ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

WATER SENSITIVE URBAN DESIGN: A CASE STUDY OF BAHÇELİEVLER NEIGHBORHOOD IN BALIKESİR

M.Sc. THESIS

Sevde KEMANECİ

Department of Interdisciplinary Urban Design

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ISTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

SUYA DUYARLI KENTSEL TASARIM: BALIKESİR BAHÇELİEVLER MAHALLESİ İÇİN TASARIM ÖNERİSİ

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Sevde Kemaneci, a M.Sc. student of ITU Graduate School student ID 519161027, successfully defended the thesis/dissertation entitled "WATER SENSITIVE URBAN DESIGN: A CASE STUDY OF BAHÇELİEVLER NEIGHBORHOOD IN BALIKESİR", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my beloved family,

FOREWORD

I would love to point out that I would not be able to finish this thesis without the help of my family, professor, and friends. I am forever grateful to all of them who have been there with me whenever I needed them and provided their unconditional full support.

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ABBREVIATIONS

ABC Waters : Active, Beautiful, Clean Waters
AFAD : Afet ve Acil Durum Yönetimi Başkanlığı
ARI : Average recurrence interval
AT : Alternative techniques
BCI : Blue City Index®
BGI : Blue-Green infrastructure
BMPs : Best Management Practices
BOD : Biological Oxygen Demand
CBF : City Blueprint® Framework
CDS® : Continuous deflective separation
ÇEDBİK : Eco-friendly green buildings association
CIRIA : Construction Industry Research and Information Association
COFAS : Comparing the Flexibility of Alternative Solutions
CRC : Cooperative Research Centre
CSO : Combined sewer overflows
CuDS : Conventional urban drainage systems
DSI : State Hydraulic Works
DST : Decision Support Tool
ESC : Erosion and sediment control
GCF : Governance Capacity Framework
GHG : Green House Gas
GI : Green Infrastructure
GIS : Geographical Information Systems
GPTs : Gross pollutant traps
GRACE-FO : Gravity Recovery and Climate Experiment Follow On
IDF Curves : Intensity-Duration-Frequency Curves
ISA : Impervious surface area
ITU : Istanbul Technical University
IUDS : Integrated urban drainage systems
IUWM : Integrated urban water management

IWRM **:** Integrated Water Resource Management

LID **:** Low Impact Development

LID-DP **:** Low Impact Development district planning model

LIUDD **:** Low Impact Urban Design and Development

MED regions : Mediterranean regions

MGM **:** General directorate of meteorology

NBS **:** Nature-Based Solutions

NTS **:** Natural treatment system

OECD **:** Organization for Economic Co-operation and Development

OSD **:** On-site detention

PA **:** Porous asphalt

PC **:** Pervious concrete

PICP **:** Permeable interlocking concrete pavement

PPS **:** Permeable pavement systems

RTC **:** Real time control

SCC **:** Sponge City Concept

SCM **:** Stormwater control measure

SQIDs **:** Stormwater quality improvement devices

SUDS **:** Sustainable Urban Drainage System

SUEN **:** Su Enstitüsü

SUSTAIN **:** System for Urban Stormwater Treatment and Analysis Integration

SWITCH **:** Sustainable Water Management Improves Tomorrow's Cities' Health

TMFA **:** Turkish Ministry of Foreign Affairs

TPF **:** Trends and Pressures Framework

TÜİK **:** Turkish Statistical Institute

UASB **:** Anaerobic fermentation

UNEP **:** United Nations Environment Programme

USA **:** United States of America

USEPA **:** United States Environmental Protection Agency

UWC **:** Urban Water Cycle

WMO **:** World Meteorological Organization

WSC **:** Water Sensitive City

WSS **:** Water Sensitive Settlements

WSUD **:** Water Sensitive Urban Design

WWTP **:** Wastewater treatment plants

SYMBOLS

C	**:** Runoff Coefficient
K	**:** Soil Permeability
Tc	**:** Time of concentration

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WATER SENSITIVE URBAN DESIGN: A CASE STUDY OF BAHÇELİEVLER NEIGHBORHOOD IN BALIKESİR

SUMMARY

Addressing water related problems is crucial and drawing more attention each day. Population growth, the population shift from rural to urban areas, rapid urbanization, climate change and many more are fueling the problems such as weather extremes and capriciousness, increase in impervious surfaces, unconscious human intervention on the natural systems, etc. The hydrological cycles in urbanized areas are studied as the 'Urban Water Cycle' to understand the system to address the acute and tardive problems more effectively. The responses given to these problems change from region to region where environmental, social, and economic drivers are playing a great role. However, their common ground is the integrated approach towards the urban water resources which is called Integrated Urban Water Management (IUWM). While it is named as Water Sensitive Urban Design (WSUD), Green Infrastructure, Sponge City Concept (SCC), Active, Beautiful, Clean Waters (ABC Waters), Low Impact Development (LID) etc. around the World depending on where it is originated and labeled, the technologies used show similarities which are called best management practices (BMPs), sustainable urban drainage systems (SUDS), stormwater control measures (SCMs), stormwater quality improvement devices (SQIDs), and alternative techniques (ATs).

WSUD is one of the pioneering concepts that has been developed with government, specialists, and scholars and recognized not only in Australia where it is originated, but by around the world. WSUD recognizes all water entities as alternative resources and considers the roles of water in urban environments; where stormwater is one of them which was perceived as a sub cycle rather than a main component of the UWC for quite some time but gained importance as the understanding of the UWC widened.

Traditional approach towards stormwater where the main aim was to get rid of it as quickly as possible evolved towards the getting the most of it as a source. In order to understand the performance of the applied technologies for the stormwater management, the criteria are categorized as volume, flow, quality, water conservation and efficiency of use; while the processes follow the collection, treatment, storage, and distribution stages; in order to avoid (where it is possible) and get rid of the pollutant load of the stormwaters for reuse or discharging also resulted in various technologies and methods which are: preserving and maintaining waterways and riparian areas, erosion and sediment control (ESC), sweeping streets and litter control, urban /housing design, rainwater tanks, detention basins, on-site detention (OSD) tanks, downpipe

diverters, pervious pavement systems, green roofs and walls as the avoidance methods; and gully baskets, gross pollutant traps (GPTs), bioretention systems (raingardens, suspended pavement systems, bioswales), vegetated swales, wetlands, floating wetlands, water smart street trees as the mitigation options.

Turkey is facing floods droughts and pollution while dealing with the loss of life and property. However, awareness towards the topic (recent law, legislations, implementations etc.) are far from where the topic deserves while the advantage of leapfrogging towards better results is possible. Also, in most parts, rainwater harvesting gives favorable results. In that context, Balıkesir's Bahçelievler neighborhood has been studied as it is one of the provinces where faces these problems comparatively more than other places and which BMPs can be implemented were analyzed with USEPA's SUSTAIN decision support system's BMP siting tool. As a result, out of 14 BMPs (constructed wetland, grassed swale, green roof, infiltration basin, infiltration trench, porous pavement, bioretention, vegetated filter strip, sand filter (surface), sand filter (non-surface), rain barrel, cistern, wet pond, and dry pond) when site considerations were taken into account along with restrictions that are place bound, the area's needs, and determined goals for the area; while some options (infiltration trench, infiltration basin) are found unsuitable, some (porous pavement) were considered despite site constraints which may necessitate extra measures. On the other hand, some (constructed wetland, sand filter (surface), sand filter (non-surface), wet pond) were opted out when the area's needs and goals were considered. As a result, the selected BMPs for the area are: vegetated filterstrips, grassed (vegetated) swales/buffer strips, bioretention, dry ponds (retarding basins), rain harvesting systems coupled with green roofs, and porous pavements.
After spatial distributions of the BMPs were determined, the scenarios that consider 15% and 30% error margins on them were compared with current situation and BASKİ's conventional plan with the help of E^2Stormed decision support tool. As a result, it has been seen that even though BMPs require extra maintenance, other factors such as energy costs, insulation benefits and many other that BMPs brings are considered altogether, WSUD systems provide economic advantage along with other ecosystem services. However, it has been seen that the scenario with 30% error margin is more favorable than the scenario with 15% error margin which shows that finding the optimum gap and determining priorities have grave importance.

SUYA DUYARLI KENTSEL TASARIM: BALIKESİR BAHÇELİEVLER MAHALLESİ İÇİN TASARIM ÖNERİSİ

ÖZET

Canlıların hayati fonksiyonlarını devam ettirebilmesi için gereken su son derece sınırlı bir kaynak olmakla birlikte yokluğu ekonomik sorunlar gibi birçok sorunu da beraberinde getirmektedir. Hızlı ve çarpık kentleşme, nüfus artışı, kırsaldan kente artan göç oranları, iklim değişikliği gibi birçok etken birbirini beslerken su ile ilgili sorunları da alevlendirmektedir. Hava olayları daha tahmin edilemez hale gelirken, artan geçirimsiz yüzeyler bunların sellere ve kuraklığa evrilme sürecini arttırmakta, artan nüfus ve bu nüfusun kentsel alanlar gibi belli alanlarda yoğunlaşması ise suyun dengesiz kullanımına yol açmaktadır. Öte yandan kentsel alanlarda suyun yeraltı sularını beslemesi, su kaynaklarının kirlenmesi vb. sorunlar kentleşmiş alanlarda yeni bir su döngüsünün oluşmasıyla sonuçlanmış olup bu döngü Kentsel Su Döngüsü (UWC) olarak ele alınmaktadır. Bu döngünün iyi anlaşılması, sorunun tespiti ve çözümü için gerekli olmakla birlikte araştırmaların eskiden döngüye dahil edilmeyen elemanlarını da önemli birer kaynak olarak kabul etmeye itmiştir.

Kentsel alanlarda karşılaşılan sorunların çözümüne yönelik yaklaşım ise, UWC'deki tüm süreçlerin ve girdilerin ayrı ayrı ve beraber değerlendirilerek bütüncül bir yaklaşımla disiplinlerarası hale getirilmesidir. Uluslarası literatürde Bütüncül Kentsel Su Yönetimi Yaklaşımı (IUWM) olarak anılan bu yaklaşım, Dünya'nın farklı coğrafyalarında yere, kültürlere, ekonomilere, iklimlere ve daha pek çok parametraye bağlı olarak, markalaşmanın da etkisiyle farklı olarak anılmıştır. Avustralya ve Yeni Zelanda'da Suya Duyarlı Kentsel Tasarım (WSUD) iken Singapur'da Aktif, Güzel, Temiz Sular (ABC Water) adıyla, Çin'de Sünger Şehir Konsepti (SCC) olarak, Birleşmik Krallık'ta Sürdürülebilir Kentsel Drenaj Sistemleri (SUDS), Amerika'da Düşük Tesirli Gelişme (LID) ve daha pek çok isimle benzer ilkeleri hayata geçiren konseptler bulunmaktadır. Yöntem olarak kullanılan metotlar ise En İyi Yönetim Uygulamaları (BMPs), Yağmur Sularını Kontrol Yöntemleri (SCMs), Alternatif teknikler (AT) gibi pek çok adla anılmaktadır.

Bahsi geçen IUWM yaklaşımlarından kimi diğerine göre daha geniş kapsamlı yaklaşımlar olup, kiminin merkeze koyduğu problem değişiklik göstermektedir. Bunlardan WSUD en köklü ve sofistike yaklaşımlardan biri olarak tüm Dünya'da kabul görmüştür ve geliştirilmesinde yönetimler, uzmanlar, akademik personel birlikte rol almakta olup devletin de yıllardır benimsediği ve başarılı bir şekilde uyguladığı bir yaklaşım haline gelmiştir. UWC'deki tüm su elemanlarını birer potansiyel kaynak

olarak gören bu yaklaşım suyun kentsel alanlardaki rolü ve öneminin altını çizmektedir. Bunlardan biri olan sel suları da döngünün içinde önemli bir yere sahip olmakla birlikte geleneksel yaklaşımdaki mümkün olan en kısa sürede yağmuru düştüğü yerden uzaklaştırmanın sorunu çözeceği düşüncesi, bu sulara birer kaynak olarak yaklaşıp sorunun kaynağını hedefleme yaklaşımına dönüşerek yağmur sularının sel sularına dönüşmeden, yıkıcı olmaktan çıkarak yapıcı bir özellik kazanmasına olanak tanımaktadır.

WSUD unsuru olan sel sularının entegre yönetimi, uygulanan yöntemlerin performans kriterleri dikkate alındığında akış hızı, miktarı, kalitesi, ve su kaynaklarının korunması ve kullanım verimi olarak ele alınırken; süreç toplama, arıtma, depolama, ve dağıtma aşamalarından oluşur. Bu aşamalardan geçerken su mümkün olduğunca kirletici kaynaklardan uzak tutulur veya sonrasında kirletici yükünü azaltmak adına bir takım arıtma işlemlerine tabi tutulur. Bu süreçlerde kullanılan yöntem ve teknolojiler basit veya karmaşık sistemleri içerirken, bazıları süreç veya yaklaşım değişimleridir (sokakların temiz tutulması gibi).

Türkiye'de her yıl karşılaşılan baraj seviyelerindeki endişe verici haberler, plansız yapılaşmanın yıkıcı sonuçları pekiştirdiği sel olayları, öte yandan bir diğer uç olarak kuraklık ve kuruyan göller, barajlar, beraberinde gelen yeni yatırım ihtiyaçları (ki kendi içlerinde pek çok tartışmayı da beraberinde getiren insan yapımı bu müdahaleler kısa süreli çözümlerdir) ve daha pek çok ekonomik, politik, çevresel, ve insan kaynaklı sebepler Türkiye'de konunun önemini daha da ortaya koymaktadır. Son zamanlarda çıkarılan yönetmeliklerle konunun ayırdına varılmaya başlandığı ve önlem alınmaya başlandığı görülse de, bu tedbirler durumun ciddiyeti göz önüne alındığında son derece yetersiz kalmaktadır. Türkiye'deki literatür taramasında da kentsel sel kavramı ile ilgili büyük boşluk olduğu saptanmış olup, seller ve önlemleri dere ve nehir taşkınlarına yönelik yöntemlerle kısıtlı kalmıştır. Bu anlamda bahsi geçen sorunların en çok yaşandığı yerlerden biri olan Balıkesir ilinden Bahçelievler mahallesi çalışma alanı seçilerek burada uygulanabilecek BMP'ler incelenmiş, alanın ihtiyaçları değerlendirilmiş ve varsayımsal senaryolar günümüz koşullarıyla karşılaştırılmıştır.

Ülkenin büyük kısmında yapılması hedeflenen birleşik kanalizasyon sistemlerinden yağmursuyu drenaj sistemlerinin ayrılarak oluşturulmasıyla hazırlanan yeni planlar Balıkesir için de yapılmış olup bu planların yaklaşımının da geleneksel olarak yapıldığı saptanmış ve yağmur suları kaynak yerine sorun olarak ele alınmıştır. BMP uygulamalarıyla alternatif su kaynakları oluşturup su ve enerjinin verimli kullanılması, ekosistem servislerinin arttırılması, çevresel kalitenin yükseltilmesi, hava kalitesinin arttırılması, kaynağın tüketim noktasına yaklaştırılması olarak özetlenebilecek hedefler doğrultusunda, alanın topografik ve coğrafi kısıtları değerlendirilerek Bahçelievler'de kullanılabilecek BMP'ler belirlenmiş ve bunların alansal konfigürasyonu, mevcut durum, ve Balıkesir Su ve Kanalizasyon İdaresi (BASKİ)'nin hazırlamış olduğu yağmursuyu drenaj sisteminin birleşik sistemden ayrı olarak hazırladığı plan senaryoları karşılaştırılmıştır.

Alanın fiziksel kısıtlarının değerlendirilmesi ve uygun alanların mekansal olarak yerlerinin belirlenmesi için Amerikan Çevre Koruma Ajansı'nın hazırlamış olduğu SUSTAIN yardımcı aracı kullanılmış ve programın elverdiği, değerlendirmeye alınan 14 BMP'den (yapay sulak alanlar, bitkilendirilmiş yağmur hendekleri, yeşil çatılar, sızdırma havzaları, sızdırma hendekleri, geçirgen yüzeyler, yağmursuyu tankları ve depoları, kum filtreleri (yüzeysel ve yüzeysel olmayan), göletler, kuru göletler, biyolojik tutulma, bitkilendirilmiş filtreleme şeritleri), mekansal kısıtlar göz önüne

alındığında sızdırma havzaları ve hendekleri ile geçirgen yüzeylerin toprak yapısından dolayı uygun olmadığı görülmekle birlikte faydaları ve alınabilecek altyapı önlemleriyle sorunun çözümü yapılabileceği için geçirimli yüzeyler senaryoya dahil edilirken diğer iki seçenek edilmemiştir. Bununla birlikte mekansal olarak uygunluklarına bakıldığında yapay sulak alanlar, göletler, ve kum filtreleri için uygun alanlar olduğu görülse de bu alternatifler alanın ihtiyaçları ve belirlenen hedefler göz önünde bulundurulduğunda senaryolara dahil edilmemiş olup değerlendirilen BMP konfigürasyonları bitkilendirilmiş yağmur hendekleri, yeşil çatılar, geçirgen yüzeyler, yağmursuyu tankları ve depoları, kuru göletler, biyolojik tutulma, bitkilendirilmiş filtreleme şeritleri olarak belirlenmiştir.

BMP'lerin dahil edildiği 2 senaryo, %15 ve %30 hata payı verilerek değerlendirmeye alınmıştır. Bu 4 senaryo arasından enerji kullanımı, sera gazları salınımı, ve ekonomik getiri boyutları incelendiğinde BMP uygulanan senaryolarda gözle görülür bir fark olduğu gözlemlenmiştir. BMP uygulamaları inşa edildikten sonra bakım gerektirmelerine rağmen geleneksel yöntemlerden daha karlı olduğu ortaya konmuştur. Ekonomik faydanın yanı sıra çevresel etkileri de göz önüne alındığında BMP uygulamalarının uygulandığı alana getirisinin çok boyutlu olduğu saptanmıştır. Ancak BMP'lerin dahil edildiği 2 senaryo arasından, %30 hata payı verilerek değerlendirilen senaryonun enerji tüketimi, sera gazı salınımı, ve maliyet fayda analizi göstergelerinin üçünde de daha az pay verilerek hesaplanan alternatifinden daha avantajlı olduğu görülmüştür. Bu da alanın ihtiyaçlarının iyi saptanarak buna yönelik optimum alternatifin bulunması için alanın fiziksel elverişliliğinin yanı sıra alan özelinde belirlenecek gereksinimlerin değerlendirilmesinin ve senaryoları çeşitlendirmenin önemini ortaya koymuştur.

1. INTRODUCTION

Water that people can use is a scarce source and even though it is scarce, its share per capita gets even smaller with population growth. Population growth coupled with rapid urbanization results in increase on impervious surfaces, which especially concentrates some parts of the world. Aging constructions are getting over capacitated and the natural hydrological cycle is disrupted with the manmade impervious surfaces which even caused a specific term derived to describe the hydrological cycles in urbanized areas that is called urban water cycle (UWC).

The rainfall that turns into runoff with the increased impervious surfaces is considered as a nuisance in traditional approach since it causes floods and damage which necessitated the integrated urban water management (IUWM). As rainfall events gets more unpredictable and extreme (water gets either too scarce or too much to handle and causes floods and/or polluted) with climate change which is fed with rapid urbanization as well becomes more and more disastrous and increases loss of property and lives.

Concerning all these, as problems get unique and dire, different regions/countries respond in various ways where all share a common IUWM ground. Water Sensitive Urban Design (WSUD); Green Infrastructure (GI); Sponge Cities Concept (SCC); Low Impact Development (LID); Active, Beautiful, Clean Waters (ABC Waters) are some well-known terms of the matter. In order to achieve the goals of these concepts, implemented techniques and technologies are called best management practices (BMPs), sustainable urban drainage systems (SUDS), stormwater control measures (SCMs), stormwater quality improvement devices (SQIDs), and alternative techniques (ATs).

As a country with limited fresh water resources and dealing with problems related to conventional approach toward the water made Turkey to take steps toward the shifting towards to integrated management of water resources. Even though the norm is still newly recognized by the state to act towards the goal such as legislating regulations,

and creating guidelines, they are still not sufficient. Where countries such as Turkey has the advantage of leapfrogging through the stages of the processes, learning from the experienced results and applications have grave importance to not repeat the similar mistakes. Therefore, one of the pioneering approaches that is accepted and taken example of many other countries, WSUD approach has been studied in this thesis.

It is aimed to find answers of whether these BMPs are applicable in a Turkish settlement that is facing water related problems and if they are applicable which results in suitable locations, how would they benefit to the area.

1.1 Aim of Thesis and Research Questions

The main purpose of the thesis is to understand the effectiveness of the WSUD technologies and provide a base research on how applicable are these solutions in Turkey's context. It is expected to answer the following questions:

- Which Best management practices (BMP) can be applied when the spatial constraints are applied? What are the other factors affecting BMP choices? How does the design get affected by these constraints?
- What outcomes can be expected from the applicable BMPs? What are the purposes for the included BMPs?
- Are applicable technologies giving the desired results?

First question aims to find out which BMPs can be applied when the general BMP siting criteria are applied in a settlement in Balıkesir and aims to answer how these BMPs can be located in the settlement to improve the environment with IUWM policies towards becoming more water sensitive.

Second and third questions aim to find answers to first question's outcomes which investigates the applicable BMPs effectiveness and whether they are beneficial in different aspects which cover social, environmental, and economical aspects.

1.2 Research Scope

The thesis starts with literature review to provide the scientific background of the study and give related approaches and scopes about the topic which supports the following chapters to build on.

The literature review chapter of the study explains about the perception of water resources and the problems that arise from not managing it to today's conditions with future needs considered and how urbanization effects the hydrological cycles. Water as a constrained resource is considered with its relating matters which are population increase, rapid urbanization and increase of impermeable surfaces, population shift from rural to urban, and climate change. In order to understand the hydrological cycles in urban areas which follow unique ways when compared to its original natural cycle, urban water cycle (UWC) has been explained: urban water cycle section explains the hydrological cycle in urban areas and the challenges that arise from the urbanization; which is followed by the integrated urban water management (IUWM) approaches as a solution. Water sensitive urban design which is one of the IUWM concepts is explained and one of its key elements 'stormwater management' has been explained with its performance and design criteria; processes within the stormwater management; avoidance methods for stormwater pollution; mitigating the level of pollutant from stormwater; and examples around the world has been viewed.

The third chapter explains the concept and provides possible insight about the data that are important to understand the situation in an environment, legislations and encouragements are given, and examples were given which fits the concept.

The fourth chapter of the thesis is the case study conducted in a settlement from Turkey which is in Bahçelievler neighborhood in Balıkesir province where water related problems are intact but the approach toward the water and possible resources are still conventional.

The fifth chapter is the final chapter where the conclusion remarks and recommendations were made. The assessments of the case study area's analysis results are examined parallel with the previous chapters and given concepts.

1.3 Methodology

In order to provide a scientific base for the researched topic, comprehensive literature review was made and one of the concepts of integrated urban water management (IUWM) which is Water Sensitive Urban Design (WSUD) is explained with further detail. In that context, stormwater which is usually is not seen as an alternative water resource and approaches toward it has been studied in a more detailed way. As a result, it is divided into four ways how it is approached which are: performance measures, management processes, avoidance methods for stormwater pollution, and mitigating the pollution level in the stormwater.

After providing the base for the study, Turkey's stand about the topic is analyzed through literature review, and reports handed by the relevant institutes. Which is follow by the Bahçelievler neighborhood in Balıkesir province where literature review, reports and papers given from the institutions, interviews with personnel, analysis of the area with the data obtained from the institutions and government websites which is done in AutoCAD and ArcGIS, with the obtained results, alternative layout of the BMPs were given and calculated to analyze them in E^2Stormed tool.

Primary data is obtained from the Balıkesir Metropolitan Municipality to conduct the suitability analysis of each BMPs which are calculated accordingly to USEPA's SUSTAIN tool's default values given for 14 BMP. These BMPs are reevaluated according to determined goals and site constraints and prioritization among these options were made. Obtained results were reevaluated with 15% and 30% error margins that can occur and these results are compared with the current situation and BASKİ's planned scenario in E^2Stormed tool.

2. LITERATURE REVIEW

Water takes many shapes and sizes in the World as water vapor, rivers, lakes, glaciers, oceans, and more; and about 71% of the surface of the Earth is covered with it; where oceans take 96.5% of the whole sum which means it is saline and life-nourishing freshwater only takes a small portion in that whole (Figure 2.1.) (Water Science School, 2019).

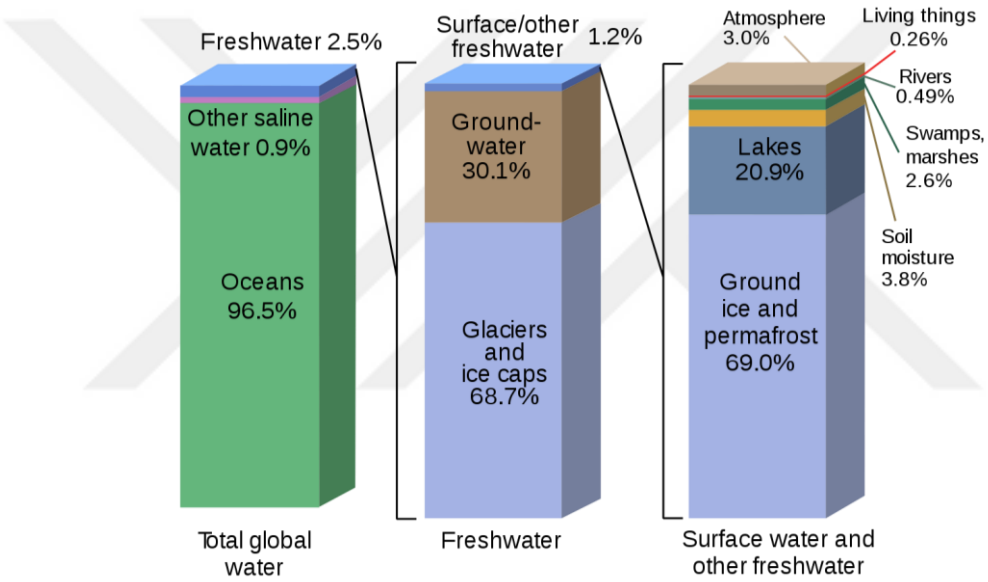


Figure 2.1: Earth's water sources distribution (Pacific Institute for Studies in Development, Environment, and Security & Stockholm Environment Institute, 1993 As cited in Regan, 2012, pp.4).

Freshwater scarcity is considered an international systemic risk and World Economic Forum is considering the water crisis as one of the five biggest threats to the global economy in their risk reports since 2012 (DSİ Vakfı, 2019).

The world's total water demand is expected to increase 55% from 2000 to 2050; while on the other freshwater supplies are decreasing due to global warming and population increase (DSİ Vakfı, 2018). Saline waters need extra desalination process to use and the remaining fresh water's 70% is used for agricultural purposes (FAO,2017) which are expected to increase (food production) 69% by 2035 (DSİ Vakfı, 2018); but

according to FAO's (2011 as cited in FAO 2017) estimations, more than 40% of the world's rural population is living in water-scarce river basins and to top it off, in some of those areas, agricultural water usage rises up to 80-90% of water usage (FAO,2017). Tripled world population has resulted in water consumption to sextuple (TMFA, n.d.). Every two out of three people are living their one month of a year with intense water scarcity and these people are mostly concentrated in China and India (DSİ Vakfı, 2019); conversely overuse of water is another global issue; some rivers are no longer have the chance to meet with the ocean due to withdrawal for various purposes where some lakes are also dried up due to the same reason (UN Chronicle, 2018 as cited in DSİ Vakfı, 2019). As a result of sector demand competition, water resources are suffering terribly (FAO, 2017) (Figure 2.2).

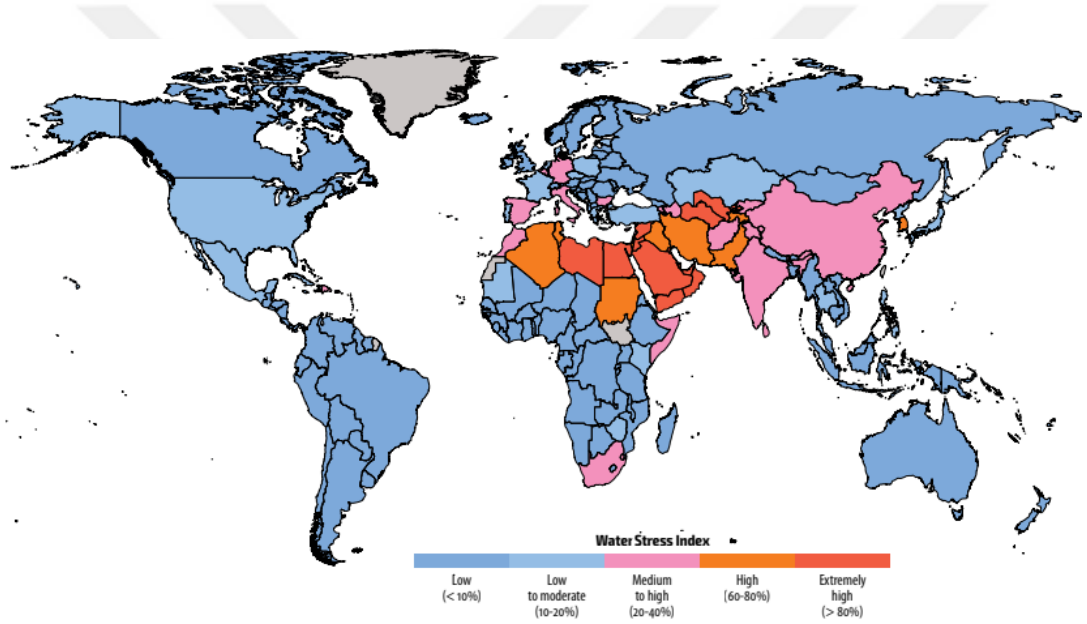


Figure 2.2: Freshwater withdrawals as a percentage of total renewable resources (FAO, 2016 as cited in FAO, 2017, pp.37).

For a country to be considered as a water-rich country, it must have at least 8000-10000 m^3 water per capita per year (Dinç, 2019). As Dinç (2019) states, West Europe's mean value is 5000 m^3, South America's mean value is 23000 m^3, World mean value is 7600 m^3 while it is 1430 m^3 for Turkey which shows that Turkey is under water stress which is projected to fall 100 m^3 with increased population and other factors and become a water-poor country in the end (Figure 2.3).

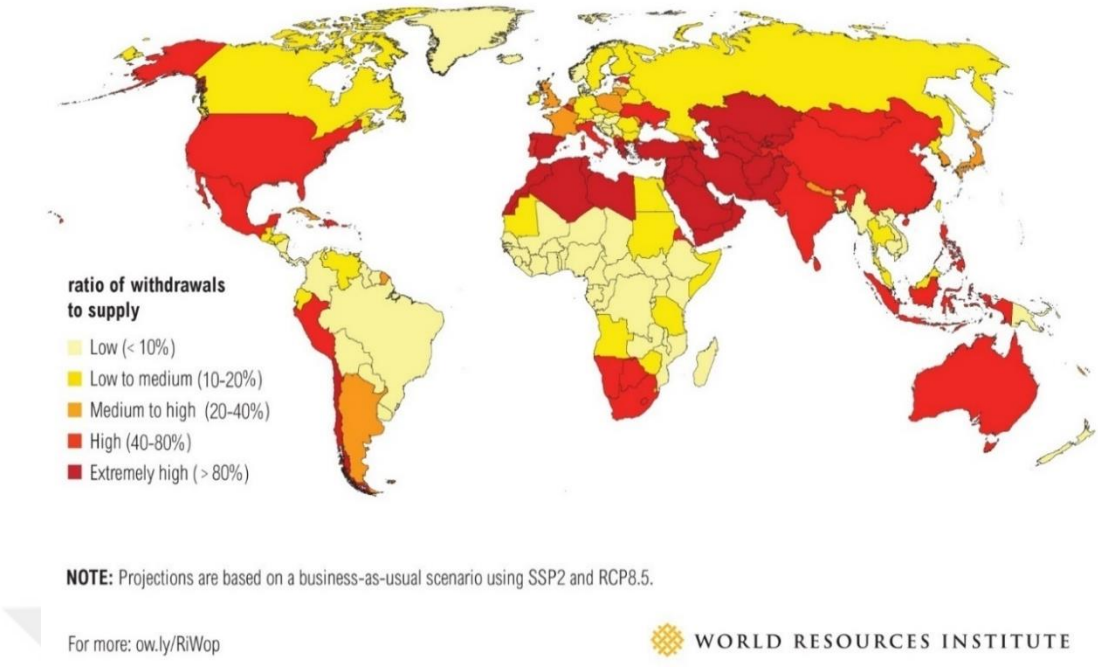


Figure 2.3: Water Stress by Country in 2040 (Maddocks et al., 2015).

Another factor for countries to be considered as water-stressed is their withdrawal percentages; where the water is withdrawn more than 25% of their renewable fresh waters they are considered water-stressed; while withdrawing more than 60% results in physical water scarcity and it becomes severe when it exceeds 75% (FAO, 2016 as cited in FAO,2017). Agricultural water use is about 70% of all withdrawals (FAO, 2017).

The water stress will be affected by the availability of resources as well as demand in the future as a result of climate change (FAO, 2017).

The average water footprint value of the world is 1385 m^3/year while this value is 2842 m^3 for America, 1071m^3 for China, and 1642m^3/year for Turkey which is about 20% higher than the world average and keeps increasing (DSİ Vakfı, 2019).

According to World Meteorological Organization (WMO) (2021), water-related hazards are the dominant hazard type in the last 50 years, and nowhere is safe in that regard be it developed or developing countries due to climate change; therefore, investing to adapt is mandatory. While 2.1 billion people have no access to safe drinking water, 3.4 million people die annually because of scarce and contaminated water sources globally (WHOlives, n.d.). With climate change, especially water-borne

diseases are expected to increase; since increased temperature and decreased rainfall result in clean water becoming scarce which leads to lack of hygiene (FAO, 2017).

Climate change also comes with a price that is expected to reach 10.9% of a city's GDP by the end of the century in the cities having the worst-case scenario while the global mean is 5.6% (Estrada et al., 2017). As WMO (2021) states, water is one of the first and most means to observe the effects of climate change therefore they must not be separated in the mindset and must be considered as one thing rather than two. Between the years 1970 to 2019, floods and storms are the most damaging causes which are seconded by the extreme temperatures; among the total 1672 disasters that are resulted in 159438 deaths and US$ 476.5 billion financial loss, when the frequencies are analyzed, floods were the 38%, storms were the 32% of the causes which take first 2 spots; but the deaths were caused mostly by extreme heats (93%) (WMO, 2021).

Estimations and studies show that the need for alternating water sources has grave importance with emphasis put on reuse of water for long-term sustainability and Europe is considering the topic as a high priority (Lundy et al., 2017).

The three water problems that are mostly associated with east Asia "too little, too much, too dirty/polluted" (UNICEF EAPRO, 2013) actually applies globally (Kundzewicz and Kowalczak, 2009 as cited in Wagner & Breil, 2013), and especially in urban areas; as the landscape is highly altered to meet the needs of urbanized areas and concentrated population and its effects on water and heat balance are bone-deep: as the impermeable surface proportion increases, it results in decrement of evapotranspiration, infiltration, and groundwater recharge while at the same time increasing surface runoff when it is compared with pre-development state (Wagner & Breil, 2013); where water sheds are used as an input, stormwater infrastructures that cannot cope up with the new rapid growths get overwhelmed, the natural balance between the water cycle is disrupted with changed evaporation, infiltration and runoff amounts, as a result of decreased pervious surfaces runoff increases which causes floods and infiltration decreases where water flows too fast (or even cannot its way through at all) that causes several negative impacts on groundwater resources (Segedy & Hollingsworth-Segedy, 2013). Increased runoff volume and speed frequently result in urban floods which are especially worse in countries where development can not

catch up with population increase and results in bad infrastructure let alone even developed countries are trying to figure out better solutions that address the urban water problem. In research from Elvidge et al. (2007), the World's mean value of constructed impervious surface area (ISA) is calculated as 93 m^2 ISA per person with 579,703 ISA km^2 total value (Figure 2.4 and Figure 2.5).

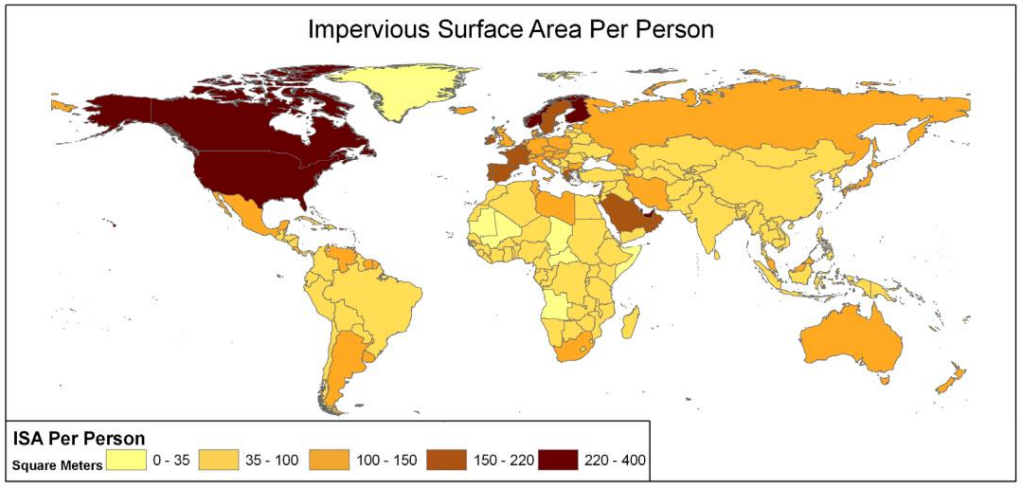


Figure 2.4: Impervious surface (m^2) per capita around the world (Elvidge et al., 2007, pp.1973).

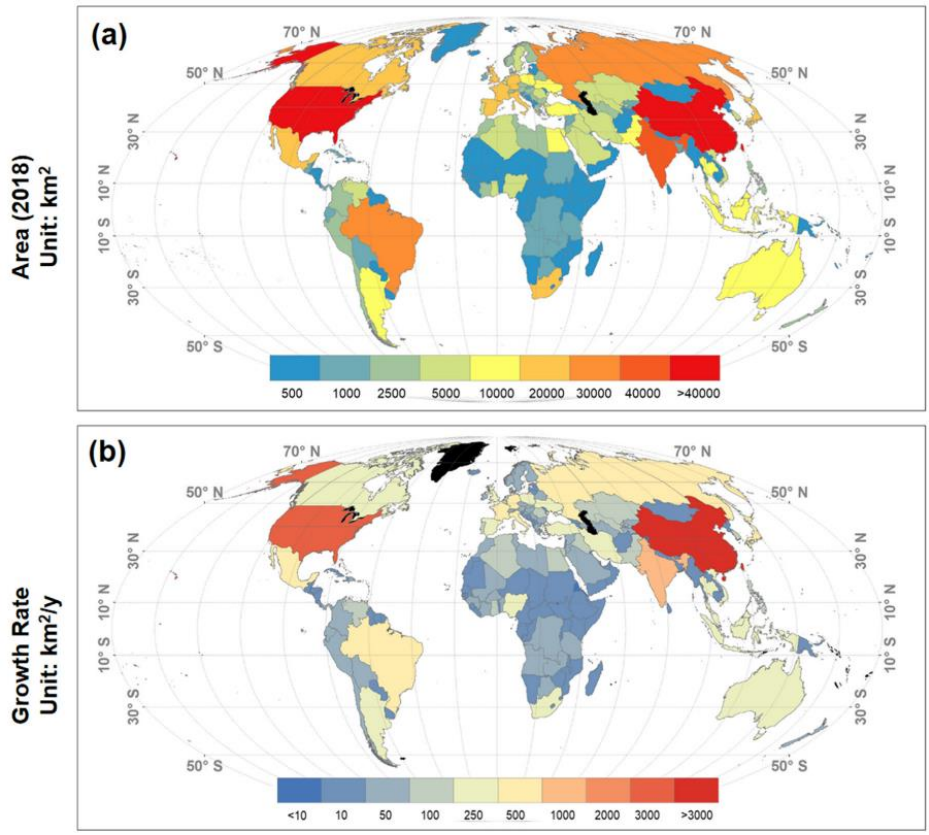


Figure 2.5: Country-based statistics of artificial impervious areas (2018) (a) and their growth rates from 1990 to 2018 (b) (Gong et al., 2020, pp.6).

The regulation of floods is highly related to settlement preferences and population growth (Schuch et al., 2017). Also, the water cycle is bounded with strict aging impermeable infrastructure systems (grey infrastructure) where the main aim is to remove water as quickly as possible to the nearest water source where they have no flexibility to adapt to changing needs and situations with their fixed diameters and parameters and their operational approach is formed by the urban organization rather than the receiving source (Wagner & Breil, 2013). The negative effects of this approach include hydrological cycle change, peak flow increment, groundwater and surface water level changes, extreme weather resulting in incapacitated infrastructure systems, and downstream risk increment (Casiano Flores et al., 2021). The result suggests Blue-Green infrastructure adaptation (Brears, 2018 as cited in Casiano Flores et al., 2021).

Even though cities cover 1% of land in the World, those are the places using 78% of the world's energy and populate over half of the world (University of Sussex, 2017). The share is projected to increase even more as the urban population is expected to increase from 55% to 68% from 2018 to 2050; especially in some parts of the regions such as Asia and Africa where the urban population ratio is expected to increase up to 90% (UN, 2018b) (Figure 2.6 and Figure 2.7). Therefore, urban agglomerations and population concentration will increase as a result. Mouritz (1996) claims that a city must include water, wastewater, stormwater infrastructure plans where new questions are raised due to economic and environmental reasons which are the type and form of those urban infrastructures. İncreasing urban population amount and rates, urbanization and climate change problems pressure the cities and their systems more and more day by day (van Leeuwen et al., 2012; Butler et al., 2016; Nieuwenhuis et al., 2020).

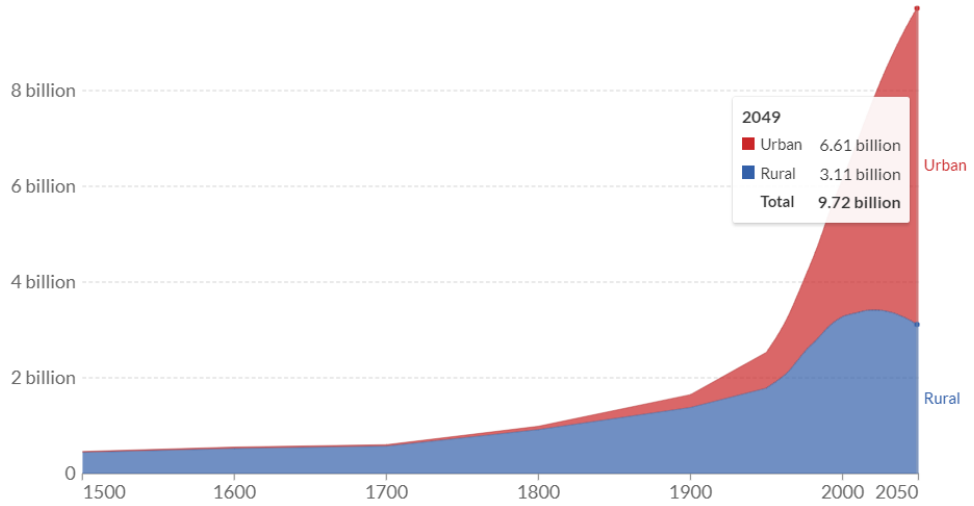


Figure 2.6: Urban and rural population history and projections of the World (Ritchie, 2018).

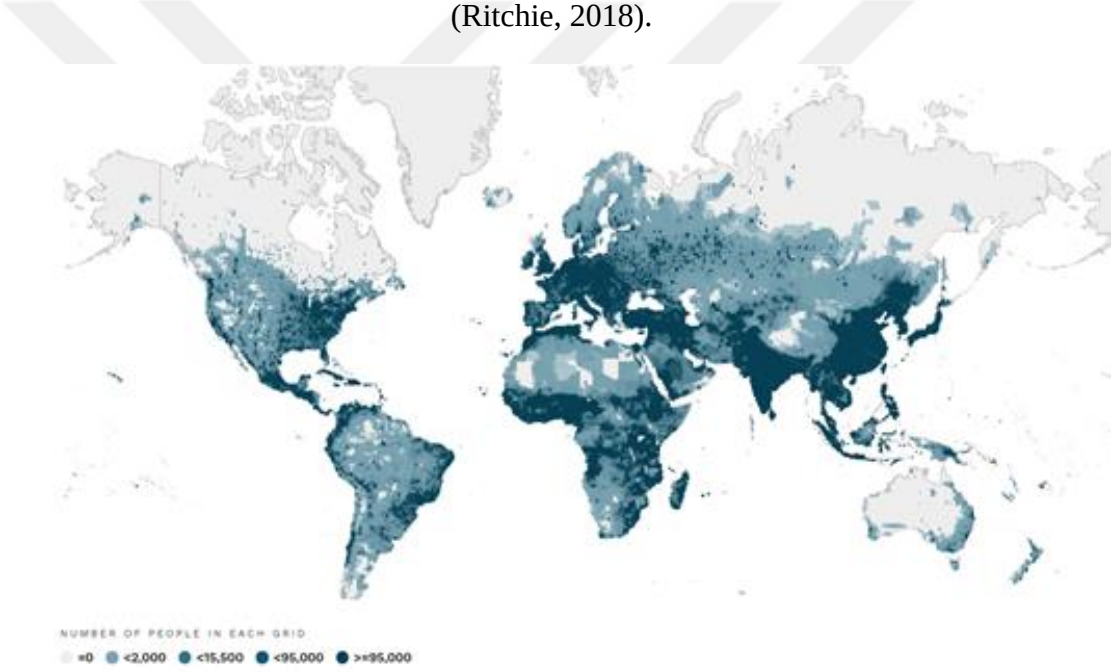


Figure 2.7: World population in 2030 and where they concentrate (World Water, n.d.).

As the famous quote of Albert Einstein (n.d.) says: “Problems cannot be solved with the same mindset that created them.”. Using the same methods that produced the current problems only stokes up the negative effects rather than solving them and scales them up; investing hard infrastructure furthermore with end-pipe solution mentality only results in increasing the costs but does not help with resiliency; therefore, contemporary thinking produced various approaches where basics (sewage treatment and water procurement) were enhanced with new laterals such as stormwater

management (Wagner & Breil, 2013). Even though all can be categorized under Integrated Urban Water Management, different countries adopted different strategies that are similar on most parts but differentiate while addressing their needs. Therefore, it cannot be said that one is superior to another, rather, it is about understanding the problems and addressing the needs of the study area to solve the problem. How it can be achieved may be changed though. According to where it is adapted it is described as Green Infrastructure (GI), Low Impact Urban Design and Development (LIUDD), Low Impact Development (LID), Water Sensitive Cities (WSC), Sustainable Urban Drainage System (SUDS), Water Sensitive Urban Design (WSUD), Best Management Practices (BMPs) and Alternative Techniques, which are the most common terms. In order to understand the solutions, firstly the way water cycles in the urban areas must be understood which is called the urban water cycle (UWC).

2.1 Urban Water Cycle (UWC)

According to Marsalek et al. (2014), the definition of the hydrological cycle is the circulation and storage of the water between the Earth's systems (biosphere, atmosphere, hydrosphere, and lithosphere). A modern UWC is with and within an interwoven system (Sitzenfrei et al., 2017). As Peña-Guzmán et al. (2017) describe, the general explanation about UWC concept in the literature covers the spatiotemporal interactions between the water and its hydrological processes, that covers how the water is supplied for the uses with different purposes, its fit-to-purpose treatment, distribution of it, and after the consumption, how it is collected, discharged, and/or treated, whether it is reused in urban/semiurban areas within time and space variables; which has four main inputs: water, contaminants, chemicals, and energy as their relationships can be seen clearly in Figure 2.8 where the paradigm shifts toward the integrating and innovating the natural and technical factors in the system (Wagner & Breil, 2013).

While the water is stored in different places (atmosphere, snowfields, glaciers, oceans, lakes, rivers, streams, soils, and groundwater aquifers); the circulation between these storages are the results of the water cycle components which are condensation, precipitation, percolation, evapotranspiration, infiltration, snowmelt, and runoff (Marsalek et al., 2014). As given, water is the essence of the cycle and comes from two main sources which are precipitation and supply sources (which refers to

groundwater resources, surface water) which are also used for the balance calculations (Peña-Guzmán et al., 2017).

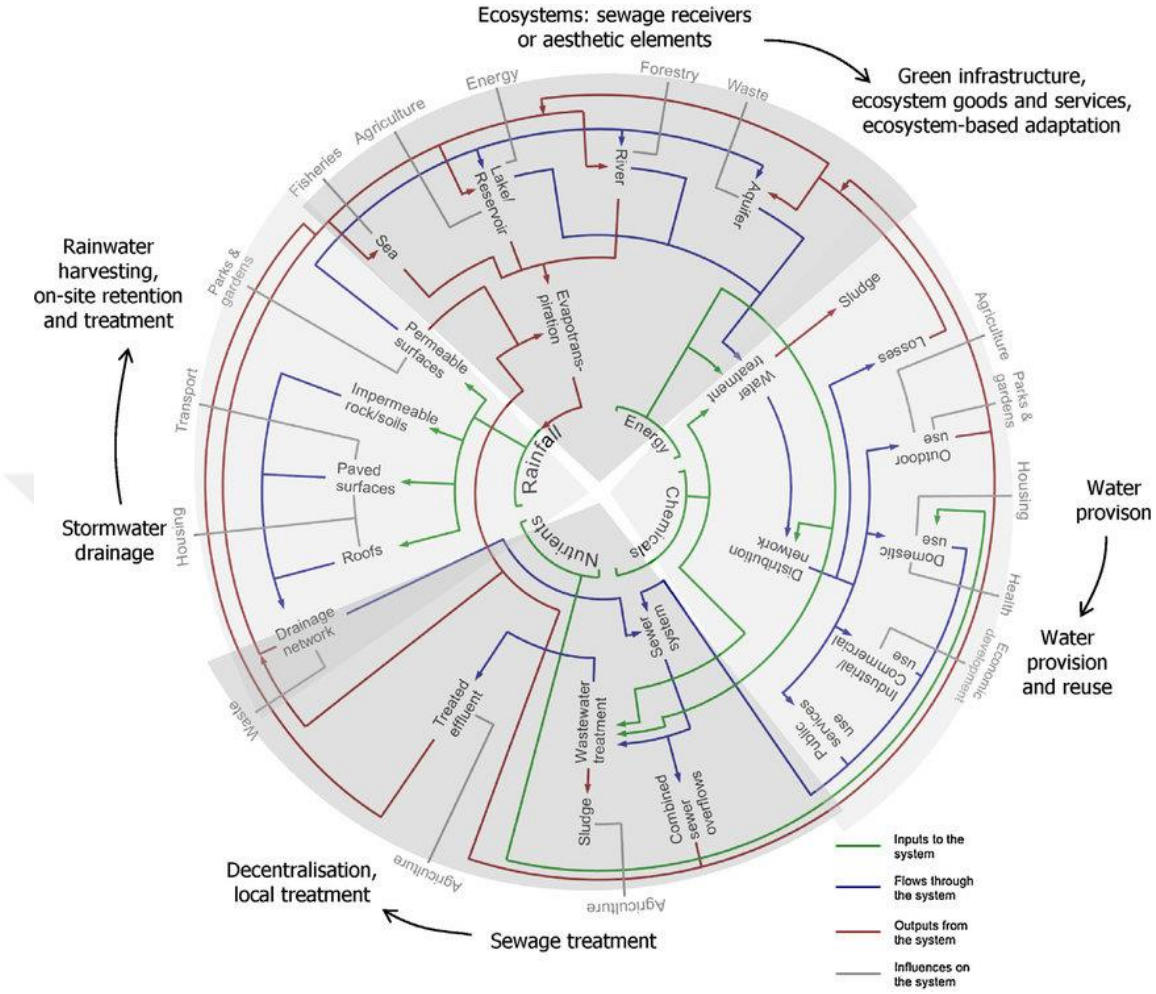


Figure 2.8: The paradigm changes in UWC management and approach changes in IUWM elements (Wagner & Breil, 2013, p.116).

Contaminants, the second input, are linked with water flows that can be involved through the cycle via surface and groundwater flows, wastewater flows and rainwater flows that are correlated with the surface types, the chemical uses relevant to the surfaces, and atmospheric water (Peña-Guzmán et al., 2017).

The third input chemicals are the chemicals used for the treatment of the wastewater and drinking water where their environmental and health impacts, as well as the treatment processes' costs, are the main topics of discussion (Peña-Guzmán et al., 2017).

The final input is the energy included because of its effects on costs and environmental impacts that are associated with greenhouse gasses as well as the uses of the natural resources (Peña-Guzmán et al., 2017).

The UWC is affected by internal and external agents that may directly or indirectly affect it with and within the system and makes it even more complicated (Peña-Guzmán et al., 2017). The main combination that affects the natural cycles is the combination of population growth, urbanization, and industrialization (Figure 2.9.); even though anthropogenic factors interfere with the natural processes, the principal structure of the hydrological cycle keeps its composure fairly whole (Marsalek et al., 2014). In order to supply water, provide drainage, collection and management of wastewater, and beneficial uses of receiving waters; the hydrological cycle is considerably twisted in order to meet these needs of the urban population and urbanization itself which makes the water cycle in urban areas more complex and as a result this new cycle is called urban water cycle (UWC) (Marsalek et al., 2014).

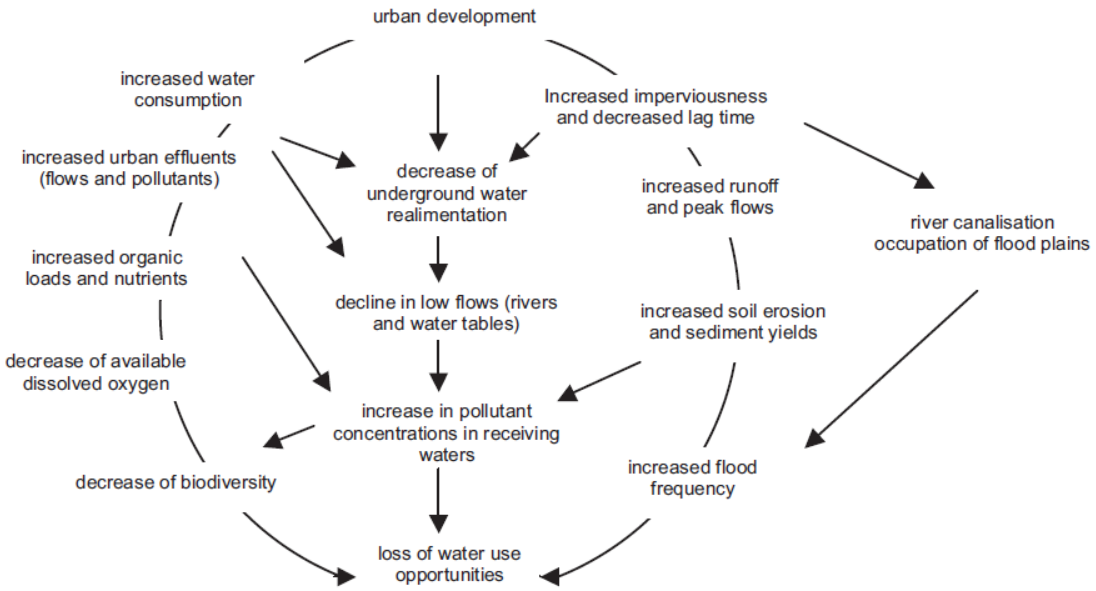


Figure 2.9: Effects of urbanization on the water cycle (Chocat et al., 2007, pp. 275).

Dealing with UWC requires a holistic and integrated approach where all urban water sources are considered as potential and interconnectedness between water supply, groundwater, wastewater, stormwater, flooding, wetlands, watercourses, estuaries, coastal waters, and the quality of water is provided with efficiency, reuse and recycling are taken into consideration as main components of UWC management (Government of Western Australia Department for Planning and Infrastructure & Western

Australian Planning Commission, 2008). Including all elements of a UWC improved the water management as a whole which included surface and groundwater resources' supply, treatment, distribution, usage, collection (wastewater), urban drainage, quality, and quantity (Peña-Guzmán et al., 2017).

Understanding the UWC is important to understand the water balance/water budget which is approached in certain time intervals such as annual, seasonal or so, and carries great importance for urban planning and coping with possibilities such as weather conditions, climate changes etc.; therefore, understanding water balances is crucial for integrated management of the urban water (Marsalek et al., 2014).

Water, sediment and chemical balance gives a base for the urban water cycle's quantification by measuring flows and fluxes of sediments and chemicals, analyzing component variations, and going through the physiographic, climate, and population changes on the UWC (Marsalek et al., 2014).

Municipal water supply which is often imported from the outside accordingly to the needs of the urban areas and precipitation are the two main water sources in UWCs: while municipal water is brought, distributed, some part is missed to the groundwater and the rest is used by the people, it is turned into wastewater and finally returns to surface water; precipitation usually follows a longer route: it falls in several forms; abstracted which includes interception, evapotranspiration and depression storage; some part is missed to the groundwater and also contributes the soil moisture; and the other part turns into surface runoff that is transferred to receiving waters by manmade or natural systems (Marsalek et al., 2014). Even though some connections are pre-established (conveying and storing water), others may occur (e.g., sewer exfiltration, water main leaks) during the UWC and need to be addressed in water management; and other than flow components of the UWC, fluxes of energy and materials that are carried by water, air, and/or anthropogenic activities must be considered as well (Marsalek et al., 2014).

The atmospheric pollutants can be carried by precipitation (wet) and gasses and particulates (dry); where major pollutants are identified by Novotny and Olem (1994, as cited in Marsalek et al., 2014) as acidity (fossil fuel combustion originated nitrogen and sulfur dioxides), trace metals, agricultural chemicals, and mercury (Marsalek et al., 2014). Land use activities and poor housekeeping, building material types,

construction activities, elution or attrition or corrosion of hard surfaces, deficient solid waste collection, erosion, and others are some of the pollution sources; the main way how these get mixed into the water is being washed off and carried with runoff water or as bedload while at the same time settling, resuspension, biological and chemical reactions occur on the pipes and the catchment surfaces; where all these events are happening more intense during the initial phase of a storm (first flash effect) (Marsalek et al., 2014). Figure 2.10 and Figure 2.11 give a clear portrayal of the relations between these systems in schematic and simplified ways.

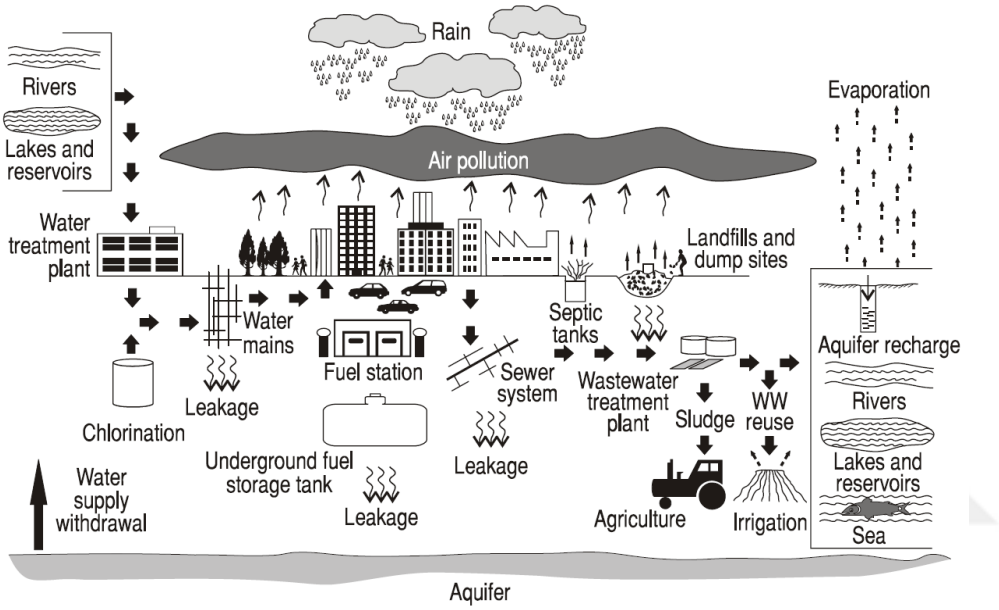


Figure 2.10: Urban Water Cycle (UWC) (Marsalek et al., 2014, pp.3).

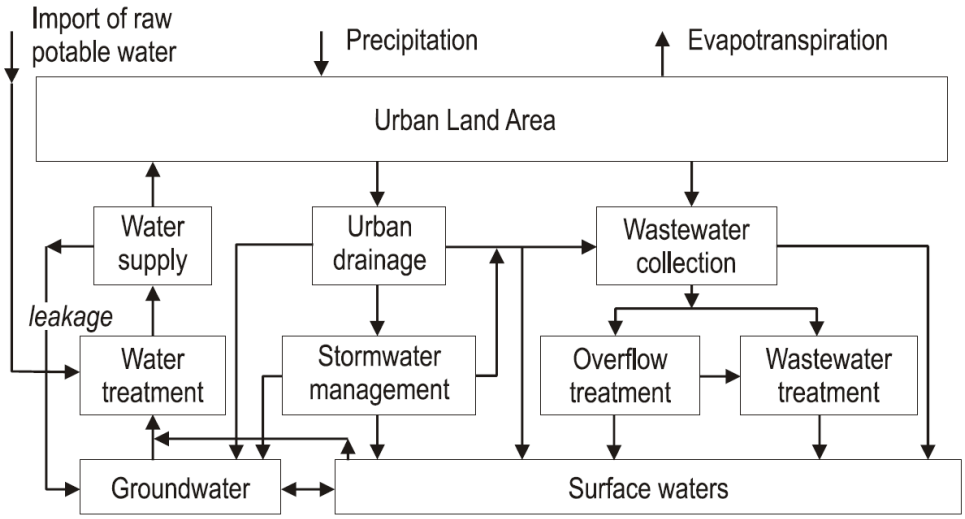


Figure 2.11: Main components of UWC and their pathways (Marsalek et al., 2014, pp.4).

Cultural aspects of people's interactions with water must be considered for a solution to be sustainable where two have a direct impact on water resources management which are the lifestyle of the residents and urban architecture (Marsalek et al., 2014).

According to Sitzenfrei et al. (2017), urban form is the most important determinant for urban water demand. Studies by Bouziotas et al. (2014) show the dynamics between urban growth and UWC, which are enhanced into water-aware technology integration models within the urban context that are studied by Rozos et al. (2016, as cited in Sitzenfrei et al., 2017). Density changes, construction materials, wastewater, and rainwater collection systems are major affecting factors in UWC that are categorized under urban architecture; lifestyle on the other hand affects UWC with demand changes: as for large cities, watering public spaces and domestic water use per capita are the main determinants of the lifestyle where although economic factors play a great role, cultural and traditional circumstances have the most significant effects on lifestyle determinants (Marsalek et al., 2014).

UWC shows both connectivity and interdependence of urban water resources and human activities as well as the integrated management's necessity (Marsalek et al., 2014). The basic categories that are included in UWC are:

-the reuse of the wastewater after treatment;

-integrated management of water supply, groundwater, stormwater, and wastewater; to have reliable and economic water supply, management of environmental flow, protecting downstream from pollution, procuring urban water/landscape, and substitute sub-potable water sources (stormwater and wastewater reuse);

-conservation of the water by managing the demand which is achieved by using water more efficiently, substituting landscape forms and industrial processes (Marsalek et al., 2007).

Even though the priorities may differ from case to case, the general principles used in the identification process of the main resources of water, pollutants, sediments, biota and chemicals, pathways and changes that the system allows and the extent of the intervention measures, which all in all serves the integrated management of the natural resources stays the way they are (Marsalek et al., 2014, p.6).

Improving the UWC offers various benefits such as climate mitigation by reducing greenhouse gas emissions (Rodríguez-Sinobas et al., 2018).

According to the National Water Commission's (2007, as cited in Government of Western Australia Department for Planning and Infrastructure & Western Australian Planning Commission, 2008) definition, integrated UWC management is integrating water supply, wastewater, and stormwater for optimal uses within all scales that also encourages plan, develop and manage water, land and relevant resources (energy use is included) which are linked to the urban areas and water sensitive urban design application.

There are computational models that are developed to initially understand the relationships between water bodies, drainage, and treatment systems which were introduced first at the INTERURBA conference in 1992 which later included rainwater managements into these models in 2001 (Peña-Guzmán et al., 2017).

2.2 Integrated Urban Water Management (IUWM)

To provide water supply for drinking, collecting, and treating wastewater to protect human health and mitigate the urban flood risks, wastewater and stormwater systems have been functioning for a long time; however, integrating these issues are needed to counterattack the relatively new challenges the urban population facing due to rapid urbanization and population growth, climate change, over capacitated and aged infrastructure systems (Sharma et al., 2016).

In order to meet the global and local quality and quantity standards of the water, the management of it gets more attention and importance (Peña-Guzmán et al., 2017). Towards the sustainability of the urban areas, the recognition toward the integration of the water management, supply, and planning is required where the term integrated urban water management (IUWM) comes in with its regards to comprehensive approach towards taking water supply, drainage, and sanitation as a whole interwoven physical systems of urban water services and that physical aspect must match with the organizational system and natural landscape (Mitchell, 2006). Urban planning and design also takes into increasing account, as well as other professions, into the matters about water and nutrient cycles that try to mimic their natural origins as much as possible where other factors are playing a great role such as stormwater quality and flow management, harvesting rainwater and stormwater, mitigating the flood risk while greening the environment to make it more habitable for all species which also improves the overall wellbeing and reduces the urban heat island effect at the same

time (Radcliffe, 2018). The complexity of the water problems is IUWM's main focus (Nieuwenhuis et al., 2021) which revolves around the integration of water supply, wastewater, and stormwater components of the UWC; in addition to all anthropogenic and ecological requirements of the water must be met within an integrated manmade and natural system to minimize the impact on the natural environment (Mitchell, 2006), as Nieuwenhuis et al. (2021) also mentions, that shows IUWM does not only sees the system as an integrated physical system but also considers the broader natural landscape and the socio-institutional structure that comes with it.

Van Leeuwen et al. (2012) proposed a method that is fed on other methodologies as well such as water footprint, ecosystem services, and urban metabolism which is called 'the city blueprints' that uses twenty-four indicators for a better understanding of IUWM and they analyze these indicators under eight main categories which are: (1) water security following the water footprint approach developed by Hoekstra and Chapagain (2007, as cited in van Leeuwen et al., 2012), (2) surface and groundwater quality, (3) drinking water, (4) sanitation, (5) infrastructure, (6) climate robustness, (7) biodiversity and attractiveness and (8) governance.

As State Planning Policy 2.9 Water Resources (Government of WA, 2006, as cited in Government of Western Australia Department for Planning and Infrastructure & Western Australian Planning Commission, 2008) states, integrated water cycle management's (IUWM) key principles can be summarized in five subjects which are: while planning all sources of water (as well as wastewater) must be considered; water and land use planning should be integrated; industry, people and the environment (all water users) must be able to have their fair shares sustainably from all water sources; human water use and natural water cycle must be integrated; and integrating a whole-of-catchment to natural use and management. IUWM includes water management's every aspect in environmental, social, economic, political, and technical at the same time and the opinions of local communities are taken into consideration during problem-solving (Bahri, 2012). Various usage alternatives for different kinds of water that fits several parameters is an important stand in IUWM where freshwater sources (groundwater, rainwater, surface water) and desalinated water supply the domestic needs, appropriately fit-to-purpose treated wastewater (grey, yellow, brown, and black water) can be used to support agricultural, industrial, and environmental demand;

using water efficiently like this (reclaiming and reusing) results in water to cycle more efficiently as well (Bahri, 2012).

Both new and readapted technologies are used to support IUWM which are: membranes, nanotechnology and microbial fuel cells, natural treatment system (NTS), and source separation of the waste stream (Bahri, 2012).

Membrane-based technologies and membrane bioreactors make wastes turning into alternative sources possible; nanotechnology concepts are developed for the sake of the membranes with higher performances to have them less polluting, improve their hydraulic conductivity, and have higher stats on having a more selective reject/transport properties; microbial fuels are expected to catch electrical energy from the organic matters' (that exists in wastes) microbial activities as they move through the drainage systems; NTSs use natural processes that enable them to filter variable contaminants in a natural way which makes it very convenient for improving the quality of the water, supporting natural environment and replenishing groundwater sources; and finally source separation differentiates wastewaters according to their pollution load where different kinds have not only different loads in percentages but their polluting content loads differ as well where technologies such as systems that separate urine in toilets or vacuum sewage systems (Bahri, 2012). A summary of these innovative technologies and their benefits for the IUWM are as given in Table 2.1.

The concept of integration has been researched and detailed by many researchers which each deliberately targets a specific subsystem or flow within the UWC and its translation varies internationally as well (Nieuwenhuis et al., 2021). According to Fletcher et al. (2014), as urban drainage management got more integrated and sophisticated through time; while its concern was only flood mitigation in the 1960s, respectively recreation and aesthetics, water quality (pollution) concerns, flow regime restoration, receiving waters' ecological situation and considering stormwater as a resource and finally the resilience and microclimate, etc. of the urban areas are adopted within the context.

Table 2.1: Innovative technologies that benefit IUWM (Bahri, 2012, pp.64).

Innovative technology	Benefits it provides for the IUWM
1. Natural treatment system	1.1. They are multi-functional both in terms of environment and treatment. 1.2. Improvement of the quality of the environment. 1.3. Enables taking advantage of the natural processes, features, and elements that promote nutrient recovery and water reuse. 1.4. Provides robustness and flexibility to the system that minimizes energy and chemical use.
2. Nanotechnology and microbial fuel cells	2.1. Provide a cheap 'green' energy source which uses electric currents to produce energy directly from the organic matter in the waste stream.
3. Membrane bioreactors (wastewater)	3.1. Alternative strategy for the reuse of the water. 3.2. Can be easily applied for the enhanced wastewater treatment alternatives and results and reduces the footprint of the plants. 3.3. Flexible operation enables remote operation of the system. 3.4. Enables environmental issues management such as odor and noise.
4. Membrane technologies (both water and wastewater)	4.1. Minimizes environmental footprint by promoting decentralization and enhances system flexibility. 4.2. Provides contaminants removal enhancement and encourages water recycling. 4.3. Provides chemical use minimization.
5. Source separation	5.1. Makes water reuse and nutrient recovery processes easier. 5.2. Enables easier operation and management with decentralization.
6. Anaerobic fermentation (UASB)	6.1. Enabling recovery of the energy from the wastewater while producing biogas.

2.2.1 IUWM concepts

IUWM's implementation differs depending on where it is addressed internationally (Mitchell, 2006). There are many terms and they significantly overlap where even though they share two similar broad principles which are: improvement of the water quality and reducing the pollutants; and lightening the changes of hydrology and conversion to the natural flow regimes of the natural water cycle as much as possible towards its natural levels or local environmental objectives (Fletcher et al., 2014). As

mentioned by Mitchell et al. (2007), there are more than 65 models that are developed for IUWM practices to meet the needs of the new integrated approach that sees water supply, drainage, and sanitation as parts of the UWC that takes a large amount of space; which also results in large and complex systems that are large in terms of attribute and behavior inputs which results in technical and practical challenges for turning them into computational programs.

The differences that come within the terms are the result of how each practitioner expresses their needs according to local development and institutional context which enables an understanding of these contexts (Fletcher et al., 2014). Depending on the communities' needs and where they want to put their major emphasis in, addressing their cultural structure, climate, infrastructure, climate, water cycle, etc., the components and contributing causes differ (Radcliffe, 2019). North America introduced Low Impact Development (LID) and Green Infrastructure later on in response to Clean Water Act (1972) (Radcliffe, 2018). Barlow et al. (1977, as cited in Li et al., 2018) was the one who first presented LID and it has been used the most in North America and New Zealand. While Europe responded to EU *Water Management* and *Flooding Directives;* China introduced a new term called Sponge City Concept (SCC) in 2013 in response to rapid urbanization challenges; Africa adopted WSUD with extra other concerns in mind that are responding to development and/or equity issues which are more topical in developing countries especially the ones which still has legacies from their apartheid or colonial past and named it Water Sensitive Settlements (WSS) (Radcliffe, 2019). Singapore's National Water Agency (PUB) introduced its Active, Beautiful, Clean Waters (ABC Waters) Program in 2006 to become a City of Gardens and Water in mind (PUB, 2018) which aims to overreach canals, drains, and reservoirs' conventional uses and beautify them into lakes, rivers, and streams that are well integrated with the surrounding landscape (Yau et al., 2017). ABC Waters has a greater focus on cleansing function compared to other approaches (Yau et al., 2017) as well as making community get closer to the green environment and water bodies by interconnecting all together by creating a 'postcard-pretty' environment; therefore, by improving the quality of the natural elements, brings together the improvement on the quality of life of the citizens (PUB, 2018).

In the 1970s, the United States Environmental Protection Agency (USEPA) stated their concern for lake and stream health that can be deteriorated from the stormwater runoff;

and Australia was among the first to research WSUD in 1989; in 2006, British CIRIA (Construction Industry Research and Information Association) broadened the scope from drainage to water management's (including wastewater) sustainability that takes many other fields into consideration such as social, economic, environmental aspects that are linked together with land use planning (Rohilla et al., 2017).

The concepts' focuses range from the techniques that are used to overarching principles; best management practices (BMPs), sustainable urban drainage systems (SUDS), stormwater control measures (SCMs), stormwater quality improvement devices (SQIDs), and alternative techniques (ATs) can be mentioned while naming the terms that evolved from the descriptions of practices and techniques (Fletcher et al., 2014). IUWM concept is mostly linked with WSUD (Fletcher et al., 2014) since WSUD is the integration of both IUWM and urban design fields (Wong & Brown, 2009); and even though in Australia, WSUD and water sensitive cities (WSC) are called interchanging (Fletcher et al., 2014), WSCs are considered the end result/product while WSUD is the process/philosophy of the concept (Brown and Clarke, 2007; Fletcher et al., 2014). About WSC and LID, it can be said that they are broader concepts than the management of the urban drainage system (Fletcher et al., 2014). SCC of China also has similarities with WSUD; however, with an emphasis on some non-water issues where other driving factors such as air quality also play a role (Zevenbergen et al., 2018). On SCC, the main driving factor is flooding (especially pluvial) therefore IUWM is shaped accordingly; on the other hand, WSUD focuses on ecological aspects as well as water management where the emphasis is weighted more on ecological protection of waterways; management of runoff and stormwater quality has importance as well (Hawken et al., 2021). On SuDS, the main emphasis is weighted on surface water drainage which aims to increase the quality and quantity of the runoff water while minimizing the effects of anthropological factors and maximizing the opportunities that can be gained through providing amenities and biodiversity options (Ballard et al., 2007; Woods-Ballard et al., 2007).

Terms like BMPs and SuDS are interested in especially one part of the UWC, such as stormwater, in a multifunctional manner while approaches like WSUD and SCC has a more holistic approach (Zevenbergen et al., 2018).

SuDS is adopted by Britain (Radcliffe, 2019); where the aim is to slow down and reduce the surface water runoff quantity by the means of retention and detention

(harvesting, storing, slowing, and conveying), infiltration, and treatment as much as close to the source of it, preferably on the surface rather than underground so that water can be used as a part of the built environment and become a link between the green networks (Ballard et al., 2007; Zevenbergen et al., 2018). While SuDS uses natural processes (such as evapotranspiration, natural treatment, and infiltration) to complement grey infrastructure, Green Infrastructure (GI) uses both natural and/or semi-natural solutions (for example Nature-Based Solutions (NBS)) to provide services like treatment, pollution control, containing flood risk and urban heat island effect mitigation (Zevenbergen et al., 2018).

Within the scope of the infrastructure, the broad term can refer to gray infrastructure with roads, sewers, utility lines, etc.; social infrastructure with hospitals, schools, libraries, etc. which are often come together under the name of 'built infrastructure' where another kind of crucial infrastructure type is being discussed which is called green infrastructure (GI) (Benedict & McMahon, 2002). Even though the term can refer the energy management consideration from time to time (Radcliffe, 2018), GI is the system that supports the natural life within the whole system that includes supporting the native species, air, and water resources, maintaining ecological processes while enhancing the quality of life and overall health of the urban and pre-urban dwellers which provides multifunctional environmental, cultural, social and economic benefits (Benedict & McMahon, 2002; Molla, 2015). GI components are analyzed under 'hubs' and 'links' that can be seen in various sizes, functions, and ownerships where hubs secure the source for the ecological processes and wildlife to thrive, links connect these so that GI can properly function and provide a ground to protecting and restoring existing ecosystems while enabling a framework for the future developments with augmented benefits such as prospering the biodiversity, cleaner water and air, better and increased recreational services and connection between them and people which also promotes a sense of place, etc. (Benedict & McMahon, 2002). As Benedict and McMahon (2002) state, green spaces contribute to the increment of the property values while decreasing the infrastructure service costs with its natural course of flood control, water treatment, and management of the stormwater; therefore, it makes GI a more cost-effective solution than conventional ones.

Integrated urban drainage systems (IUDS) are, according to the formal definition of it which was given by Rauch et al. (2002a, as cited in Bach et al., 2014), involve two or

more physical systems' interaction which is considered outdated, lacking and ambiguous therefore boundaries stay too general even though only physical systems are included (Bach et al., 2014).

Even though WSUD is widely recognized all over Australia, there are differences in applications even between the local governments (Radcliffe, 2018); in the United States, the best management practices (BMPs) are now called stormwater control measures (SCMs) (Butler et al., 2018); all in all, not just the scope of the concepts but other conditions cause them to be used differently for one reason or another. Therefore, rather than choosing a model and assuming that is a rigid application model or even when describing a specific one, in order to prevent confusion and not stray from the main philosophy and risk the technologies applying their own sake before they accomplish what they aim to fulfill in terms of environmental, economic and social objectives, being clear about the base philosophy and stating the main **principles and objectives** carry grave importance (Fletcher et al., 2014). Giving clear explanations on **what the measures aim to control for what purpose** gives clearer context and minimizes the contradictions that may arise due to the inevitable changes that stem from the evolution of the meanings over time (Fletcher et al., 2014).

SWITCH (Sustainable Water Management Improves Tomorrow's Cities' Health) is one of the first projects that aims IUWM on a global scale which include 33 partners (17 from Europe and 12 from South America, Asia, and Africa) and was implemented during the period 2006 to 2011 when the total urban population overcame the rural population for the first time (Howe et al., 2012).

Also, as Hawken et al. (2021) mention, water management has gotten broader in recent years with increasing and diversified needs and findings such as recycling and reusing of stormwater, groundwater maintenance and control, and drought resilience.

Mechanisms/specialists that evaluate and give guidance for cities such as Water Sensitive Cities Index and The City Blueprint® Approach provide diagnosing tools and frameworks to work on and educate relevant staff. The City Blueprint® Approach has three frameworks that complement each other which are the Trends and Pressures Framework (TPF) where the main challenges of the cities are specified, the City Blueprint® Framework (CBF) where how cities are managing their UWC and gives an idea about their Integrated Water Resource Management (IWRM) performance, and

the Governance Capacity Framework (GCF) where water governance improvement is provided (Watershare, 2020). More than 70 cities in 40 countries are assessed and scored with performance-oriented indicators and their spider diagram are prepared and shown in the Blue City Index® (BCI) that has 25 indicators with 0-10 score range as some can be seen in Figure 2.12 (Watershare, 2020).

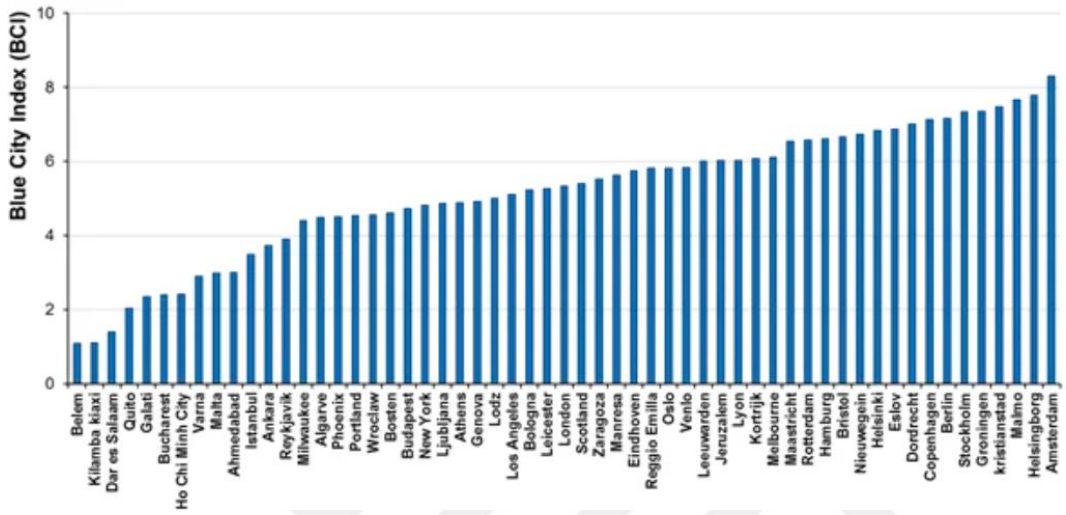


Figure 2.12: BCI comparison of the cities around the World (Watershare, 2020).

Amsterdam has a prominent international position in IWRM (van Leeuwen & Sjerps, 2014, pp. 407). Dutch has a sophisticated way of approaching water; with risks and responsibilities in mind and WSUD is applied and used planning as a place-making process (Dolman et al., 2013). According to BCI scoring, Amsterdam has the highest score with BCI looking as given in Figure 2.13:

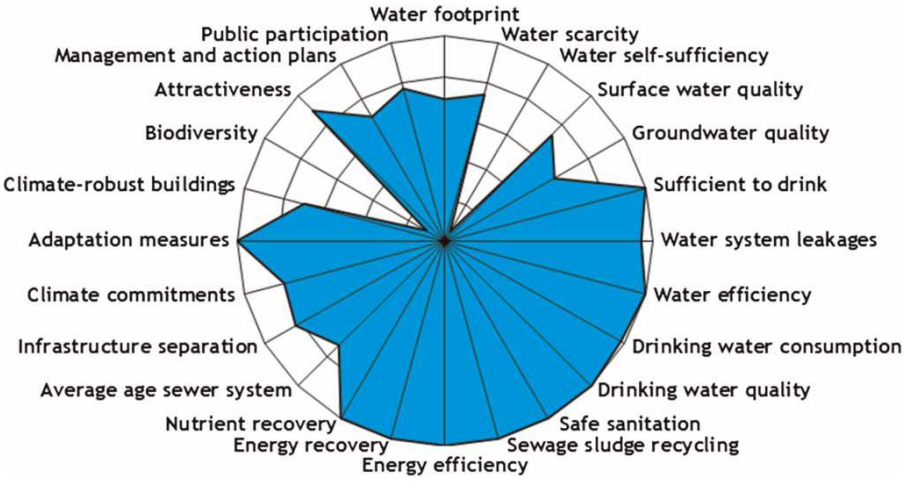


Figure 2.13: City Blueprint of Amsterdam (van Leeuwen & Sjerps, 2014, pp. 407).

There are many outstanding examples as WSUD is developed to meet the needs of Australian cities that were fighting with drought and seasonal flooding subsequently (Dolman et al., 2013) and found wider application areas independently from geographical, cultural, institutional, and many more differences; therefore, they set a great example.

2.3 Water Sensitive Urban Design (WSUD)

The term was first used in Australia as adoption of Low Impact Development (LID) by Mouritz (1992); then in 1994, Whelans and Halpern (1994, as cited in Fletcher et al, 2014) prepared the first formal guidance of it as a report (Fletcher et al, 2014). According to the Department of Planning and Local Government of South Australia, Water Sensitive Urban Design Technical Manual for the Greater Adelaide Region (2010), Water Sensitive Urban Design (WSUD) is an approach that incorporates the total water cycle's management to the urban development process with urban planning and design. As Wong (2000) describes, WSUD realizes the advantages of intrinsically associating the landscape architecture, urban design, and stormwater management infrastructure and combines numerous stormwater management objectives pro-actively to them. However, only peak flow management has been the main focus of traditional urban stormwater design (Water Sensitive SA, 2020). Also, during WSUD's applications in the early years, the concept was more revolved around stormwater management even though its definition was given fairly broad (Fletcher et al., 2014). With evolved design standards and catchment condition changes that are due to urbanization must be considered during the process of stormwater design (Water Sensitive SA, 2020). All in all, it is argued that rather than a resource management challenge, WSUD should be seen as an embracive design philosophy that reflects an essential re-consider the role and place of water in urban environments (Ward et al., 2012). Rather than being a function hidden underground, WSUD becomes a part of the urban landscape and occupies a space within the scene where the land itself is especially valuable in denser cities as a resource (Lerer et al., 2015).

The field of application can be varied from a single housing unit to a whole catchment (Lloyd et al., 2002). By using an approach that is able to deliver numerous valuable outcomes at both local and the regional levels, the concept grounds a holistic approach for stormwater management (Wong, 2000). According to Brown and Clarke (2007),

WSUD and urban stormwater are more complex concepts than urban water management with their multi-sectoral matters; while regarding the most immediate acts, creating resilient urban environments to the climate change and using alternative water resources can be counted which also contribute to building a water sensitive city; therefore amplifying these measures makes the topic extend from urban water management to a much complex and sophisticated approach that includes multi-sectoral disciplines like WSUD and urban stormwater. WSUD also pays regard to the rehabilitating the degraded urban waterways; where their health is affected by many factors where the management of it typically consists of a variety of catchment-wide attempts that are based on WSUD (that helps improve waterway health and water quality which promotes all waterway health improvement or protection interferences) and on-site works (Wong & Brown, 2009).

WSUD acts during the development scale (at the source) that is resulted in the reduced structural stormwater system which pursues minimizing the impervious surfaces, reusing the water where it is generated, uniting retention basins for reduced peak flows, and treatment systems to remove pollutants (South Eastern Councils, 2013). Stormwater and wastewater are seen as sources that are needed to be integrated into the UWC through groundwater, urban design, water supply, and environmental protection (Radcliffe, 2018).

Urban catchments are complicated systems that include variables regarding water supply, disposal of wastewater, and stormwater drainage where the water supplies which are high in quality are treated and delivered to meet the needs of the domestic (such as drinking water) and industrial uses after harvested (from the catchments which usually are far from the urban areas); treated and delivered to the demanding area; generated wastewater transfers to the nearest treatment facility to be discharged (to rivers, bays et.); while in order to prevent floods and stormwater to pond, stormwater is conveyed to trunk stormwater drainage systems (Lloyd et al., 2002).

WSUD includes the integrated management of groundwater, runoff water (surface runoff that includes stormwater), wastewater, and drinking water; in order to protect water-related values that include cultural, environmental, and recreational aspects; storing, treating, and reusing the runoff waters where treatment and reusing also applies for the wastewater as well; using natural solutions, especially vegetation, for the treatment processes and enhancement of the biodiversity; integrating water-saving

measures in all areas that include outside and within domestic, industrial, commercial, and institutional domains to minimize drinking water use in every area and instead encourages the fit-to-purpose use of it and minimize the requirement of non-drinking water supplies as well with efficiency and drought countermeasures are important inputs as well (Water Sensitive SA, 2020). Therefore, WSUD values every water stream in the cycle as possible resources which are: surface water, groundwater, drinking water (potable mains water), rainwater (that is collected from the roofs), runoff water (that is collected from all impervious surfaces which include stormwater), greywater (water that is used but no toxic chemicals are involved which include water from bathroom taps, showers, and laundries), and blackwater (contaminated waters which come from kitchen sinks and toilets that contain toxic chemicals and/or excrement) (Government of South Australia, 2010).

According to what Fletcher et al. (2014) mention, terms WSUD and Water Sensitive City (WSC) are often used parallel in Australia, yet there is a subtle difference between them which is while WSUD defines the process, WSC defines the destination/objective (Brown & Clarke, 2007, as cited in Fletcher et al, 2014). The Water Sensitive City approach focuses especially on how cities can be transformed by reconnecting best thinking and practice in urban water management, urban design, and social and institutional systems (Wong & Brown, 2009). Wong and Brown (2007) also add WSCs are achieved by the whole city's commitment to the WSUD which addresses the issues such as alternative water sources, water's efficient use, water supply security, and the protection of waterway rehabilitation and aquatic ecosystem issues in a sophisticated manner.

According to Wong and Brown (2009), stormwater management of a water sensitive city consists of three main pillars to build on which are (1) having a variety of water sources that are supported centralized and decentralized infrastructure; (2) enabling ecosystem services for the built and natural environment; and (3) providing socio-political capital for sustainability and water sensitive way of designing policies which can be categorized into three themes which are: (1) water resources; (2) ecosystem services for the built and natural environments; and, (3) social and institutional capital (Wong et al., 2013).

According to Wong and Brown's (2009) categorization, there are six phases a city goes through till it can be named as a water sensitive city which are respectively: water

supply city, sewered city, drained city, waterway city, water cycle city, and finally water sensitive city. These transitions occur when the socio-political drivers and delivered service functions are implemented; where previous stages form the following ones which makes this system a nested continuum and the cumulative socio-political drivers that change between each stages are respectively: providing water supply access and security in water supply cities to supply hydraulics to the city, having public health protection by separating sewerage schemes in sewered cities, ensuring flood protection by providing proper drainage and channelization systems in drained cities, offering social amenities and environmental protection with the management of point and diffuse source pollution in waterway cities while water cycle cities put limits on natural resources to provide diverse, fit-for-purpose sources and conserving/promoting the waterway protection and water sensitive cities enjoys the intergenerational equity, resilience to climate change privileges by having adaptive, multi-functional infrastructure and urban design that reinforces water sensitive behaviors of the city (Wong & Brown, 2009); however, there is no example of a water sensitive city that can ensure these sustainable water futures (Brown et al., 2009). The first three stages are to provide basic needs of a city such as providing access to drinkable water, protecting public health and from floods; whereas they are followed by the last three stages which provides a range of services that are similar to what 'Sponge Cities' aim which includes social amenities and environmental protection while providing more livability, community and environmental resiliency to climate change, ensuring flood control, public health, giving consistent water services under constrained resources which makes it possible for its citizens to have access to non-climate dependent resources, satisfying economic sustainability and enabling intergenerational equity regarding its natural sources and ecological integrity (Brown et al., 2009; Radcliffe, 2018).

WSCs' key principles are based on exporting the wastewater from the urban areas and minimizing the potable water's import to the area while considering optimizing the use of the water resources within its boundaries. Creating an ecological landscape in urban communities requires the designs to buffer the pressure of the climate changes to the aquatic environments or/and re-establishing the ecosystem services (Wong & Brown, 2009). Developing cities can have an advantage over developed cities by leapfrogging the stages when more than 50% of the cities' not having proper sewer

and stormwater drainage system is considered, the potential to develop right from the start gives them a different kind of encouragement since developed cities usually have single-purpose systems installed quite a while back and deal with the maintenance and upkeep of these systems (Dolman & Ogunyoye, 2018) (Figure 2.14). The Cooperative Research Centre (CRC) for Water Sensitive Cities which is established in 2012 is offering a variety of research initiatives as well as providing an index for benchmarking water sensitive cities (Radcliffe, 2018).

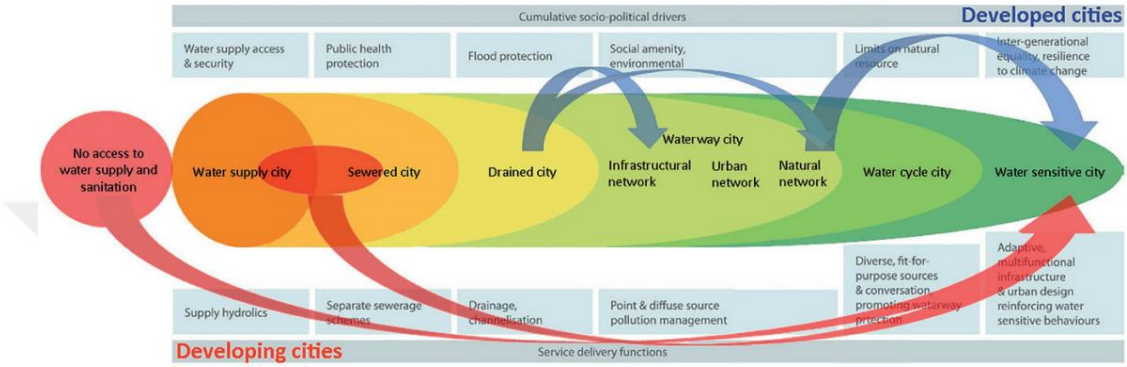


Figure 2.14: Developing cities could leapfrog developed cities in becoming 'water sensitive' (Dolman & Ogunyoye, 2018, pp.13).

As the Australian Government's National Water Commission (2010) states, WSUD's key principles are:

- minimizing the impacts on the natural environment (such as erosion), behaviors (such as hydrological cycles), and ecological processes, improving the water quality of the receiving sources by reducing the pollutant load generated from the discharging;
- protecting the quality of the water resources that include surface and groundwater;
- reducing peak flows and the generated amount of runoff water (flood management) that are originated from the urbanization;
- minimizing the demand on the water supply network;
- minimizing the development and maintenance cost requirements while adding extra value to the whole system which also includes social amenity with the integration of multi-purpose landscaping that considers both water and landscape while designing to enhance their amenities for the strengthened effect of social, cultural, visual, and ecological amenities;
- creating alternative sources of water which include wastewater, stormwater, and rainwater with the means of collection, treatment, and/or reuse;

- incorporating institutions, increasing awareness, and providing education on all levels where inclusion in the system is relevant.

WSUD systems offer many benefits that include conserving water, improving the quality of the stormwater, as well as its quantity (for flood control management), providing visual and landscape amenity, and healthy vibrant environments (Sharma et al., 2016). Selection and application of appropriate measures for the individual areas with their unique needs provide the achievement of the WSUD's key principles (Government of South Australia, 2010).

WSUD combines the utilization of Best Practices (Best Planning Practices on the design part and Best Management Practices in technological side) and urban planning to accomplish the objectives of SUDs; which uses urban planning as the medium to achieve the utilization of stormwater best management techniques (Wong, 2000; Wong&Eadie,2000) (Figure 2.15). While choosing what to take from the BMPs approach; in order to understand the characteristics and limitations of the relevant case, many disciplines play great roles such as landscape architecture, drainage engineering, ecology, etc. (Wong, 2000).

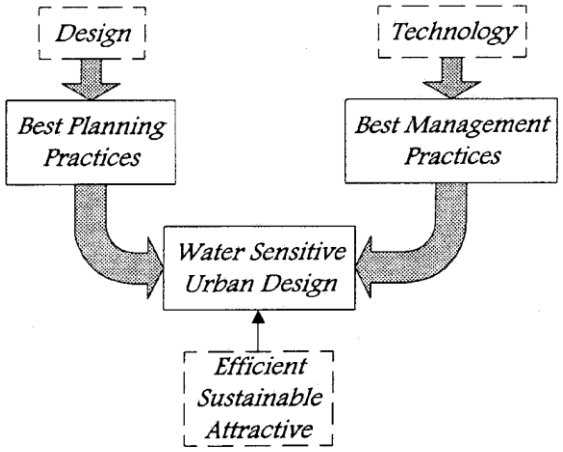


Figure 2.15: Best Management Practices and Best Planning Practices coming together and contributing to the WSUD (Whelan et al., 1994).

The stormwater control measures which constitute the BMPs, which include treatment train can be viewed as BPP, where these two go together. From the local to the regional level, there are many stages that BPP can be used such as roads, lot sub-divisions, streetscapes on the local level and regional parks, pollution control ponds and wetlands, gross pollutant traps on the regional level. Many design concepts can be implemented to increase the local amenities (along with value) while providing better

management of stormwater quality and quantity. Relatively undeveloped or sub-catchments are the places where planning tools such as zoning, design specifications, and paralleling the land's capabilities with land use activities are most effective; therefore, the opportunities for the BPP has the highest potential in those areas; because, in those areas, BPP reaches out and meshes to all planning, scheduling and management stages of the construction activities (Wong & Eadie, 2000).

Runoff waters can carry numerous pollutants with changing sizes and types where most of the time, only one type of treatment would not be sufficient and a series of treatments is needed to get rid of the pollutants effectively which is called treatment trains. In order to develop these treatment trains, the selection and order of the treatments play a huge role; to remove fine pollutants more effectively, coarser ones must be removed first. Other important considerations that must be considered are the proximity of the treatment to its source and the distribution of treatments throughout a catchment. The treatment processes can be encountered through the processes that are: screening which is pre-filtering technologies, litter baskets, gross pollutant traps; sedimentation which is sedimentation basins, ponds, wetlands; adhesion and filtration which are bioretention systems, infiltration systems, and wetlands; and biological uptake which is wetlands and biofiltration systems (Government of South Australia, 2010).

The measures used for WSUD are sediment traps, gross pollutants traps, filter strips, grass swales, bioretention systems, infiltration trenches (which requires also pretreatment to remove litter and sediment), rain gardens, pervious pavements, sedimentation basins, constructed wetlands; while their potential constraints are described as steep site/catchment slopes, high water tables, shallow bedrocks, land availability limitation, possible requirement of underground installation, high sediment inputs, requiring pre-treatment, hydraulic head loss limitation, installation in the tidal system (Government of South Australia, 2010).

According to Butler and Davies (2018), wastewater and stormwater are the two that defines urban drainage fluids; even though both should be considered while planning an urban drainage system (Burian & Edwards, 2002), as Marsalek et al. (2014) state, stormwater runoff is the most important component of the UWC while dealing the flood protection and drainage. However, the two systems can be constructed as a single canal as in combined sewers or can be separated for collecting and disposing of as in

separate sewers (Burian & Edwards, 2002). While stormwater is the water created by the precipitations, wastewater is created from human activities such as industrial uses, daily activities and contains various pollutants which require collection and disposal of it to prevent unwanted situations (Burian & Edwards, 2002).

The gravity of the WSUD discipline has been weighted on reducing the stormwater pollutant loads that also include sediments; but since coarse sediment are relatively seen as inert and can offer possible advantages for the diminished (because of the runoff waters) urban streams (Hoban, 2019).

2.3.1 Stormwater management

Stormwater used to be perceived as a sub-cycle rather than a part of the UWC (Rodríguez-Sinobas et al., 2018) and neglected which belated the proper stormwater and drainage provision as they were not included in past water reforms (Productivity Commission, 2020). On the other hand, traditional stormwater solutions only recline upon peak flow management (Water Sensitive SA, 2020); however, climate change, rapid urban population growth, increased and changed urbanization requires the recognition of the importance of stormwater management and design solutions as the old drainage systems cannot cope with the new trends with their aging structure and reaching their capacity constrains (Water Sensitive SA, 2020; Radcliffe, 2019; Sharma et al., 2016). Stormwater management has the potential to take control of the intense rainfall events while regenerating the local water resources (Bahri, 2012).

Combined sewer/stormwater systems are no longer permitted since the mid-1900s in many parts of the world, yet there are still cities that inherited it from older times (Radcliffe, 2019). The sudden increase in stormwater can cause it to enter the sewage system and result in sewer overflow and contamination of the other water sources even in separated systems (Radcliffe, 2019). Increased population density that is resulted in more areas getting covered with impervious surfaces leads to increased stormwater runoff quantity and velocity that also disrupts the water cycle further and causes problems such as urban floods, droughts, decreased groundwater quality and quantity, decreased water quality (Radcliffe, 2019). The traditional solution, also in older version of separated sewer systems, is to discharge it from the source as quickly as possible (Mitchell et al., 2001; Rodríguez-Sinobas et al., 2018; Radcliffe, 2019) without the consideration of quality and quantity (flow and volume) effects on the

downstream (Rodríguez-Sinobas et al., 2018, Marsalek et al., 2012) with means that uses concrete channels which are also impermeable and causes other problems such as sedimentation and pollution increase; which creates the need for another solution that results in detentions that are created by constructing large holding basins or wetlands that holds stormwater and aims to reduce the peak flow and by decreasing the flow rate and holding the water in these areas reduces the risk of flood and erosion; however such approaches give way to more integrated solutions because of the nature of the urbanization and its bringing such as frequency and severity of the floods and runoffs and many other problems that are associated with impervious surfaces (Radcliffe, 2019) therefore evolved into systems that enables reclaiming and detaining stormwater so runoff volumes can be taken under control, increasing infiltration levels for underground water sources, and providing quality control systems (Marsalek et al., 2014). Considering stormwater and wastewater as possible alternative sources are considered more holistic where the water demand and availability of the stormwater and wastewater are evaluated and their interactions are analyzed (Mitchell et al., 2001).

As a result of urbanization, soil and vegetated areas turn into impervious surfaces that results in increased runoff when a rainfall event occurs, increment of the velocity of that flow, and reduced volume of the infiltrated water to the underground which is addressed by drainage systems that are impervious surfaces themselves and shortens the distances the water takes, increases the flow velocity (due to smooth and straighter track when compared to their natural flow route), decreases evaporation rates, increases the frequency and magnitude of the high flow events, causes flood peaks (flashiness), rainfall events that are resulted in both riverine (fluvial) and stormwater (pluvial) flooding increases, causes change rates to become unstable, seasonality of high flows becomes ambiguous that even affects daily flow variations (Coombes & Roso, 2019). Overall, urbanization has also become one of the causes that affect changes in stream ecology, quality of water, and sediment loads (Walsh et al, 2005, as cited in Coombes & Roso, 2019). Urbanization shifts the conveyance of water from natural paths to constructed paths; therefore, changes the overall process of it; therefore apprehension of the conveyance of the water during overland flooding is crucial in stormwater management where its paths and carrying capacities must be considered to reduce flood risks; that behavior's complexity also comes from the changes between the nature of large floods and small flood events which can result in

unexpected results such as riverine (fluvial) flooding by a levee which in smaller events stormwater goes under the levee but when storm over capacitates the system, the water backs up and causes rapid flooding which decreases the predictability of the event, therefore, becomes more dangerous (Coombes & Roso, 2019).

When rural and urban areas are compared in that sense, for runoff to occur in rural areas rainfall has to exceed evapotranspiration while runoff flows occur anytime the rainfall takes place because of the impervious character that urban areas gained; also, the most common response to urbanization is decrement in base flow in urban streams (Coombes & Roso, 2019). Urbanization overall changes the hydrologic regimen; and changed runoff regime is one of the most notable results of the urbanization and affected in three ways which are increasing the impervious surfaces that results in decreased infiltration and evapotranspiration, increasing the speed/velocity of the runoff water that is the result of changed conveyance systems, and reducing the catchment response time that results in flash floods (peak discharge) by increasing the maximum rainfall intensity (Figure 2.16); which can somewhat be controlled with storage solutions but these solutions cannot solve the increased runoff volumes which contributes to increment on the runoff flows and combined with channel erosion, contributes the downstream pollution (Marsalek et al., 2007).

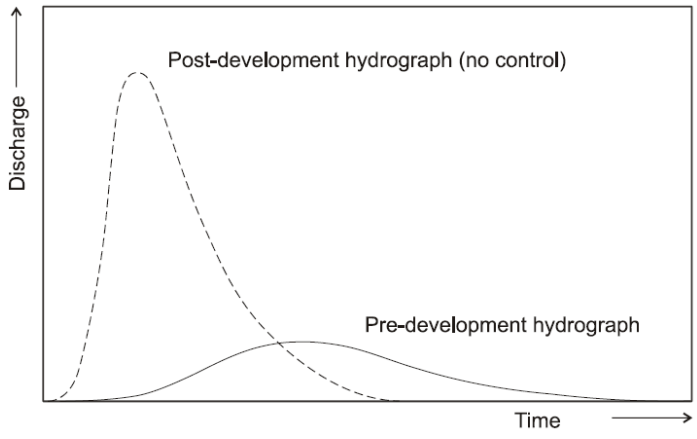


Figure 2.16: Runoff hydrograph before and after urbanization (Marsalek et. al., 2007, pp. 13).

While runoff quality and quantity increase, so is the demand for the visual amenity/aesthetics, ecological protection, and interaction with existing drainage systems (wastewater systems included); therefore, reliance only on the pipe networks create more problems than solutions, especially for the developing countries; which

solidifies the necessity of an integrated approach (Chocat et al., 2007). So, once the end of pipe approach toward stormwater management evolved into an integrated and holistic version that accepts source control and rainwater harvesting approaches as the point of departure (Marsalek and Chocat, 2002, as cited in Wagner & Breil, 2013). Even though BMPs are playing an important role, they are end-of-pipe structural methods therefore they are important but must be integrated into the whole LID-based management program (Lin et al., 2009).

In the traditional approach, the system has to transport the peak flow rates that can be calculated with the Rational Method equation where rainfall intensity (that is defined from the IDF (Intensity-Duration-Frequency) curves) and runoff coefficient (that depends on the impervious surface coverage) are the variables to be defined; however, with detention systems introduced to the system, the duration and peak intensity play crucial roles and with these considerations in mind more than one design solution that supports each other might be needed depending on case to case (Rodríguez-Sinobas et al., 2018).

Since stormwater unavoidably contacts with other possible pollution sources/surfaces, which causes concern for the receiving waters (Marsalek et al., 2014); where a schematic depiction is given in Figure 2.17.

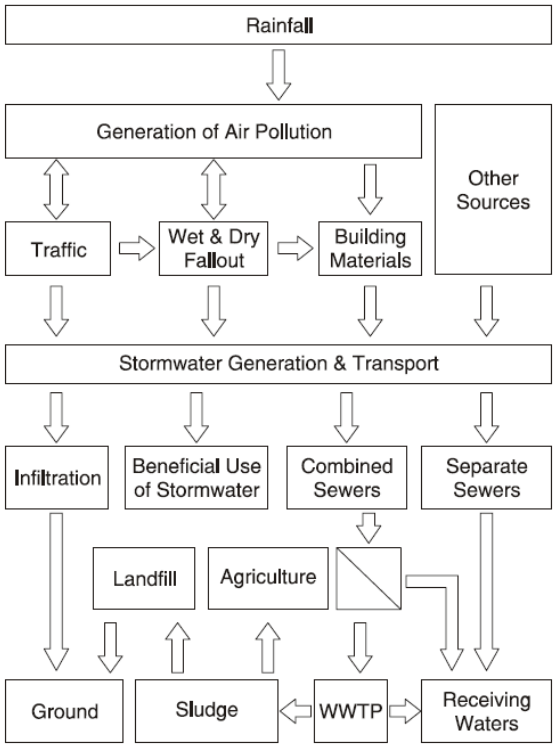


Figure 2.17: Water flows and course of pollution (Marsalek et al., 2014; pp33).

Urban stormwater management systems take impervious areas (that results in increased flow volumes, increased flood frequency and magnitude, faster flood peaks/flashiness, increased runoff frequency, changed base flows), conveyance of water, and receiving environment's condition into consideration (Coombes & Roso, 2019).

When its input, operating, and design aspects are considered, the stormwater application is unique because of these aspects' variability; therefore, understanding and applying the fundamentals depending on the case gives the best results (Davis et al., 2010).

As Matzinger et al. (2014) state, different spatial scales to implement stormwater management control measures to maximize the use while minimizing the negative effects of the impervious surfaces include:

-at the building level: green roofs, local infiltration or rainwater use, etc. (SenStadt 2010);

-at the city quarter level: artificial ponds, filters at manholes, street cleaning improvement, and changing impervious surfaces as much as possible, etc. (Zweynertl et al. 2007);

- at the catchment area level: sewerage management, end-of-pipe treatment, storage in sewers, etc. (DWA, 2005).

Stormwater management techniques applied at the building level can reduce and/or stop the negative impacts on the environment and harvested water can be used directly or indirectly which enables inhabitants to enjoy positive effects directly such as energy and water-saving (Matzinger et al., 2014).

At the city quarter level, it can be decomposed into several components such as street layouts, housing/dwelling units and their functions, etc. As the scale gets bigger, changing factors and their complexity, relationships with each other get complicated as well. Such as at street layout, the solutions are highly dependent on traffic volume, topography, and development density along with other constraints such as climate, soil type, etc. and solutions get more flexible as the traffic load gets lower (Department of Planning and Local Government, 2010). The WSUD strategies that are used in street layouts are mostly: landscaping, pervious pavements, infiltration systems, bioretention

systems, swales and buffer strips, gross pollutant traps, and sedimentation basins (Department of Planning and Local Government, 2010).

Each scale has its own strategies it follows to implement which affects the techniques used as well. In lot scale: harvesting and using rainfall on the site with rainwater harvesting methods such as rainwater tanks and channelizing the overflow to the infiltration systems, making changes in gardening practices, using stormwater for raingarden irrigation, reducing the demand, and increasing the water use efficiency by the means of efficient fittings and installations, and changing impervious surfaces with pervious alternatives; on the block and neighborhood scale: channelizing stormwater to parklands by removing kerbs from some parts of the roads, installing infiltration methods along the roads, and changing impervious surfaces with pervious alternatives; on the catchment scale: rehabilitation of open urban drains or allowing surface flow through swales to promote natural infiltration mechanism, removing gross pollutants within the system (Department of Planning and Local Government, 2010).

There are numerous approaches for source control that varies in relevant scope and complexity; but what they all have in common is restoring local water by the infiltration and detention means and releasing it under control to have a healthier environment (Wagner & Breil, 2013). The gist of the WSUD/LID policies aim to emulate the natural version of the cycles as much as possible with decentralized means which especially emphasizes the importance of early-stage involvement of the stormwater management where costs are lower than the end-of-pipe solutions and much more effective (Li et al., 2018; Radcliffe, 2019). Both structural and non-structural measures to prevent pollution during the processing the stormwater retention of it are called BMPs (Nieuwenhuis et al., 2021; Wagner & Breil, 2013); SUDS is its UK equivalent (Wagner & Breil, 2013); while GI refers to a more conceptual approach that aims the maximization of the ecosystem services that can be provided therefore it includes stormwater but at the same time more than that (Fletcher et al., 2014). As Radcliffe (2019, pp.6) claims, investing in GIs provides triple-win measures through: climate change countermeasures that mitigate the impacts; the protection/restoration of the floodplains and coastal ecosystems; and cost-effective protection solutions that both include system costs and the costs that may arise from the possible extreme events that also results in loss of lives along with economic losses. Also, the improvement of

the GI has a crucial role in reducing the need for end-of-pipe treatment system solutions (OECD, 2014, as cited in Radcliffe, 2019).

There are a lot of practitioners who are inclined more on the mitigation aspect of the subject, yet prevention actually has as much importance in stormwater management (Hoban, 2019). Following measures and means can reduce and mitigate the causes and effects of the stormwater runoffs and reduce the pollution as well: preserving and maintaining waterways and riparian areas, urban design/housing design, erosion and sediment control, permeable paving, rainwater tanks, downpipe diverters, green roofs, street sweeping, litter control, gully baskets, vegetated swales, gross pollutant traps, wetlands, floating wetlands, bioretention (rain gardens), water-smart street trees, proprietary filtration devices (Hoban, 2019); which can be categorized under: permeable areas, infiltration trenches, retention ponds, and natural systems (Bahri, 2012).

The performance and design criteria of stormwater management are: volume, flow, quality, and water conservation and water-use efficiency (Water Sensitive SA, 2020).

2.3.2 Performance and design criteria of stormwater management (Performance measures)

Performance and design evaluation criterion of a settlement that is planned with WSUD includes the measures of volume, flow, quality, and water conservation and efficiency of use.

2.3.2.1 Volume

The ultimate goal of the volume management is to keep predevelopment and post-development quantity the same with a 10 % error margin by harvesting, re-using, and/or infiltrating the stormwater to replenish underground water resources which eventually aims to benefit: decrease urban heat island effect by increasing soil moisture and green areas, protection of the existing downstream stormwater systems, maintaining natural behaviors of hydrological balances, their stabilities and reducing scour while increasing aquifer water storage levels and availability of water sources for use and harvesting (Water Sensitive SA, 2020). The volume mentioned here is different from the flow which causes the floods with the peak stormwater discharge events (Water Sensitive SA, 2020).

2.3.2.2 Flow

Flow management is about controlling the peak stormwater originated discharge flows and/or volume that in the end aims to not exceed the previous 5 years (18.13% AEP or 0.2 EY) for residential areas, 20 years (5% AEP) for the industrial, commercial, and institutional areas' average recurrence interval (ARI) of the storm events that are accepted as the critical threshold of that areas' predevelopment state in order to limit peak flood flows of the minor flooding events (major to rare events requires further precautions such as consideration of the water's path and properties and assets where it passes); which provides the benefits of reducing the infrastructure damage and upgrade costs, reducing property and health losses (Water Sensitive SA, 2020).

> ***Annual exceedance probability*** is defined as: The probability that a given rainfall total accumulated over a given duration will be exceeded in any one year. With ARI expressed in years, the relationship is: AEP = 1 – exp (-1/ARI).
>
> ***Average recurrence interval*** is defined as: The average, or expected, value of the periods between exceedances of a given rainfall total accumulated over a given duration. Some institutions discourage ARI usage and use the equivalent AEP / EY value.
>
> ***Exceedances per year*** is the number of times an event is likely to occur or be exceeded within any given year (Water sensitive SA, 2020, pp.26).

Input flow depends on the surface that the water hits (land use) and rainfall pattern; but after the water enters the stormwater control measure (SCM), its flow is oriented within the system (Figure 2.18) (Davis et al., 2010).

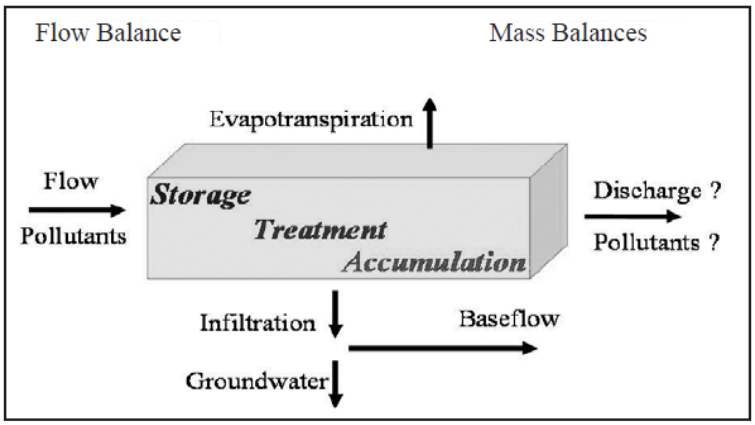


Figure 2.18: Flow and mass balance in stormwater control measure (Davis et al., 2010, pp.4).

2.3.2.3 Quality

The quality measures, as it suggests by the name, target the quality improvement of the stormwater runoff waters (Water Sensitive SA, 2020).

Stormwater is a potential nonpotable water source (that the area of uses can involve irrigation (agricultural, garden, landscape), industry, firefighting, toilet flushing, recreational purposes, and water features (Hatt et al., 2006)) which constitutes about 50-80% of domestic water consumption; which requires less treatment than potable water and wastewater while reducing the erosion and pollution problems that threaten the receiving water bodies in a more economic and sustainable way; however storing and using stormwater also carries its own risk that is associated with human health; however, the primary concern of the SUDS measures is quantity control even though the quality is considered too, the point of departure was the health betterment of the receiving water sources, not public health which requires more strict restrictions (Lundy et al., 2017).

Urban stormwater quality can pose a threat to human health and aquatic life when they contaminate water sources which can carry more than 600 chemical components where about 140 of them are more important (which constitutes trace metals, solids, chloride, dissolved oxygen, pesticides, nutrients (P and N), polycyclic aromatic hydrocarbons and indicator bacteria) (Marsalek et al., 2014). As Marsalek et al. (2014) state, pollution loads are inversely proportional to the development levels of a country because of the infrastructure scheme, urban layout and actions, and many more variables (Figure 2.19 and Figure 2.20).

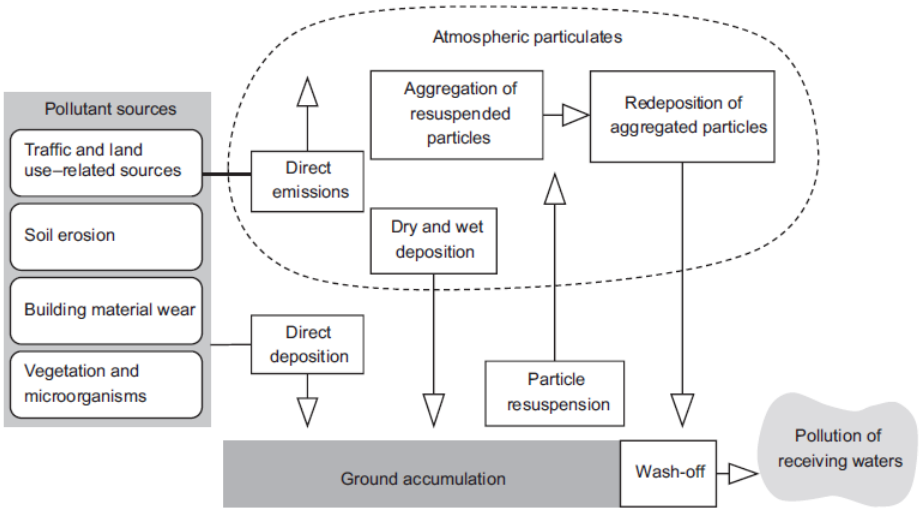


Figure 2.19: Schematic of pollutant process (Goonetilleke & Lampard, 2019, pp.53).

The treatment of these waters has grave importance; therefore, as recommended by the Government of Western Australia Department for Planning and Infrastructure and Western Australian Planning Commission (2008, pp.4; Water Sensitive SA, 2020, pp.8), as compared to a development that does not actively manage stormwater quality, the minimum reduction expected from the system is at least 80% of total suspended solids (TSS), 60% of total phosphorus, 45% of total nitrogen, and 70% of gross pollutants.

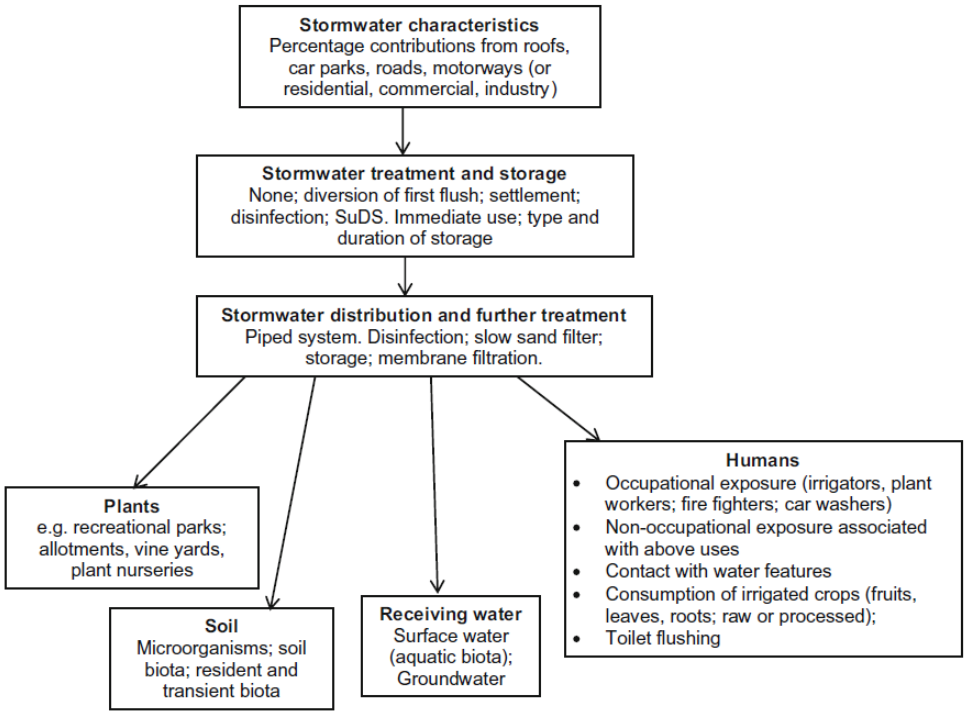


Figure 2.20: Source-pathway-receptor that models the stormwater collection and end recievers (Lundy et. al., 2017, pp.8).

By improving the quality, it is expected to protect coastal environments, maintain waterway amenities, biodiversity, and aquatic health (Water sensitive SA, 2020).

Devices that come into stormwater quality service sizes depend on the peak discharge during the storm which should be between a 4 EY (3-month ARI) and a 1 EY (1-year ARI) storm event; which is designed to control the sediment flow and is expected to bypass larger flows to minimize the damage for the device (Water sensitive SA, 2020).

2.3.2.4 Water conservation & efficiency of use

Water-saving features are installed with the 25% potable (mains) water-saving expectancy when compared with a building that does not have these features which

helps with ensuring improved drought resiliency with dependable sources, increase the flexibility to adapting climatic changes and anthropologic changes, reduces the need for other facilities such as desalination plants and reservoirs, that overall helps with the natural environmental flow for aquatic ecosystems (Water Sensitive SA, 2020).

These systems can be improved by combining them with wastewater recycling types of equipment; however, that scenario requires the consideration of system getting more complex and cost issues must be considered as well (Water Sensitive SA, 2020).

All in all, the collection of the stormwater process is followed by three other steps which are treatment, storage, and finally distribution for relevant uses which in total creates the stormwater management (Hatt et al., 2006).

2.3.3 Stormwater management processes

The water be it wastewater, rainwater, or stormwater, has to be collected, properly treated for the intended use, stored for later use or volume management, and distributed to the end-users or natural environment (Figure 2.21).

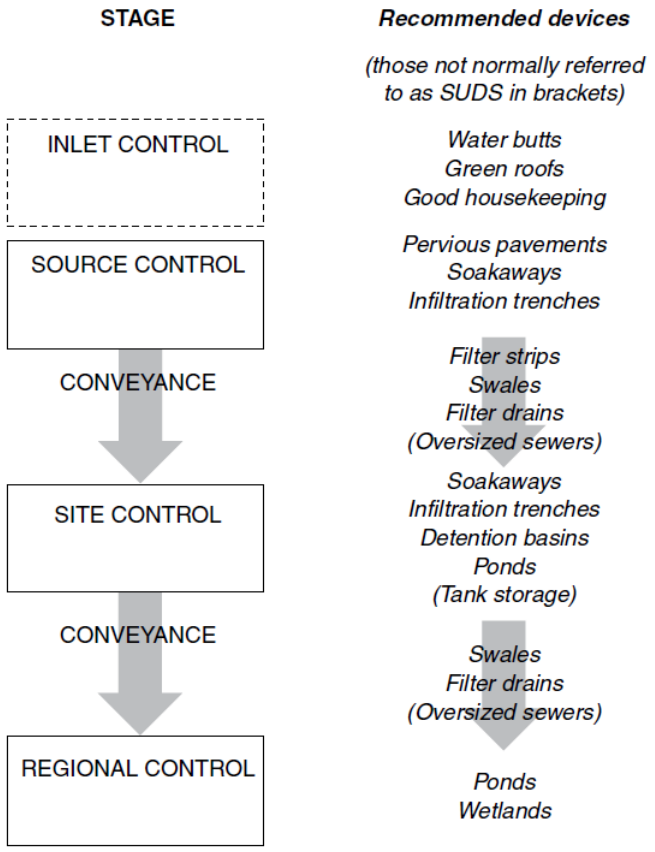


Figure 2.21: SuDS management train (Butler et al., 2018, pp.466).

2.3.3.1 Collection

According to Hatt et al. (2006), accustomed conventional urban drainage systems are used for most of the Australian systems (60% of the studied cases) which include gutters, pipes, and channels even though these systems do not provide treatment amenities they are strong on carrying large amounts of runoff water carriage to the treatment or storage systems), while other 40% of the cases uses natural drainage and pollution control methods such as swales and buffers and at the same time these systems were restricted to address smaller-scaled environments.

2.3.3.2 Treatment

Having combinations of different devices in WSUD are called treatment trains (Goonetilleke & Lampard, 2019). Litter and sediment traps, swales and buffers, ponds, lakes and basins, wetlands, infiltration systems, advanced treatment, and disinfection are the methods that are largely used in Australian systems (Hatt et al., 2006) (Table 2.2).

Table 2.2: Typical WSUD Devices and Target Pollutants (Goonetilleke & Lampard, 2019, pp. 67)

	Target Pollutants								
WSUD System	litter	fine particles	medium sediment	coarse Sediment	coarse sediment larger than 5mm	nutrients	particle-bound pollutants	toxitants	microorganisms
Gross pollutant traps	X				X				
Pervious pavements				X					
Sediment traps/ sedimentation ponds			X	X					
Swales				X		X			
Biofilters/ bioretention basins, rain gardens and tree pits	X	X	X	X	X	X		X	X
Constructed wetlands		X				X	X		X

2.3.3.3 Storage

According to Hatt et al. (2006)'s research, Australian solutions inclined more on the tanks which are followed by ponds and basins which are mostly shaped as reservoirs or dams, that is followed by wetlands and aquifers; as the volume of the water dealt increases, tanks give way to ponds and basins (Hatt et al., 2006).

2.3.3.4 Distribution

Depending on the end-use, distribution methods, and used systems changes which decrease respectively between: various irrigation related uses which are the most common types (underground piping with sprinklers and drippers), dual reticulation, and finally pressure pumping (Hatt et al., 2006). According to Hatt et al. (2006)'s research, stormwater recycling is mostly used for smaller scales, stormwater is used mostly for nonpotable purposes that have a low potential for human contact, and treatment is conducted accordingly but where the possibility of human interaction increases, other treatment means such as advanced techniques that are coupled with disinfection acquires currency due to increased health risk possibilities.

Real-time control operation systems of sewer systems mostly coupled with combined sewer systems to avoid combined sewer overflows (CSO) or overburdening wastewater treatment plants (Colas et al., 2004, as cited in Marsalek et al., 2014).

Water retention, clarification of water, and preventing erosion are the expected main ecosystem services from the floodplains (Radcliffe, 2019); also using the rainwater where it falls reduces energy costs and greenhouse gas emissions for off-site treatment at the same time (Rodríguez-Sinobas et al., 2018) and as Hatt et al. (2006) states, recycling stormwater and consideration of stormwater as an alternative nonpotable water source offers the benefits of improved water quality of received water, decreased potable water demand, ecological improvements, reduction in stormwater pollution which also reduces the need for downstream pollution mitigation measures (therefore its costs) while protecting sources, reduction in volume and peak of stormwater flows (that protects downstream waterways and reduces the need for downstream stormwater infrastructure, and offers recreational amenities.

Water shortage restricts economic development and combining with pollution risks human health while the flipside getting too much water at once to a degree that results in floods and waterlogging are serious problems for the settlements (Radcliffe, 2019)

where comes LID strategies for the rescue which are needed for: determining the proper needs and requirements of each water demand and controls the amount used for water-saving; providing alternative water resources available for use such as rainwater harvesting, reuse of wastewater, desalination of seawater, as well as a source of energy; controlling pollution at the source with quality management; and with quantity management of stormwater, the impacts of floods and waterlogging are prevented (Qian, 2016, as cited in Radcliffe, 2019, pp. 17); improving the quality of water; reducing the costs; preserving the local ecosystems; and improving the landscape (Sharma et al., 2016).

These tools are used in variable combinations in the LID designing process:

1) Reducing the impervious surfaces; which aims to minimize the changes within the UWC after the development process of the area and preserves the natural elements within it to reduce storage needs and help maintain the predevelopment runoff volumes.

2) Disconnecting impervious surfaces that are unavoidable to make; by doing so, additional environmental benefits are expected and hydrological impacts are reduced.

3) Preserving naturally sensitive features of the site; which includes stream buffers, floodplains, wetlands, woodlands, conservation areas, highly erosive and permeable soils, steep slopes, etc.

4) Maintaining the predevelopment time of concentration (Tc); which aims to minimize the peak runoff rate increment by extending the route that flow paths take while decreasing the length of the appointed to runoff conveyance systems.

5) Mitigating impervious surfaces with BMPs; which can provide retention for peak and volume control, water quality control.

6) Favoring permeable areas over impervious surfaces (Prince George's County, 1999).

Efficient management of the stormwater offers multiple social, economic, and environmental benefits such as quantity control of stormwater that reduces flood risks and associated live and property losses, quality control of stormwater so that the receiving environment health is improved, the integrity of urban watercourses are protected against erosion, treating used water for fit-to-purpose uses which decreases

treatment costs and potable water supply costs, effectiveness and economic life of the existing/built infrastructure is increased, reducing impervious surfaces results in reduced urban heat island effect and reduced runoff water; and while offering all these, the visual amenity of the environment gets higher as more green solutions are used (Water Sensitive SA, 2020, pp. 5).

Small scale stormwater treatment solutions are the symbols of LIDs such as bioretention systems, green roofs, etc. that can be implemented as close as possible to the source (Li et al., 2018). The idea behind the changing LID solutions and their combinations lies within the unique needs of each area of application. For example, in Canada, thirteen LID solutions were especially taken into account which also enables the snow water storage as well which are reducing the lot grading, roof discharge to surface ponding areas and soakaway pits, pervious catch basins and pipes, grass swales, wet and dry ponds, wetlands, infiltration basins and trenches, sand filters, vegetated filter strips (Radcliffe, 2019). While on the other hand another approach that is developed for highly urbanized areas where impermeable surfaces cover a great area, in this case for South Korean cities, a Rainfall-Storage-Drain modeling system which was developed by Kim Y.J. et al. (2015b, as cited in Radcliffe, 2019) proposes collecting rainwater from the rooftops in large underground tanks which after the storm fades, slowly discharges water into the sewers and becomes available for the next storm (Radcliffe, 2019). While estimating the behavior of the short and intense storms is important, the ones that have lower intensity but last longer are usually more critical in terms of estimating the detention element need due to their higher runoff volumes (Rodríguez-Sinobas et al., 2018).

The solutions to all these include: rainwater tanks, infiltration systems, pervious pavement systems, bioretention systems (raingardens, bioswales, and bioretention), grass buffers and swales, green roofs and living walls, on-site detention (OSD) tanks, water-efficient fixtures and appliances; using soil as an intermediary medium for infiltration and storage is a common feature in nature-based SCMs which also avails quality improvement thanks to processes such as sedimentation, biological transformation, and filtration (Davis et al., 2010).

2.3.4 Avoidance methods for stormwater pollution

The alternatives developed to counter the potential harms that pollutants and loads carried by stormwaters for the receiving end source: infiltration facilities, swales and ditches, ponds and wetlands, oil and sediment separators, and real-time control operation systems (Marsalek et al., 2014).

Infiltration is achieved through gravel units that are placed underground as percolation basins that have been used for rural areas and brought into urban use for larger scaled applications; but also can be provided with permeable surfaces, drainage swales, and ditches; which helps with the nourishment of the vegetation and create a better microclimatic environment by helping with the maintenance of the groundwater table; at the same time comes with a cheaper cost (drainage with infiltration facilitations) than conventional ones (Marsalek et al., 2014).

Swales and ditches are mostly positioned in the upstream reaches of drainage which makes achieving both quality and quantity measures possible since they allow infiltration to the ground that helps with both flow and quality management, while as the water flows through the turf it gets infiltrated within the soil layer and low flow areas provide solids deposition which overall helps with the enhancement of the quality (Marsalek et al., 2014).

Ponds and wetlands are used as an attenuant cause for drainage flows and treatment solution for the stormwater that helps with the removal of the heavy metals, suspended solids, and nitrogen and phosphorus to an extent (Marsalek et al., 2014). These tools are beneficial when the cost-benefit of them are considered and even though their visual amenities are high since they are not natural water bodies but stormwater treatment facilities, they should be treated accordingly (Marsalek et al., 2014).

Oil and sediment (grit) separators are used for heavily polluted stormwater that comes from truck service areas or highways, or where receiving sources are sensitive and can get highly negatively affected by the polluted stormwater; but these systems are more for increasing the quality of the water relatively when compared with its first highly polluted state since their efficiency lacks due to various reasons (Marsalek et al., 2014).

Methods used for reducing the generation of stormwater and pollution are firstly preserving and maintaining waterways and riparian areas, providing erosion and

sediment control, sweeping streets and litter control, urban/housing designs, rainwater tanks, downpipe diverters, permeable paving, green roofs and walls (Hoban, 2019).

2.3.4.1 Preserving and maintaining waterways and riparian areas

Urban streams are seen as a part of the major drainage system (lakes share a similar fate as well) as the natural drainage lines in the urban drainage system and they are utilized as an alternative source for channeling increased flows that arise from urbanization and must be considered as a part of the integrated stormwater management (Rohilla et al., 2017; Marsalek et al., 2007) but the problem solving is concerned mostly the quality of the water (Marsalek et al., 2007). Since there are many urban areas that are adjacent to water bodies, apart from fluvial flooding, pluvial and estuarine flooding are considerations worth mentioning, as well as sea levels; however, since the water in these bodies is harvested for the urban areas' needs, their flows decrease and can even result in a decrement in flooding in streams while urban waterway flows increases and therefore these factors are into consideration list as well (Coombes & Roso, 2019).

Riparian zones are stream and shorelines' buffer zones and hold the excess runoff water other than the normal stream flow and play a disproportionally important role when their sizes are considered (Dosskey et al., 2010). Intact waterways and riparian areas are excellent treatment systems on their own but once waterways are degraded, it is hard to restore the sensitive balance of them; therefore, development areas should avoid them as much as possible to avoid direct or indirect damages (Hoban, 2019). Open spaces have the advantage of being public open spaces with habitat for natural life while operating as a pollution control mechanism and stormwater management tool; integration of these systems (as well as stormwater streams) into the urban fabric enables benefitting from them while sharing the benefits with other living environments (Rohilla et al., 2017). The linear shape (rather than circular or similar) of them (streams) consolidates the positive effects with increased longer frontage and increased service/impact area and enables more engagement for a longer ground (Rohilla et al., 2017).

Buffers of the water channels must be preserved as they contribute to continuing natural cycle of erosion, accretion, and flood resiliency while adding value to the environment; unless otherwise specified, these buffers should be minimum of 10 m on

each side of the centerline and can be increased for each stream order by 10 meters (Hoban, 2019).

It is highly likely to lakes and water bodies are contaminated with sewage systems in especially dense urbanized areas; therefore, they should be planned with their buffer zones as well to act as their treatment zone and pose as a protective layer to these areas which play an important role in the hydrological cycle (Rohilla et al., 2017).

When recreational spaces are designed to be hand in hand with natural stream systems, their irrigation can be done while enhancing the stream systems' advantages on stormwater management aspect (Rohilla et al., 2017). Also using them for active/passive recreational purposes allows enjoying the visual amenity while harvesting the benefits of habitat supply, stormwater storage, and recycling objectives (Hatt et al., 2006).

2.3.4.2 Erosion and sediment control (ESC)

Erosion and sediment control (ESC) is the term used for the broad principle that is used for restricting the sediment loaded runoff to leave construction sites; when ESC is poor, it affects other stormwater measures in a negative way too (that can smother bioretention systems and others) (Hoban, 2019); however, as McIntosh et al. (2013) states, if the primary impacts can be tracked to construction act, improving ESC, changing the way the land clearing, building on and revegetating may be effective.

Erosion control is prior to sediment control since it handles the problem at the source which does not require sediment to deposit out of runoff but instead avoids it dragging the sediments with the runoff (Hoban, 2019).

Main techniques include consideration of the climate during earthwork activities, good drainage that includes diverting cleaner runoff get around, paying attention to soil cover, stockpile management, sediment fences and basins (Witheridge, 2012, as cited in Hoban, 2019). High-efficiency sediment basins are noteworthy on the matter as their impacts on quality outcomes are significantly improved (Hoban, 2019) (Figure 2.22).

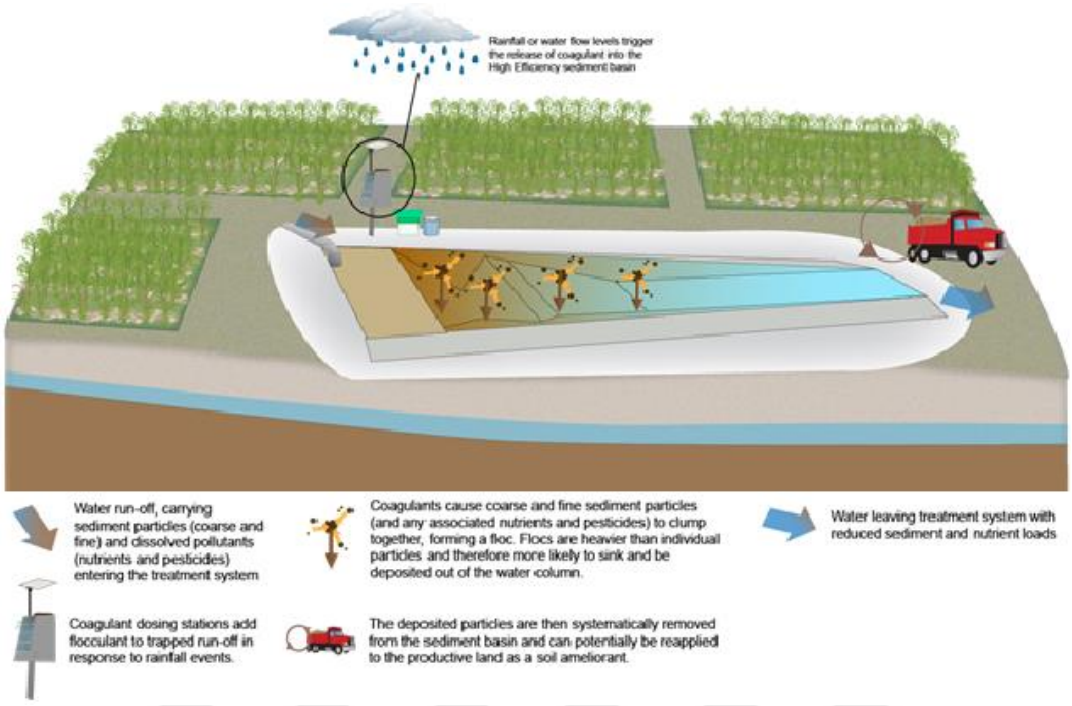


Figure 2.22: High Efficiency Sediment (HES) Basin Scheme (Department of Environment and Science, Queensland, 2018).

2.3.4.3 Sweeping streets and litter control

Street sweeping is done for the general litter loads (which includes dog owners to take care of droppings) and does not aim fine sediment control and related pollutants (Hoban, 2019).

2.3.4.4 Urban/housing design

Urban design patterns play a great role in affecting the distribution of surface types since roads and lots are developed accordingly, decreasing the footprints of the buildings to leave more space for the impervious areas enables not overburdening the bearing capacity of the environment (Hoban, 2019).

2.3.4.5 Rainwater tanks

Rainwater harvesting is easy to install alternative to counter water scarcity even at the household level which can be a complementary solution for long-term infrastructure investment since they are immediate solutions and help with providing alternative water supply and drainage (Bahri, 2012). They are good for both providing alternative nonpotable water sources (that helps with demand reduction) and managing the stormwater runoff volume (they can be used as detention means with controlled gaps

left on top of them); and these systems typically can capture, screen, and store the water; where overflows can be dealt by channeling them to the landscape areas, drainage systems, other stormwater treatment facilities (swales, bioretentions, etc.) (Hoban, 2019).

Rainwater tanks' performance is affected greatly by the local climate, roof area and material (the biggest N source in the stormwater runoff is roof runoff (Gray & Becker, 2002)), tank size, and demand of that water; but all these can be modeled easily with computational methods; however, there is another problem that is associated with rainwater tanks in warm climates which is they are linked with dengue fever vector which is mostly originated from the insect screens (Hoban, 2019).

Maintenance of these systems carry great importance and should include roof, guttering, downpipes, tanks, insect screens, leaf screens, valves, and pumping systems; wherein the end the life of these systems depends on the system used for storage, material, and place of it, how well it is maintained, their construction quality, and intensity of use (Hoban, 2019).

Also, out of the consideration of the health risks that are born from the mosquitos, it is better to design the retention and detention systems in a way that still water is fully infiltrated no longer than 96 hour time period so that the system remains empty between the months November and May which is; out of the same reason, it is not encouraged to design permanent water bodies but where they are unavoidable, they must be designed with the natural predator of the larvae to the degree that satisfies the standards of the Departments of Water and Health (Government of Western Australia Department for Planning and Infrastructure & Western Australian Planning Commission, 2008, pp.4).

2.3.4.6 Detention basins

Detention basins (retarding basins) are instrumentalities to reduce peak discharge by temporarily storing the stormwater which can be sized accordingly to the catchment addressed and when they are designed in regional scale, they offer extra benefits such as visual amenity and even give countenance to sports and the ones used for passive recreational purposes can be coupled with vegetation (Coombes & Roso, 2019) (Figure 2.23).

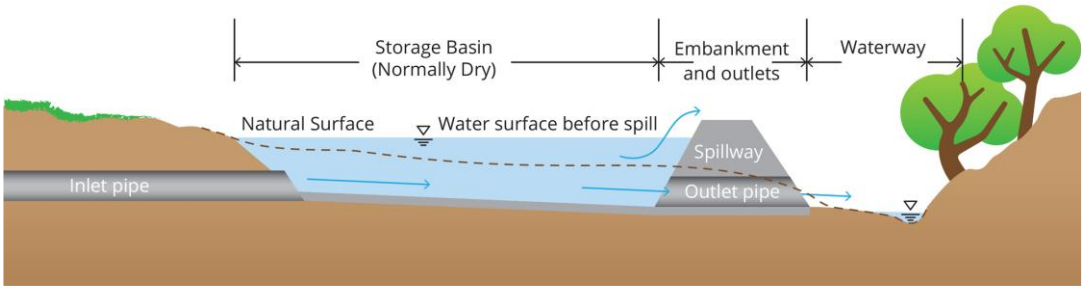


Figure 2.23: Detention basin typical section (Coombes & Roso, 2019, pp. 69).

Their purpose is solely based on peak discharges therefore infiltration, quality management of the water, or harvesting it are not default features but can be achieved when merged with other facilities (Coombes & Roso, 2019).

The design considerations should include the hydraulic behavior of the basin outlet to estimate the flood capacity which should be able to withstand extreme floods when needed, in cases where it is located in-stream, stream conditions and flows discharging through the basin as well as directed urban areas extra considerations (Coombes & Roso, 2019).

As the scale gets bigger they are considered as dams and can pose a threat to settlements downstream of the basin; on the other hand, a settlement can have more than one basin depending on the urbanization of the area and the needs, these should be considered as a whole system rather than individual facilities and evaluations on a basin's failure to results in flowing through the downstream basins and these basins' release schedules and effects on each other should be considered as well (Coombes & Roso, 2019).

2.3.4.7 On-site detention (OSD) tanks

Other than discharging the detained water slowly back at the system, detention systems are similar to retention systems; other than during or right after the rainfall event, they are kept empty so they hold water temporarily and contribute to the drainage system by helping it not getting over capacitated; therefore, they are especially useful where existing infrastructure is aged and urbanization took place during that time as well (Water Sensitive SA, 2020) (Figure 2.24).

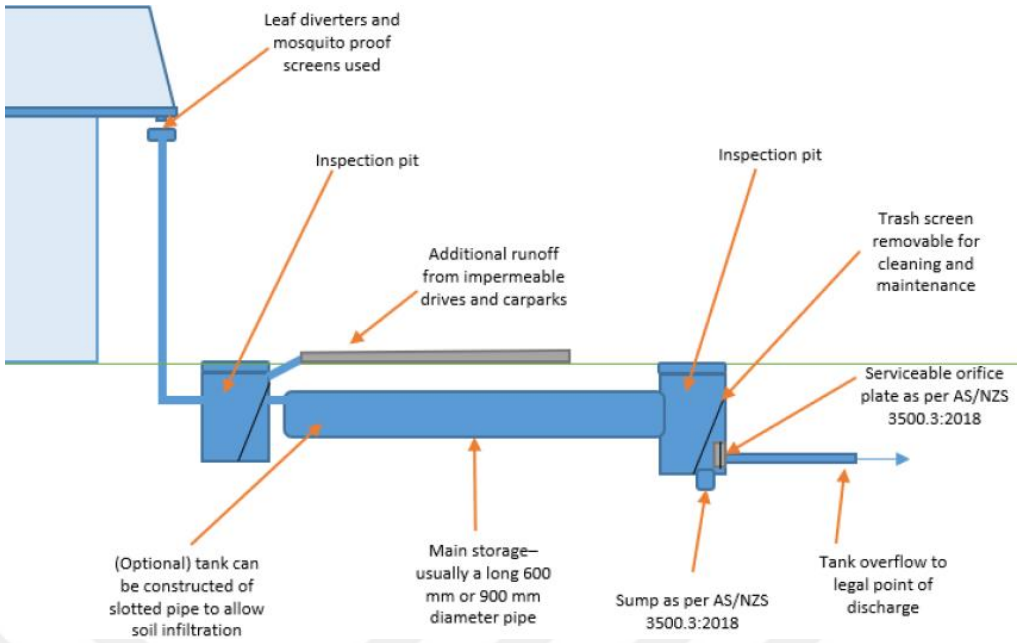


Figure 2.24: Typical underground stormwater detention tank (Water Sensitive SA, 2020, pp.24).

2.3.4.8 Downpipe diverters

Downpipe diverters are integrated into the existing downpipes to help channel rainfall to gardens for irrigation; therefore, their efficacy depends on the soil type and slopes (Hoban, 2019). They are alternative systems for rainwater tanks where space or mosquitos are concerned (Hoban, 2019). Downpipe diverters have a flap valve that can be controlled manually to channel rooftop runoff water for irrigation (for minor rainfall events), and for large storm flows automatically channeled to the drainage system (Hoban, 2019) (Figure 2.25). These diverters should include an angled mesh above them to filter leaves and also its periodic cleaning should not be delayed for the accumulated debris to work them properly (Hoban, 2019).

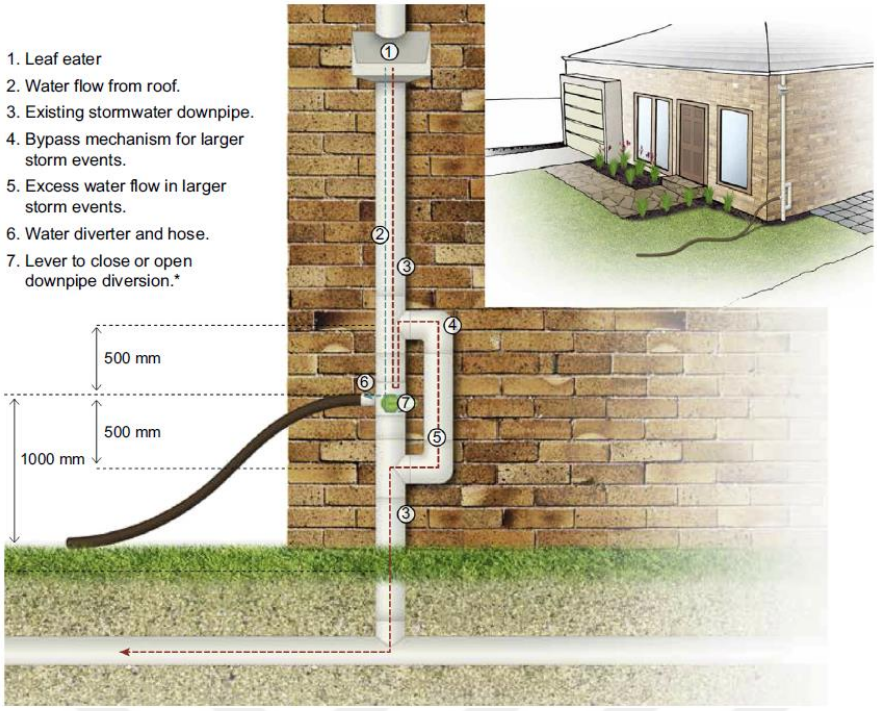


Figure 2.25: Downpipe diverter scheme (Melbourne Water, n.d.).

2.3.4.9 Pervious pavement systems

Roads and streets cover up to 70% of the impervious areas in the urban context (Rohilla et al., 2017). Pervious pavement systems are the systems where the stormwater is percolated through to a subsurface course where it is either infiltrated to the soil (which mimics the natural soil (Monrose & Tota-Maharaj, 2018)), channelized to the drainage system, or stored to reduce the runoff volume (Water Sensitive SA, 2020, pp.17). There are various alternatives for various purposes to water permeate through the pavements (Hoban, 2019). When compared with impervious examples, they have they provide improved water quality and reduced stormwater flow (Water Sensitive SA, 2020).

Permeable pavement systems (PPS) can be consisting single-sized gravels as well mostly in areas with low-traffic loads but the more common application of it includes the lamination of interlocking block paving with porous concrete or plastic grids to increase structural durability and stability to the system which can be applied in gravel or grassed paths, driveways and car parks (Water Sensitive SA, 2020, pp.17). they can include an inbuilt under-drainage system but more common practice is to let the water pass through the subsoil where the water gets infiltrated as it passes through the elements of the system and receives its primary treatment at source (Hoban, 2019) (Figure 2.26).

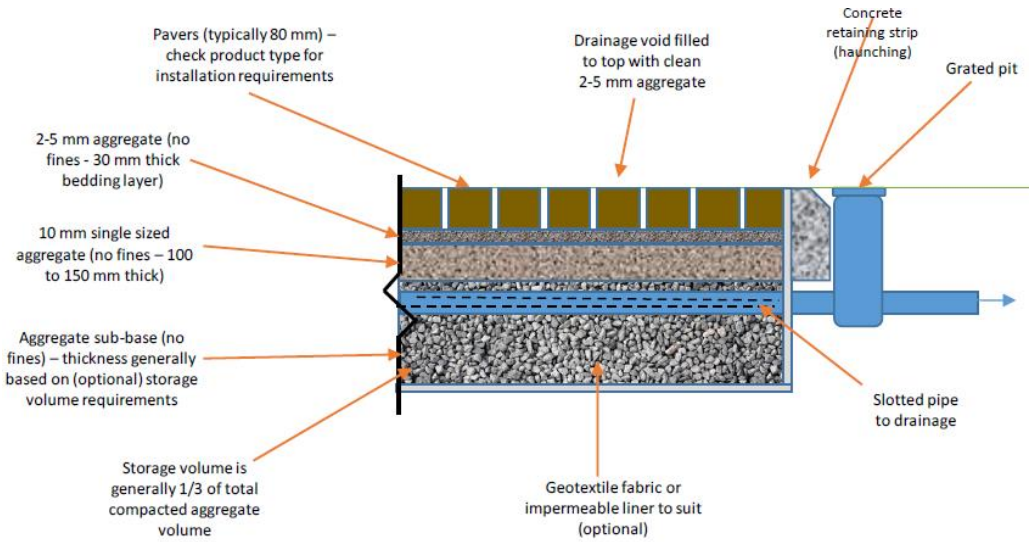


Figure 2.26: Example cross section of permeable pavement (Water Sensitive SA, 2020, pp.18).

These systems are either porous surfaces themselves that the character comes from the material or permeable pavements that are constituted by interlocking paving blocks that can be both shaped in a way to let water through or porous material; other considerations while designing them include planning them accordingly to the traffic load, storage sizes, allocation of them to prevent damages arising from surface flow (Water Sensitive SA, 2020).

Their design can be modified (Figure 2.27) accordingly to the traffic load; but the optimum condition is low traffic areas (such as car parks, pedestrian areas, and driveways) where rainfall can meet the surface directly rather than runoff coming with sediments since those sediments can cause them to lose their edges by accumulation; that is to say, their maintenance is also important to keep their capacity at best (Hoban, 2019).

PPS also contributes to the infrastructure damage management since trees seek water and while searching for it they can outgrow into the pipes, roads, building a foundation so allowing matters (air and water) in and out of the pavement layer, they encourage healthier growth for the trees while improving the quality over the ground (Mullaney & Lucke, 2013) (Figure 2.28).

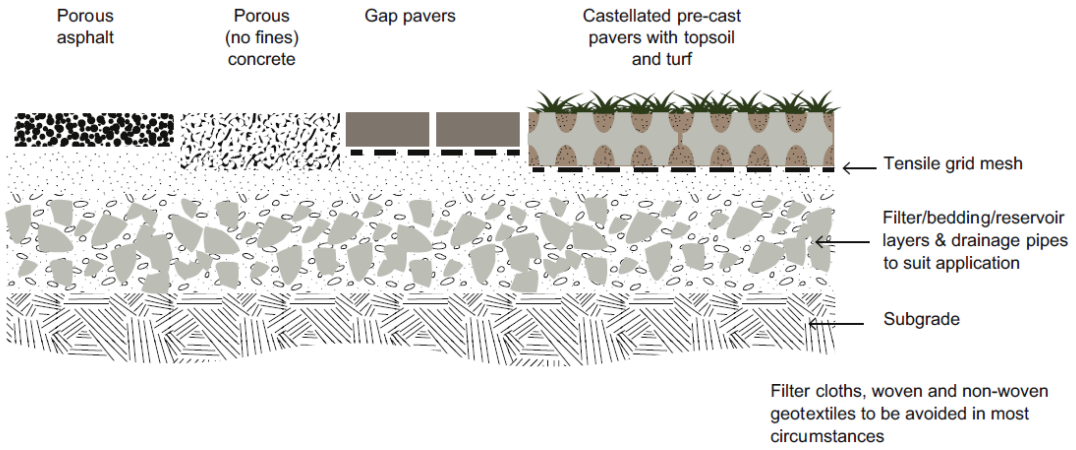


Figure 2.27: Various profiles that enable various purposes (Hoban, 2019, pp. 33).

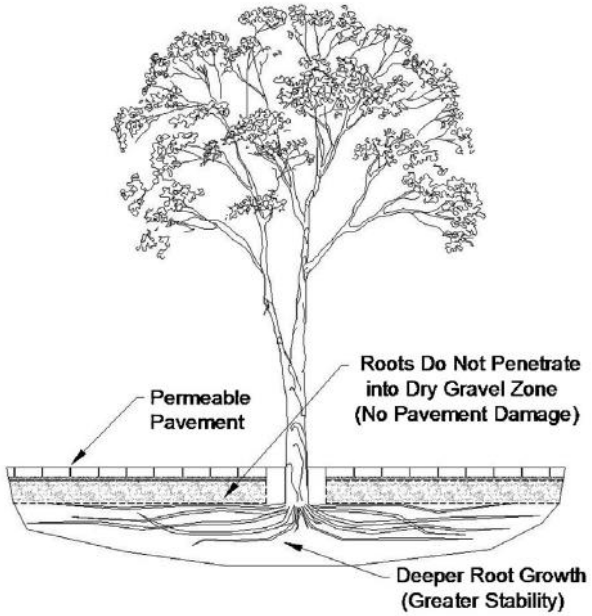


Figure 2.28: Typical street tree and permeable paving configuration (Mullaney & Lucke, 2013, pp. 120).

2.3.4.10 Green roofs and walls

Green roofs provide various benefits to both the building itself and its environment by mitigating urban heat island effects, providing insulation for the building, improving urban amenities and vision, reducing runoff volumes (Hoban, 2019), and can double the life of the roof they are implemented (DC Government Department of Energy & Environment, n.d.-a). They are categorized as extensive and intensive green roofs according to their growing media size as extensive ones are lightweight and shallower in depth so they are preferred on roofs where the slope is up to 33% while intensive green roofs have deeper growing media that can support bigger plants such as trees

and can be used as amenity areas as well (Beecham et al., 2019). The buildings' location, their bearing capacity, accessibility for maintenance, choosing the right plant alternatives, considering the green tissue's needs such as shade, solar aspect of the building, and climatic conditions, having a proper base for the system so the roots and moisture to not affect the building in a negative way are some of the considerations that must be bear in mind before and during the system installation (Hoban, 2019). The runoff quality is affected by the material used in soil (growing media) and roof, additives (fertilizer), vegetation, and atmospheric deposition (Berndtsson et al., 2009) (Figure 2.29).

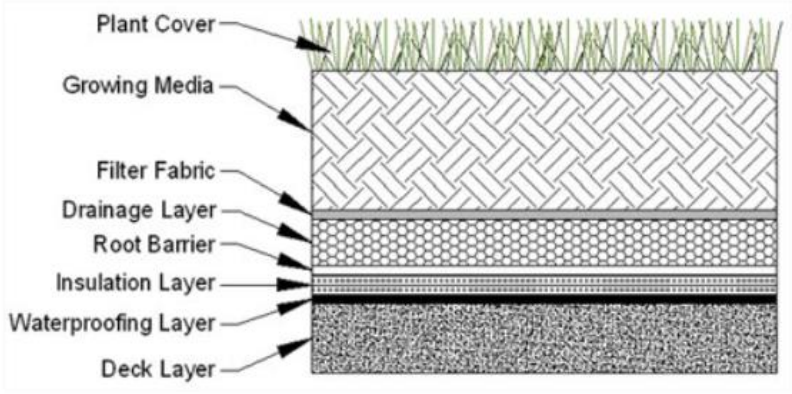


Figure 2.29: Green roof section (DC Government Department of Energy & Environment, n.d.-b).

The green wall is the wide description of vertical surfaces covered with a vegetated layer which are categorized according to the system's installation and growing method which are green façades and living walls; the definition is named in various terminologies such as bioshaders, vertical greenery systems, vertical gardens, vertical landscaping (Beecham et al., 2019).

Green façades are divided into two subcategories which are direct and indirect green façades; direct green façades are the systems where the vegetation is rooted in the ground and entwines the wall whine indirect green façades has a supporting structure/installment like trellises, meshes, cables rather than the building itself (Beecham et al., 2019). Living walls are the systems where the roots are supported with additional envelopes to hold the roots since the vegetation is not rooted on the ground which can be felt pockets, planter boxes that can be categorized by modular or vegetated mats (Beecham et al., 2019). Both walls or façades are all effective measures against reducing the urban heat island effect as well as contributing the insulation of

the building itself by creating microclimate but living walls are a more immediate solution since façades require time to plant to grow up (Beecham et al., 2019).

The maintenance of these systems depends on the system used but can include weed, soil, irrigation system management, and landscape care (Hoban, 2019).

There is also a concept called blue roofs that are not vegetated systems and uses impermeable surfaces (membrane) to hold water either temporarily or permanently which has benefits on its own such as rainfall retention as a nonpotable water source and since it holds runoff water, related consequences can be expected; however, because of the leakage risk factor that they hold, they are rarely utilized (Beecham et al., 2019).

Rainwater harvesting can be performed on green roofs which provides primary pollutant screening for the rainwater along with its other benefits and an extensive green roof retains roughly 50-60% of the stormwater (*Stormwater Management & Rainwater Retention*, 2017).

2.3.5 Mitigating the level of the pollutant of the stormwaters

Gully baskets, gross pollutant traps, vegetated swales, bioretention (rain gardens), wetlands, floating wetlands, water-smart street trees are the main means to mitigate the pollutant loads in urban stormwater (Hoban, 2019).

2.3.5.1 Gully baskets

Gully baskets are made from meshes that are installed existing stormwater gully; depending on the size of the mesh width, they can be used as filters and they are affordable, easy to adapt, keep the collected material dry, and can be replaced when needed; however the most effective use is where littering happens the most such as commercial and industrial areas, city centers, around schools, and recreation areas; but they are not good choices for leaf litter loads in the absence of regular street sweeping or enhanced maintenance (Hoban, 2019). In order to not hindrance the normal working mechanism of the gully inlet to function as a proper drainage function, gully baskets need to have an effectively working bypass system in case it is full; also, their periodic cleaning is important (Hoban, 2019).

2.3.5.2 Gross pollutant traps (GPTs)

Gross pollutants are coarse matters such as coarse sediments, leaf litter, and anthropogenic litter which is mostly constituted by organic materials; and gross pollutant traps (GPTs) are used for capturing these mostly before they reach downstream treatment measures to optimize maintaining measures (Hoban, 2019). GPTs are in various styles and configurations such as floating litter traps, generic sumps, and trash racks and provide pretreatment for harvesting systems which makes them supreme to the bioretention systems in the sense of having less runoff volume loss and more water to harvest: GPTs have a wide range of working mechanism as they can use the hydrodynamic force of the stormwater for the suction to mechanical screening; but they mostly do that in a visible fashion therefore used as an awareness increment medium to draw attention on the matter (Hoban, 2019) (Figure 2.30, Figure 2.31, and Table 2.3).

Figure 2.30: Gross pollutant traps in many forms (Hoban, 2019, pp.36).

There are systems that keep the collected materials in a dry state (which is more preferable, especially in high littering areas) or wet sump style (which is actually more common); however, due to the natural process of organic matters to decompose and create an anaerobic environment that eventually leads leaching, desorption of metal and favorable nutrient content when these systems are not cleaned and stays in wet condition for a while, it is advised to pair wet-sump types with other treatment measures for the nutrient management of the materials for the sake of the receiving environment (Hoban, 2019).

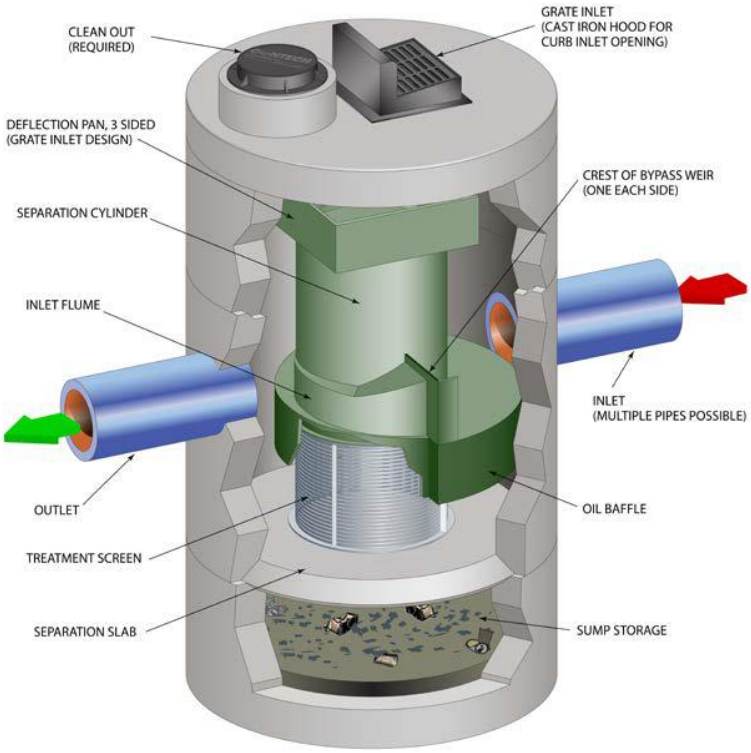


Figure 2.31: Graphic of typical inline continuous deflective separation (CDS®) unit and core components (Contech Engineered Solutions LLC, 2014, pp.2).

Table 2.3: Overall classification of GPTs (Government of Malaysia Department of Irrigation and Drainage, 2004, pp. 2).

Group	Description and Function	Catchment Area Range	Purpose-built or Proprietary
Floating Debris Traps (booms)	Litter capture on permanent waterbodies	>200 ha	Proprietary
In-pit devices	Litter and sediment capture in existing pits	0.1 - 1 ha	Proprietary
Trash Racks & Litter Control Devices	Hard or soft litter capture devices on drains	2 - 400 ha	Usually purpose built from modular components
Sediment Traps	Sediment removal only, on drains	>200 ha	Purpose built
'SBTR' Traps	Sediment and litter capture for drains or pipes	5 - 2000 ha	Purpose built
Proprietary devices	Range of devices, mainly for pipes	2 – 40 ha	Proprietary

2.3.5.3 Bioretention systems (rain gardens, bioswales and bioretention)

Bioretention systems are also known as raingardens (bioretention basins), biofilters, bio-infiltration systems, and bioremediation systems (Water sensitive SA, 2020, pp.19). The term bioretention is mostly used as the ***rain gardens***' synonym (Hoban, 2019; Ahiablame & Chaubey, 2012). However, the term raingarden also refers to the smaller areas that do not require extra permits for the application (ECI, 2015) and even though they work similar, bioretention areas refer mostly more highly engineered areas to promote infiltration such as underdrains, gravel beds, engineered soils, and overflow inlets (*Bioretention Areas & Rain Gardens*, n.d.). Bioretention systems are vegetated soil layers that help both with quality and quantity means of the stormwater while slowing the runoff; they provide stormwater treatment with especially soil layer where the quality of the water is managed with the combination of several means which are: filtration, denitrification, transformation, sorption, exfiltration, and plant uptake (Hoban, 2019), selected plants and their microbial community is a helping factor as well (Water Sensitive SA, 2020) (Figure 2.32 and Figure 2.33).

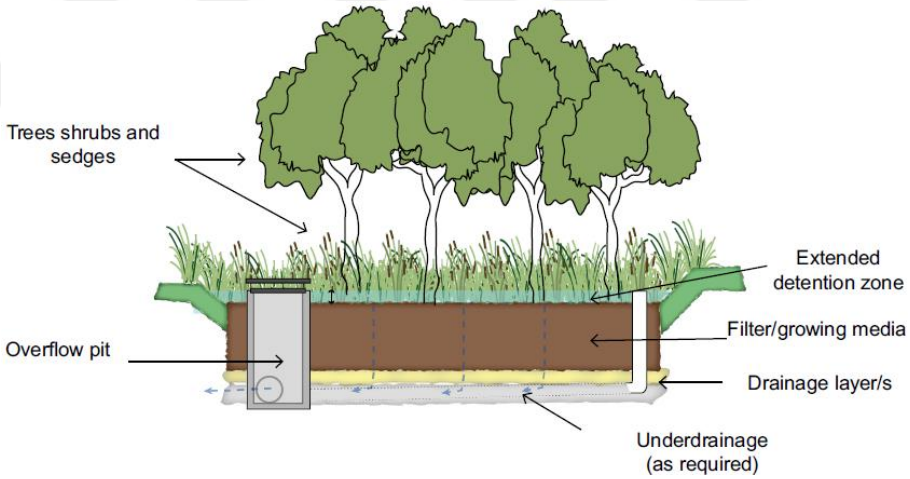


Figure 2.32: A typical bioretention system scheme (Hoban, 2019, pp. 38).

Bioretention basins are helping mediums with the redistribution of the excess water that may be coming from the runoff, rainwater and so, they are shallow compositions and their mechanism helps with assisting the infiltration, reducing peak flows, and recharging groundwater (Water Sensitive SA, 2020). They are flexible in terms of size and shape options which enables them easily adapted into the different settings in the urban scenario but at least 1 m depth for soil and under-drainage (if needed) gives the optimal results (Hoban, 2019). To make their management easier and increase the integration with the urban context, the area of a single bioretention system should be

limited (Hoban, 2019) (Figure 2.34 and Figure 2.35). Typical size range bioretentions range from 0.1 to 2.5 acres but smaller practices such as rain gardens take smaller places (Tennessee Department of Environment and Conservation & University of Tennessee, 2014).

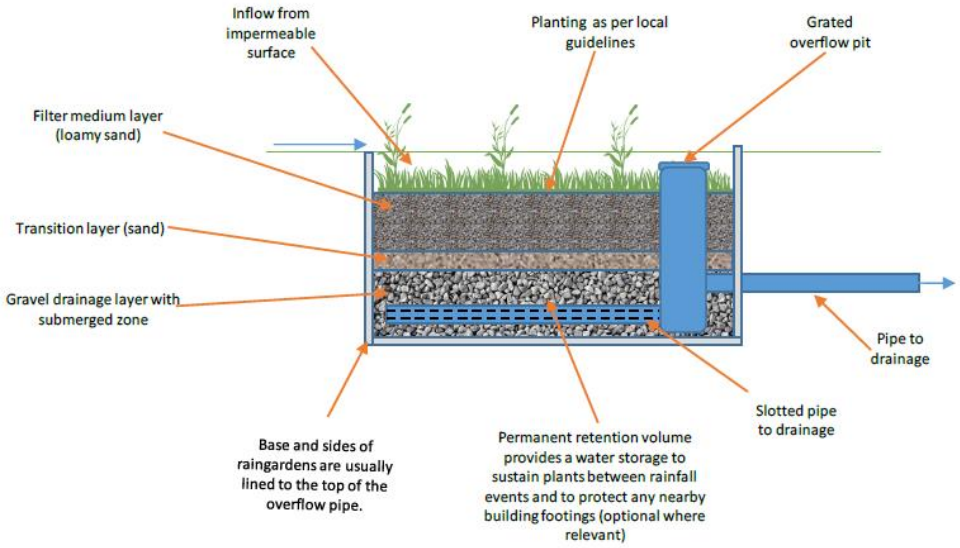


Figure 2.33: Bioretention raingarden (Water Sensitive SA, 2020, pp.20).

Figure 2.34: Bioretention system (raingarden) examples that are fitting into various environments (Hoban, 2019, pp.39).

Figure 2.35: Typical bioretention basin/raingarden (left) and bioretention swale (right) implementations (Water Sensitive SA, 2020, pp.19).

Main concerns involving bioretention systems include proper construction, runoff content, weeds, filter media blockage (that can originate from the sediment, slimes (because of excessive wetness), when constructed upslope they can be smothered with sediments from erosion, vegetation maintenance (long dry periods or regular plant water stress that originates from shallow filter media can kill the plants; but using a saturated zone underneath that also helps with an anaerobic environment and denitrification for the plants, and including organic media (for denitrification reactions and increment of the water holding capacity) to the filter can minimize that concern (Hoban, 2019).

Processes as infiltration and evapotranspiration play an important role in runoff retention (Ahiablame & Chaubey, 2012, pp 4256). Pollutant reduction results of these systems have promising potential, especially with the volume reduction of the runoff that reduces pollutant load. The places where these pollutants are held or transformed are biofilters (for sediment, heavy metals, and P), nitrification/denitrification processes (for N), and plant uptake (Hoban, 2019).

Suspended pavement systems

The term suspended pavement was first used in 2006 by Smiley et al. in a study that was searching different environments for trees that are surrounded by concrete (Marritz, 2014). Suspended pavement (also known as cantilevered sidewalks) is the technology that enables paving on the surface while creating a subsurface void space beneath the concrete or any other paving material to support root growth with filled soil material (Figure 2.36) which makes them perfect for highly urbanized areas, areas with high traffic/pedestrian volume and/or where land is expensive and therefore the field of application areas within the city are streets, parking areas, promenades, public squares, light railways, etc. (Marritz, 2014). They are

functionally equivalent to bioretention systems when bioretention soils are used and versatile LID BMPs (DeepRoot Green Infrastructure et al., n.d.).

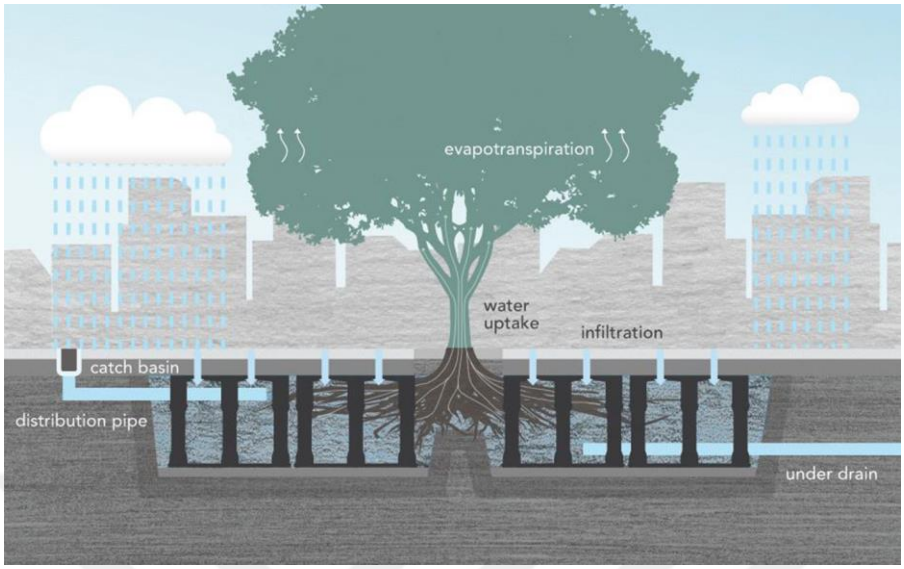


Figure 2.36: Typical section of a suspended pavement system (Innovex, 2019).

They can be filled with bioretention soil mix to hold 20% of its equivalent volume of water and can be coupled with green roofs, pervious pavements, curb cuts, etc. to enhance the stormwater management capacity of the system (Marritz, 2014).

While supporting large tree growth, they also enable interception, evapotranspiration, pollutant uptake, and storage of the stormwater (DeepRoot Green Infrastructure et al., n.d.). They are long-lasting and require easy to no maintenance; and can provide structural support for various surface systems that also includes natural surfaces (DeepRoot Green Infrastructure et al., n.d.) (Figure 2.37).

Figure 2.37: Suspended pavement systems installed in Vancouver (Hunter, 2022).

2.3.5.4 Vegetated swales and grass buffers

Bioretention swales and bioretention buffer strips are similar to bioretention basins in terms of working mechanism but they usually have gravel storage added to store extra water (Water Sensitive SA, 2020).

Swales are drains with vegetation so while conveying runoff which can be an alternative to underground pipe drainage system as a green infrastructure measure, therefore, helps with the urban heat island effect mitigation, they do sedimentation, gear down the runoff flow, and infiltration at the same time which can have various forms that range from turf-lined systems to densely vegetated channels that gives them a wide range of use within the urban setting (Hoban, 2019), but they are mainly used for slowing down the runoff velocity and improving the quality of water; swale systems include bioswales, biofilters, grassed swales, filter strips, and infiltration swales, and vary from grassed channels to dry swales and wet swales (Ahiablame & Chaubey, 2012, pp. 4261). Their working logic is infiltrating the water into underlying soils and filtrating it with a vegetated layer and soil while doing so, which can be improved even further with installed biofiltration trenches underneath that enhances decreasing sedimentation by slowing down the runoff (Hoban, 2019) (Figure 2.38).

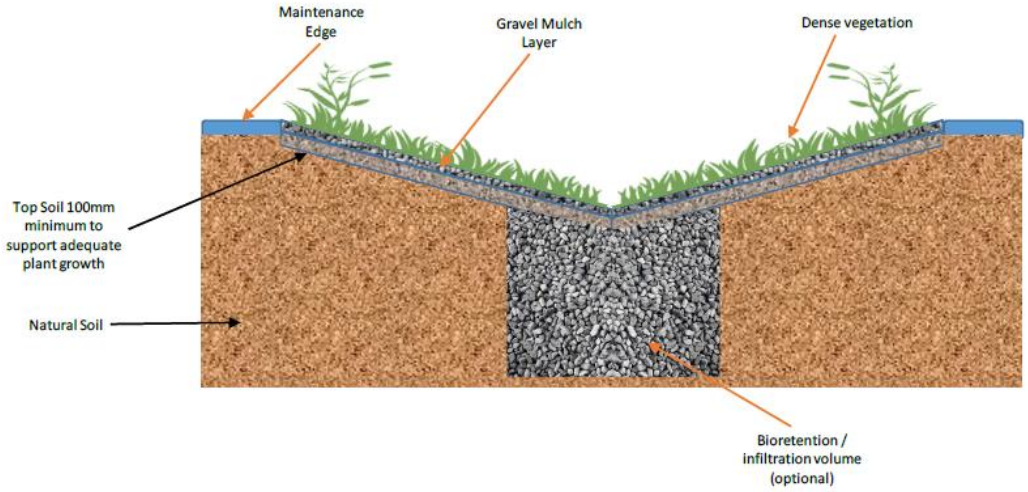


Figure 2.38: Simplified swale diagram (Water Sensitive SA, 2020, pp. 21).

Their irrigation is provided with runoff water and their maintenance can be minimized even further when applied in an open space or parkland (Hoban, 2019).

The best slope range for swales is between 2% to 5%; as the ground gets flatter or steeper, the system needs other coupling additions such as under-drainage in flatter areas and check dams or/and rock linings as a bed scouring measure (Hoban, 2019).

Building swales on where multiple driveway crossovers, both installation costs and maintenance costs arise since the risk of blockage increases as well which results in localized flooding (debris, sediment, waste accumulate also causes that); allowing driveways to cross at grade with swales is preferred instead of culverts (Hoban, 2019). Their performance depends on the configuration of the swales and stormwater composition; but they are quite resilient, can last long ages, and are maintenance friendly which requires mowing, weeding, plant care (depends on type), waste management (debris, litter), and depending on the sediment accumulation, reprofiling (Hoban, 2019).

Main considerations about swales are getting muddy, ponding (when false installations include heavy soil, flat grades, and vehicle traffic rooted compaction), scouring, and erosion (depending on the steep slopes or soil type) (Hoban, 2019).

The systems called ***grass swales*** are basically channels that are enhanced with vegetation; they are shallow and low maintenance but cannot withstand large flows; and they vary from bioretention swales by not having a gravel drainage layer underneath (Water Sensitive SA, 2020).

Grass buffers are also vegetated strips; they carry off runoff water to downstream drainage systems and are effective against coarse and medium-sized sediments' removal (Water Sensitive SA, 2020) (Figure 2.39 and Figure 2.40).

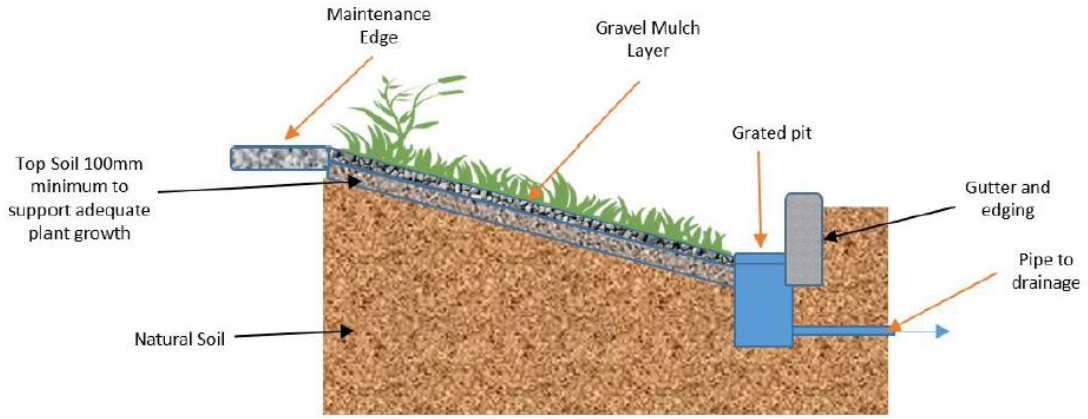


Figure 2.39: Simplified grass buffer diagram (Water Sensitive SA, 2020, pp. 21).

Figure 2.40: Swale examples from Australia (Hoban, 2019, pp.37).

2.3.5.5 Wetlands

Stormwater treatment wetlands are structurally shallow waterbodies that are vegetated which detain stormwater to just about slowly release them afterward which should not be confused with wastewater treatment wetlands since the ones that are designed as a stormwater measure has a variety of sizes because of the changing nature of the rainfall volume changes that changes from place to place and can treat influent water that is richer in variety poorer in the concentration level of the water treated (Hoban, 2019).

The methods that stormwater wetlands use to remove pollutants include forebay sedimentation, adhesion, fine filtrations, biological uptake, and transformation processes; a common configuration consists of a trash rack (for litter), sediment pond (for collecting coarse sediment and easy access for maintenance), a high-flow bypass, an outlet pool (for the regulation of maximum and minimum water levels and in charge of controlling the rerelease of the water after the storm ends which also has a connection with macrophyte zone to minimize the blockage originating from buoyant debris), and a shallow macrophyte zone (Hoban, 2019) (Figure 2.41).

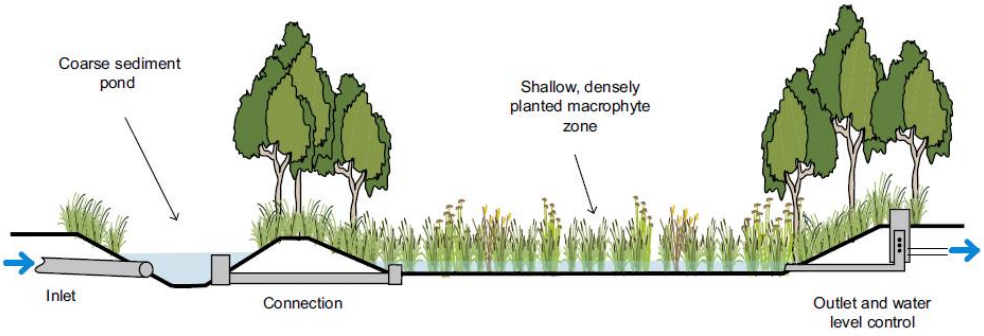


Figure 2.41: Typical configuration of a constructed wetland's scheme (Hoban, 2019, pp. 41).

Various benefits can be enjoyed from the wetlands which include improved water quality, weakened peak flows (they are unlikely to reduce overall volume though), they can be pleasing to look at and inviting, therefore, create many possibilities with engagement and interaction to the design (Hoban, 2019). Their optimum system requirement is being located on low-lying flat land that covers 3% to 10% of the serviced catchment area; when they are smaller than that, their capacity is overwhelmed and get drowned even at small events (Hoban, 2019). These systems are also vulnerable against weeds, roosting and grazing of large bird species, and long-termed dry seasons, chemical stressors that can be in the runoff waters (such as herbicides); also, mosquito problems can be associated with wetlands and must be considered (Hoban, 2019). The scenery is one of the most variable performance criteria since it is hard to install and keep a good plant cover together since they are vulnerable to plant diebacks; but the best approach is to mimic the local natural wetlands as much as possible (Hoban, 2019) (Figure 2.42).

Figure 2.42: Constructed stormwater wetlands (Hoban, 2019, pp.42).

2.3.5.6 Floating wetlands

Floating vegetation rafts are common occurrences in natural settings, so floating wetlands manipulate these groups' size and location and propagate them to the desired location to benefit from them to reduce runoff flow velocity and pollutant load reduction (with their root mass); however, they can attract waterfowls and ibis to an extent that defecation affects water quality badly so in some places, they are removed (Hoban, 2019).

Also, the route water flow takes must be channelized through the dense roots with various methods (such as vertical training roots) to avoid short-circuiting of the flow; another noteworthy point is in shallow systems, the vegetated raft can root the ground and inundated with water level rise which should be considered (Hoban, 2019).

2.3.5.7 Water smart street trees

A simple twist in the design can provide channeling runoff water from the kerbs to the street trees and allows passive irrigation for them (Hoban, 2019) (Figure 2.43). Also, research that is conducted by Denman et al. (2011) shows that irrigation that is made with stormwater provides faster growth for the trees than the trees that are watered with tap water.

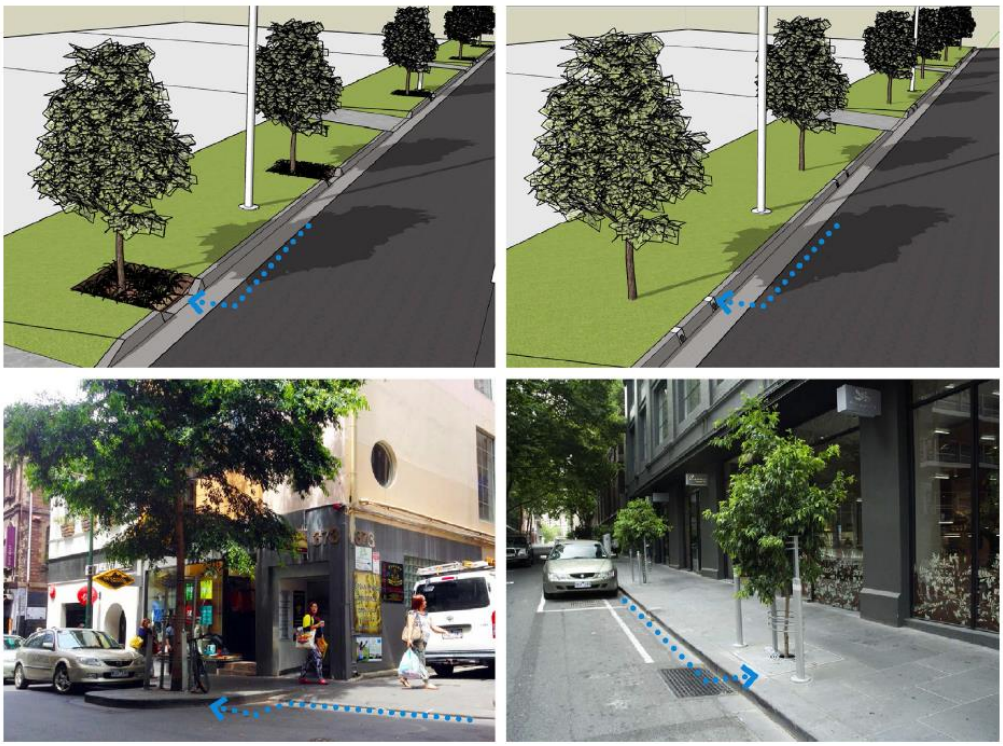


Figure 2.43: Water-smart street tree examples (Hoban, 2019, pp. 44).

Using a single type of LID facility is effective but combining retention and infiltration LID facilities offers the benefit of synergy effect with undeniable results which enables decreasing the runoff flow volume that is channeled to the sewer system (Kwak et al., 2016) (Table 2.5 and Table 2.6). Also, these alternatives can be used in the design and planning on their own or as a complementary component with grey infrastructure: for example, watersheds and wetlands filters and improves water quality which reduces treatment requirements; retention areas reduce drain and pump requirements; watersheds reduce sediment inflows and increase life and efficiency of power plants and reservoirs, etc. (Browder et al., 2019). As discussed so far, WSUD techniques, their application areas, implementation objectives, functions, benefits, constraints, and issues are summarized in the given tables below (Table 2.4, Table 2.5, Table 2.6, Table 2.7, Table 2.8, Table 2.9).

Table 2.4: Potential WSUD options for various development types and scales (BMT WBM Pty Ltd, 2009, pp. 43).

	Option	Household	Medium Density	High Rise	Commercial and Industrial	Subdivision	Urban Retrofit
Potable water demand production echniques	Water efficient appliances	Y	Y	Y	Y	Y	?
	Water efficient fittings	Y	Y	Y	Y	Y	Y
	Rainwater tanks	Y	Y	Y	Y	Y	Y
	Reticulated recycled water	N	N	Y	Y	Y	N
	Stormwater harvesting and reuse	N	N	?	Y	Y	Y
	Greywater treatment and reuse	Y	Y	Y	?	Y	Y
	Changing landscape form	N	?	N	N	Y	N
	Water use education programs	Y	Y	Y	Y	Y	Y
Stormwater management techniques	Sediment basins	N	N	N	N	Y	N
	Bioretention swales	?	Y	N	Y	Y	N
	Bioretention basins	Y	Y	N	Y	Y	Y
	Sand filters	N	?	N	Y	Y	Y
	Swales and buffer strips	Y	Y	N	Y	Y	?
	Constructed wetlands	N	N	N	?	Y	?
	Ponds and lakes	N	N	N	?	Y	?
	Infiltration systems	?	?	N	Y	Y	Y
	Aquifer storage and recovery	?	?	N	?	Y	?
	Porous pavements	Y	Y	?	Y	Y	?
	Retarding basins	N	N	N	?	Y	N
	Green roofs/roof gardens	Y	Y	Y	Y	N	Y
	Stream and riparian vegetation rehabilitation	N	N	N	?	Y	Y
	Water quality education programs	Y	Y	Y	Y	Y	Y

Table 2.5: Commonly adopted WSUD tools/systems and their functions (Sharma et al., 2019, pp. 77).

	WSUD Systems/Technique	Function				
		Flow Rate Reduction	Water Quality Management	Flood Management	Harvesting Potential	Enhancing Amenity/ Biodiversity
House and Streetscape WSUD Approaches	Rain tanks	X		X	X	
	Rain garden	X				X
	Roof systems (green/blue roofs)	X	X	X		X
	Siphonic roof water systems			X	X	
	Gardens, landscape	X	X			X
	Porous pavements	X	X			
	Vegetated filter strips	X	X			
	Swales and bioretention swales/bioswales	X	X	X		X
	Infiltration basins/trenches	X		X		X
	Sand filters		X			
	Buffer strips	X	X			
	Infiltration basins/trenches/ chambers and pipes	X			X	
	Geocellular/modular systems	X	X			
	Underground storage/ vaults	X		X	X	
Development Scale WSUD Approaches	Gross pollutant traps		X			
	Catch basins		X			
	Detention basins			X		
	Ponds and urban lakes		X	X	X	X
	Sedimentation basins	X	X			
	Constructed wetlands	X	X		X	X
	Subsurface wetland		X			X
	Large stormwater storage units	X		X	X	
	Natural aquifers-Managed Aquifer Recharge				X	

Table 2.6: Relationship between various WSUD approaches and management objectives (Hoban, 2019, pp. 27).

	Peak Flow Reduction	Runoff Volume Reduction	Gross Pollutants	TSS/TP/TN	Hydrocarbons	Amenity
Preserve and maintain waterways and riparian areas						
Urban design/housing design	High	High				High
Erosion and sediment control				High		
Permeable paving	High	High		Med	Med	
Rainwater tanks	High	High				
Downpipe diverters	Med	Med				
Green roofs		Med				High
Street sweeping			Med	Low		
Litter control			High			High
Gully baskets			High	Med		High
Vegetated swales	Med			Med	Med	Med
Gross pollutant traps			High	*	Med	
Wetlands	Med	Low		*	Low	High
Floating wetlands				*		
Bioretention (rain gardens)	Med	High	Med	Med	Med	High
Watersmart street trees	Low	Med		Med	Med	High
Proprietary filtration devices			Med	Med*	Med*	

TN, total nitrogen; TP, total phosphorus; TSS, total suspended solids; *, highly variable.

Table 2.7: Structural BMP functions and their benefits (Collett et al., 2013, pp. 138).

● primary function ◯ secondary function △ incidental + additional benefit			runoff reduction							peak flow reduction		improved water quality			
												biological treatment		physical treatment	
			rain garden	rainwater harvesting	permeable paving	green roof	trees	bioretention cell	infiltration structure	vegetated detention basin	wet ponds	constructed wetlands	vegetated swales	sand filter	filter strip
hydrologic funtions	stormwater quantity	retention	●	●	●	●	●	●	●	△	◯	△	△	◯	◯
		infiltration	●	△	●		◯	●	●	△	△	△	△	◯	◯
		detention	◯			◯	◯	◯	△	●	◯	△	◯		◯
		evapotranspiration	◯	△		●	●	●		◯	△	●	●	△	◯
	stormwater quality	sedimentation	●	△	◯			◯		●	●	●	●	●	●
		filtration	●	△	●	●	△	◯		△		●	◯	●	●
		straining	◯	△				◯		△		●	●		●
		extended treatment (chemical)	◯			△				△	△	●	◯	◯	
		extended treatment (biological)	●			●	●	◯		△	△	●	●	●	△
additional benefits (ecosystem services)		provides wildlife habitat	+				+	+		+	+	+	+		+
		aesthetic quality	+	+	+	+	+	+		+	+	+	+		+
		stores runoff for alternative use		+							+				
		provides additional permeable surfaces			+	+	+	+	+	+					+
		improves air quality	+		+	+	+	+		+		+	+		+
		provides educational opportunuties	+		+			+	+			+			+

Table 2.8: Potential constraints associated with WSUD application (Department of Planning and Local Government, 2010, pp. 2-4).

WSUD Measure	Potential constraints								
	Steep site/catchment slope	High water table	Shallow bedrock	Land availabilty limitation	Installation underground is required	High sediment input	Requires pre-treatment	Hydraulic head loss limitation	Installtion in tidal system
Sediment traps	●	●	○	●	○	○	○	○	○
Gross pollutants traps	●	○	○	○	○	○	○	△	○
Filter strips	△	△	○	△	△	●	●	●	△
Grass swales	△	△	○	△	△	●	●	●	△
Bioretention systems	△	○	●	●	●	○	●	△	○
Infiltration trenches*	△	△	△	○	●	△	●	○	△
Rain Gardens	△	△	△	△	○	△	●	○	△
Pervious pavements	△	△	△	△	●	△	●	○	△
Sedimentation basin	○	○	○	△	△	△	●	○	○
Constructed wetlands	△	○	○	△	△	○	●	○	○

●: Generally not a constraint, ○: Constraint may be overcome with appropriate design,
△: Constraint may preclude this measure, * Pretreatment required to remove litter and sediment

Table 2.9: WSUD technologies, functions, application areas, and issues (adapted from Kuller et al., 2017, pp. 268, 277).

WSUD technology	Function	Footprint	Application scale	suitable urban environments	retrofit difficulty	issues
Aquifer storage and recovery	c, e, f	Small	N, B	Low density	Low	Needs advanced pre-treatment
Bioretntion / raingardens	a, c, d, e, f	Flexible, small to large	L, S, N, B	Flexible: streetscape, gardens, parks.	Low	Clogging, low resilience against draught, sanitation and tropical disease vectors
green roofs	a, d, e, f	N/A	L, S, N, B	Rooftops	Low	Needs irrigation in dry climates, little experience in dry climates, not taken up in models
green walls / living walls	a, d, e, f	N/A	L, S, N, B	Walls	Low	See: green roofs
Infiltration systems	c, e	Small	L, S, N, B	Dense urban areas, along roads and highways	Moderate	Clogging, soil contamination, system failure
Oil and sediment seperators	e	N/A	S, N, B	sewer inlet	Very low	
Permeable pavement	a, c	N/A	L, S, N, B	Any paved area	Low	High maintenance and system failure
Ponds and lakes	a, d, e, f	Medium to large	N, B	Public open space, parks	High	Bank erosion, algal blooms, flocking birds, mosquitoes, sanitation, tropical disease vectors

Table 2.9 (continued): WSUD technologies, functions, application areas, and issues (adapted from Kuller et al., 2017, pp. 268, 277).

WSUD technology	Function	Footprint	Application scale	suitable urban environments	retrofit difficulty	issues
Sand filters	e, f	Flexible, above or underground	L, S, N, B	Any	Very low	Clogging, high maintenance
Screens / GPTs	e	N/A	N, B	river, stream, sewer	Very low	
Sediment basins	e	Flexible, small to large	S, N, B	Flexible: streetscape, gardens, parks.	Moderate to high (depending on size)	Sanitation and tropical disease vectors
Swales	b, c, d, e	Dependant on hydraulics	S, N	Streetscape: median strip, carpark	Low	High maintenance, sanitation, tropical disease vectors and mosquitoes when inundated
Tanks	a, b, d, e, f	Small, above or underground	L, N, B	any	Very low	Water quality, trade-off between flood protection and water supply
Wetlands		Large	N, B	Public open space	High	Mosquitoes, Clogging, low resilience against draught, sanitation, tropical disease vectors

L: lot, S: street, N: Neighbourhood, B: sub-basin/district.
a: retention/detention b: conveyence c: infiltration d: evapotranspiration e: treatment f: harvesting

2.4 WSUD Projects Around the World

2.4.1 Valdebebas, Spain - new development example

Valdebebas which is located in Spain and newly developed area, offers knowledge about a district-wide approach for the newly developed areas since the solutions are constructed in a large area which covers 1065 ha area where half of it is preserved for green areas, projected with 50000 people estimated population (Rodríguez-Sinobas et al., 2018). The project was implemented in 2 stages because of the economic crisis in 2010 that brought a halt to the implementation (Figure 2.44) but thanks to that, more experience was gained and the project became more sophisticated: permeability capability of the parks improved and increased from 53% to 65% in stage 2, storage capacity increased, used approach evolved to analyze rain water movement, climate, topography, porosity of surfaces, etc.; therefore, the shared results shows the end result which is after the 2nd part is completed (Rodríguez-Sinobas et al., 2018).

Figure 2.44: Valdedebas urban parks with SuDS (Rodríguez-Sinobas et al., 2018, pp.406).

Building density increased in order to ease public transportation (to reduce GHG emissions) and create more green spaces (where it is increased to 50 % of the area when compared with the neighboring development area which has 31 % green areas. Alternative transportation methods are encouraged to support decreasing GHG emissions by providing bike routes, train, subway, and bus alternatives, also green areas are connected to encourage walking (Rodríguez-Sinobas et al., 2018).

Even though recycled water is used for irrigation, that source is also limited and required further water efficiency measures such as preferring drought-resilient plant selection, using subsurface drip irrigation that is automated by the central weather station, and applying these systems to all planned park and garden areas (Rodríguez-Sinobas et al., 2018).

The traditional system used in stormwater collection was conveying it to the sewer system (Figure 2.45) but changed into considering stormwater as a valuable source (Figure 2.46) (Rodríguez-Sinobas et al., 2018).

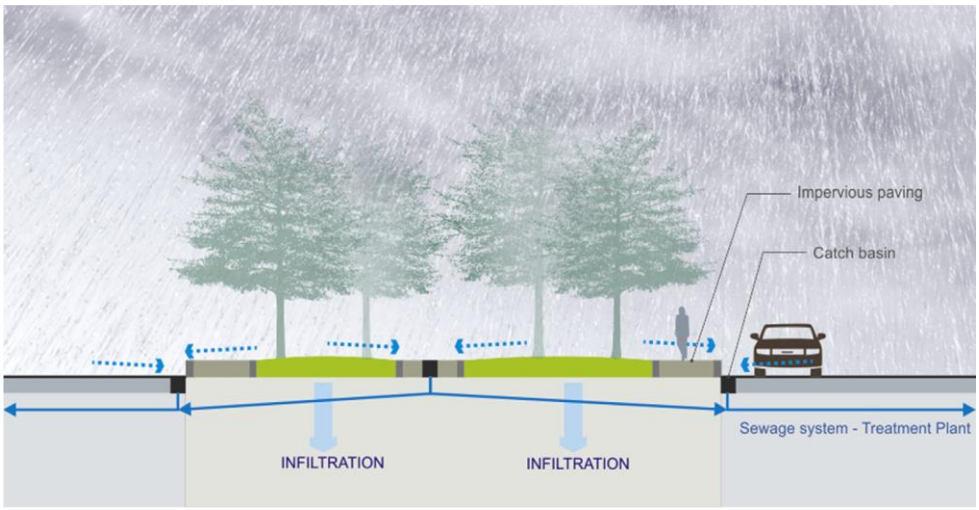


Figure 2.45: Conventional stormwater management scheme (Rodríguez-Sinobas et al., 2018, pp. 405).

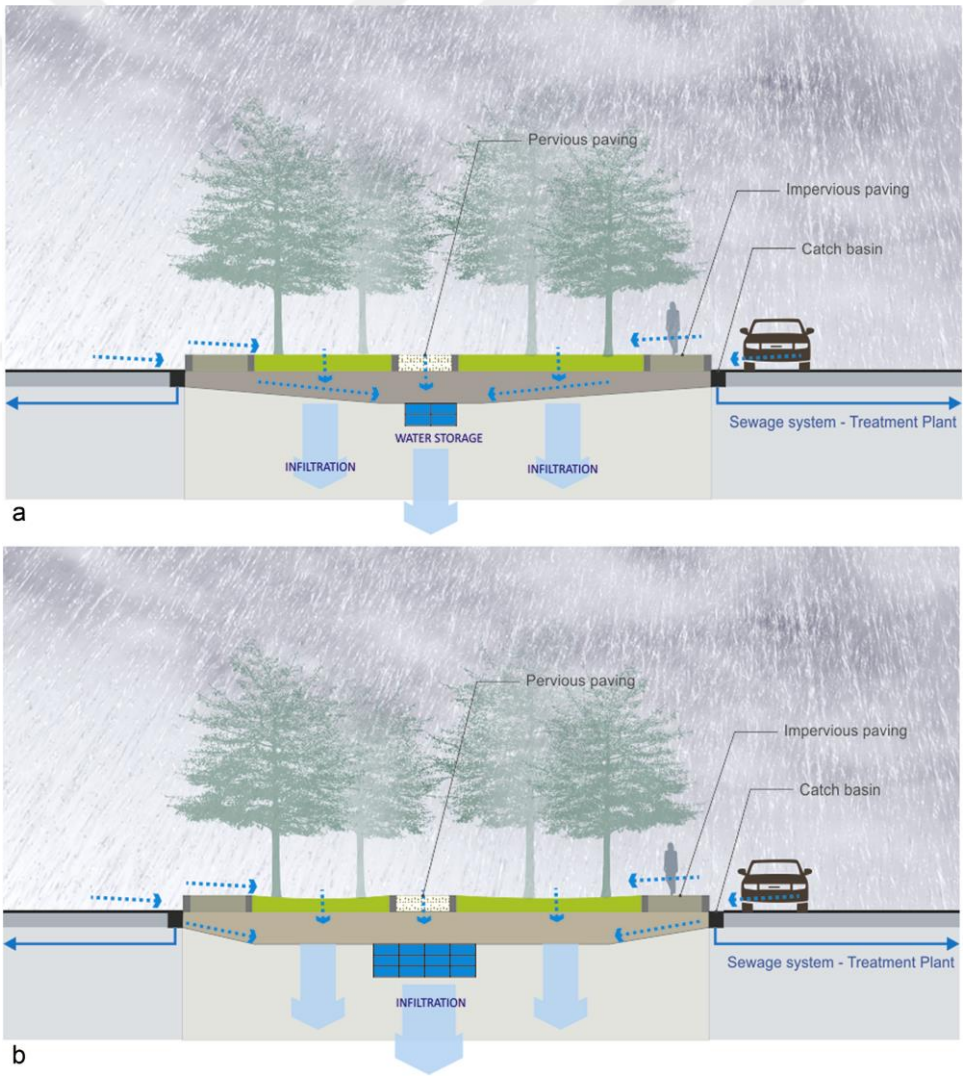


Figure 2.46: Scheme of SuDS systems (a) installed in 2009, and (b) installed in 2017 (Rodríguez-Sinobas et al., 2018, pp. 407).

General capturing the water at source and using it there is one of the main objectives; it nourishes local habitat and replenishes valuable underground water resources while decreasing the off-site treatment costs and energy. To capture and use stormwater, pavements are sloped toward the planting areas and pervious surfaces preferred where foot traffic was less intense; which then increased 12% more and became 65 % of the surface area during the 2nd stage (Table 2.10). Storage capacities are also enhanced with the intention of monitoring infiltration and rainfall, local climate, soil, and environment in general (Rodríguez-Sinobas et al., 2018).

Table 2.10: Surface areas for each land use in every analyzed stage (Rodríguez-Sinobas et al., 2018, pp.408).

Zone	Impervious pavement (m^2)	Pervious pavement (m^2)	Planted surface (m^2)
Stage 1	86279.83 (47.08%)	21563.58 (11.77%)	75407.46 (41,15%)
Stage 2	20212.51 (34.95%)	14356.09 (24.83%)	23257.07 (40.22%)

Since traditional stormwater management disregards the captured stormwater's effects on the natural system, therefore the peak flow rates that the system has to transport is calculated by defining the runoff coefficient (that depends on impervious areas) and rainfall intensity (that is defined from IDF Curves (Intensity-Duration-Frequency Curves) for the site time of concentration); but when detention systems are introduced to the system, it gets complicated and the duration of the storm gains importance as well (Rodríguez-Sinobas et al., 2018). While for urban systems, intense storms are important even when they do not last long, but for detention systems, due to the consideration of the storage capacity assessment, longer storms gain importance even when they have lower intensity (Rodríguez-Sinobas et al., 2018).

Data series from 1920 to 2014 were used to estimate annual average rainfall and accordingly, the designed system should be able to compete with storm events without stressing the conventional network (Rodríguez-Sinobas et al., 2018). Also, the time needed for the system to absorb and store the runoff water is considered as a key element which should be half empty in 24 has Woods-Ballart et al. (2015 as cited in Rodríguez-Sinobas et al., 2018) recommends (Rodríguez-Sinobas et al., 2018). Since volume management is considered along with peak flows while designing SuDS; therefore, for the 1st stage, storm duration is considered 100 min with 2 years return period similar to rainfall no2 in Table 2.11 to prevent overflowing the existing

conventional system outside the parks; and stage 2 is planned by analyzing 10 min interval events for a full year and the year 2007 used as the model and 6 design storms were used for the 2nd stage (Table 2.11); peak flow for the storages and existing SUDs compared with hypothetically implemented CuDS (Rodríguez-Sinobas et al., 2018).

Table 2.11: Design storms for the design of the stormwater management systems of phase 2 parks in Valdebebas (Rodríguez-Sinobas et al., 2018, pp.407).

Rainfall nº	Return period (years)	Storm time (min)	Intensity (mm/h)	Cumulative precipitation (mm)
1	2	1440	0.7	17.2
2	10	10	67.8	11.3
3	10	15	55.7	13.9
4	10	30	36.5	18.2
5	10	60	21.7	21.7
6	20	10	78.6	13.1

The land use is divided into 3 categories in terms of runoff coefficients: impervious pavement (c = 0.9), pervious pavement (c = 0.6), and planted areas (c = 0.2); and the area each category covers are as given in Table 2.10 (Rodríguez-Sinobas et al., 2018).

According to calculated IDF curves for climatic scenarios and it is accepted that for urban basins, the time of concentration is equal to 10 mins and in the worst-case scenario, the storm's duration equals the concentration time (Rodríguez-Sinobas et al., 2018).

The drainage system simulation has been done to test overloading possibilities: results of calculations and observations show that SuDS were significantly superior to CuDS (Table 2.12); where hypothetical scenarios for CuDS were created for comparison (Rodríguez-Sinobas et al., 2018).

Table 2.12: Peak flow (m^3/s) and volumes (m^3) discharged to the conventional sewer network during the pilot event (Rodríguez-Sinobas et al., 2018, 409).

Return period	Storm time (min)	Peak flow		Volume	
		CuDS	SuDS	CuDS	SuDS
10	10	0.46	0	338.3	0
2	1440	0.01	0	496.5	0
10	15	0.45	0.05	460.3	24.5
10	30	0.3	0.16	611.9	108
10	60	176.30	129.5	680.8	186.5
20	10	529.2	32.8	388.8	20.2

As it can be seen in Table 2.12 as well, the reduction flow and volume compared with CuDS, also SuDS channelizes water for infiltration areas and reduces outflow rates (when compared with inflow rates) of the sewage at least 74% among the calculated parks and the total of the system; all in all, SuDS relieves the sewage system to work more conveniently (Rodríguez-Sinobas et al., 2018).

As a result of reliving the municipal system, economic, energy, and GHG emissions were benefitted from the situation as well (Rodríguez-Sinobas et al., 2018). The water collected from the system that did not channelize to the sewage is accumulated for 9269.7m^3 which is used for aquifer recharging and moisturizing the soil (if passive irrigation of SuDS can be confirmed, it means irrigation water demand decrement as well which in the end brings more benefits), also it is expected to increase the effects of the SuDS systems with them decreasing the effects of the climate changes (Rodríguez-Sinobas et al., 2018).

SuDS provides 10% energy conservation and GHG emission decrease; also, SuDS are cheaper to construct and maintain (Rodríguez-Sinobas et al., 2018).

Table 2.13 which has been prepared for a better understanding of SuDS working under different climatic conditions for a better grasp in climate change perspective which shows SuDS provides resiliency to the system and increases its adaptability of it (Rodríguez-Sinobas et al., 2018); and Table 2.14 has been prepared for the scenarios differentiating soil permeability (K) and runoff coefficient (C); as a result, the system is more sensitive towards the C (Rodríguez-Sinobas et al., 2018).

Table 2.13: Peak flow (l/s) and stormwater volumes (m^3) conveyed under the climatic scenarios considering various stormdesign (Rodríguez-Sinobas et al., 2018, pp.414).

Design	Scenario	Return period (years)	Storm time (min)	Peak flow (l/s)	Volume (m^3)
Without SuDs	Current	10	10	88.1	64.6
		10	30	57.8	121.1
With SuDS	Current	10	10	0	0
		10	30	22.6	17.7
	A1B	10	10	5.0	3.2
		10	30	38.0	37.5
	A2	10	10	20.3	8
		10	30	50.7	51.7
	B1	10	10	23.9	9.4
		10	30	32.3	29.4

Table 2.14: Peak flow (l/s) and volumes (m3) conveyed to the sewage system in park 21, considering different values for the runoff coefficient and soil permeability (Rodríguez-Sinobas et al., 2018, pp.414).

Return period	Storm time		Without SuDS		SuDS K = 0.036 m/h; C = 0.9		SuDS: K = 0.036 m/h; C = 0.2		SuDS: K = 0.0036 m/h; C = 0.9	
Peak Flow	Peak Flow	Volume	Peak Flow	Volume	Peak Flow	Volume	Peak Flow	Volume	Peak Flow	Volume
10	10	10	88.1	64.6	0	0	0	0	0	0
2	1440	1440	1.1	98.8	0	0	0	0	0.5	10.1
10	15	15	87.3	82	12.5	5.2	0	0	14.6	6.9
10	30	30	57.8	121.1	22.6	17.7	0	0	25.1	25.3
10	60	60	34.4	133.8	17.7	29.6	2.3	1.3	25.1	42.3
20	10	10	99.8	74.7	4.4	3	0	0	6.2	4.5
Representative event 3/27/2007			73.7	2082.1	18	237.7	6.4	49.5	36.9	773.3
Year 2007			73.7	94.4	18	19.5	0	0	21.9	27.6

The reduction of the water conveyed to conventional urban drainage system with SuDS was more than 41% in both stages when they are compared with CuDS; costs were reduced significantly where the unitary cost (V/m^2) of building and drainage infrastructure decreased from 6.03 to 1.06 on stage 1 SuDS and 1.39 on stage 2 SuDS with the extra benefit of reduced water treatment surcharges (Rodríguez-Sinobas et al., 2018).

It is advised to work with different climate scenarios and several rainfall events (Rodríguez-Sinobas et al., 2018).

2.4.2 Melbourne, Australia – the city as a catchment approach

The City of Melbourne, the city center of the 31 municipalities of the metropolitan area 'Melbourne' which is the second most populous city in Australia, is at the junction point of 2 rivers was facing a prolonged period of drought, water sources getting polluted by stormwater runoff, and population increase; and in the end adopted WSC approach and implementation of WSUD techniques which resulted in becoming a successful example for the cities with similar concerns (Mitrotta, 2011).

Regarding stormwater as a negative element in urban contexts since it causes floods in conventional systems results in pollution increase, wasting; but the solution is despite getting rid of it as quickly as possible, collecting, treating it for fit-to-purpose needs and using it; in Melbourne's case, it was even satisfactory source of water for local demands. Stormwater harvesting principles are inspired by the WSUD key

principles established in the Urban Stormwater - Best Practice Environmental Management Guidelines (CSIRO, 1999) which can be summarized as protecting water systems and water quality, integration to landscape, reducing runoff and peak flows, and adding value simultaneously decreasing costs; measures implemented covers groundwater concerns, minimizing roof and ground runoff (Mitrotta, 2011).

First residents of the area (Aboriginal Australians) were using available surface water supplies, and first European settlers relied on intermediate creeks in the vicinity, as the demand for reliable water sources increased with development, people installed pumps on the rivers and nearest water bodies as they became insufficient day by day (Mitrotta, 2011).

In order to increase its resiliency, The City of Melbourne which is challenged by climate change, drought, pollution, and population increase at the same time is trying to diversify its water resources by sustainably managing the total water cycle, since its main source is heavily dependent on river catchments and affected by the climate change which decreases the average rainfall (21,260 ml mean annual value) and dries the climate (moderate oceanic climate), and pollution caused mainly by anthropologic factors (Mitrotta, 2011).

Conventional systems do not take water as a limited valuable source and allow wantoning, Melbourne's new approach to become a 'water sensitive city' since 2002, aims to manage all components in UWC in an integrated way with special attention paid to rainwater harvesting with the involvement of various actors on all levels, and the city itself as acting as a catchment area for the rainwater to rely on local sources rather than external support which aims to improvement of water bodies in regional scale in the end with the momentum gained (Mitrotta, 2011).

The determined targets are put on probation and annual reports on them have been prepared for the fine-tuning during the process to keep up with changing ecological, socio-economic, and political circumstances, and catch up with fastly developing technologies, and high participation rates on all levels of citizens have been achieved. The targets set were revised and sometimes exceeded thanks to the cooperation of the people (Mitrotta, 2011) (Table 2.15).

Table 2.15: Targets set for the city as a catchment approach (Mitrotta, 2011).

targets set (%)												
	per employee			per resident			Council		non-council land managers	total 'absolute'		
targets set (indicator)	first target	revised to x% by 2020	achieved (2011)	first target	revised to x% by 2020	achieved (2011)	first target	revised to x% by 2020		first target	revised to x% by 2020	Achieved (2011)
Water saving												
reduction in potable water	40	50	48	40	40	39	40	90		12	25	34
alternative water use								30	9			
Water quality												
reduction of TSS								20				
litter reduction								30				
Total phosphorus								15	25			
total nitrogen								30	40			
wastewater reduction										20	30	40
groundwater quality	The water re-injected to prevent land subsidence has to be of equal or better quality than the water in the aquifer											

Despite the increasing population, due to high participation and having great responses, some of the targets have been raised during the process such as: ‘absolute’ water-saving raised from 12% to 25% and even passed that with 34% savings which is achieved by demand reduction (increasing efficiency on appliances, using suitable landscape species and limiting garden irrigation, covering swimming pools, increasing the awareness by educating people), and alternating water sources (rainwater use for fit-for-purpose(rainwater tanks, incentives, regulatory measures, education), recycling and reusing waters); thanks to stormwater harvesting, the quality of waters increased dramatically and resulted in widening the scope of quantitative measures from suspended solids only to all parameters; the council has been implementing measures to alternate their water resources by the means of rainwater harvesting, sewer mining, and water recycling; and wastewater reduction is ensured by reducing use from mains and reusing wastewaters (Mitrotta, 2011).

Targets and strategies that Melbourne has set for themselves are given in Table 2.16, and the actions they took in given years are in Table 2.17.

Table 2.16: Targets from relevant strategies (City of Melbourne, 2017, pp. 27).

Strategy	Target
Urban Forest Strategy (2012)	• Increasing plant cover to 40 % on public land across the catchment by 2040. • Increasing the diversity of species. • Improving vegetation health.
Total Watermark (2012)	• 8 % of all municipal water use and 30 % of all counsil water use sourced from alternative water sources. • 40 % of the Elizabeth Street Catchment's soil surface is unsealed by 2030. • 20 % total nitrogen reduction. • Contributing to the waterways
Open Space Strategy (2012)	• Increase the open space by 42 hectares (municipal level and below).
Elizabeth Street Catchment Integrated Water Cycle Management Plan (IWM) (2015)	• Reducing Melbourne Water Flood Risk rating from extreme to high. • Increasing open space, soil moisture and areas of unsealed soil in Elizabeth Street Catchment. • Increasing retention measures by the means of mimicing the natural system to hold rainwater at the upper stream catchment to reduce stormwater runoff in the lower sections. • Improving the well-being of existing vegatation cover with alternative water resources.
Nature in the City (2017)	• Practising pioneering biodiversity and urban ecology projects that are innovative and outstanding. • By 2027: • Increment of biodiversity, habitats, and ecosystem health within the City of Melbourne. • City of Melbourne will be a more ecologically-connected city than in 2017. • Private premises also play significant role to integrating nature into the city. • Increasing awareness.
Climate Change Adaptation Strategy (2017)	• This strategy uses the targets within above strategies. • Relevant goal is the enhancement of the natural environment and green spaces.
Municipal Integrated Water Cycle Management Plan (2017)	• All habitable finished floor levels within private development are free from flooding from Council drains during a 100 year Average Recurrence Interval (ARI) rainfall event. • 1:20 ARI (or equivalent) flow capacity of all council drains within the central city and growth areas. • Minimum 20 % of each catchments surface is considered permeable by 2030.

Table 2.17: Greening actions taken by the City of Melbourne (City of Melbourne, 2017, pp. 11).

Year	Action
2005	Construction of the extensive green roof and green facades on City of Melbourne building Council House 2
2008	Developing and continuing Australia's first quarterly green roof forum – Canopy: Melbourne's Green Roof Forum
2008	Sponsoring and staff involvement in the Committee for Melbourne Growing Up project to build a green roof on a Melbourne building (131 Queen Street).
2010	Design and construction of the Venny green roofs and associated research project.
2010	Feasibility studies for green roofs on council buildings.
2011-14	Developing the Growing Green Guide for Melbourne project, Policy Options Paper and investigating demonstration sites.
2014-16	Funding Australian Research Council and Cooperative Research Centre projects to further research into green roofs, walls and facades.
2014	Creating a green facade in Fitzroy Gardens.
2015	Mapping all roofs in the municipality to determine their potential for green roofs.
2015	Mapping laneway on ground and vertical surfaces in the central city to determine their potential for greening (Figure 2.47).
2016	C270 Planning Scheme Amendment (State Government) put in place to allow floor area uplift in exchange for provision of public benefit including publicly accessible open space. This resulted in Design and Development Overlay (DDO) 10.
2016	Creation of a position for coordination of green infrastructure across City of Melbourne in urban sustainability.
2016-17	Green Your Laneway pilot project.
2017	Commenced literature study, gap analysis and priorities for 'Quantifying the Benefits of green roofs, walls and facades in Melbourne' to establish evidence base.
2017-21	Partnering with the Department of Environment, Land, Water and Planning to deliver a publicly-accessible 'demonstration' green roof.

The Urban Forest Strategy includes plans for greening streets but precinct plans do not include small-scaled laneways which cover 60 ha area and when vertical spaces that can be used for greening are included, that area rises to 210 ha (City of Melbourne, 2017) (Figure 2.47).

Figure 2.47: Opportunity mapping of park laneways (City of Melbourne, 2017, pp.17).

When the rooftops are analyzed according to their constraints, a total of 880 ha of rooftop area in the city which contribute heat island effect can actually contribute to the sustainability of UWC which poses a great opportunity for the city as the open space network of the city covers 480 ha area (City of Melbourne, 2017).

Appreciating the dynamic and interactive relationship between built and non-built up areas and adjusting management approaches accordingly, receiving support and commitment from everyone included, and fit-for-purpose alternative water use popularization (Figure 2.48) are the main valuable lessons learned from the project (Mitrotta, 2011).

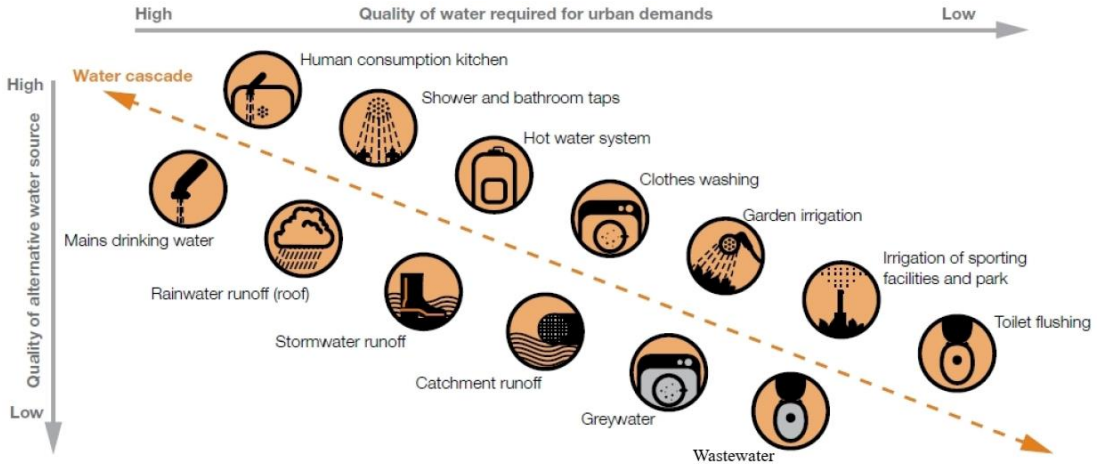


Figure 2.48: The fit-for-purpose concept (Holt, 2003 as modified by Melbourne City Council, 2009, pp.19).

2.5 Chapter Summary

Water resources are limited all around the World. water consumption exceeding its renewing pace, urbanization, population increase, and many other anthropologic factors coupled with natural changes in precipitation regimes, climate change, etc. create water scarcity, water stress, and many other water-related problems definitions. Decreased precipitations and increased temperatures result in hygiene and health problems as well. Therefore, using existing resources more efficiently and finding alternative solutions gain much more importance.

Water-related problems can be summarized as too much, too little, too dirty in the briefest way. These problems intensify in urbanized areas as these areas are altered to meet the densified activity of humans. As impervious areas increase in these areas, the natural cycle of the water that it follows in natural conditions gets more complicated with added drainage systems, disrupted infiltration processes, wastewater production, etc. As water can not find enough surface to infiltrate, it easily becomes runoff water and accumulates in volume in very short times without proper channeling whereas, in the traditional approach, it is considered as a nuisance to the settlement and tried to get rid of as quickly as possible. Since the water cycle is different from its natural state in urban areas, its cycle is named Urban Water Cycle (UWC) which includes reuse of wastewater, groundwater, surface water, stormwater, and all other possible water resources' conservation and use; as well as demand management. Understanding these processes and relationships is a crucial first step towards the management approach. The approach which considers all these is called Integrated Urban Water Management (IUWM). IUWM treats water resources, drainage systems, and wastewater management as components of a whole system and tries to imitate the water's natural cycle as much as possible. The complexity of the water systems and problems are its main focus which includes integrating stormwater and wastewater into the area with the consideration of the needs of the ecological and anthropologic factors with minimum intervention to the nature as much as possible. All users must be able to benefit from water resources equally and sustainably. To make it possible, fit to purpose treatment and reuse of water, taking advantage of the possible alternative water resources, and demand management are crucial which also affect UWC positively as well.

IUWM in the 1960s was mainly focused on floods but evolved to include aesthetic, recreation, pollution, flow regulation, ecological improvement, considering stormwater as an alternative water resource, resilience, and microclimatic effects. Over 65 concepts were developed as an IUWM approach which has similar aims but slightly different focuses or with the branding of the region they emerged where some of the most commonly used terms are: Water Sensitive Urban Design (WSUD), Low Impact Development (LID), Sponge City Concept (SCC), Green Infrastructure (GI), Sustainable Urban Drainage Systems (SUDS), Active Beautiful Clean Waters (ABC Waters). Even though the concept names vary, their common feature is to improve water quality and decrease polluting sources while conserving the hydrological cycle as much as possible and mitigating the impacts it has been exposed to. And to achieve IUWM, used techniques, technologies, and methods are also named differently such as Best Management Practices (BMPs), Alternative Techniques (AT), SUDS et. All in all what matters is to define the principles and objectives, and the purpose as the concepts and methods are evolving as a term and changing over time as well.

WSUD is the concept that is most associated with the IUWM approach which combines the integrated management of water with urban design. Cities with WSUD are categorized under 6 categories when their service and socio-political situations are taken into account; their ranking in each stage is dependent on these indicators towards becoming a Water Sensitive City (WSC). Developing countries have the advantage of leapfrogging through these stages by benefiting from the example set by the developed countries. With WSUD, the impact and burden on the natural environment can be minimized, quality of the water sources can be increased, peak flow rates can be decreased, alternative water resources can be provided, demand and dependency can be decreased, and infrastructure and maintenance costs can be decreased while increasing the amenity and added-value to the built environment. Therefore, resiliency is provided with economic, social, and ecologic sustainability.

The stormwater component of UWC is fairly new to be accepted as a component of the cycle rather than a subcycle within the system which resulted in not getting the attention it needs and was not included in early reforms. However, its importance is grasped in its void. Climate change, population increase, the population shift from rural to urban areas, rapid urbanization, and old infrastructure which can not keep up

with them resulted in a more comprehensive and integrated approach and controlling the weather extremes and conserving water resources became possible.

Performance measures of stormwater management are volume, flow, quality, and efficiency of use and conservation of the water. While the processes can be summarized as collection, fit-to-purpose treatment, storage, and distribution.

As precipitation turns into runoff water becomes stormwater, it sweeps the materials it touches through its route. These pollutants can vary from chemical components to biological ones, can be big particles such as urban litters or small pollutants such as molecules. In order to avoid stormwater pollution, there are several methods used which are: preserving and maintaining waterways and riparian areas, erosion and sediment control (ESC), sweeping streets and litter control, urban / housing design, rainwater tanks, detention basins, on-site detention (OSD) tanks, downpipe diverters, pervious pavement systems, green roofs and walls. As it can be seen, they are mostly holding up the water as it is and treating it as much as possible before the pollution spreads on its course. On the other hand, the methods used for the mitigation of the level of the pollutant charge are: gully baskets, gross pollutant traps (GPTs), bioretention systems (raingardens, suspended pavement systems, bioswales, etc.), vegetated swales and grass buffers, wetlands, floating wetlands, water-smart street trees. As it can be seen, these are the methods where pollutants are filtered as the water flow is allowed but in a slower manner which is mostly provided with biological/natural alternatives.

All can be applied in various scales with one or multiple benefits. They are usually flexible and easily retrofillable. They can work as an alternative to conventional systems or can be used as a complementary to the grey system. Therefore they are a valuable contribution to the system where they are used.

When examples around the world are analyzed, results gained from the WSUD frequently exceed expectations. It has been seen the importance of working with different scenarios, participation, raising awareness, keeping track of the efficiency of the system planned/designed, and making adjustments accordingly to changes give better results.

3. WSUD IN TURKEY

Turkey's water resources are highly variable depending on the geographical and seasonal differences which makes it hard to meet the need of each area because while some parts have lots but unavailable water resources to use, other parts where population and industrial activities densifies do not have sufficient water (TMFA, n.d.). On the other hand, changes occurring in the water cycle are expected to result in less rainfall in a shorter but more intense way which brings flooding as a consequence (Turkish Ministry of Environment and Urban Planning, 2018). As Turkish Meteorology and Disaster Management professor Mikdat Kadıoğlu states, as climate change increases the variables in the weather, climatic conditions get more extreme which results in droughts and heavy rainfalls occurring concurrently; since Turkey has a semi-arid climate, it becomes arid with a slight drought which makes it very vulnerable (Koyuncu, 2019). Therefore, the Ministry of Environment and Urbanization prepared the Black Sea Climate Change Action Plan in 2019 and stated that due to the highest risk in the area, priority has been given to this part of the country: in the plan, separating sewage from the rainwater drainage system and permeable surface usage are encouraged and natural water holding capacity of the soil is considered the most efficient and cheapest way of detention mediator (DSİ Vakfı, 2019).

Climate change's outcomes such as sudden and heavy rainfalls, droughts, desertification risks, and water resource decrement underline the importance of rainwater harvesting to cope with the new climatic conditions (DSİ, 2019). When Turkey's green, blue and grey footprint rates are examined, the green footprint has the highest share which emphasizes the importance of rainfall and climate variabilities when production and consumption rates are considered (The World Bank, 2016).

Basic info about the water resources of Turkey is given in Table 3.1. As Dinç (2019) states, Turkey is under water stress with 1430 m^3 water per capita/year which is projected to fall 100 m^3 with increased population and other factors and become a water-poor country in the end.

Table 3.1: Basic information about Turkey (Arranged from DSİ 2019, DSİ 2020 and MGM 2020 data).

Turkey's Water Resources		
Annual average rainfall (arithmetic)	574	Mm/year
Turkey's total surface area	783.577	Km^2
Total basin area of precipitation (2020)	778.493	Km^2
Average annual rainfall	450	Billion m^3
Annual mean basin runoff (2020)	185.37	km3
Evaporation mean value (1985-2020)	6	mm/day
Leaking to aquifers		
Surface Water		
Annual Surface runoff	186.05	Billion m^3
Annual flow/rainfall rate	0.37	
Annual exploitable surface water	95	Billion m^3
Actual annual consumption	33.9	Billion m^3
Surface water used for irrigation	34.706	km^3/year
commissioned by DSİ	19.779	km^3/year
commissioned by other institutions	14.927	km^3/year
Groundwater		
Annual drawable water potential	17.81	Billion m^3
Annual exploitable groundwater	15.06	Billion m^3
Annual groundwater recharge	23	Billion m^3
Sectoral use of groundwater (2020)		
groundwater irrigation cooperatives and public institutions	4.61	km^3/year
documented personal irrigation	6.77	km^3/year
irrigation	11.38	km^3/year
drinking, using, and industrial	5.64	km^3/year
total allocated groundwater	17.03	km^3/year
Total usable water (net)	112	Billion m^3
Irrigation water	44 billion m^3	
Drinking-general use and industrial use of water	13 billion m^3	
Total water used	57 billion m^3	

The national Basin Management Strategy is followed in Turkey since 2014 in order to have a common ground with relevant institutions and organizations (Kunt et al., 2020). Turkey is divided into 25 hydrological/stream basins (Figure 3.1) (SUEN, 2021, pp.12; State Hydraulic Works, n.d.) where most of them are born and disembogued within the national borders while few of them arise from other countries and disembogued within Turkey's borders and some arise within the borders of Turkey and disembogues in other countries (State Hydraulic Works, n.d.). Sharing a valuable source can get complicated and create political stress on the region which is especially valid for Turkey (*Turkey and Transboundary Water – The Politics of Water*, n.d.). 5 basins are transboundary river basins which constitute 35% of Turkey's water resources (*T.C. Dışişleri Bakanlığı*, n.d.-b). Especially the Euphrates and Tigris Rivers are coming forward when it is about water politics as they are born from Turkey and constitute 31% of Turkey's water resources and then flows through to supply water-scarce countries which creates tension between these countries (*Turkey and Transboundary Water – The Politics of Water*, n.d.). The GAP Project aims to use these rivers as resources for agricultural irrigation, hydropower generation, etc. with projects such as building dams through the rivers that do not only use water but also creates pollution for downstream countries as well (*Turkey and Transboundary Water – The Politics of Water*, n.d.). As SUEN (2021) mentions, by using the basin management model, it is aimed to achieve basin-scale management of the water resources. Integrated Water Resources Management (IWRM) approach is adapted and according to UNEP, the country score was 70/100 in 2017 where the assessment is based on 4 criteria which are enabling environment, institutions and participation, management instruments, and financing. As it is highlighted in SUEN (2021)'s report, in line with EU Water Framework Directive, River Basin Management Plans and Sectoral Water Allocation Plans for all basins in the country will be completed by 2023; the Central Board of Basin Management was formed and participation with actors from different fields to have a say in provincial and basin level decision-making process is enabled, and a national water information system that holds water-related data has been created.

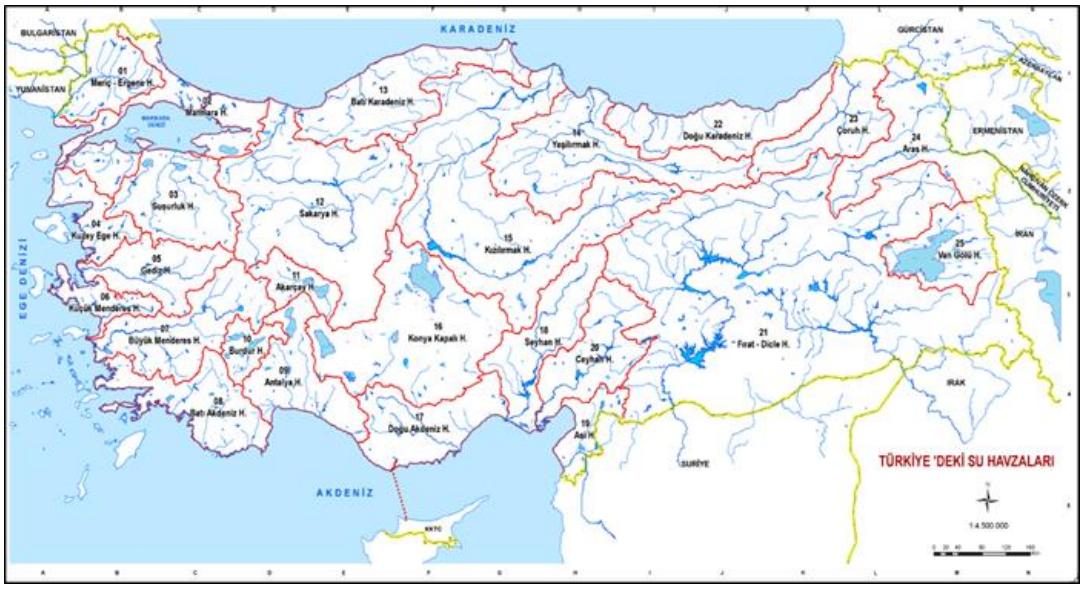


Figure 3.1: Turkey's basins (State Hydraulic Works, n.d.).

Usable water per capita was 1653 m3 in 2000, 1544 m3 in 2009, and 1346 m3 in 2020; when the usable water potential is analyzed, Turkey is among the countries that are facing water suppression; therefore the fact that water resources must be used more efficiently and optimally and every water resource must be considered as a potential source for fitted purposes by the means harvesting, storing and distributing it when needed are getting more attention with the support of various projects (State Hydraulic Works, n.d.). Drainage problems that affect the quality of the soils and contemporary solutions for irrigation and water loss are getting more attention each year (State Hydraulic Works, n.d.).

Since rainfall is highly variable (Figure 3.2) depending on the region, months, seasons, and years (Kunt et al., 2020) and streambed slopes are variant, their water volumes, velocities, sedimentation amount, and erosion capacity are highly variable as well during the year (State Hydraulic Works, n.d.). Streambeds' slopes are steep which allows them to become a potential hydroelectrical energy source but makes them unfavorable for transportation (State Hydraulic Works, n.d.).

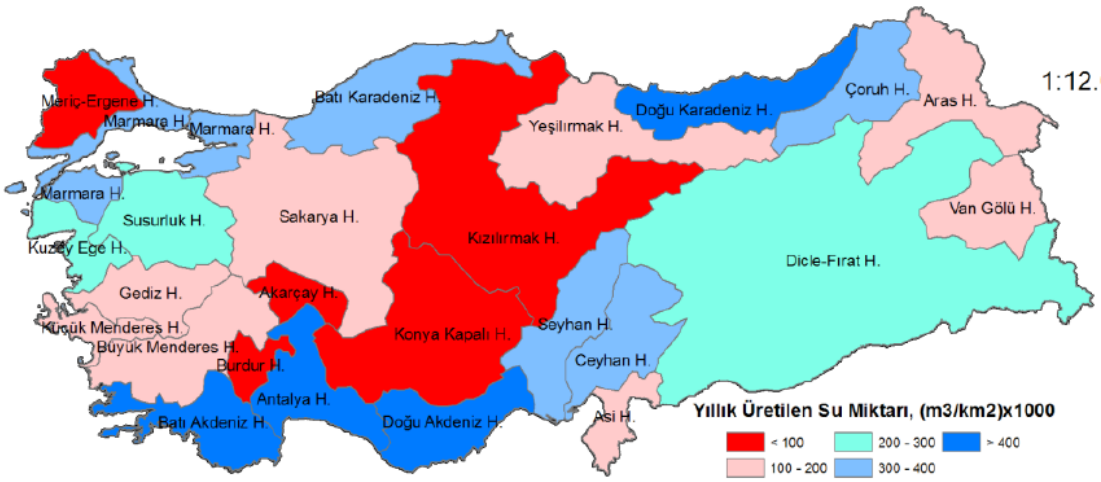


Figure 3.2: Distribution of the annual water produced in Turkey according to the basins (Usta, 2016, pp.5).

There are 320 natural lakes in Turkey where some are seasonal and dry during summer; and there are 861 active dams (State Hydraulic Works, n.d.).

As Kibaroglu and Baskan (2011) state, State Hydraulic Works (DSI in Turkish synonym) plays the role of coordinator in water sector planning in Turkey; where be it a project or individual purposes, any agencies or private parties are obliged to have cooperation and approval of DSI for the source and volume management for having the optimum benefit purpose. Irrigation and drainage networks, swamps' drainage, reclamation of lands, providing protective measures from flood and torrent hazards, hydropower generation facility constructions, and river navigability improvement measures are within DSI's responsibility and authorization (Kibaroglu & Baskan, 2011).

As cities grow, water infrastructure starts to use surface water and groundwater sources outside of the area (Apaydın, 2018). Aquifers are fed through the medium of capillary channels which are vital for them; wherein urbanized areas, these natural systems are disrupted but other feeding mechanisms are created in the meantime (Apaydın, 2018). As Vries and Simmers (2002) explains, groundwaters are recharged in 3 ways which are: direct, indirect, and localized recharge which can be summarised as direct vertical percolation for a direct recharge which occurs in pervious surfaces, percolation through surface water beds such as streams and lakes for indirect recharge, and localized recharge occurs through where water is pooled up in the areas without well-defined drainage which is not the desired situation and the most common type in cities and they are veerable (Apaydın, 2018).

According to Baba and Yazdani's (2017, as cited in Apaydın, 2018) study in İzmir's Bornova region, depending upon urbanization, groundwater dynamic has been disrupted and hig-hrise buildings with deep footings block the natural flow of groundwater sources to the sea axis which resulted in depletion of the sources' to getting feed up with precipitations from 25% to 13% between the years 1925 and 2012 which is projected to become 1% in 2030. Today, many Turkish cities are settled completely or partly on extensive and highly productive alluvial and carbon aquifers (Figure 3.3) which resulted in pollution and overuse; therefore, many wells and pump stations became unoperational or blazed away (Apaydın, 2018).

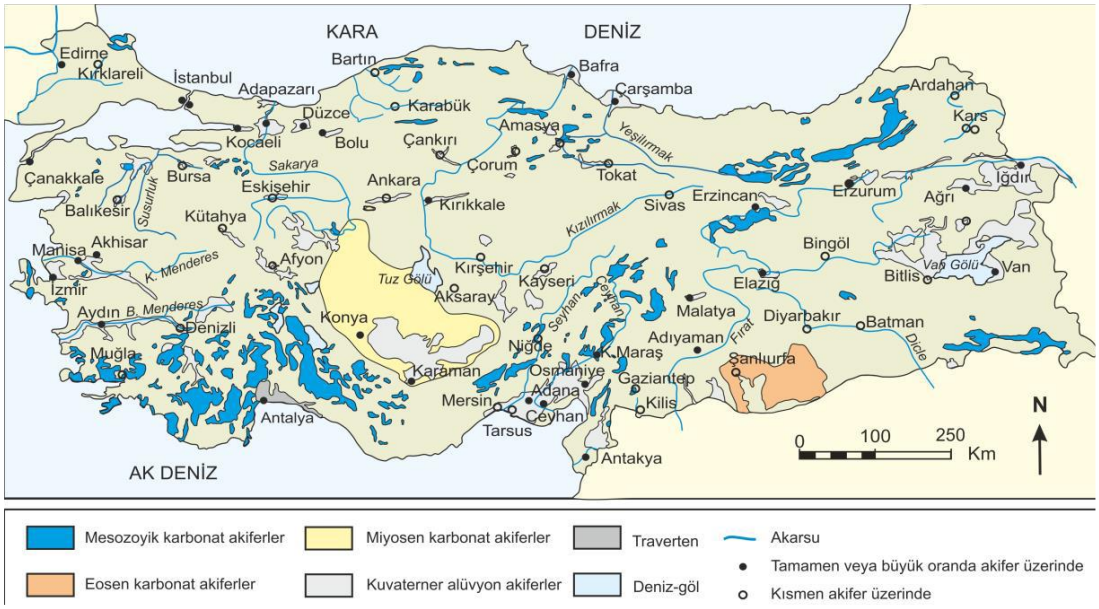


Figure 3.3: Map showing aquifers and alluvions of Turkey (Apaydın, 2018, pp. 6).

Increasing urbanization in Turkey and the increasing population at the same time makes it impossible for springs and groundwater resources to provide the needed amounts; therefore, along with these sources, most of the need is supplied with streams, dams, and lakes after purification (Usta, 2016). It can also clearly be seen from the water abstraction percentages in Figure 3.4.

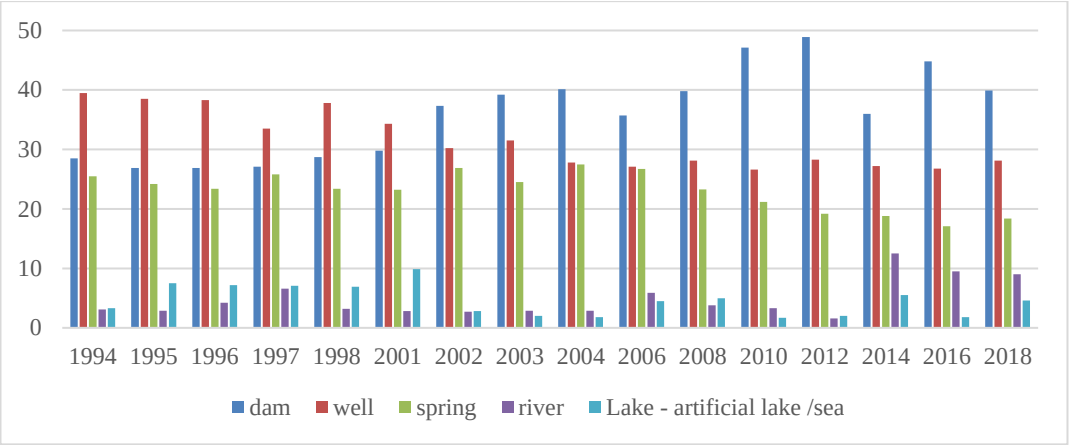


Figure 3.4: Water abstraction percentages of different water sources for municipal water supply network of Turkey between 1994 – 2018 (TÜİK, 2019).

Out of 81 cities of Turkey, 27 of them are having water pollution as their first primary environmental problem while it is stated as a significant problem in 73 cities in total; when the problem is considered in basin scale, the problem concentrates especially in the cities in Meriç-Ergene, Susurluk-Gediz, Kızılırmak-Yeşilırmak, East Karadeniz-Çoruh, and Van Lake basins (Nuray et al., 2020). Primary pollutant sources for the surface waters are domestic wastewater (sewage) and agricultural pesticide/fertilizer usage which is followed by domestic solid wastes; primary pollutant sources for groundwater are respectively agricultural pesticide/fertilizer usage, domestic wastewater, livestock raising; as for seas, domestic wastewater is the primary pollutant source (Nuray et al., 2020). Pollution that is carried over by streams has a great impact on the Sea of Marmara and the Aegean Sea; especially rainfall and stormwater are especially influential on the Aegean Sea (Nuray et al., 2020). Where wastewater is the primary pollutant source, the main reason for domestic wastewater pollution is insufficient or nonexistent wastewater collection network at city centers, and nontreated domestic wastewater for the districts (Nuray et al., 2020). Rainwater and stormwater are the probable pollution causes with 10%, 30%, 2%, and 14% share from 100% for the Mediterranean Sea, Aegean Sea, Blacksea, and Sea of Marmara respectively (Nuray et al., 2020).

In research from Elvidge et al. (2007), Turkey's ISA has calculated 74.6 m^2 ISA per person with 4988 ISA km^2 and stated as one of the top hundred countries in terms of constructed impervious surface area.

3.1 Population

Population growth trends are one of the most important parameters that show where human activities densify and are highly possible spots where environmental pressure occurs (Kunt et al., 2020). The population and annual growth rate of Turkey show that even though population increases every year, growth rate and household sizes are decreasing (Kunt et al, 2020), population density is increasing due to population increment (Table 3.2); while the shift from rural to urban increases (Figure 3.5).

Table 3.2: Population, the annual growth rate of population, and population density, 2007-2020 (TÜİK, 2021a), and average household sizes of Turkey (TÜİK, 2021b).

Year	Population	Annual growth rate of population (‰)	Population density	Household Size
2007	70586256	-	92	
2008	71517100	13.1	93	4
2009	72561312	14.5	94	4
2010	73722988	15.9	96	3.84
2011	74724269	13.5	97	3.76
2012	75627384	12.0	98	3.69
2013	76667864	13.7	100	3.63
2014	77695904	13.3	101	3.57
2015	78741053	13.4	102	3.57
2016	79814871	135	104	3.52
2017	80810525	12.4	105	3.45
2018	82003882	14.7	107	3.41
2019	83154997	13.9	108	3.35
2020	83614362	5.5	109	3.3

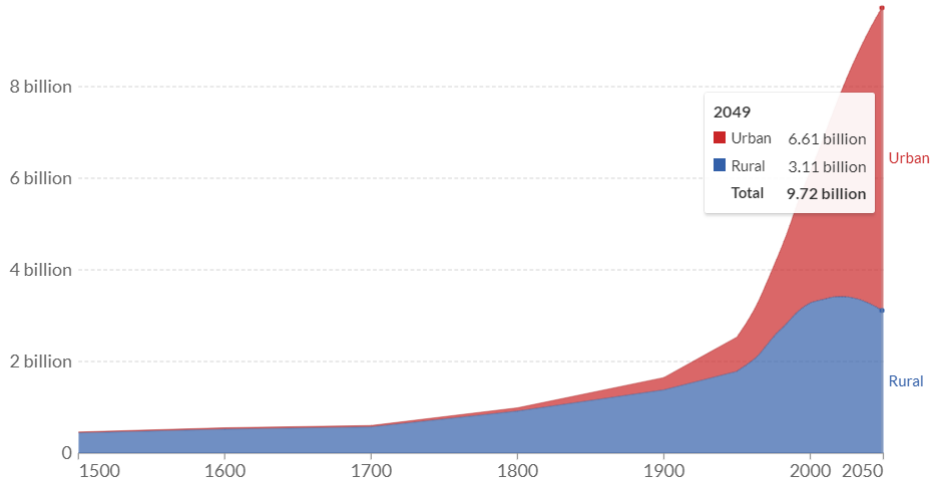


Figure 3.5: Urban and rural population history and projections of Turkey (Ritchie, 2018).

3.2 Climate

Turkey's climate is semi-arid (Figure 3.6). Since Turkey is surrounded on three sides by the sea, high mountain chains rise through the shores, elevation increases from west to east while getting away from the sea, the temperature, precipitation, and winds vary from region and time (State Hydraulic Works, n.d.). Turkey's long-term precipitation average is 574 mm while the East-Blacksea region has the most rainfall 1200-2500 mm/year), the Central Anatolia region has the least (250-300mm/year) (State Hydraulic Works, n.d.). Except for Mediterranean and South Aegean region seafronts, other regions have snowfall (State Hydraulic Works, n.d.).

Turkey's arid and semi-arid parts receive rain only for about 4-5 months over the year which makes water-related development projects vital for socio-economic and sustainable development; therefore, for natural water resource management, integrated basin management programs are in use (TMFA, n.d.).

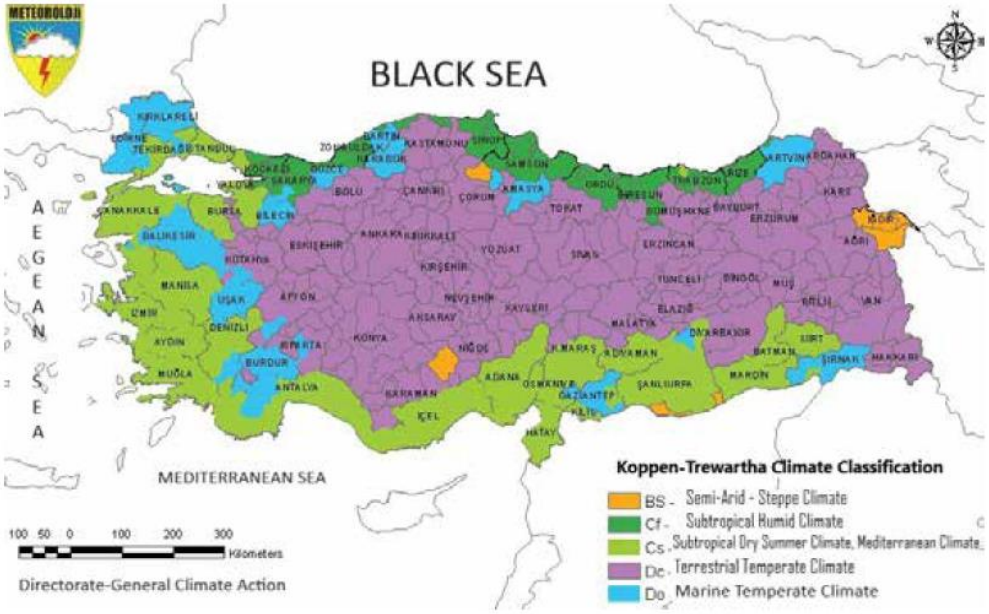


Figure 3.6: Turkey's Climate (General Directorate of Meteorology, 2020 as cited in Kunt et al., 2020, pp.17).

3.3 Rainfall

Turkey's rainfall regime is highly variable depending on the region, months, seasons, and years (Kunt et al., 2020). When the long-term data is analyzed, annual areal precipitation is 574 mm throughout Turkey (Figure 3.7) (MGM, 2021). According to the long-term average (1981-2010), the East Black Sea part of the country has the most

rainfall while the middle parts of the country have the least (Figure 3.8) (MGM, 2021). The production amount of water in a unit of km^2 area is 246.485m^3/km^2/year (Usta, 2016).

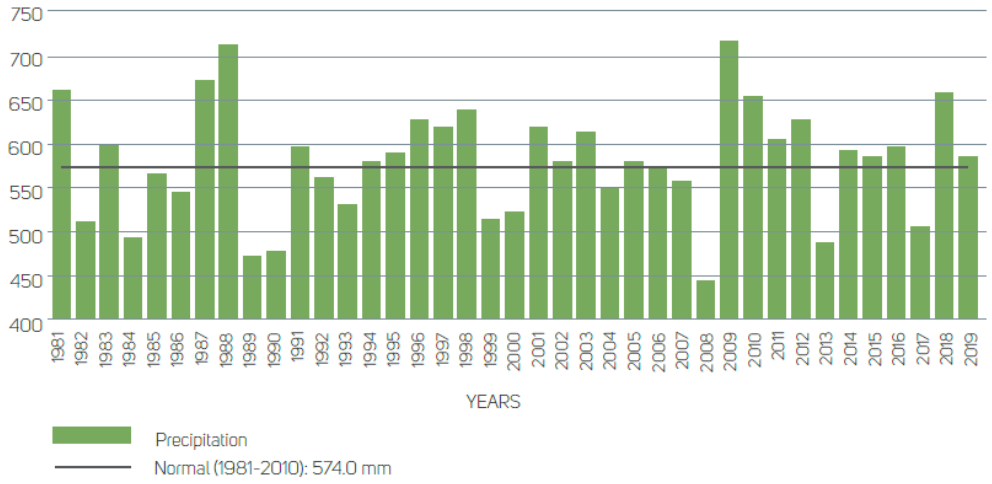


Figure 3.7: Precipitation distribution of Turkey by years 1981-2019 (general directorate of meteorology, 2020 as cited in Kunt et al., 2020, pp. 18).

Figure 3.8: Total annual areal precipitation normal (1981-2010) (MGM, 2021, pp.4).

2020 average value was 500.1 mm which was less than the previous year; and when it was compared with long-term values, 2020 has 12.9% less rainfall than the countrywide normal (574 mm) and 14.5% less rainfall than the last year (585.2 mm was 2019's rainfall value) (MGM, 2021). While 2008 was the most drought year since 1981, 2020 was the 6th year with the least rainfall (MGM, 2021) (Figure 3.9).

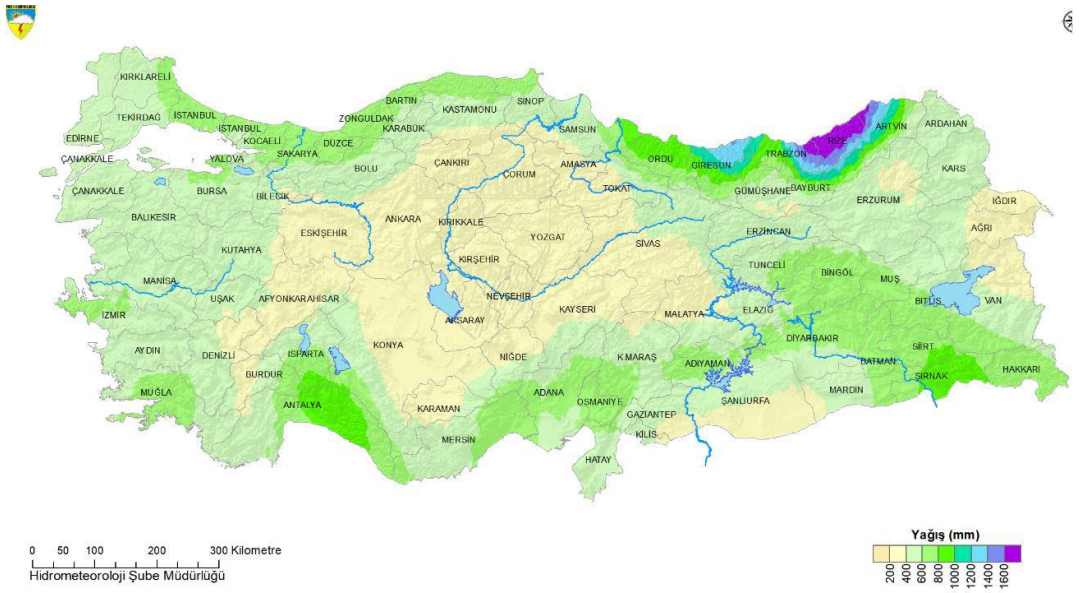


Figure 3.9: 2020 areal rainfall distribution (MGM, 2021, pp.6).

While some parts of the country had more than 40% of their normal regime, most parts of the country had less rainfall than the normal in 2020 (Figure 3.10) (MGM, 2021).

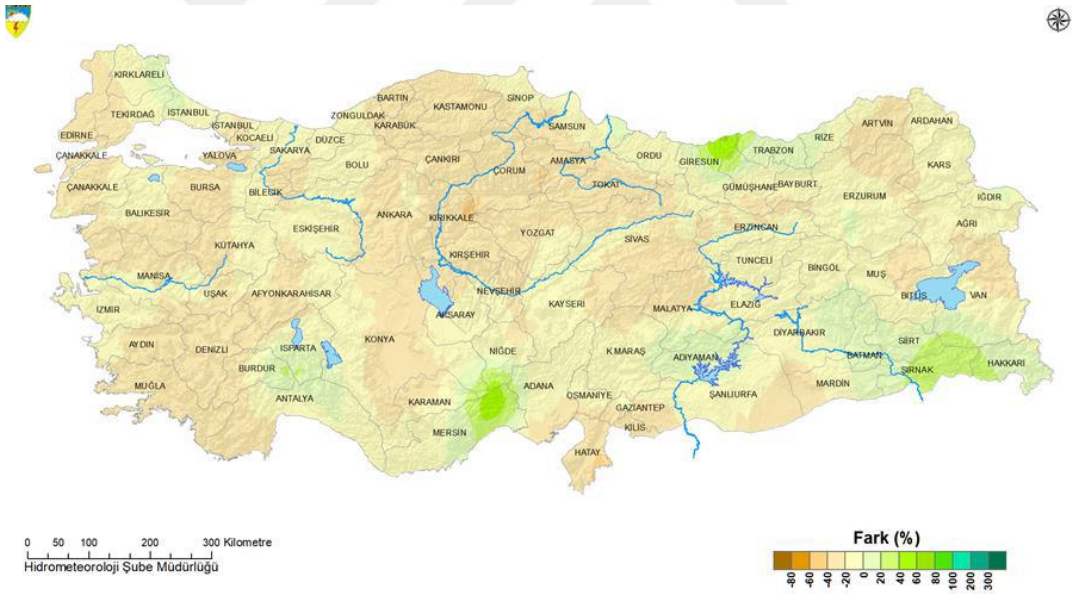


Figure 3.10: Comparison of 2020 rainfall with normal values (MGM, 2021, pp. 6).

Decreasing precipitation coupled with rising temperatures is causing serious water problems, especially in the west and south parts of the country (Turkish Ministry of Development, 2014).

3.4 Floods

Climate change causes ecological, environmental, social, and economic damages in Turkey; when the losses are compared with other countries from the Commonwealth of the Independent States and Europe, Turkey has the highest record (Turkish Ministry of Development, 2014). Climate change is also a major problem which is especially important for developing countries like Turkey; along with erosion and drought (JICA, 2004).

For Turkey, flooding is mostly referred to stream-originated flooding rather than stormwater flooding which refers to rainfalls; in the literature, urban flooding (Akyürek, 2013) is the closest term but it includes river flooding that is located in the city itself as well (Figure 3.11). As Mikdat Kadıoğlu states, there is no such concept for urban floods that are occurring because of urbanization; institutions and organizations group all floods in the same category, and as a result, proposed solutions are constructing dams and similar proposals (Koyuncu, 2019). Therefore, it can be said that there is a remarkable gap in the concept. However, the subject is getting more attention when Turkey's sensitive standing is considered. It is a known fact while the surface runoff coefficient is 0,1-0,2 for natural surfaces, it increases to 0,8-0,9 in impermeable surfaces (Turkish Ministry of Forestry and Water Affairs, 2017) in the reports, and water is considered undeniably important actor in the sustainable development of the countries (DSİ Vakfı, 2019).

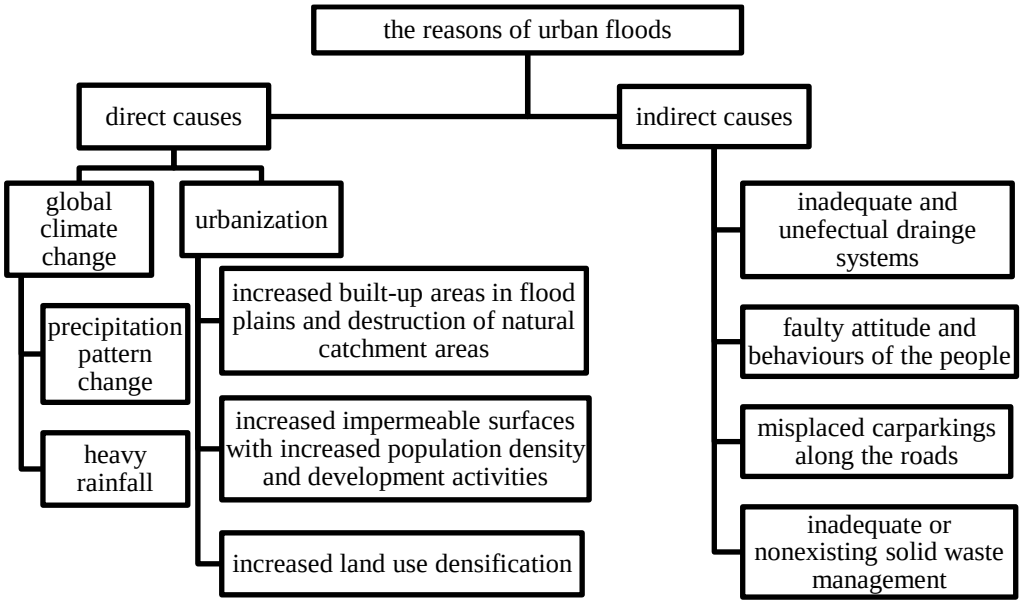


Figure 3.11: The reasons for urban floods (Ceylan et al., n.d., pp.6).

According to WMO (2021), the most common hazards in Europe are respectively riverine floods (22%), general storms (14%), and general floods (10%). When Turkey is analyzed, among natural hazards, flooding is the second most harm-causing disaster type after earthquakes and the most frequent type of natural disaster; when its effects on the economy and human lives are considered; according to the 1955-2009 flood database of Turkey, there were 4067 flooding events that caused 1400 loss of lives and ruined 30800 settlements (Turkish Ministry of Development, 2014). Even though their magnitude and frequency depend on the local climate changes and natural deformations; when generalized, local meteorological conditions, topography, and vegetation play a major role in increasing the devastating effects of flash flooding; also, deforestation in Turkey also leads to erosion and increases the destructive effects of the stormwaters' destructive results. Disregarding meteorological and hydrogeological aspects, determination of proper land uses accordingly to the area's needs and availabilities, and application of the relevant construction techniques while urbanizing results in increased devastating effects of the rainfall events (JICA, 2004) (Figure 3.12).

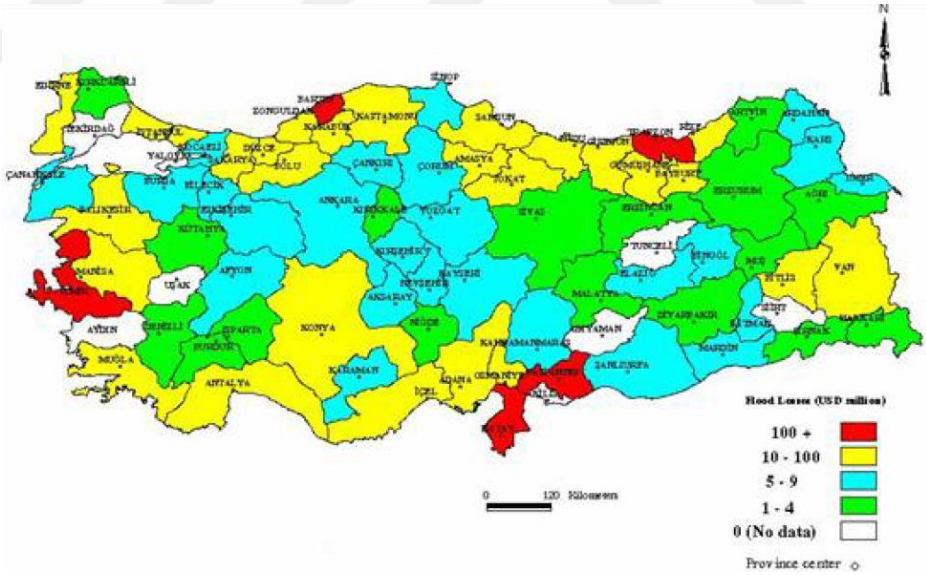


Figure 3.12: Flood risk map and economic losses (JICA, 2004, pp.33).

According to MGM (2020 as cited in Kunt et al., 2020), when extreme events in 2019 are analyzed, heavy flood rains has the share of 36% and storms have the share of 27% which are the first two meteorological disasters with the most percentage that are followed by hails (18%).

15 cities that face flooding the most in Turkey are as given in Table 3.3.

Table 3.3: Cities with the most exposure to flood hazard (DSIGM as cited in JICA, 2004, pp.34).

Order	City	Annual frequency	Population exposed to the hazard
1	İzmir	3.484	450000
2	Rize	1.841	55000
3	Kahramanmaraş	1.608	35000
4	Denizli	0.596	20000
5	Trabzon	0.508	32000
6	Antalya	0.408	400000
7	Kırıkkale	0.396	10000
8	Balıkesir	0.172	15000
9	Bartın	0.132	60000
10	Bitlis	0.132	10000
11	Sivas	0.132	10000
12	Van	0.132	70000
13	Batman	0.044	5000
14	Zonguldak	0.024	25000
15	Ankara	0.024	100000
Total			1297000

General Directorate of Meteorological Service of Turkey (2021)'s analysis, beginning from the 2000s shows that flooding events have been increasing drastically where it does not fall under 100 events each year and there were 297 flooding events in 2020 only which is recorded as 3rd the most eventful year till 1940 (Figure 3.13).

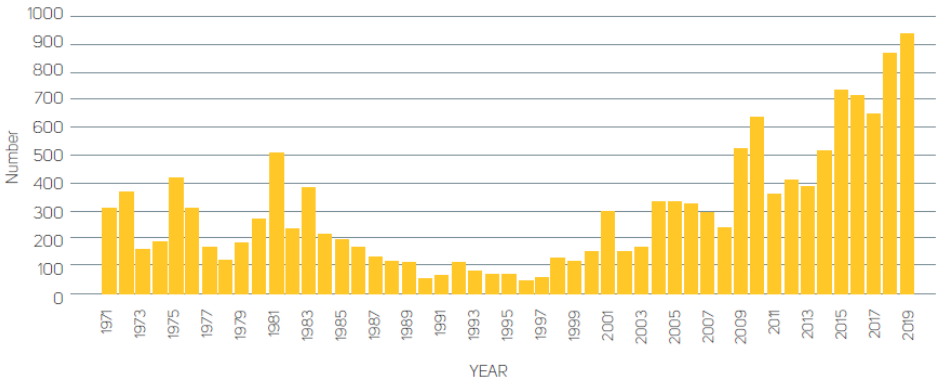


Figure 3.13: Number of annual extreme meteorological events in Turkey (MGM, 2020 as cited in Kunt et al., 2020, pp.79).

When the distribution of the floods is analyzed, summer has the most events with 186 (64%) recorded occurring; even though the most rainfall in the winter (Kunt et al., 2020) (Figure 3.14).

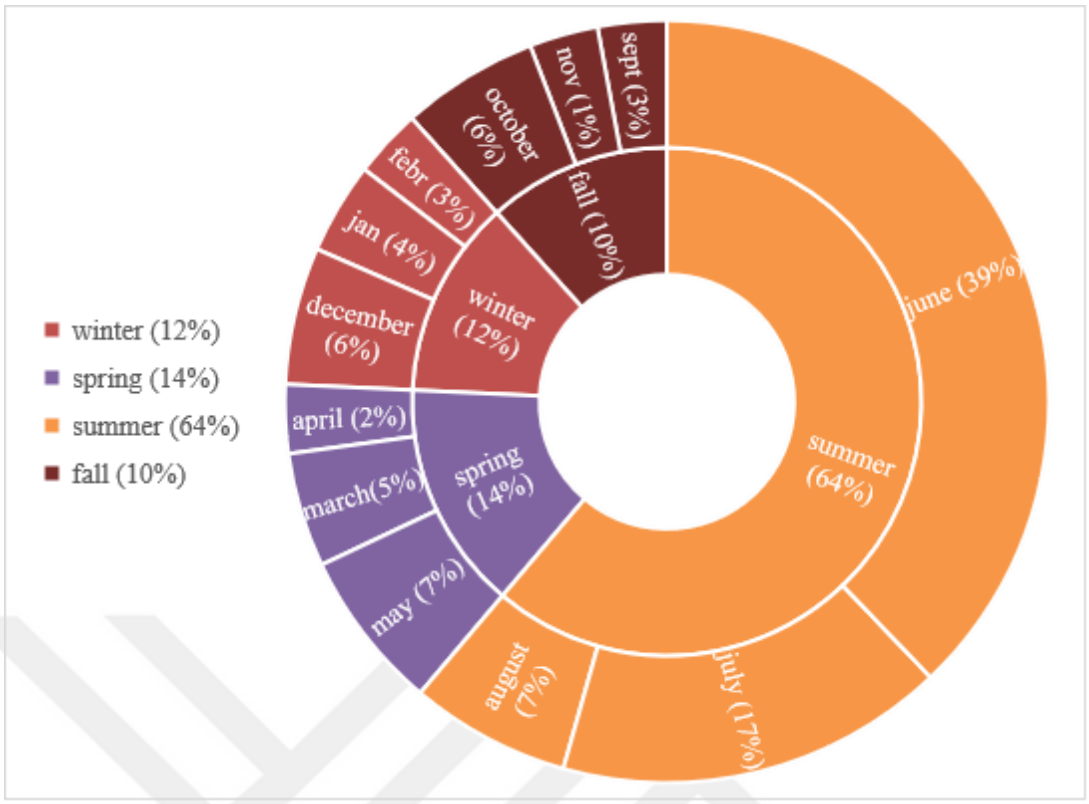


Figure 3.14: Flood disaster pattern of 2020 (adapted from General Directorate of Meteorological Service, 2021, pp.52).

Table 3.4 has been prepared to understand the severity of the situation better:

Table 3.4: Physical vulnerability in terms of natural hazards in Turkey (Ergünay, 2003 as cited in JICA, 2004, pp.110).

Annually	Floodings
Case	26
Loss of life	24
Wounded	100
Hard-hit buildings	1220
Moderately damaged buildings	700
Lightly damaged buildings	3000
Affected population	25000
Economic loss (million US$)	120

3.5 Drought

During the 1999-200 spring season, extreme drought conditions resulted in 30% of agricultural production loss in southern parts of the country. Heatwaves caused forest fires and also caused an increment in human and animal losses. Some of the surface water resources in some basins are expected to dry up by the year 2030, and climate

change is causing groundwater levels to decrease resulting in percolation of seawater into the aquifers, especially in Mediterranean parts of Turkey; while the soils are facing erosion in different levels where 63% is having severe erosion, 20% have an intermediate level of erosion, and 14% have mild erosion (Turkish Ministry of Development, 2014).

As Dr. Erol Kesici states, “Hydrological drought enhances meteorological drought.” (SÖZCÜ, 2021). Especially 2nd half of the year did not have the expected rainfall (SÖZCÜ, 2021) and short-term drought maps show the hypervariability of the rainfall and droughts (Figure 3.15 and Figure 3.16).

The PNI method map of the last quarter of 2020 shows that except for some parts, more than 80% of the country is facing extreme drought (SÖZCÜ, 2021).

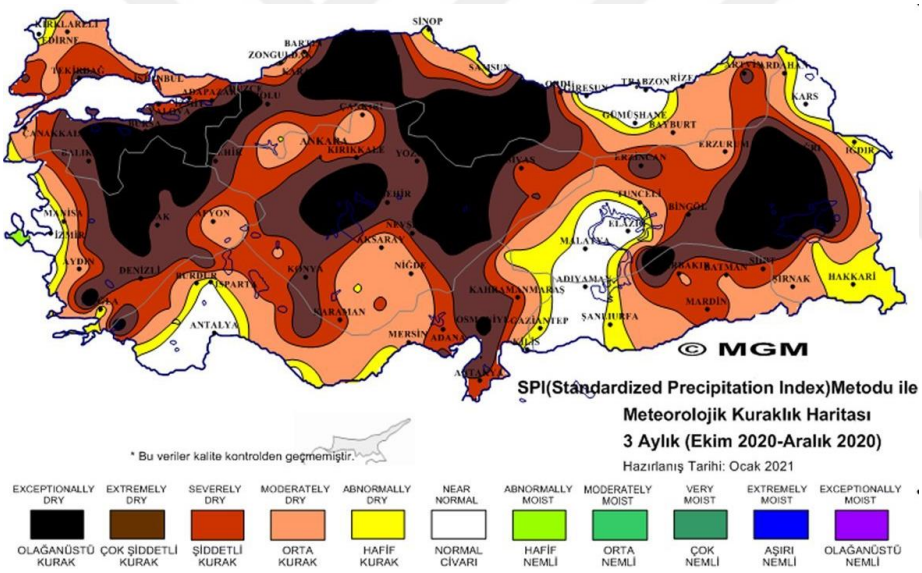


Figure 3.15: Turkey 2020 drought map of 3 months (October-December) according to standard precipitation index (SÖZCÜ, 2021).

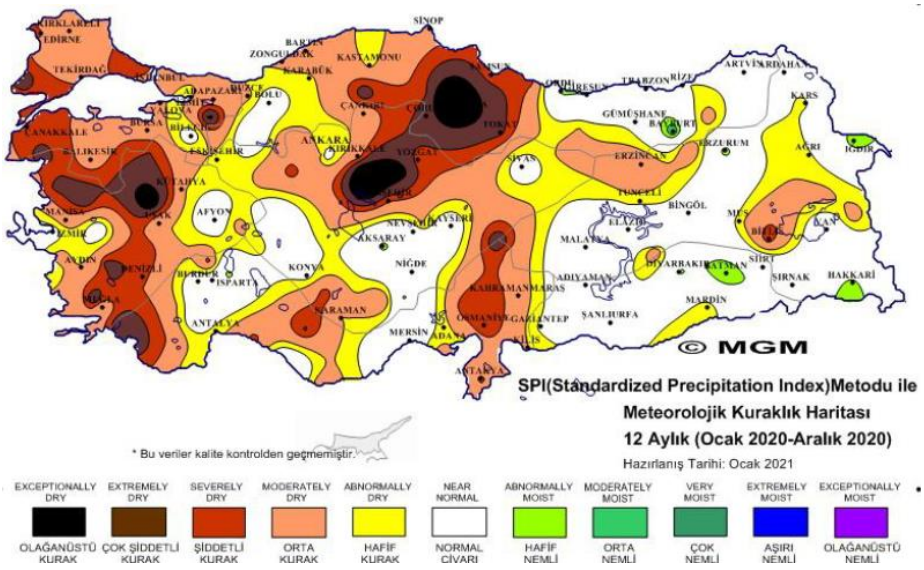


Figure 3.16: Turkey 2020 drought map of 12 months according to standard precipitation index (General Directorate of Meteorological Service, 2021, pp. 56).

Agricultural Engineers Chamber (ZMO in Turkish acronym) Antalya branch's president Vural Şahin states because of the lack of rainfall, wheat planting time is delayed; sizes of the products are affected and crop deprivation has been seen in olive production in the Aegean region; wherein Mediterranean parts, orange and citrus crop deprivation reached 60% because of heats seen in April-may (SÖZCÜ, 2021).

According to meteorological data, 2020 is the most drought year of the last 90 years and specialists state that with WSUD techniques, up to 30% of savings can be achieved in a year (DHA, 2021). Therefore, the reuse of rainwater is accepted to have a crucial role in agricultural production management while reducing erosion and sedimentation and increasing soil productivity (Tanık, 2017).

At the beginning of 2021, most parts of Turkey experienced severe drought and a lot of reservoirs around Istanbul reached their 15 years lowest storage level (Patel, n.d.). The situation occurred because of persistent low rainfall that has been happening for several seasons and water levels in reservoirs dwindled due to that; last quarter of the year, precipitation was 48% lower than 1981-2010 normal (Patel, n.d.). The precipitation decrease is expected to happen in the winter the most; which is more dangerous than summer droughts since winter precipitations are the ones that nourish the land and water sources the most (Saygılı, 2018). Given Figure 3.17 shows the shallow groundwater storage on January 11, 2021, which is measured by the Gravity Recovery and Climate Experiment Follow On (GRACE-FO) satellites that shows the

comparison of the amount of groundwater's long-term data (1948-2010) between red and blue scale, where reds show the areas that have less water when compared (Patel, n.d.).

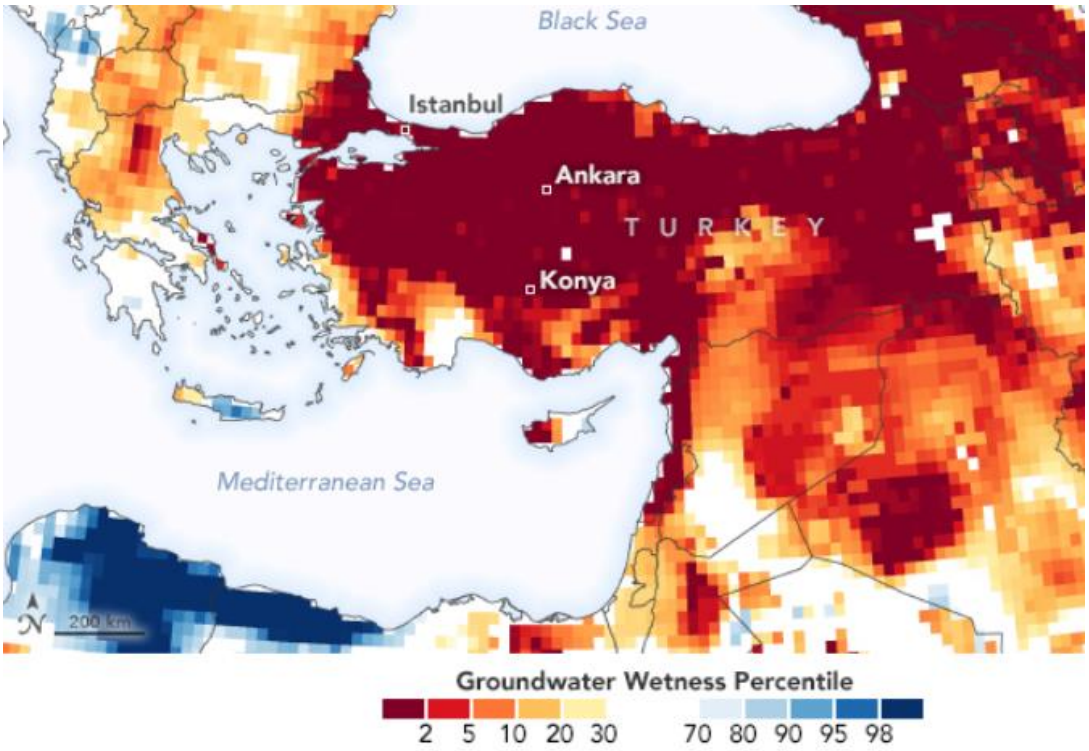


Figure 3.17: Shallow groundwater storage as of January 11, 2021 measured by the Gravity Recovery and Climate Experiment Follow On (GRACE-FO) satellites (Dauphin, n.d.).

Groundwater stored in aquifers is an important freshwater source for drinking and crop irrigation, and also, they can support streams during dry periods; but it takes months to rebound from drought for groundwaters since their replenishment is bound to slow the process of infiltration and surface moisture to seep down through the soil to reach water table (Patel, n.d.); since their recovery takes a lot of time and depending on the severity of the situation, it takes a lot of time to replenish, some sources accept groundwater as 'not a nonrenewable resource, such as a mineral or petroleum deposit, nor is it completely renewable in the same manner and timeframe as solar energy.', also because of that, all today and future of these sources must be planned carefully (Alley et al., n.d.); while FAO (2003) states, deep aquifers' (groundwater bodies) recharge time is negligible when measured in human time-scale and considered non-renewable. Another important fact about groundwaters is that they are commonly the only available source of water before surface water is instituted for use for new developments (Alley et al., n.d.).

Figure 3.18 shows GRACE-FO estimates of soil moisture in the root zone (the top meter) of soil as of January 11, 2021 (Patel, n.d.). The moisture of this part of the soil is important for the crops since their roots are mostly within this area and can get affected easily in short periods of time (Patel, n.d.).

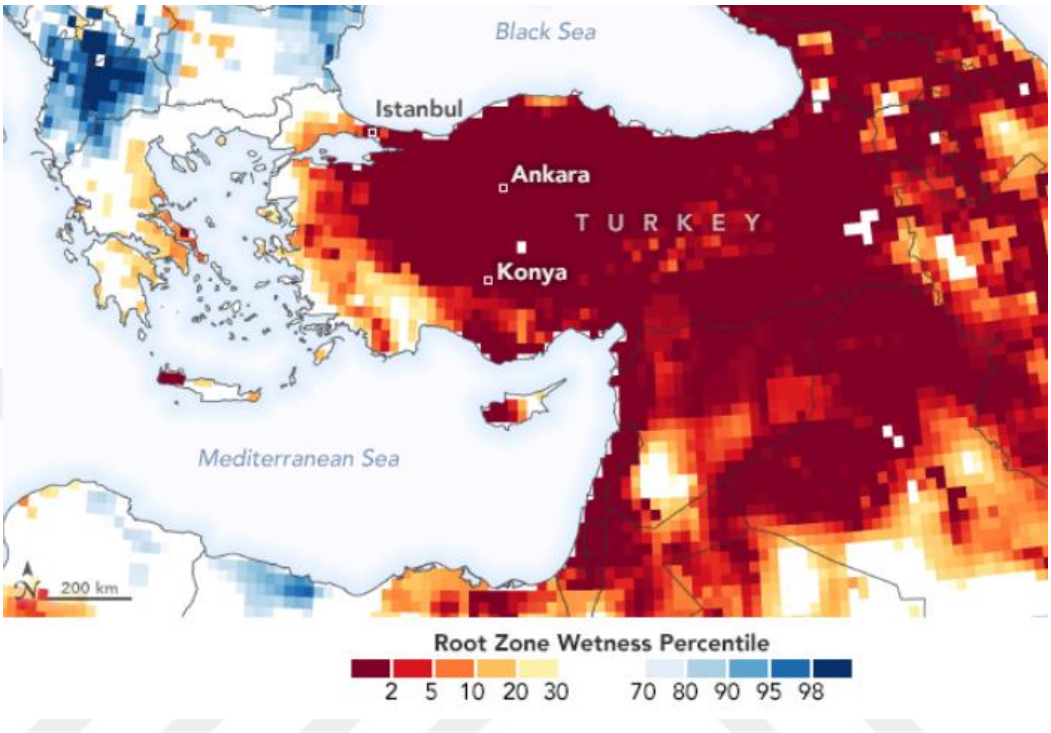


Figure 3.18: GRACE-FO estimates of soil moisture in the root zone—the top meter (39 inches) of soil—as of January 11, 2021 (Dauphin, n.d.).

In order to fight desertification better, TÜBİTAK and the Turkish Ministry of Agriculture and Forestry General Directorate of Combating Desertification and Erosion cooperated and created the Basin Monitoring and Evaluating System [Havza İzleme ve Değerlendirme Sistemi] which shows Turkey's desertification model and risk maps with a range of professional fields and data (TÜBİTAK, n.d.).

3.6 WSUD Applications in Turkey

Rainwater harvesting in traditional and historical structures in Turkey is a common extension (water wells and cisterns); but the recent development on the subject is rather underdeveloped today (Tanık, 2017). Basilica Cistern in Istanbul that is built by Byzantium Emperor Justinian (527-565) can hold 80 thousand m^3 of rainwater (DSİ Vakfı, 2018).

Using municipal water for purposes such as irrigation, or industrial uses, which does not require drinkable quality water, imposes a huge burden on both environment and the economy even though there are incentives in every field, they are insufficient (Tanık, 2017).

Harvesting rainwater in stadiums, airports, military zones, tourist facilities, and buildings with roofs big enough and treating them for further use is an important measure; on the other hand, using rainwater on residential areas for flushing (an example from Germany decreased their hospital water expenses by 20% and the amount reaches more than a million euro), laundering (dermatological tests approve that using rainwater and tap water has no difference in sense of bacteriological load), and other cleaning purposes, irrigation, and car washing do not only bring monetary value but also helps to decrease the disadvantages and risks by up to 30% (Tanık, 2017). When Turkey's domestic end uses are analyzed (Figure 3.19), the amount of water that can easily be replaced with rainwater harvesting are: laundering (13%), reservoirs (25%), and garden irrigation (5%) which sums up to 43% of the total residential use (DSİ Vakfı, 2019), for further use of the stormwater/rainwater, other treatment methods are necessary since the water becomes directly used by the household.

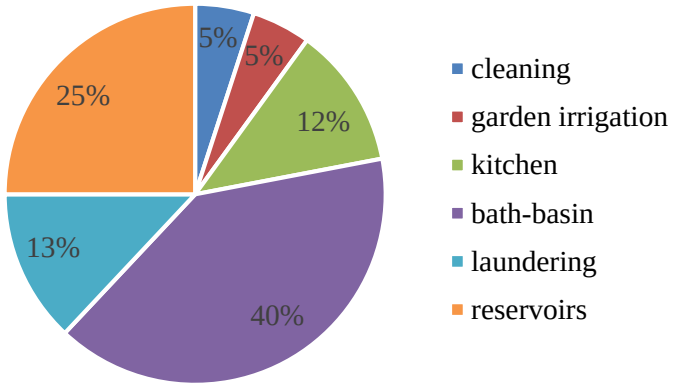


Figure 3.19: Domestic end-uses of water (DSİ Vakfı, 2019, pp. 51).

The precipitation regime of Turkey is opportune for rainwater harvesting; a study conducted in Konya's Meram district shows that the need for a house of 4 person who lives in a house with 200 m^2 catchment area with 100m^2 planting area with water sparing species' water need can be met with 20-25 tons capacity rainwater tank for 10 months (excluding September and October) (Tanık, 2017).

Turkey's long-term annual precipitation is 574 mm which means 574 liters/m^2; therefore

574 liters X 100 m2 = 57400 liters of water can be collected from 100m2 roof surface which is multiplied with 0.75 safety coefficient regarding different roof materials, gutters, loping water, and leakages (Tanık, 2017):

57400 litres/year X 0.75 = 43050 ~ 43 ton /year

224 liters/person daily X 3.3 person/house ~ 739 litres /day per house

43000 liters /year ÷ 739 liters / day = 58 days

Around 2 months of water need of an average house can be met with harvested water.

According to DSİ Vakfı (2019), supposedly an ecological garden that is located in an area with 100 cm rainfall in a year can collect 90 tons of water from 90 m^2 roof area which supplies a 90 m^2 garden's 250 days of water need, the same method saves up to 25% of energy in house cooling, can be used in reservoirs which takes 25% of domestic water use and car washing.

3.7 Sectoral and Domestic Use of Water

Water's main use is in the agricultural field for irrigation where this trend is similar for both world and Turkey; which takes 69% of total use while industrial areas use 19% of water (energy, commercial, industrial activities), drinking and domestic use takes 12% of the water consumption (DSİ Vakfı, 2019). In 2018, 54 billion m^3 of water was used in Turkey where 40 billion m^3 is used for irrigation, 7 billion m^3 for drinking/domestic use, and 7% for industrial uses (DSİ Vakfı, 2019).

20% of the freshwater around the world is used for industrial purposes whereas Turkey has similar percentages, this number rises to 40% in European countries (DSİ Vakfı, 2019). Energy production (quench cooling) takes 4% for Turkey and 10% for European countries in that sum which makes energy and water consumption inseparable two terms; the water usage ratios change depending on the process (DSİ Vakfı, 2019), electricity production only is expected to increase 20% in near future (DSİ Vakfı, 2018).

According to the Turkish Statistical Institute (TÜİK in Turkish acronym) (2019), 17.5 billion m^3 of water has been drawn off by municipalities, villages, manufacturing

industries, organized industrial sites, thermal power plants, and mining works during 2018; 56.2% of that water came from the seas, 15.1% from dams, 14% from wells, 8.7% from sources, 3.9% from streams, 1.8% from lakes/ponds, and, 0.2% from the other water sources (Table 3.5).

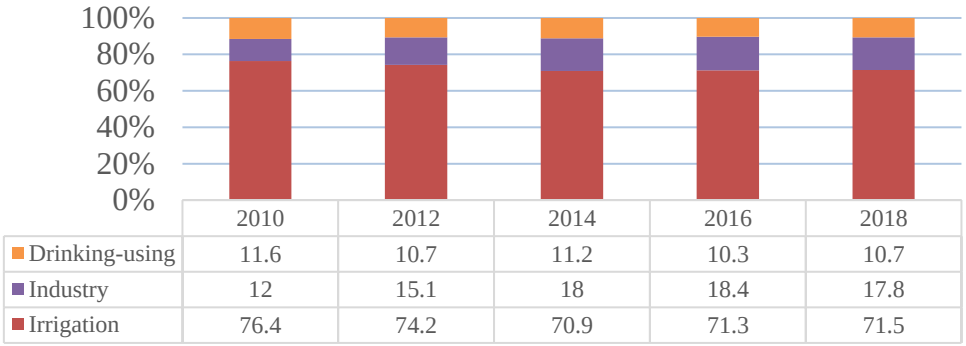
Table 3.5: Data on indicators of drinking and potable water use in Turkey (TURKSTAT, 2019 as cited in Kunt et al., 2020, pp.119-120).

	2014	2016	2018
Population of Turkey	77,695,904	79,814,871	82,003,882
Total number of municipalities	1,396	1,397	1,399
Total municipal population	72,505,107	74,911,343	76,888,607
Number of municipalities served by drinking and potable water networks	1,394	1,394	1,397
Municipal population served by drinking and potable water network	70,522,136	73,587,584	75,779,007
The ratio of the population served with drinking and potable water to the total municipal population (%)	97	98	99
Total amount of water drawn for drinking and potable water network (thousand m^3 / year)	5,237,407	5,838,561	6,193,158
Dam	1,886,617	2,618,225	2,468,103
Well	1,423,751	1,563,154	1,740,116
Source	984,869	1,000,205	1,138,388
Stream	652,37	552,624	560,356
Lake-pond / sea[1]	289,8	104,354	286,196
The amount of groundwater drawn for drinking and potable water (thousand m^3 / year)	2,408,620	2,563,359	2,878,503
Daily amount of water taken per person (liter / person-day)	203	217	224
The amount of water distributed by the drinking and potable water network (thousand m^3 / year)	3,394,545	3,732,875	4,045,486
Number of drinking and potable water treatment plants	381	519	629
Physical	69	54	22
Conventional	165	197	197
Advanced	147	268	410
Drinking and potable water treatment plant capacity (thousand m^3 / year)	5,346,014	5,558,307	6,023,791
Physical	148,052	115,489	31,000
Conventional	4,955,564	4,989,372	5,437,331
Advanced	242,398	453,446	555,461
The amount of water treated in drinking and potable water treatment plants (thousand m^3 / year)	2,995,001	3,350,389	3,574,058
Physical	47,875	33,653	3,677
Conventional	2,860,041	3,113,183	3,292,165
Advanced	87,085	203,553	278,216
Number of municipalities served by drinking and potable water treatment	436	436	443
Municipal population served by drinking and potable water treatment	41,610,124	43,881,160	46,229,893
The ratio of the population served with drinking and potable water treatment plants to the total municipal population (%)	58	59	60

(1) Includes water drawn from the sea since 2010

Even though the water use in agricultural uses is decreasing (Figure 3.20) thanks to the new technologies and increasing awareness, on the other hand, the demand for

water is getting more and more spatially concentrated because of increasing urbanization (FAO, 2017).



	2010	2012	2014	2016	2018
Drinking-using	11.6	10.7	11.2	10.3	10.7
Industry	12	15.1	18	18.4	17.8
Irrigation	76.4	74.2	70.9	71.3	71.5

Figure 3.20: Sectoral water use (2010-2018) (Turkish Republic Ministry of Environment, Urbanization, and Climate Change, n.d.)

Water use tendency is associated with income levels and geographical conditions of the countries as well: where the average of agricultural water use is 41% in high-income countries, it gets 79% for middle-income countries, and rises 90% for low-income countries; therefore, there is a negative correlation between the agricultural share of water use and income levels (Ritchie, 2017) (Figure 3.21 and Figure 3.22).

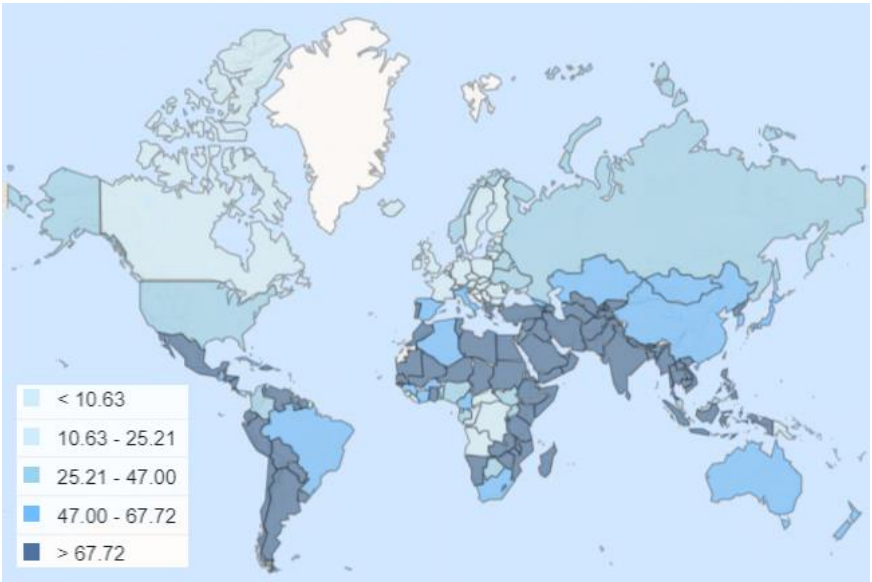


Figure 3.21: Annual freshwater withdrawals, agriculture in 2017 (% of total freshwater withdrawal) (FAO AQUASTAT data, n.d.).

As it can be seen in Figure 3.22, even though Turkey's GDP is higher than the World's mean value, its agricultural water usage is higher; therefore, Figure 3.23 Is also

provided which includes only Asian and European countries to see Turkey within its upper group.

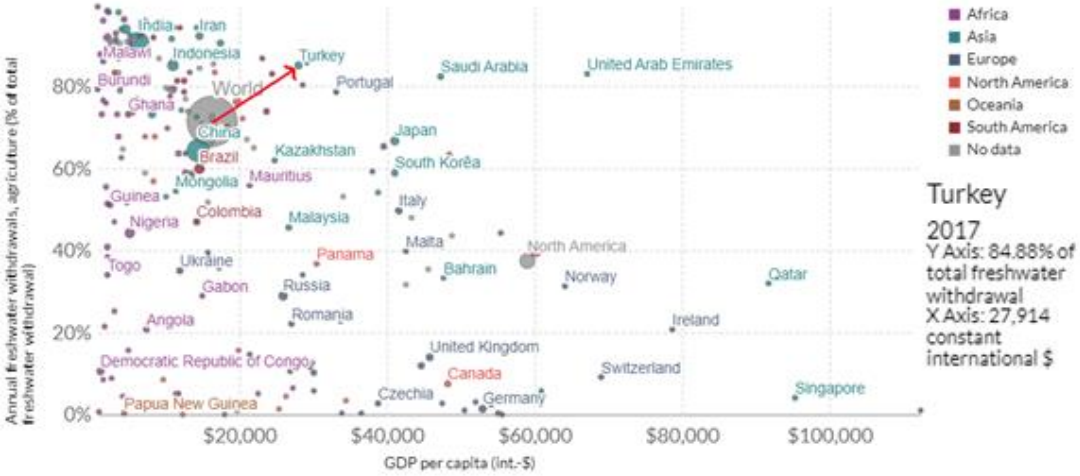


Figure 3.22: Agricultural water withdrawals of the World (self-supplied water withdrawn for irrigation, livestock and aquaculture purposes) and GDP per capita (in constant international-$) relationship in 2017 (Ritchie, 2017).

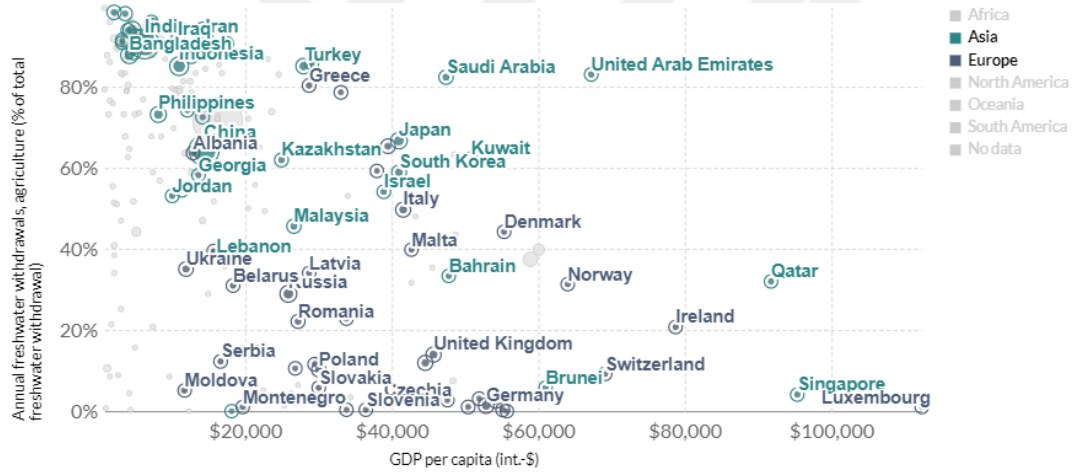


Figure 3.23: Agricultural water withdrawals of Asia and Europe (self-supplied water withdrawn for irrigation, livestock and aquaculture purposes) and GDP per capita (in constant international-$) relationship in 2017 (Ritchie, 2017).

Some literature gives Turkey's statistics in separate columns to emphasize the difference as can be seen in Figure 3.24.

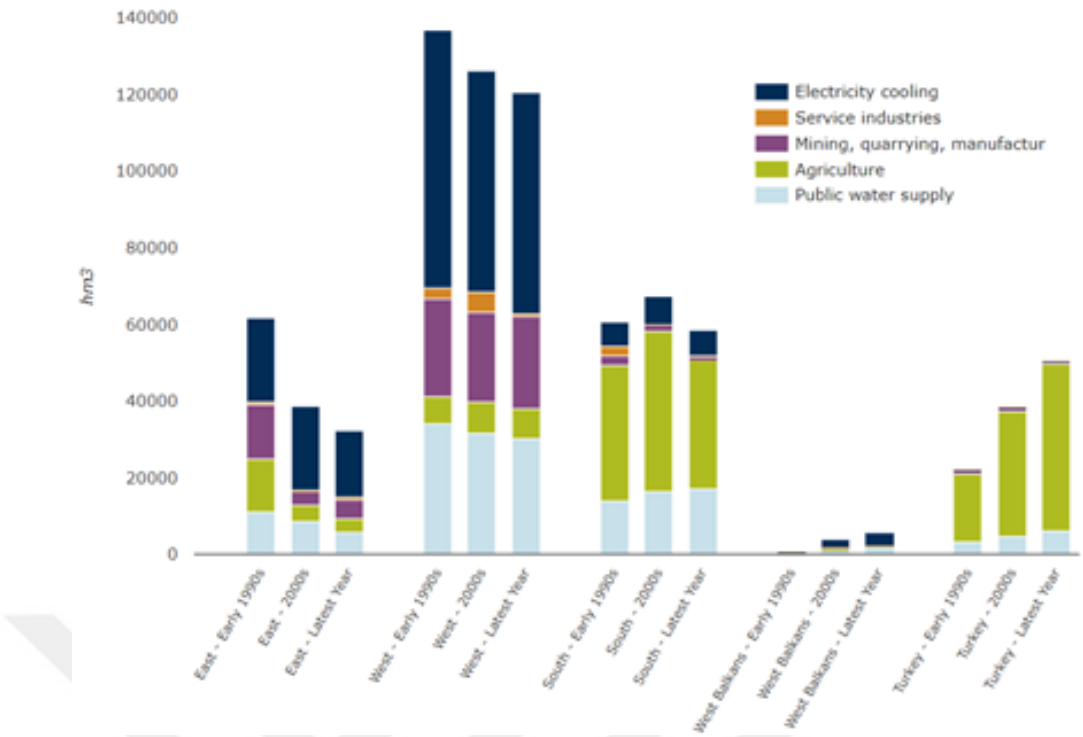


Figure 3.24: The development of water abstraction since 1990 in Europe (Statistical Office of the European Union (Eurostat), n.d.).

Even though agriculture has a serious share in Turkey, traditional irrigation systems are still being used in most areas regardless of their inefficiency (Uyduranoğlu Öktem & Aksoy, 2014).

In the 1950s, draining wetlands which started as fighting against malaria has been continued to open new agricultural lands and including Lake Amik (which is one of the most well-known examples) many wetlands lost their characteristics or dried up (Dıvrak et al., 2008). Wetlands are important features, but Turkey's wetlands are especially important since 2 of the 4 major bird migration routes of the world passes through the country (T.C. Tarım ve Orman Bakanlığı, 2019) almost 33% of the dried-up wetlands are within important bird areas (Dıvrak et al., 2008). On top of it, expected results were not gained as these areas were not suitable for agriculture, resulting in climate and precipitation change (Dıvrak et al., 2008). 1300000 ha area has lost its ecologic and economic characteristic in the last 40 years in Turkey due to draining, filling, and interference with the system which is almost half of the whole (Arı, 2006; Dıvrak et al., 2008).

It is estimated that more than 90% of Europe's wetlands have been lost; draining wetlands with different purposes increased in USA and Europe, especially after the 19th century and threats towards wetlands got bigger and bigger (Yeniyurt et al., 2011).

87% of the wetland have been lost in the last 300 years (Ramsar, 2018) where 35% happened after the 1970s because of factors such as urban development, pollution, and overusing in the World; just like it happened in the whole World, Turkey lost wetland area equals almost 3 Lake Van (or The Marmara Sea (*Türkiye'nin Sulak Alanları*, 2013)) in the last 50 years (which is the biggest lake in Turkey) and inefficient agricultural use is seen as one of the biggest problems when its share is considered since only about 2% of the agricultural irrigation use efficient irrigation systems (İstanbul BİA News Center, 2022).

As a countermeasure, the Ramsar Convention which is the 1st international treaty for the conservation of wetlands has been opened up for signature in 1971 (*Türkiye'nin Sulak Alanları*, 2013). Even though Turkey contributed Ramsar Convention by providing knowledge and hosting 1967 meeting for Ramsar and being one of the 18 countries, which shaped the international treaty, Turkey joined the community in 1994 with 5 wetlands and became the 82nd country that signed the treaty which is 23 years later (Arı, 2006). Today, Turkey has 14 Ramsar areas (Tükçev, n.d.).

However, despite their conservation status, wetlands and other water resources are under threat because of the overuse of agricultural irrigation, not having proper treatment before discharging used waters, rapid urbanization, underestimated water infrastructure projects such as dams and hydroelectric power stations, mining, etc. (Dıvrak et al., 2008; *Türkiye'nin Sulak Alanları*, 2013). Therefore the main problem is considered as an insufficient approach towards the matter which results in loss of precious water resources and overusing groundwaters that cause changes in the water flow direction (Dıvrak et al., 2008). In Konya, which is referred to as the grain silo of Turkey, 65% of the wetlands have been lost because of overirrigation or infrastructure projects that have not been evaluated enough (*Türkiye'nin Sulak Alanları*, 2013); also groundwater level has been dropped drastically increasingly (Dıvrak et al., 2008). Uncontrolled over-extraction of groundwater, in the end, causes sinkholes and land subsidence (Khorrami et al., 2021). Also, wrong agricultural policies that adopted the production of species that do not fit the climate of the region resulted in productivity loss and inefficient water use (Orhan, 2021).

Turkey takes part in various communities in international platforms for climate change which are: Vienna Convention, United Nations Framework Convention on Climate Change, Kyoto Protocol, and the Paris Agreement (T.C. Dışişleri Bakanlığı, n.d.-a).

3.8 Legislations and Incentives in Turkey

Wastewater infrastructure systems terminology is included sewage systems and rainwater & wastewater treatment plants (WWTP) in Turkey; where in recent years, sewage systems are constructed separately but most of the system is still formed from existing combined systems (Kunt et al., 2020). Therefore, the reports are prepared accordingly. When the numbers are evaluated accordingly, the total wastewater treated for reuse in the world is 7 billion m^3/year in the world which is 0.59% of total water usage according to 2011 data where it is used agricultural irrigation (32%), landscaping (20%), and industrial uses (19%); which is expected to increase to 26 billion m^3/year in 2030 with 1.66% ratio (Kunt et al., 2020).

Urban wastewater is considered a significant potential for Turkey and measures are taken in order to prevent pollution and encourage the reuse of treated water (especially in agriculture and industry); in this respect, The Ministry of Environment and Urbanization is working up on reuse of treated wastewater and carried out the "Reuse of Treated Wastewater Project" in 2017-2018, published various guidelines for different target users in the industrial sector (Kunt et al., 2020). Also using treated wastewater in agricultural irrigation is mentioned in Urban Infrastructure of the 11th Development Plan covering the years 2019-2023; and The Ministry of Agriculture and Forestry's project prepared in 2017-2019 about the "Evaluation of Wastewater Treatment Alternatives for Different Water Reuse" aims to offer alternative reuses of treated urban wastewater and agricultural irrigation (Kunt et al., 2020), as it can be seen, the agricultural field where the water is used the most with the potential of alternative source use is being prioritized.

Ministry of Environment and Urbanization's first "legislation about rainwater harvesting, storing, and discharging" is issued in 2017 aimed at general awareness about the issue evolved into necessitating rainwater tanks for the constructions that are constructed on lands bigger than 2000 square meters in 2021 with an addition to the 'Planned Areas Building Bylaws'. The addition in article 57 that are about building projects also states that these waters which are collected from the roofs are to be filtered and must be used in toilets flushes, in case the water is more than needed in toilets, it can be used for the gardens or other common areas as long as it is shown in installation project; these waters cannot be discharged into the wastewater network but

must be discharged to the separate rainwater collecting systems when existent. The buildings that have greywater systems at present can collect rainwaters in these tanks with proper project design and no extra rainwater tank is required for those projects.

According to the bylaw, the size of the tank is calculated with the considerations of the surface area of the roof and the maximum monthly precipitation that falls in a square meter area in the city where the building is located.

The area of the minimum parcel and volume calculations can be changed with the local government's initiatives.

According to the same bylaw that is issued on 3 July 2017 dated official gazette's article 36 that is about the regulations for the water tanks, it is stated that water tanks cannot be smaller than 30 cubic meters for very high rise buildings, 15 cubic meters for public and high-rise buildings, 3 cubic meters for the residential buildings with 10 independent units (after 10 unit, the volume of the tanks is increased 0.50 cubic meters for each unit), and 5 cubic meters for other buildings and the capacity must be calculated with the considerations of the intended use of the building, daily water need, selected fire extinguishing systems, etc. criteria, as well as national and international standards must be met and necessary drainage and insulation precautions must be taken.

In 2018, the Ministry of Environment and Urbanization published a "rain garden preparation guideline" (Turkish Ministry of Environment and Urban Planning, 2018).

Even though there are precautions regarding the various pollutions, there is no clause regarding underground water recharging but in some cases, DSİ's view is taken (Apaydın, 2018).

Turkish Ministry of Agriculture and Forestry's report on "Guide Document on Applications of Reuse of Used Waters" draws attention to sustainable water management methods and techniques (Kitiş et al., 2019); and Turkish Ministry of Agriculture and Forestry (2019) claims their perpetual politics include encouraging the reuse of greywater and rainwater harvesting, and the 2019-2023 planning horizon includes harvesting rainwaters and collecting them in underground.

Green buildings certification system that is built on sustainable designs is one of the incentives that many countries, institutions are encouraging and seen as a prestigious certificate in the projects by providing legislations, standards, or scientific guidelines

to how to install the newest technologies for the developers/constructors; which includes water management in the project (Ozturk et al., 2015; Tanık, 2007). While some of these certifications are accepted internationally, there might be some changes in scoring due to the special climate of the region such as water saving scorings being higher in Gulf Countries when compared with European version of Breeam (Ozturk et al., 2015).

Eco-friendly green buildings association (ÇEDBİK) in Turkey achieved the full councilship in World Green Buildings Council (WGBC) in 2012 and is supporting LEED certification with their collaboration with USGBC (ÇEDBİK, n.d.-b). ÇEDBİK prepared B.E.S.T.-Konut [*housing*] for the newly constructed project that is suitable with Turkish environment (ÇEDBİK, n.d.-b), and with having that as a reference, new exercises in different fields such as commercial buildings, existing buildings, schools, hospitals are being prepared with government support (ÇEDBİK, n.d.-a).

Certificates used in Turkey at present are LEED, BREEAM, DGNB, and B.E.S.T.-Konut (ÇEDBİK, n.d.-d).

3.9 Examples from Turkey

Examples are on a smaller scale due to recent attention attraction increase on the topic which has not found a place for bigger scaled applications yet. However, even though they are small-scaled projects (in urban scale), with the green building certification system getting popular, there are 518 certified projects in Turkey where 23 of them have B.E.S.T. certificates, 425 of them have LEED, and 70 of them have BREEAM certifications (ÇEDBİK, n.d.-c) (Table 3.6).

Green campus applications are getting wider. In 2021, 71 universities from Turkey got in rankings in IU Green Metric (Figure 3.25) which evaluates and scores campuses where 3 of them are in the top 100, 11 of them are in the top 200; where Istanbul Technical University (ITU) got the most score among them with a total score of 8150 (900/1000 on water category) and became 57th in the world ranking and 3rd in Middle East ranking (IU Green Metric, n.d.-a).

Table 3.6: Projects certified in Turkey (ÇEDBİK, n.d.-c).

BREEAM	pass	good	very good	excellent	outstanding
	3	12	25	14	16
DGNB	certified	bronze	silver	gold	platinum
	0	0	0	1	0
B.E.S.T.	certified	good	very good	excellent	
	23	0	0	0	
LEED	certified	silver	gold	platinum	
	27	61	269	64	
EDGE	final	preliminary			
	2	1			

Figure 3.25: Green Campuses in Turkey (IU Green Metric, n.d.-b).

According to ITU's 2017-2021 strategic plan, rainwater is harvested for feeding the pond within the Ayazağa campus (Figure 3.26), and maintaining the green areas; also, the carbon footprint is projected to decrease from 4kg/person to 2kg/person from 2017 to 2021 (ITU, 2017a). Also, local plants have been chosen to make it possible for them to live with minimum gardening activities, and a new garden with permaculture principles has been established (ITU, n.d.-c).

Figure 3.26: ITU Ayazağa campus (ITU, n.d.-a).

ITU is also part of a jointly planned project with the Ministry of Environment and Urbanization of Turkey which aims to reduce carbon footprint and implement WSUD applications with various other methods in Eskişehir Kocakır Site which is aimed to form a basis for the future implementations to create a "national ecological settlement standard infrastructure" in Turkey (ITU, n.d.-b).

Another project of ITU is HİDROTÜRK which is a joint project with the Ministry of Forestry and Water Affairs of Turkey's General Directorate of Water Management branch; it is a decision-making tool for sustainable water management that is suitable for Turkey's needs and environment (ITU, 2017b).

There are many examples such as Sabancı University NANODAM building having both LEED (Gold) and BREEAM (very good) certificates at the same time that uses rainwater harvesting and other water saving measures; Unilever's Umraniye office having LEED (first project that had LEED certificate in Turkey) certificate and having 40% water saving and 30% energy saving in their building can be given as some of the examples from Turkey (Ozturk et al., 2015).

3.10 Chapter Summary

Turkey's water resources vary from geography and season which is resulted in water being more scarce in some parts of the country. Turkey has its fair share from climate change; temperature increments and precipitation decrements result in droughts and floods continuously as the weather gets more unpredictable and precipitation extremes get more frequent. Flood events happen in dry summer seasons as one of the results. By floods, it is mostly referred to as fluvial floods, and prevention measures are usually constructing dams and the problem is dealt with similar approaches. However pluvial floods are also a serious problem but still have not gotten enough attention. As Turkey is not water-rich and categorized as a water-scarce country, resource management has grave importance; as a result, relevant measures and mentions are gaining more attention in reports and precautions. Even though pluvial floods are still lacking as a term, rainwater is seen as an alternative resource.

Turkey's population is increasing and the infrastructure system is getting old similarly to the international situation. On the other hand, as cities grow, they provide their water needs from further resources such as dams and local resources are thrown out of focus

which contradicts sustainability. On the other hand, pollution is another problem water resources are facing. From 81 province, 27 of them has water pollution as a primary concern while it is stated as a problem for 73 provinces. Insufficient infrastructure and pesticide/herbicide use are shown as the primary pollutant sources. This pollution also carried with rivers to the seas and create serious problems on the receiving sources as well.

Turkey has a semi-arid climate that turns into arid easily and therefore in a fragile condition. Precipitation falls concentrate on 4-5 months period which makes management especially important to manage the demand and natural balance. As droughts have economical and political damage to the country.

Since 2014, The National Basin Management Strategy is being followed and Turkey is divided into 25 basins where 5 of them are transboundary river basins. Euphrates and Tigris River basins are especially important in political aspects as 35% of the country's water resources come from these rivers but downstream countries are also water-scarce countries and dependent on these resources which created tension between the countries and has political importance. Turkey is part of various international agreements and conventions regarding climate change and water resource conservation; however, the implementation is still far from adequate and pollution and overuse are serious problems.

Wastewater has been seen as an alternative water resource since 2017-18 with published guidelines and reports especially for industrial and agricultural use since these fields require a lot of water consumption and require less treatment when compared with domestic water use. Regulations announced in 2017 drew attention to rainwater harvesting and water reuse which evolved to requirements for plots bigger than 2000 square meters to include rainwater harvesting in the projects for toilet flush tanks in 2021. Also, discharge to the local drainage system is specified.

Project scaled applications are evaluated by ÇEDBİK in Turkey and given international certificates such as LEED, BREEAM, EDGE, etc. Also, ÇEDBİK prepared an evaluation system for Turkey which is called B.E.S.T Konut for residential projects. Also, green campuses such as ITU and Boğaziçi include alternative water uses and some WSUD principles in their campuses.

4. WSUD BMP APPLICATION IN BALIKESİR BAHÇELİEVLER NEİGHBORHOOD

WSUD aims, objectives, the field of applications are explained in the 2nd section of the thesis. Within this framework, in order to understand the benefits of the suitable BMPs that can offer to the area and evaluation of the suitable BMP options in Bahçelievler neighborhood in Balıkesir province which is selected as the study area are analyzed; and a scenario that uses these implementations were compared with the current system and the newly planned drainage system that separates the wastewater from the rainwater drainage, but still has the conventional system approach towards the stormwater which sees it as riddance rather than an alternative source. With that comparison, selected BMPs' contributions to the area studied with the analysis that shows the optimum places for different BMPs.

Balıkesir is located between 39.20° - 40.30° north latitudes and 26.30° - 28.30° east meridian and covers 14299 km^2 area (Erdem, 2013). When looking at its location in the country, it is in the south Marmara region and north Aegean region; it is one of the 6 cities that has a coast on 2 seas and the city has islands on both of these seas (Erdem, 2013).

As aforementioned in the Turkey section, Balıkesir is one of the 15 cities that is having the most floods in Turkey which shows that water management is especially important for the area (Figure 4.1).

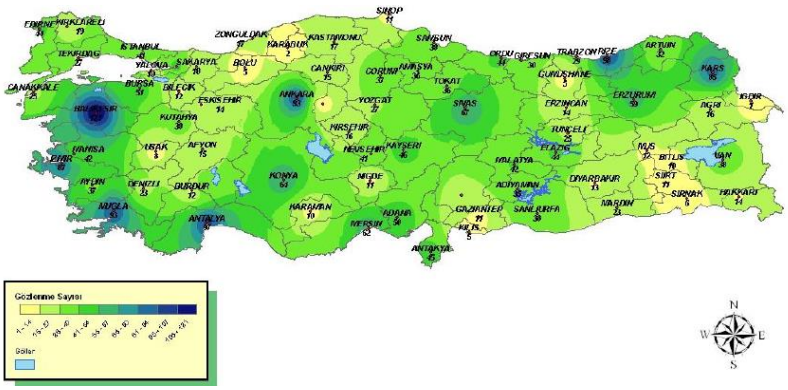


Figure 4.1: Number of observed floods- overflowing- heavy rainfall disasters that happened between the years 1940-2010 (Ceylan et al., n.d., pp.4; MGM, n.d.-a).

Balıkesir is one of the 27 cities in Turkey where water pollution has first priority in terms of environmental concerns (which is followed by air pollution and wastes) and the reasons of water pollution in order of priority are: institutional and legal inadequacy, lack of supervision, lack of treatment facility constructions due to financial impossibility, and lack of consciousness among the residents (Nuray et al., 2020). Even though BASKİ is working on the matter, 73% of the wastewater is discharged after treatment but 27% of it is discharged without getting treated according to 2018 data (Nuray et al., 2020).

Providing surface water and groundwater resources for drinking, utility, and industrial purposes is within Balıkesir Water and Sewerage Administration's (BASKİ) responsibilities in Balıkesir; used water and stormwater collection and removing them from the urban areas and conveying them to discharge or treatment spots is among BASKİ's responsibilities, in addition to that, preventing water resources from used water and industrial water, and preventing activities that threaten them are among their area of responsibilities as well. That is how BASKİ declares its missions and responsibilities in a very brief way; however, it can be understood that the approach to water is a conventional method that disregards the value of rainwater and stormwater and their role in UWC and tries to get rid of them as quickly as possible. Also, stormwater is not considered a water type that needs to be treated before being discharged to the receiving water bodies.

According to BASKİ's institution opinion, Bahçelievler, Paşaalanı, and Plevne neighborhoods are the ones that especially has pluvial flooding. Since Bahçelievler is also one of the neighborhoods in the central district where water consumption is the most (Aliağaoğlu & Mirioğlu, 2019), and when the city's flood risk, water resource pollution, and BASKİ's opinion taken into consideration, Bahçelievler neighborhood that is located in Altıeylül Municipality is selected as the study area.

4.1 Natural Characteristics of the Area

Balıkesir has lands in three basins within its municipal borders which are: Susurluk, Marmara, and Northern Aegean basins but most part of it is within Susurluk Basin which includes the center (Erdem, 2013) where the case study area is located. Susurluk basin has eight subbasins which are: Orhaneli Subbasin, Emet Subbasin, Mustafakemalpaşa, Uluabat, Nilüfer Subbasin, Simav-Susurluk Subbasin, Kocaçay –

Manyas Subbasin, Göynük Subbasin, and Bandırma – Kapıdağ Subbasin (T.C. Tarım ve Orman Bakanliği Su Yönetimi Genel Müdürlüğü, 2018c). The study area is located in Simav-Susurluk Subbasin that is coded as 03-5 in Figure 4.2.

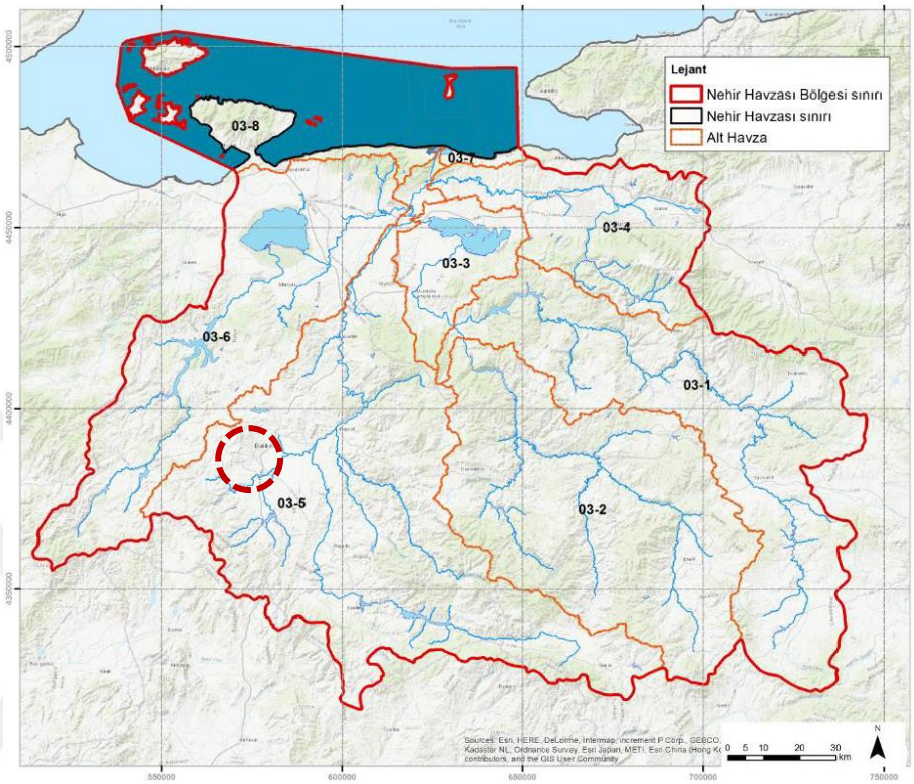


Figure 4.2: Susurluk basin's subbasins (T.C. Tarım ve Orman Bakanlığı Su Yönetimi Genel Müdürlüğü, 2018c, pp.3).

Balıkesir's subbasins are: Gönen, Manyas, Çaprazçay, Biga, Umurbey, Menderes, Edremit, Tuzla, Madra, Simav, Değirmen, Kocakan, and Kestane (Erdem, 2013). Gönen Plain, Manyas Plain, Balıkesir Plain and Körfez Plain are the main plains of Balıkesir; Manyas and Tabak are important lakes; Susurluk, Gönen, Koca, Havran, Simav, Atnos, and Üzümcü streams are noteworthy streams; and Karadağ, Edincik, Kapıdağ, Sularya, Keltepe, Çataldağı, Alaçam, Madra, Kaz, and Hodul mountains are its important mountains (Erdem, 2013).

4.1.1 Climate

Balıkesir's climate and soil are suitable for various and sundry agricultural production and the province is an important production center for Turkey with especially its Manyas, Balıkesir, and Sındırgı plains (Su Yönetimi Genel Müdürlüğü, 2018).

According to Koeppen's climate classification, Balıkesir's climate is Csa Mediterranean climate (winters are temperate, summers are very hot and dry) (MGM, n.d.-b). The basic climatic data are as given in Table 4.1 and Table 4.2.

Table 4.1: Balıkesir's climate data for the years between 1991-2020 (MGM, n.d.-c).

1991-2020	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Mean temperature (°C)	4.5	6.2	8.7	12.9	17.7	22.4	24.9	24.9	21	15.9	10.2	6.6	14.7
Mean highest temperature (°C)	8.9	11.3	15.4	19.8	25.4	30.1	32.6	32.5	28.7	22.7	16.4	10.5	21.2
Mean lowest temperature (°C)	0.8	1.8	3.5	6.3	10.5	15	18	18.5	14.2	10	5.2	2.3	8.8
Monthly total mean precipitation (mm)	83.8	72.9	63.8	51.7	37.9	34.8	10.5	4.6	30.3	53.4	74.2	80.4	598.3

Table 4.2: Balıkesir's highest and lowest temperatures between the years 1938-2020 (MGM, n.d.-c).

1938-2020	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Highest temperature (°C)	23.5	25.2	29.6	33.1	37.8	42.5	43.2	43.2	40.3	38.3	29	26.1	43.2
Lowest temperature (°C)	-10.5	-18.8	-6.2	-4	1.1	5	11	9.4	5.4	-1.6	-7.9	-10.1	-18.8

When Balıkesir's center's long-term humidity (Figure 4.3), precipitation (Figure 4.4), and average temperature (Figure 4.5 and Figure 4.6) data are analyzed, climate change's effects can be seen as temperature normal is rising while precipitation trend is declining and humidity is rising which is a result in the air holding up the precipitation and soil getting drier which makes alternative water sources especially important, particularly rainwater.

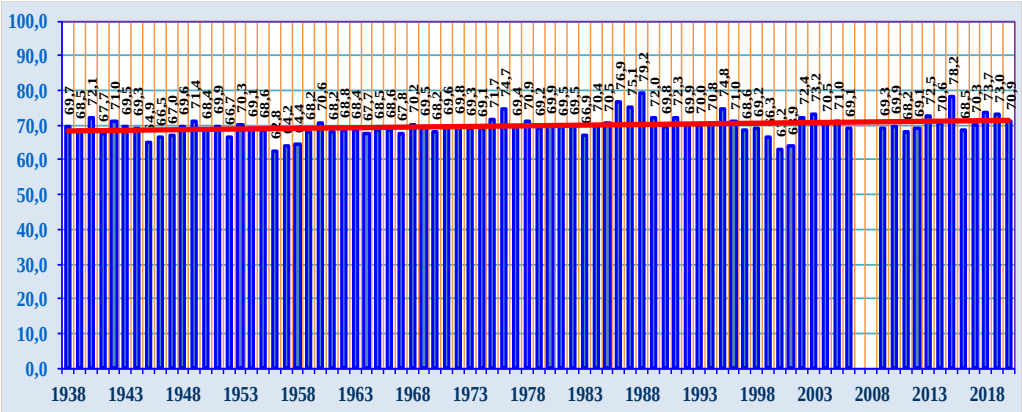


Figure 4.3: Balıkesir center annual average humidity distribution and trend between the years 1938-2020 (Data obtained from MGM, 2021).

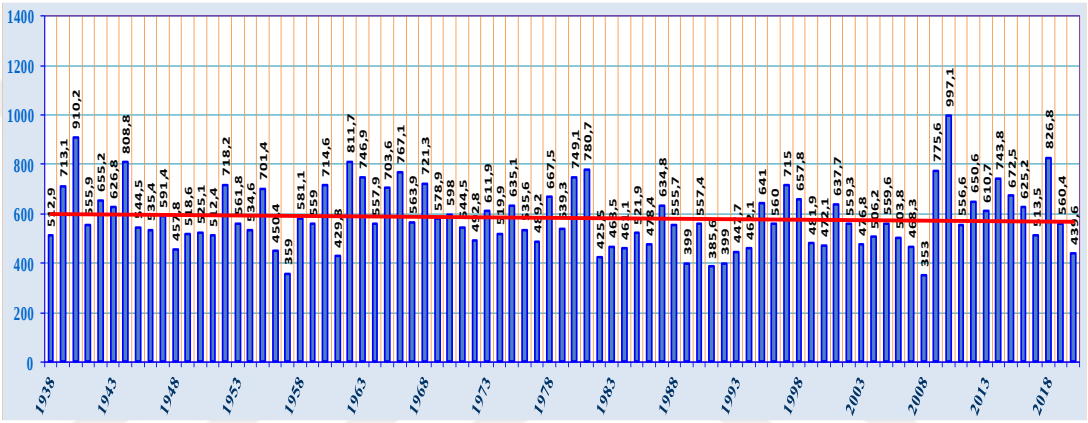


Figure 4.4: Balıkesir center annual precipitation distribution and trend between the years 1938-2020 (Data obtained from MGM, 2021).

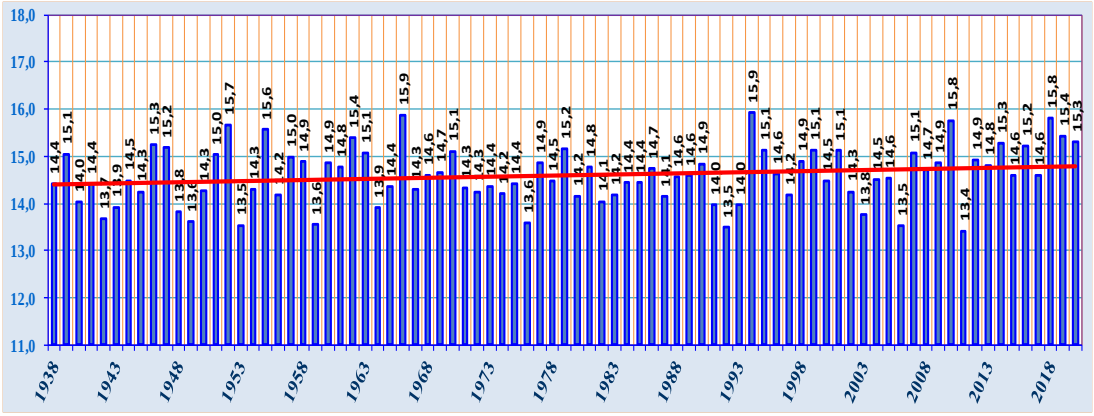


Figure 4.5: Balıkesir center monthly average temperature's annual average distribution and trend between the years 1938-2020 (Data obtained from MGM, 2021).

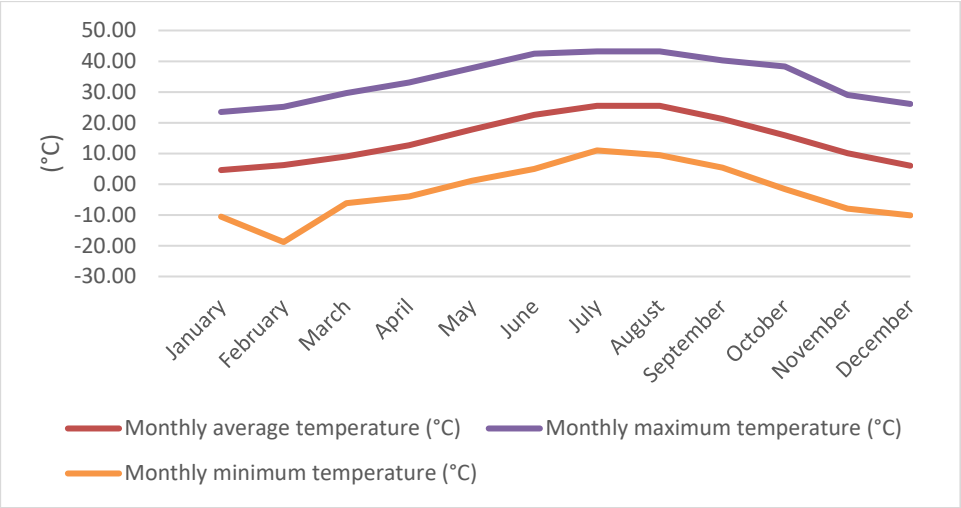
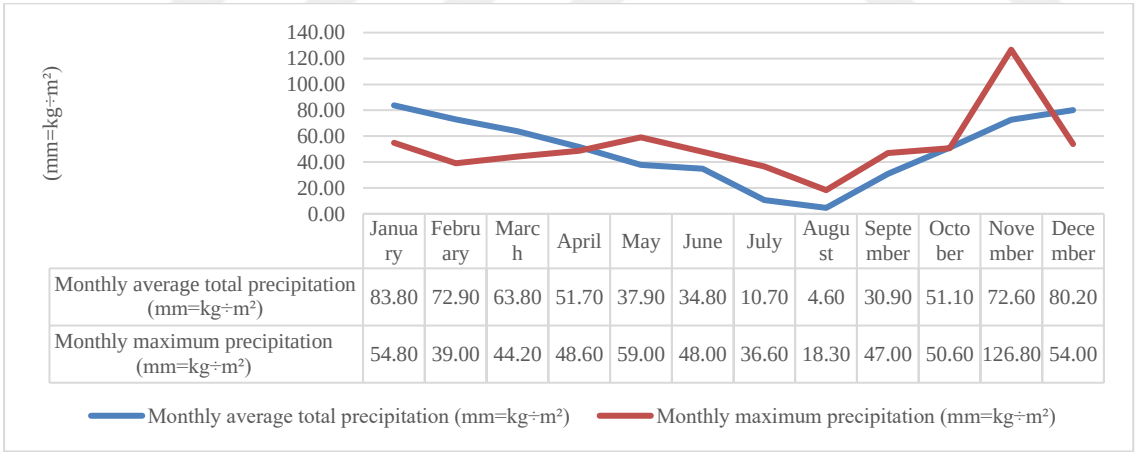


Figure 4.6: Balıkesir's temperature information for the years between 1999-2020 (prepared from data obtained MGM, 2021).

4.1.2 Rainfall

Balıkesir's 1991-2020 average precipitation is 598.3 mm, but when the 1999-2020 data is analyzed, it is 595 mm and the amount of precipitation is decreasing. Winter months are the rainiest season in Balıkesir which can also be seen in Figure 4.7. Where Balıkesir's monthly precipitation distribution between the years 1999-2020 is shown.



	January	February	March	April	May	June	July	August	September	October	November	December
Monthly average total precipitation (mm=kg÷m²)	83.80	72.90	63.80	51.70	37.90	34.80	10.70	4.60	30.90	51.10	72.60	80.20
Monthly maximum precipitation (mm=kg÷m²)	54.80	39.00	44.20	48.60	59.00	48.00	36.60	18.30	47.00	50.60	126.80	54.00

Figure 4.7: Balıkesir's precipitation information for the years between 1999-2020 (prepared from data obtained MGM, 2021).

4.1.3 Floods

Between the years 1955-2018, 169 flood events recorded in Susurluk Basin (Su Yönetimi Genel Müdürlüğü, 2018) (Figure 4.8). According to AYDES's (n.d.) statistics, when event type distributions are analyzed, events that happened in Balıkesir's 7,2% is floods which is the 3rd most frequent natural disaster type after

forest fires (37,9%), earthquakes (16,7), and landslides (12,6). Along with precipitation regime anomalies and extremes, human-induced factors such as unconscious planning approaches disregarding UWC within the urban planning context that leads to disproportional destruction of the natural pattern of the area, and planlessness all lead to flooding or contributing the devastating effects of them.

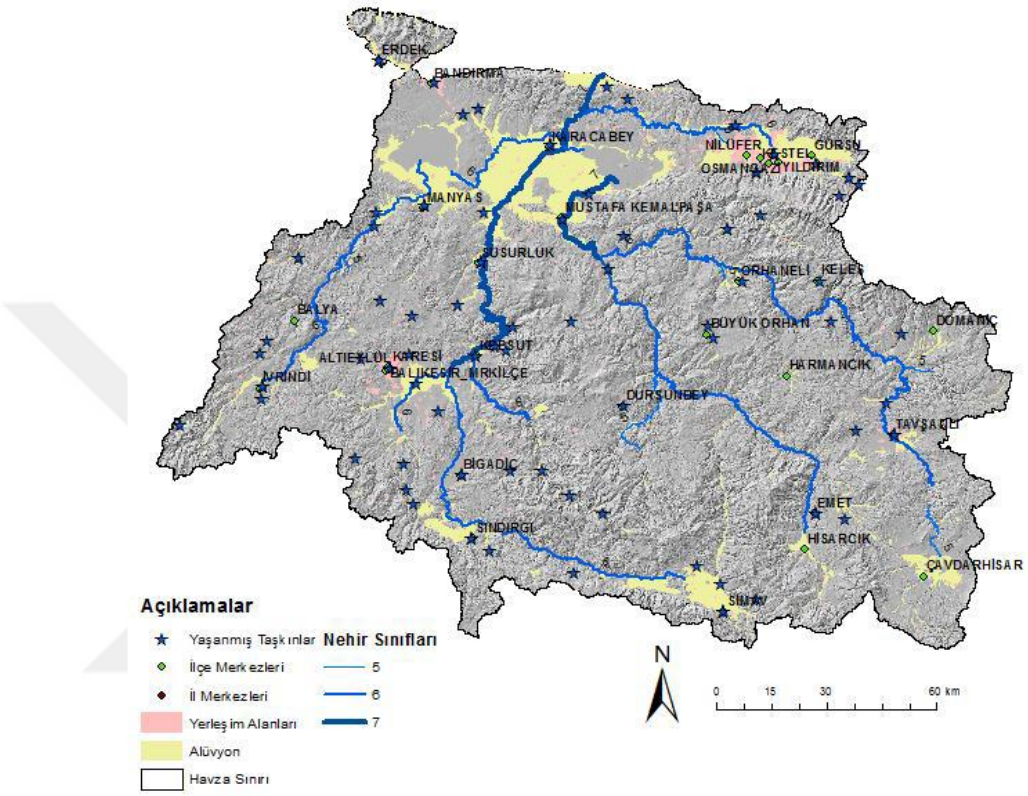


Figure 4.8: Floods happened in Susurluk Basin between 1955-2018 (Su Yönetimi Genel Müdürlüğü, 2018, pp.122).

4.1.4 Water resources and demand

Balıkesir is rich in terms of streams but these are small and none of them are big rivers and some are intermittent rivers (Analiz Engineering, 2018).

According to data obtained from BASKİ and personnel, the center's water demand was used to be provided from the wells around Halalca Village but after the construction of İkizcetepeler Dam, the water is provided from there by the means of transferring it into the drinking water treatment facility where it is distributed to the water tanks in various places with pipes (Table 4.3). Altıeylül's only water source is the water coming from the İkizcetepeler Dam; and the water consumption's minimum 30% is non-revenue water.

Table 4.3: Water abstraction for municipal water supply networks by water resources in 2018 (Water amounts are given in thousand m^3) (TÜİK, 2019).

Province	The total amount of water abstracted	Spring	Lake / artificial lake/sea	River	Dam	Well	The average amount of water abstraction per capita (Liter/capita/day)
Turkey	6193158	1138388	286196	560356	2468103	1740116	224
Balıkesir	138060	13209	7952	0	45770	71129	308

4.1.4.1 Surface water

Balıkesir's drinking and utility water source is İkizcetepeler Dam (Figure 4.9) that is constructed on Kille Stream (Aliağaoğlu & Mirioğlu, 2019) which has 960 ha surface area and provides drinking water for approximately 250000 people is also categorized as a protected area (Su Yönetimi Genel Müdürlüğü, 2018) (Figure 4.10). the storage capacity of the dam is 157.294 hm^3 and the active volume is 148.56 hm^3 (Analiz Engineering, 2018).

Figure 4.9: İkizcetepeler Dam (Photo taken in 04.12.2021).

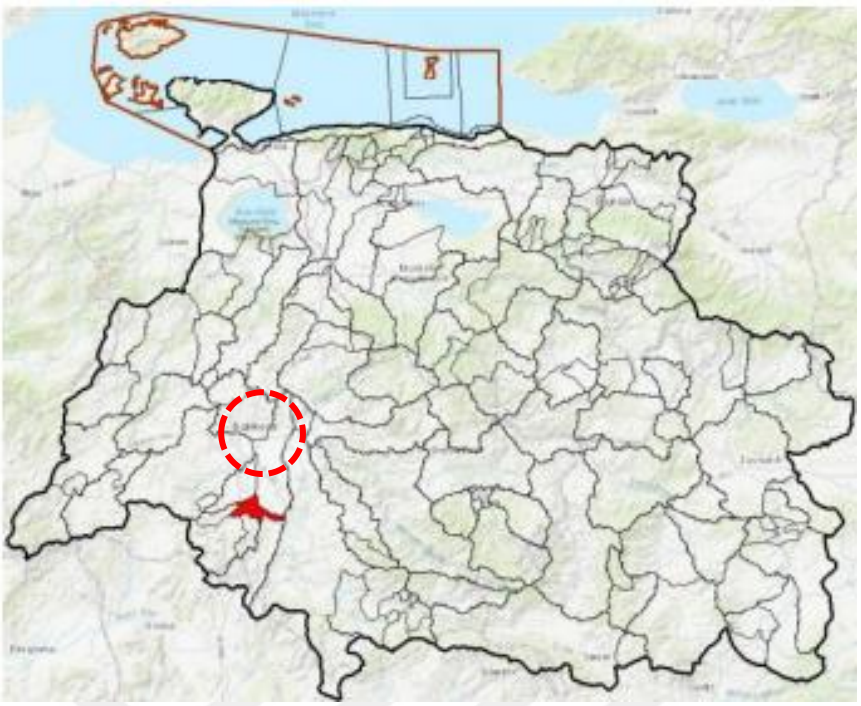


Figure 4.10: İkizcetepeler Dam's location (T.C. Tarım ve Orman Bakanlığı Su Yönetimi Genel Müdürlüğü, 2018a, pp. 574).

According to Balıkesir Provincial Directorates for Environment and Urbanization (2020), the water provided for the distribution of drinking and utility water network's distribution by the source is 53% from wells, 35% from dams, 10% from springs, and 2% from the ponds. Balıkesir has multiple dams and ponds as sources to provide its drinking and utility waters and İkizcetepeler Dam is one of those dams which is the one serving the center districts and 53 hm^3 water is drawn annually from it (Balıkesir Provincial Directorates for Environment and Urbanization, 2020). Alluvion areas and river beds of the area are as given in Figure 4.11 and Figure 4.12.

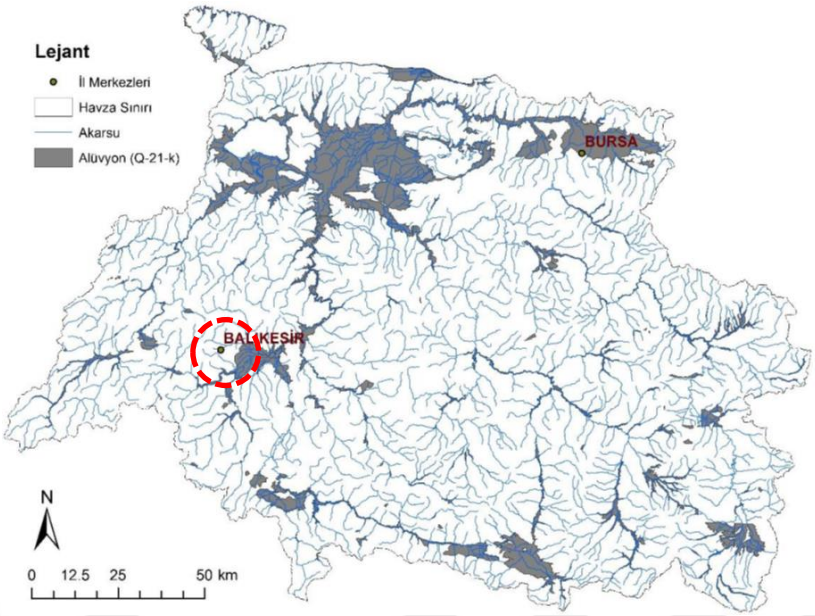


Figure 4.11: Alluvion areas (Su Yönetimi Genel Müdürlüğü, 2018, pp.54).

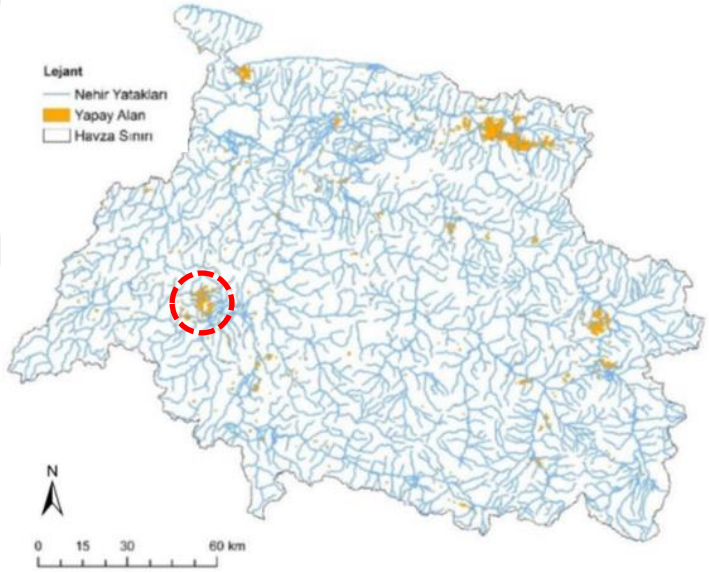


Figure 4.12: Map showing river beds and settlements (Su Yönetimi Genel Müdürlüğü, 2018, pp. 72).

4.1.4.2 Groundwater

Groundwater quality and quantity are taken under control with "By-Law on the Protection of Groundwater against Pollution and Deterioration" since 2012 parallel to EU groundwater management requirements (Kunt et al., 2020). Groundwater used for irrigation (42hm^3) is 3% of the total water usage in the category where 25% of it is drained illegally and cost recovery costs are reflected on the other 75% of users (31 hm^3) and the water extracted is mostly concentrated on one water body (T.C. Tarım ve Orman Bakanlığı Su Yönetimi Genel Müdürlüğü, 2018c) (Figure 4.13).

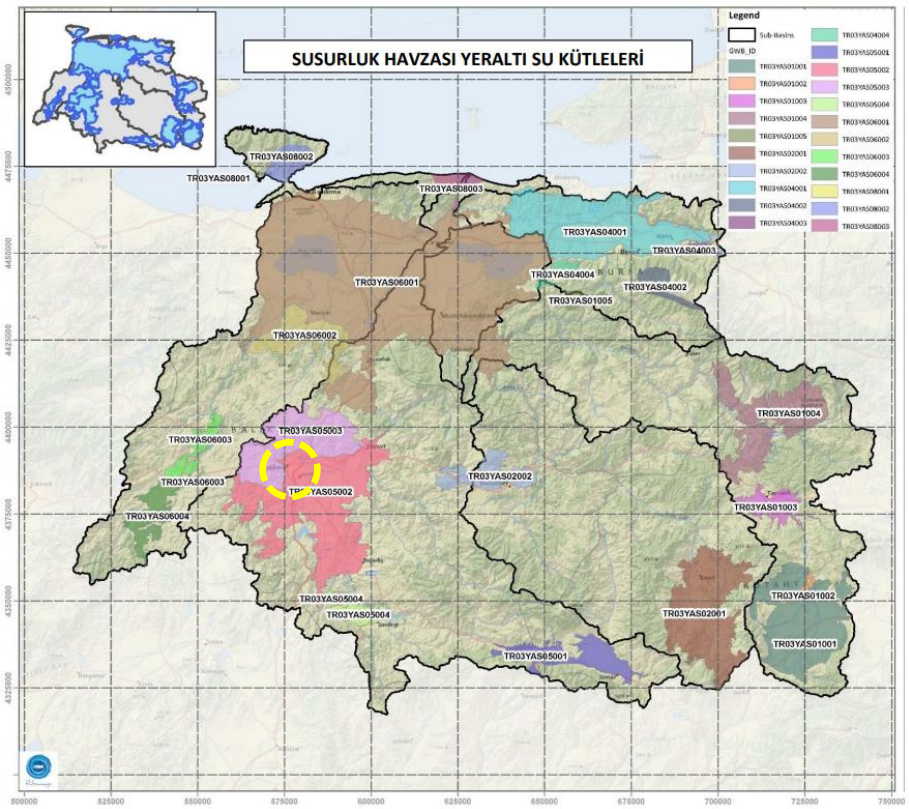


Figure 4.13: Groundwater masses in Susurluk Basin and Balıkesir center's location within context (T.C. Tarım ve Orman Bakanlığı Su Yönetimi Genel Müdürlüğü, 2018c, pp.10).

Two out of the 100 groundwater dams planned to be constructed in Turkey are planned to be constructed in Balıkesir (Palabıyık, 2021), one of them is opened in 2020 that has 60 m depth with 640000 m3 water capacity which aims to minimize water loss with evaporation with less with lower costs (DSİ, 2021).

There are two types of wells used which are type1 (up to 70m deepness) and type2 (71-250m deepness); while type2 wells are used for the groundwater mass that is labeled as "1" in Figure 4.14 and the water extraction cost is stated as 0-500 TL for, mass "2" uses type1 wells and water extraction cost is stated as 1000-5000 TL; average unit cost among the basin is 0.21 TL/m3 and repayments cover 38% of the expenses (T.C. Tarım ve Orman Bakanlığı Su Yönetimi Genel Müdürlüğü, 2018c). Even though these two masses are categorized as 'in good condition' about their quantity and stated that there is no issue of overusing groundwaters, their quality tests came out 'poor' (T.C. Tarım ve Orman Bakanlığı Su Yönetimi Genel Müdürlüğü, 2018c). Draw/recharge ratio for mass 1 is 0.31 and for the mass 2 is 0.69; urban and industrial areas are considered as one of the chemical polluting resources for the mass 2 (T.C. Tarım ve Orman Bakanlığı Su Yönetimi Genel Müdürlüğü, 2018b).

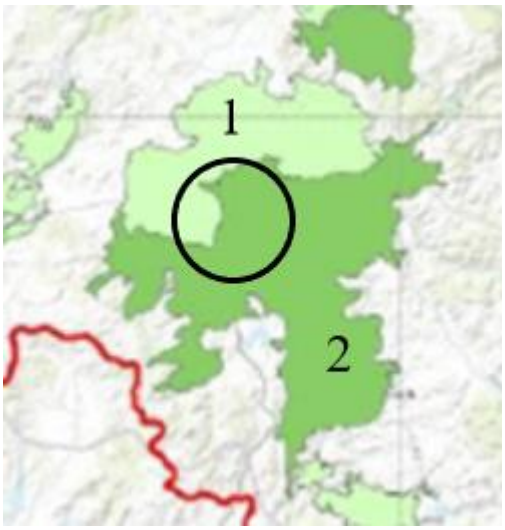


Figure 4.14: Groundwater masses where Balıkesir is located (adapted from T.C. Tarım ve Orman Bakanlığı Su Yönetimi Genel Müdürlüğü, 2018b, pp. 157).

According to Directorate General for Water Management's (2018), report prepared for the groundwater resources, the groundwater level in the area (Figure 4.15) is categorized as good and stated that the water level is not under threat which affected the decision-making period during the BMP selection and big detention structures were not proposed.

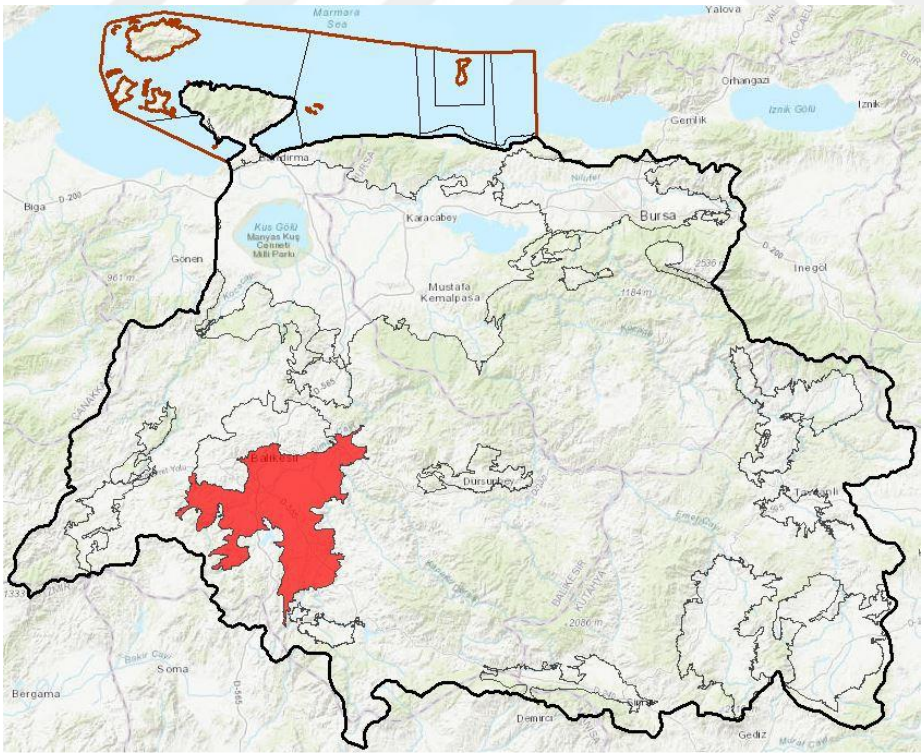


Figure 4.15: Case Study Area's settled groundwater source map (Directorate General for Water Management, 2018, pp.58).

According to BASKİ personnel's statement during the interview, the groundwater level map prepared by Aktimur et al. (1994) (Figure 4.16) is still viable; but the seasonal changes are occurring due to the precipitation regime.

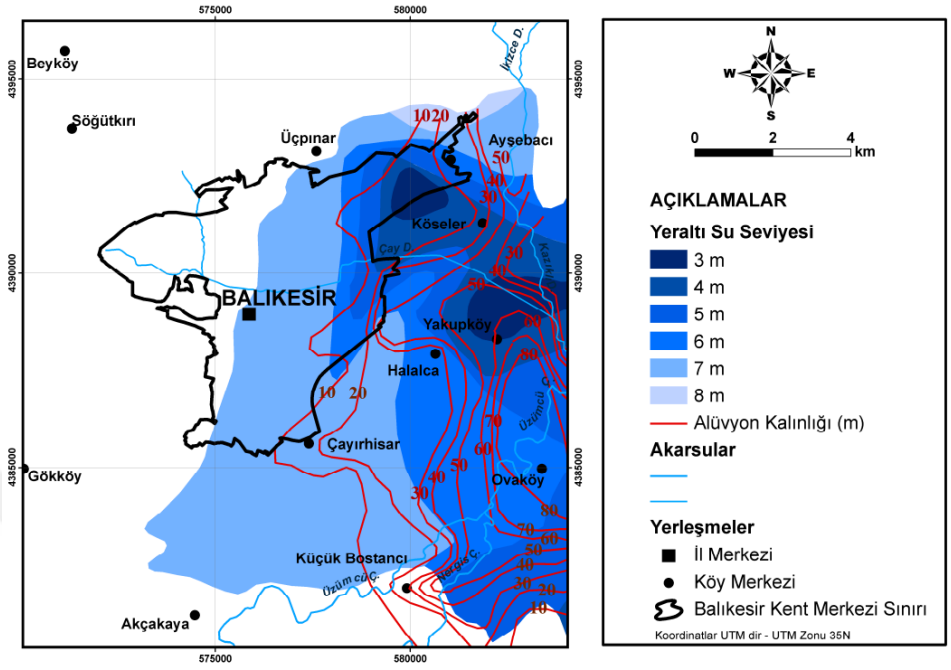


Figure 4.16: Altıeylül and Karesi districts' groundwater levels and alluvion depths (Aktimur et al., 1994 as cited in Gülen, 2008, pp.42).

4.1.5 Population

Balıkesir's population density is 87 person/km^2 (TÜİK, 2021a). It is a metropolitan municipality where the Center district has two municipalities which are Altıeylül and Karesi along with Metropolitan Municipality. Center districts are the two districts with the highest population (Table 4.4).

Table 4.4: Population of province/district centers, towns/villages and annual growth rate of the population by provinces and districts of the year 2020 (Prepared with the data obtained from TÜİK).

Province and district	Population			Annual growth rate of the population (‰)
	Total	Province and district centers	Towns and villages	
Turkey	83614362	77736041	5878321	5.5
Balıkesir	1240285	1240285	-	9.4
Altıeylül	182073	182073	-	4.3
Bahçelievler	40419	40419	-	n.d.

The average household size in Balıkesir is showing similar trends with Turkey and declining (Figure 4.17).

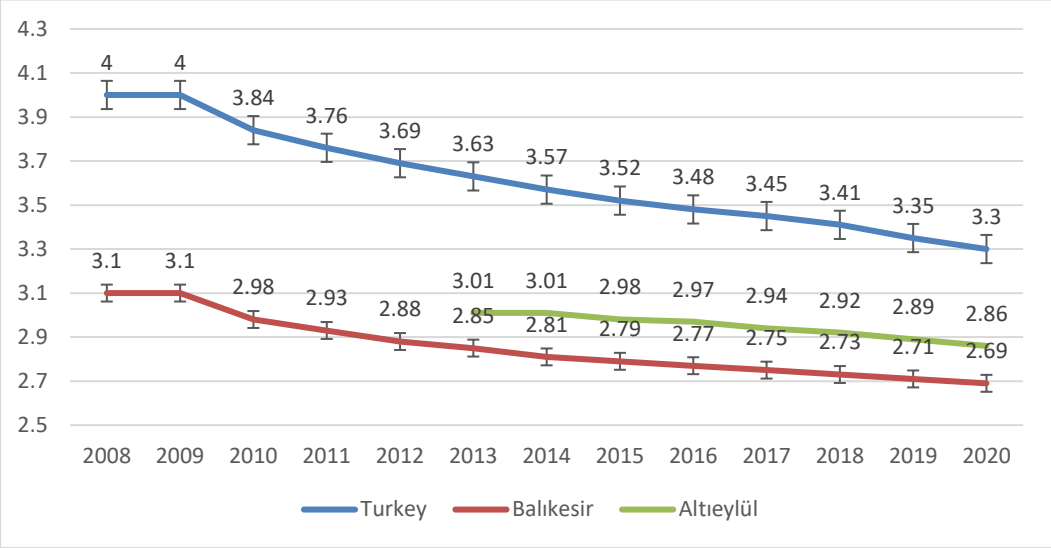


Figure 4.17: The average household sizes of Turkey and Balıkesir (TÜİK, 2021b).

Bahçelievler's 2020 household size is defined as 2,8 (enspd, 2017). Balıkesir's population is increasing (Figure 4.18), but with a declining trendline (Figure 4.19).

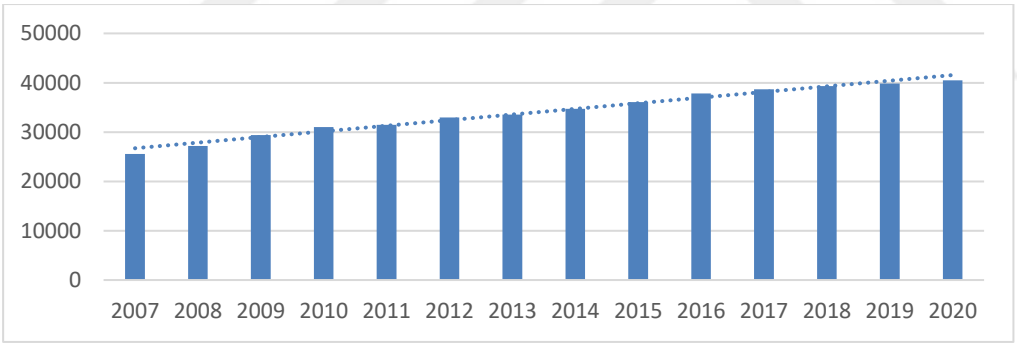


Figure 4.18: Bahçelievler Neighborhood's population change in years between 2007-2020 (prepared with the data obtained from TÜİK).

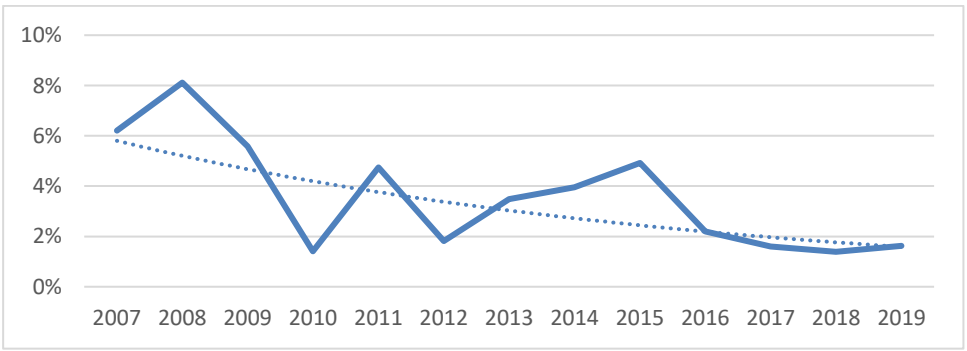


Figure 4.19: Bahçelievler Neighborhood's population growth rate in the years between 2007-2019 (prepared with the data obtained from TÜİK).

4.2 Study Area and Methodology

The case study area (Bahçelievler neighborhood) covers 240.69 ha area (Figure 4.20). The contour lines are between 118-151m and the area is not steep and almost flat.

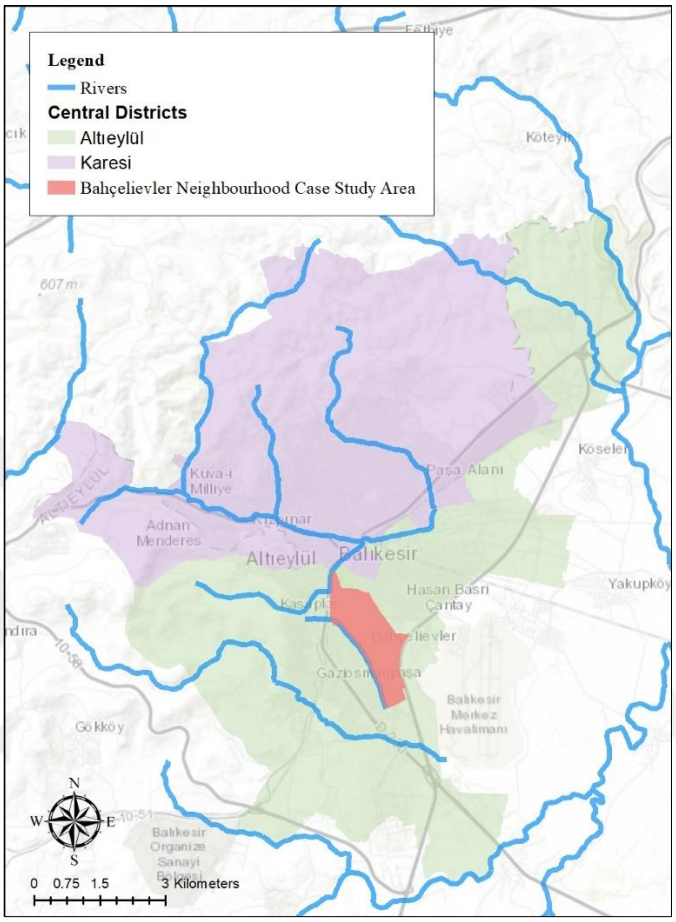


Figure 4.20: Balıkesir's central districts and case study area's relationship.

For the data used in the study, used data are as specific as the data is obtainable, whenever the data were not available at the current scale for Bahçelievler neighborhood, respectively Altıeylül's, Balıkesir Center districts', and Balıkesir's data were used. Reports, papers, and books were analyzed related to the topic and/or data; institutional opinions were taken in verbal form and/or written reports. For the site suitability of the BMPs, USEPA's System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) system's BMP Siting Tool were used which has an open to public access, and for the evaluation of the system with BMPs, the E^2Stormed tool has been used which is again an open to public access tool.

SUSTAIN is a decision support framework that is developed by the USEPA to select and place stormwater BMPs in the most appropriate locations that are compatible with

various scales based on their cost-effectiveness (Shoemaker et al., 2009). The tool is publicly available and can be downloaded from https://www.epa.gov/water-research/best-management-practices-bmps-siting-tool. The components of SUSTAIN are: BMP siting tool, watershed runoff and routing module, BMP simulation module, BMP cost database, post-processor, and an optimization module; and the process starts with the BMP siting tool to determine suitable areas for 14 BMPs which are: constructed wetland, grassed swale, green roof, infiltration basin, infiltration trench, porous pavement, bioretention, vegetated filter strip, sand filter (surface), sand filter (non-surface), rain barrel, cistern, wet pond, and dry pond (Shoemaker et al., 2009).

The BMP siting tool assists the user in selecting the most suitable location for the BMPs by using site suitability analysis in ArcGIS with 8 criteria which are elevation, slope, soil type, urban land use, roads, water table depth, stream location, and drainage area (Table 4.5); the default criteria can be changed accordingly to user preference; but for this study, default values are used and for dry pond areas, the suitability is refined to public lands.

Table 4.5: Default criteria for BMP suitable locations used in SUSTAIN BMP Siting Tool (Shoemaker et al., 2009, pp.29).

BMP type	Drainage area (acre)	Drainage slope (%)	Impervious (%)	Hydrologic soil group	Water table depth (ft)	Road buffer (ft)	Stream buffer (ft)	Building buffer (ft)
Bioretention	< 2	< 5%	> 0%	A–D	> 2	< 100	> 100	--
Cistern	--	--	--	--	--	--	--	< 30
Constructed Wetland	> 25	< 15%	> 0%	A–D	> 4	--	> 100	--
Dry Pond	> 10	< 15%	> 0%	A–D	> 4	--	> 100	--
Grassed Swale	< 5	< 4%	> 0%	A–D	> 2	< 100	--	--
Green Roof	--	--	--	--	--	--	--	--
Infiltration Basin	< 10	< 15%	> 0%	A–B	> 4	--	> 100	--
Infiltration Trench	< 5	< 15%	> 0%	A–B	> 4	--	> 100	--
Porous Pavement	< 3	< 1%	> 0%	A–B	> 2	--	--	--
Rain Barrel	--	--	--	--	--	--	--	< 30
Sand Filter (non-surface)	< 2	< 10%	> 0%	A–D	> 2	--	> 100	--
Sand Filter (surface)	< 10	< 10%	> 0%	A–D	> 2	--	> 100	--
Vegetated Filterstrip	--	< 10%	> 0%	A–D	> 2	< 100	--	--
Wet Pond	> 25	< 15%	> 0%	A–D	> 4	--	> 100	--

After finding the potential site locations for each BMPs, 4 scenarios (current situation, BASKİ's conventional plan that has a separate drainage system, BMPs with 15% error margin, and BMPs with 30% error margin) are compared with E^2Stormed software was used which is developed by the Polytechnic University of Valencia (Spain) with the assistance of the University of Abertay Dundee for the E^2STORMED project that was conducted in Mediterranean cities with the cooperation of 8 other project partners from different countries for the energy efficiency improvement with stormwater management interventions (Morales Torres et al., 2015). The software is a Decision Support Tool (DST) used for urban stormwater management that considers social, environmental, and energy criteria as well as financial criteria and allows the comparison of different drainage scenarios and their effectiveness (Morales Torres et al., 2015). The tool helps with the construction and maintenance costs of the proposed BMPs and the project results indicate that the costs of SUDS are similar to conventional options therefore SUDS options provide the benefits of ecosystem services and energy efficiency without the need for an extra monetary source for the stormwater management (*E2STORMED - Improvement of Energy Efficiency in the Water Cycle*, 2019). It is also publicly available which can be downloaded from E2STORMED - Improvement of energy efficiency in the water cycle by the use of innovative storm water management in smart Mediterranean cities | RBMP Life Malta.

E^2Stormed DST includes common variables and combines them with energy efficiency parameters and seeks to combine the knowledge obtained from other EU programs and improve it for use in MED regions; therefore, it is stated that the tool is an enhanced version of the Comparing the Flexibility of Alternative Solutions (COFAS) tool which was developed for SWITCH program (Berwick et al., 2015).

The case study area covers 240.69 ha area. Buildings cover 50.7 ha area. Roads cover 48 ha area when refuges (1.34 ha) are excluded. More detailed information is given in Figure 4.21 and Table 4.6.

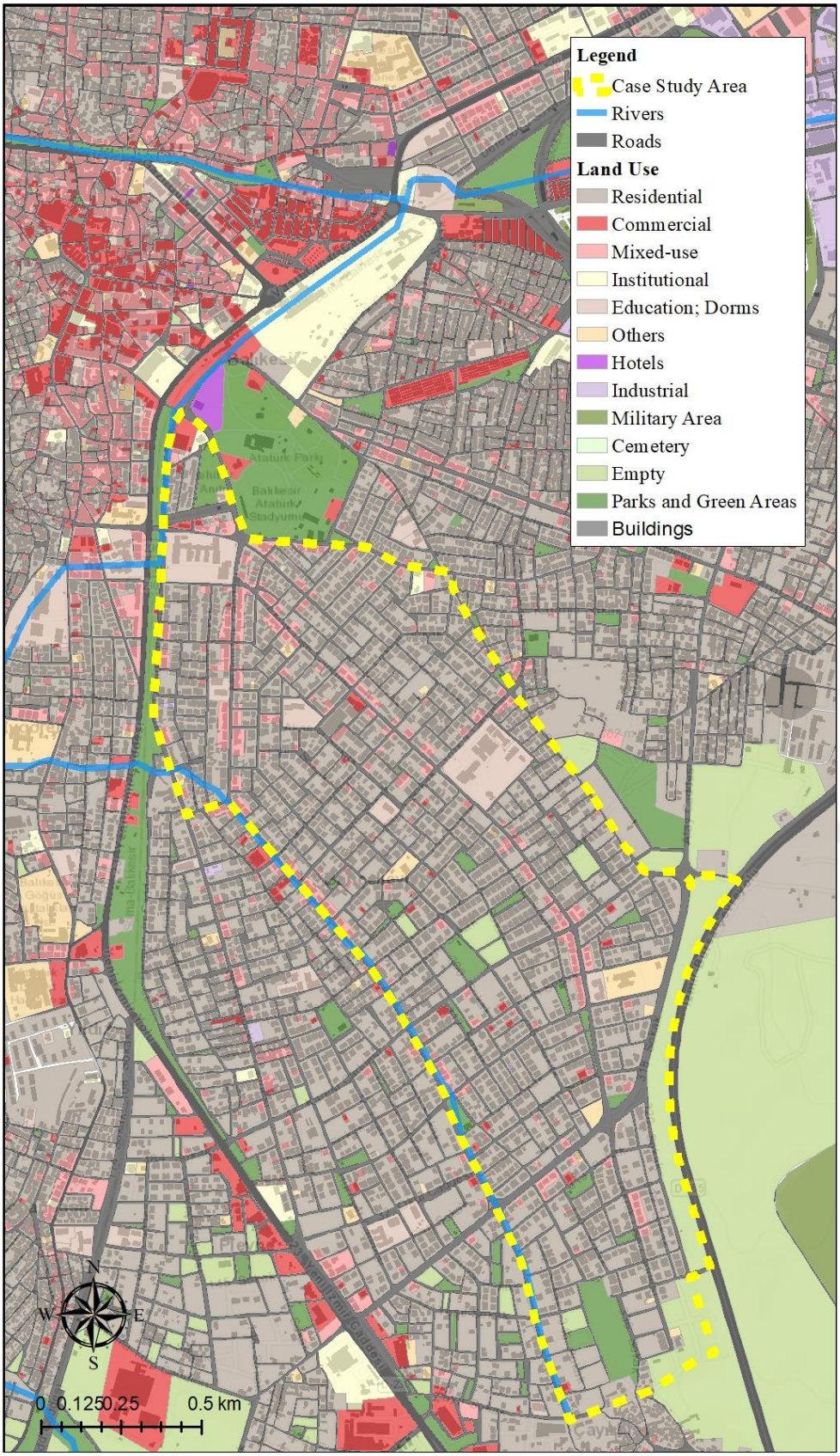


Figure 4.21: Land use and spatial distribution of the buildings.

Table 4.6: Basic land use distribution of the case study area and their areas.

		building area (ha)	plot area (ha)	Total (ha)
buildings	residential	41.9	95.77	137.67
	educational	1.91	7.53	9.44
	health	0.2	1.55	1.75
	commercial	0.74	1.5	2.24
	mixed use	5.19	10.45	15.64
	dormitory	0.15	0.23	0.39
	religious	0.18	0.68	0.86
	Other	0.42		
	total	50.7	117.71	
parks and recreational areas				8.45
roads				48
median strips				1.34
empty lots				14.1
*numbers may not add up due to rounding				

4.2.1 Bahçelievler's water resources

Altıeylül district has Simav, Kazıklı, and Koz streams (Figure 4.22) (Analiz Engineering, 2018). There is 1 reclaimed river in the area. Altıeylül's only source of water is İkizcetepeler Dam, which also applies to Bahçelievler Neighborhood. Therefore, the water demand of the area relies on only one source, and one of the purposes of the BMP applications is to diversify the sources while minimizing the non-revenue water consumption which is minimum 30%.

There are both wastewater treatment plant and drinking water plant that serve the center districts; wastewater treatment plant's capacity is 67117 m^3/day, has biologic filters that are doing trickling filtering and discharging into the Üzümcü stream (Balıkesir Provincial Directorates for Environment and Urbanization, 2020) (Figure 4.23).

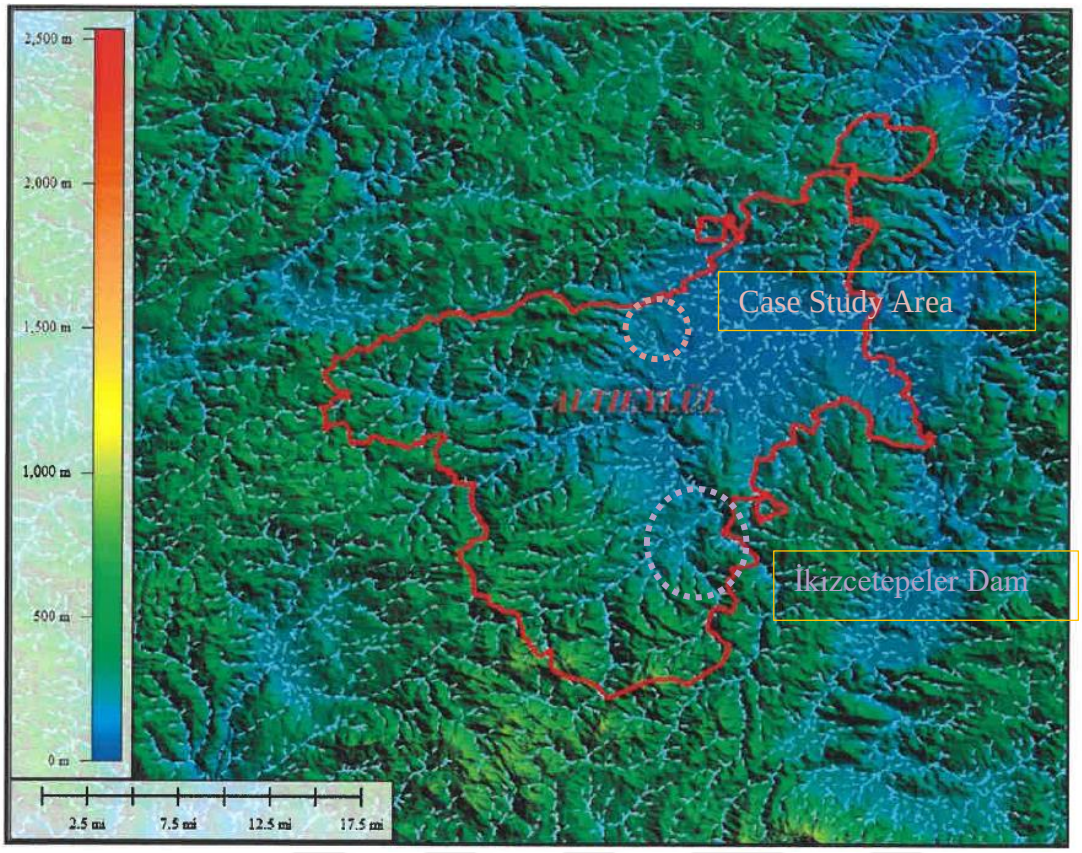


Figure 4.22: Altıeylül district's drainage and streams (Analiz Engineering, 2018, pp.107).

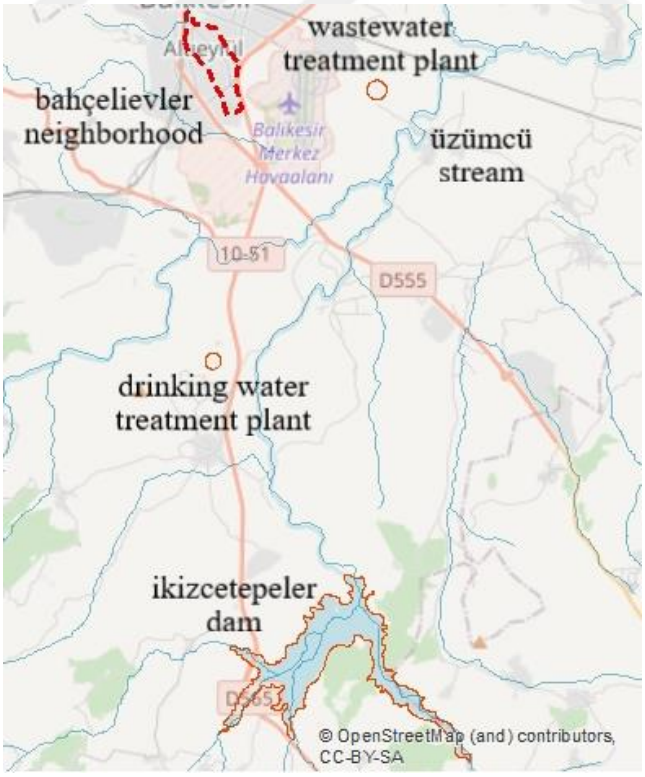


Figure 4.23: Balıkesir Center wastewater treatment plant and Üzümcü Stream.

4.2.2 Sectoral and domestic water use

100% of Bahçelievler's water is coming from İkizcetepeler Dam which is transferred to the drinking water treatment plant and then transferred to the water tanks with pipes and distributed from there; the end uses of the neighborhood are as given in Table 4.7.

Table 4.7: Bahçelievler neighborhood water end uses and their share in total use (Prepared with the data obtained from BASKİ).

Annual water end-uses in m^3	2016	2017	2018	2019	2020	%
Residential	1562137	1573905	1633419	1625176	1783973	93
Office/commercial	66798	73203	75916	76983	63410	3
State office	6725	18888	21.972	22896	17994	1
Park/garden irrigation	31	0	846	1067	2041	0
Construction sites	15658	17731	17745	14005	21458	1
Associations and foundations	0	8	26	67	155	0
School/health	53654	57590	48321	43248	25203	1
Total	1705261	1741325	1798245	1783442	1914234	100

As it can be seen, the end uses of the water in the neighborhood is consistently domestic uses. As mentioned in chapter 3.6, domestic end-uses of water that can easily be replaced with rainwater harvesting are: laundering (13%), reservoirs (25%), and garden irrigation (5%) which sums up to 35% of the total residential use, for further use of the stormwater/rainwater, other treatment methods are necessary since the water becomes directly used by the household.

In Susurluk Basin, the graduated tariff is prevalent which can result in great payment gaps, especially in urban areas; monthly average payment calculated for a house that uses 14.46m3 water is 67 TL for urban users and 18 TL for rural users where more than 75% of that amount is for procurement; total amount paid is about 1.6% of the disposable household income which is categorized as great exertions (T.C. TARIM VE ORMAN BAKANLIĞI SU YÖNETİMİ GENEL MÜDÜRLÜĞÜ, 2018c).

According to BASKİ personnel, water losses in the supply system are minimum of 30%.

4.2.3 Drainage system

The drainage system installed in Balıkesir is still combined where rainwater, stormwater, and wastewater are all collected in a single system and carried to treatment facilities. According to the Republic of Turkey Climate Change Action Plan prepared for 2011-2023 (BASKİ, 2019), separating stormwater and wastewater drainage system

from each other in settlements is a goal that has been set and them being combined system is counted as a subject to be improved (BASKİ, 2019). Separate system plans are due to be prepared in 2019 and completed in 2024 according to BASKİ's report. However, as BASKİ's project branch manager explained, even though its project design and reports are completed, the construction phase has not started yet due to economic reasons. As he explained further during the interview, rainwater that falls on urban areas are not collected for treatment or other purposes but just channelized from the urbanized areas as soon as possible to prevent flooding; therefore, the main principle Is to discharge them to the closest receiving environment with the pipe connections (ARISU, 2018). According to the project report, ARI value is taken 3 years, which shows parallelism with Liu et al.'s (2016) opinion which states that using smaller ARI events that do not last long but has a high intensity for the design gives more feasible results since these events are the main pollutant sources even though they may seem to generate smaller portions of runoff water, they happen more frequently; therefore this approach leads to more cost-efficient results with possibly less land. Runoff coefficient (C) is taken as 0.6; however, that calculation leads to very large pipe radiuses which are stated that almost impossible at some points (ARISU, 2018), which could be prevented with detention systems when WSUD policies are adopted.

4.2.4 A BMP configuration proposal for Bahçelievler

As explained so far, BMPs, which are also named LIDs are a great contribution to a place without bringing extra monetary burden. Therefore, in order to understand which types of BMPs are suitable and how they can contribute to the site they are applied to are investigated. To sum up, the basic info about the general data about the neighborhood is as given in Table 4.8.

Table 4.8: Population and water use in Bahçelievler (Prepared from the data obtained from TÜİK, 2021b and BASKİ).

	2016	2017	2018	2019	2020
household size	2.71	2.73	2.75	2.77	2.69
population	37844	38678	39299	39845	40491
growth rate %	2	1.6	1.4	1.6	
water use (m^3)	1705261	1741325	1798245	1783442	1914234
water demand per capita	45.0	45.0	45.7	44.8	47.3

In order to determine the needs of the area, aims are reviewed to fit and meet the area's unique and common needs while trying to minimize the problems the area is facing. Accordingly, determined aims for the case study area are:

- Revitalizing the area not for just humans but all living environments,
- Increasing environmental health,
- Reducing the pollutant load of the runoff water,
- Providing an alternative water source for fit-to-purpose usage of the water,
- Mitigating the effects of flooding,
- BMPs complimenting each other,
- Easiness of the applying and maintenance,
- Flow and volume control of runoff water,
- Water quality improvement for the groundwater and surface waters,
- GHG emission decrement,
- Providing visual improvement,
- Economic benefits from the harvested water and less dependency on utilization water,
- Source usage getting closer to the consumption area,
- Decreasing the urban heat island effect and increasing thermal comfort while decreasing the energy needed for it
- Increasing the awareness
- Reducing energy costs for the transporting of the water and building energy costs
- Decreasing stormwater management costs and treatment costs
- Integrating water and functional landscape more into the built environment
- Decreasing wastewater and its treatment costs
- Improving the air quality

When choosing the BMPs for the proposal, out of 14 BMPs (constructed wetland, grassed swale, green roof, infiltration basin, infiltration trench, porous pavement, bioretention, vegetated filter strip, sand filter (surface), sand filter (non-surface), rain barrel, cistern, wet pond, and dry pond) that SUSTAIN enables are refined according to their benefits; and BMPs that provide multiple benefits are preferred which is evaluated from the E^2Stormed's benefit table since that is the tool used for the benefit evaluation part of the project.

According to information obtained from BASKİ, the water table depth of the area changes between 7 to 10 meters depending on the seasons; which makes it suitable for all BMP types given in SUSTAIN's criterion. As the reports present, the groundwater level in the area is not under stress, therefore extra measures with the primary aim as groundwater recharging are discarded, and determined measures' level is seen as sufficient for extra recharge. Therefore, infiltration trenches and infiltration basins are opted out.

Even though there are suitable locations for constructed wetlands (Figure 4.24) and wet ponds which have the same default constraints when the water table level is reconsidered, the default criteria for the wet ponds and constructed wetlands are given as greater than 4 ft (1.22 m); however, the deeper the groundwater table gets, it gets harder to maintain; also, their location configuration was seen as unsuitable when built environment around the available areas are taken into consideration. Therefore, they are opted out of the scenario.

Porous pavements, infiltration basins, and infiltration trenches are calculated as unsuitable according to SUSTAIN's criteria; however, when porous pavements' positive aspects are considered, and since they are versatile systems that can be modified into the areas' needs with small changes such as underdrains; porous pavements are included in the scenario.

The soil hydrological soil type of the area is C-D according to the information obtained from the BASKİ; therefore, infiltration trenches, infiltration basins, and porous pavements are not suitable for the area as can be seen from table 4. The drainage areas' digital data is also obtained from BASKİ.

Rain barrels and cisterns are considered as a single solution since rain barrels are the simpler version of the cisterns and the option is combined with green roof alternative on the roofs.

Vegetated filterstrips are preferred over sandfilters as they are supporting the natural habitat and are easy to construct and maintain.

Figure 4.24: Suitable areas for constructed wetlands and wet ponds.

As a result, the selected BMPs for the area are: vegetated filterstrips, grassed (vegetated) swales/buffer strips, bioretention, dry ponds (retarding basins), rain harvesting systems coupled with green roofs, and porous pavements (Table 4.9).

Table 4.9: Proposed systems and their benefits (adapted from Morales Torres et al., 2015, pp.167-168).

-	Green roofs	Permeable pavements	Bioretention areas	Rain gardens	Vegetated swales	Detention basins or dry ponds
Aesthetics	*	*	*	*		*
Air quality improvement	*					
Amenity	*	*	*	*		*
Baseflow augmentation			*			*
Community education and engagement	*				*	
Cost savings for surface water management	*					

Table 4.9 (continued): Proposed systems and their benefits (adapted from Morales Torres et al., 2015, pp.167-168).

-	Green roofs	Permeable pavements	Bioretention areas	Rain gardens	Vegetated swales	Detention basins or dry ponds
Cost-effective to construct						*
Decreased burden on the sewage system	*					
Extension of the operational life of roof	*					
Firm dry surfaces to park and walk on after heavy rain		*				
Food growing			*	*		
Groundwater recharge		*			*	*
Gross value added growth						*
Habitat provision and enrich biodiversity	*	*	*	*	*	*
Improved community cohesion	*		*	*		
Improved insulation	*					
Improvements to public health			*	*		
Increase in property values	*		*	*	*	
Noise attenuation	*					
Protection of receiving waters		*				
Provision of educational opportunities	*				*	
Recreational use			*	*	*	
Reduced land take/small footprint		*				
Reduction in energy bills/ costs	*	*	*	*	*	
Reduction of flood risk	*		*	*	*	*
Reduction of greenhouse gas emissions	*	*	*	*	*	
Reduction of gullies need		*				
Reduction of surface ponding cost-effective and durable source control technique		*				
Regulation of urban microclimates	*		*	*	*	
Removal of urban pollutants	*	*	*	*	*	*
Restore natural hydrology	*	*				
Retrofittable		*	*	*		
Runoff reduction and attenuation	*	*	*	*	*	*
Visual and landscape benefits	*	*			*	
Water quality control	*	*	*	*	*	*
Water quantity control	*	*	*	*	*	
Water storage and re-use		*				
total score	24	19	19	18	16	11

Whenever an area is suitable for more than one BMP and options overlap, respectively bioretention areas, dry ponds, grassed swales, and vegetated filter strips are prioritized; porous pavements and green roofs do not overlap with other alternatives since they are situated impervious areas which are opted as unsuitable areas in the suitability part of the study. The bioretention areas, dry ponds, grassed swales, and vegetated filter strips are considered with 15% and 30% error margins.

4.2.4.1 Green roofs and water harvesting

The green roofs are taken into consideration for every building to understand the full capacity of the system; as mentioned in chapter 2.3.4.10, green roofs and walls also allow rainwater harvesting even though the water obtained from the green roofs are less than the conventional roofs which is taken into consideration; on the other hand, they help with the filtration of the pollutants and provide other benefits such as better insulation, creating habitat for the flora and fauna, decreasing the urban heat island effect, increasing the roof life they implemented, increase the amenity and the value of the property as well as environmental quality improvement, increase air quality etc.

Rain harvesting of the area is considered to be a solution as an alternative water source for domestic use as well, but cisterns and rain barrels are not considered as different solutions since both of their restraints are the same and rain barrels are the simplified version of cisterns.

While calculating the rain harvesting tank capacities, the month that has the most precipitation has been taken into consideration which is 83.8 mm in January. As a result, the required tank capacity is calculated as 30590 m3.

When the whole roof areas' (50.7 ha) (Figure 4.25) rain catchment capacity is calculated, Balıkesir's long-term annual precipitation is 598.3 mm which means 598.3 liters/m^2 therefore:

598.3 liters/m^2 x 507000 m^2 = 303338100 liters of water can be obtained from the roof surfaces.

When this amount is multiplied by 0.9 filter efficiency coefficient (DIN, 1989 as cited in Yalılı Kılıç & Abuş, 2018) and 0.8 rational runoff coefficient:

303338100 x 0.8 x 0.9 = 218403432 liters of water can be harvested from the roofs annually.

Since the green roofs are used, 50% of that value is used by the green roofs (which is the default value given in the E^2Stormed tool) themselves, as a result, 109201716 liters of water can be harvested from the green roofs for nonpotable water consumption. However, when the safety coefficient is taken as 0.75 as mentioned in chapter 3.6 that is given for different roof materials, leakages, and other situations, 182002860 liters is found where 50% is 91001430 liters in a year.

The area is 93% residential, therefore calculations have proceeded accordingly with the residential demands where 43% of the water used can be replaced with nonpotable harvested rainwater. For the calculations, the latest year's data are considered which is the year 2020. 1914234 m^3 water used in Bahçelievler in 2020. 43% of that amount is 823120.62 m^3 which can be used from the harvested rainwater; which means 11% of the nonpotable water demand can be met with the harvested rainwater from the roofs.

As mentioned in chapter 4.8, since the Ministry of Environment and Urbanization's "legislation about rainwater harvesting, storing, and discharging" necessitates rainwater tanks for the constructions that are constructed on lands bigger than 2000 square meters, the parcels bigger than 2000 m^2 are calculated and as a result, they cover 33.9 ha area.

The parcels where the building coverage ratio (BCR) is higher than 40% cover 58.95 ha area which can be said urbanization densifies and can be prioritized during the phasing period.

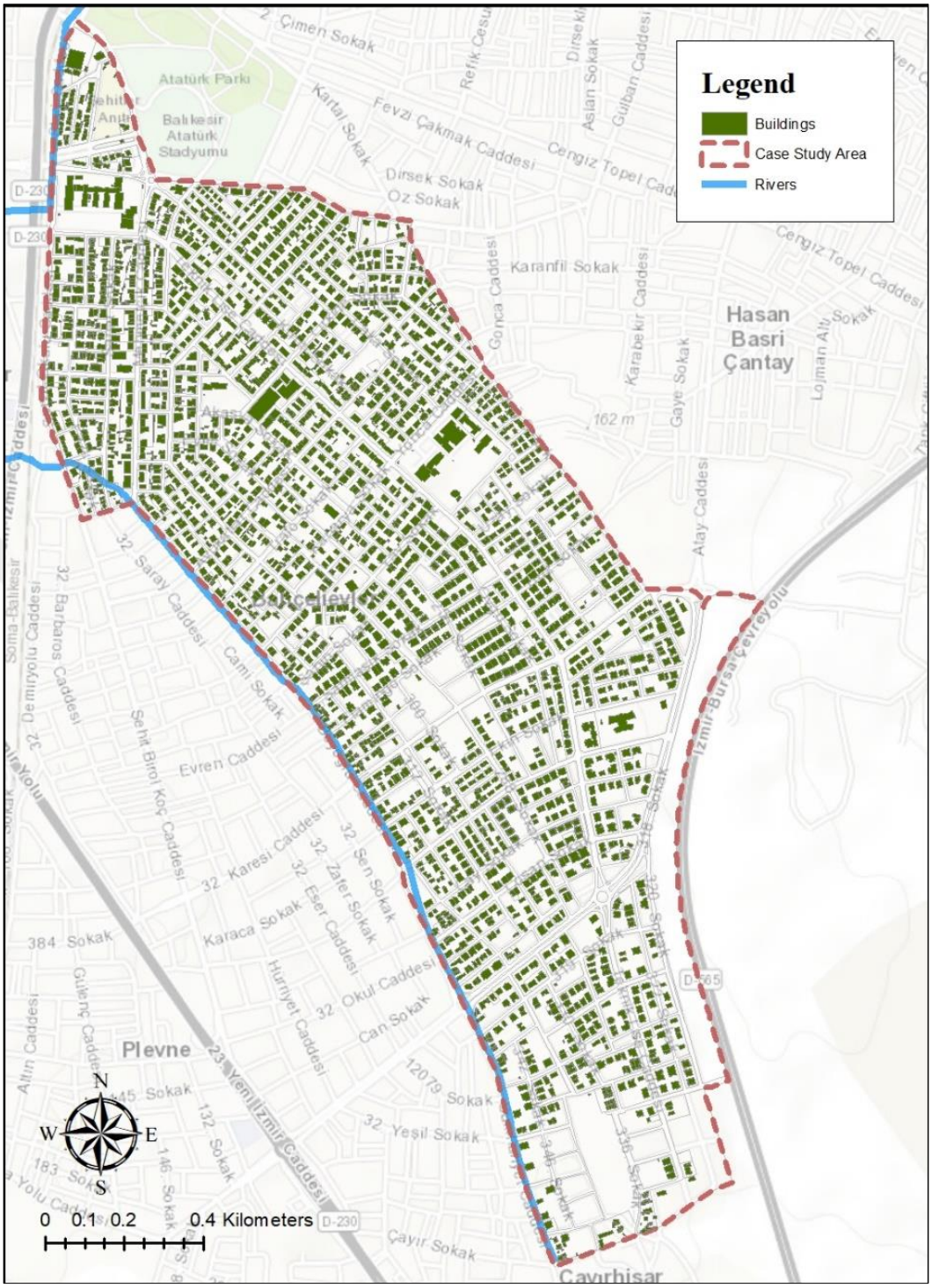


Figure 4.25: Green roofs.

4.2.4.2 Permeable / porous pavements

Roads cover 48 ha area which makes it 20% of the whole area (Figure 4.26) and therefore even though the natural soil type of the area is unsuitable for the solution, it is worth the extra effort to make modifications on the system such as underdrains. Also, as mentioned in Chapter 2.3.4.9, they contribute the infrastructure system by supporting healthier growth of the trees as well.

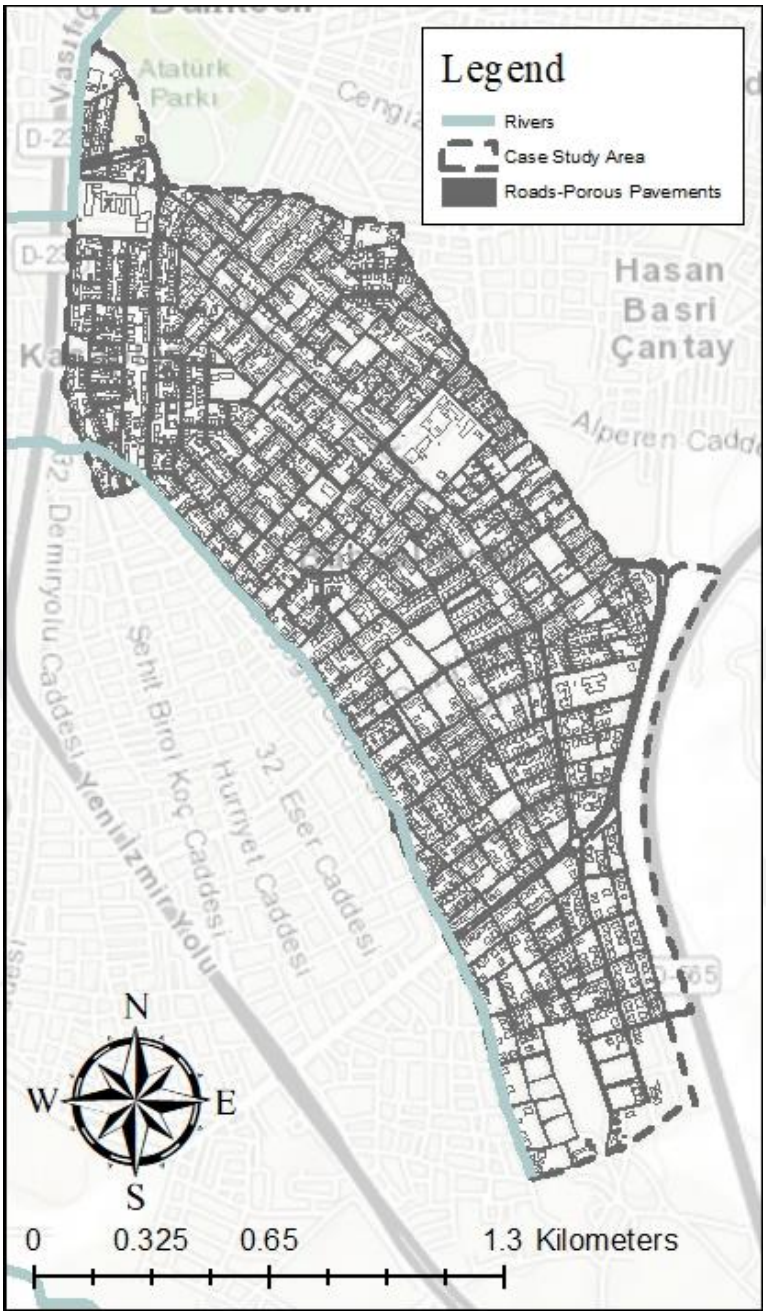


Figure 4.26: Roads.

4.2.4.3 Bioretention areas and rain gardens

As aforementioned, bioretention areas are great at pollutant removing and when applied properly, and distributed around the properties, they improve the aesthetic amenity of the area and maintenance easiness which usually can be handled by the homeowners or gardeners with proper guidance.

Bioretention areas are calculated and the 15% margin for impervious areas and error was given to recheck the area sizes. As mentioned in chapter 2.3.5.3, their sizes usually change between 0.1 to 2.5 acres; therefore, when the results are analyzed, there was

not an area bigger than 2.5 acres, but areas smaller than 0.1 acres are considered raingardens rather than bioretention areas. Areas available for bioretention are calculated as 25 ha and after the bioretention-raingarden division, 22.4 ha area is calculated as available areas for bioretention and 2.6 ha for raingarden areas where 15% is excluded, respectively 19.04 ha and 2.21 ha areas are considered in 15% error margin scenario (Figure 4.27). The same steps are followed to find the suitable areas when the error margin is given 30 %; which resulted in 21.67 ha area for bioretention areas and 3.34 ha area for raingardens; which are calculated 15.16 ha and 2.34 ha as the remaining area after the error margins are excluded (Figure 4.28).

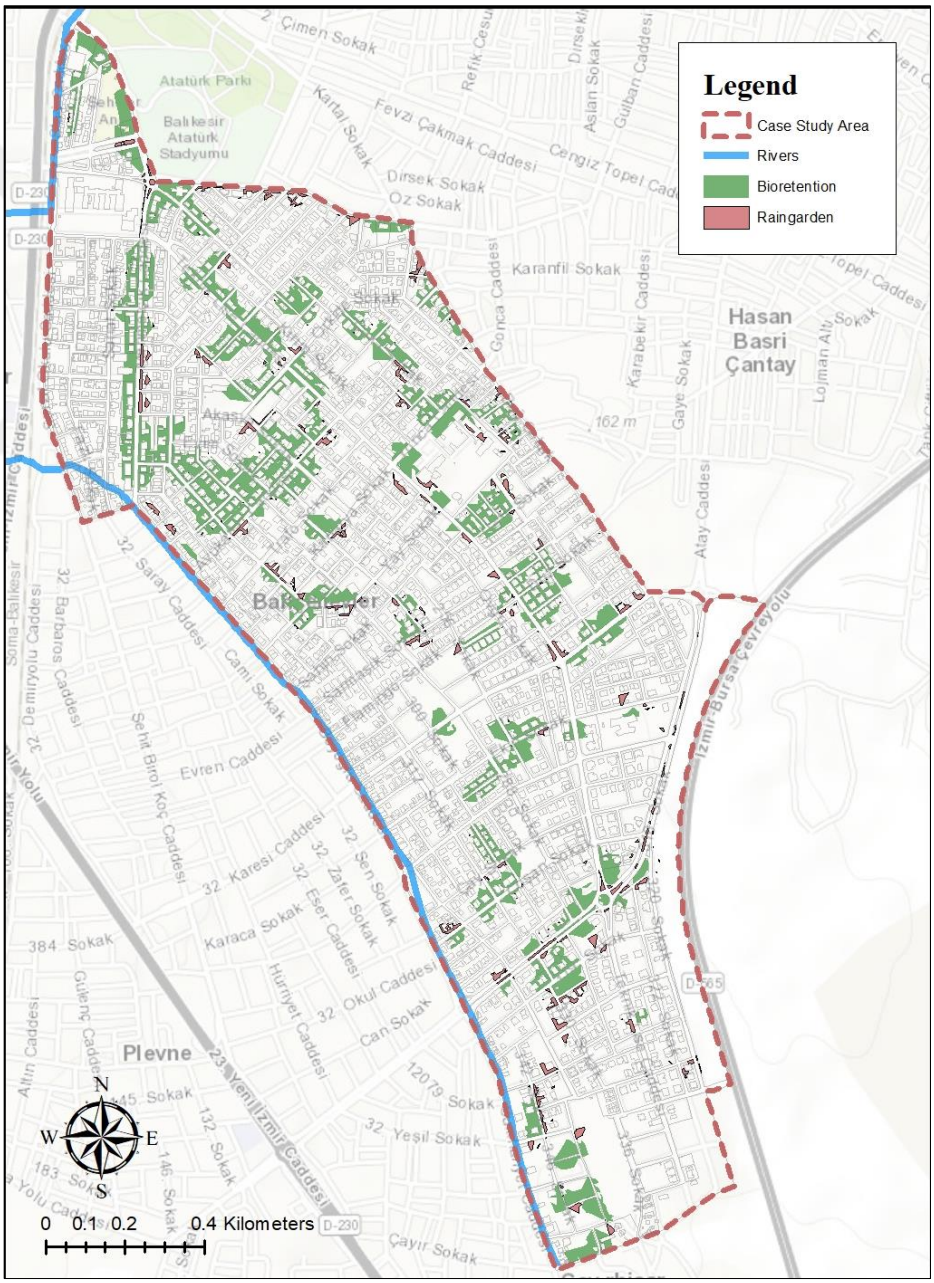


Figure 4.27: Bioretention and raingarden areas with 15% error margin.

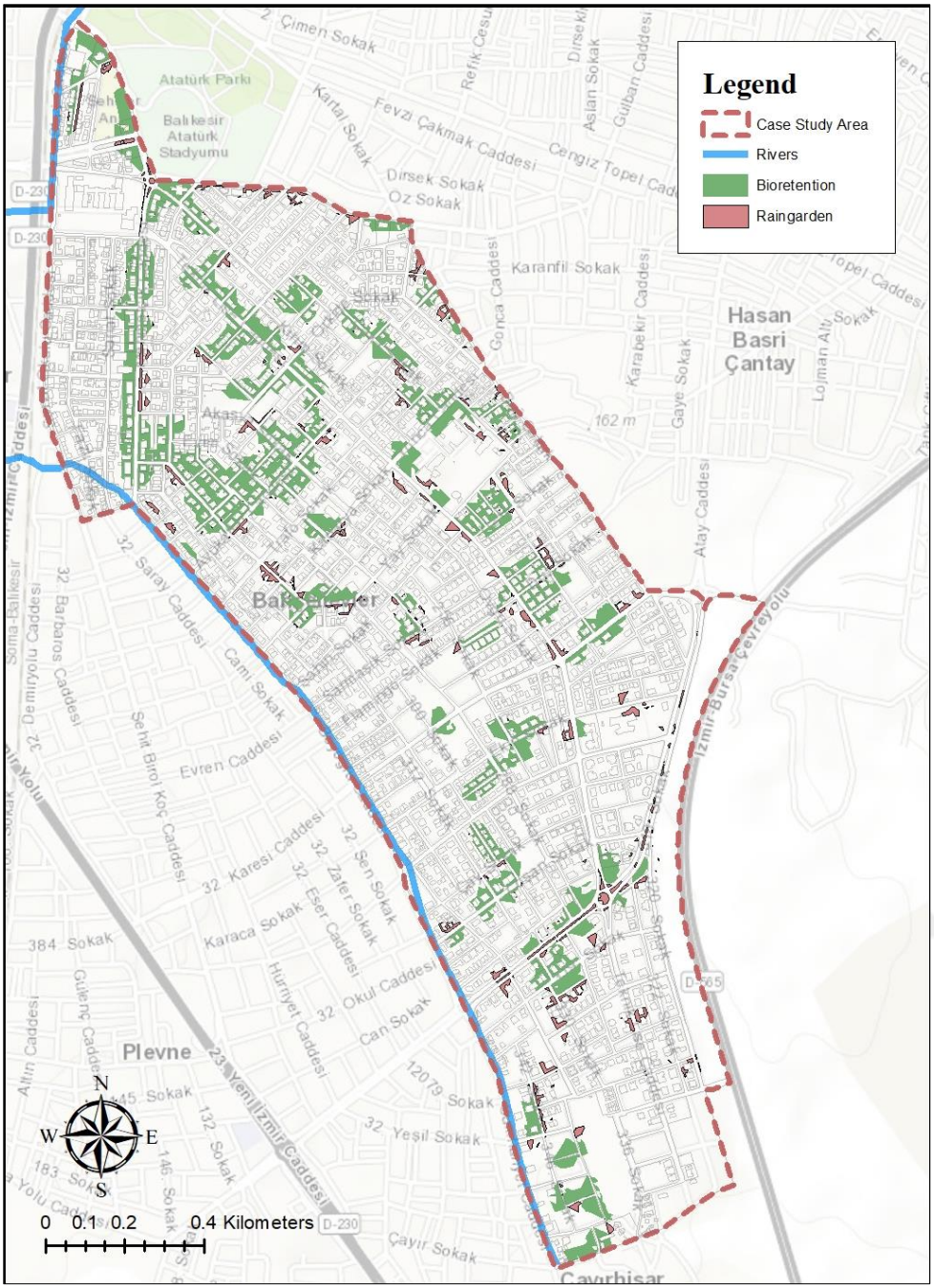


Figure 4.28: Bioretention and raingarden areas with 30 % error margin.

4.2.4.4 Grassed (vegetated) swales / buffer strips

Grassed swales work in a similar manner with bioretention areas but usually have gravel storage added underneath and can be said that they are drains with vegetations added and have various forms and applications within the urban context. Their irrigation is provided from the stormwater and easy to maintain and fairly resilient.

52.14 ha (Figure 4.29) of the area is suitable for grassed swale application, but after excluding bioretention areas and dry ponds, the remaining area covers 30 ha (Figure 4.30).

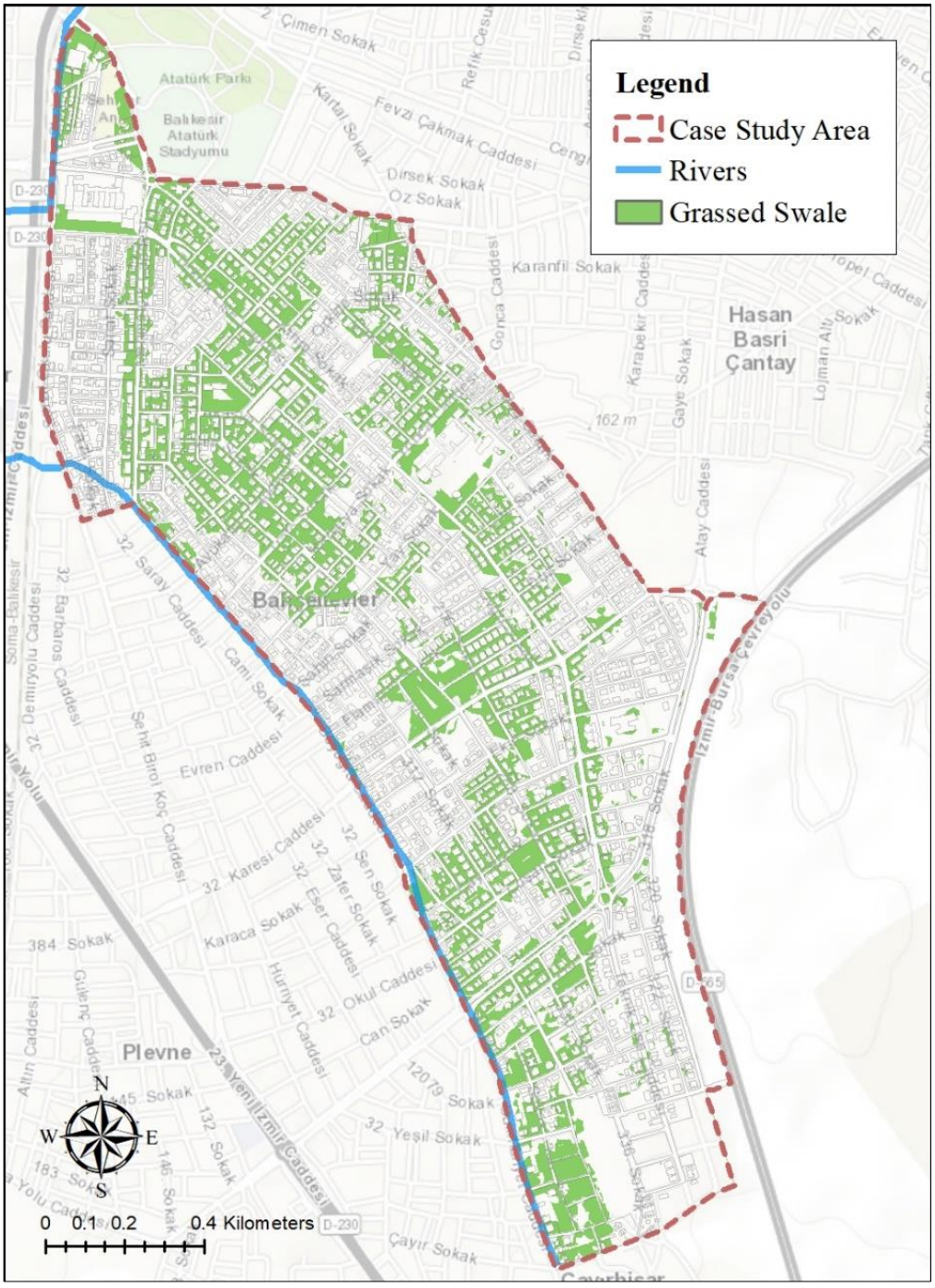


Figure 4.29: Available areas for grassed swale.

Figure 4.30: Available areas for grassed swale after the prioritization process.

4.2.4.5 Detention /retarding basins or dry ponds

Dry ponds can store stormwater temporarily and can provide alternative landscape features to the area depending on the ponding level.

Dry ponds are calculated 26.46 ha with default values but the measure is also superposed with public properties and when it is restricted with public property, the remaining area covers 6.14 ha area before the error margins are calculated (Figure 4.31).

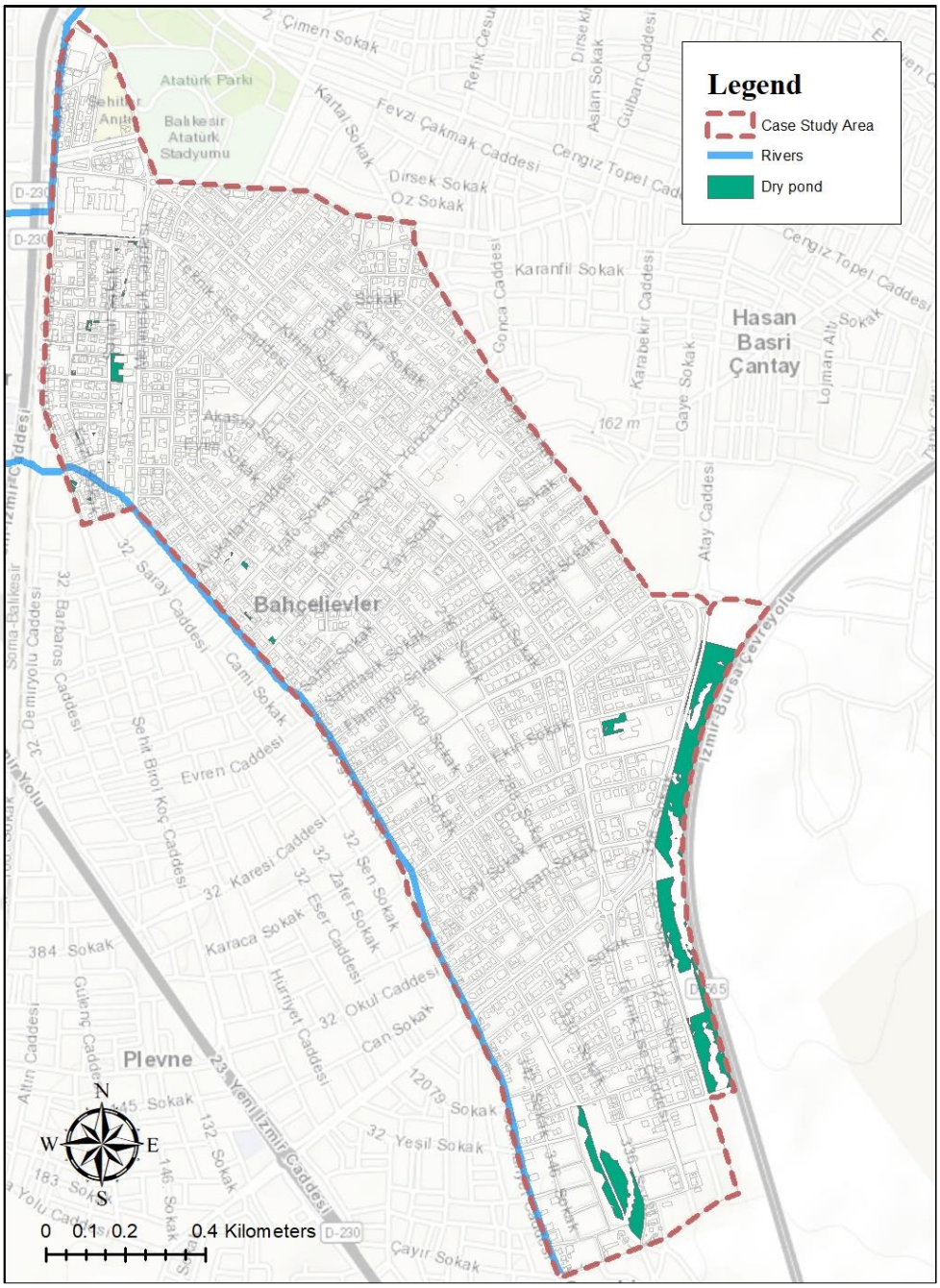


Figure 4.31: Available areas for dry ponds.

4.2.4.6 Vegetated filterstrips

Vegetated filterstrips / grass buffers are kind of swales as well and easy to maintain. As they are flexible options, most of the area is suitable for the application as it can be seen in Figure 4.32; which covers 123 ha area when calculated. However, after prioritized options are excluded, the remaining area covers 65.12 ha area (Figure 4.33).

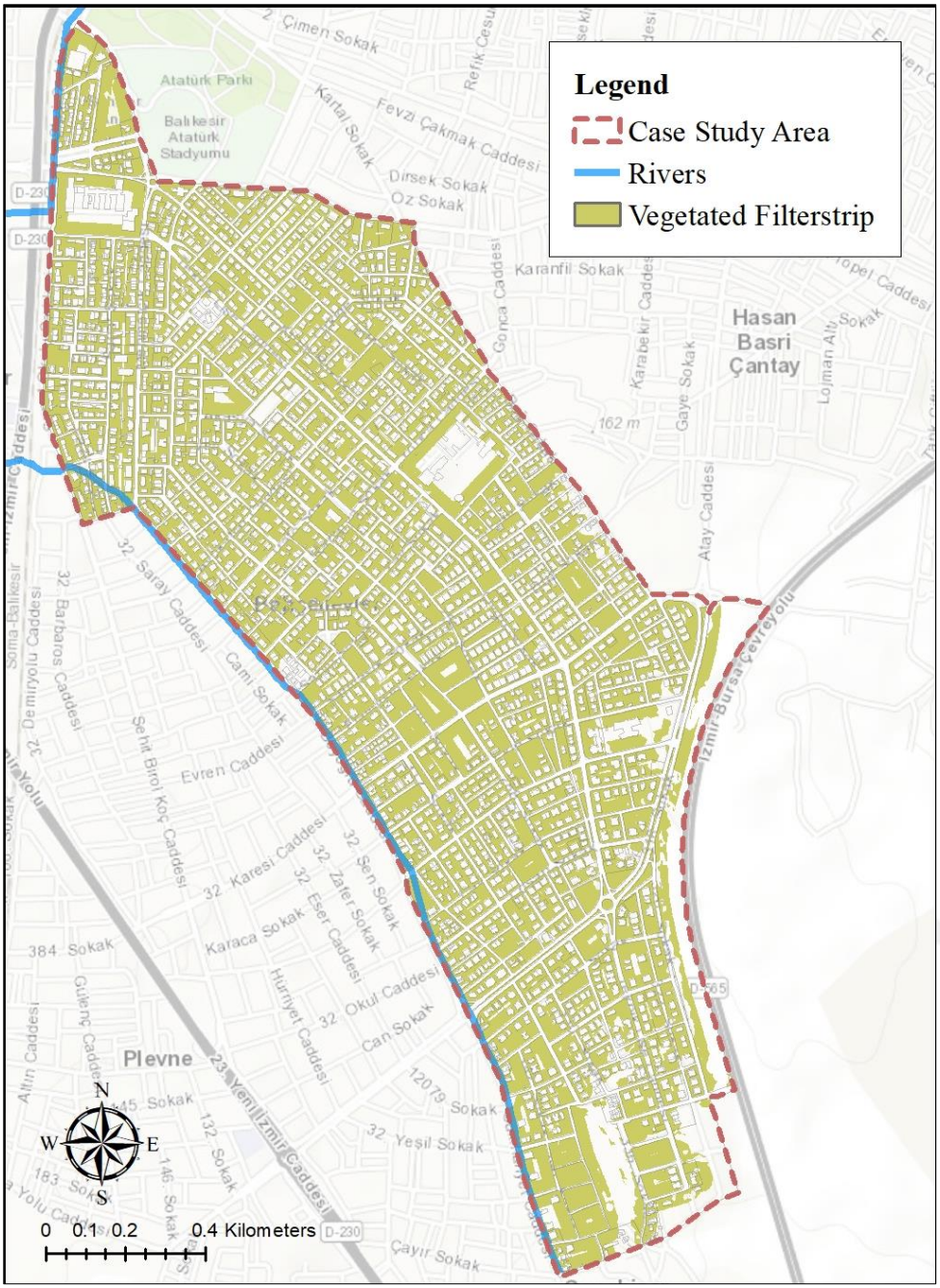


Figure 4.32: Available areas for vegetated filterstrip.

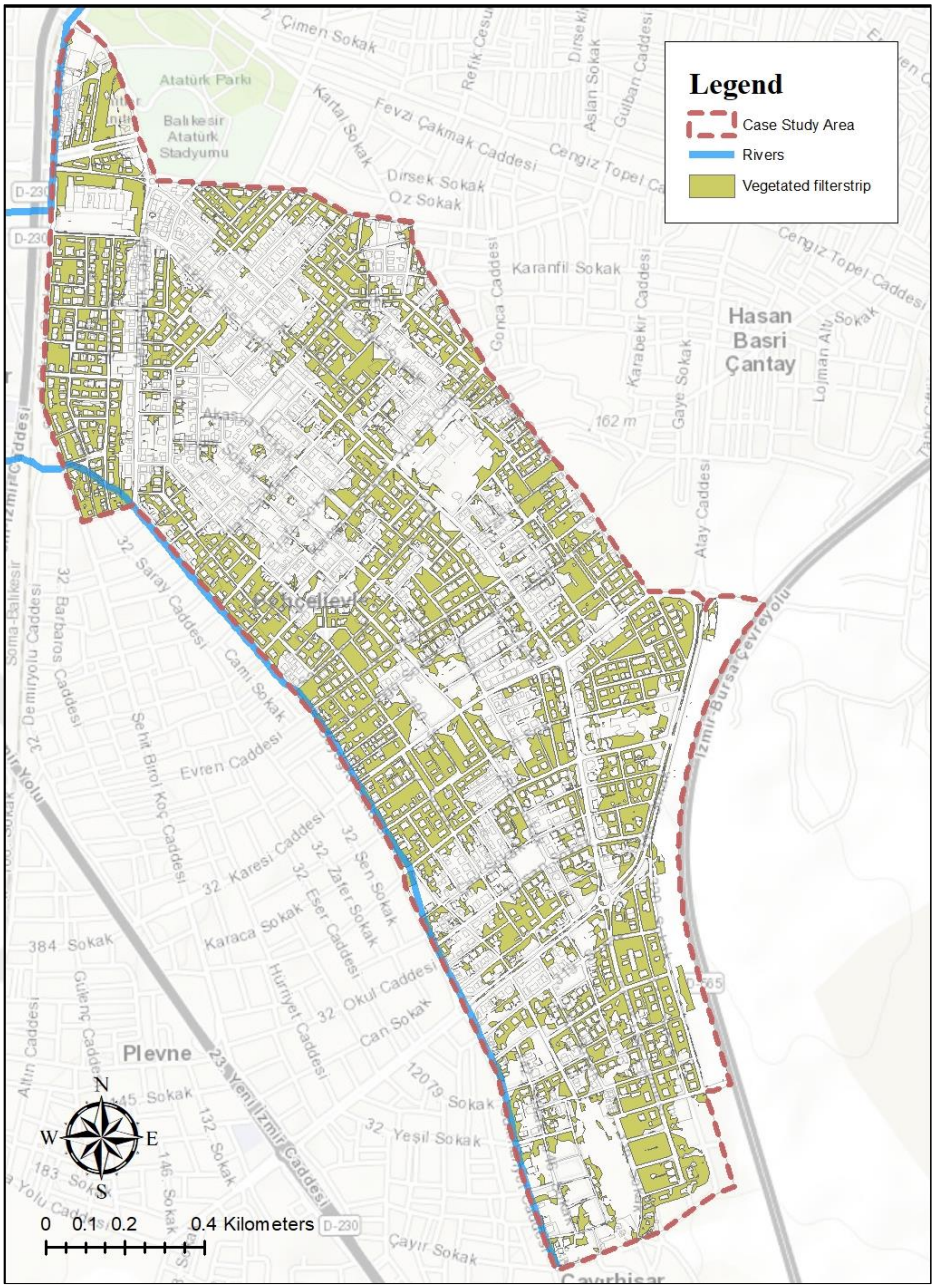


Figure 4.33: Available areas for vegetated filterstrip after the prioritization process.

As discussed so far, it can be seen that most of the area is suitable for a kind of BMP. After some options are prioritized over others, the proposed system looks as given in Figure 4.34 with 15% error margins; and Figure 4.35 with 30% error margins, and their areas can be seen in Table 4.10.

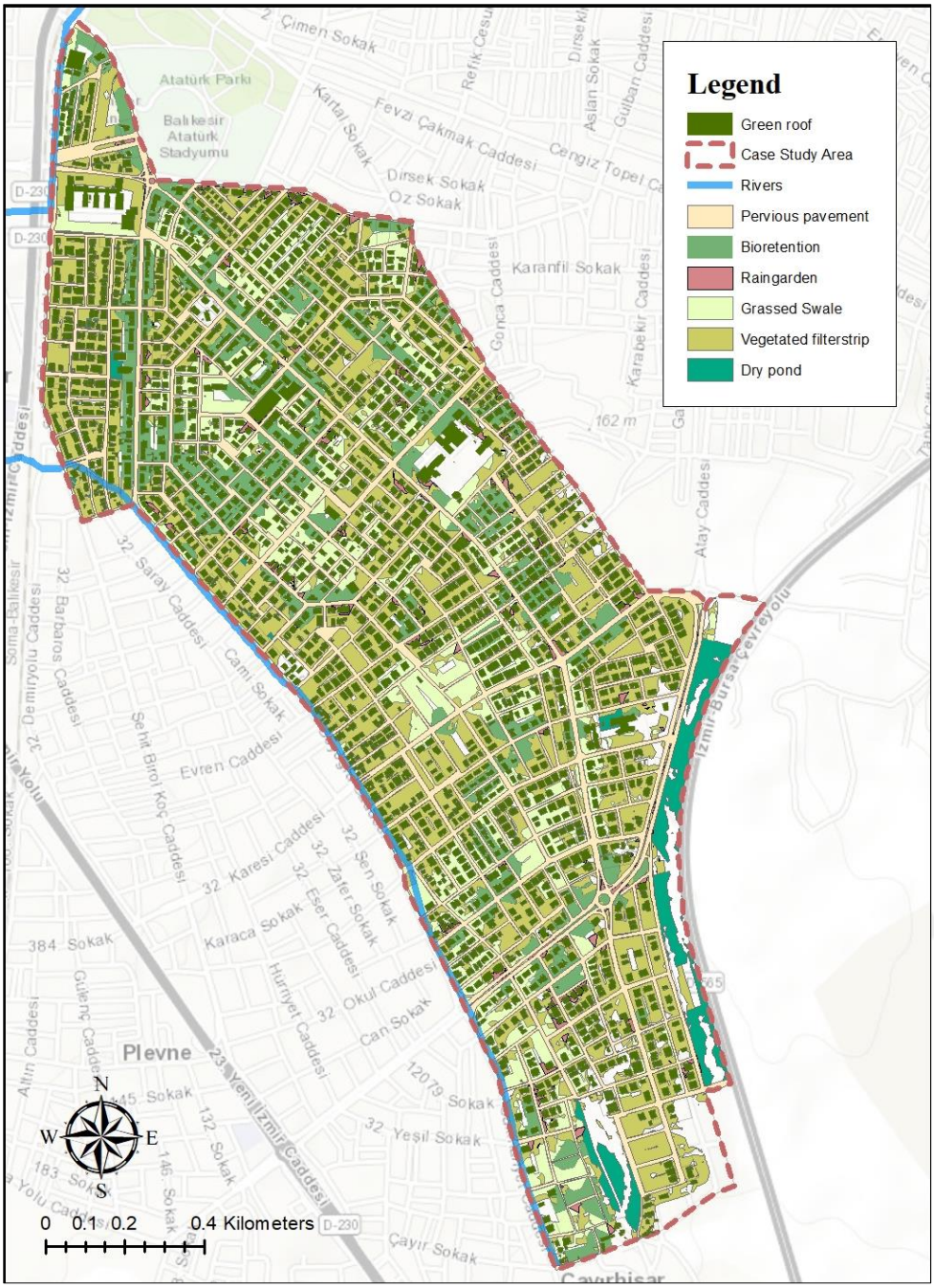


Figure 4.34: The neighborhood with all BMPs included (with 15% error margins).

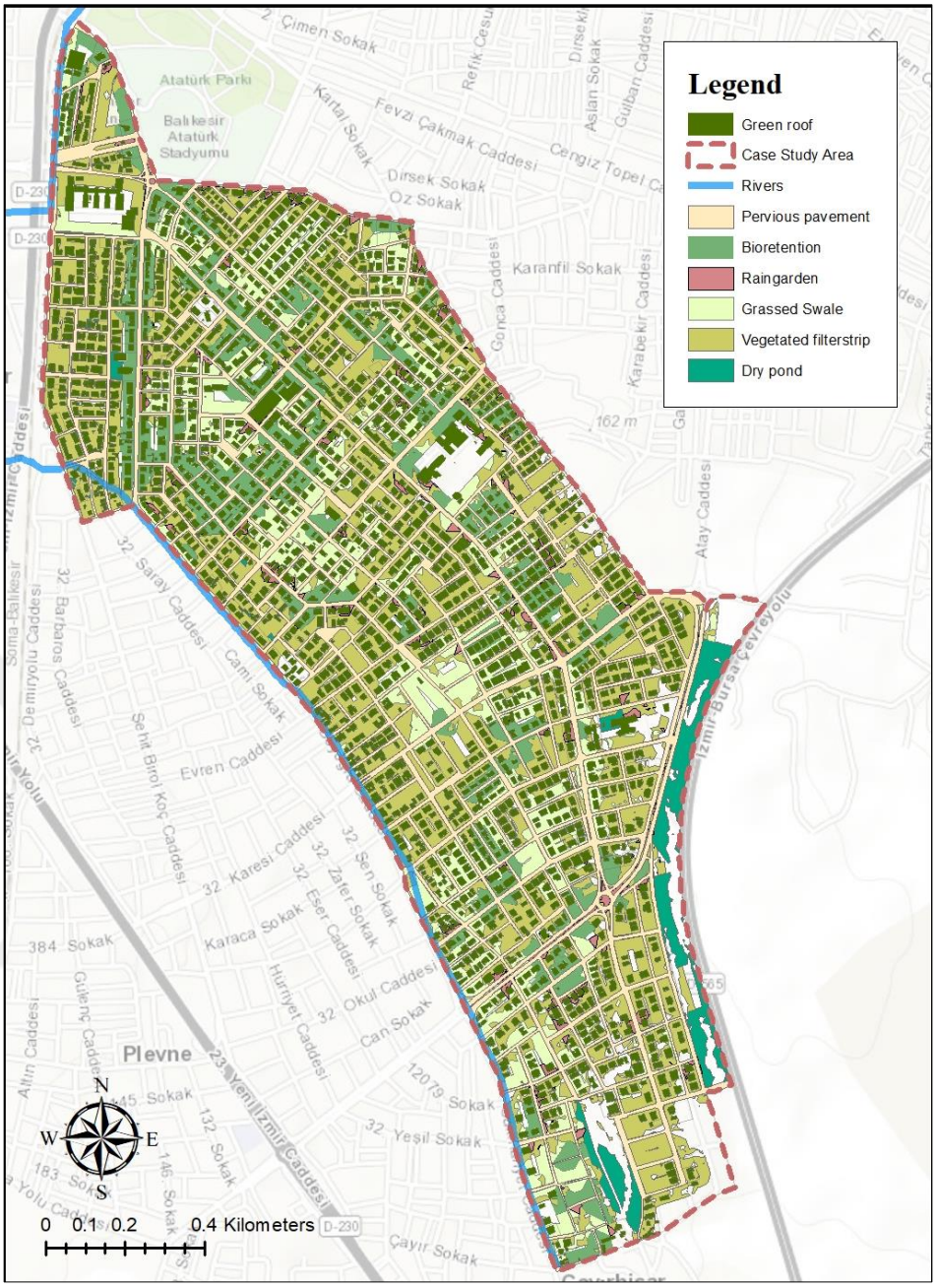


Figure 4.35: The neighborhood with all BMPs included (with 30% error margins).

Table 4.10: Areal BMPs' footprints.

All values are ha	Bioretention	Raingarden	Dry pond	Grassed swale	Vegetated filterstrip	Permeable pavements	Green roofs
Suitable areas	25		26.46	52.14	123	-	50.7
After prioritization	25		6.14	30	65.12	48	50.7
Designed (with 15% error margins)	22.4 19.04	2.6 2.21	5.21	25.5	55.35	48	50.7
Designed (with 30% error margins)	21.67 15.16	3.34 2.34	4.29	21	45.58	48	50.7

Since the priority is given to bioretention areas, it can be seen that almost all rainwater drainage system is surrounded by bioretention areas which provide a good tampon and first treatment to the water joined to the system which especially densifies in the northwest side of the study area (Figure 4.36).

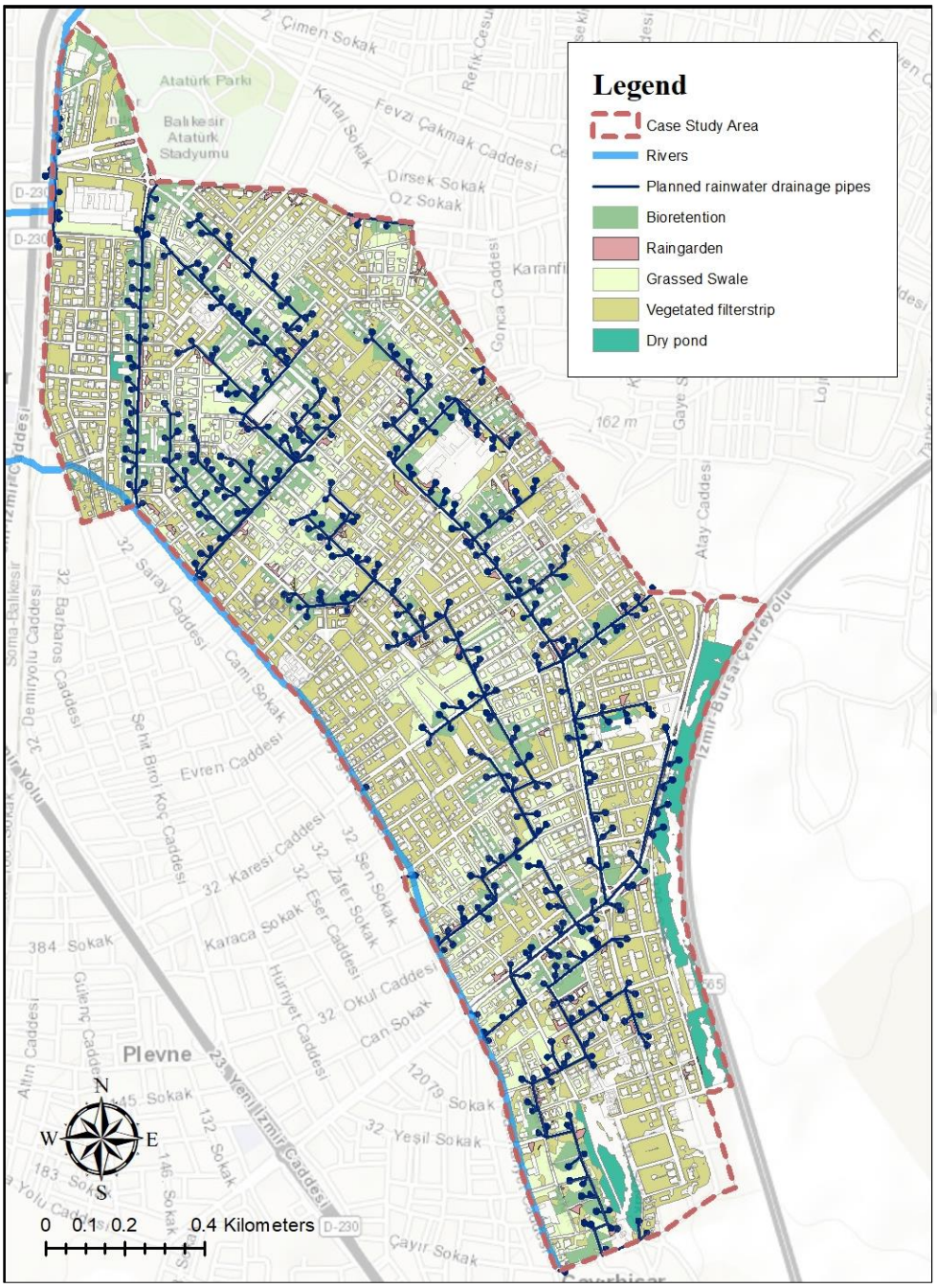


Figure 4.36: BMP options and BASKİ's rainwater drainage system.

4.3 Comparative Evaluation of the Scenarios

The evaluations of the 4 scenarios are calculated with the E^{2}Stormed tool which are: current situation, BASKİ's conventional approach (that separates rainwater drainage system from the sewage system but still has the traditional ideology that tries to get rid of stormwater as quickly as possible without considering the receiving environments), BMPs with 15% error margin, and BMPs with 30% error margin.

The analysis results are given as weighted utilities that include the net cost of stormwater management, net energy consumed by stormwater management, net emissions of stormwater management, global outflow water quality, and ecosystem service evaluations.

As it can be seen from figure 4.37 and figure 4.38, with the addition of the rainwater drainage system to the system, even though it is still conventional, ecosystem services increase. The changes in the graphs are more drastic as the system changes from conventional to integrated stormwater management technologies applied (Figure 4.39, and Figure 4.40).

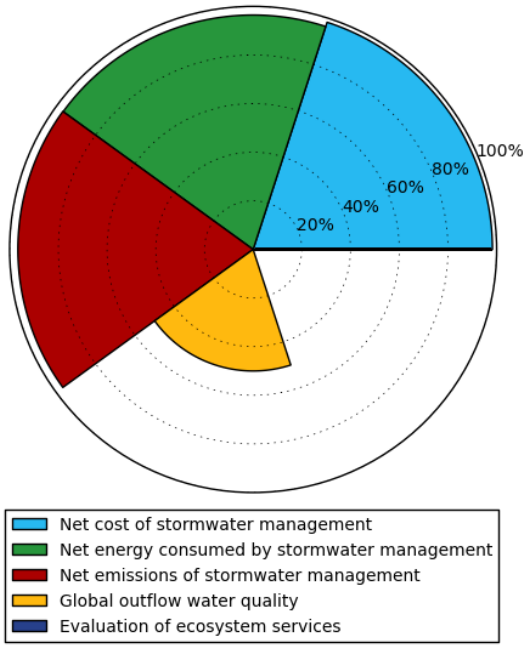


Figure 4.37: Current system evaluation.

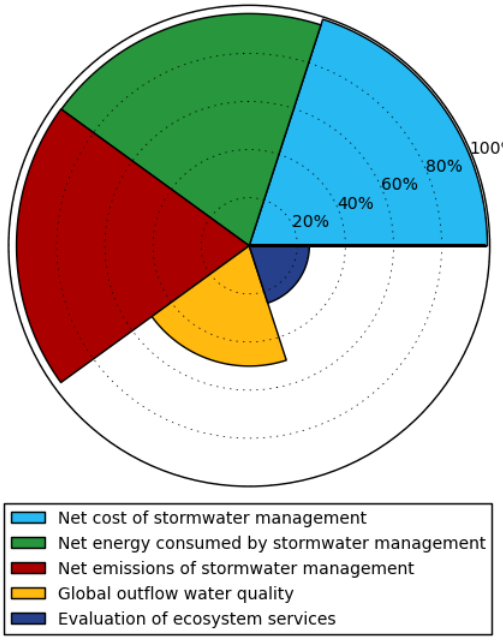


Figure 4.38: BASKİ's conventional plan evaluation.

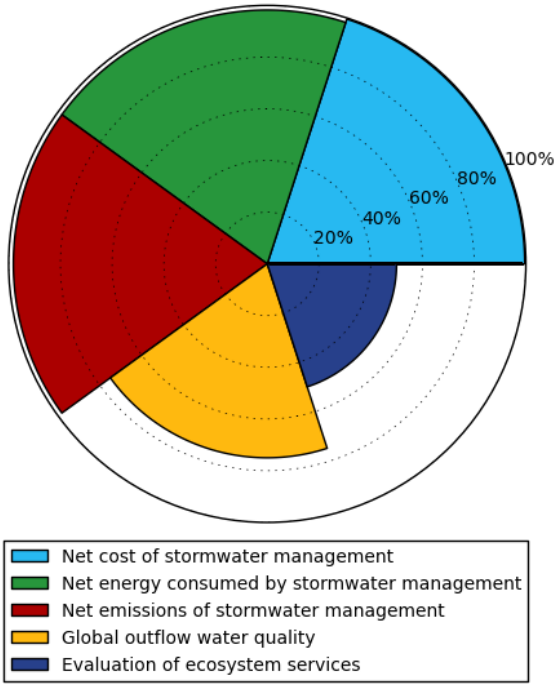


Figure 4.39: Evaluation of the scenario with BMPs applied with 15% error margin.

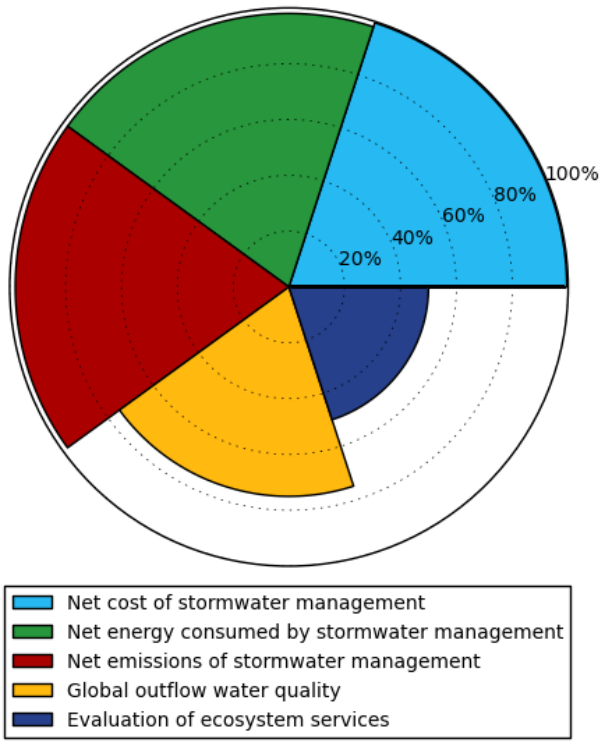


Figure 4.40: Evaluation of the scenario with BMPs applied with 30% error margin.

As mentioned in chapter 4.2, the costs for stormwater management do not burden the system more than the conventional means; but provide extra benefits such as increment in water quality and ecosystem services (Figure 4.41).

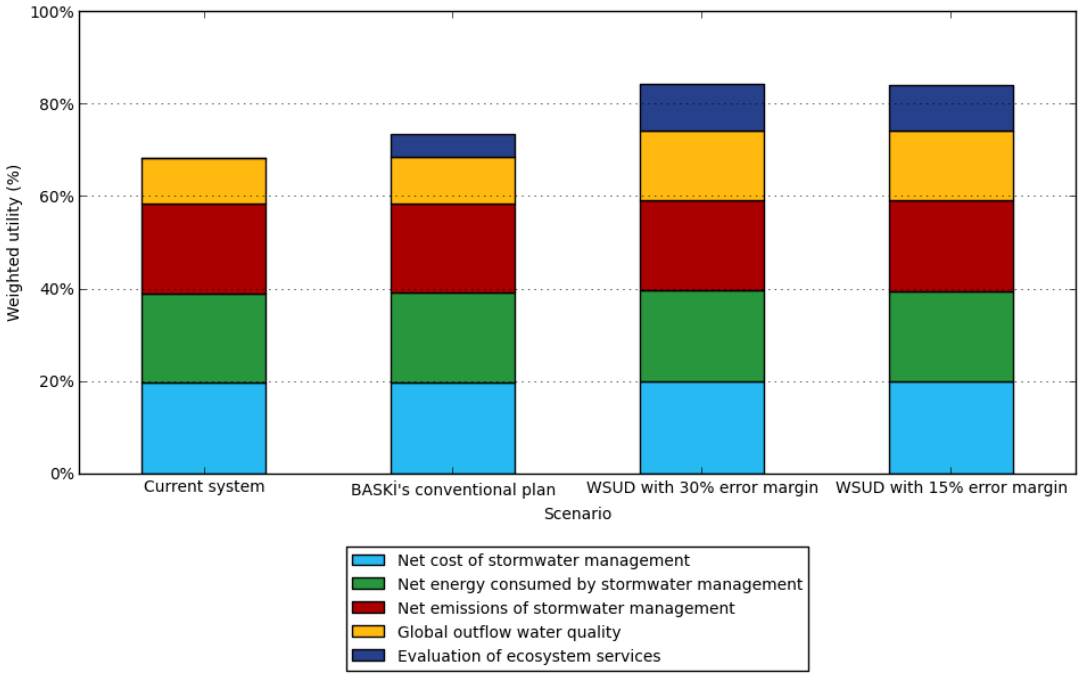


Figure 4.41: Comparison of the weighted utilities of the 4 scenarios.

On the other hand, when cumulative energy consumptions of the four scenarios are compared (Figure 4.42), the difference between the conventional system and WSUD approach becomes clear once again. As the water resources are getting closer to the consumption area with water harvesting, the energy consumption and unnecessary source exploitation are minimized; with green roofs providing extra insulation to the buildings that provide extra energy efficiency; and green areas promoting the decrement of urban heat island effect and increasing thermal comfort, it can be said that not only indoors but outdoors becomes more pleasant with the added features.

Not only the starting point is almost half of the amount of conventional systems, but it also can be seen that in both of the conventional systems, energy consumption gets higher as time passes while it decreases on the systems where BMPs were applied.

Other than initial energy savings, the reason why scenarios with BMPs' energy consumption decrement is the result of the insulation provided by green roofs.

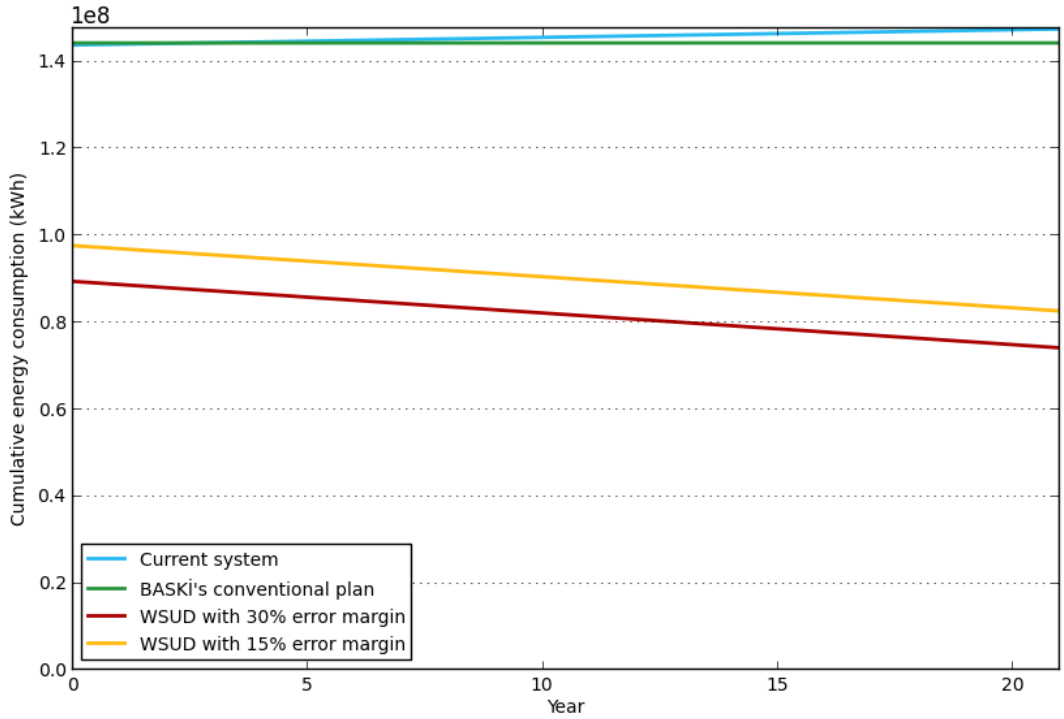


Figure 4.42: Comparison of cumulative energy consumption of the four scenarios.

Cumulative emissions comparison (Figure 4.43) is similar to the energy consumption figure since the two terms are related and are proportional to each other.

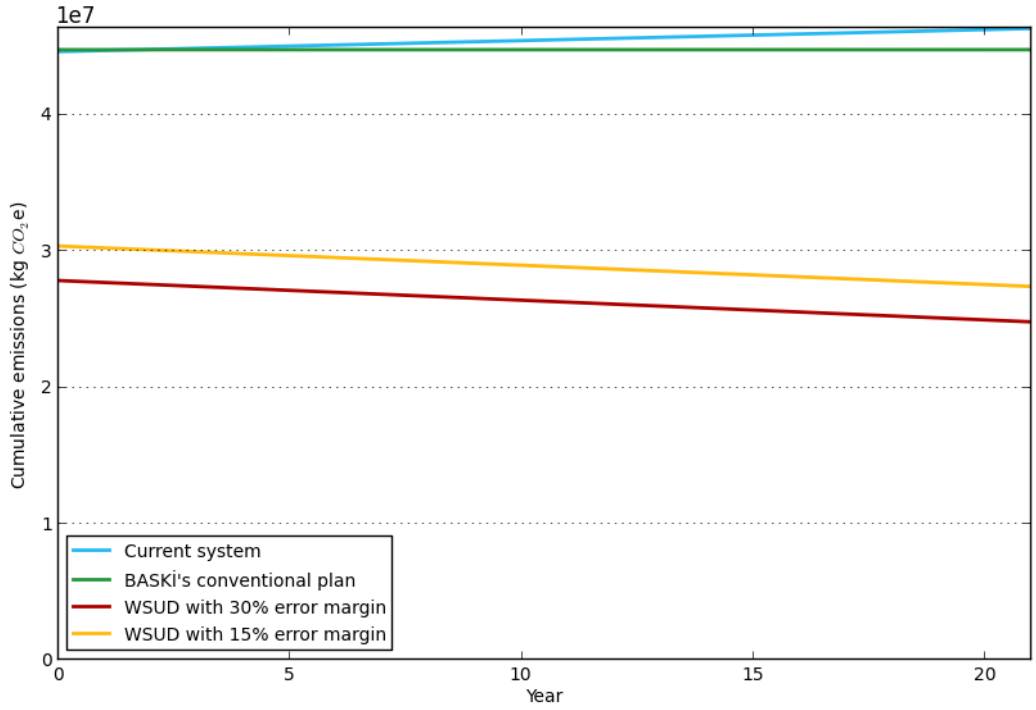


Figure 4.43: Comparison of cumulative emissions of the four scenarios.

Costs and benefits considered in the DST are: construction of infrastructures, maintenance of infrastructure, water reuse, conveyance and treatment, flood protection, building insulation, CO_2e reduction, and other costs and benefits (which must be monetized to be considered). No other benefits have been added to the scenario which is not included in the program as a default; therefore, are not included in the comparison such as: aesthetics, air quality, amenity, microclimate regulation, community space improvement, etc. as mentioned in Table 4.9.

Building insulation is a benefit enjoyed from the green roofs therefore only scenarios with BMPs profit from it.

When construction costs are analyzed, Figure 4.44 shows that there is not much construction cost difference between the scenarios with BMPs and they are both considerably less than the conventional system. However, since BMPs require maintenance to work efficiently, their maintenance costs are higher than the conventional systems (Figure 4.45). Both figures show that more BMPs bring more infrastructure cost and maintenance cost when scenarios with BMPs are compared.

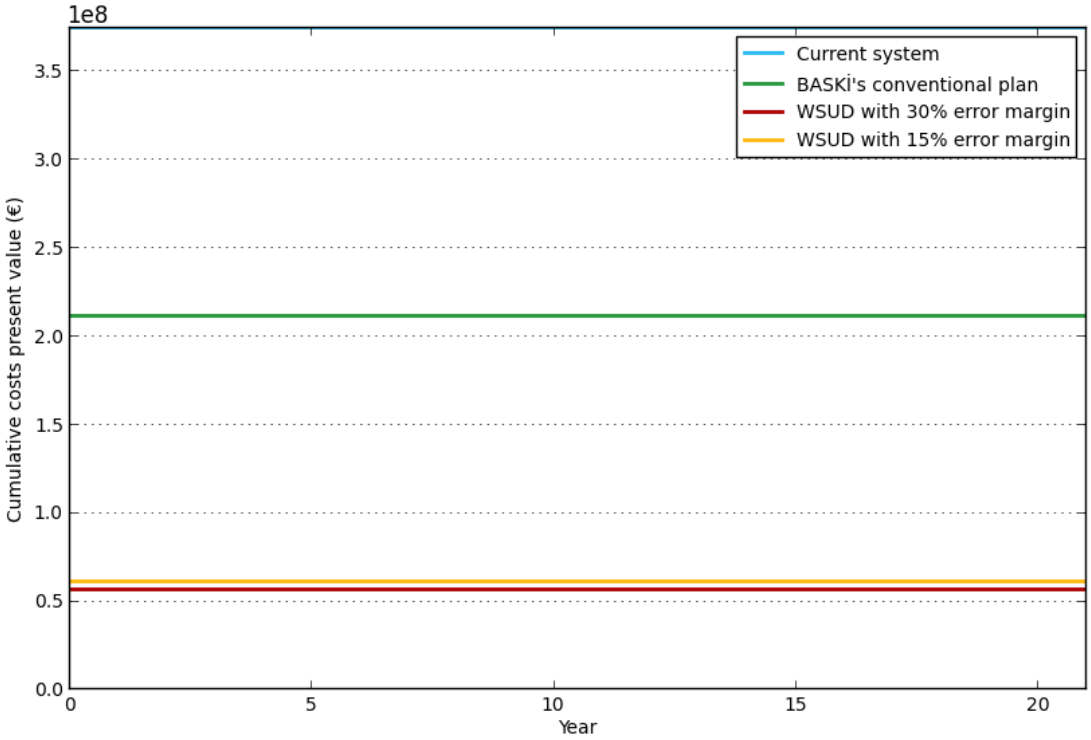


Figure 4.44: Comparison of cumulative costs present values of the four scenarios (construction of infrastructures).

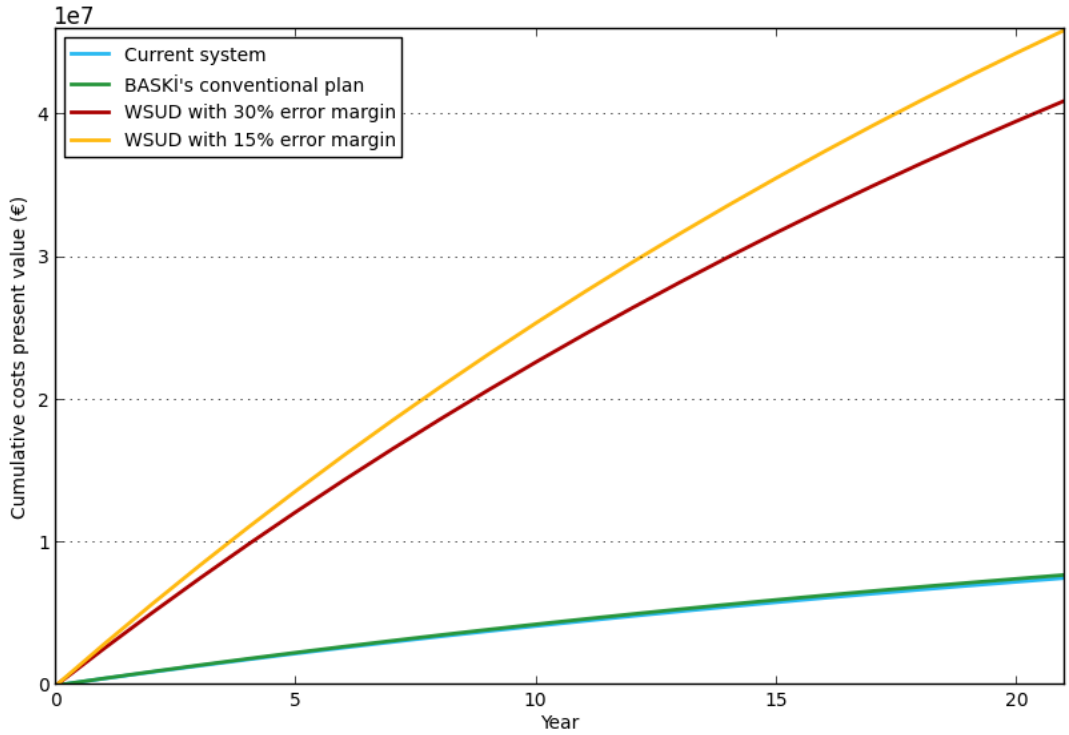


Figure 4.45: Comparison of cumulative costs present values of the four scenarios (maintenance of infrastructures).

Even though maintenance costs are higher in WSUD scenarios, when all cost-benefit parameters are considered (Figure 4.46), it can be seen that the conventional system is

the most expensive system which is followed by the separated rainwater network plan of BASKİ and BMPs. Even though the two WSUD scenarios are close to each other, the scenario with a 30% error margin has the cheapest version; which means maintenance costs and construction cost balance must be studied further to find the optimum gap if the cost is the main concern in the design.

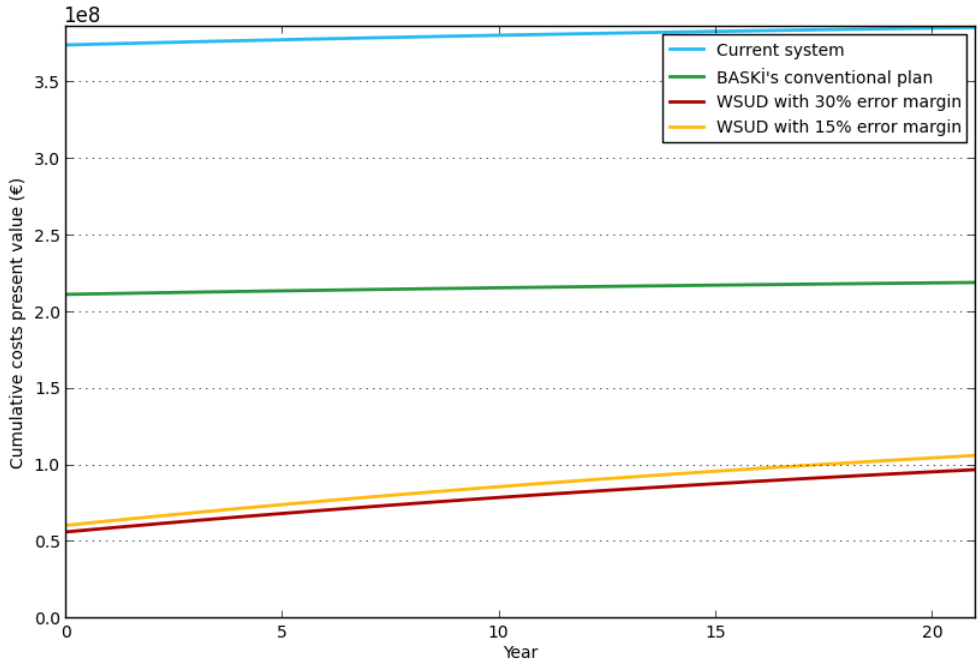


Figure 4.46: Comparison of cumulative costs present values of the four scenarios.

As a result, a significant difference between the two approaches can be seen. The scenarios with BMPs included provide more benefits; however, the key approach is to define the needs and priorities while designing.

5. CONCLUSION

IUWM concepts are getting more widespread and sophisticated with the studies conducted and experiences gained. There are many concepts aiming the IUWM and WSUD is one of them which is shaped by the experience and innovations of international knowledge sharing of specialists, scholars, institutions, and governments. Even though the concept is widely implemented in other parts of the world, Turkey does not have a settlement where it seeks to achieve becoming a Water Sensitive City. The concept shows that understanding the water cycle and water's influencing factors that vary from the way of living to choosing local species for landscaping affects the quality and quantity of the resources. Understanding meronymy and each part's capabilities expand the knowledge and understanding. BMPs used to achieve Water Sensitive cities have site constraints to work properly such as slope, hydrological soil type of the area, existing water bodies, etc.; geographical constraints such as climate, rainfall, and temperature; and economic and social constraints. The system works its best when all these support each other. There are measures that can be taken to overcome the difficulties. In this thesis, site constraints were discussed along with determined aims and the needs of the area; and answers were sought over these questions which are also mentioned in Chapter 1:

- Which Best management practices (BMP) can be applied when the spatial constraints are applied? What are the other factors affecting BMP choices? How does the design get affected by these constraints?

Balıkesir's Bahçelievler neighborhood is selected as the case study area when national reports prepared by different institutions and institutional opinions are considered. When USEPA's SUSTAIN tool's BMP Siting Tool considerations were used for the suitability analysis in the area to determine the suitable areas for each BMPs (14 BMPs which are constructed wetland, grassed swale, green roof, infiltration basin, infiltration trench, porous pavement, bioretention, vegetated filter strip, sand filter (surface), sand filter (non-surface), rain barrel, cistern, wet pond, and dry pond), it has been seen that because of the hydrological soil of the area, some of them are not suitable to apply

which are: porous pavements, infiltration basins, and infiltration trenches. However porous pavement from these 3 is still included in the scenario due to the consideration of its multiple benefits and availability of the modifications of the option. On the other hand, some BMPs were opted out when the area's needs are considered which are: constructed wetlands, wet ponds, infiltration trenches, and infiltration basins.

Constructed wetlands and wet ponds were opted out because of the maintenance hardships they may encounter when the water table depth is considered as these are permanent water bodies and even the river in the area is seasonal and does not run all year long. This also brings other problems in the case of wetlands and ponds such as mosquitos and other sickly vectors. Also, the availability of the land is another concern with them since they require comparatively larger areas.

Infiltration basins and infiltration trenches, on the other hand, opted out because of the nonnecessity; since they are mainly for groundwater charging which is not a problem within the area as groundwaters are not used in the urban areas and do not stress out the aquifers. Therefore, the infiltration level from the other proposed BMPs would be sufficient for the area where the natural cycle is supported.

Rain barrels and cisterns are similar in terms of logic. In this thesis, rainwater is considered an alternative water resource. However, the alternatives within the proposed BMPs can be addressed. Such as tank sizes, types (individual or clustered), etc.

There are areas where more than one BMPs are suitable. In those areas, BMPs are prioritized according to their benefits to understand the general concept WSUD can offer to the area. However, rather than generalizing them, each area can be studied with more sophisticated data and where interrelationships are considered more deeply. Also, some generalized terms include various applications such as bioretention areas which include raingardens to suspended pavement systems which can result in differences whenever they are considered in a more detailed way which may result in more favorable or the opposite. The local flora can play a greater role in deciding which to use as suspended pavement systems can support large trees while raingardens can support smaller species in the general application which is not intrinsic to the study area.

Therefore, when the technical conveniences are though together with the necessities; vegetated filterstrips, grassed (vegetated) swales/buffer strips, bioretention, dry ponds (retarding basins), rain harvesting systems coupled with green roofs, and porous pavements are selected for the scenario.

As it can be seen, just as much the BMPs are restricted with the environmental restrictions, also anthropogenic factors play a great role in determining the possible alternatives. Therefore, as mentioned in Chapter 2.2.1, defining main principles and objectives carry grave importance to specify which technology to use for what purpose; and giving them time-bound and specific expectations help with the improvement process.

After the application, measuring their performances, providing proper maintenance, and improving them towards possible future scenarios are also just as important.

The world trends are evolving towards creating more innovative solutions rather than applying the ones that are present which should be of the approach.

The proper analysis can be done by the local governments to support the most convenient result as a whole which can be achieved with incentives such as tax deductions, or can be more enforcing manner, or in between where the areas need prompt action.

- What outcomes can be expected from the applicable BMPs? What are the purposes for the included BMPs?

The study area is dependent on one resource which is İkizcetepeler Dam which makes the area very vulnerable. Even though the study is applied in a residential urbanized area, these implementations can be adapted to different uses and areas such as agricultural usage, industry, etc. where non-potable water uses have a greater share in demand.

While the area's needs are identified, the aims considered can be generalized as: bringing the environment closer to its pre-settlement cycle, providing energy and water consumption efficiency/saving, securing alternative water resources, protecting receiving environments, minimizing/preventing devastating results of the rainfall events, enhancing environmental quality in terms of landscape and air, and easiness of construction and maintenance.

Determined aims shaped both the BMP selection phase and their priority to one another. BMPs that provide multiple benefits and them working well together are chosen for the scenario. When the energy consumption, CO_2 emission, and cost present values of the scenarios are analyzed, WSUD scenarios show the most favorable results. However, among the two WSUD scenarios where the BMPs were calculated with 15% and 30% error margins that are given for the infrastructure and other possible differences resulted in BMPs with 30% error margin as slightly more favorable than the 15% alternative which brings other questions to be answered such as "What is the optimal percentage of the BMPs?"; out of consideration of bioretention and raingarden difference, "How these changes in the system or preferences affect the system?" where the choices get more variable instead of categorizing them as 'bioretention' therefore alternatives as well as the proposed BMPs must be considered thoroughly; instead of planning a large area, dividing it to smaller pieces, especially where prioritization made can give healthier results which can be another consideration as well.

As the area is studied as its own, its relationship with other parts of the city can be a consideration that is valid to not only study area. The design can be made for a bigger area to create a better connectedness and synergy. Where the system synergy can be studied if rather than choosing a BMP with many benefits, are there systems that support each other to amplify the effects of the overall system?

The data collection can get more sophisticated, detailed, and systematic to achieve more accurate results. Also, their effects must be tracked properly and required adjustments must be made to maximize the results. Learning from experience is a must through the journey to take needed steps, support from the locals and education are also other important factors achieving the desired results. The results should be shared and contribute to the bigger system.

- Are applicable technologies giving the desired results?

The desired results change from case to case and even within the case, some parts of the study areas can require special treatment than the rest. Constructing these means helps to an extent. However, the root of the cause which is unconscious human intervention must be overcome with the cooperation and education of the individuals.

Whenever the alternatives can be converted into monetary values, the results show that WSUD alternatives are obtrusively more favorable. Even though the maintenance

costs are higher for the BMP technologies, comparing it with not performing necessary treatment actions (which can be studied as an alternative scenario where proper treatment is provided) which results in a less economic burden in the short term is not just a matter of moral and can be added in the scenario comparison. However as economic factors are also important, it can be studied that “How long does it take to compensate initial capital and they become profitable?”. Also, qualitative measurements such as visual amenities and thermal comfort can get involved in the evaluation phase; habitants’ participation can be provided to an extent to increase the sense of ownership. Complex problems require complex solutions, therefore detailing each phase would give better results.

Even though the evaluation phase gives a general idea, the extent of it must be studied further as the system requirements change each application and may result in differently with extras of the BMPs such as pretreatment requirement, filter media necessity, underdrains, etc.

The scenarios can be diversified which also includes climate change scenarios.

Aims and strategies can get time-bound and more innovative as the norm is shifting towards generating ideas rather than just applying and watching over them.

Precautions are not enough to provide satisfactory progress at the moment. More stringently approaches can be followed till the system is put back on track. Rather than taking it slow, legislations and laws must be more throughout and be supportive of the implementations to have the leapfrogging advantage. Staging of areas, needs, necessities must be done with the cooperation of various disciplines.

Even though the results are promising, their capacity can be studied such as to what extent can these scenarios be enough? Such as different ARI events can be studied.

Another important point is to vary the programs and tools that are used and compare the results and their reliabilities. Each tool offers intrinsic benefits while lacking other aspects. Therefore, experimenting with them would provide a better understanding.

When Turkey’s fragile condition is considered where it does not only have a changing climate and scarce source to begin with, it also has an obligation to use these sources responsibly when transboundary river basins are considered as they are causing both political tenseness and put downstream water-scarce countries in a tough position as well. All water resources must be considered in planning comprehensively with an

integrated approach where specialists, academics, users, and stakeholders act together to get solid results.

Along with groundwater levels and their sensitiveness, their routes must be considered as well since they are also affected by the inadequate consideration; and as mentioned in chapter 3.7, along with directly expected outcomes such as pollution and drought, other chain phenomenons occur and results in even bigger consequences such as ecosystem thrown out of balance, sinkholes and land subsidence appear and cause property and life loss, etc. Techniques that are thought to bring economic advantage such as trying to produce non-local species without resource management bring ecological imbalances along with economical inefficiency. Therefore, defining the role of the natural system and adapting to it has crucial importance. Also, technical and environmental topics must be discussed with social, economic, and political perspectives in mind.

Another important issue that must be solved is the pollution which happens as a result of lack of inspection, insufficient legal basis, overuse of pesticides and herbicides in agricultural areas and urban recreational, sports areas, etc. Wastewater management must be done with the consideration of the receiving environment's health and reuse of these waters must be generalized with fit-to-purpose treatment. Fertilize, herbicide, and pesticide uses along with other chemical detrimental substances use must be limited and controlled. Also, periodic water and soil quality tests must be conducted to monitor these systems and possible pollutants and their resources must be identified and acted on before the problem gets bigger more complicated than it already is.

With this thesis, it has been sought to review the current approaches and methods that are being implemented around the world and WSUD has been chosen as an example guide; however, regardless of the special name used for it, water management must be considered as an integrated field where multiple professionals, users, and stakeholders must act together in local, national, and international levels and adapted to not urban design but all sectors and actors such as agriculture and industry. The topic's importance must be grasped by all stakeholders, specialists, academics, and user groups; uptodate methods and approaches must be followed and surpassed; precautions must be taken; and possible threats must be foreseen with cooperation.

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