IJEPEM

Int. J. of Environmental Pollution & Environmental Modelling, Vol. 2(4): 219-226 (2019)
(Original Paper)

Urban Drainage Design According to Turkish Rainwater Harvesting and Disposal Guideline

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Abstract: Urban areas become more prone to flood disasters due to the rapid urbanization with increasing rate of impermeable layers. Integrated green infrastructure is one of the most effective tools for stormwater management and runoff reduction in urban areas. Identification of flood-prone regions is crucial for flood mitigation. Improving permeable paving and sustainable drainage system can reduce floods in urban areas. In this study, Barış Street in Selçuklu district of Konya is selected for stormwater drainage design using rational method. The study area is very well developed in terms of constructed buildings, but there is lack of green infrastructure. Hence, this area might be prone to urban flood. Intensity-Duration-Frequency (IDF) curves were used for the intensity determination. Seven different periods of 2, 5, 10, 25, 50,100 and 200 years were selected for stormwater drainage design. Rainfall intensity determination was based on 15 minutes of duration. Rain yield was calculated for each period. The pipe diameter for drainage system was calculated for the selected periods according to partially full pipe flow rate of 60%. As a result; 400 mm diameter for 2 years, 500 mm diameter for 5, 10, 25 years and 600 mm diameter for 50, 100, 200 years return periods have been found. Considering the increasing impacts of climate change, 600 mm of pipe diameter for Barış Street in Selçuklu district of Konya would be appropriate for the urban drainage system.
Keywords: Rainfall intensity, Stormwater, Runoff, Urban flood, Urban flood control

INTRODUCTION

Rapid urbanization changed the natural cover of the ground. The impervious surfaces are increasing day by day in urbanized areas. In urbanized areas, the rate of runoff is increasing dramatically and the rate of infiltrations is decreasing. The high rate of runoff is one of the biggest problems in urbanized areas which responsible for urban floods. During the history the urban drainage has been considered as a cleaning mechanism, an effective waste transportation tool, a flooding concern, a nuisance wastewater and a transmitter of diseases [1].

Some stormwater management models have been developed recently. Australian water authorities have developed a Model for Urban Stormwater Improvement Conceptualization (MUSIC) which is used as a decision support system in urban flood management [2]. Sustainable Drainage System (SuDS) developed by Woods-Ballard et al. [3] is a system which consists of water management by natural way[4]. Reed [5] developed the trajectory of environmentally responsible stormwater management. A regenerative urban stormwater management methodology was developed by Perales-Momparler et al.[6]. A low-impact development (LID) urban stormwater drainage system is used worldwide for reducing the negative hydrologic and water quality effects of urbanization [7]. Zakaria et al. [8] developed a model of bio-ecological drainage system for water quality and quantity control. Best management practices (BMPs) in stormwater management, traditionally in a centralized manner, have been widely used worldwide for urban runoff mitigation [9]. In Australia, an integrated system of rainwater harvesting storage tanks and bio-filtration has been developed for urban flood mitigation [10]. Recently developed models for urban flood management are given in Table 1. Most of the models among these models are Geographic Information System (GIS) based models.

Floods in Turkey

Floods cause severe damages such as property damages and death of people to many communities every year. The amount of flood events has been increased dramatically due to climate change. Mersin province affected by severe floods during November and December in 2001 [11]. In Turkey, about 51% of floods occurs during the end of spring season, and the big portion of the rest of flood events happen

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This paper was presented in International Symposium for Environmental Science and Engineering Research (ISESER 2019, May 25-27, Konya).

during the winter season. Regions which are more prone to frequent floods are Black Sea region, Mediterranean Sea region and Marmara region respectively which approximately 52% of the floods occur in these regions [12].

Table 1. Recently developed models for urban flood management

Model	Country	Purpose	References
Urban Stormwater Improvement Conceptualization (MUSIC)	Australia	Decision support system in urban flood management	Wong et al. [2]
Sustainable Drainage Systems (SuDS) landed rocket	United Kingdom (UK)	Flood mitigation	Woods-Ballard et al. [3]
Trajectory of environmentally responsible stormwater management	United States of America (USA)	Flood mitigation	Reed [5]
Regenerative urban stormwater management methodology	Spain	Stormwater management	Perales-Momparler et al. [6]
Low-impact development urban stormwater drainage system (LID)	New Zealand	Reducing the negative hydrologic and water quality effects of urbanization	Elliott and Trowsdale [7]
Bio-Ecological Drainage System (BIOECODS)	Malaysia	For water quantity and quality control	Zakaria et al. [8]
Stormwater BMPs	USA	Urban runoff mitigation by centralized manner	Loperfido et al. [9]
EPA Stormwater Management Model (SWMM)	USA	Stormwater management	EPA [13]
Integrated system of rainwater harvesting storage tanks and bio-filtration system	Australia	Urban flood mitigation	Burns et al. [10]
GIS model by using ASTER satellite	Turkey	For detecting the damages and measures to be taken for flood mitigation	Yılmaz and Kaya [14]
Multi-criteria decision support model using GIS	Turkey	Developing flood risk maps by using multi-criteria decision support model	Oğuz et al. [15]
Platform of *Türkiye Taşkın Bilgi Sistemi* (TABİS) by using GIS	Turkey	Flood modeling and information system	Haltaş and Demir [16]
Threshold rainfall data and 3-10 days rainfall prediction	Turkey	Flood disaster prediction	Turgu and Ceylan [17]
Flood hazard maps by using GIS and Hec-GeoRAS and HEC-RAS program	Turkey	Urban flood mitigation	Uslu et al. [18]
Stormwater management by Netcad	Turkey	Sewerage, wastewater and stormwater management	Netcad [19]

Turkey suffers from three types of natural disasters related to gravity flows. These are floods, landslides and snow avalanches. Turkey is a prone country to the gravity flow disasters due to its geographical location, geology and topography. Floods are the second important natural hazard with causalities after earthquakes with an annual average of 18 significant flood events that cause 23 deaths [20]. Floods and flash floods have become frequent disasters in recent years in Mersin. Mediterranean climate is effective around Mersin. The most important factors for transformation of meteorological events into a disaster are; climate characteristics, vegetation, earth shapes and human activities [21]. Flood distribution in Turkey is illustrated in Figure 1. An average of around 200 floods occur every year in Turkey, resulting in an average loss of $100 million per year [22].

GIS by using ASTER satellite images with 15 m terrestrial resolution satellite imaging have been used for detecting the damages and measures to be taken for flood mitigation in Atakum district of Samsun province [14]. Sönmez and Demir [23] conducted a study in Istanbul for flood maps and determination of water levels in every building under the flood effect. GIS was used in Artvin province for developing flood risk maps by using multi-criteria decision support model (MDSM) [15]. In Turkey, a platform of *Türkiye Taşkın Bilgi Sistemi* (TABİS) by using GIS was tried to develop for flood modeling and information system [16]. The integrated usage of historical methods with modern methods in flood mitigation studies could provide healthier results in flood mitigation planning. Flood mitigation might be possible by accurate analysis of historical data in regions which are prone to flood disaster [24]. Determining appropriate mitigation methods for each settlement is a necessity in Istanbul. Measures should be taken uninterruptedly until the decision makers make it a policy [25]. Eastern Black Sea Region of Turkey is among the regions which is prone to floods due to intense rainfall events [26]. According to the natural disaster records for the last 67 years in Turkey, floods have the share of 29% out of natural disasters occurred [27]. Threshold rainfall data which may cause flood for 182 meteorological stations in Turkey between 1980-2006 years and 3-10 days rainfall predictions are used for flood disaster prediction [17]. According to Turkish Disaster Data Bank, regions with climatological, meteorological and hydrological disasters were assessed for 1987-2017 years. 2507, 1359 and 1340 climatological disasters were detected in Eastern Anatolia, Black Sea and Aegean Regions respectively [28]. Flood hazard maps were developed by using Hec-GeoRAS and HEC-RAS program for 10, 25, 50, 100, 500 and 1000 year periods in Samsun province [18]. In recent years, Netcad [19] has gained a wide usage in sewerage, wastewater and stormwater management.

In natural ground cover; the breakdown of processes are 50% infiltration, 10% runoff and 40% evapotranspiration. These rates would be 15%, 55% and 30% respectively for 75%-100% impervious surfaces [29]. The rates of infiltration, runoff and evapotranspiration are shown in Figure 1 for various impervious surfaces. High rate of runoff (55%) is responsible for urban floods in highly urbanized areas characterized by 75-100% impervious surfaces.

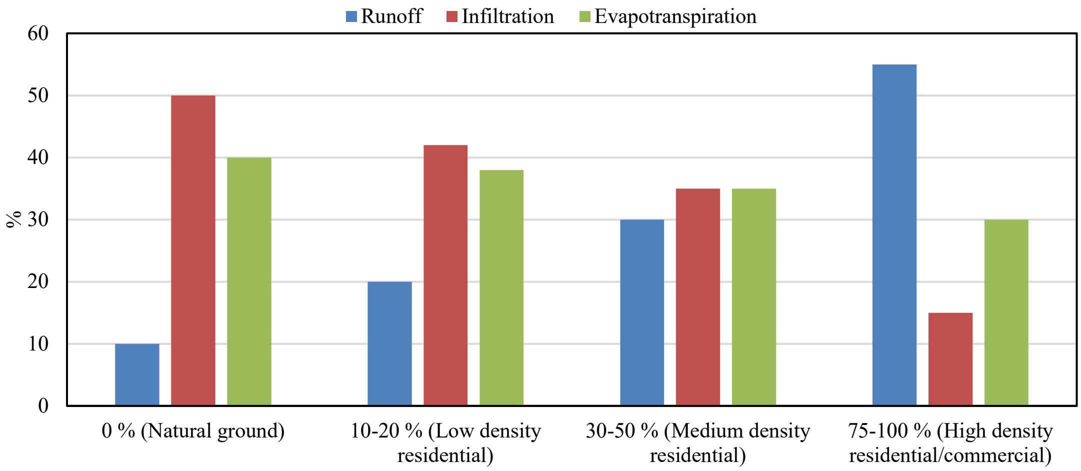

Figure 1. The rates of runoff, infiltration and evapotranspiration in various impervious surfaces adapted from Shields et al. [29]

The guidance of stormwater management planning and design for Canadian province Ontario published in 1994 and updated in 2003 with some advancements especially groundwater recharging [30]. The regulation on stormwater collection, storage, and discharge systems for Turkey published in 2017 with some advancements such as groundwater recharge, rooftop rainwater harvesting, planning and design of drainage [31].

In this study, Barış Street in Selçuklu district of Konya was selected for stormwater drainage design using rational method according to the regulation on stormwater collection, storage, and discharge systems which was published in 2017. The study area covers 11.04 ha. The study area has many grey infrastructures beside having lack of green infrastructures. Appropriate diameter of pipes for various return periods has been calculated using rational method.

MATERIAL AND METHOD

Study Area

In this study, Barış Street in Selçuklu district of Konya is selected for stormwater drainage. This street would be prone to floods during the heavy rainfall events due to the rapid high-dense urbanization in the area. The study area covers 11.04 ha and located 8.7 km away from the city center. The study area was divided into three parcels. The slope of the area is %0.2 between parcel 1 and parcel 3. Study area is illustrated in Figure 2. There is lack of green infrastructure in the study area, so the infiltration rate is low. The high rates of runoff would cause flood event during the heavy rainfall.

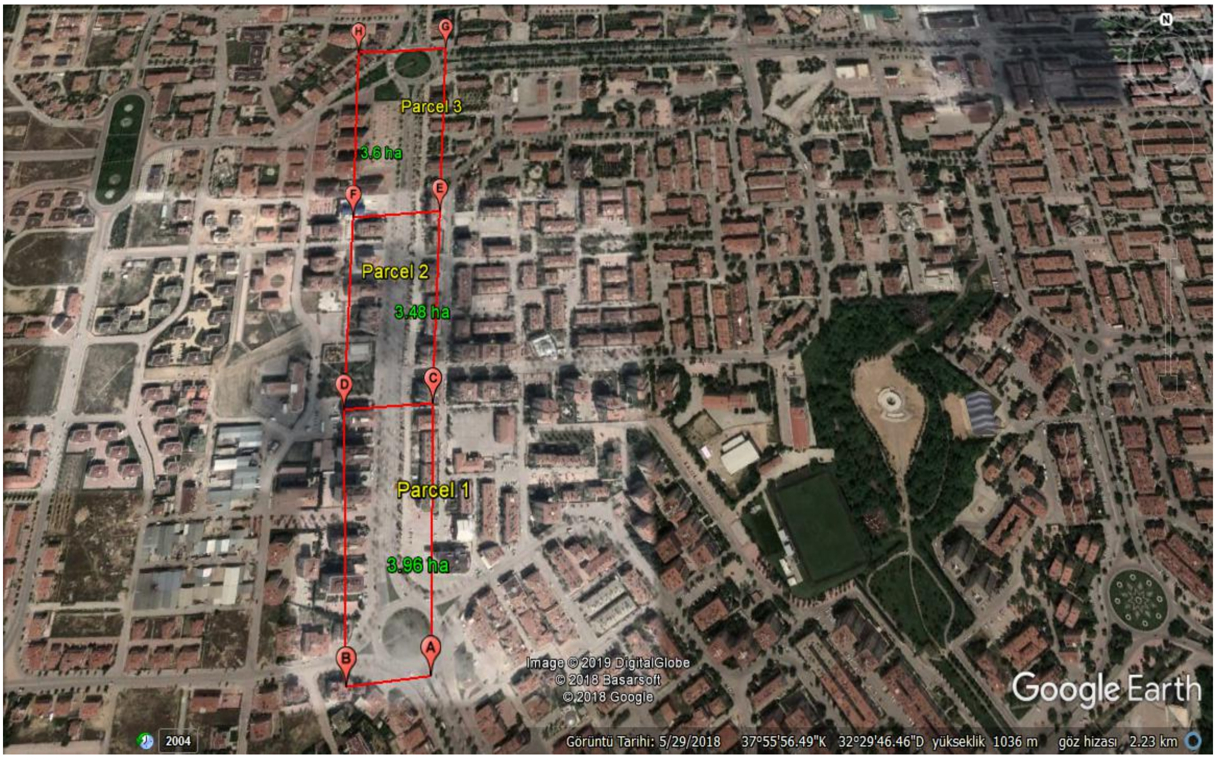

Figure 2. Study area: Barış Street in Selçuklu district of Konya (Google Earth, Digital Globe)

The distance between inlets are recommended between 50-70 m for pipes <1200 mm. In this study, 70 m distance was selected due to the estimated pipe diameters. The location of 24 stormwater inlets have been determined. The study area with parcels and runoff inlets is illustrated in Figure 3.

Figure 3. Study area with parcels and runoff inlets (Google Earth, Digital Globe)

Calculation of Rainfall Yield

IDF curve of Konya meteorological station was used for stormwater drainage system according to regulation on stormwater collection, storage, and discharge systems 2017 guideline. IDF rainfall curves are illustrated in Figure 4. Rainfall intensities for 2, 5, 10, 25, 50, 100 and 200 years period have determined using IDF rainfall curves for 15 minutes. Partially-full pipe flow calculations have been conducted according to the regulation on stormwater collection, storage, and discharge systems. Maximum of 90% partially full pipe flow is recommended by the guideline. In this study, 60% partially full pipe flow was selected due to the upstream. Time interval of 5, 10, 15 and 20 minutes are the most commonly used intervals for urban drainage design. Therefore, time interval of 15 minutes was selected. The most commonly used periods are 2, 5, 10, 25 and 50 years. All periods between 2-200 years were selected for the comparison of results. The dots in graph correspond to the calculated data while the lines correspond to the corrected data by using regression (Figure 4).

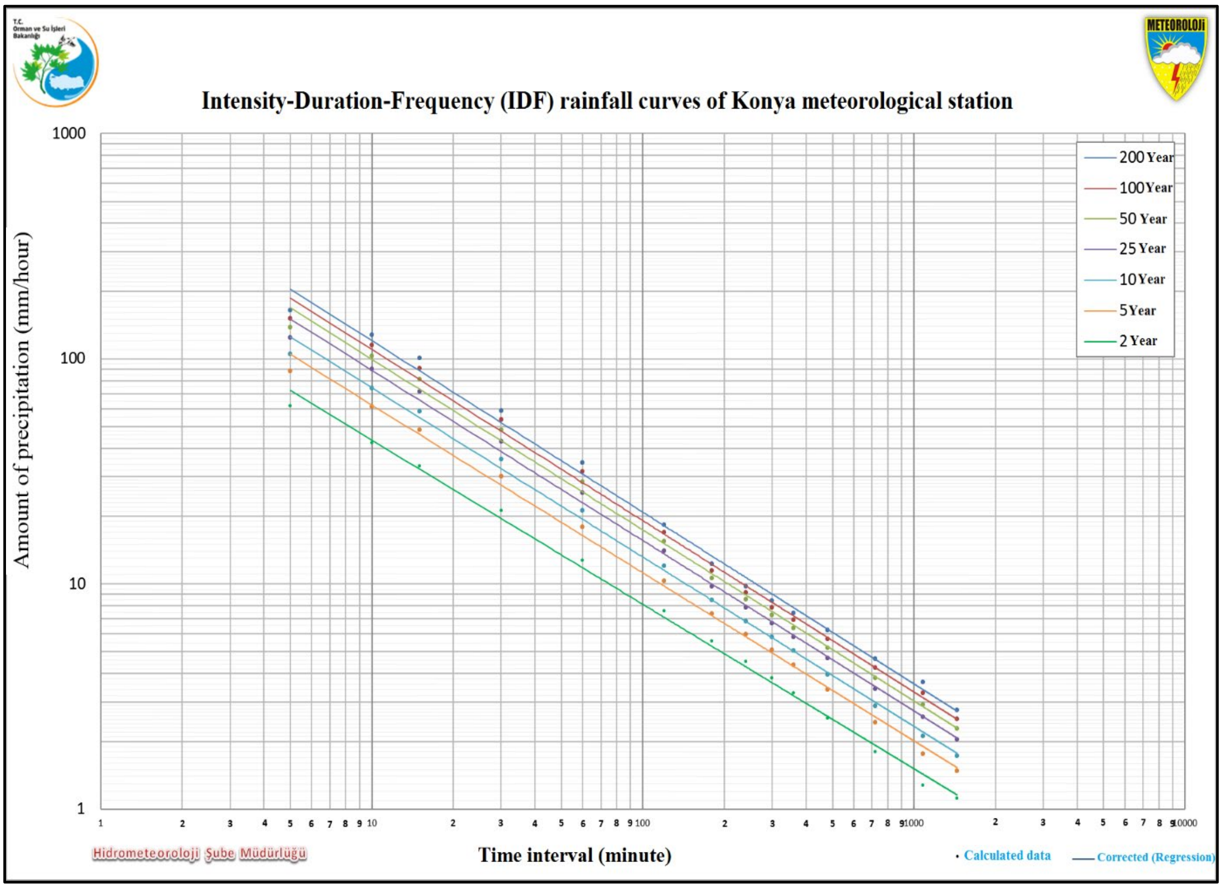

Figure 4. Rainfall IDF curves of Konya meteorological station

Intensity was determined from IDF curves using 15 minutes. Rainfall yield (r) was calculated by using $r = 166{,}7 \times i$ equation. Runoff coefficient (C) 0.5 was selected according to the urban multi-story residential buildings. The amount of runoff was calculated by using the $Q = C \times r \times A$ equation. The range for velocity (V) in channels is recommended between 0.5-5 m/s by the regulation on stormwater collection, storage, and discharge systems, 3 m/s was selected in this study.

RESULTS AND DISCUSSIONS

Summary table of runoff calculations is given in Table 2. Pipe diameter of 400 mm for rainfall drainage was calculated for 2 years period. Pipe diameter of 500 mm for 5, 10, 25 years periods and 600 mm for 50, 100 and 200 years periods were calculated. The recommended partially full rate of the drainage pipes is 90% maximum. In this study, 60% partially full rate in the drainage pipes is assumed that the drainage pipes are already 30% full at the upstream.

Table 2. Summary table of runoff calculations

Frequency (year)	Duration (min)	Intensity, i (mm/min)	Rainfall yield, r (L/s.ha)	Runoff coefficient, C	Area (ha)	V (m/s)	Length, L_0 (m)	Q (m^3/s)	Diameter, D (mm)
2	15	0.58	96.69	0.50	11.04	3	920	0.32	400
5	15	0.78	130.03	0.50	11.04	3	920	0.43	500
10	15	0.93	155.03	0.50	11.04	3	920	0.51	500
25	15	1.13	188.37	0.50	11.04	3	920	0.62	500
50	15	1.27	211.71	0.50	11.04	3	920	0.70	600
100	15	1.40	233.38	0.50	11.04	3	920	0.77	600
200	15	1.52	253.38	0.50	11.04	3	920	0.84	600

The rainfall intensity at Konya meteorological station for various return periods of 15 minutes rainfall is illustrated in Figure 5. The intensity of rainfall is 35, 47, 56, 68, 76, 84 and 91 mm/hr for 2, 5, 10, 25, 50, 100 and 200 years periods respectively for 15 minutes. As obtained results show in Table 2; the pipe diameter of 500 mm has been found same for 5, 10 and 25 years which are globally commonly used return periods. However, considering both increasing climate change impact and the result of 600 mm of pipe diameter for 50, 100 and 200 years return periods, 600 mm diameter for the drainage pipeline would be appropriate for the urban drainage design.

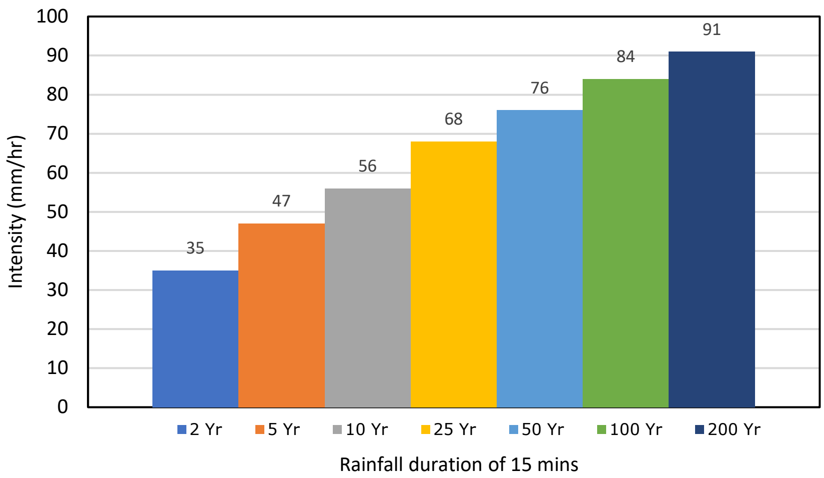

Figure 5. The rainfall intensity at Konya station for various return periods

CONCLUSION AND RECOMMENDATIONS

Turkey is prone to hydro-meteorological disasters especially floods. Due to the rapid urbanization, the natural cover of land has been changed to impermeable layers in most of urban areas of the country. Therefore, urban areas become more prone to flood disaster. The rate of infiltration is higher in natural land cover and lower in impervious surfaces. The high rates of runoff are responsible for urban flood event due to the impervious surfaces. The factors such as climate change which cause increasing in rainfall intensity should be taken into consideration for accurate drainage design. Identification of flood-prone regions is crucial for flood mitigation. Improving permeable paving and sustainable drainage system can reduce flood damages in urban areas. There is need to develop/reserve green infrastructure areas for flood mitigation.

Rain yield calculation is recommended for drainage design in the regulation on stormwater collection, storage, and discharge systems published in 2017. Therefore, rain yield was calculated for various return periods. The required diameters of drainage pipes were calculated for the selected periods according to the partially full pipe flow rate (60%). In conclusion, the pipe diameter of 500 mm has been found effective for 5, 10 and 25 years return periods. However, considering the increasing impacts of climate change, 600 mm of pipe diameter for Barış Street in Selçuklu district of Konya would be appropriate for the urban drainage system.

REFERENCES

[1] Burian, S. J. and Edwards, F. G., 2002, Historical perspectives of urban drainage, In 9th International Conference on Urban Drainage (pp. 8-13).

[2] Wong, T. H., Fletcher, D., Duncan, H. P., Coleman, J. R. and Jenkins, G. A., 2002, A Model for Urban Stormwater Improvement Conceptualization, 1st International Congress on Environmental Modelling and Software- Lugano, Switzerland. 48-53.

[3] Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray, R. and Shaffer, P., 2007, the SUDS Manual, CIRIA C697, London.

[4] Charlesworth, S.M., 2010, A review of the adaptation and mitigation of global climate change using sustainable drainage in cities, Journal of Water and Climate Change, 1 (3), 165-180.

[5] Reed, B., 2007, Shifting from 'sustainability' to regeneration, Building Research and Information, 35 (6), 674-680.

[6] Perales-Momparler, S., Andrés-Doménech, I., Andreu, J. and Escuder-Bueno, I., 2015, A regenerative urban stormwater management methodology: the journey of a Mediterranean city, Journal of Cleaner Production, 109, 174-189.

[7] Elliott, A. H. and Trowsdale, S. A., 2007, a review of models for low impact urban stormwater drainage, Environmental modelling and software, 22(3), 394-405.

[8] Zakaria, N. A., Ab Ghani, A., Abdullah, R., Mohd. Sidek, L. and Ainan, A., 2003, Bio-ecological drainage system (BIOECODS) for water quantity and quality control, International Journal of River Basin Management, 1(3), 237-251.

[9] Loperfido, J. V., Noe, G. B., Jarnagin, S. T. and Hogan, D. M., 2014, Effects of distributed and centralized stormwater best management practices and land cover on urban stream hydrology at the catchment scale, Journal of Hydrology, 519, 2584-2595.

[10] Burns, M. J., Fletcher, T. D., Walsh, C. J., Ladson, A. R. and Hatt, B. E., 2012, Hydrologic shortcomings of conventional urban stormwater management and opportunities for reform, Landscape and urban planning, 105(3), 230-240.

[11] Karabulut, M., Sandal, E. K. ve Gürbüz, M., 2007, 20 Kasım-9 Aralık 2001 Mersin Sel Felaketleri: Meteorolojik ve Hidrolojik Açıdan Bir İnceleme, KSU Journal of Science and Engineering, 10(1), 13-23.

[12] Özcan, E., 2006, Sel olayı ve Türkiye, Gazi Üniversitesi, Gazi Eğitim Fakültesi Dergisi, 26(1), 35-50.

[13] EPA, 1969, Stormwater Management Model (SWMM), United States Environmental Protection Agency, Washington, D.C., US.

[14] Yılmaz, C. ve Kaya, M., 2018, Oluşum Sebepleri, Verdiği Zararlar ve Alınan Önlemler Bağlamında Samsun-Atakum Sel ve Taşkınları, TÜCAUM 30, Yıl Uluslararası Coğrafya Sempozyumu, 3-6 Ekim, Ankara.

[15] Oğuz, K., Oğuz, E. and Coşkun, M., 2016, Coğrafi Bilgi Sistemleri İle Taşkın Risk Alanlarının Belirlenmesi: Artvin İli Örneği, Ulusal Taşkın Sempozyumu Tebliğler Kitabı, 793-804.

[16] Haltaş, İ. ve Demir, İ., 2014, Türkiye Taşkın Bilgi Sistemi (TABİS), V. Uzaktan Algılama ve Coğrafi Bilgi Sistemleri Sempozyumu (UZAL-CBS 2014), 14-17 Ekim, İstanbul.

[17] Turgu, E. ve Ceylan, A., 2008, ECMWF Yağış Verileri Yardımıyla Türkiye'de Sel Tahmini Çalışmaları, Uluslararası Katılımlı VI. Atmosfer Bilimleri Sempozyumu, 25-28 Mart, İstanbul, Türkiye.

[18] Uslu, G.., Sesli, F. A, Uzun B., Yılmazsoy, B., Akdemir, Ç. ve Güler, S., 2018, Coğrafi Bilgi Sistemleri İle Taşkın Tehlike Haritalarının Belirlenmesi, Urban Academy, Rewieved Journal of Urban Culture and Management, 11 (36), 545-558.

[19] NetCAD, 1989, Kanalizasyon Şebekeleri Projelendirme, Atıksu & Yağmursuyu, Netcad Yazılım A.Ş. web page: http://portal.netcad.com.tr/pages/viewpage.action?pageId=100827256 (retrieval date: 15.08.2019).

[20] Gürer, I., 1998, Flood Disasters and Preventative Measures in Turkey, Journal of natural disaster science, 20(1), 1-9.

[21] İçel, G., 2014, Mersin'de Meteorolojik Ve Hidrometeorolojik Afetler, Electronic Turkish Studies, international Periodical for the Languages, Literature and History of Turkish or Turkic, 9(11), 263-282.

[22] Ün, Y., 2013, Türkiye'de Taşkın Gerçeği ve Meteorolojik Erken Uyarı Sistemleri, T.C. Orman ve Su İşleri Bakanlığı, Metroloji Genel Müdürlüğü, 33. Ankara.
[23] Sönmez, O. ve Demir, F., 2017, Ağva ilçe merkezine ait taşkın yayılım haritalarının ve mevcut binaların taşkın su seviyelerinin tespiti, Sakarya University Journal of Science, 21(2), 105-112.
[24] Sunkar, M. ve Toprak, A., 2016, Sel ve Taşkın Çalışmalarında Tarihi Veri Kaynaklarının Önemi, TÜCAUM Uluslararası Coğrafya Sempozyumu, 13-14 Ekim, Ankara.
[25] Bodur, A., 2018, Sel ve İstanbul: Sel Riskine Karşı Yapılan Dere Islah Çalışmaları ile İlgili Bir Değerlendirme, Resilience, 2(1), 57-68.
[26] Gürgen, G., 2004, Doğu Karadeniz Bölümünde Maksimum Yağışlar ve Taşkınlar Açısından Önemi, Gazi Üniversitesi, Gazi Eğitim Fakültesi Dergisi, 24(2), 79-92.
[27] Ceylan, A. ve Kömüşcü, A. Ü., 2007, Meteorolojik karakterli doğal afetlerin uzun yıllar ve mevsimsel dağılımları, İklim Değişikliği ve Çevre, 1(1), 1-10.
[28] Çelik, M. A., Bayram, H. and Özüpekçe, S., 2018, An assessment on climatological, meteorological and hydrological disasters that occurred in Turkey in the last 30 years (1987 2017), International Journal of Geography and Geography Education, 38, 295-310.
[29] Shields, F. D., Cooper Jr, C. M., Knight, S. S. and Moore, M. T., 2003, Stream corridor restoration research: a long and winding road, Ecological engineering, 20(5), 441-454.
[30] Bradford, A. and Gharabaghi, B., 2004, Evolution of Ontario's stormwater management planning and design guidance, Water Quality Research Journal, 39(4), 343-355.
[31] YTDDS, 2017, Yağmursuyu Toplama, Depolama ve Deşarj Sistemleri Hakkında Yönetmelik, Çevre ve Şehircilik Bakanlığı, Ankara, Türkiye, 67.