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The Impact of Blue-Green Infrastructure on Climate Resilience for Hydrometerological Hazards: The Case of Bayraklı, İzmir*

Mavi-Yeşil Altyapının Hidrometerolojik Tehlikeler İçin İklim Direncine Etkisi: İzmir Bayraklı Örneği

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Abstract

Urban areas are one of the most affected systems by climate change. Blue-green infrastructure systems make significant contributions to reducing the vulnerability against climate change and disaster risks in urban areas and adapting to the climate with the ecosystem services they provide. This study aims to determine blue-green infrastructure (BGI) and their water related disaster mitigation functions in Bayraklı, İzmir. Therefore, the research question is defined as: how effective the existing BGI of Bayraklı is to handle a 100-year frequency storm. In this context, the components of BGI were defined, and their runoff were calculated by considering a 100-year frequency storm event taking into account their ecological characteristics of these areas, such as vegetation, and surface permeability. The findings showed that BGI is inadequate to remove 1269857,30 m^3 stormwater runoff from the city in the events of a 100–year of rainfall. Potential water retention capacity of BGI varies according to characteristics of the green infrastructure components. Based on the outcomes of the study, recommendations were presented to increase climate resilience of Bayraklı district by the existing BGI.

Keywords: Climate Change, Ecosystem Services, Flood Mitigation, Natural Infrastructure

Özet

Kentler, iklim değişikliğinden en çok etkilenen sistemlerden biridir. Mavi-yeşil altyapı sistemleri sağladığı ekosistem servisleriyle kentlerde iklim değişikliğinden etkilenebilirliğin ve afet riskinin azaltılmasına, dolayısıyla iklim değişikliğine uyum sağlanmasına önemli katkılarda bulunur. Bu nedenle araştırma sorusu, Bayraklı'nın mevcut mavi-yeşil altyapısının 100 yıl tekerrürlü yağışlar karşısında ne kadar etkilidir? şeklinde tanımlanmıştır. Bu kapsamda mavi-yeşil altyapı bileşenleri tanımlanmış, 100 yıl tekerrürlü yağışın gerçekleşmesi durumunda bu alanlarda yüzey akışa geçecek su miktarları hesaplanmıştır. Araştırmada mavi yeşil altyapının ilçenin % 37`sini kapladığı bu alanların birbiriyle bağlantılı bütüncül bir sistem oluşturmadığı belirlenmiştir. 100 yıl tekerrürlü yağışta mavi yeşil altyapı bileşenlerinde 1269857,30 m^3 suyun yüzey akısla tutulamadığı belirlenmiştir. Çalışmada, Bayraklı ilçesinin mevcut mavi-yeşil altyapısının olası ekstrem yağışlara karşı yeterli su tutma kapasitesine sahip olmadığı, bu durumun yeşil altyapı bileşenlerinin özelliklerine göre değişiklik gösterdiği görülmüştür. Bulgular doğrultusunda iklim değişikliği ve ekstrem yağış miktarları göz önünde bulundurularak mevcut mavi-yeşil altyapının ve kentin iklim direncinin artırılmasına yönelik uyum önerileri sunulmuştur.

Anahtar Kelimeler: Doğal Altyapı, Ekosistem Servisi, İklim değişikliği, Kent Seli Önleme

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1. Introduction

Cities are extremely vulnerable to climate hazards due to high levels of impermeable surfaces and the lack of infrastructure that cannot handle extreme events. Furthermore, urban floods are one of the most significant problems that are exacerbated by climate change in terms of intensity and frequency (IPCC, 2013- 2023). In addition, there are critical consequences of socio-economic problems such as structural damage, financial loss, and health issues caused by floods.

Urban floods have become increasingly frequent in many cities across the globe (WMO, 2023; WRR, 2023; Alves et al., 2018; Donnell & Thorne, 2020; Ncube & Arthur, 2021). In 2021, floods became the most frequent natural disaster, increasing by approximately %48, causing 4,393 deaths and direct economic losses reaching USD 74.607 billion compared for the last 30 years (1991-2020) (GNDAR, 2022). For example, Pakistan experienced the worst floods in decades during monsoon season. In four months (from June to September) the country received almost three times more rainfall in the 30-year average. One third of the country and almost eight million people were affected, and they had to been displaced (MSRNA, 2022). In 2023 nearly every region of the world was inundated with floods. Libya (Derna) experienced one of the most tragic floods incidences with more than 4,000 casualties (CRED, 2023). According to annual Meteorological Disaster Assessment Reports, urban floods are the most common meteorological disaster in Turkiye. 38% of extreme weather events in 2023 were heavy rainfall and floods. Since 1940 the year highest flood disaster has been 2023 has the highest flood disaster (TSMS, 2000-2021-2022-2024). In 2023, due to the floods in Adıyaman and Şanlıurfa, 21 people lost their lives and more than three thousand houses were damaged. Additionally, 18 people died floods in İstanbul, Kırklareli, Batman, Zonguldak and Diyarbakır (TSMS, 2024).

It is clear that there is an urgent need for proactive solutions to mitigate problems related to urban flooding (Sörensen et al., 2016). The United Nations 2022 Report emphasizes that very few measures have been taken to prevent disasters in cities, and much more efforts are needed to tackle the problem. In this context, Blue-Green Infrastructure-BGI (natural infrastructure) is recommended as an effective tool for climate change adaptation and mitigation (UNEP, 2022).

BGI is defined as the network of blue and green elements of nature across urban and rural landscapes that deliver social, economic and ecological benefits supporting ecosystem functions and societal wellbeing (Mell & Scott, 2023) (Figure 1). BGI can play an important role to increase urban resilience to climate change by providing multiple ecosystem services such as air, water and soil quality improvement, urban cooling, carbon sequestration and biodiversity increase (Ncube & Arthur, 2021; Coşkun Hepcan & Cangüzel, 2021; Yüksel & Coşkun Hepcan, 2023). BGI alleviates the risk of urban flooding and potential effects of climate change by reducing surface run off and complementing grey infrastructure`s ability to cope with water during flooding (Thorne et al., 2015). Therefore, BGI is being considered as the best alternative to grey infrastructure. The European Adaptation Strategy and United Nations have emphasized the use of BGI. Furthermore, BGI has become popular over the recent years in urban planning with one of its major functions that reduces urban flooding risk by detention, retention and infiltration of stormwater (Sörensen & Emilsson, 2019; Coşkun Hepcan, 2019; Pallathadka et al., 2022; Cangüzel, 2022). BGI also has the potential of achieving urban sustainability by fulfilling the Sustainable Development Goals 9,11,13.

Figure 1. Potential components of BGI.

Like many other cities, İzmir is also highly affected by urban floods. According to Turkish Meteorological Service, floods are the most frequent climate related hazard after storms in Turkey between 2010 and 2021, and İzmir is one of the prominent cities with the highest number for floods (TSMS, 2022). The city has experienced more than 95 urban floods in these twelve years period. Bayraklı is one of the districts that was seriously affected by these hydrometeorological events and urgent climate actions are required to be taken in the district. In this study, it is aimed to determine the hydrometeorological disaster prevention functions of BGI in Bayraklı. Therefore, the research question of the study is defined as: how effective the existing BGI of Bayraklı is to handle a 100-year frequency storm.

2. Material and Method

2.1. Material

In this research WorldView2 and Sentinel satellite images, soil maps, and meteorological data were used to generate dataset for analysis.

2.1.1. Study Area

Bayraklı is one of the central districts of İzmir with an area of 25,06 km^2 and population of 306.988 inhabitants (TUİK, 2020). It is located between the northeast corner of İzmir Bay and the southern slopes of Yamanlar Mountain (27º6'42"E 38º30'32"N – 27º12'26"E 38º27'1"N) (Figure 2). The climate of the study area is Mediterranean with an average annual temperature of 17,9 °C and precipitation of 713,8 mm.

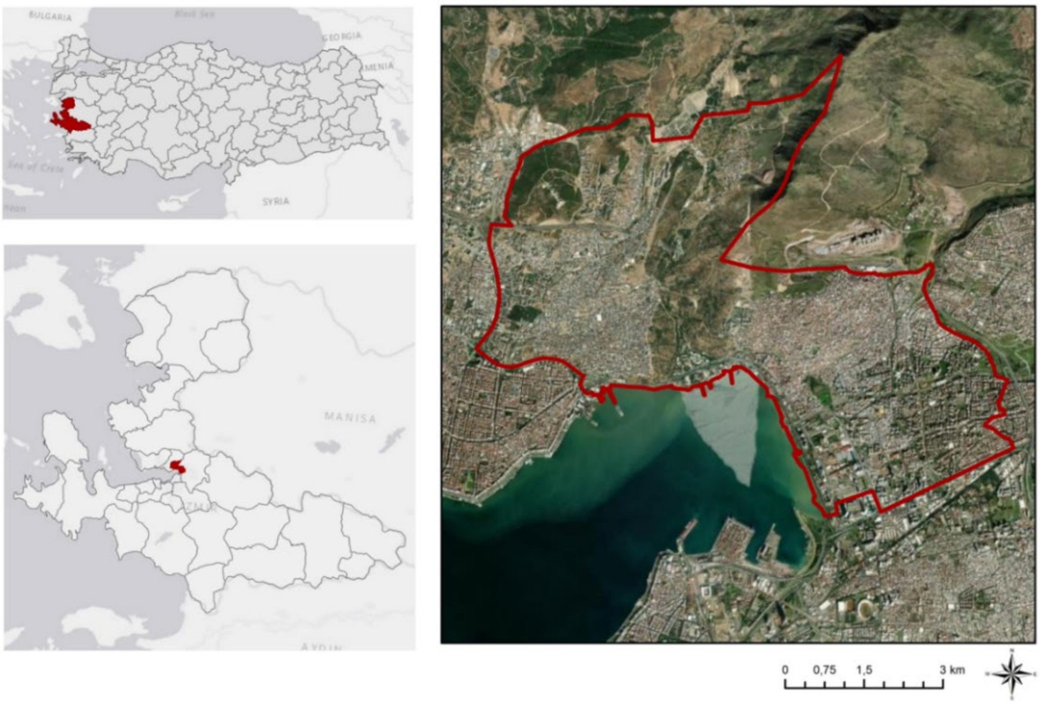

Figure 2. Study area.

The district includes both residential and commercial settlements. The urban area is settled on the lowlands (coastal plain) in the East, on hilly areas in the West and North. It receives extreme rain occasionally and experiences fluvial, pluvial, and coastal floods. For instance, for the last three years, Bayraklı experienced severe precipitation events and floods. Especially in 2021 the district received approximately 140 mm rain fell within only eight-hour period, causing pluvial and fluvial flooding (TSMS, 2021).

2.2. Method

The methodology of the study has two stages: defining BGI and calculating the surface runoff potential of the BGI.

BGI map were derived from orthorectified WorldView2 satellite image (Pan+MSbundle, 0.5 m ground resolution, dated September 2018) and SENTINEL (2020) by screen digitization. Natural areas, agricultural lands, urban parks, playgrounds, private and institutional gardens, green (street) corridors, river corridors and water bodies larger than 150 m^2 were defined as BGI components. Then, based on their shape they were defined as patches and corridors.

In this research surface runoff values of BGI are considered as retention potential to mitigate urban flood risk. The SCS-CN method was used to estimate the surface runoff of the components of BGI (USDA, 1989) based on the soil type, permeability capacity, and vegetation cover.

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \quad (1)$$

$$S = \frac{2540}{CN} - 25.4 \quad (2)$$

$$V_r = \frac{Q \times A}{1000} \quad (3)$$

In the equation Q is runoff (mm), S is potential maximum retention after start of runoff (mm), P is rainfall (mm), CN is a runoff curve number, Vr is the volume of runoff (m^3), and A is the size of the drainage area (m^2). CN numbers were interpreted based on USDA (1989) and İzmir Soil map. Runoff calculations were made based on 192 mm rainfall event that represents total rainfall based on a 100-year return period with 24-hour duration rainfall for İzmir (TSMS, 2020). The meteorological data for a 100-year frequency storm for İzmir was obtained from Turkish Meteorological Service.

3. Results and Discussion

BGI covers 37 % (9.35 km^2) of Bayraklı. The BGI is dominant with patches (97%). The largest proportion of BGI is natural areas that occupy 79 % of the BGI. These areas form a large intact patch with phrygana vegetation, lie from the North to South in the center of the district and divides the urban area into two sections. The urban area expands on the coastal plain in the east, on the hills in the west (Figure 3, Table 1).

Table 1. Elements of BGI and their runoff value (retention potential).

Land use/cover type	Area km^2	Area % of BGI	Runoff m^3
Natural vegetation	7,38	78,93	1000529,04
Agricultural area	0,30	3,21	40071,00
Park	0,53	5,67	73484,40
Garden	0,39	4,17	52640,98
Cemetery	0,11	1,18	13948,75
Open space	0,51	5,45	69504,02
Canal	0,13	1,39	-
Total	9,35	100	1269857,30

Urban parks occupy just 5% of the BGI, they are unevenly distributed throughout the study area with smaller patches in the east and west, and with larger patches on the coast. Most of the parks are neighborhood parks located between building blocks with low tree canopy coverage. Their size is mostly between 1000 and 2000 m^2. Linear coastal parks on the bay and by the river are the largest parks among them. Agricultural lands cover only 0.30 km^2 area and they are mostly located at the edge of the urban development zone as small patches near the natural land in the east and northwest. Private and institutional gardens occupy a small percentage of the district with 0.39 km^2. They are mostly located in the new urban development zones (Figure 3, Table 1).

Open spaces between building lots with little or no vegetations are scattered homogeneously in the urban development zone. They occupy 0.51 km^2 of area of different size in the district. Corridors cover only 3% of the district and they are composed of green and blue corridors. The total length of green corridors is 11,5 km while blue corridors is 10 km. There are two blue (engineered) corridors. The first one, Bornova River extends from east to west in the east and meets its tributary, Laka River. The other one, Ilıcadere located in the west lies in the North to south direction. The width of the blue corridors varies (Table 1, Figure 4).

Results showed that in the event of 100-year rainfall, 4812082,56 m^3 rainwater will reach the study area and more than ¾ of this rainfall will be surface runoff. While natural areas have the highest runoff retention potential with1000529,04 m^3, parks follow them with 73484,40 m^3 (Table 1, Figure 4). The estimated runoff retention of open spaces with little or no vegetation is close to the parks that is 69504,02 m^3. Runoff retention potential of private gardens is predicted as 52640,98 m^3. Agricultural lands and the cemetery have 40071 m^3 and 13948,75 m^3 runoff retention potential, respectively.

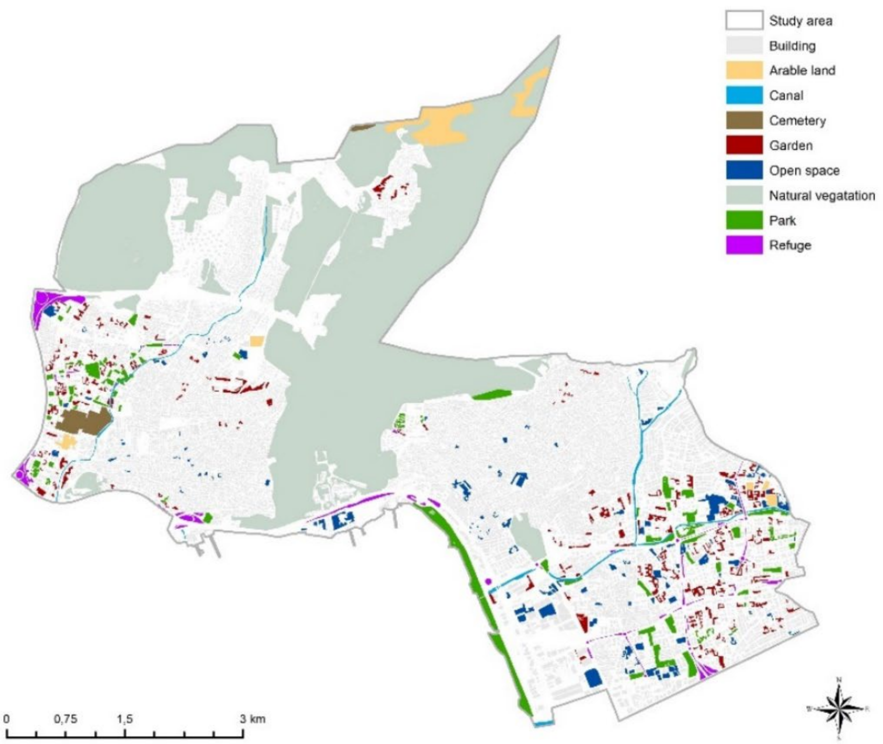

Figure 3. BGI of Bayraklı.

The runoff retention potential of BGI was analyzed by a 100-year precipitation event and that gave a clear picture for the conditions of BGI and the district. Outputs of the study prove that in the event of extreme precipitation, the existing grey infrastructure and BGI of the study area is not efficient to protect the district from urban flood. This is related to both the capacity of the grey infrastructure and physical and ecological characteristics of BGI, such as plant cover, size, and inclination of the area. It is obvious that grey infrastructure built for a 15-year precipitation event (appr. 4,5 mm/hour) in the district is unable to collect runoff and mitigate the flood risk. Actually, this is a common problem for many cities because it is routine that grey infrastructure is mostly designed and built for the return period of 10 to 25 years that is unlikely to cope with the extremes of climate change. BGI in Bayraklı was not designed as water sensitive areas. Additionally, the increased volumes of rapid runoff result in overflow in the engineered rivers fluvial flooding.

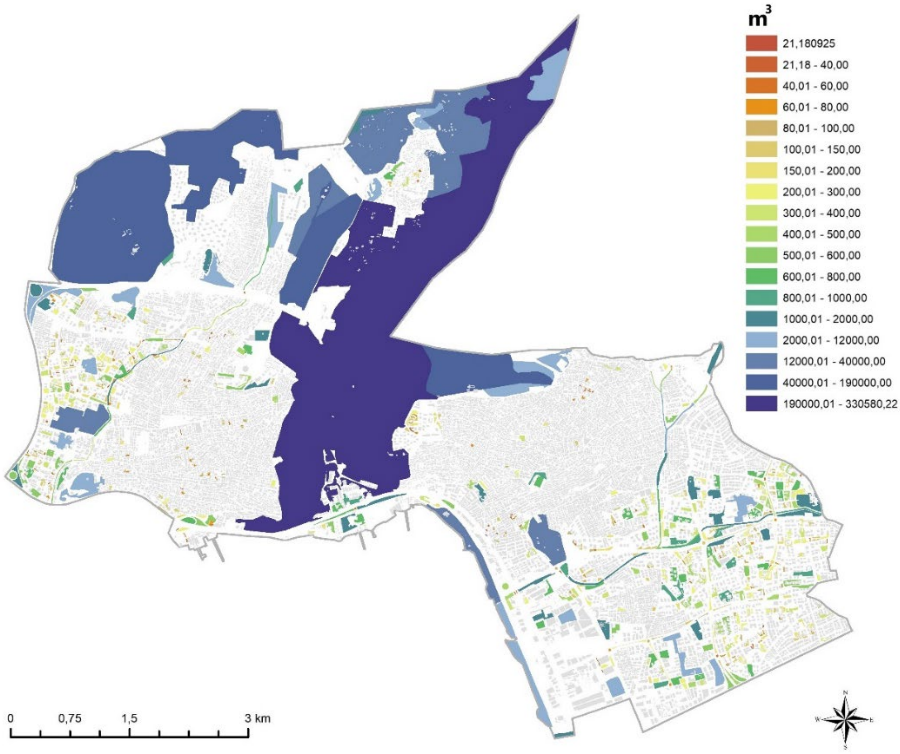

Figure 4. Surface runoff values (m^3) of BGI of Bayraklı

The results also show that natural areas presented the highest runoff retention potential. This is closely correlated with their size. Since they are located on rugged areas, runoff is relatively high. In order to reduce surface runoff, collect and recharge the groundwater, terraces and retention basins are recommended in the natural areas. Özeren Alkan & Hepcan (2022) underlined the value of natural vegetation in the region for rainwater infiltration. Therefore, this intact patch with native vegetation is a chance for the district. Urban parks have the second highest run off retention potential after natural areas. The water retention capacity of these parks could be enhanced by designing small catchments like sponge parks (floodable parks). In this case a new relationship between land and rainwater could be defined and 73484,40 m^3 runoff water could be retained and gained into the natural water cycle. Tong et al. (2022) pointed out the benefits of 23 sponge parks in the city Shangai for the stormwater management.

The coastal areas of Bayraklı are not only under risk of pluvial and fluvial flood but also coastal flood (storm and tidal surge). The flood history of the district proves that Bayraklı is vulnerable to water related hazards. Therefore, it is urgent to take flood-defense actions to increase climate resiliency on the reclaimed coastal area. The coastal parks of the district could be designed as sponge parks or elevated parks as that would act as a barricade along the waterfront by blocking and collecting water and offer protection to the residents (Firth et al., 2020; Coşkun Hepcan, 2022a). Simple design solutions such as curb-less edge or curb cuts are effective to convey and collect water into green patches in green areas with high impervious surface (Dhamma & Zimmer, 2010).

Gardens in the district are mostly represented by single family houses (in the old town) and high-story apartment gardens (in the new urban development zone). They have 52640,98 m^3 runoff retention potential. Gardens are valuable components of BGI, providing important ecosystem services (Breuste & Artmann, 2015) especially in highly urbanized settlements. They support urban drainage and reduce flood risk. For instance, Gittleman et al. (2017) stated that in New York City, USA, gardens retain almost 45 million liters of rainwater annually. Similarly in Baltimore (Maryland), USA single-family house gardens reduce runoff reduction by up to 92% (Gilroy & McCuen, 2009). Therefore, the residents could be encouraged to take action to increase the water retention capacities of their garden.

Although the agricultural areas cover only small areas at the edge of the district, they have the potential to establish rainwater solutions. In many cities agricultural areas in the city have been considered as a part of BGI and sustainable rainwater management strategy. Therefore, to ensure the permanence of urban farming and protect the water quality, policies and land use agreement options should be considered as recommended by (Deksissa et al., 2021; Freshwater Society, 2013). Small retention ponds could be established in these agricultural patches.

The future projections predict that extreme rainfalls will become common all around the world (IPCC, 2022; WMO, 2022). For this reason, many cities try to increase their resiliency to cope with the potential effects of climate change. For instance, cities like Rotterdam, Copenhagen, Boston, and Vancouver intend to implement their flood - defense solutions that include BGI (Sørensen, 2019). Climate change models for İzmir also show a similar outcome. Intense and extreme precipitation events will be expected in the future (Berberoğlu et al., 2019) and urban floods will be a serious issue for the city. Therefore, Bayraklı needs a resilience plan integrating BGI and allowing to complete water cycle in the district. A 100-year frequency storm has been considered in many cities for flood protection programs. The outcomes of this research would provide valuable data for Bayraklı's resilience plan.

As the effects of climate change are local, site-specific solutions to cope with hydrometeorological hazards should be developed based on natural features such as watersheds (Coşkun Hepcan & Berberoğlu, 2022). Sustainable rainwater management/urban drainage solutions are needed in the study area, bioswales, rain gardens, retention and detention ponds, green roofs to increase the infiltration, reduce the amount of water in the drainage system, and alleviate the risk of surface runoff and flooding can be considered for this purpose. As Bayraklı was settled on the coastal plain of a former wetland, sponge city practices would be very effective for rainwater management.

BGI plays a vital role in reducing the impacts of natural hazards and climate change the water related disaster risks by providing rainwater as an alternative way in the cities (UNEP, 2022). Solutions can be developed to increase the disaster prevention function of the BGI. Since almost 60% of the Bayraklı district is impervious, natural drainage pattern has been broken up to a great extent. Therefore, restoring this pattern by creating simple solutions, such as replacing impervious surfaces with the pervious one, building raingardens and swales, creating curb cuts to divert runoff to green patches and rainwater facilities such as retention and detention ponds is an urgent need.

Increasing green areas and enhancing BGI in the city are the keys for disaster risk reduction (Coskun Hepcan, 2022b). One fourth of Copenhagen, 20 % of Rotterdam, 28 % of Barcelona and 55 % of Vancouver is green (Arcadis, 2022, Frantzeskaki & Tilie, 2014). It is not easy to increase the number of green areas in densely urbanized cities like Bayraklı. But enhancing the existing BGI by using Nature-based Solutions to mitigate the flood risk should be a priority for the city.

Sohn et al. (2021) stated that large BGI components within a closer proximity are very effective for flood mitigation services. Therefore, it is necessary to prepare a BGI strategy for Bayraklı to tackle the hydrometeorological risks. It is obvious that BGI in the study area is mostly disconnected and green network in the city lacks corridors. In order to ensure connectivity of the BGI components and strike a balance in distribution, green streets with rain gardens and bioswales could be established in the gaps between urban green areas. The main streets of the district, perpendicular to the sea, have great potential to establish these green corridors with rain gardens. Additionally, the flood mitigation functions of the existing blue corridors could be enhanced by integration of nature and ecosystem-based solutions where it is possible. These channelized blue corridors flow only in the rainy season and restoration, or re-naturalization will help to enhance natural water flow.

The methodology of this research was designed to estimate water retention capacity of the BGI for a 100-year frequency storm by using the variables: permeability of soil and vegetation cover. These variables were chosen because it was aimed to define water related disaster mitigation functions of BGI with available data. Additional data such as elevation and terrain models could be used. This could be considered the limitation of this study. As a continuation of this study, future studies can be designed to focus on multiple variables such as 500-year and 1000-year frequency storm events on watershed scale.

4. Conclusions

The study showed that the existing BGI in Bayraklı is not sufficient and needs to be modified to increase water retention capacity to mitigate flood risk for extreme weather events.

Urban flooding is a risk for all cities around the world. In Conference of Parties-COP 28, UNEP's evidence-based report emphasized that countries needed to understand more effective measures against hydrometeorological disasters were discussed. Although many cities have already invested in BGI to reduce their flood risk, UNEP reports stated that the efforts are not enough for BGI (UNEP, 2022). BGI is necessary to achieve the Sustainable Development Goals 6 (SDG 6), 11 (SDG 11) and 13 (SDG13).

As conclusions urgent measures should be taken to reduce exposure and increase resilience to hydrometeorological hazards in Bayraklı. The district has potential with existing BGI. The enhancement of water retention capacity of the components BGI should be prioritized and barriers to BGI should be removed.

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