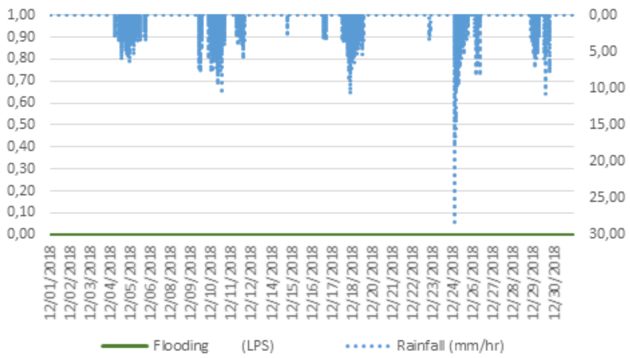


Figure 4.28 : Runoff-Flooding hyetograph with 1-Minute resolution data for Umraniye region

The other results that belong to simulation with 1-Minute resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

5.1.4. Lockwitz region

Lockwitz is the region in Germany which has very big flooding events in the past as seen in Figure 5.29 and Figure 5.30. For this region, meteorological data from Dresden-Hosterwitz meteorological station was used.

Figure 5.29 : Flooding event in Lockwitz on 03.06.2013 (https://www.youtube.com/watch?v=iKNTU-BDVLY)

Figure 6.30 : Flooding event in Lockwitz on 13.08.2002 (https://www.lockwitztal.de/html/hanichen-muhle.html)

When the model was simulated with 1-Hour resolution data, it was observed that 15 nodes of 679 nodes can be flooded at the peak precipitation event as seen in Figure 5.31. It is a very less amount of the total number of nodes. This is why that result is not realistic for that much flooding.

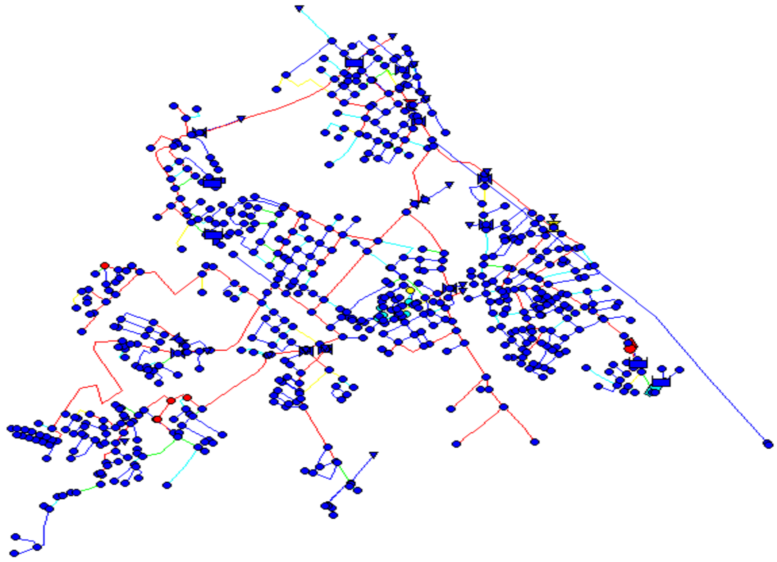


Figure 7.31 : Flooded nodes in Lockwitz region with 1-Hour resolution data

Figure 5.32 shows the relationship between flooding and rainfall and the hyetograph doesn't have a homogeneous distribution. There can be seen peak flooding events are regardless of peak rainfalls and even at the low amount of rainfall, there are some high flooding events. This hyetograph confirms that 1-Hour resolution data doesn't give us trustable results.

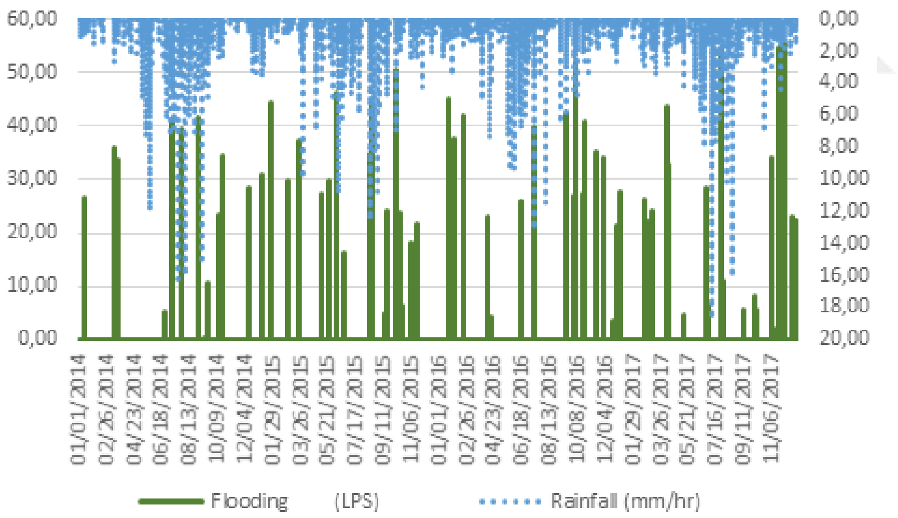


Figure 8.32 : Flooding-Rainfall hyetograph with 1-Hour resolution data for Lockwitz region

The other results that belong to simulation with 1-Hour resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.
After that, when the model was simulated with 10-Minutes resolution data, as can be seen in Figure 5.33 and Figure 5.34 that 32% of 679 nodes can be flooded at the peak rainfall amounts.

With 1-Hour resolution data the peak amount of rainfall is 19 mm/hr, besides that with 10-Minutes resolution data the peak amount of rainfall is 47 mm/hr.

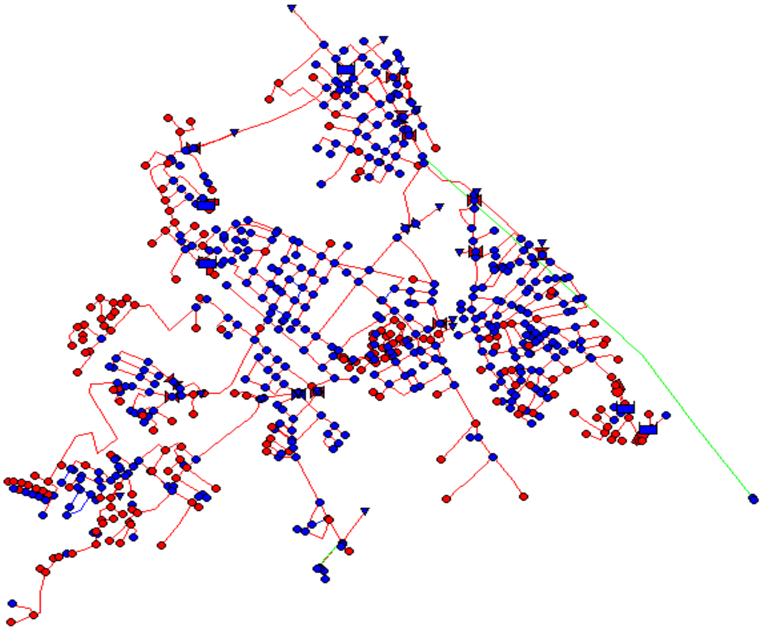


Figure 9.33 : Flooded nodes in Lockwitz region with 10-Minutes resolution data

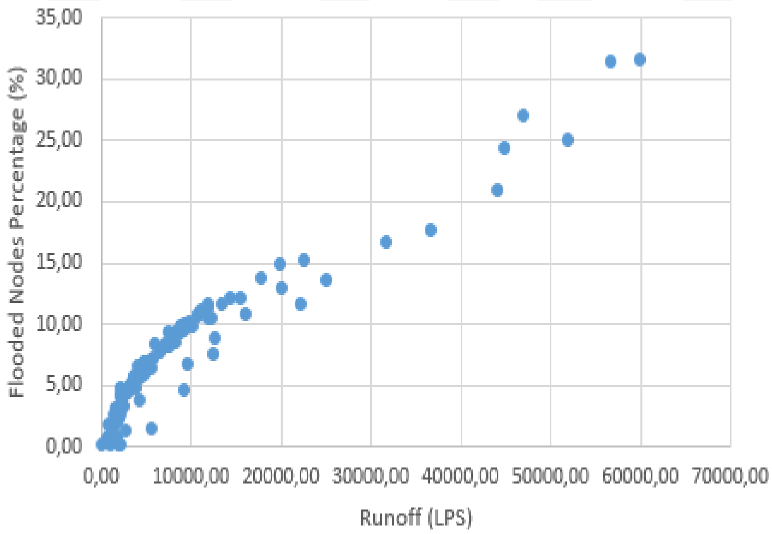


Figure 10.34 : Relationship between Flooded Nodes Percentage and Runoff in Lockwitz region with 10-Minutes resolution data

Besides that, when the relationship between rainfall and flooding events were examined in Figure 5.35, they look reasonable. There is not any flooding event regardless of rainfall similar to the other regions' results with 10-Minutes resolution data.

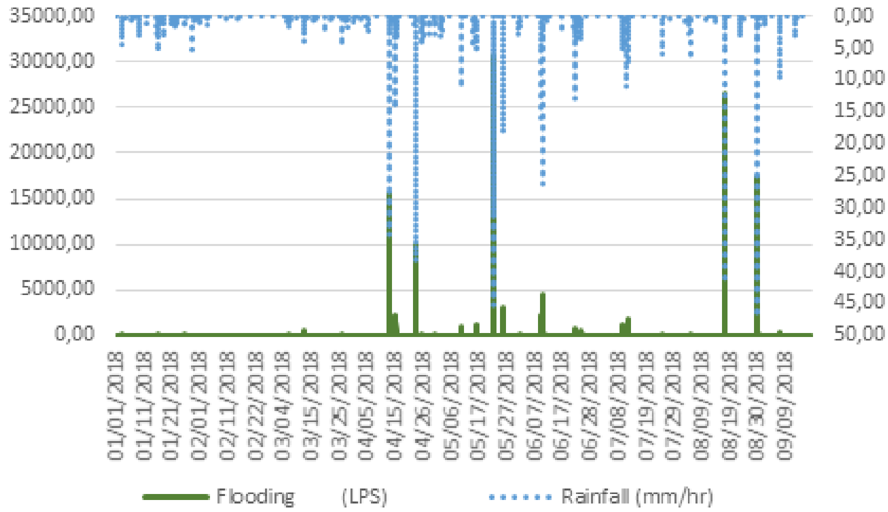


Figure 11.35 : Flooding-Rainfall hyetograph with 10-Minutes resolution data for Lockwitz region

The other results that belong to simulation with 10-Minutes resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

Finally, when the model simulated with 1-Minute resolution data, as can be seen in Figure 5.36 and Figure 5.37 that 5% of 679 nodes can be flooded at the peak rainfall amounts. With 1-Minute resolution data, the peak amount of rainfall is around 22 mm/hr. This peak rainfall is almost half of the peak rainfall with 10-Minutes data but flooding amount is much fewer. This is why the results obtained from 1-Minute resolution data were not considered as trustable.

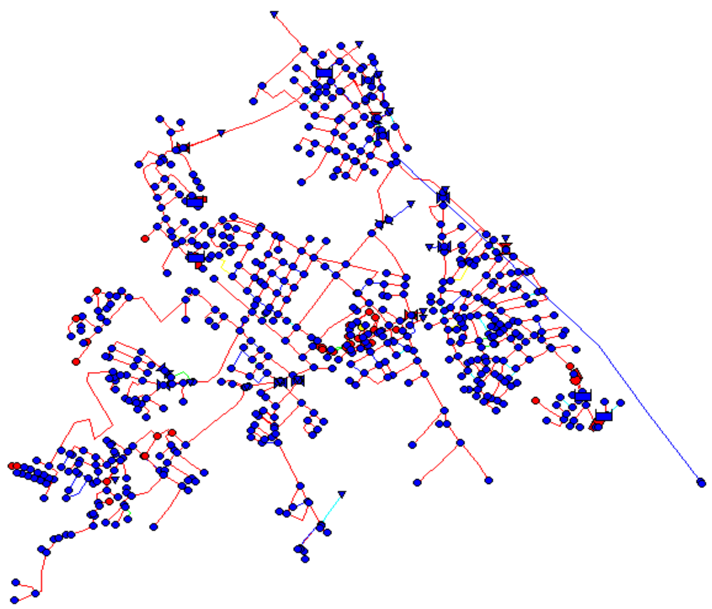


Figure 5.36 : Flooded nodes in Lockwitz region with 1-Minute resolution data

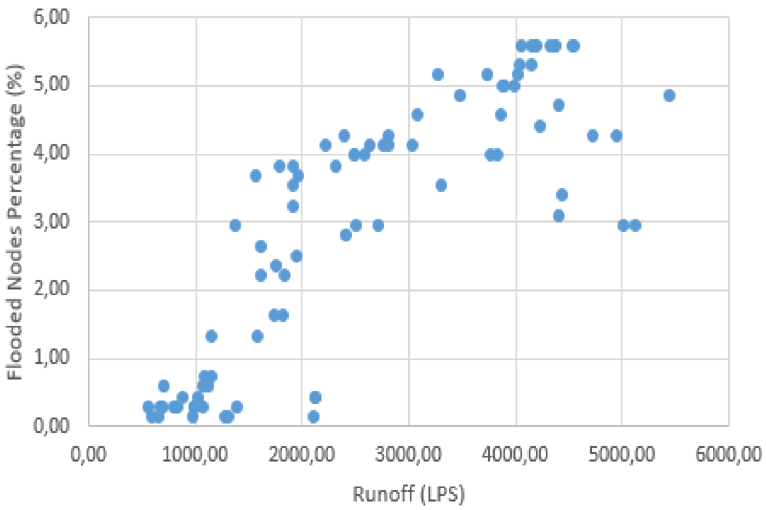


Figure 5.37 : Relationship between Flooded Nodes Percentage and Runoff in Lockwitz region with 1-Minute resolution data

However, when the relationship between flooding and rainfall obtained with 1-Minute resolution data was examined in Figure 5.38, distribution of the hyetograph is better than the results of 1-Hour resolution data but not as good as the results of 10-Minutes resolution data similarly to the other regions.

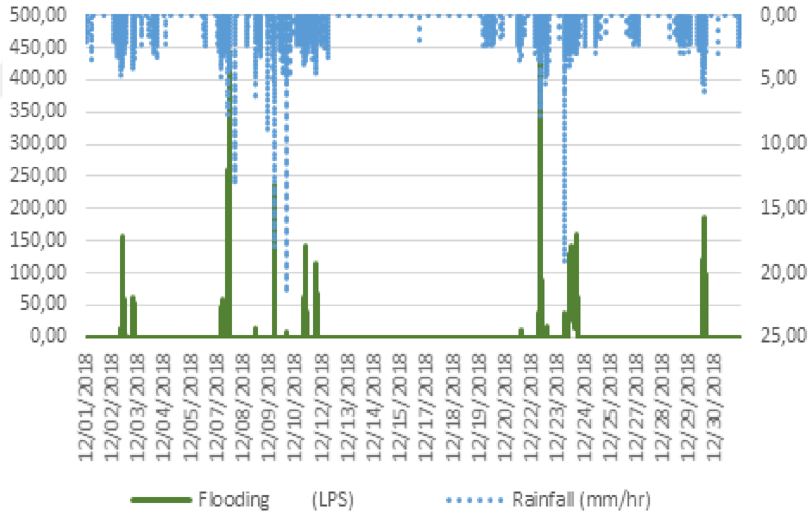


Figure 5.38 : Flooding-Rainfall hyetograph with 1-Minute resolution data for Lockwitz region

The other results that belong to simulation with 1-Minute resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

5.2. Running Models with the Regions' Scenario Data

In this part of the study, all the models of the regions in Istanbul were simulated with the meteorological data from Germany and the model of the region in Dresden was simulated with the meteorological data from Turkey.

As seen in Figure 5.39, Figure 5.40 and Figure 5.41, the rainfall amount in Istanbul is generally higher than the rainfall amount in Dresden. However, in Dresden, rainfall intensity is higher than the rainfall intensity in Istanbul. This means, there are more rainy days in Dresden than in Istanbul. Thus, it was observed how the models react to this climate difference.

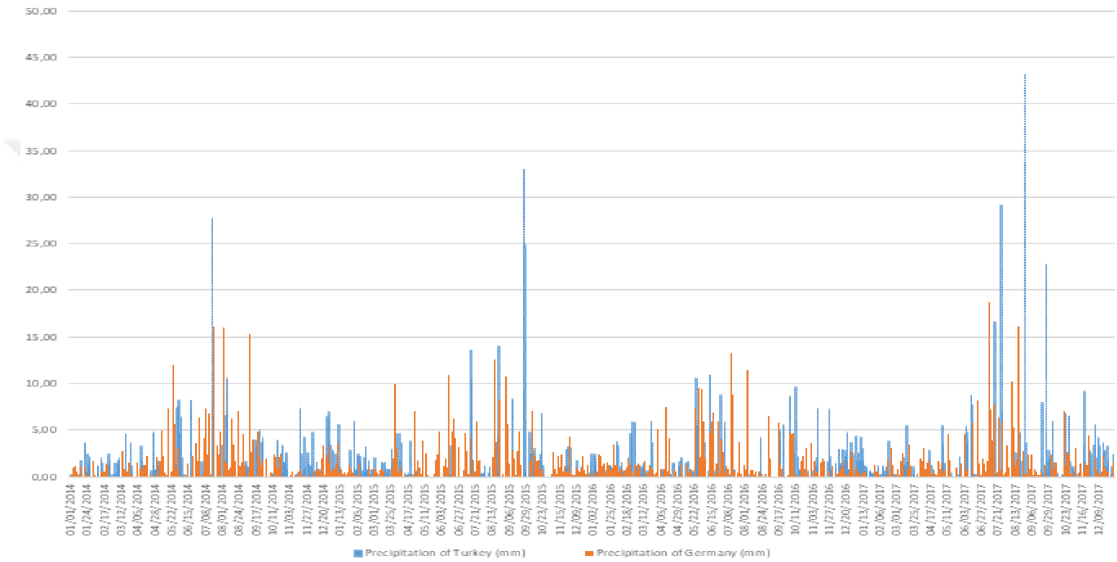


Figure 5.39 : Rainfall distribition in Turkey and Germany with 1-Hour resolution data

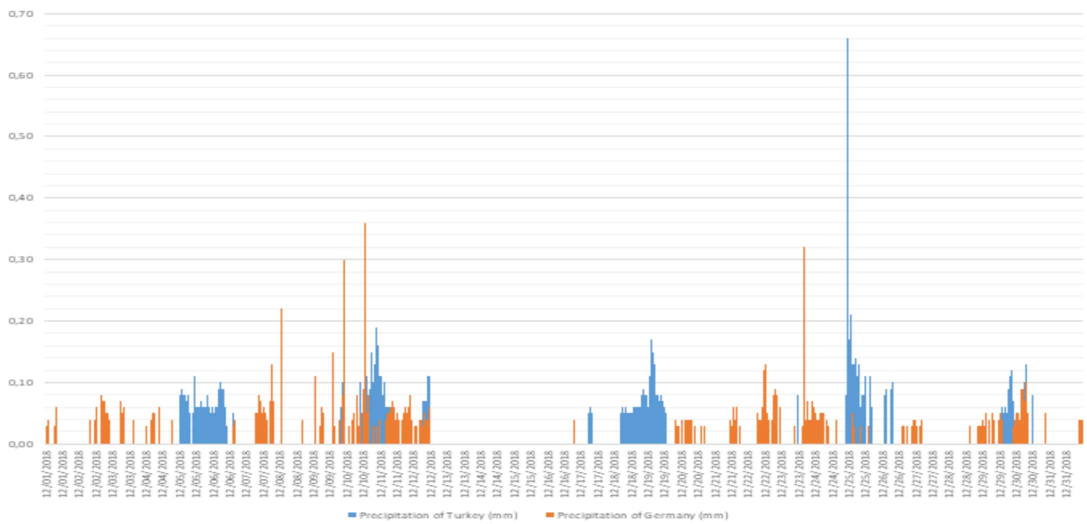


Figure 5.40 : Rainfall distribition in Turkey and Germany with 10-Minutes resolution data

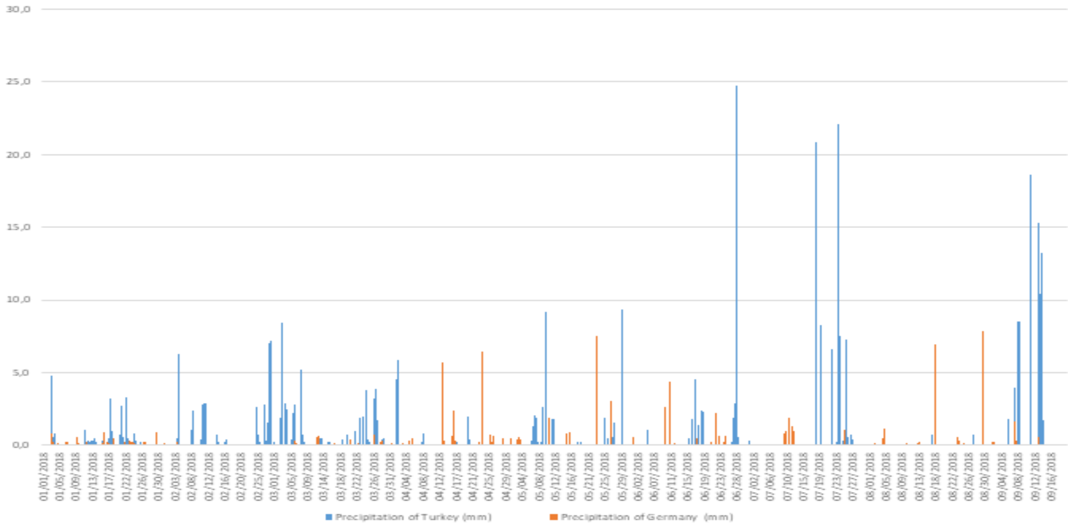


Figure 5.41 : Rainfall distribition in Turkey and Germany with 1-Minute resolution data

5.2.1. Uskudar region

In Figure 5.42, it is seen that the rainfall intensity in Germany is higher than the intensity in Turkey. However, in both situations, there is no flooding event. This means that even the cumulative rainfall amount doesn’t affect the flooding events when the resolution of data is 1 hour.

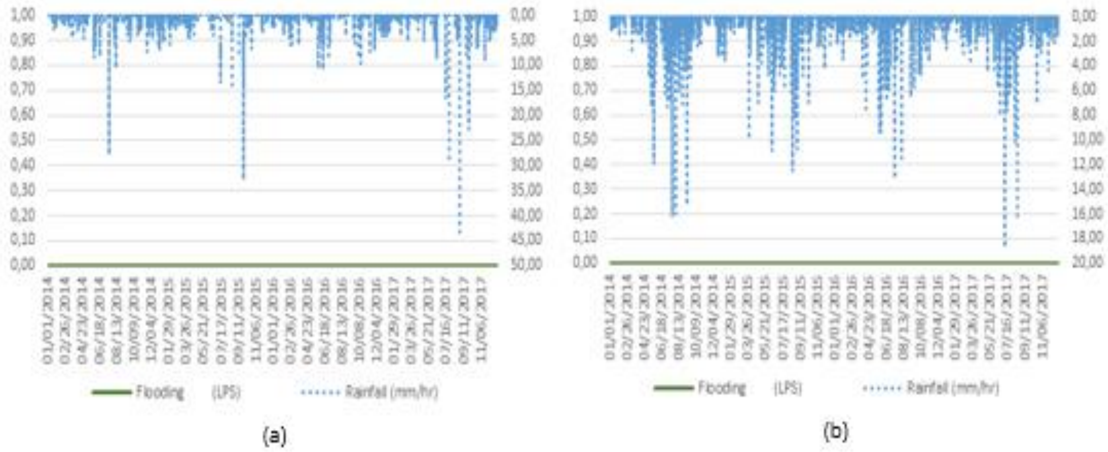


Figure 5.42 : (a) Flooding-Rainfall hyetograph of Uskudar region with 1-Hour resolution data of Tukey **(b)** Flooding-Rainfall hyetograph of Uskudar region with 1-Hour resolution data of Germany

The other results that belong to simulation with 1-Hour resolution scenario data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

In Figure 5.43, it is seen that the amount of rainfall in Turkey in 9 months period is higher than the amount of precipitation in Germany in the same period. When the model was simulated with 10-Minutes resolution data from Germany, according to Figure 5.43, the amount and number of floodings are both less than the results by the rainfall data from Turkey as it's supposed to be. As can be seen in Figure 5.44, with 10-Minutes resolution scenario data, flooded nodes percentage decreases from 57% to 26%.

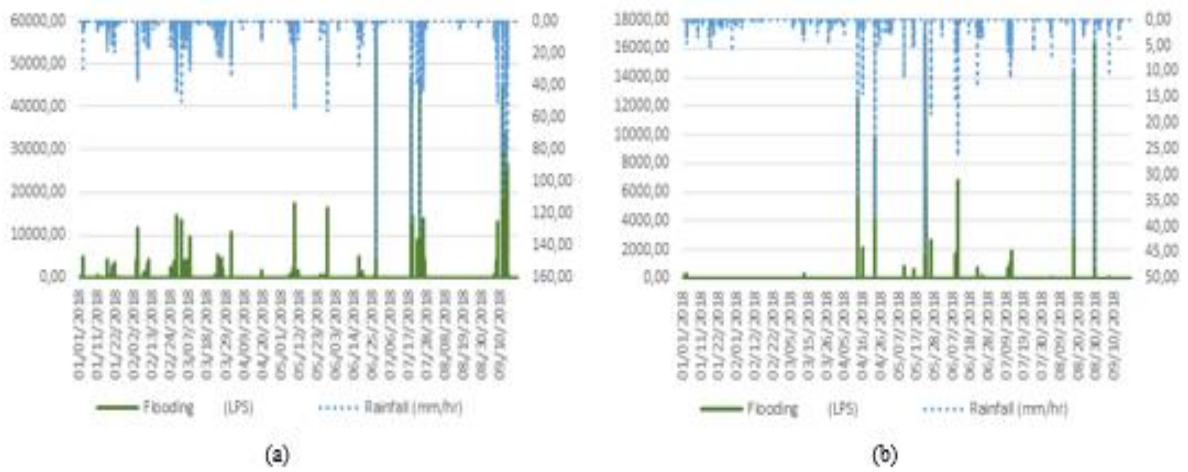


Figure 5.43 : (a) Flooding-Rainfall hyetograph of Uskudar region with 10-Minutes resolution data of Turkey **(b)** Flooding-Rainfall hyetograph of Uskudar region with 10-Minutes resolution data of Germany

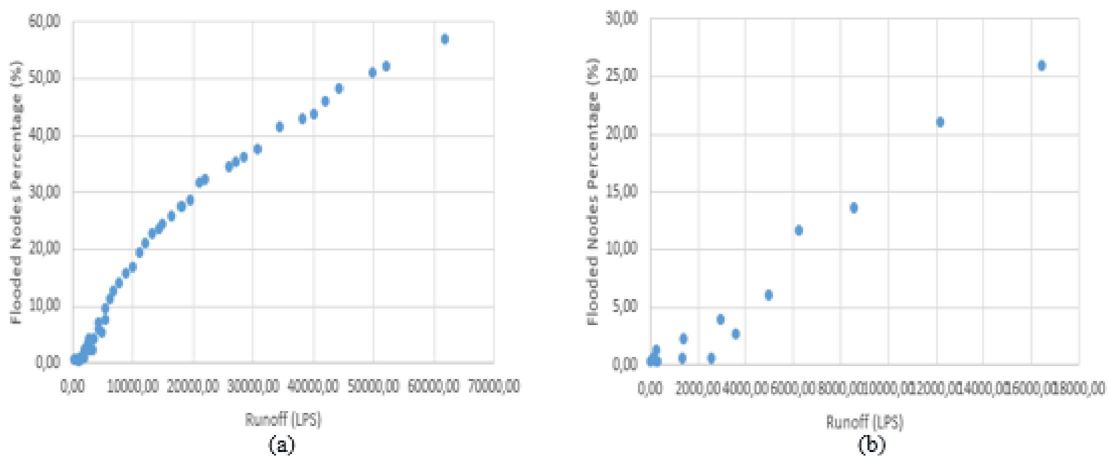
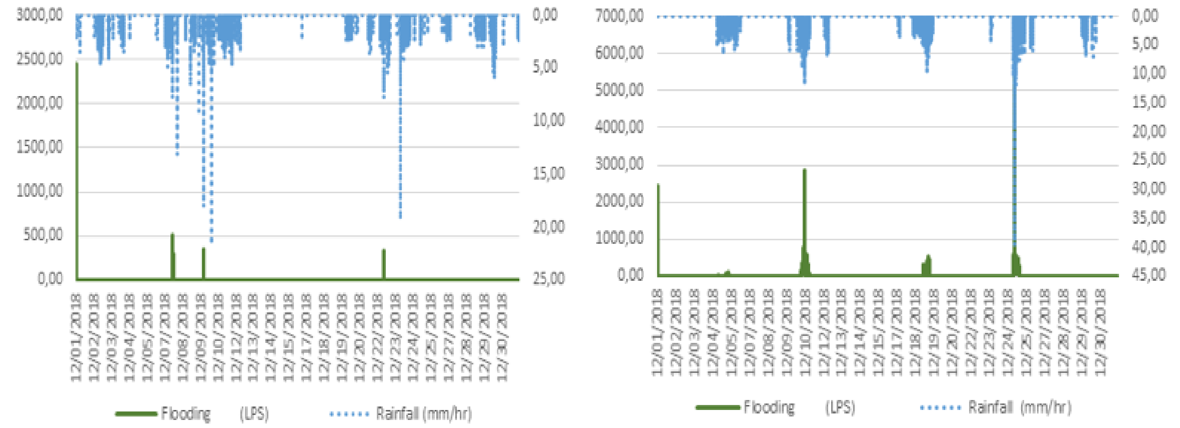


Figure 5.44 : (a) Flooded nodes percentage in Uskudar region with 10-Minutes resolution data of Turkey **(b)** Flooded nodes percentage in Uskudar region with 10-Minutes resolution data of Germany

The other results that belong to simulation with 10-Minutes resolution scenario data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

In Figure 5.45, it is seen that the amount of rainfall in Turkey in 1 month period is lower than the amount of rainfall in Germany in the same time period. However, for rainfall intensity, it is the opposite. Even though the rainfall intensity in Turkey is higher than in Germany,the flooding amount is higher in Germany because of the peak rainfall. With 1-Minute resolution scenario data, flooded nodes percentage observed as 14% and it is much more than the first case.

The other results that belong to simulation with 1-Minute resolution scenario data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.



(a) (b)

Figure 5.45 : (a) Flooding-Rainfall hyetograph of Uskudar region with 1-Minute resolution data of Turkey **(b)** Flooding-Rainfall hyetograph of Uskudar region with 1-Minute resolution data of Germany

5.2.2. Kadikoy region

In Figure 5.46, it is seen that the rainfall intensity in Germany is higher than the intensity in Turkey. Besides that, the rainfall amount in Turkey is higher than in Germany. However, in both situations, there is no flooding event, like the first region. This means that the amount or intensity of the rainfall doesn’t affect floodings when 1-Hour resolution data was used.

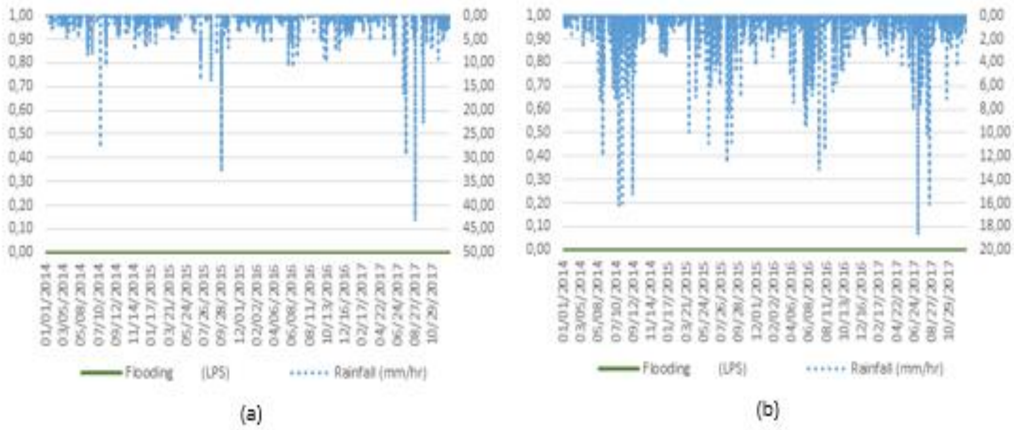


Figure 5.46 : (a) Flooding-Rainfall hyetograph of Kadikoy region with 1-Hour resolution data of Turkey **(b)** Flooding-Rainfall hyetograph of Kadikoy region with 1-Hour resolution data of Germany

The other results that belong to simulation with 1-Hour resolution scenario data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

In Figure 5.47, it is seen that the amount of rainfall in Turkey in 9 months period is higher than the amount of precipitation in Germany in the same period. Besides that when looked at the intensity, in Germany it is higher than in Turkey. When the model was simulated with 10-Minutes resolution data from Germany, according to Figure 5.47, flooding amount is less than the results by the rainfall data from Turkey as it is supposed to be. As can be seen in Figure 5.48, with 10-Minutes resolution scenario data, flooded nodes percentage decreases from 62% to 20%.

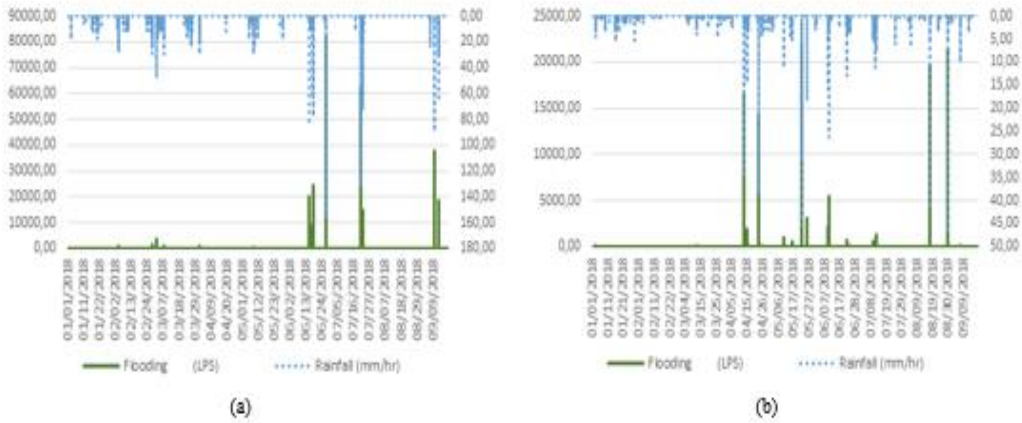


Figure 5.47 : (a) Flooding-Rainfall hyetograph of Kadikoy region with 10-Minutes resolution data of Turkey **(b)** Flooding-Rainfall hyetograph of Kadikoy region with 10-Minutes resolution data of Germany

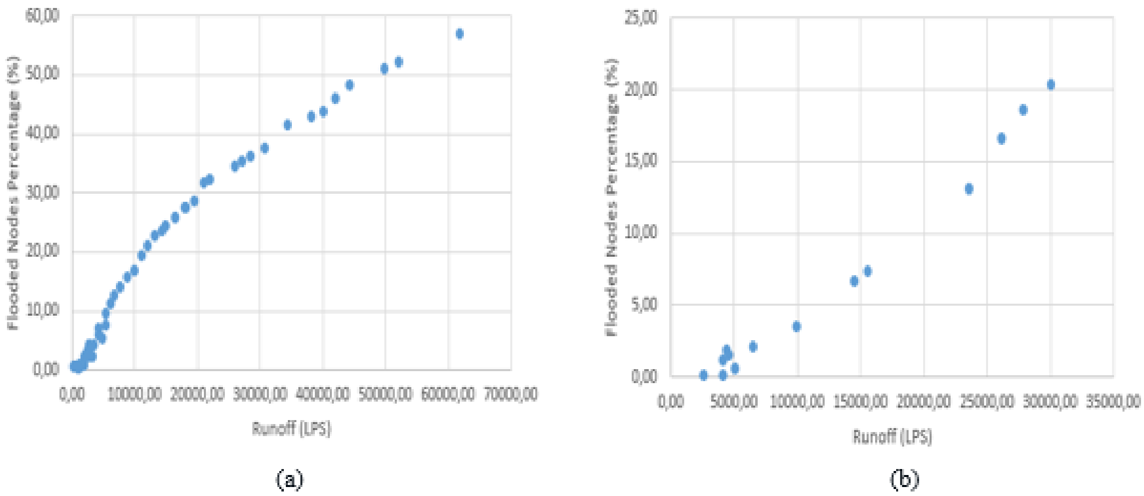


Figure 5.48 : (a) Flooded nodes percentage in Kadikoy region with 10-Minutes resolution data of Turkey **(b)** Flooded nodes percentage in Kadikoy region with 10-Minutes resolution data of Germany

The other results that belong to simulation with 10-Minutes resolution scenario data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

In Figure 5.49, it is seen that the amount of rainfall in Turkey in 1 month period is higher than the amount of rainfall in Germany in the same period. However, for rainfall intensity it is the opposite. When the model was simulated with 1-Minute resolution data from Germany, according to Figure 5.49, both the amount and number of flooding events are less in Germany than in Turkey. According to this result, it can be told that rainfall intensity is not effective in flooding events when 1-Minute resolution data is used in this region. With 1-Minute resolution scenario data, flooded nodes percentage decreases from 6% to 2%.

The other results that belong to simulation with 1-Minute resolution scenario data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

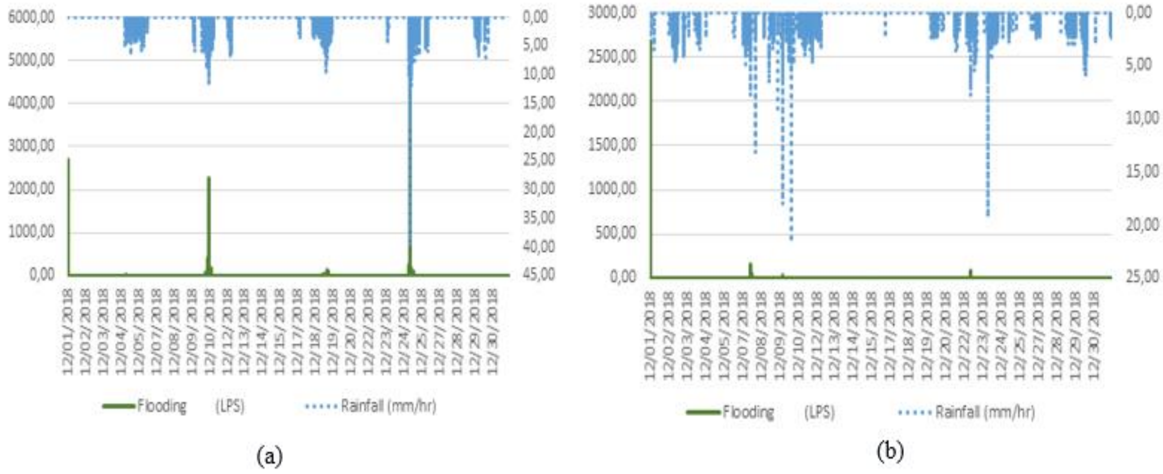


Figure 5.49 : (a) Flooding-Rainfall hyetograph of Kadikoy region with 1-Minute resolution data of Turkey **(b)** Flooding-Rainfall hyetograph of Kadikoy region with 1-Minute resolution data of Germany

5.2.3. Umraniye region

In Figure 5.50, it is seen that the intensity of rainfall in Germany in 4 years period is higher than in Turkey in the same period. However, the rainfall amount is higher in Turkey than in Germany. But, according to Figure 5.50, in both situations, there are no flooding events.

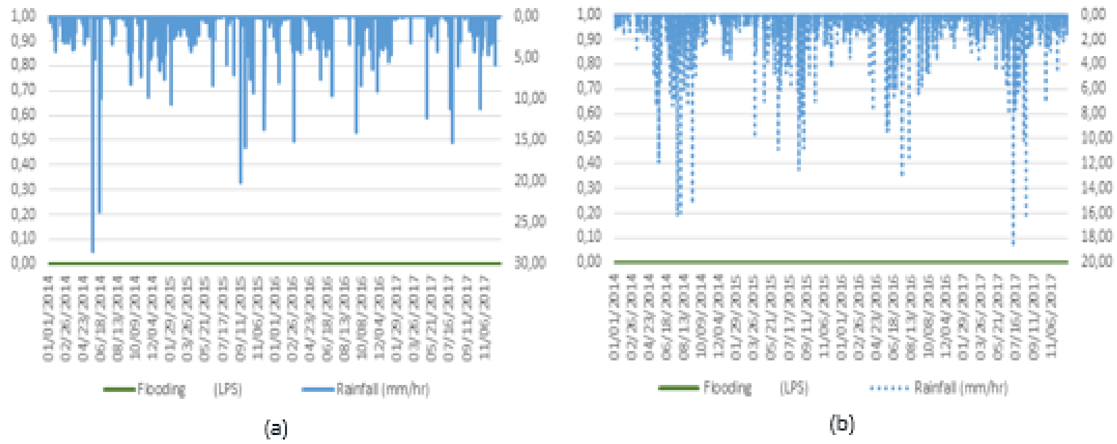


Figure 5.50 : (a) Flooding-Rainfall hyetograph of Umraniye region with 1-Hour resolution data of Turkey **(b)** Flooding-Rainfall hyetograph of Umraniye region with 1-Hour resolution data of Germany

The other results that belong to simulation with 1-Hour resolution scenario data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

In Figure 5.51, it is seen that the amount of rainfall inTurkey in 9 months period is higher than the amount of rainfall in Germany in the same period. When the model was simulated with 10-

Minutes resolution data from Germany, according to Figure 5.51, the amount and number of floodings are both less than the results by the rainfall data from Turkey as it is supposed to be. As can be seen in Figure 5.52, with 10-Minutes resolution scenario data, flooded nodes percentage decreases from 49% to 9%.

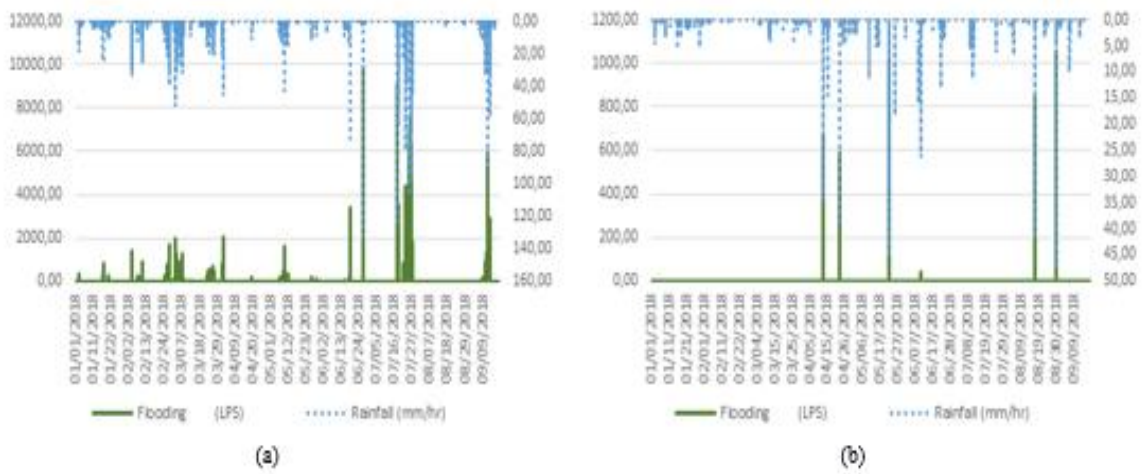


Figure 5.51 : (a) Flooding-Rainfall hyetograph of Umraniye region with 10-Minutes resolution data of Turkey **(b)** Flooding-Rainfall hyetograph of Umraniye region with 10-Minutes resolution data of Germany

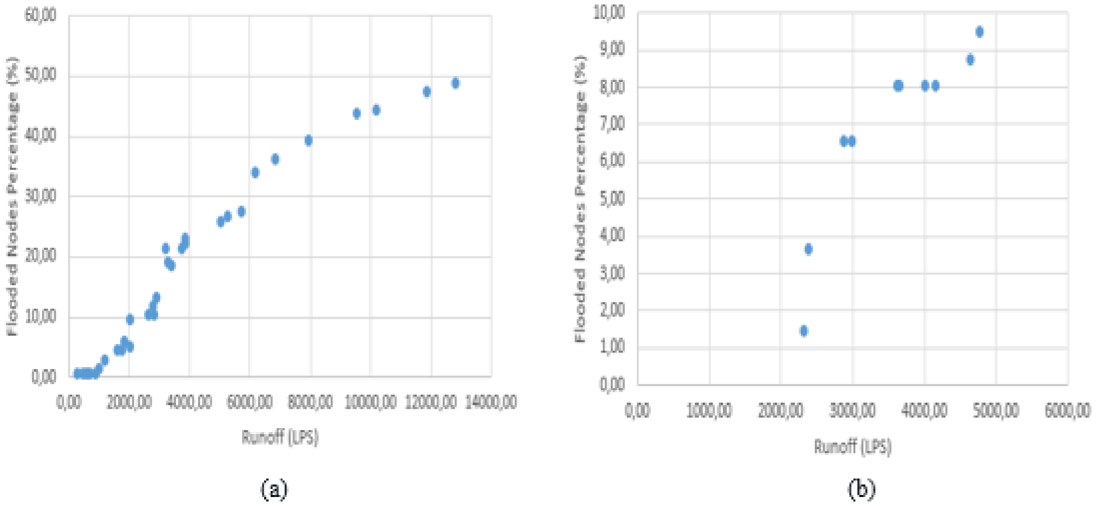


Figure 5.52 : (a) Flooded nodes percentage in Umraniye region with 10-Minutes resolution data of Turkey **(b)** Flooded nodes percentage in Umraniye region with 10-Minutes resolution data of Germany

The other results that belong to simulation with 10-Minutes resolution scenario data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

In Figure 5.53, it is seen that the amount of rainfall in Turkey in 1 month period is higher but less intense than in Germany in the same period. However, in both cases, there is no flooding event. This hyetograph demonstrates that when the rainfall is cumulative, it doesn't really effective on flooding events.

The other results that belong to simulation with 1-Minute resolution scenario data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

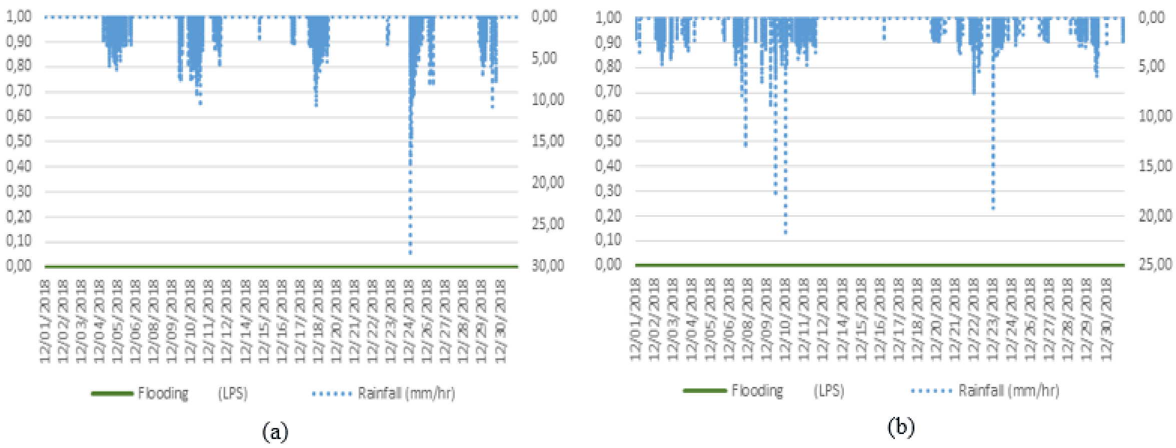


Figure 5.53 : (a) Flooding-Rainfall hyetograph of Umraniye region with 1-Minute resolution data of Turkey **(b)** Flooding-Rainfall hyetograph of Umraniye region with 1-Minute resolution data of Germany

5.2.4. Lockwitz region

In Figure 5.54, it is seen that the intensity of rainfall in Germany is higher than in Turkey. However, for the rainfall amount, the situation is the opposite. In Turkey, the rainfall amount is more than two times more than in Germany. But according to simulation results, the amount and number of flooding events by the rainfall data from Turkey are both fewer than the results by the rainfall data from Germany. This means that even with more amount of rainfall, there are less amount and number of flooding events in Germany. Peak rainfalls are not effective in flooding events as much as cumulative rainfalls for this region. But in both cases, even with more than two times more rainfall amount, the same nodes are flooded.

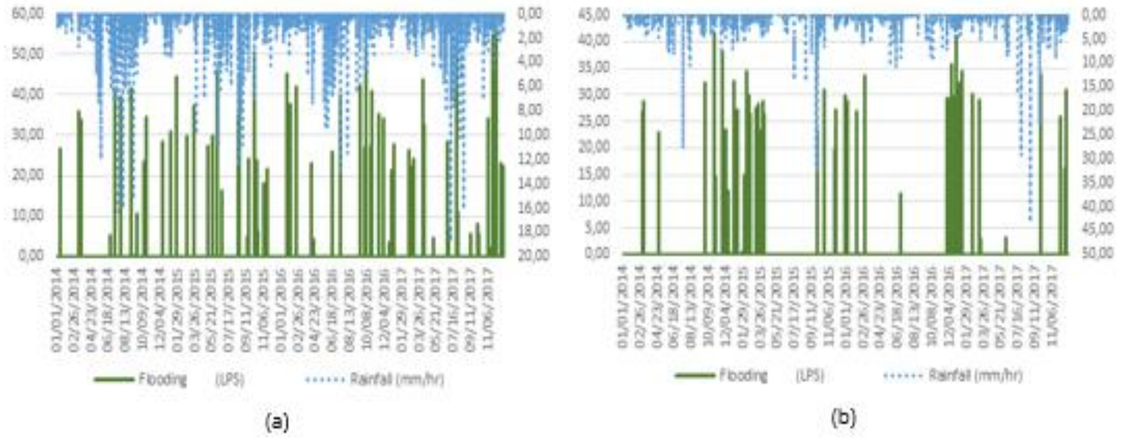


Figure 5.54 : (a) Flooding-Rainfall hyetograph of Lockwitz region with 1-Hour resolution data of Germany **(b)** Flooding-Rainfall hyetograph of Lockwitz region with 1-Hour resolution data of Turkey

The other results that belong to simulation with 1-Hour resolution scenario data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

In Figure 5.55, it is seen that the amount of rainfall in Turkey in 9 months period is much higher than the amount of rainfall in Germany in the same period. When the model was simulated with 10-Minutes resolution data from Turkey, the number of flooding events in Germany incredibly increased. As can be seen in Figure 5.56, with 10-Minutes resolution scenario data, flooded nodes percentage increases from 32% to 46%. Even with the huge difference in rainfall and flooding amounts between these two scenarios, there is not a big difference in the percentage of the flooded nodes.

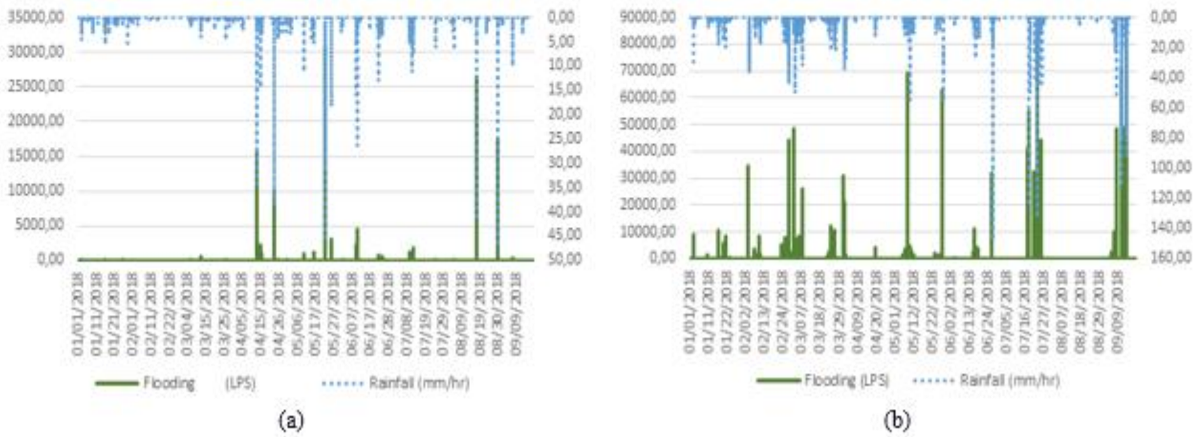


Figure 5.55 : (a) Flooding-Rainfall hyetograph of Lockwitz region with 10-Minutes resolution data of Germany **(b)** Flooding-Rainfall hyetograph of Lockwitz region with 10-Minutes resolution data of Turkey

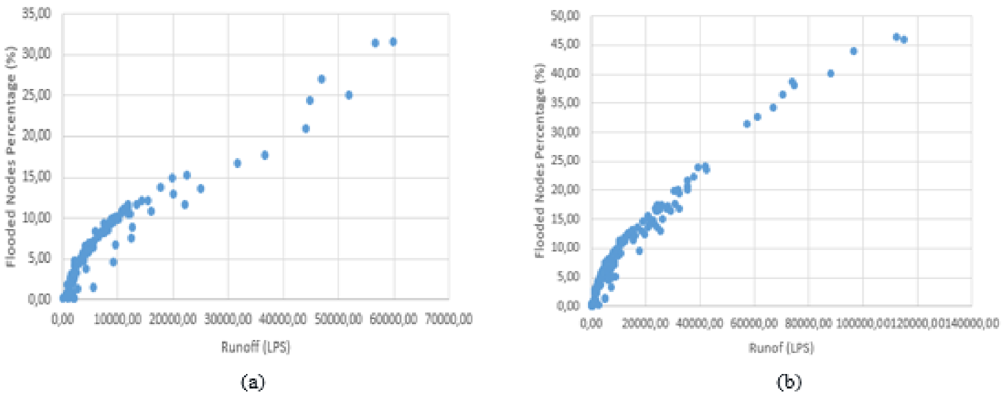


Figure 5.56 : (a) Flooded nodes percentage in Lockwitz region with 10-Minutes resolution data of Turkey **(b)** Flooded nodes percentage in Lockwitz region with 10-Minutes resolution data of Germany

The other results that belong to simulation with 10-Minutes resolution scenario data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

In Figure 5.57, it is seen that the amount of rainfall in Turkey in 1 month period is higher than the amount of rainfall in Germany in the same period. When the model was simulated with 1-Minute resolution data from Turkey, according to Figure 5.57, although the amount of floodings is higher than the results by the rainfall data from Germany, it is seen that the number of flooding events is less. With 1-Minute resolution scenario data, flooded nodes percentage decreases from 32% to 13%. This means that with cumulative rainfalls, there is more number of flooding events and more flooded nodes, even though the peak rainfalls cause more amount of floodings.

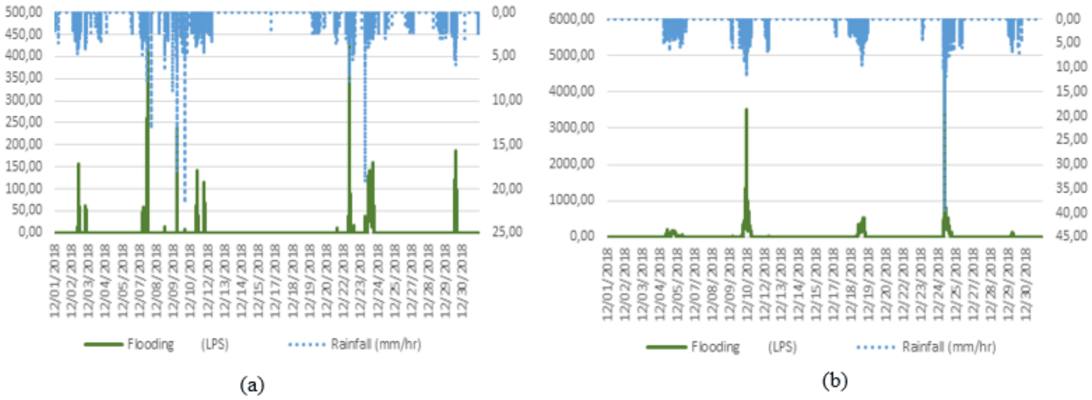


Figure 5.57 : (a) FloodingRainfall hyetograph of Lockwitz region with 1-Minute resolution data of Germany **(b)** Flooding-Rainfall hyetograph of Lockwitz region with 1-Minute resolution data of Turkey

The other results that belong to simulation with 1-Minute resolution scenario data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

5.3. Running Models with the Regions' Converted Data

In this part of the study, all the models were simulated with the 1-Hour and 10-Minutes resolution data converted from 1-Minute resolution data of each region. Thus, it was aimed to see how the models react at the same time range with different resolutions. Nodes in the catchment figures in this chapter have some meaningful colors. There can be seen a legend to understand better the meaning of the colors in Figure 5.58 below.

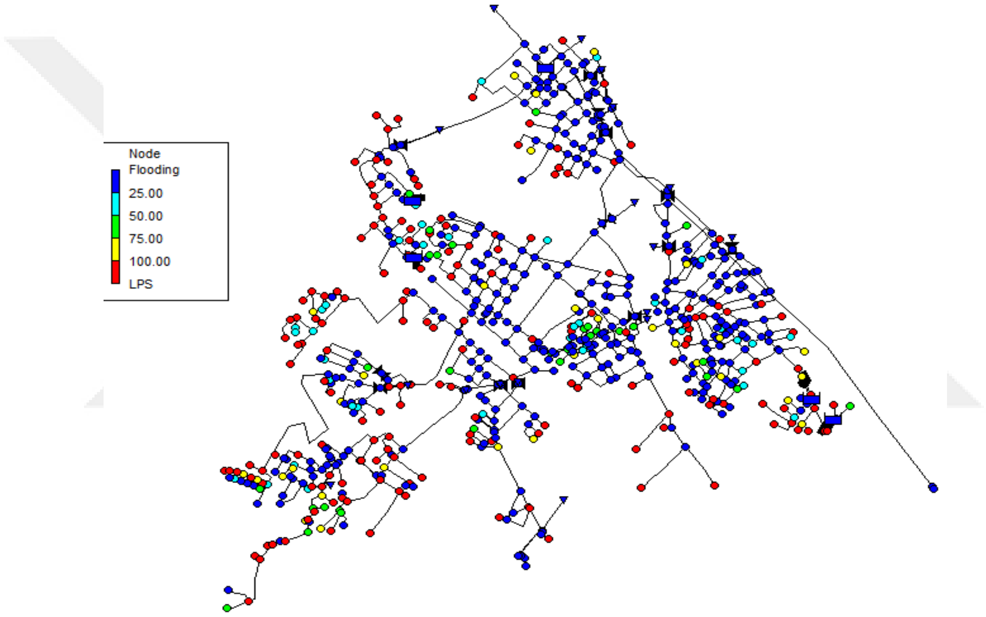


Figure 5.58 : Legent of the catcthment maps

5.3.1. Uskudar region

When the model was simulated with converted 1-Hour resolution data, as seen in Figure 5.59, in both cases, there is no flooded node.

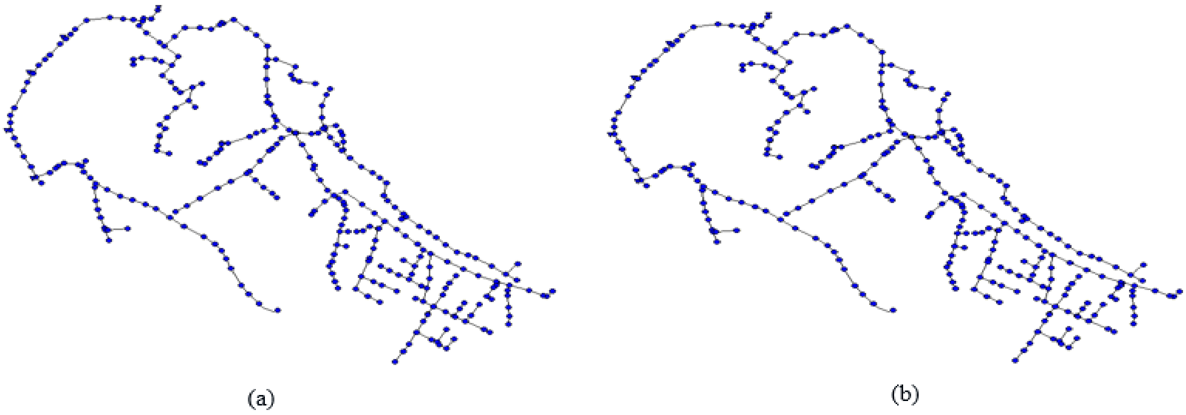


Figure 5.59 : (a) Flooded nodes in Uskudar region with original 1-Hour resolution data **(b)** Flooded nodes in Uskudar region with converted 1-Hour resolution data

The other results that belong to simulation with converted 1-Hour resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

When the model was simulated with converted 10-Minutes resolution data, 11% of 300 nodes are flooded. With original data, the percentage was 57%. Also, as seen in Figure 5.60 and Figure 5.61, compared to the first case, much fewer nodes are flooded. In the one-month time range, the peak flooding amount is ten times fewer than the peak flooding amount in nine-months time range and the network responds to this situation as it is supposed to be.

Figure 5.60 : (a) Flooded nodes in Uskudar region with original 10-Minutes resolution data **(b)** Flooded nodes in Uskudar region with converted 10-Minutes resolution data

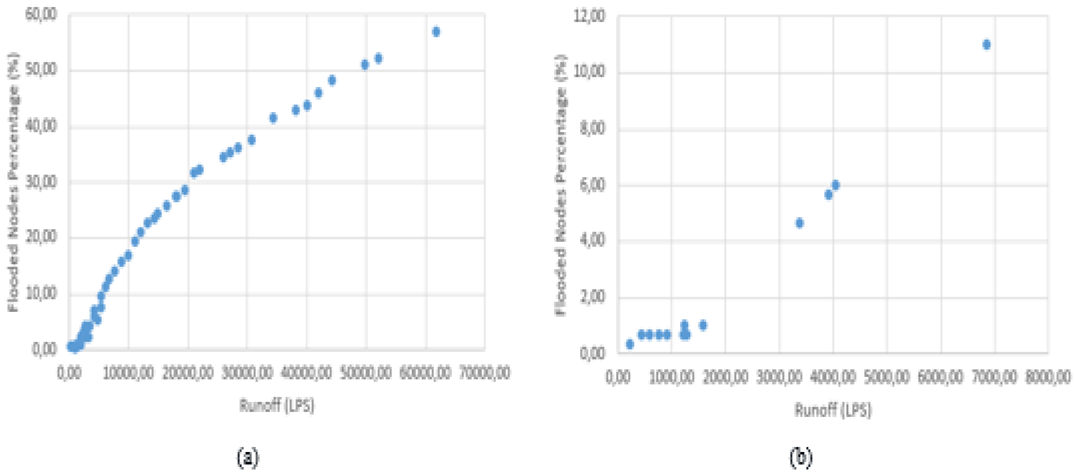


Figure 5.61 : (a) Percentage of flooded nodes in Uskudar region with original 10-Minutes resolution data **(b)** Percentage of flooded nodes in Uskudar region with converted 10-Minutes resolution data

The other results that belong to simulation with converted 10-Minutes resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

5.3.2. Kadikoy region

When the model was simulated with converted 1-Hour resolution data, as seen in Figure 5.62, in both cases, there is no flooded node.

Figure 5.62 : (a) Flooded nodes in Kadikoy region with original 1-Hour resolution data **(b)** Flooded nodes in Kadikoy region with converted 1-Hour resolution data

The other results that belong to simulation with converted 1-Hour resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

When the model was simulated with converted 10-Minutes resolution data, 6% of 511 nodes are flooded. With original data, the percentage was 62%. Also, as seen in Figure 5.63 and Figure 5.64, compared to the first case, much fewer nodes are flooded. In the one-month time range, the peak flooding amount is more than ten times fewer than the peak flooding amount in nine-months time range and the network responds to this situation as it is supposed to be.

The other results that belong to simulation with converted 10-Minutes resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

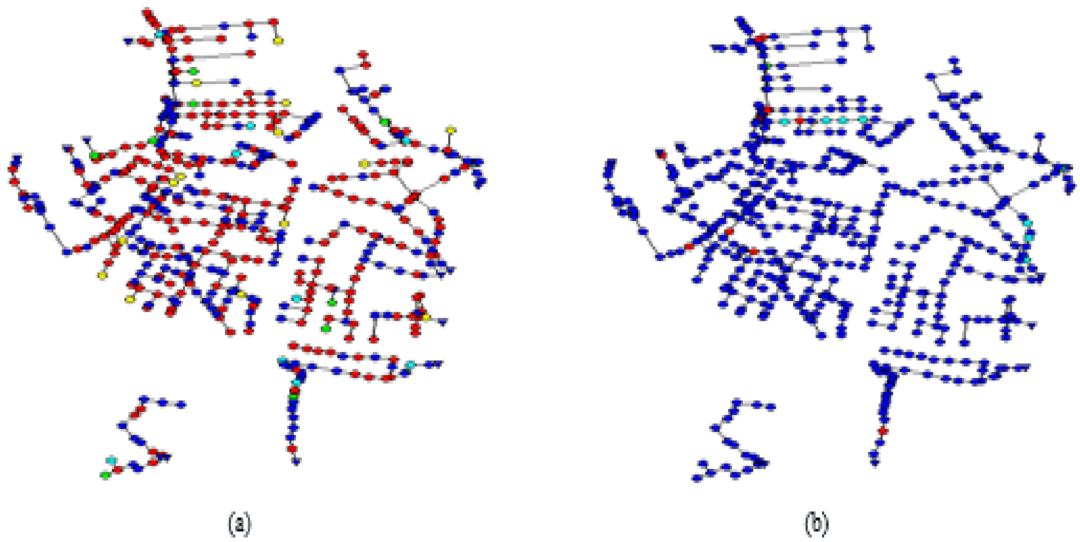


Figure 5.63 : (a) Flooded nodes in Kadikoy region with original 10-Minutes resolution data **(b)** Flooded nodes in Kadikoy region with converted 10-Minutes resolution data

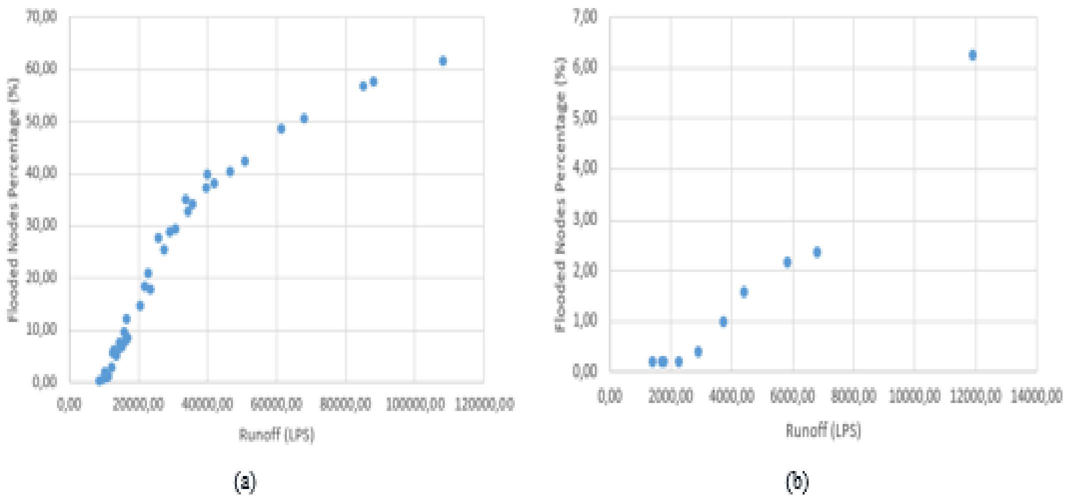


Figure 5.64 : (a) Percentage of flooded nodes in Kadikoy region with original 10-Minutes resolution data **(b)** Percentage of flooded nodes in Kadikoy region with converted 10-Minutes resolution data

5.3.3. Umraniye region

When the model was simulated with converted 1-Hour resolution data, according to Figure 5.65, it is seen the same situation. In both cases, there is no flooded node.

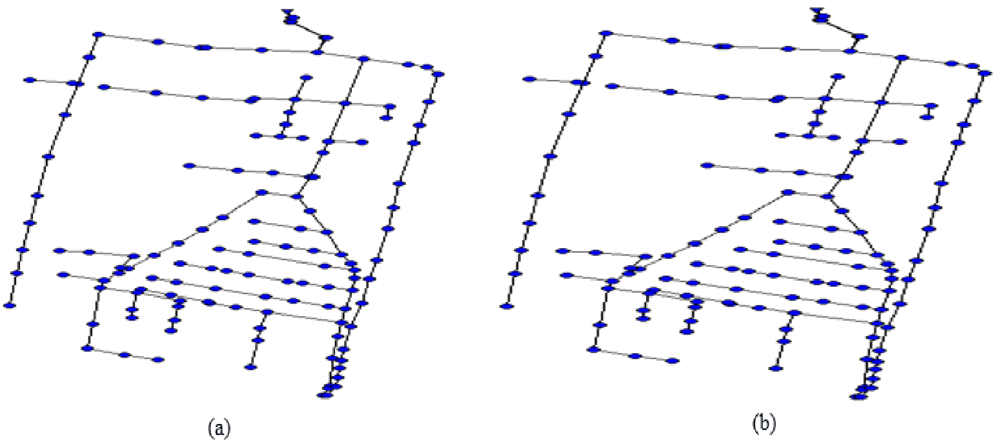


Figure 5.65 : (a) Flooding situation in Umraniye region with original 1-Hour resolution data **(b)** Flooding situation in Umraniye region with converted 1-Hour resolution data

The other results that belong to simulation with converted 1-Hour resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

When the model was simulated with original data 49% of 137 nodes are flooded. However, with converted 10-Minutes resolution data, there isn't any flooded node as seen in Figure 5.66.

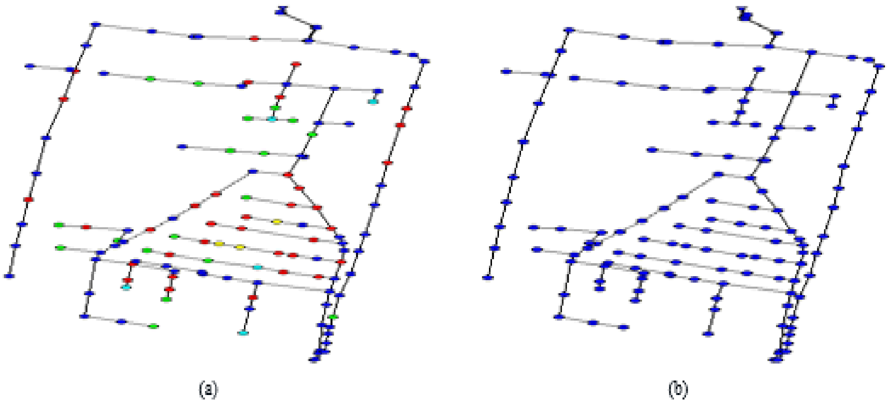


Figure 5.66 : (a) Flooded nodes in Umraniye region with original 10-Minutes resolution data **(b)** Flooded nodes in Umraniye region with converted 10-Minutes resolution data

The other results that belong to simulation with converted 10-Minutes resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

5.3.4. Lockwitz region

When the model was simulated with converted 1-Hour resolution data, as seen in Figure 5.67, the same number of nodes are flooded. In both cases, there are 15 flooded nodes. Because there is no such difference in flooding amounts like the other regions.

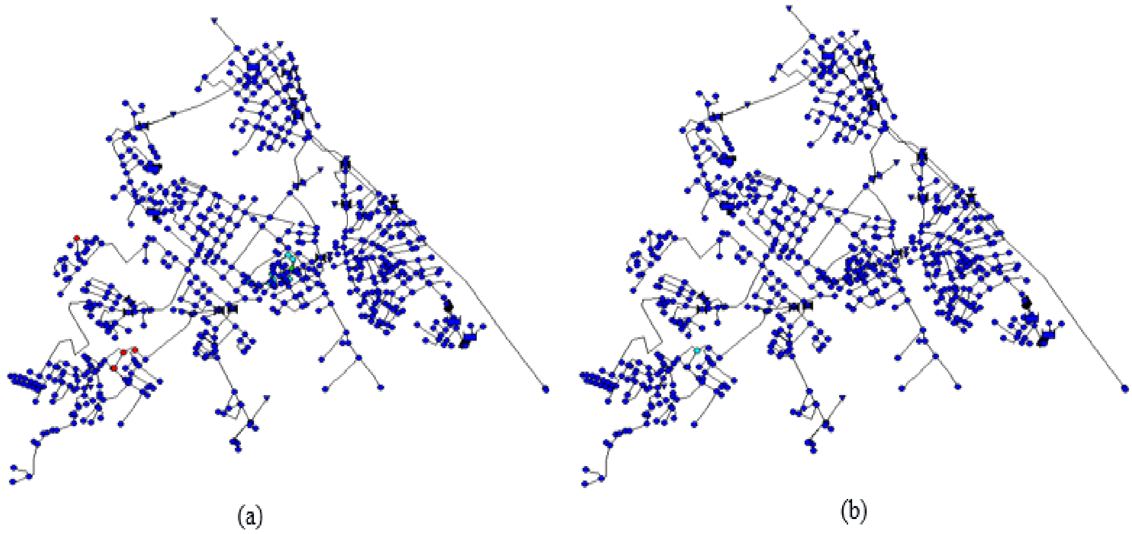


Figure 5.67 : (a) Flooded nodes in Lockwitz region with original 1-Hour resolution data **(b)** Flooded nodes in Lockwitz region with converted 1-Hour resolution data

The other results that belong to simulation with converted 1-Hour resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

When the model was simulated with converted 10-Minutes resolution data, 5% of 679 nodes are flooded. With original data, the percentage was 32%. Also, as seen in Figure 5.68 and Figure 5.69, compared to the first case, much fewer nodes are flooded. There is a huge difference between the peak flooding amounts in one-month time range and nine-months time range and the network responds to this situation as it is supposed to be.

The other results that belong to simulation with converted 10-Minutes resolution data; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

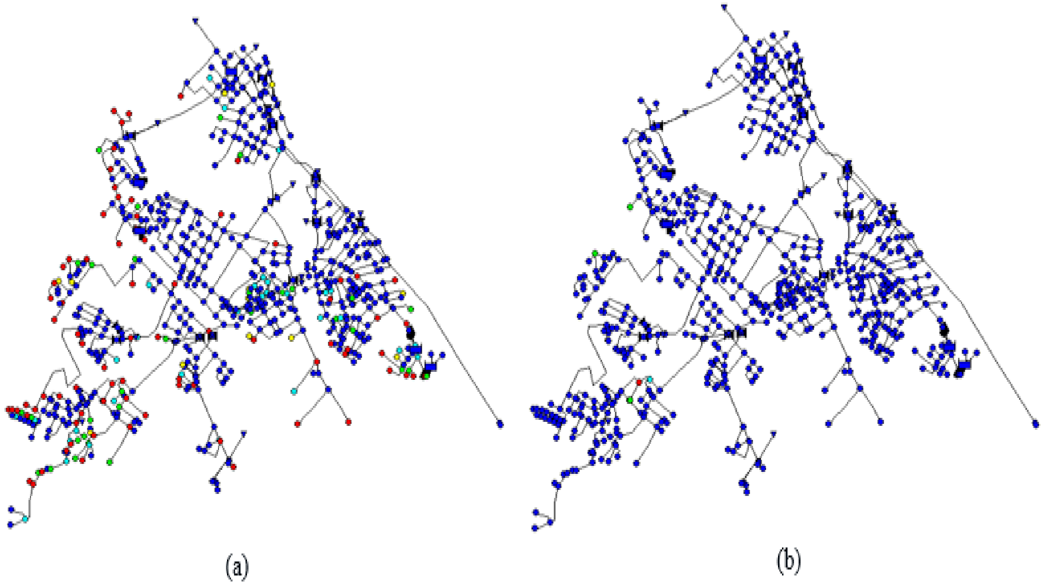
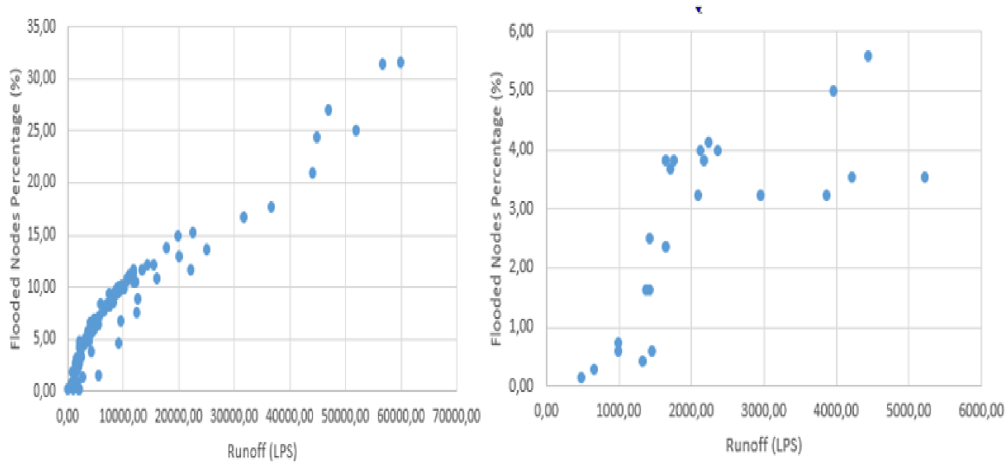


Figure 5.68 : (a) Flooded nodes in Lockwitz region with original 10-Minutes resolution data **(b)** Flooded nodes in Lockwitz region with converted 10-Minutes resolution data



(a) (b)

Figure 5.69 : (a) Percentage of flooded nodes in Lockwitz region with original 10-Minutes resolution data **(b)** Percentage of flooded nodes in Lockwitz region with converted 10-Minutes resolution data

5.4. Running Models with Physical Modifies on Network

After all meteorological scenarios, it was decided that while flooding modeling, it is better to use rainfall data with 10-Minutes resolution for the regions that have those sizes. In all cases, 10-Minutes resolution data gave more sensible and realistic results.

In this part of the study, it was aimed to see how the models react to the best resolution of meteorological data with some physical modifies on the networks. Thus, it could be tried to minimize that much flooding events.

5.4.1. Running models after the modifications made by Urbano software

For the purpose of minimizing the flooding events, utilized Urbano software. In this case, stormwater networks of all regions in Istanbul projected on Urbano software. As mentioned in part 3.2.3, Urbano software can determine the problems on the networks and it can suggest the modifications automatically for fixing those problems. After the modifications by that software (changing diameters of some conduits, changing slopes, etc.) the models were run on SWMM with their original meteorological data.

After the modifications by Urbano software, as seen in Figure 5.70, in Uskudar region, flooded nodes percentage decreased from 57% to around 43%.

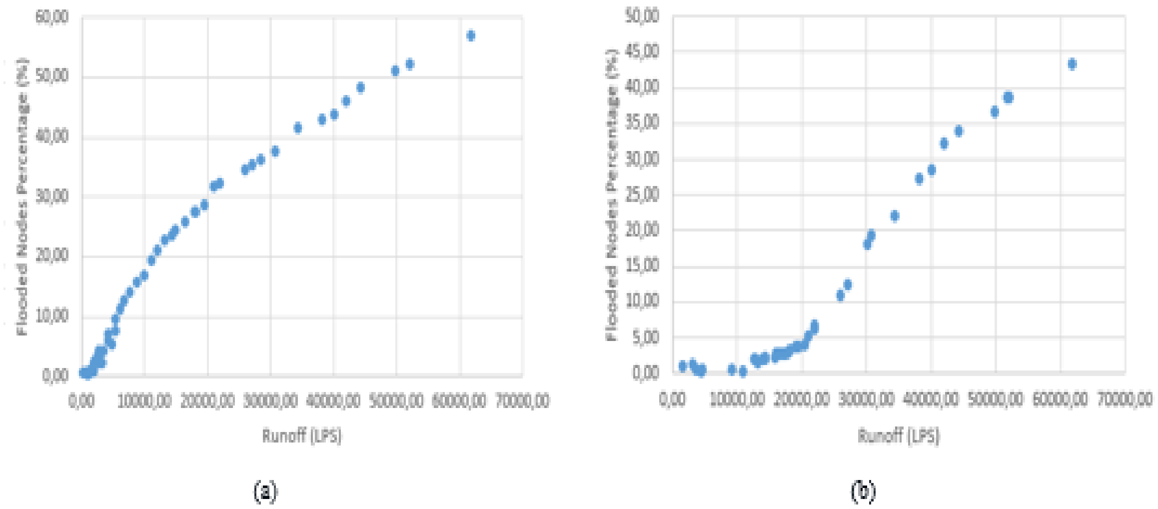


Figure 5.70 : (a) Flooded nodes percentage in Uskudar region in original situation **(b)** Flooded nodes percentage in Uskudar region after modifications by Urbano software

For Kadikoy region, flooded nodes percentage decreased from 62% to around 55% after modifications by Urbano software as can be seen in Figure 5.71.

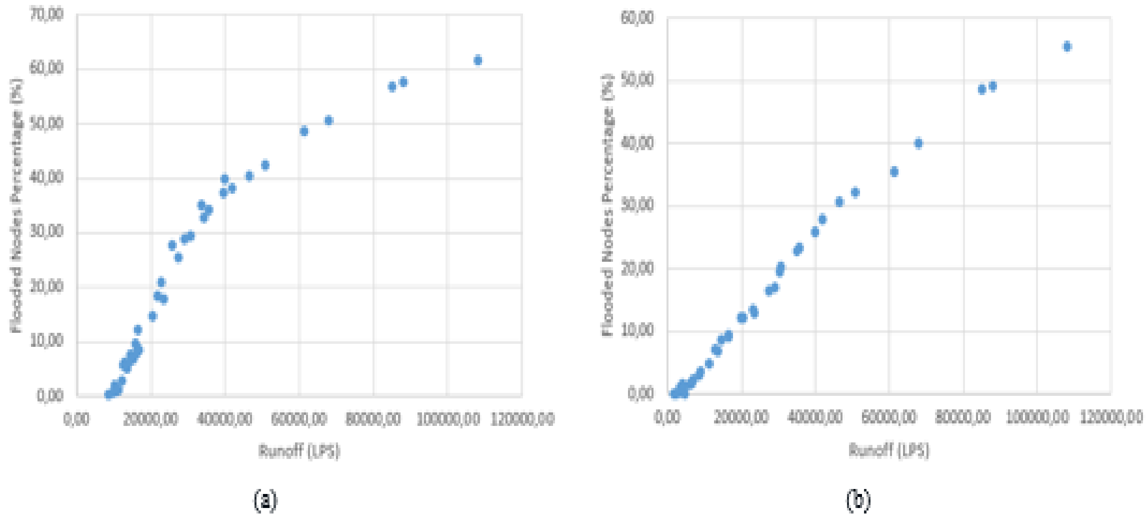


Figure 5.71 : (a) Flooded nodes percentage in Kadikoy region in original situation **(b)** Flooded nodes percentage in Kadikoy region after modifications by Urbano software

Finally, for the Umraniye region, flooded nodes percentage decreased from 49% to around 25% after modifications by Urbano software as can be seen in Figure 5.72, there is 50% improvement in this region.

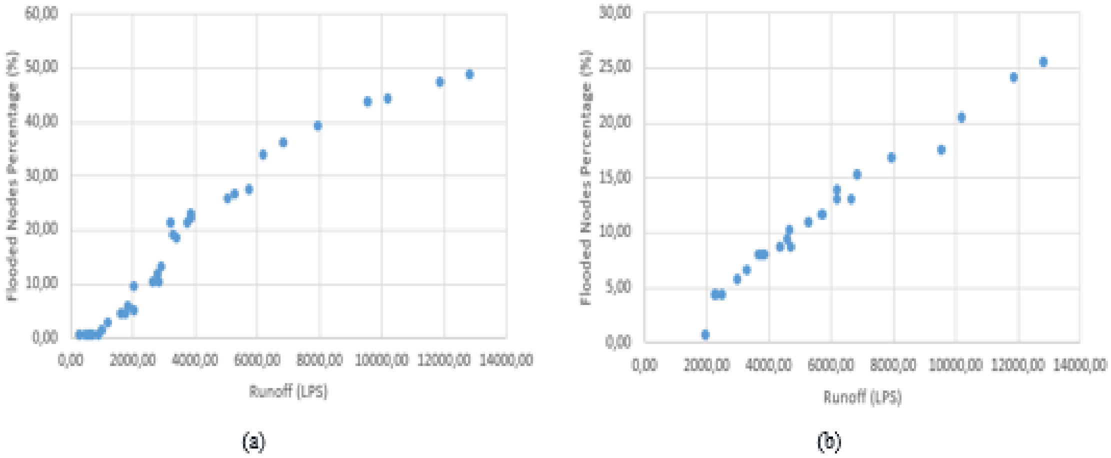


Figure 5.72 : (a) Flooded nodes percentage in Umraniye region in original situation **(b)** Flooded nodes percentage in Umraniye region after after modifications by Urbano software

The other results that belong to simulation after the modifications by Urbano software; like rainfall, runoff and flooding hyetographs, flooded nodes and their percentage; can be found in Appendices.

With the results were obtained after the modifications, it can be told that it is possible to modificate the system to make it better for responding to the rainfalls. Thus, it can be prevented that much flooding events and can be made the regions more livable.

To see the results and the difference between them easier, it can be investigated Table 5.1, Table 5.2, Table 5.3, Table 5.4 and Table 5.5. In these tables, it can be seen peak values of rainfall, runoff and floodings, also flooded nodes percentage for each case and each region. It is necessary to note that, modifications were applied by Urbano software with only 10-Minutes resolution data, due to it was already determined that 10-Minutes resolution data is the data type which the most accurate results can be observed.

Table 5.1 : Peak values of rainfall, runoff and floodings in Uskudar region

	USKUDAR REGION								
	1-Hour Resolution Data			10-Minutes Resolution Data			1-Minute Resolution Data		
	Peak Rainfall (mm)	Peak Runoff (LPS)	Peak Flooding (LPS)	Peak Rainfall (mm)	Peak Runoff (LPS)	Peak Flooding (LPS)	Peak Rainfall (mm)	Peak Runoff (LPS)	Peak Flooding (LPS)
Original Data	43.20	117.90	0	148.20	61732.08	56179.89	21.60	1996.86	2458.40
Scenario Data	18.70	118.41	0	47.16	20127.80	16976.68	39.60	9626.89	5864.44
Converted Data	0.98	130.02	0	18.12	6859.69	4842.28	-	-	-
After Modifications by Urbano	-	-	-	148.20	61712.77	55976.68	-	-	-

Table 5.2 : Peak values of rainfall, runoff and floodings in Kadikoy region

	KADIKOY REGION								
	1-Hour Resolution Data			10-Minutes Resolution Data			1-Minute Resolution Data		
	Peak Rainfall (mm)	Peak Runoff (LPS)	Peak Flooding (LPS)	Peak Rainfall (mm)	Peak Runoff (LPS)	Peak Flooding (LPS)	Peak Rainfall (mm)	Peak Runoff (LPS)	Peak Flooding (LPS)
Original Data	43.20	352.17	0	156	108144.9	90782.45	39.60	15741.12	5652.70
Scenario Data	18.70	418.87	0	47.16	32672.10	21937.65	21.60	3195.02	2682.50
Converted Data	0.98	460.25	0	18.12	11884.29	5195.55	-	-	-
After Modifications by Urbano	-	-	-	156	108144.9	82250.78	-	-	-

Table 5.3 : Peak values of rainfall, runoff and floodings in Umraniye region

	UMRANIYE REGION								
	1-Hour Resolution Data			10-Minutes Resolution Data			1-Minute Resolution Data		
	Peak Rainfall (mm)	Peak Runoff (LPS)	Peak Flooding (LPS)	Peak Rainfall (mm)	Peak Runoff (LPS)	Peak Flooding (LPS)	Peak Rainfall (mm)	Peak Runoff (LPS)	Peak Flooding (LPS)
Original Data	28.40	46.31	0	135	12827.95	9737.89	28.20	1308.90	0
Scenario Data	18.70	56.63	0	47.16	4770.77	1051.58	21.60	503.54	0
Converted Data	0.98	62.10	0	6	432.52	0	-	-	-
After Modifications by Urbano	-	-	-	135	12827.95	7491.66	-	-	-

Table 5.4 : Peak values of rainfall, runoff and floodings in Lockwitz region

	LOCKWITZ REGION								
	1-Hour Resolution Data			10-Minutes Resolution Data			1-Minute Resolution Data		
	Peak Rainfall (mm)	Peak Runoff (LPS)	Peak Flooding (LPS)	Peak Rainfall (mm)	Peak Runoff (LPS)	Peak Flooding (LPS)	Peak Rainfall (mm)	Peak Runoff (LPS)	Peak Flooding (LPS)
Original Data	18.70	1463.91	55.58	47.16	59863.43	30603.22	21.60	5609.70	445.33
Scenario Data	43.20	1343.73	41.64	148.20	124775.6	82815.09	39.60	22981.06	5148.57
Converted Data	0.90	1427.53	45.13	5.45	5215.33	433.68	-	-	-

Table 5.5 : Flooded nodes percentage with all type of data for each region

	Flooded Nodes Percentage (%)											
	Uskudar			Kadikoy			Umraniye			Lockwitz		
	1-Hour	10-Minutes	1-Minute	1-Hour	10-Minutes	1-Minute	1-Hour	10-Minutes	1-Minute	1-Hour	10-Minutes	1-Minute
Original Data	0	57	1.6	0	62	6	0	49	0	2.2	32	5
Scenario Data	0	26	14	0	20	2	0	9	0	2.2	46	13
Converted Data	0	11	-	0	6	-	0	0	-	2.2	5	-
After Modifications by Urbano	-	43	-	-	55	-	-	25	-	-	-	-

6. DISCUSSIONS

- The resolution of rainfall data is one of the most important factors for the flooding modeling process. 1-Hour resolution data is not enough for flooding modeling the regions which have those sizes. Besides that, 1 minute is too small for this kind of measurements. Also, accuracy is difficult to check because it is a very precise measurement and deviation can be high. The most accurate results were observed with 10-Minutes resolution data and real flooding events confirmed that models give us correct results. For example, according to results, peak flooding evens happened on 27.06.2018 in Uskudar and Kadikoy regions with 10-Minutes data and indeed, there is flooding event on that day in those regions as seen in Figure 6.1.

(a) (b)

Figure 6.1 : (a) Flooding event on 27.06.2018 in Uskudar region (https://www.youtube.com/watch?v=MklWoi-lv_o) **(b)** Flooding event on 27.06.2018 in Kadikoy region (https://www.sozcu.com.tr/2018/gundem/son-dakika-ataturk-havalimaninda-hava-trafigi-durdu-2491487/)

- When the scenario data applied, it was seen that the networks in the regions in Istanbul could respond better to cumulative rainfall. Between the simulation results in the original case and in scenario case, there was a big difference. Besides that, when the rainfall data of Istanbul was applied in the region in Dresden, there was not a that big difference between these cases. The region in Dresden could respond well to the peak rainfall amounts of Istanbul even though the network was planned for less amount of rainfall. This means that while modeling, taking into account the average rainfall is not enough for the regions in Istanbul. Peak rainfalls also should be considered while modeling. If the rainfall intensity increases in the future, there will be more serious flooding events in Istanbul. The infrastructural network of the regions in Istanbul can not respond to heavier rainfalls.

- After the expansion of 1-Minute resolution data to 10-Minutes and 1-Hour resolutions, in the same 1 month time period, 10-Minutes resolution data gave the most proper results again. Therefore, it can be told that it is not so important how long the time range is or the data belongs to which date.
- Green area and permeability are important factors to prevent flooding events. In urbanization, project design should be made considering the flow coefficient. By considering factors such as settlement capacity, environmental impact and green area, etc., a coefficient limit should be determined and this limit should not be exceeded since the high permeability of the catchment enables the catchment to respond even to higher amounts of rainfall. Because, when permeable surfaces are increased, some amount of water does not flow directly into the system and the load of the system decrease. In the region in Dresden, the flow coefficient is almost 0.5. However, for the regions in Istanbul, it can be considered as 1. It might be a solution that not exceeding 0.7 for flow coefficient in settlements. This situation can be considered while urban planning.
- In Istanbul, settlement has increased day by day and it is quite irregular. Increased population caused increased structures and also increased infrastructure. But increased infrastructure, instead of solving the problems, became problems due to being unplanned and poor projected. So, infrastructural systems in Istanbul is getting more and more complicated by time. Urban planning has to been made according to infrastructural capacity because the capacity can not be expanded after some point or can not respond at any change on the rainfall regime.
- If some hydraulic modifications are made (changing slopes, diameters, etc.), it was demonstrated that some optimizations are possible to prevent that much flooding events. The weak parts of the system, for example, the nodes which floods occur, the amount of floods in those nodes, rainfall amounts which cause

floods, the pipes which insufficient in transmission, can be determined by such programs like SWMM and Urbano and necessary corrections can be provided. With the help of these programs, municipalities should make some improvements in infrastructure systems and make life in the city more qualified and comfortable.

- Deficient and inaccurate parts of infrastructure data of Istanbul may cause mistakes in modeling. Inaccuracies and deficiencies in infrastructure data directly affect the reliability of the study, at the same time the results may be different from what supposed to be. Administrations should keep all the data accurate, consummate and also actual.

7. CONCLUSION

As a result of this study, it was determined that the flooding problems in Istanbul are mostly in stormwater collection systems. Especially in the old settlements, in areas where the lines are not sufficient, instead of making improvements, saving the day by making new additions, made the system more complicated and the problem reached an insoluble dimension. The high level of optimization of the problem with the changes in the physical structure of the system showed that the biggest share in the source of the problem belongs to project errors.

On the other hand, it was observed that the systems examined were generally able to respond to the existing precipitation but were not resistant to peak precipitation. It was revealed that the meteorological data chosen during the projecting is of vital importance.

In addition, with some urban and hydraulic changes, it is possible to make the regions more qualified for daily life. Authorities should consider these results for urbanization and ensure that work is guided in this way.

In conclusion, the importance of the green area in urbanization has been revealed. In spite of the cumulative rainfall, the overflow incidents are not as high as those selected in Istanbul, since most of the region selected in Dresden is a permeable surface. The destruction of permeable surfaces by destroying green areas increases the load on the systems and reduces the tolerance to any changes in the rainfall regime. For the future of the city, planning needs to be handled with a more forward-looking, environment-friendly and sustainable approach.

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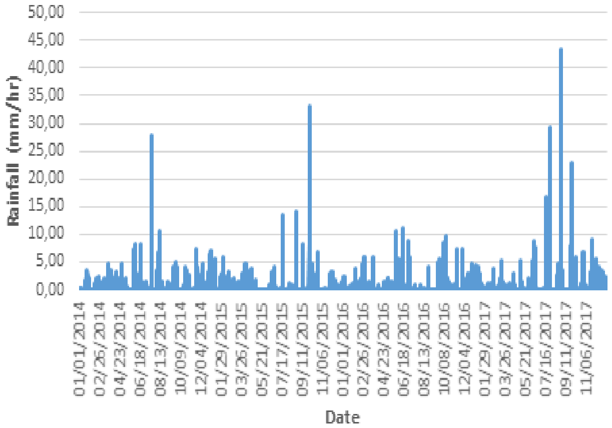
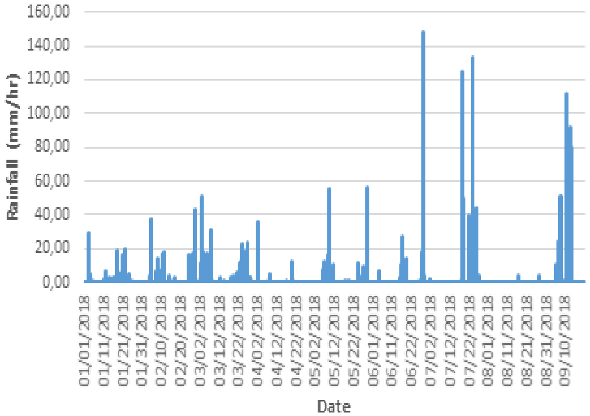
APPENDICES

APPENDIX 1

1-HOUR RESOLUTION **10-MINUTES RESOLUTION** **1-MINUTE RESOLUTION**

Figure A1.1. Rainfall hyetographs of Uskudar region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data





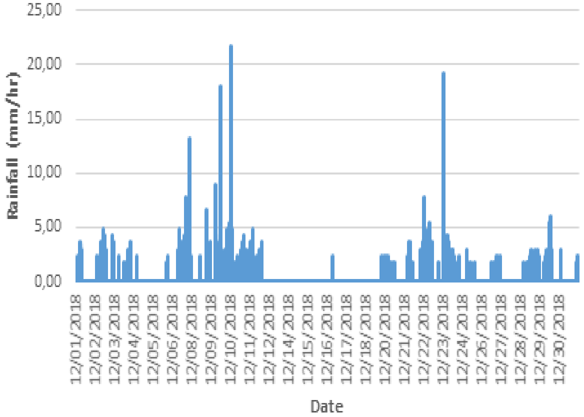


Figure A1.2. Runoff hyetographs of Uskudar region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

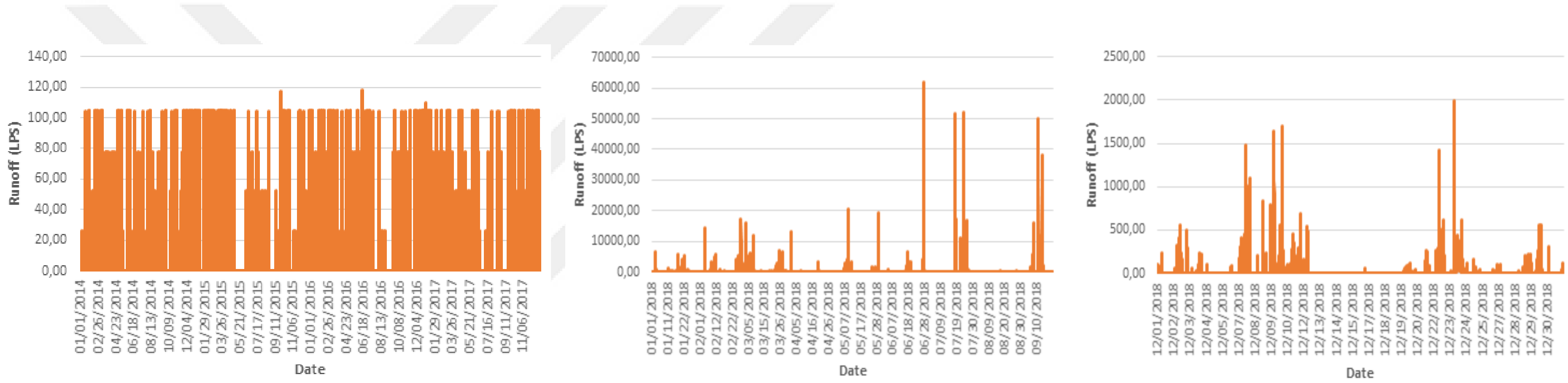


Figure A1.3. Flooding hyetographs of Uskudar region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

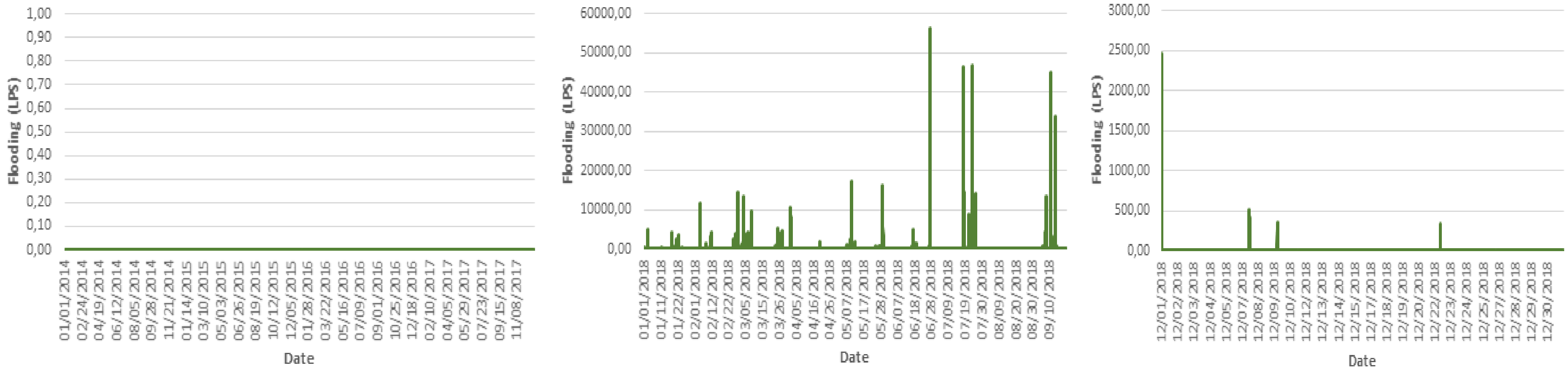


Figure A1.4. Runoff-Rainfall hyetographs of Uskudar region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

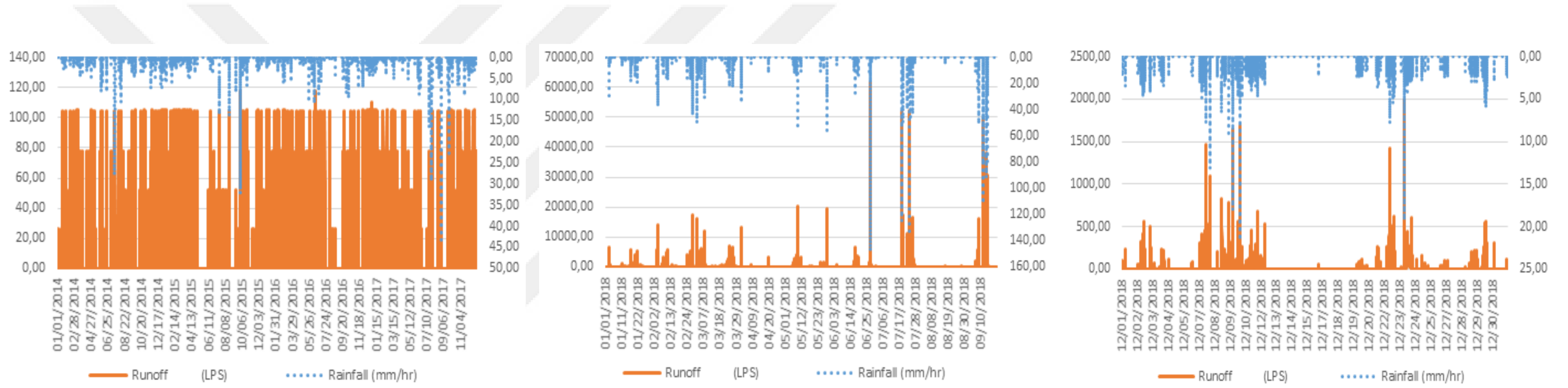


Figure A1.5. Runoff-Flooding hyetographs of Uskudar region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

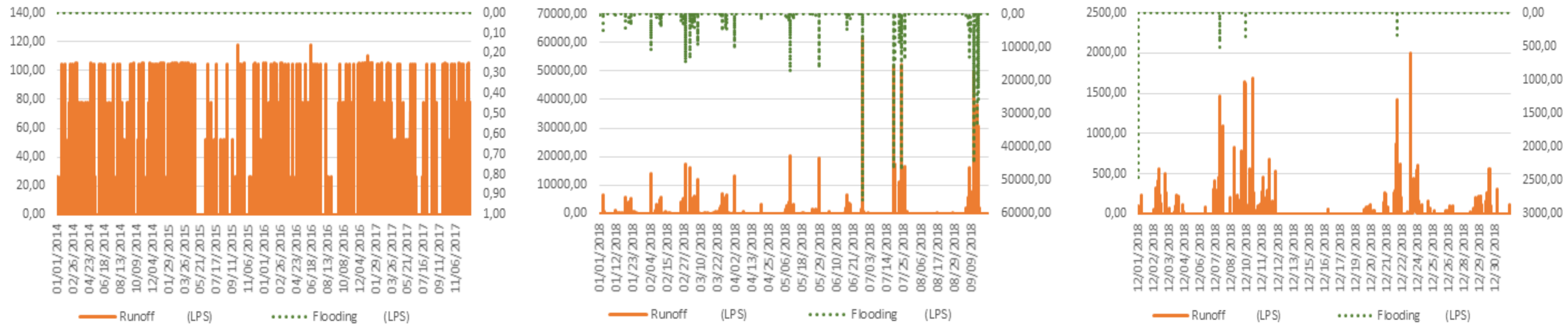


Figure A1.6. Flooding-Rainfall hyetographs of Uskudar region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

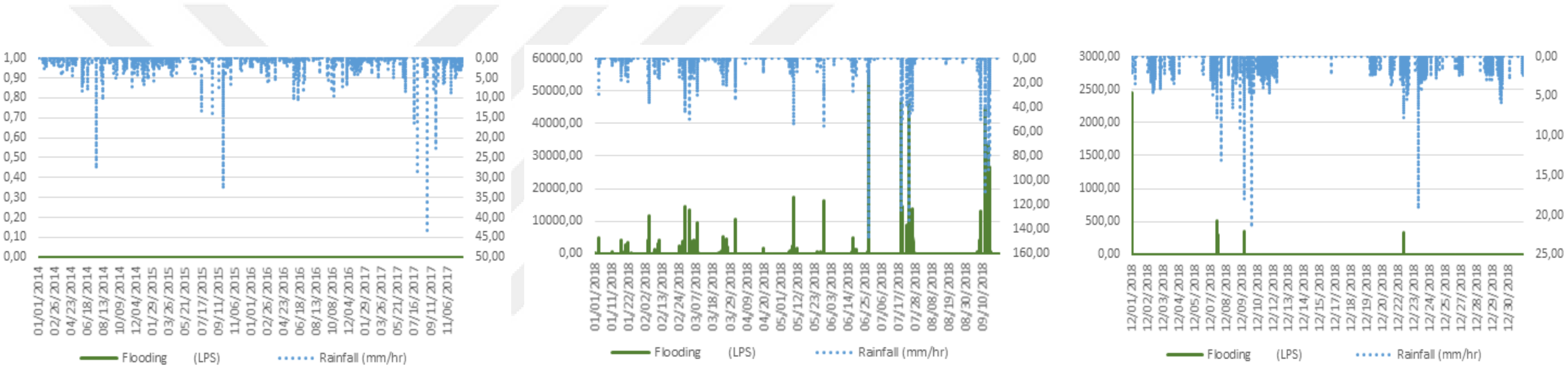


Figure A1.7. Rainfall hyetographs of Kadikoy region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

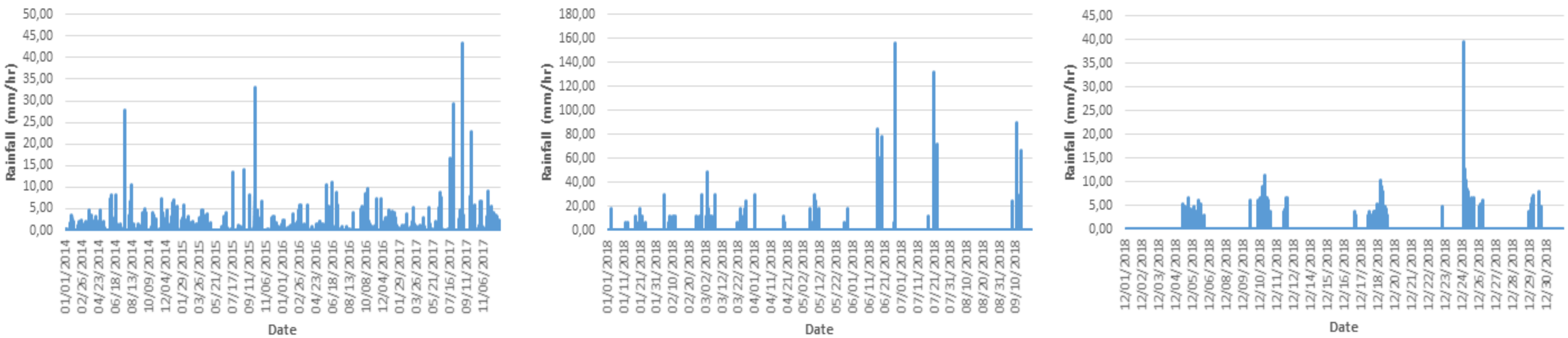


Figure A1.8. Runoff hyetographs of Kadikoy region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

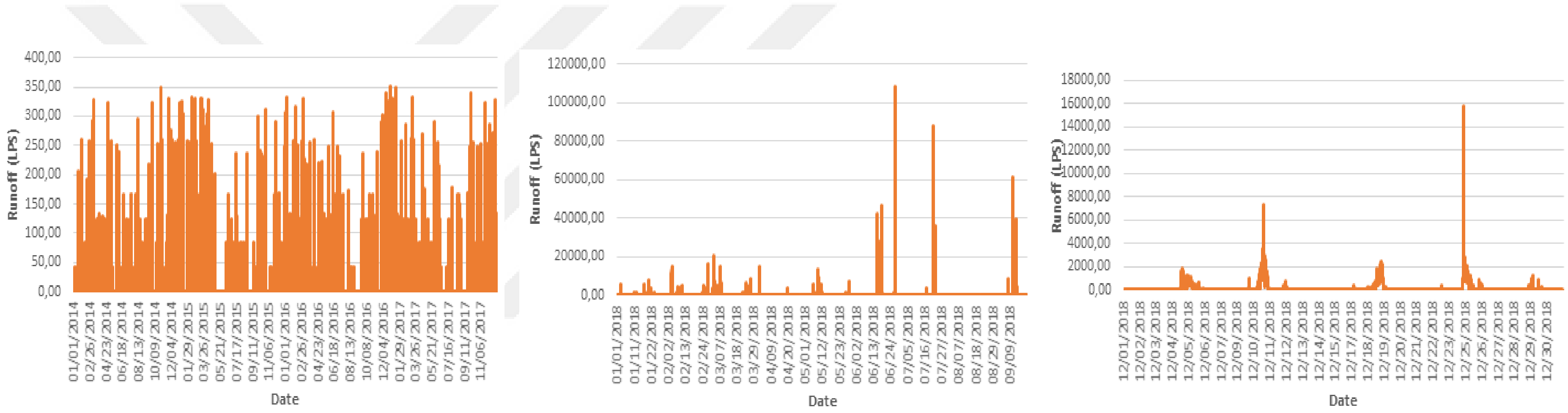


Figure A1.9. Flooding hyetographs of Kadikoy region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

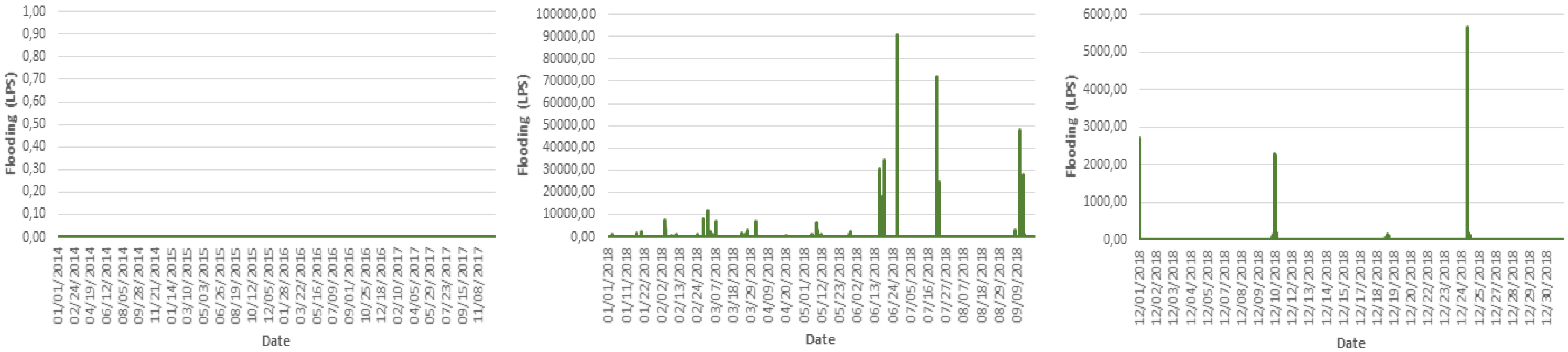


Figure A1.10. Runoff-Rainfall hyetographs of Kadikoy region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

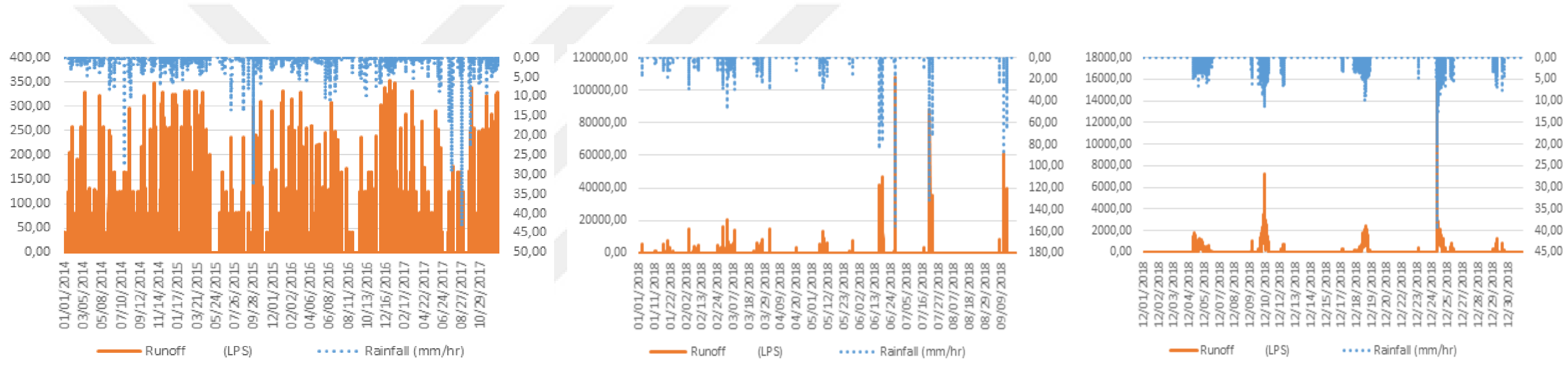


Figure A1.11. Runoff-Flooding hyetographs of Kadikoy region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

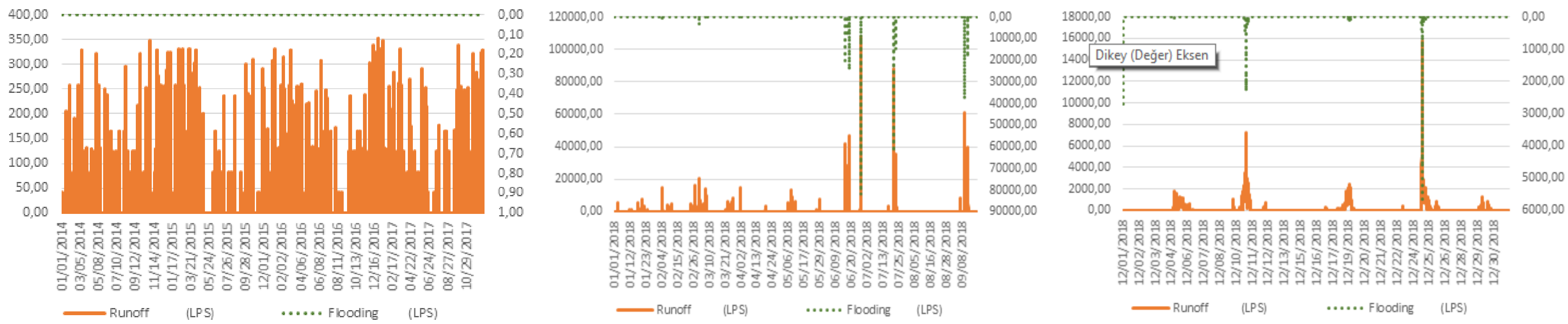


Figure A1.12. Flooding-Rainfall hyetographs of Kadikoy region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

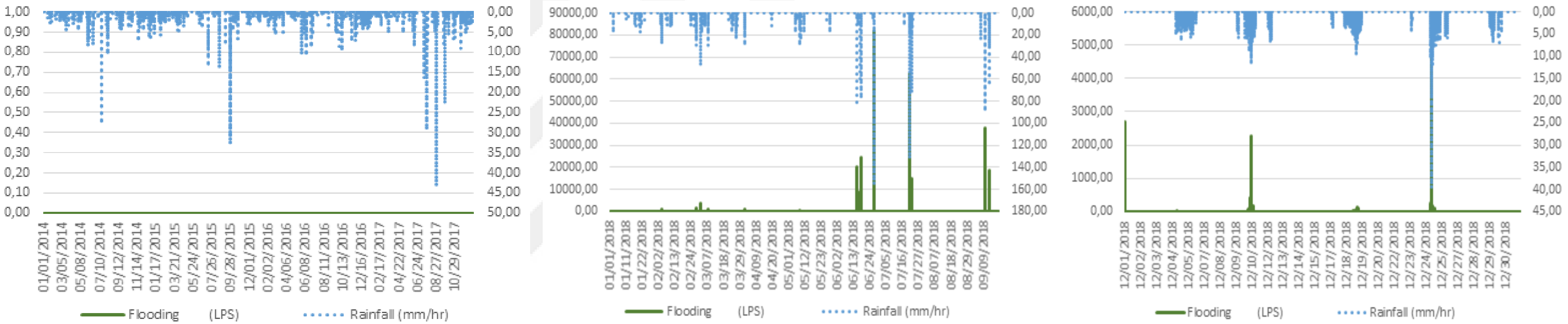


Figure A1.13. Rainfall hyetographs of Umraniye region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

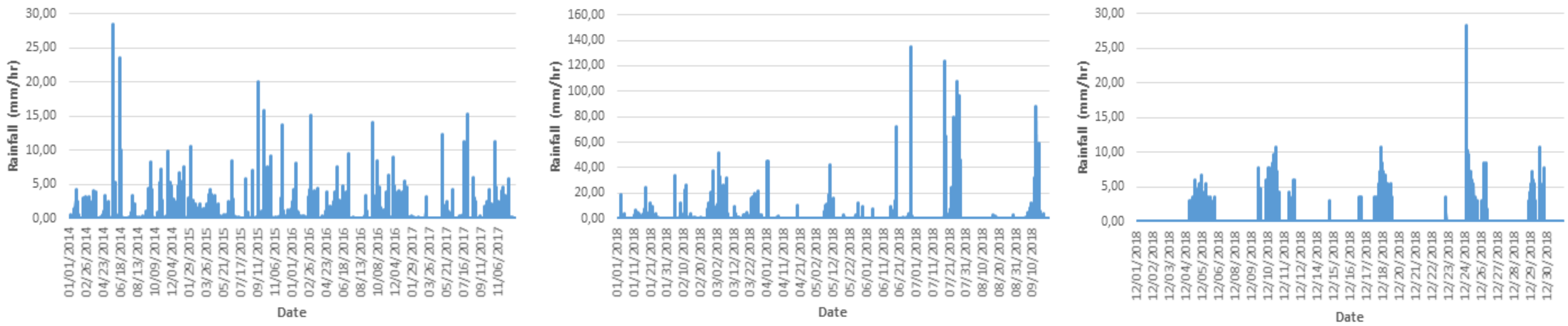


Figure A1.14. Runoff hyetographs of Umraniye region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

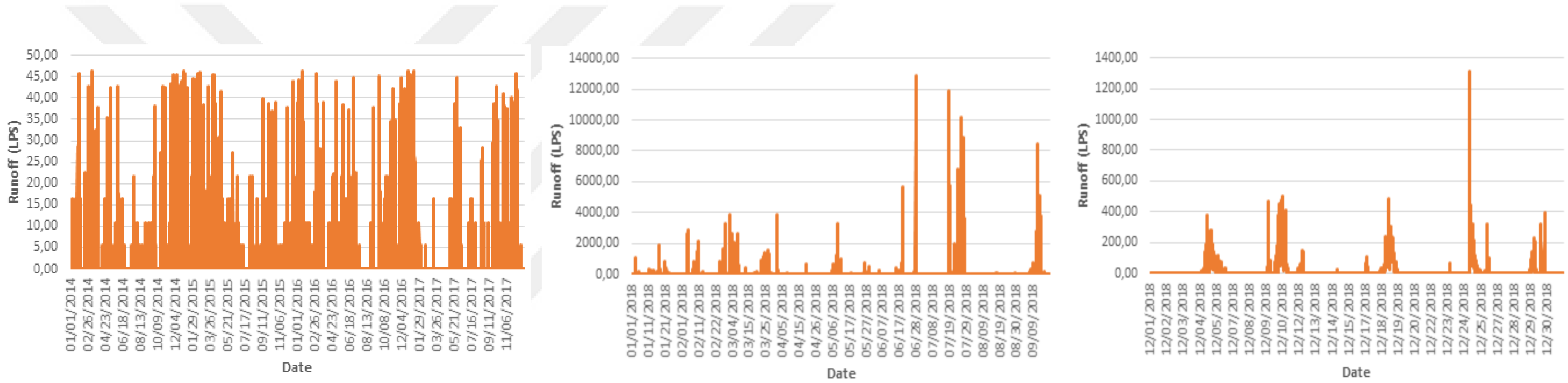


Figure A1.15. Flooding hyetographs of Umraniye region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

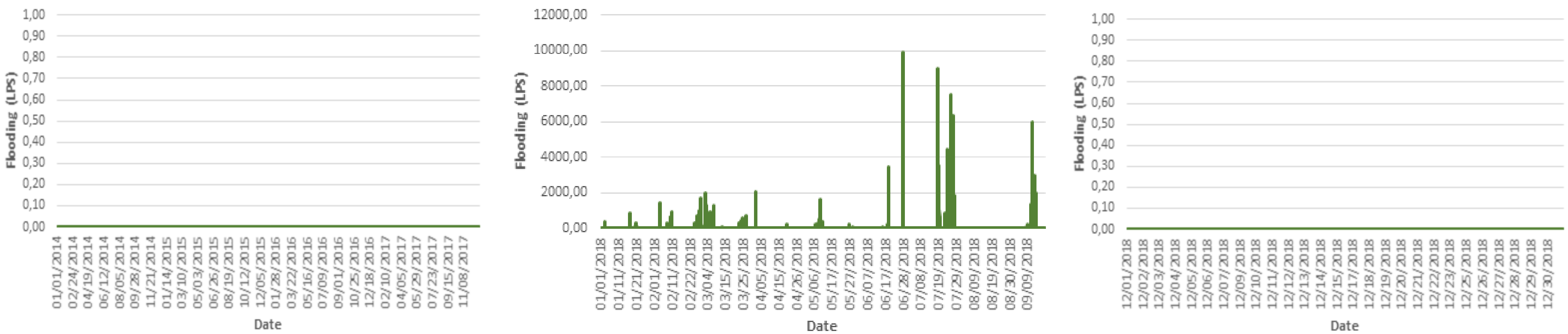


Figure A1.16. Runoff-Rainfall hyetographs of Umraniye region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

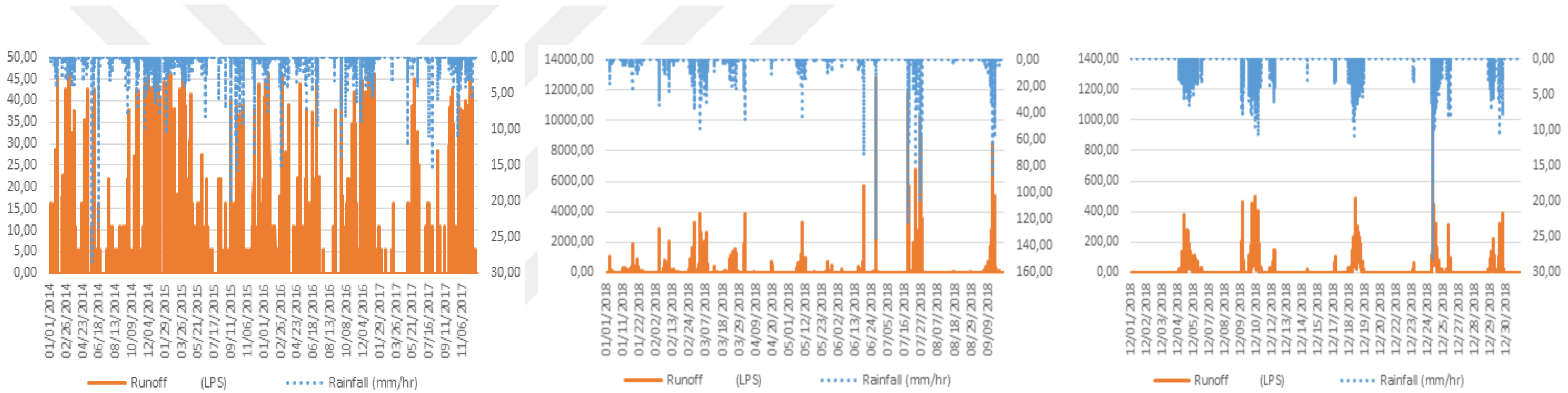


Figure A1.17. Runoff-Flooding hyetographs of Umraniye region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

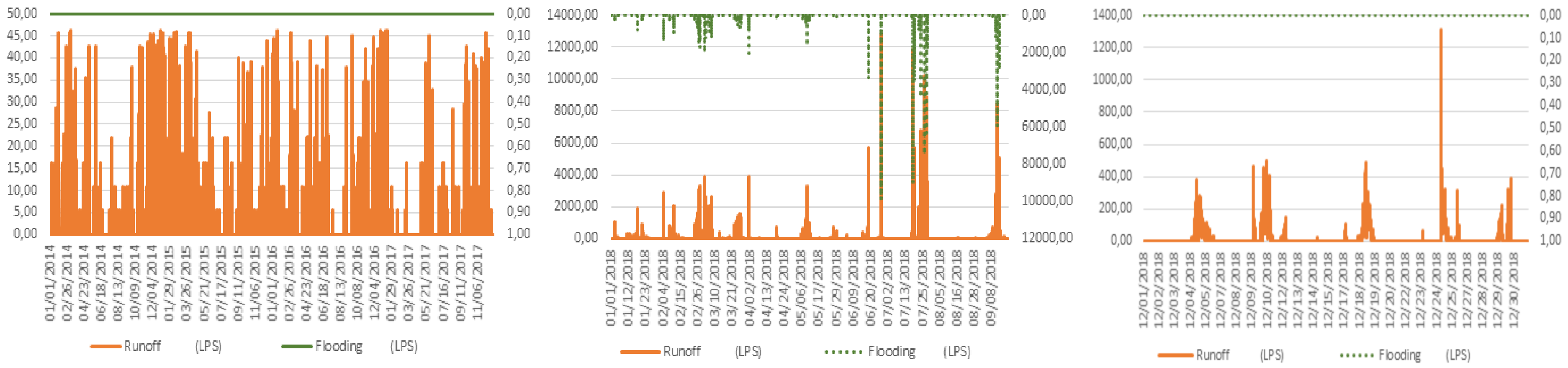


Figure A1.18. Flooding-Rainfall hyetographs of Umraniye region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

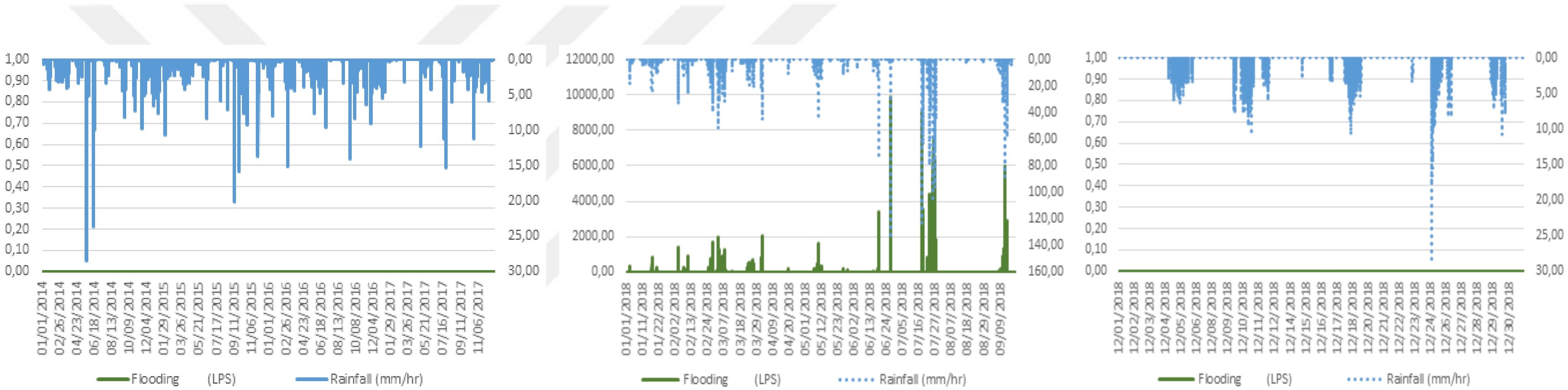


Figure A1.19. Rainfall hyetographs of Lockwitz region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

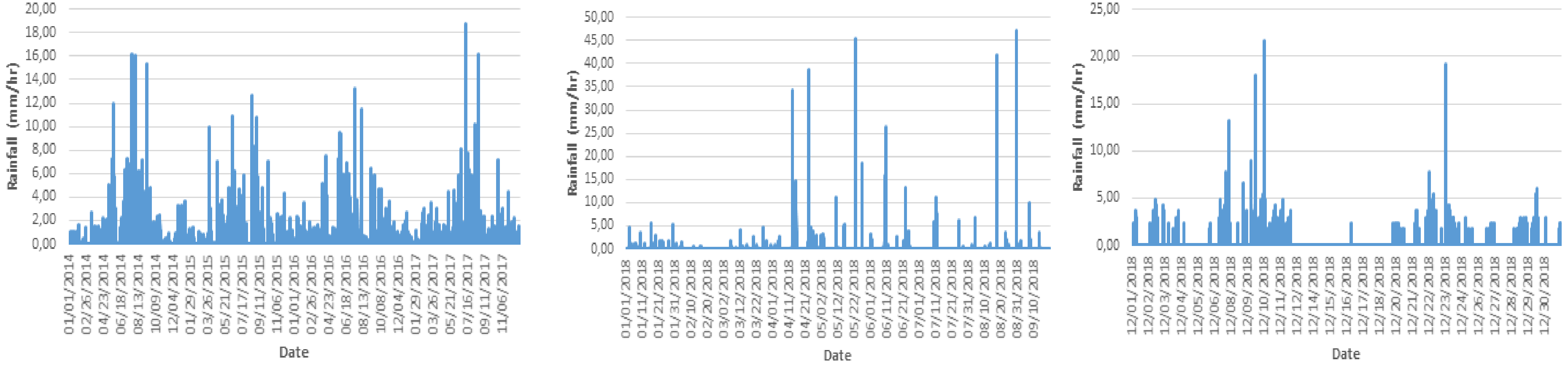


Figure A1.20. Runoff hyetographs of Lockwitz region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

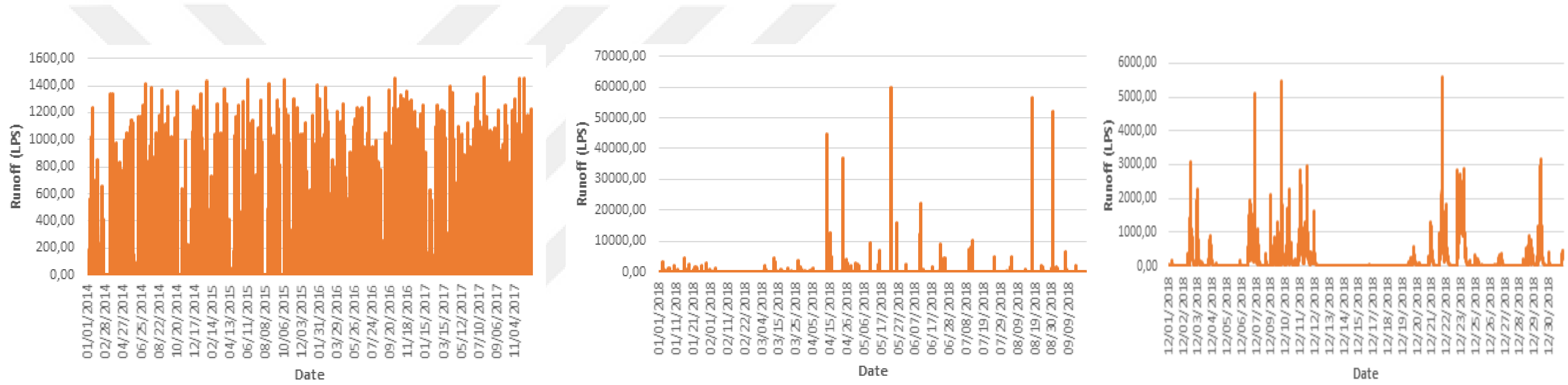


Figure A1.21. Flooding hyetographs of Lockwitz region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

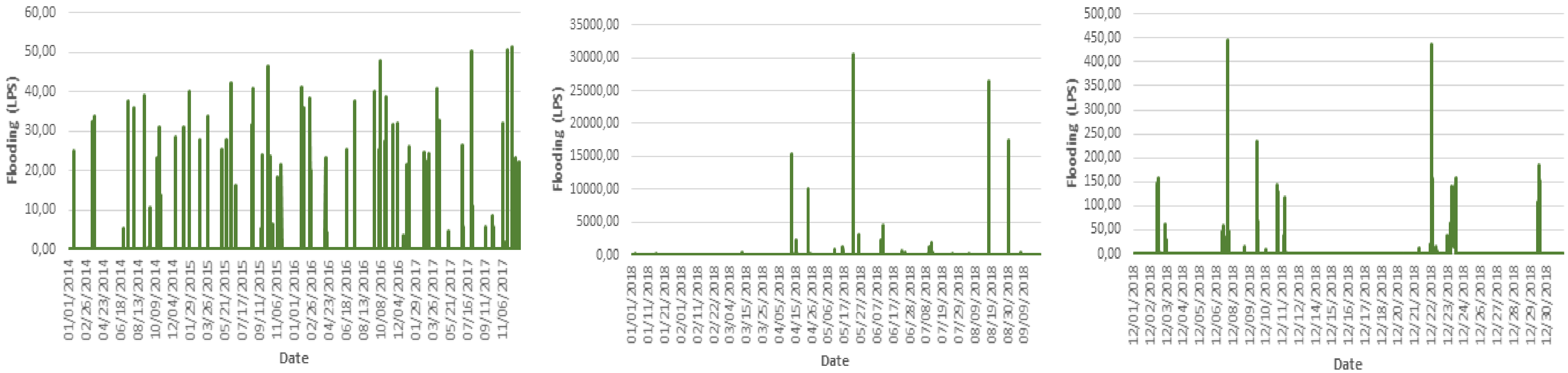


Figure A1.22. Runoff-Rainfall hyetographs of Lockwitz region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

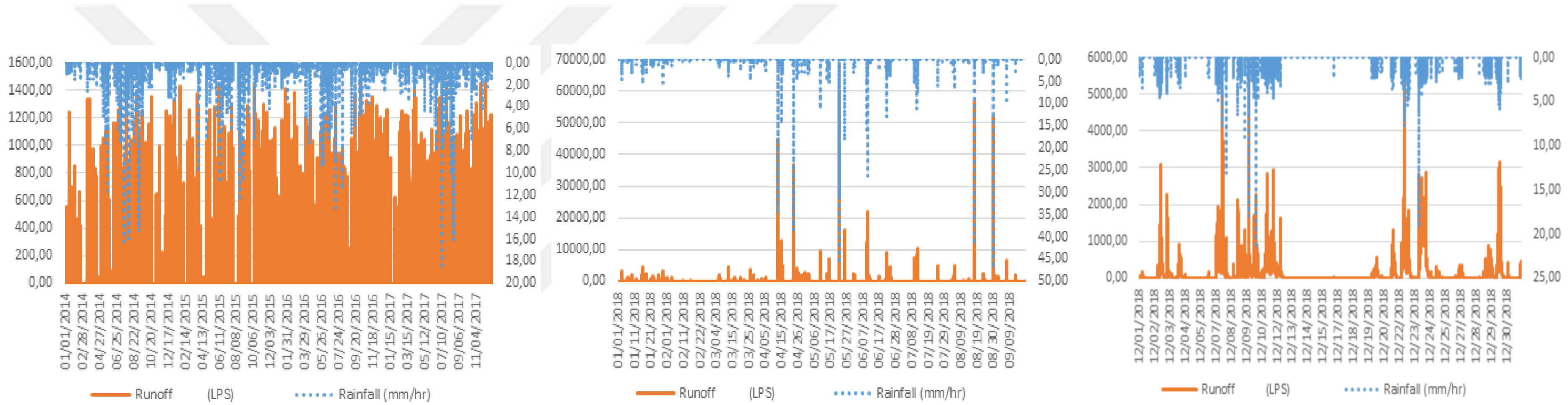


Figure A1.23. Runoff-Flooding hyetographs of Lockwitz region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

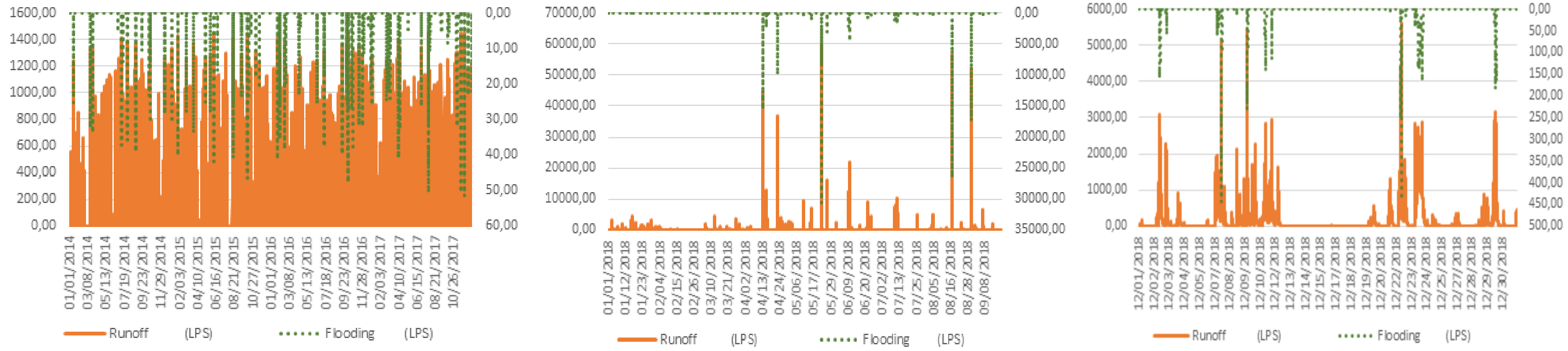


Figure A1.24. Flooding-Rainfall hyetographs of Lockwitz region with respectively 1-Hour, 10-Minutes and 1-Minute resolution data

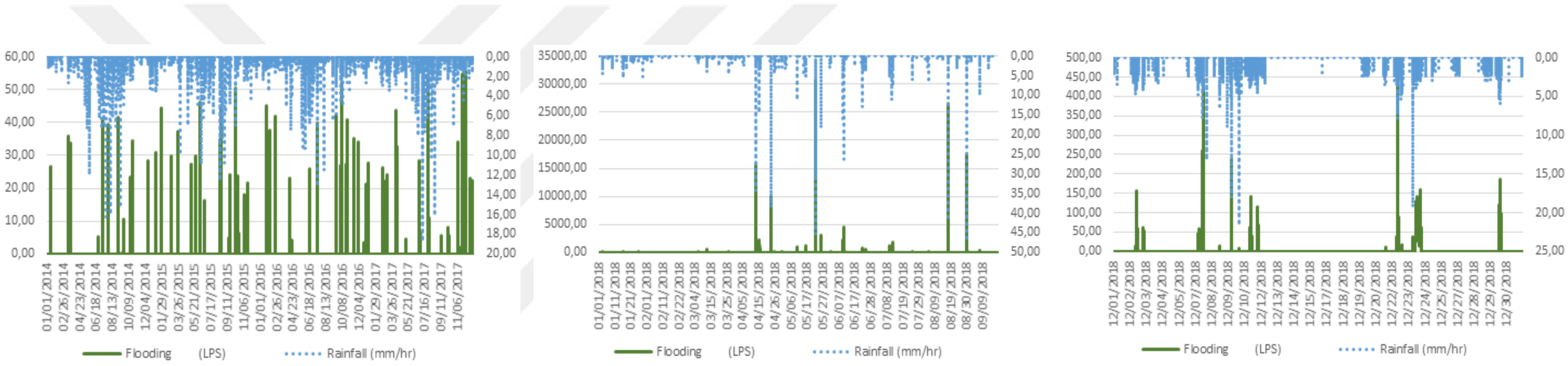


Figure A1.25. Rainfall hyetographs of Uskudar region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

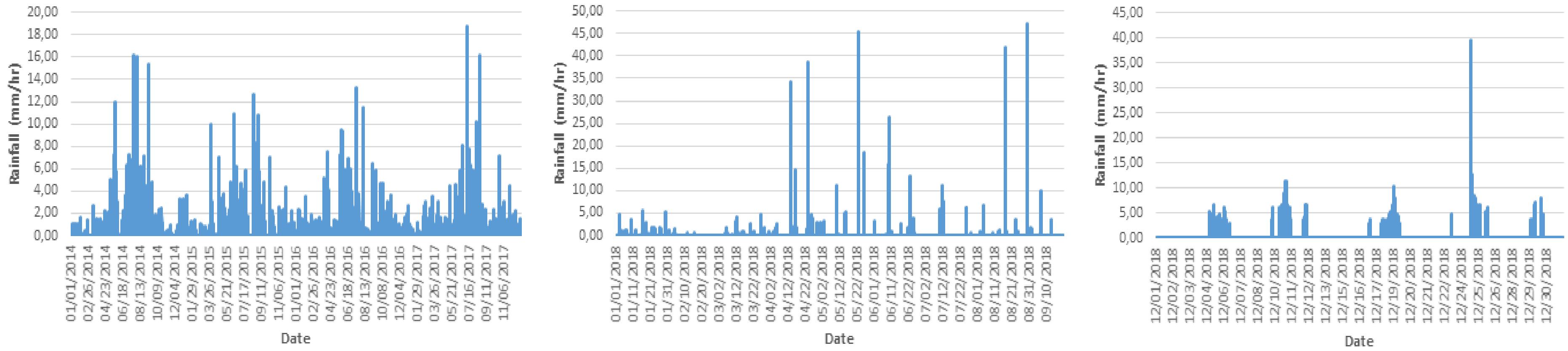


Figure A1.26. Runoff hyetographs of Uskudar region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

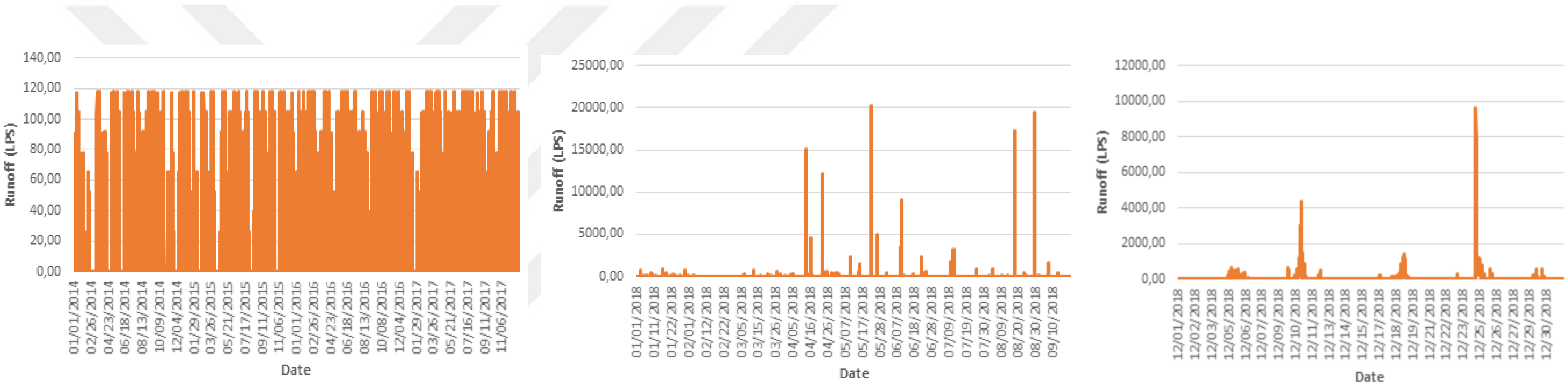


Figure A1.27. Flooding hyetographs of Uskudar region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

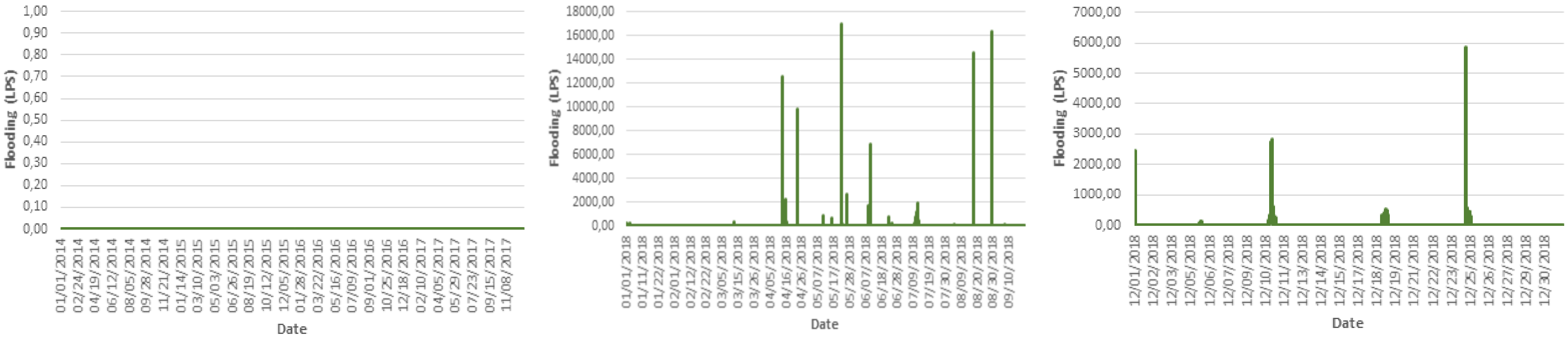


Figure A1.28. Runoff-Rainfall hyetographs of Uskudar region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

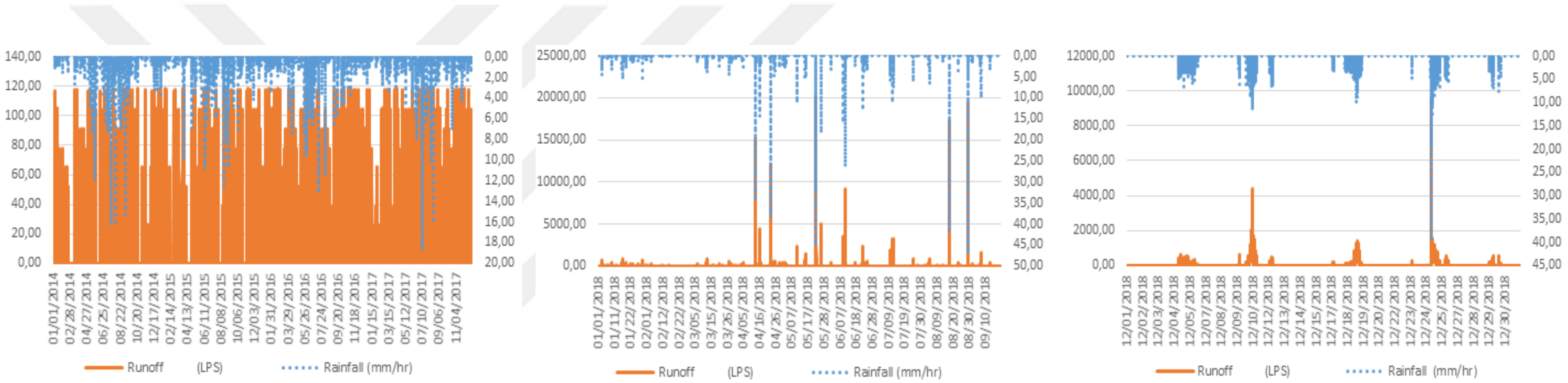


Figure A1.29. Runoff-Flooding hyetographs of Uskudar region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

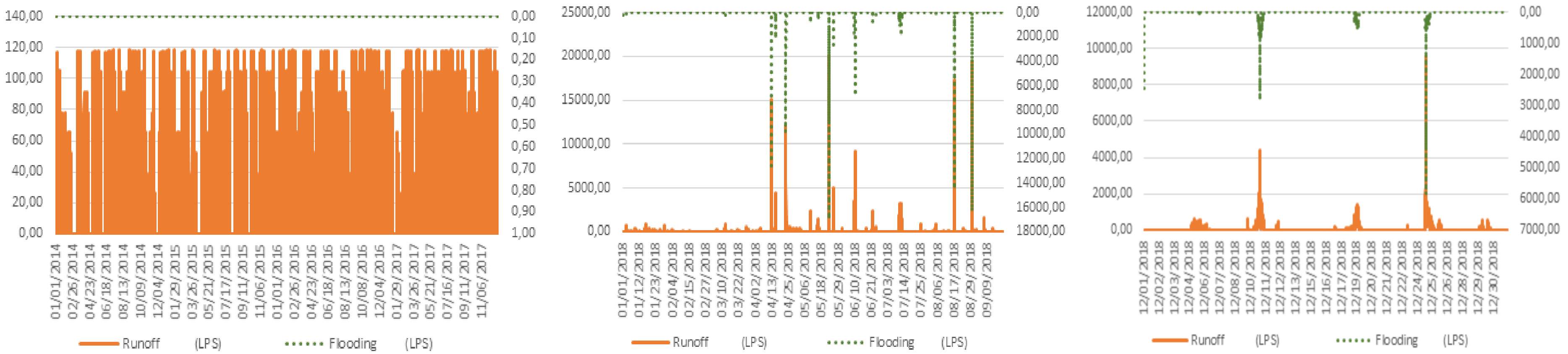


Figure A1.30. Flooding-Rainfall hyetographs of Uskudar region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

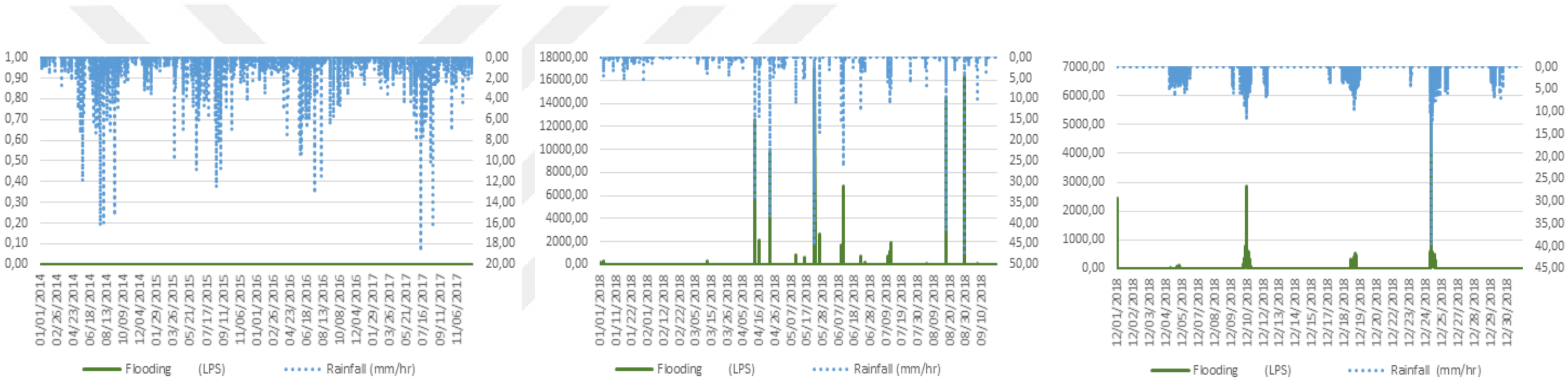


Figure A1.31. Rainfall hyetographs of Kadikoy region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

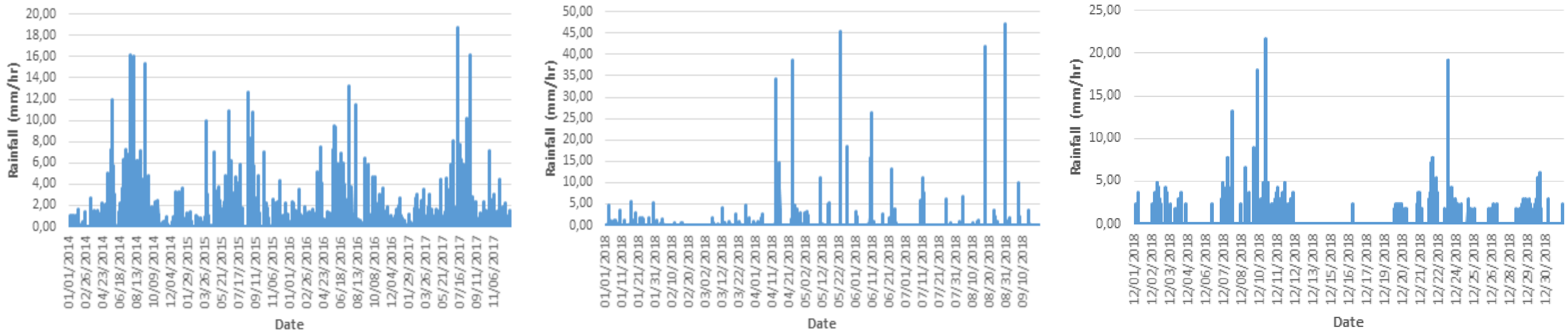


Figure A1.32. Runoff hyetographs of Kadikoy region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

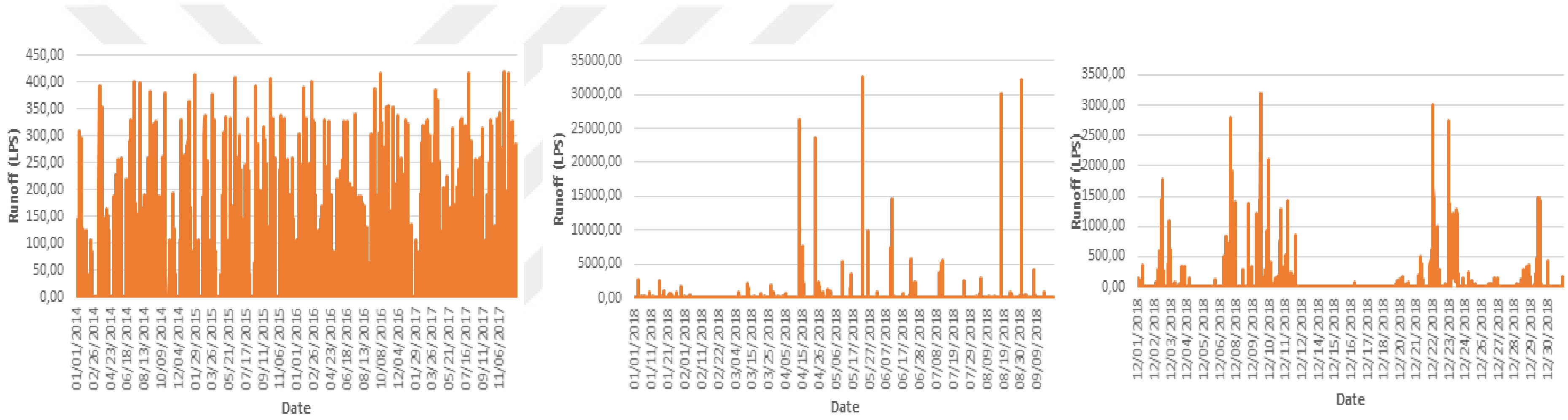


Figure A1.33. Flooding hyetographs of Kadikoy region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

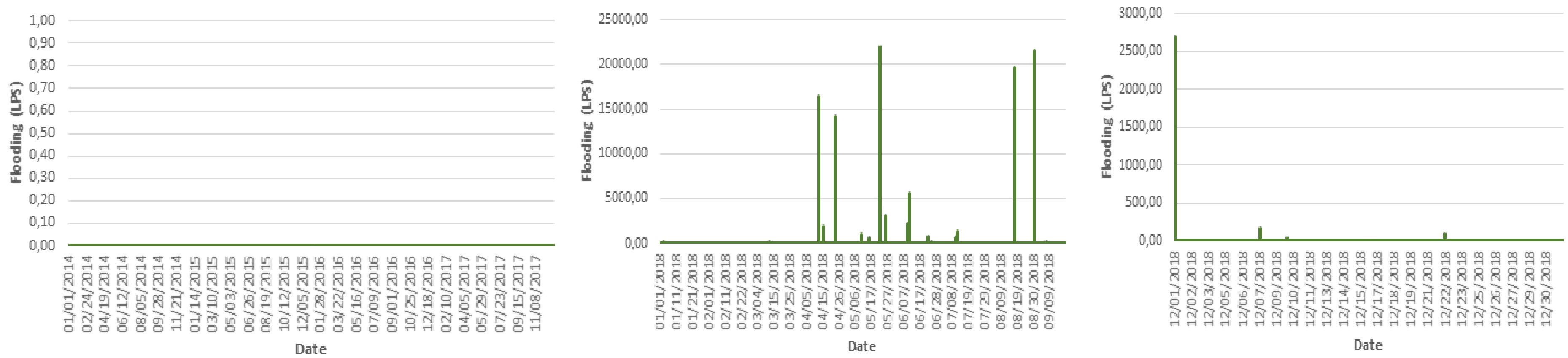


Figure A1.34. Runoff-Rainfall hyetographs of Kadikoy region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

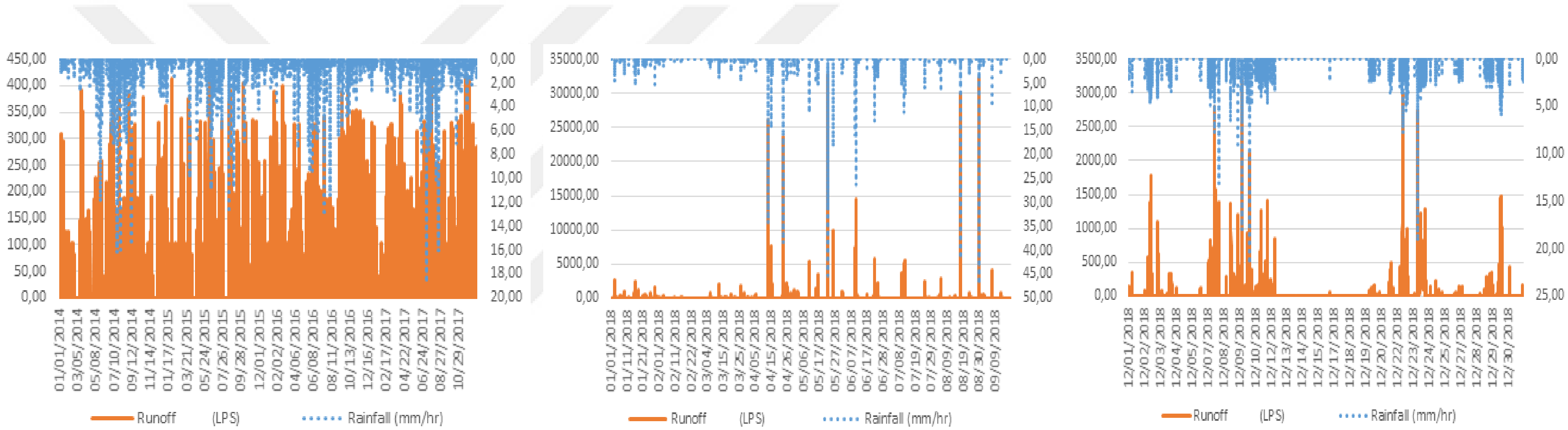


Figure A1.35. Runoff-Flooding hyetographs of Kadikoy region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

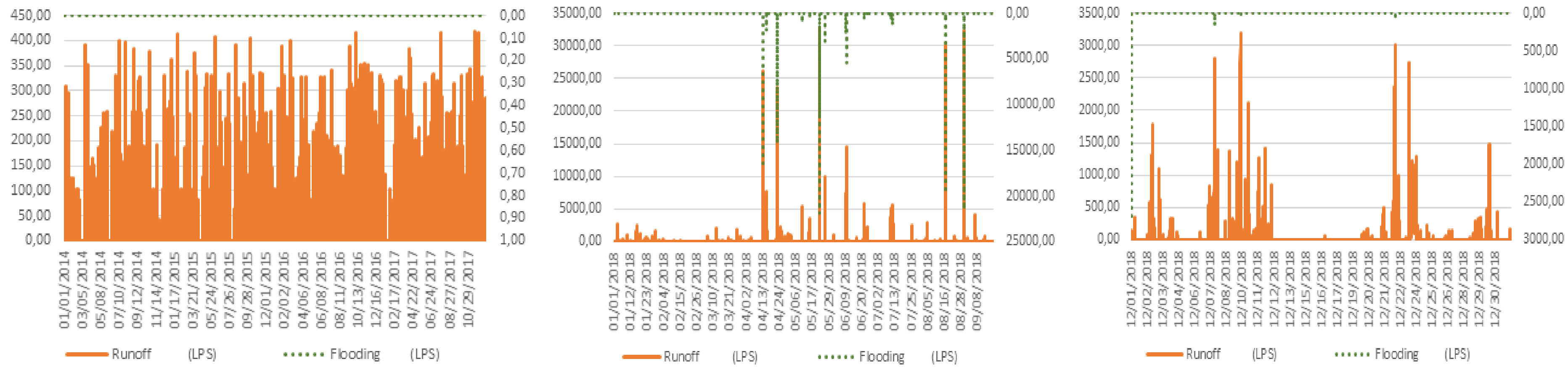


Figure A1.36. Flooding-Rainfall hyetographs of Kadikoy region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

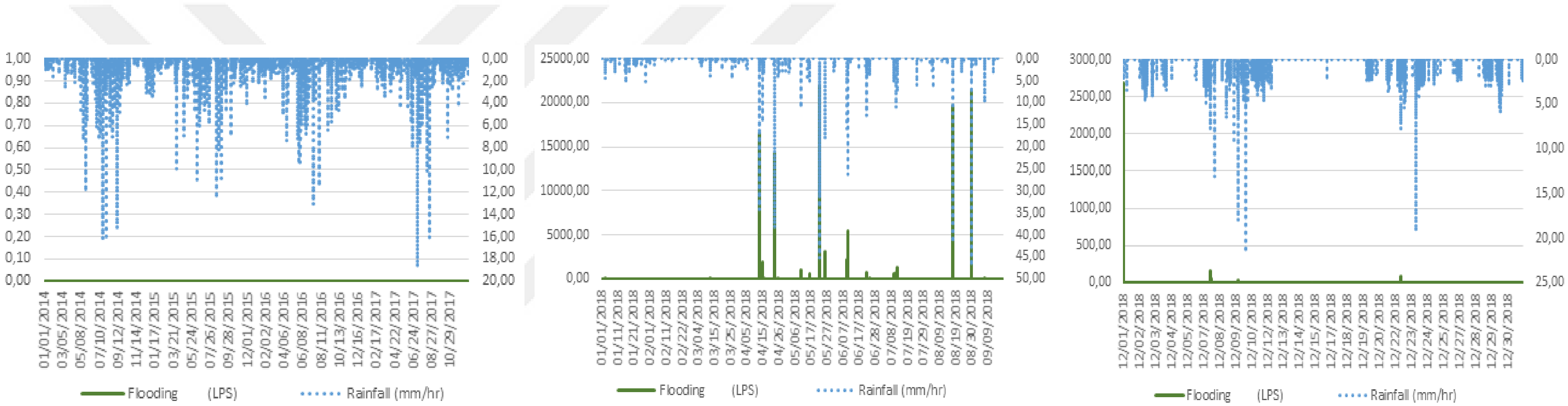


Figure A1.37. Rainfall hyetographs of Umraniye region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

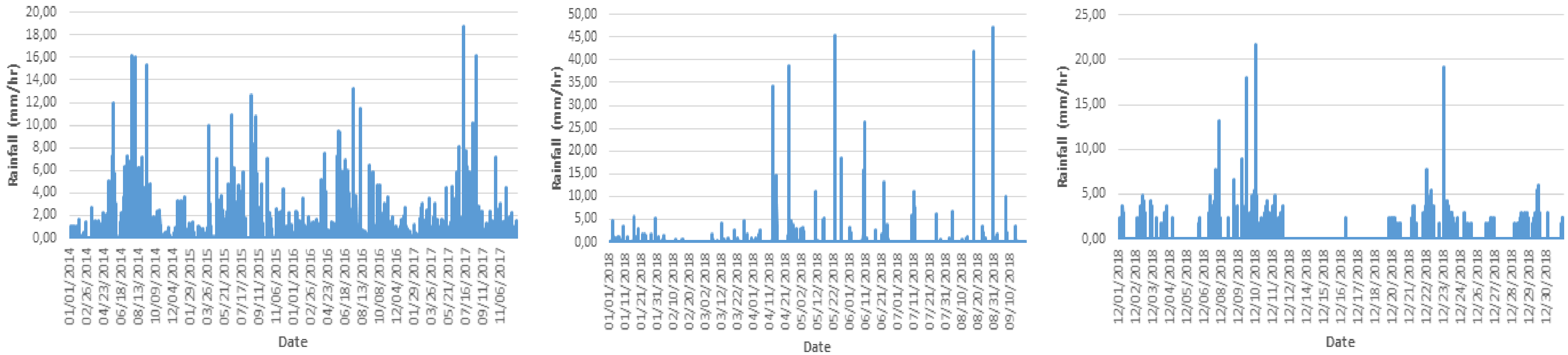


Figure A1.38. Runoff hyetographs of Umraniye region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

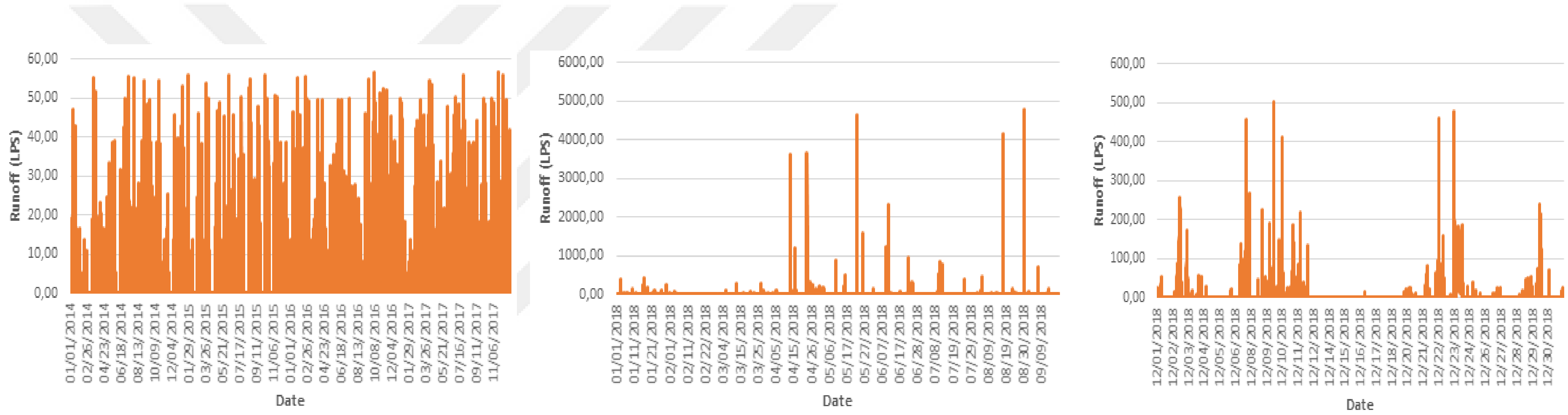


Figure A1.39. Flooding hyetographs of Umraniye region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

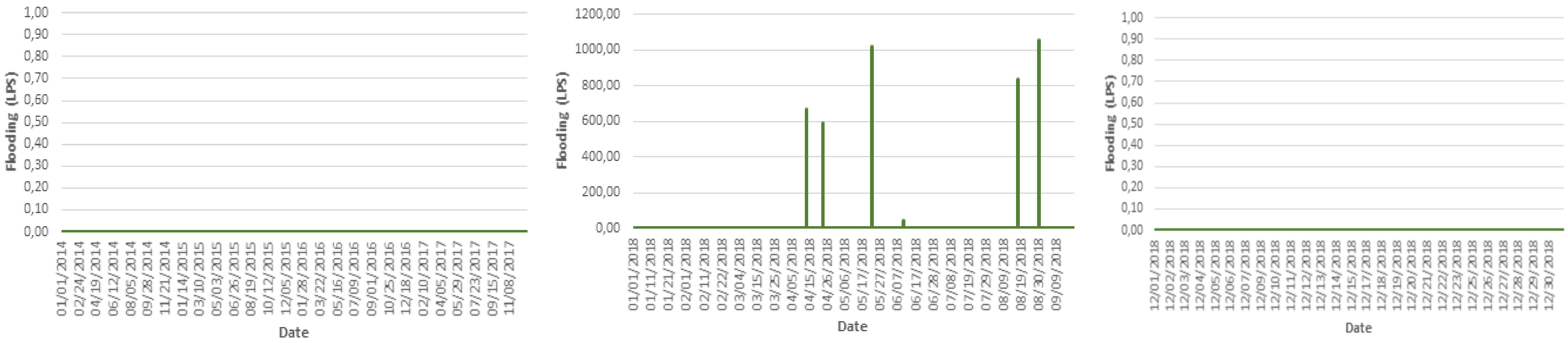


Figure A1.40. Runoff-Rainfall hyetographs of Umraniye region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

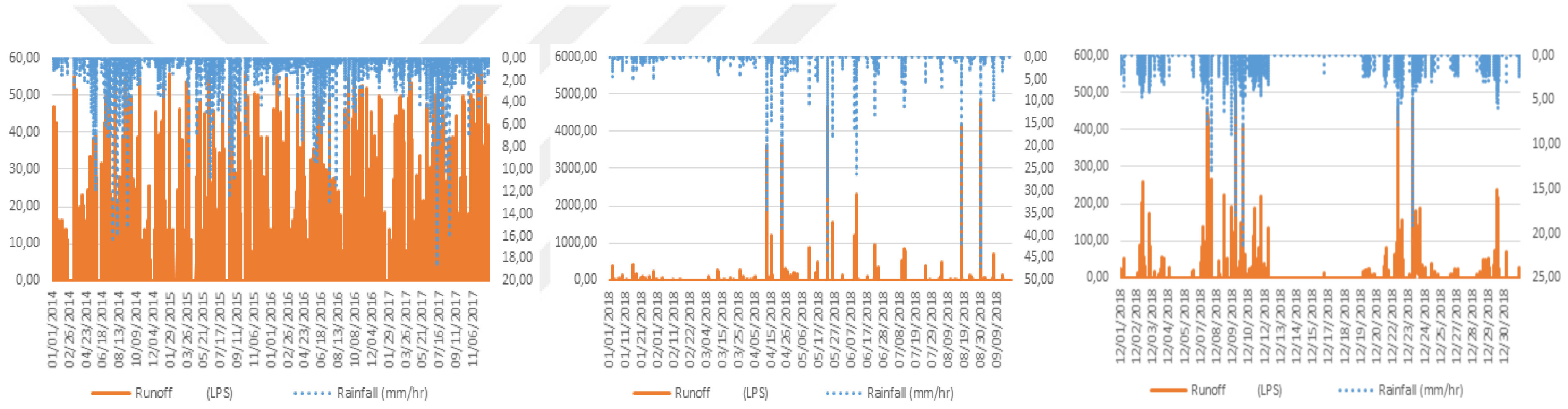


Figure A1.41. Runoff-Flooding hyetographs of Umraniye region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

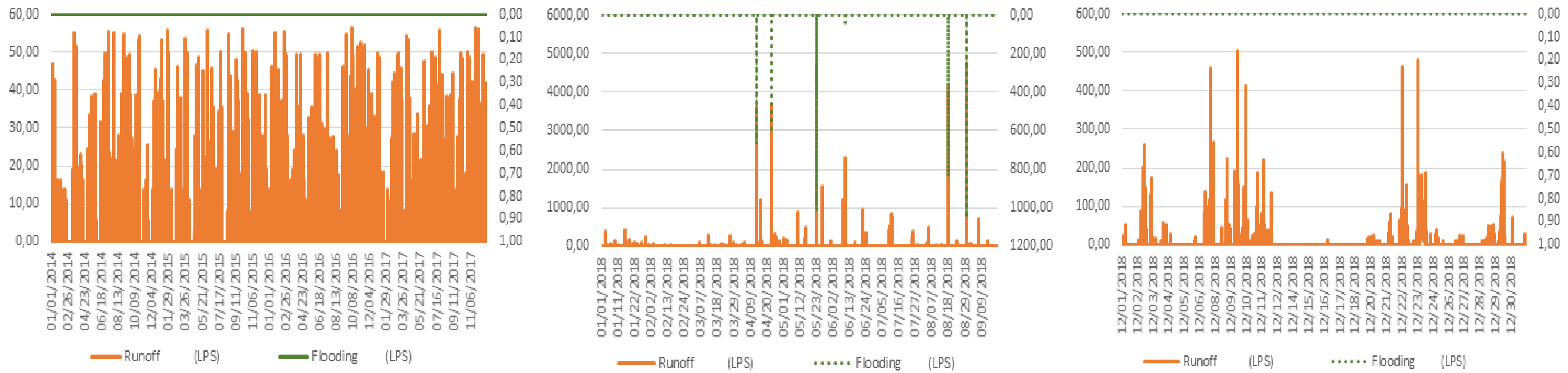


Figure A1.42. Flooding-Rainfall hyetographs of Umraniye region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

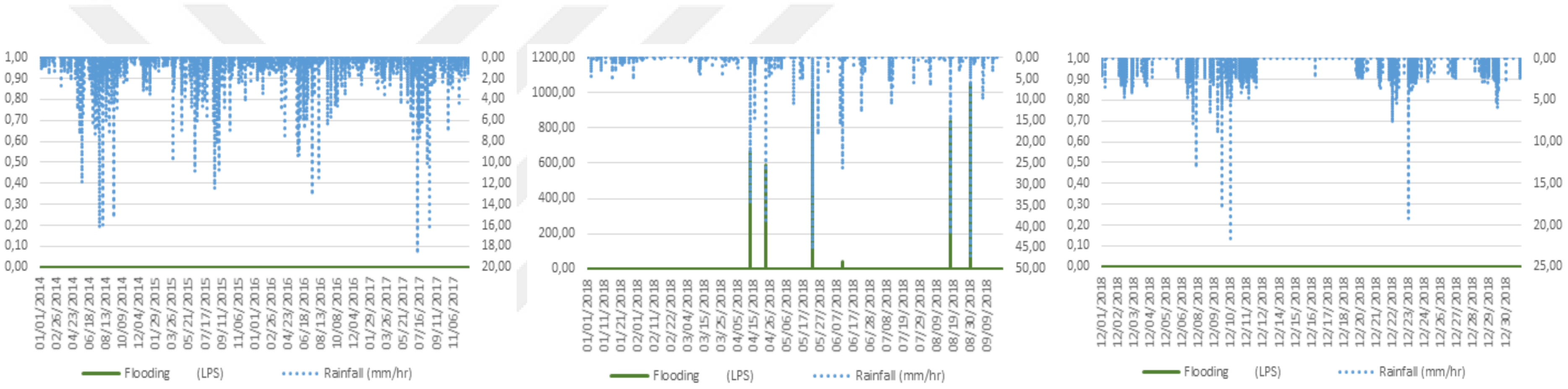


Figure A1.43. Rainfall hyetographs of Lockwitz region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

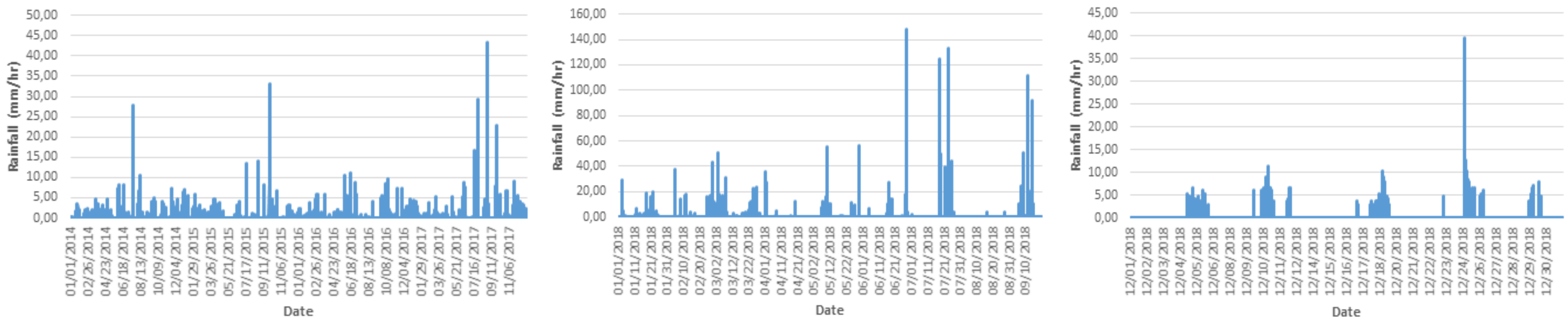


Figure A1.44. Runoff hyetographs of Lockwitz region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

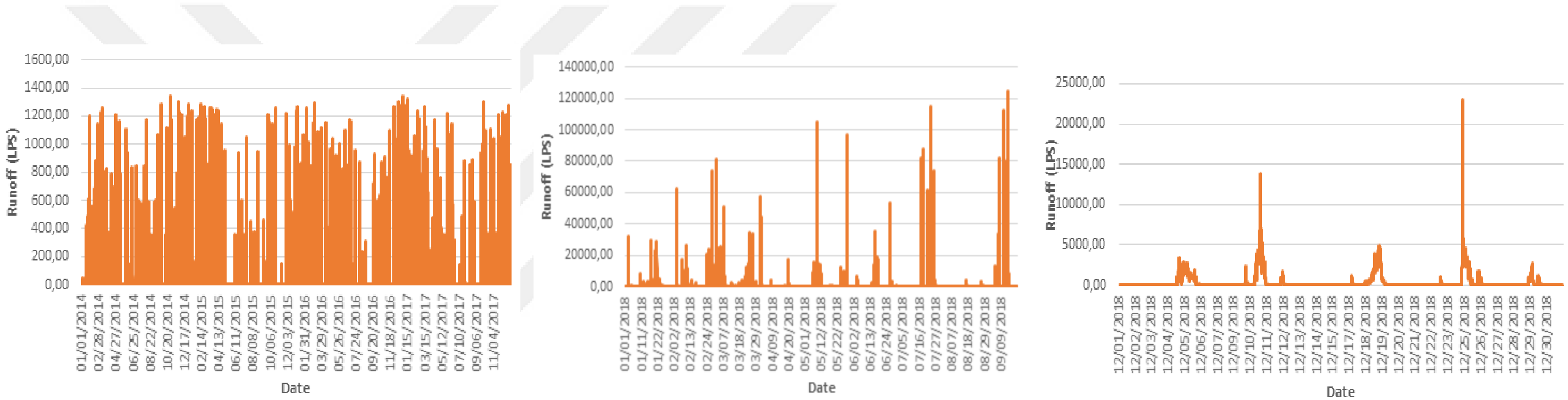


Figure A1.45. Flooding hyetographs of Lockwitz region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

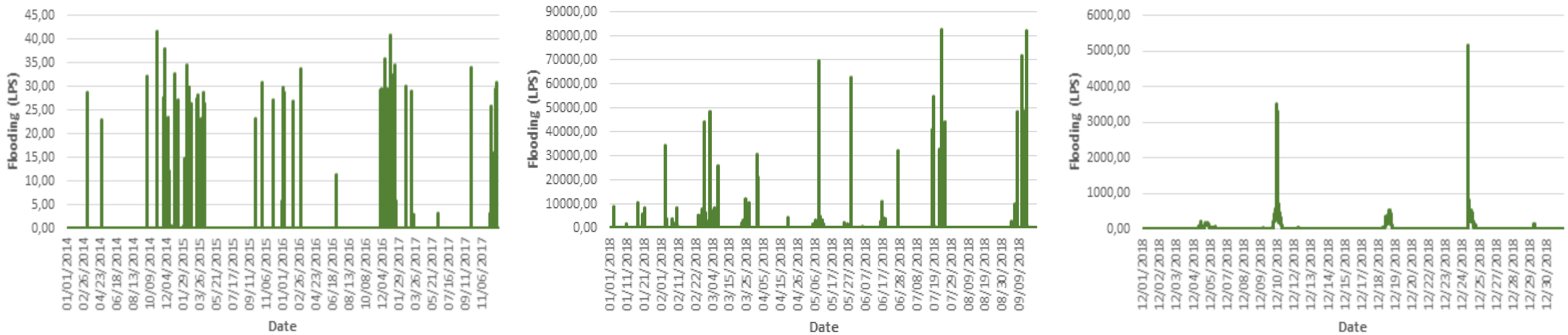


Figure A1.46. Runoff-Rainfall hyetographs of Lockwitz region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

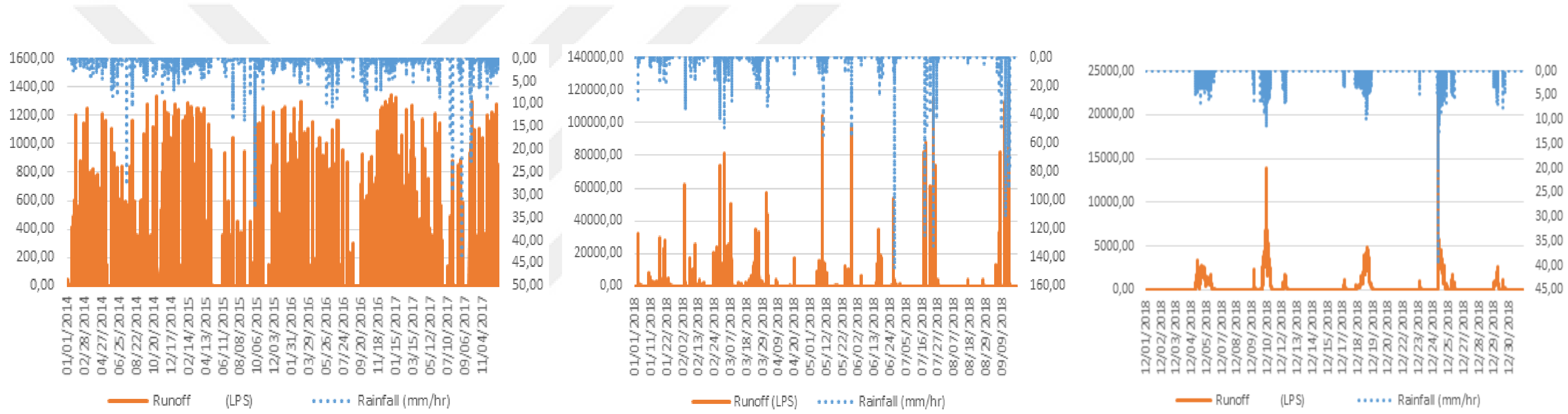


Figure A1.47. Runoff-Flooding hyetographs of Lockwitz region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

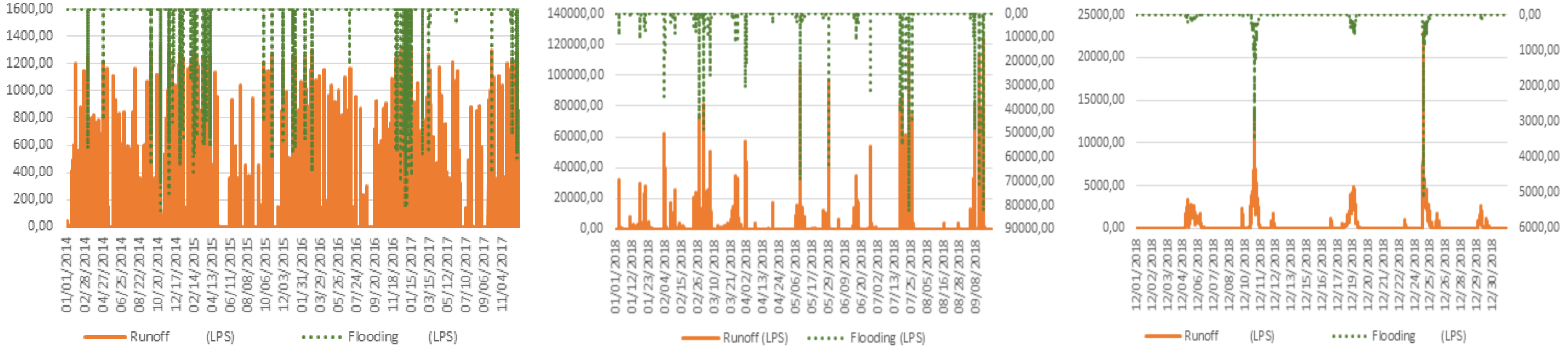


Figure A1.48. Flooding-Rainfall hyetographs of Lockwitz region with respectively 1-Hour, 10-Minutes and 1-Minute resolution scenario data

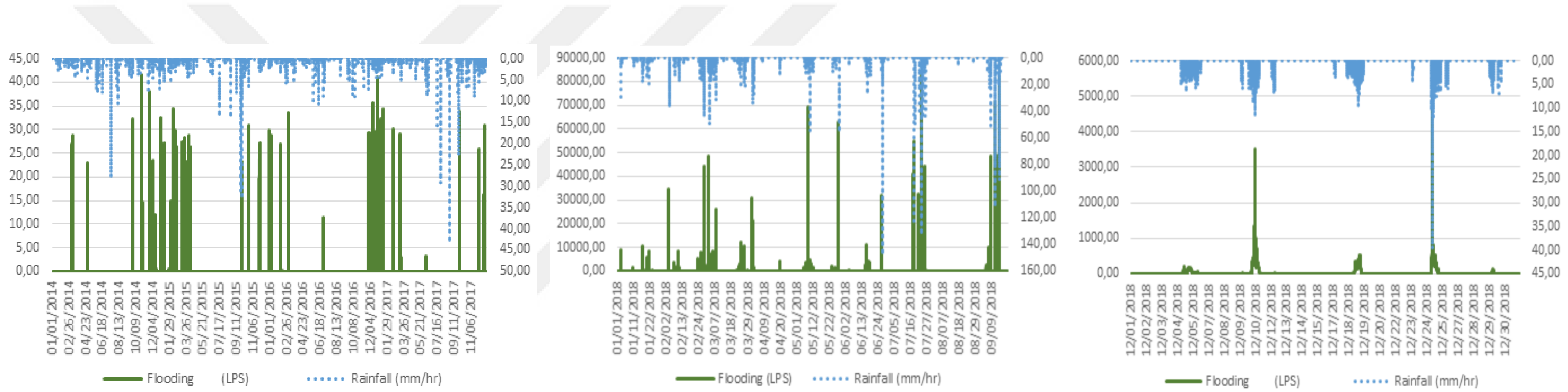


Figure A1.49. Respectively Rainfall, Runoff and Flooding hyetographs of Uskudar region with 1-Hour resolution data converted from 1-Minute resolution data

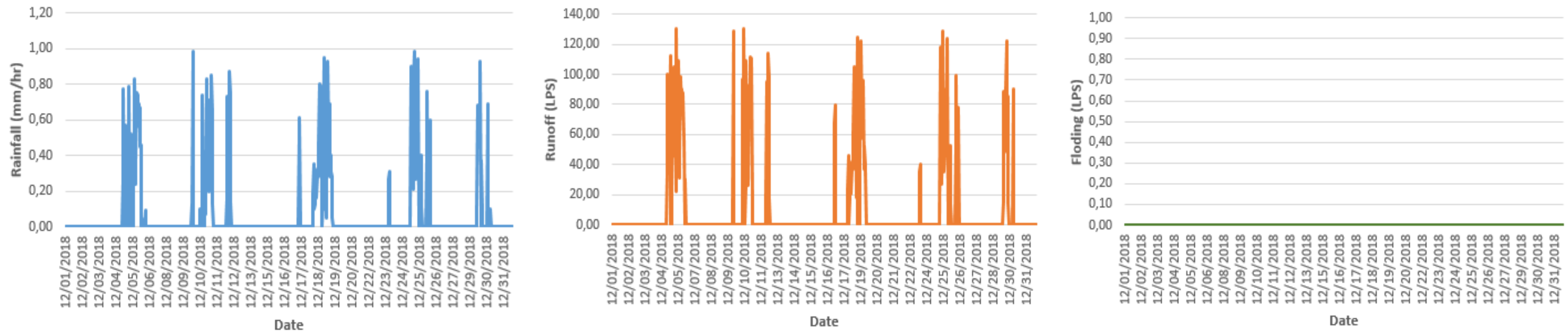


Figure A1.50. Respectively Runoff-Rainfall, Runoff-Flooding and Flooding-Rainfall hyetographs of Uskudar region with 1-Hour resolution data converted from 1-Minute resolution data

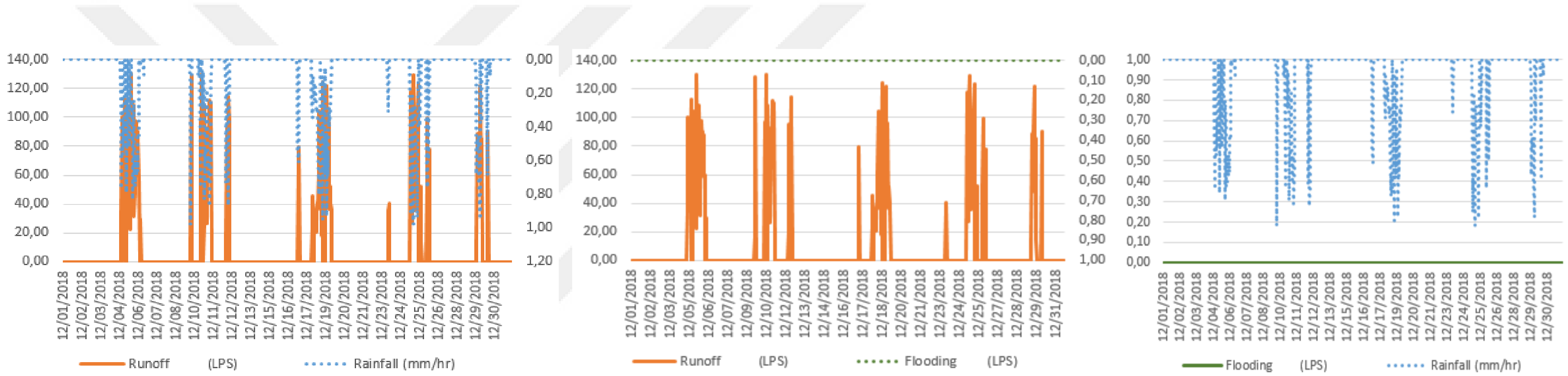


Figure A1.51. Respectively Rainfall, Runoff and Flooding hyetographs of Uskudar region with 10-Minutes resolution data converted from 1-Minute resolution data

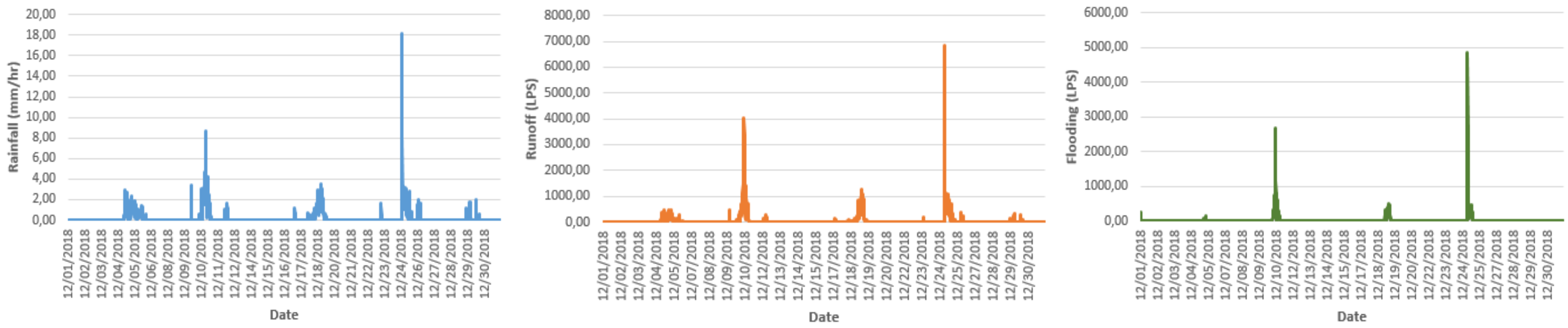


Figure A1.52. Respectively Runoff-Rainfall, Runoff-Flooding and Flooding-Rainfall hyetographs of Uskudar region with 10-Minutes resolution data converted from 1-Minute resolution data

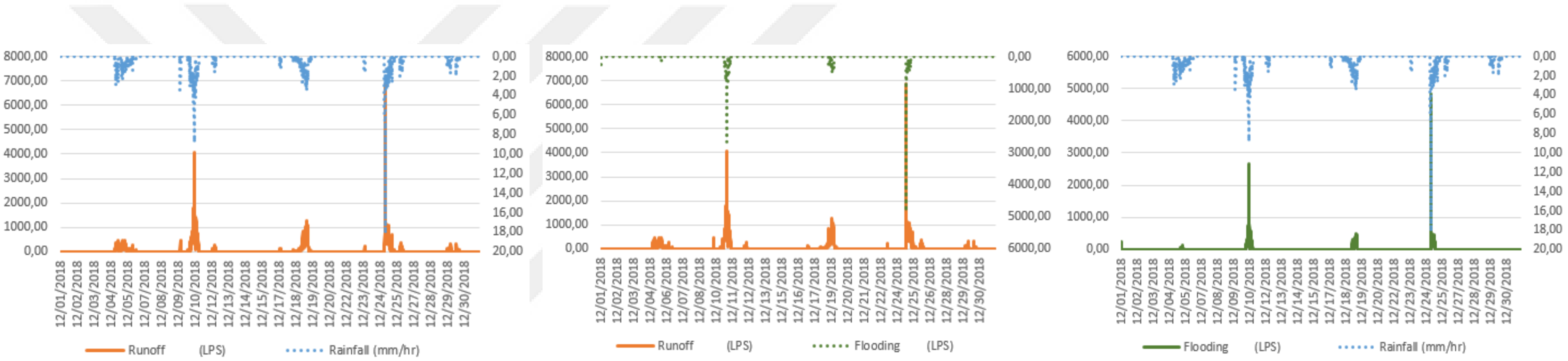


Figure A1.53. Respectively Rainfall, Runoff and Flooding hyetographs of Kadikoy region with 1-Hour resolution data converted from 1-Minute resolution data

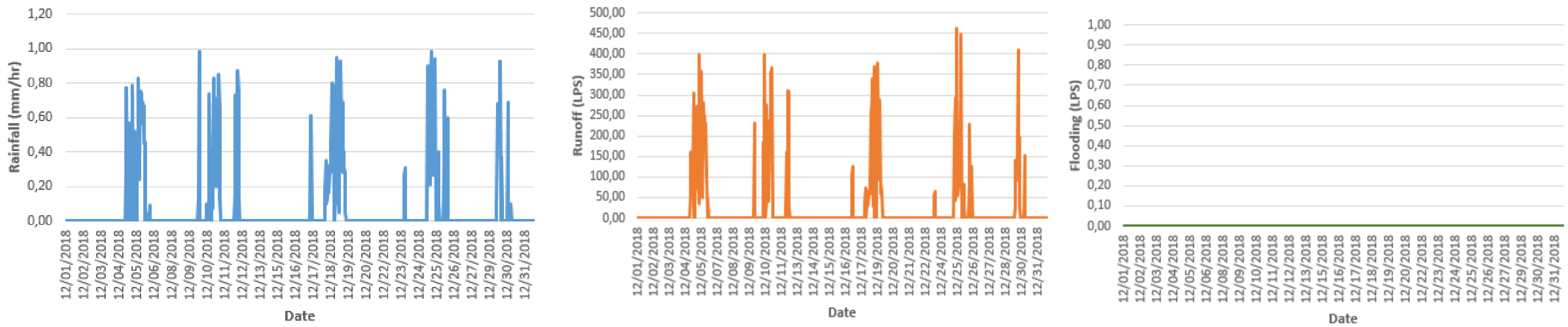


Figure A1.54. Respectively Runoff-Rainfall, Runoff-Flooding and Flooding-Rainfall hyetographs of Kadikoy region with 1-Hour resolution data converted from 1-Minute resolution data

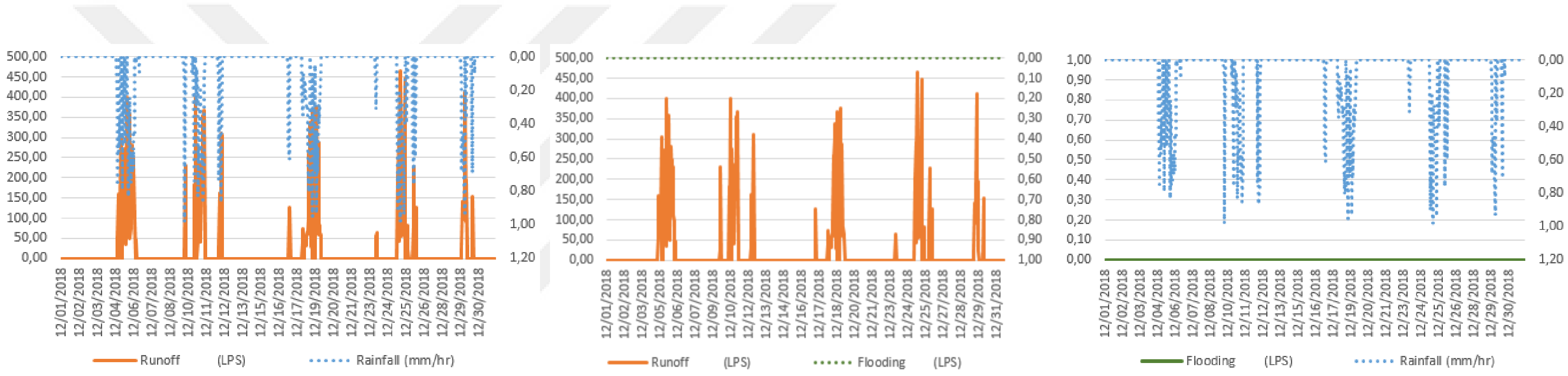


Figure A1.55. Respectively Rainfall, Runoff and Flooding hyetographs of Kadikoy region with 10-Minutes resolution data converted from 1-Minute resolution data

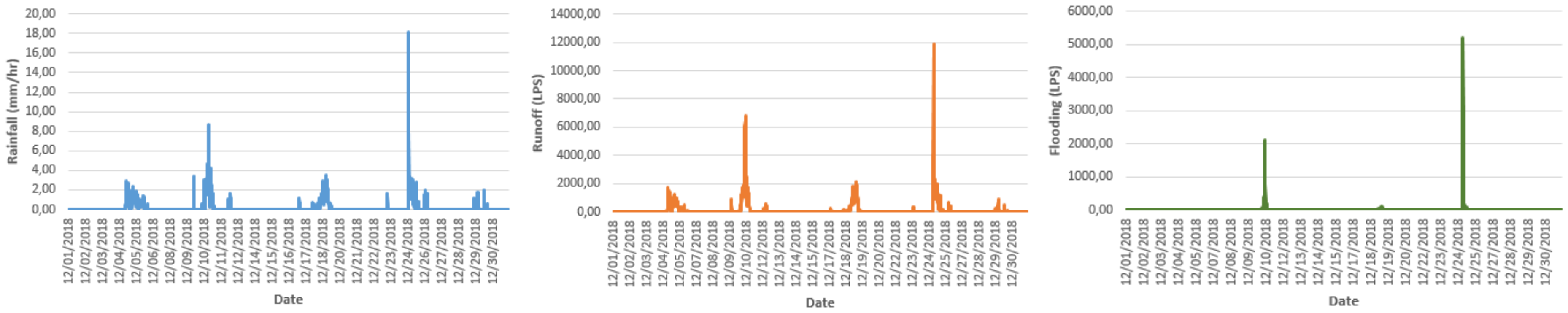


Figure A1.56. Respectively Runoff-Rainfall, Runoff-Flooding and Flooding-Rainfall hyetographs of Kadikoy region with 10-Minutes resolution data converted from 1-Minute resolution data

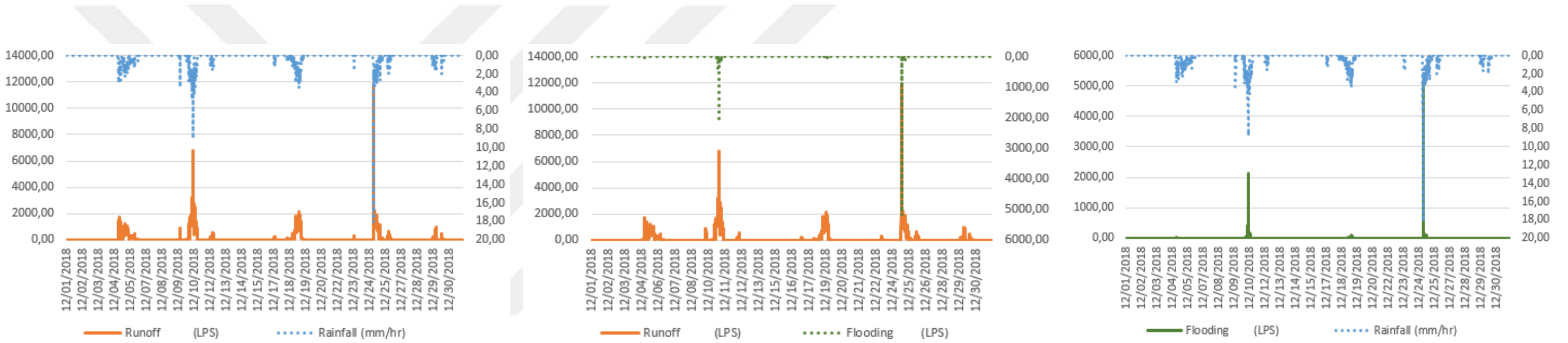


Figure A1.57. Respectively Rainfall, Runoff and Flooding hyetographs of Umraniye region with 1-Hour resolution data converted from 1-Minute resolution data

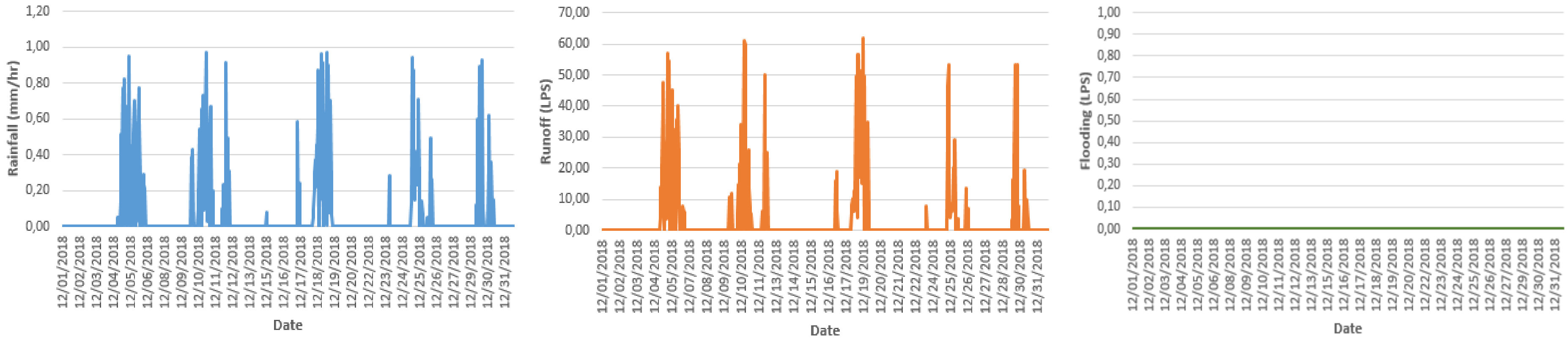


Figure A1.58. Respectively Runoff-Rainfall, Runoff-Flooding and Flooding-Rainfall hyetographs of Umraniye region with 1-Hour resolution data converted from 1-Minute resolution data

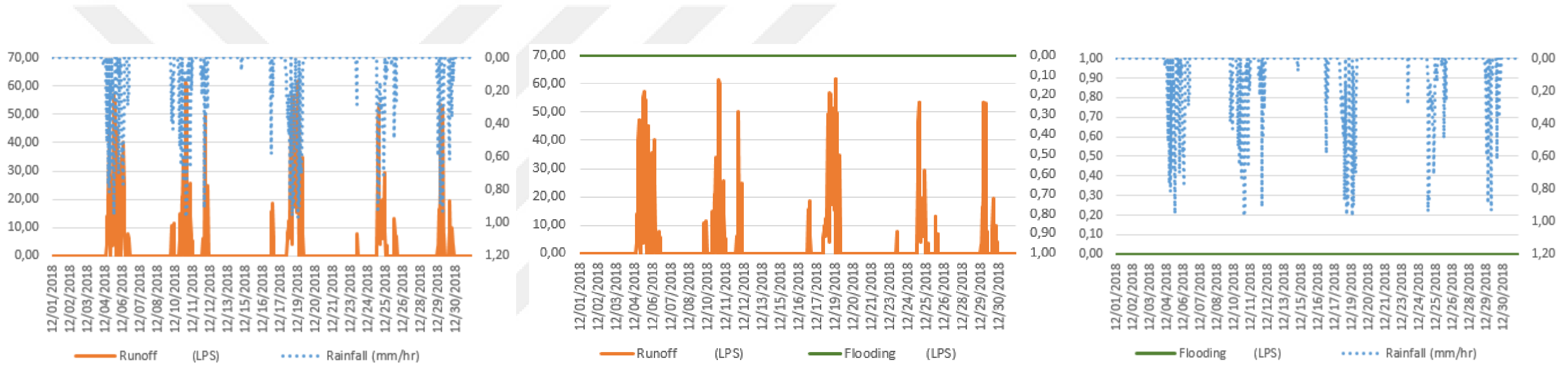


Figure A1.59. Respectively Rainfall, Runoff and Flooding hyetographs of Umraniye region with 10-Minutes resolution data converted from 1-Minute resolution data

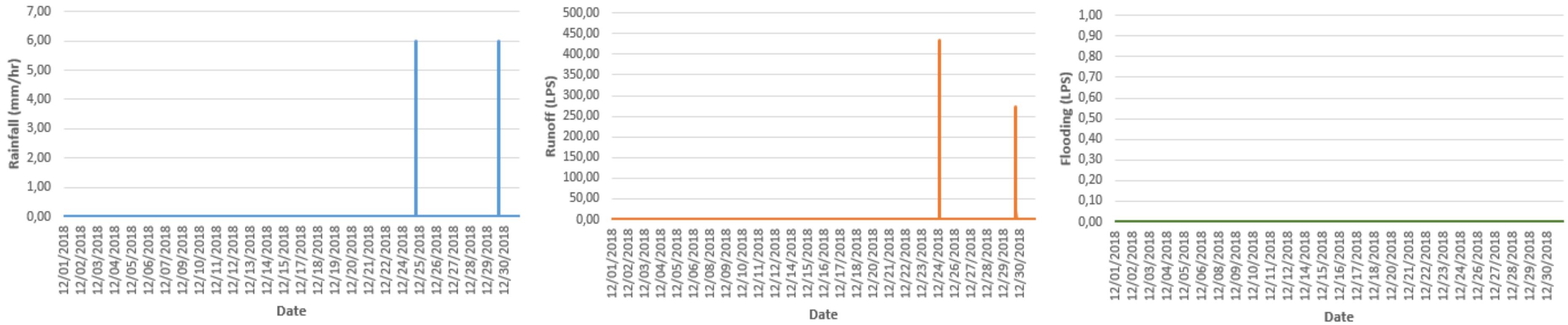


Figure A1.60. Respectively Runoff-Rainfall, Runoff-Flooding and Flooding-Rainfall hyetographs of Umraniye region with 10-Minutes resolution data converted from 1-Minute resolution data

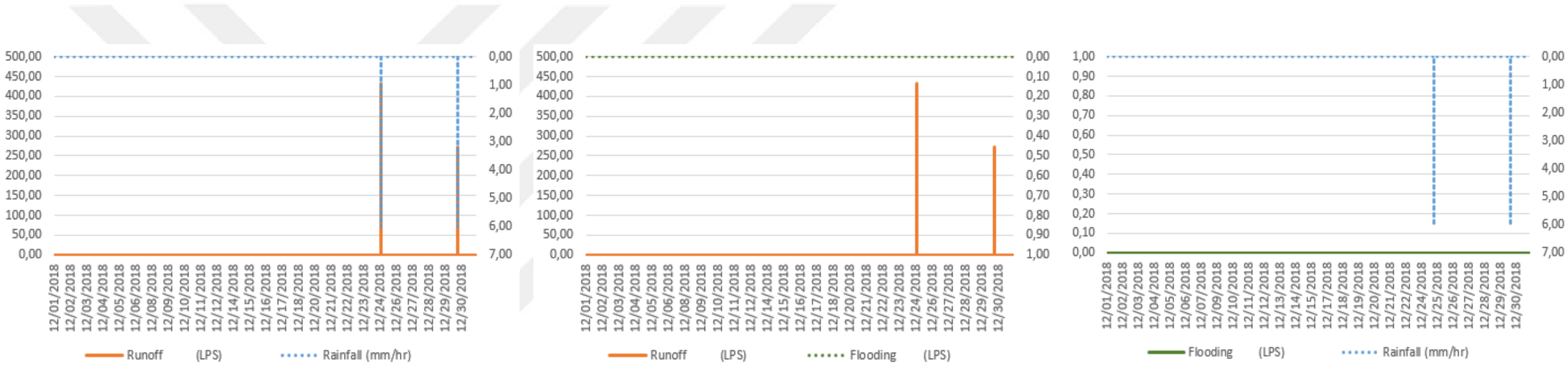


Figure A1.61. Respectively Rainfall, Runoff and Flooding hyetographs of Lockwitz region with 1-Hour resolution data converted from 1-Minute resolution data

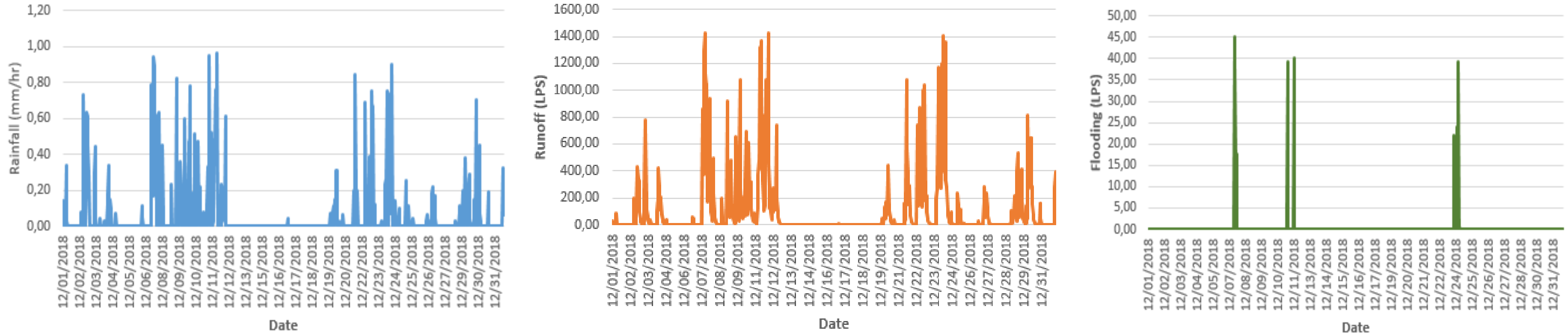


Figure A1.62. Respectively Runoff-Rainfall, Runoff-Flooding and Flooding-Rainfall hyetographs of Lockwitz region with 1-Hour resolution data converted from 1-Minute resolution data

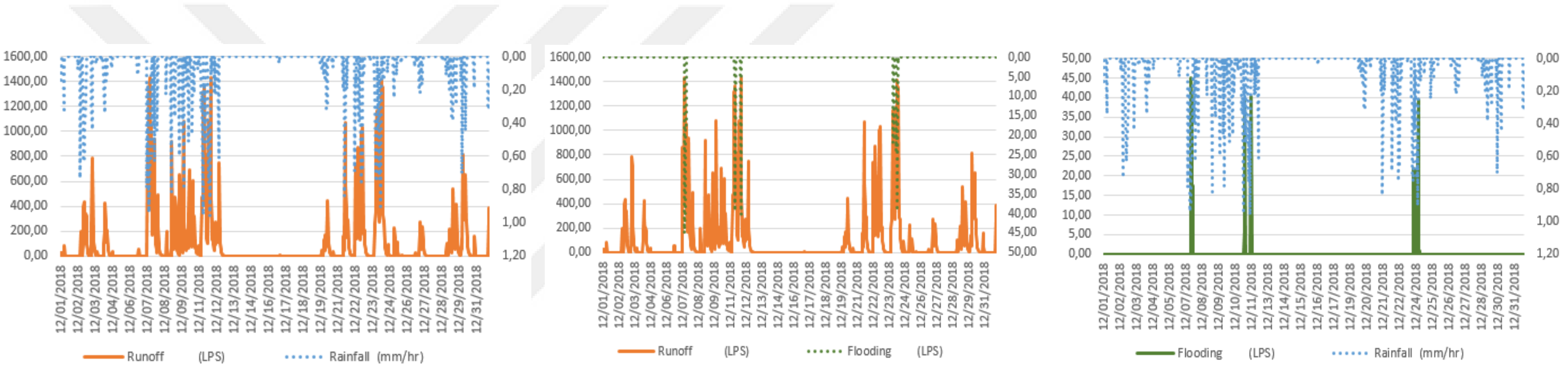


Figure A1.63. Respectively Rainfall, Runoff and Flooding hyetographs of Lockwitz region with 10-Minutes resolution data converted from 1-Minute resolution data

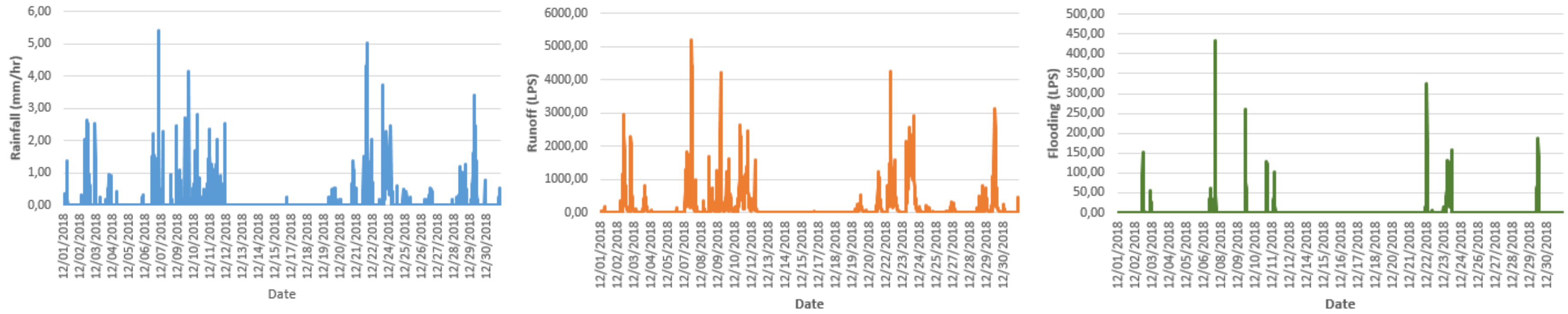


Figure A1.64. Respectively Runoff-Rainfall, Runoff-Flooding and Flooding-Rainfall hyetographs of Lockwitz region with 10-Minutes resolution data converted from 1-Minute resolution data

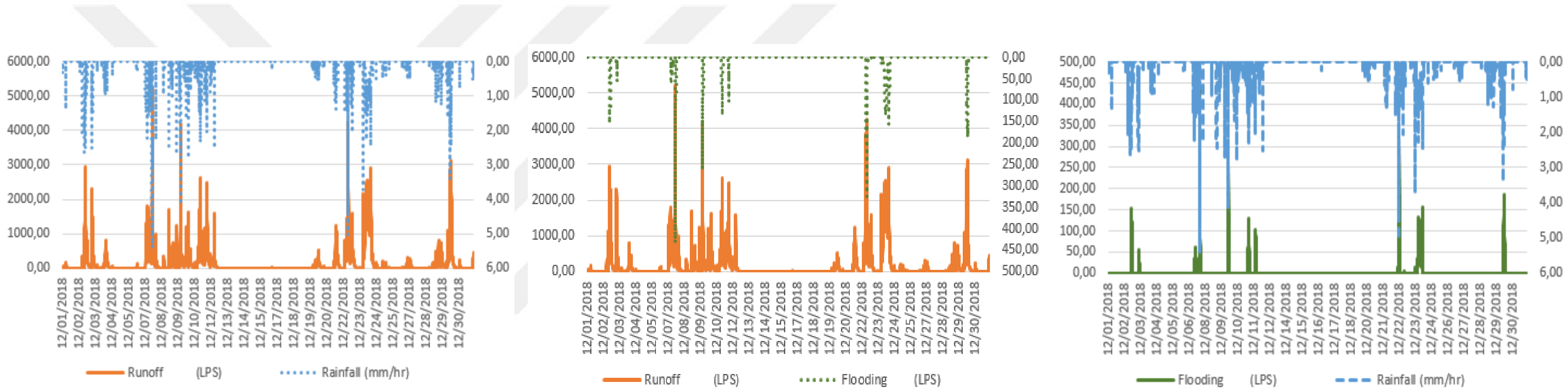


Figure A1.65. Respectively Rainfall, Runoff and Flooding hyetographs of Uskudar region after modifications after modifications by Urbano software

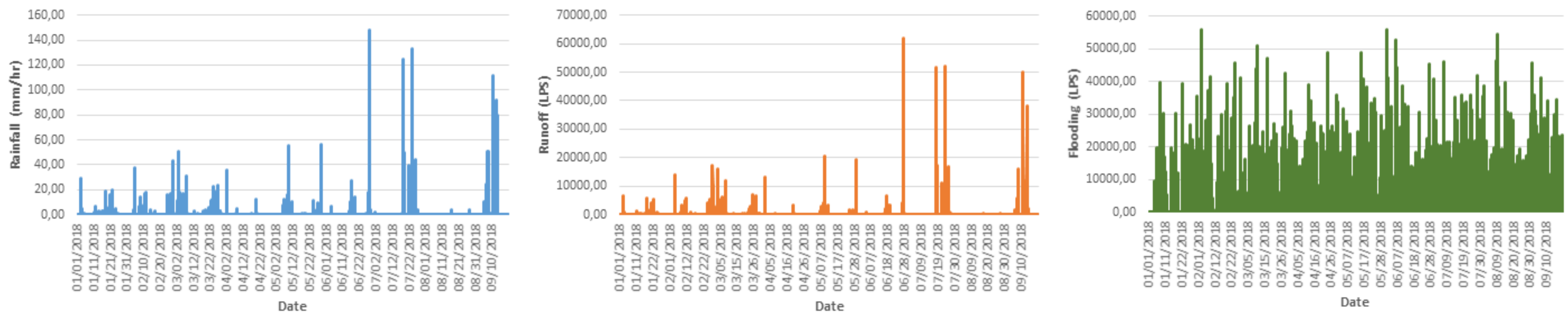


Figure A1.66. Respectively Runoff-Rainfall, Runoff-Flooding and Flooding-Rainfall hyetographs of Uskudar region after modifications after modifications by Urbano software

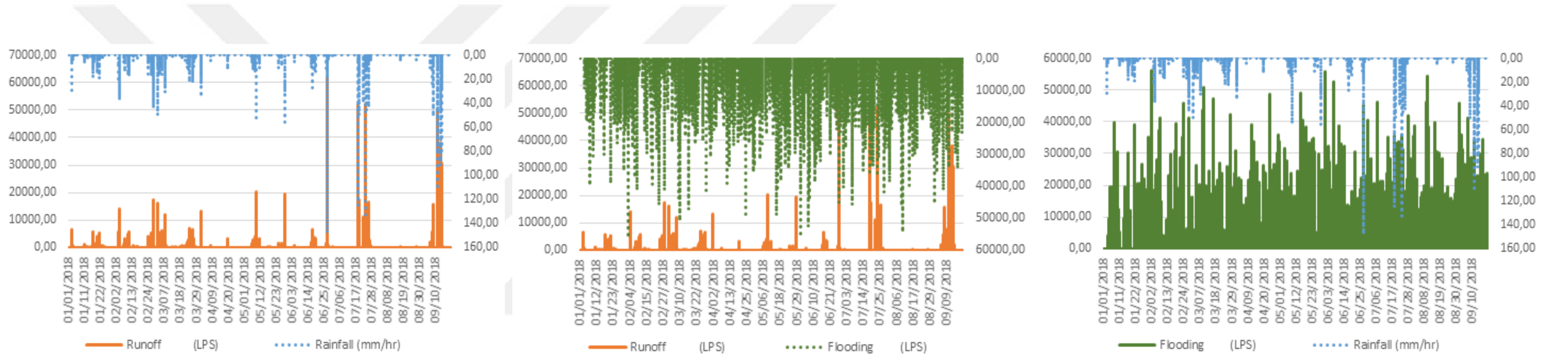


Figure A1.67. Respectively Rainfall, Runoff and Flooding hyetographs of Kadikoy region after modifications after modifications by Urbano software

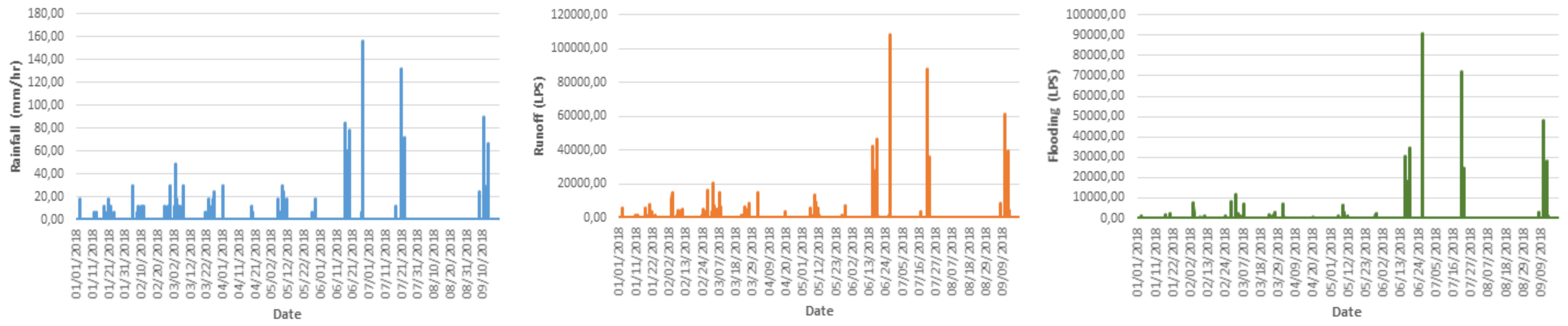


Figure A1.68. Respectively Runoff-Rainfall, Runoff-Flooding and Flooding-Rainfall hyetographs of Kadikoy region after modifications after modifications by Urbano software

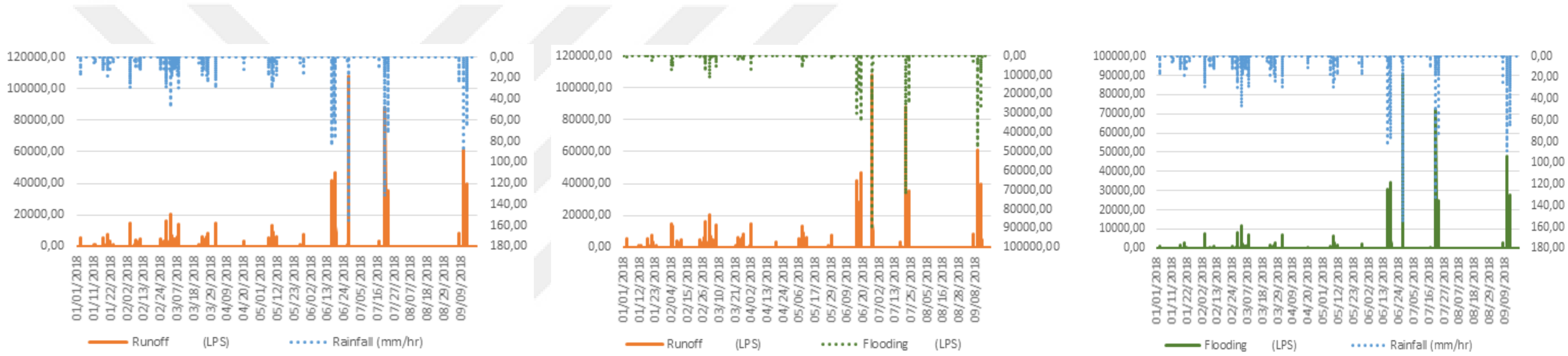


Figure A1.69. Respectively Rainfall, Runoff and Flooding hyetographs of Umraniye region after modifications after modifications by Urbano software

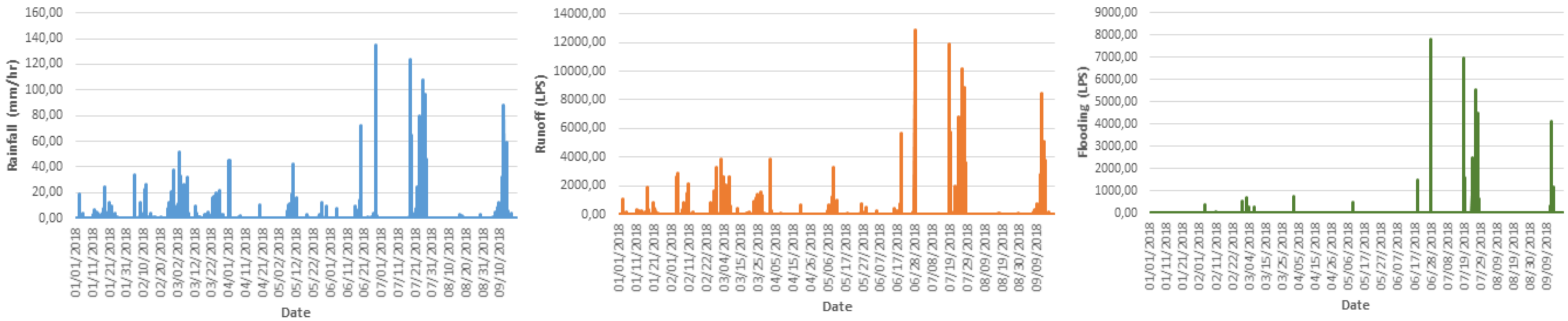


Figure A1.70. Respectively Runoff-Rainfall, Runoff-Flooding and Flooding-Rainfall hyetographs of Umraniye region after modifications after modifications by Urbano software

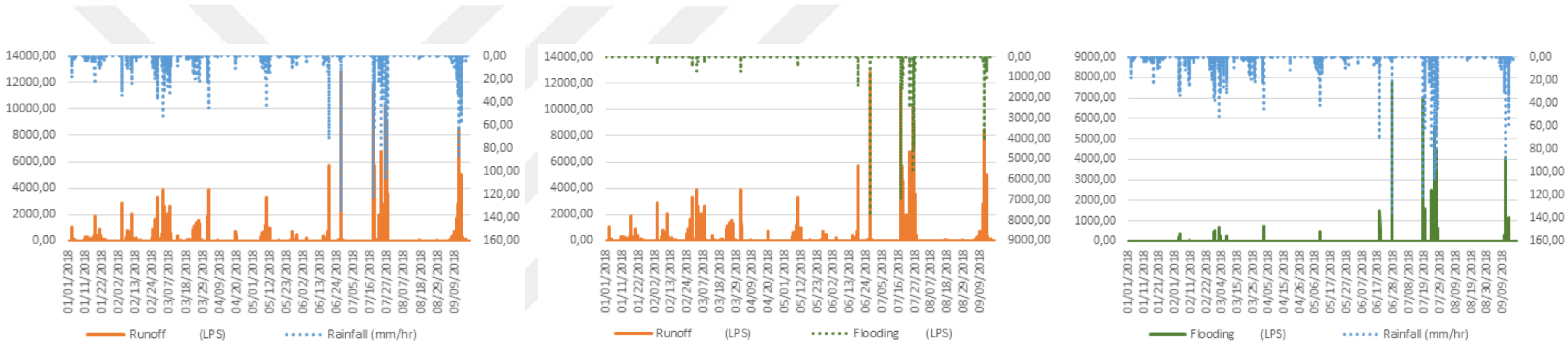
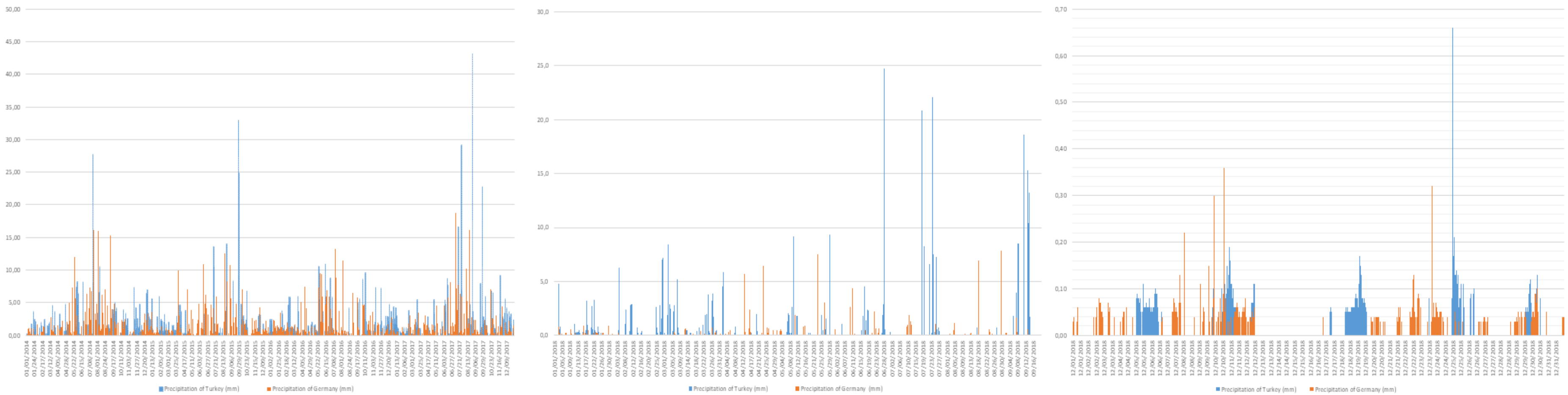


Figure A1.71. Comparison of Turkey's and Germany's rainfall distribution with respectively 1-Hour, 10-Minutes and 1-Minute resolution data



APPENDIX 2

Figure A2.1. Flooded nodes percentage graph of Lockwitz region with it's own 1-Hour resolution data

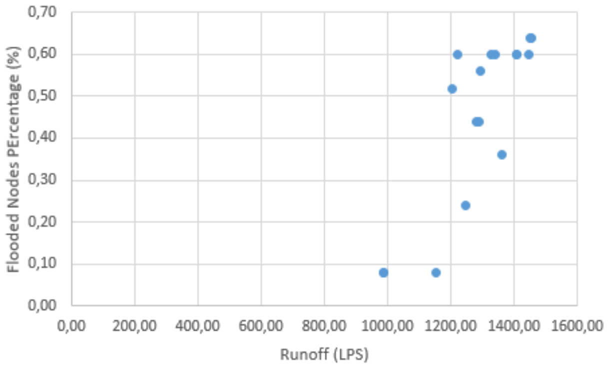


Figure A2.2. Flooded nodes percentage graphs of respectively Uskudar, Kadikoy, Umraniye and Lockwitz regions with their own 10-Minutes resolution data

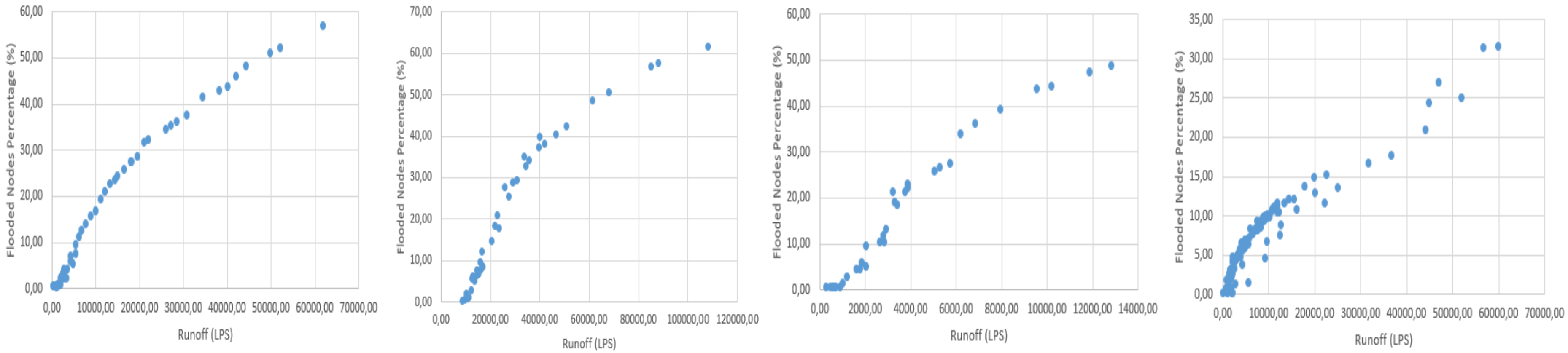


Figure A2.3. Flooded nodes percentage graphs of respectively Uskudar, Kadikoy and Lockwitz regions with their own 1-Minute resolution data

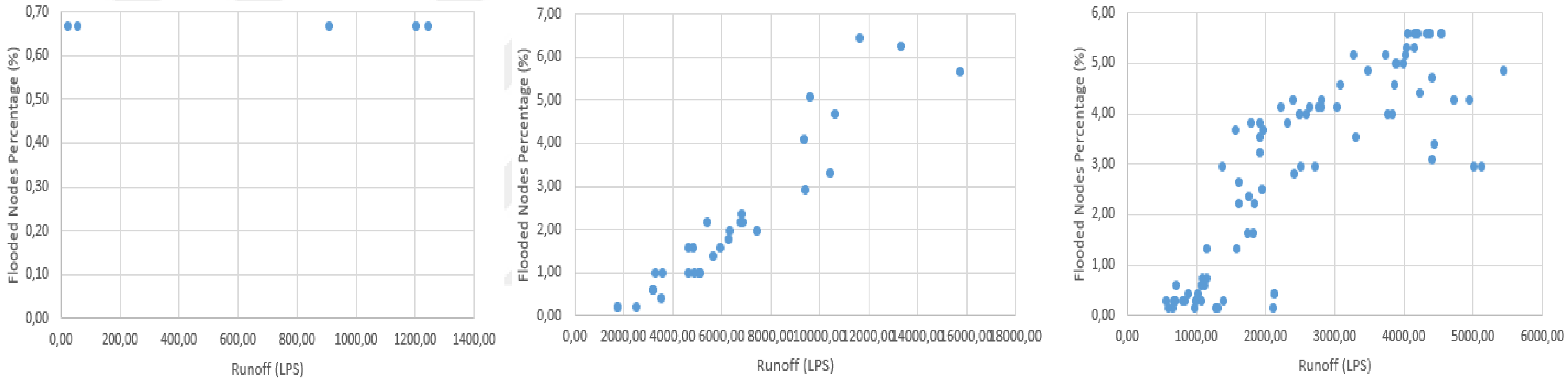


Figure A2.4. Flooded nodes percentage graph of Lockwitz region with it's 1-Hour resolution scenario data

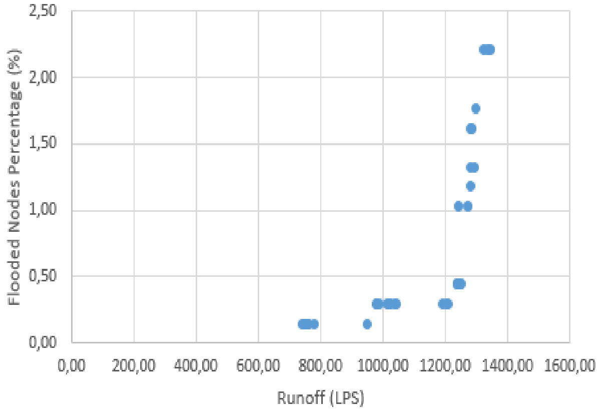


Figure A2.5. Flooded nodes percentage graphs of respectively Uskudar, Kadikoy, Umraniye and Lockwitz regions with their 10-Minutes resolution scenario data

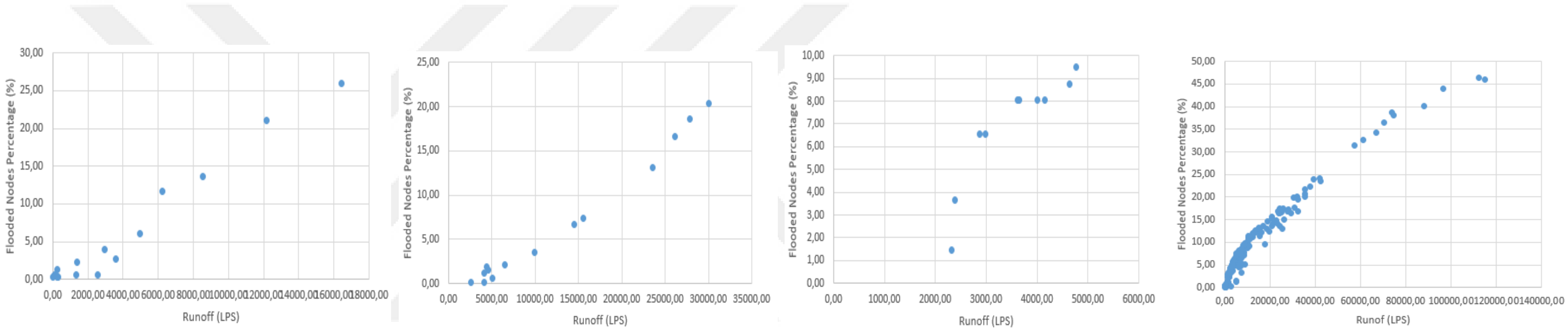


Figure A2.6. Flooded nodes percentage graphs of respectively Uskudar, Kadikoy, Lockwitz regions with their 1-Minute resolution scenario data

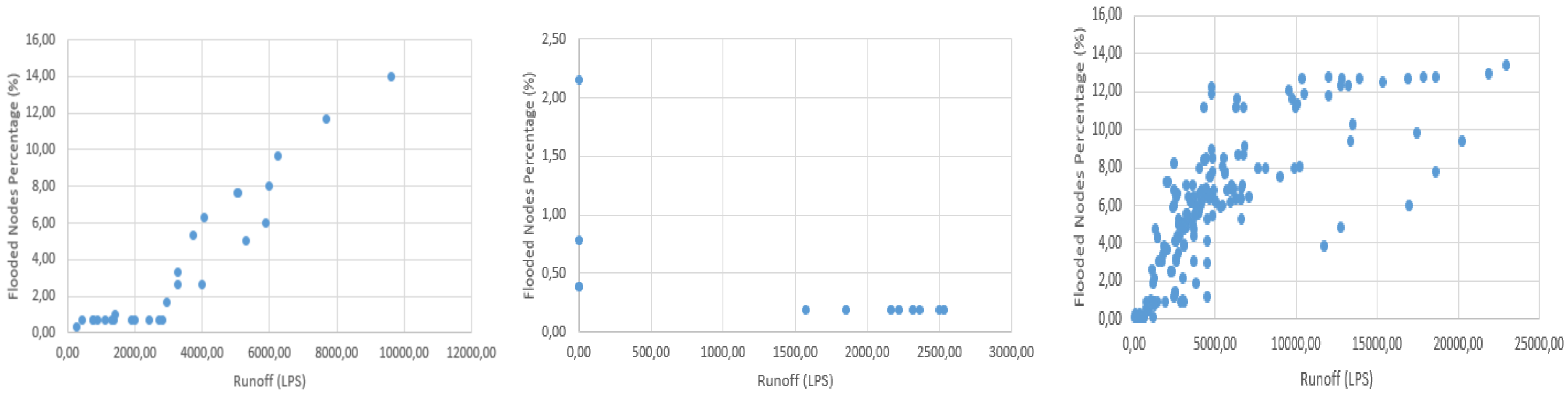


Figure A2.7. Flooded nodes percentage graph of Lockwitz region with it’s 1-Hour resolution data converted from 1-Minute resolution data

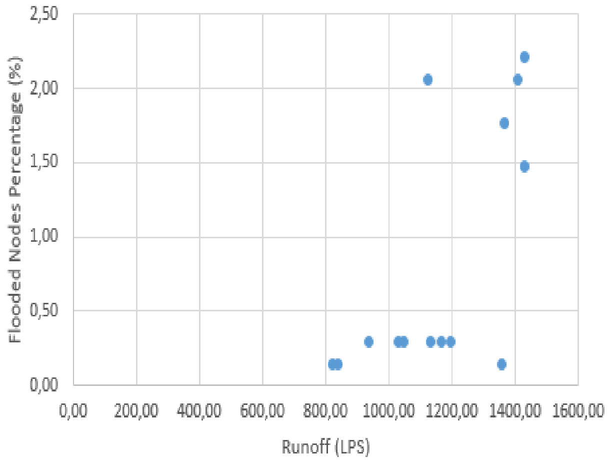


Figure A2.8. Flooded nodes percentage graphs of respectively Uskudar, Kadikoy and Lockwitz regions with their 10-Minutes resolution data converted from 1-Minute resolution data

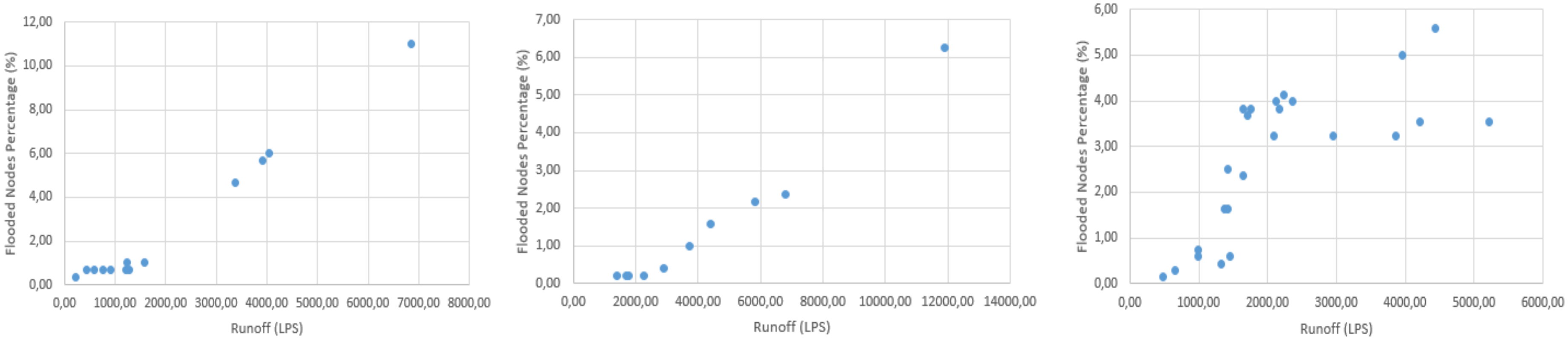
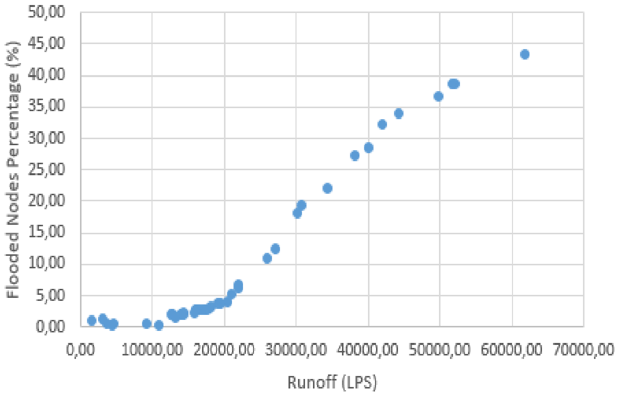
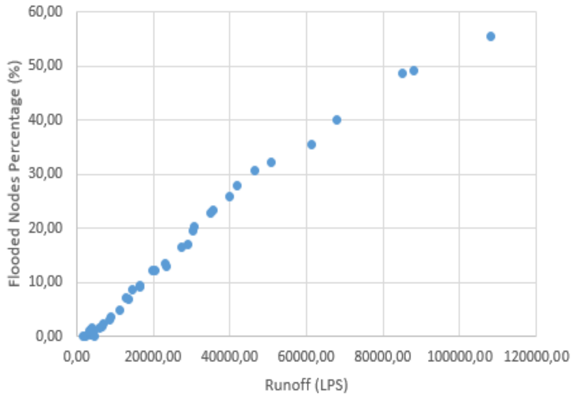


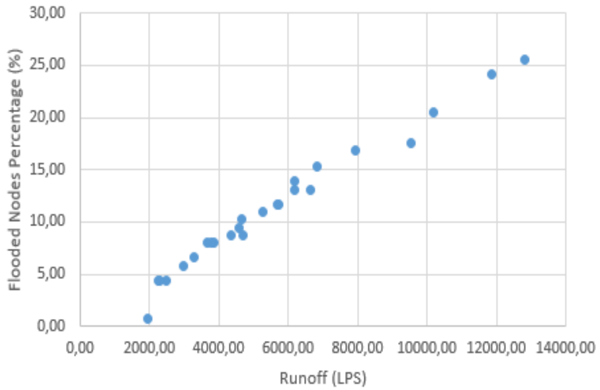
Figure A2.9. Flooded nodes percentage graphs of respectively Uskudar, Kadikoy and Umraniye regions after modifications by Urbano software



Flooded Nodes Percentage (%)
Runoff (LPS)



Flooded Nodes Percentage (%)
Runoff (LPS)



Flooded Nodes Percentage (%)
Runoff (LPS)

APPENDIX 3

Figure A3.1. Flooded nodes of respectively Uskudar, Kadikoy, Umraniye and Lockwitz regions with their own 1-Hour resolution data

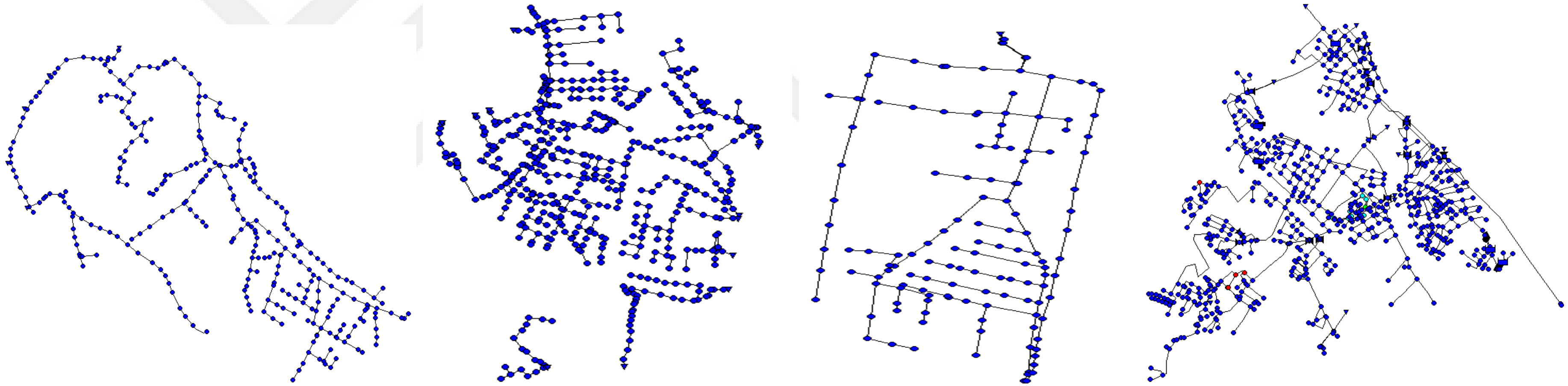


Figure A3.2. Flooded nodes of respectively Uskudar, Kadikoy, Umraniye and Lockwitz regions with their own 10-Minutes resolution data

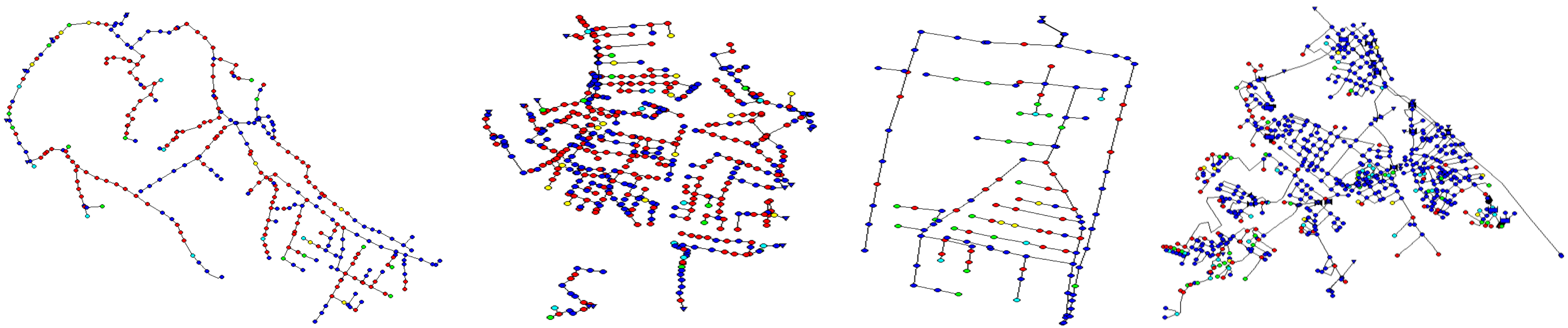


Figure A3.3. Flooded nodes of respectively Uskudar, Kadikoy, Umraniye and Lockwitz regions with their own 1-Minute resolution data

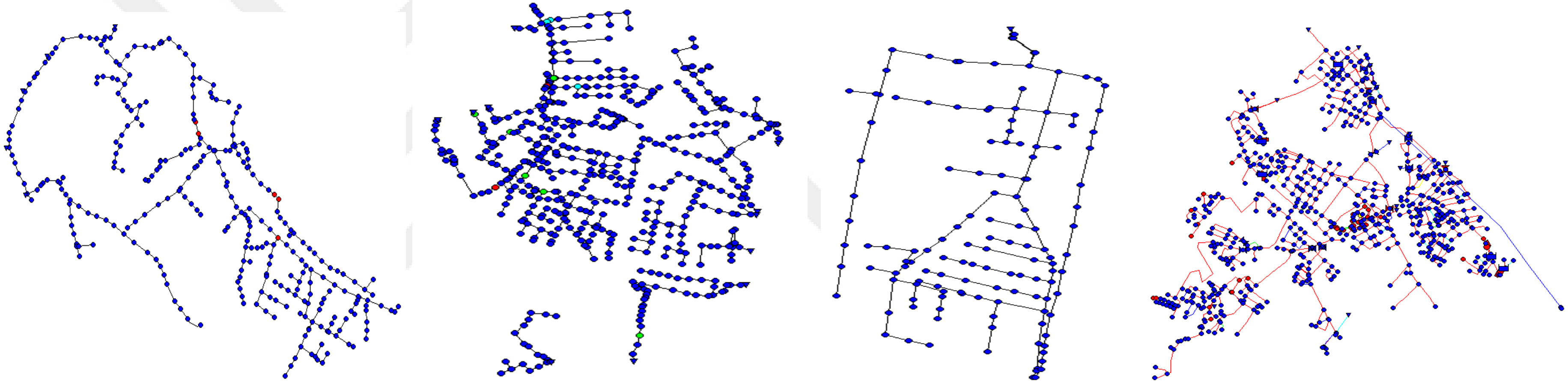


Figure A3.4. Flooded nodes of respectively Uskudar, Kadikoy, Umraniye and Lockwitz regions with their cross 1-Hour resolution scenario data

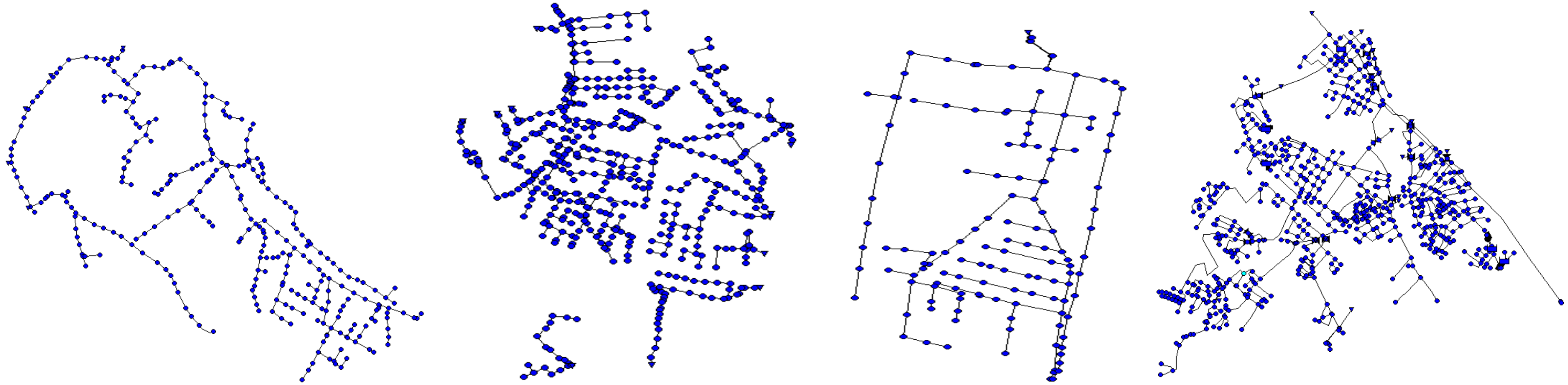


Figure A3.5. Flooded nodes of respectively Uskudar, Kadikoy, Umraniye and Lockwitz regions with their 10-Minutes resolution scenario data

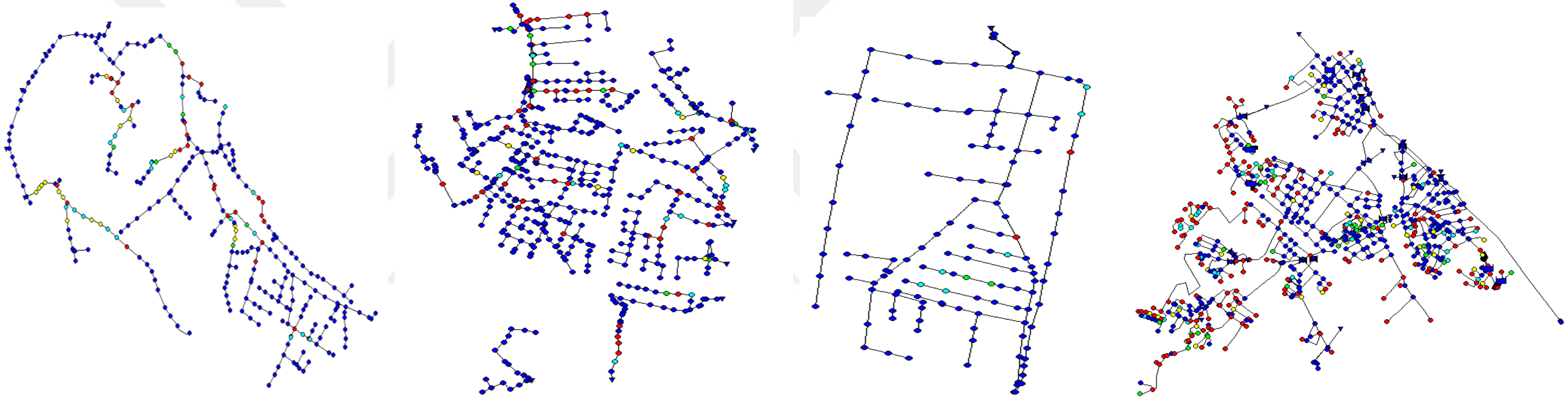


Figure A3.6. Flooded nodes of respectively Uskudar, Kadikoy, Umraniye and Lockwitz regions with their 1-Minute resolution scenario data

Figure A3.7. Flooded nodes of respectively Uskudar, Kadikoy, Umraniye and Lockwitz regions with their 1-Hour resolution data converted from 1-Minute resolution data

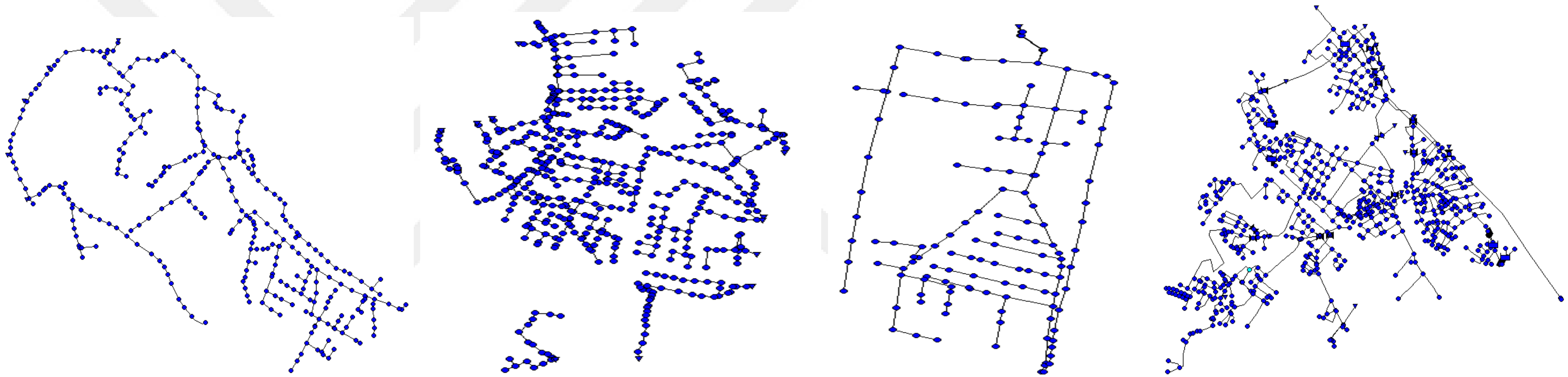


Figure A3.8. Flooded nodes of respectively Uskudar, Kadikoy, Umraniye and Lockwitz regions with their 10-Minutes resolution data converted from 1-Minute resolution data

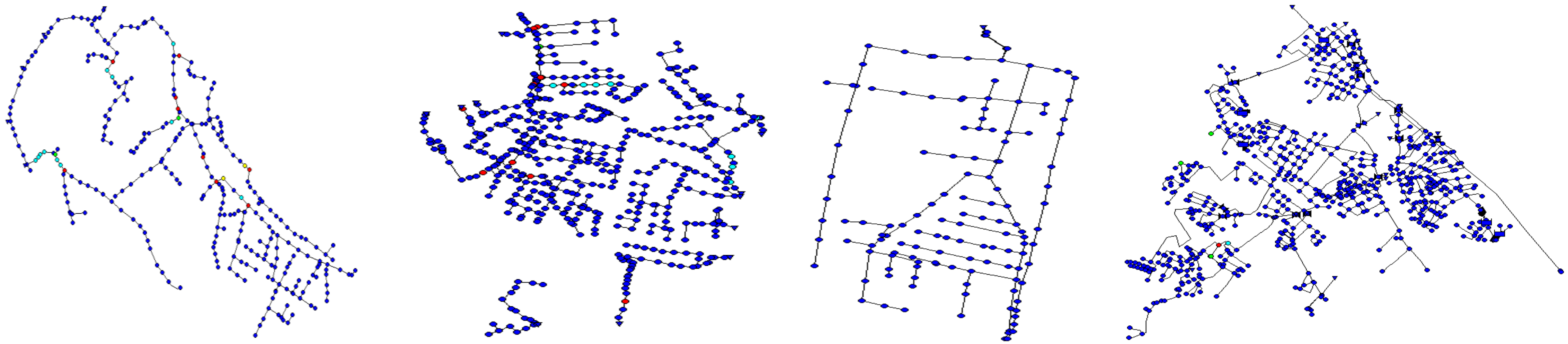


Figure A3.9. Flooded nodes of respectively Uskudar, Kadikoy and Umraniye after modifications by Urbano software

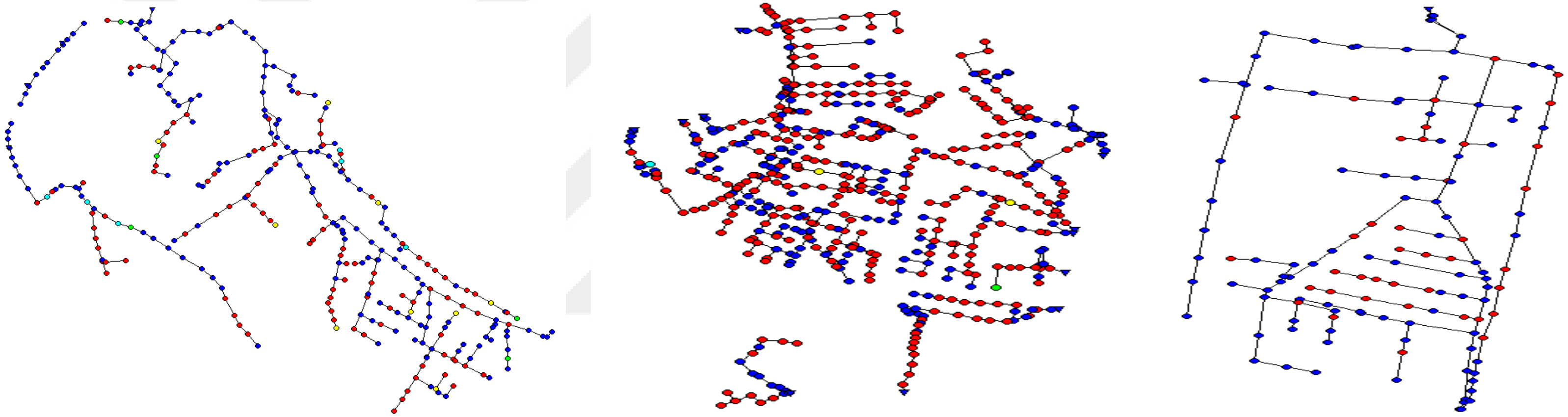


Figure A3.10. General view of catchments on SWMM

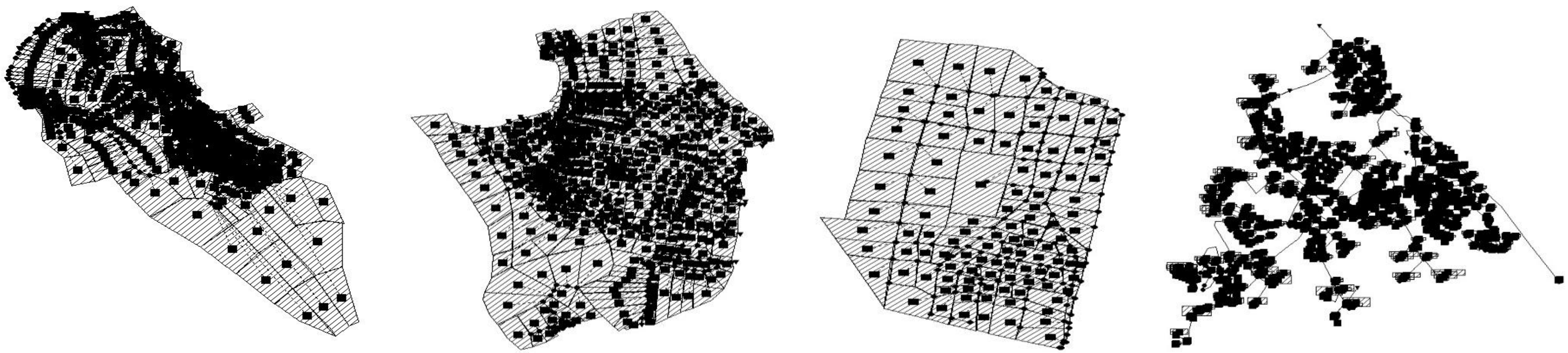


Figure A3.11. Direction of water flow

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