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Evaluating the Probability of Rainwater Collection as part of Green Infrastructure using GIS and RS Technologies in Industrial Regions, Eskişehir, Türkiye

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Abstract

The study aims to identify the possibility of rainwater harvesting in industrial zones (Eskisehir Organized Industrial Zone (EOIZ), Baksan Industrial Site, Matbaacılar Site, ESTIM Wholesalers Site, Auto Gallery, EMKO Furniture and Woodworks, Teksan Industrial Site, Auto Industrialists and Small Industry, Craft Industrial Site, New Organized Industrial Zone Development Area, and Small and Medium-sized Enterprises (SMEs)) with high water use and concentrated impermeable areas. In this case, the amount of rainwater accumulated in impermeable regions was calculated using GIS and RS to reduce the rainwater load that accumulated or reached the wastewater treatment plant. The study will directly contribute to the displaying of the green water footprint resulting from industrial impermeable zones. This work for industrial areas will be pioneering. This study was analyzed using open-source GIS software and Google Earth software, a free application that allows experts in various trade branches of rainwater harvesting in the industrial region, industrialists, and researchers who want to conduct research in this area to do so quickly and easily. When viewed from this perspective, it is clear that the work has original value in the subject and makes significant contributions to the literature. Furthermore, this work directly contributes to the Sustainable Development Goals of "Clean Water and Sanitation" and "Climate Action".

1. Introduction

Water resources are an important and essential need for living things [1, 2]. Water resources are being rapidly depleted as a result of industrialization and rising population. Current surface and groundwater resources are vulnerable to drought, a natural disaster that damages many regions every year [3–6]. With drought, water quality degrades in addition to water levels falling. Data from the State Water Works of the Republic of Türkiye show that in 2020, the annual amount of usable water per person in Türkiye was 1346 m^3. This amount illustrates that Türkiye is one of the countries suffering water stress and may become water-stressed in the future [7, 8]. In the next 30 years, a 1% rise in water demand is anticipated on a global basis. As a result of climate change, it is projected that groundwater will increasingly be used to supply water due to the rapid depletion of surface water. In addition, the importance of the issue has been better illustrated with the United Nations' declaration of the water theme of 2022 as "making the Underground visible" [9]. Unplanned and uncontrolled changes in land use/cover, which is a complex and dynamic process, occur with the increase of impervious areas in cities as a result of the abandonment of agricultural lands and the destruction of forest areas [10–12]. Non-penetrating areas can be defined as any material that prevents water from seeping into the soil. The most common and easily defined impermeable areas are roads, pavements, and roofs [13]. Especially the increase in residential and industrial areas causes an increase in temperature, negatively affecting the water cycle in the atmosphere [14]. The increasing impermeable areas prevent rainwater from penetrating the groundwater. Moreover, the reduction in evaporation-evapotranspiration increases the amount of rainfall pouring on the surface. As a result, rainwater accumulates in impermeable areas and is partially lost as direct flow, creating problems such as floods [15–17].

As a matter of fact, the development of sustainable policies in water cleanse is unavoidable [1, 3]. In the current system, only 30% of rainwater is used efficiently by mixing with groundwater [8]. Traditional rainwater management relies on the collection of rainwater in combined or separate sewage networks and discharge it to a wastewater treatment plant or directly to a receiving water mass. This management system has high operating and maintenance costs. In addition to the carbon footprint, traditional gray approaches have negative hydraulic effects, such as rainwater discharges delivering high pollution loads to receiving water and sewage overflows [28].

Green infrastructure is an innovative and sustainable rainwater management application that provides numerous environmental benefits, particularly in terms of reducing climate change when compared to gray infrastructures [29].

Table 1. Studies on analyzing rainwater harvesting methods with RS and GIS technologies

Study Area	Study Aim	Datas	Method/Program	Result	Source
Syrian Desert, Al-Badia	Identifying areas generally suitable for harvesting in order to study the watershed network and determine rainwater harvesting techniques for these areas.	• Indian satellite images, • Amount of precipitation, • Area.	• ERDAS IMAGINE • ArcGIS	It was concluded that local social and cultural aspects are important before choosing a specific rainwater harvesting method, especially in arid and semi-arid regions. In this direction, it has been determined that there is a need for projects for farmers in the Syrian Desert.	[18]
3 different residential areas belonging to 3 different cities in Rajasthan state, India	Determining the roof rainwater harvesting potential of 3 different areas and the tank capacity for the most suitable area.	• Total roof area, • Average annual precipitation (mm), • Flow coefficient.	• Google Earth • QGIS • Gould and Nissen-Petersen formula	It was concluded that among the 3 cities, Kota has the highest rainfall, so it would be best to collect rainwater in each interval. For areas larger than 3000 m^2, the rainwater that can be harvested is in liters; >1500000 for Jaipur, >1800000 for Kota, >1000000 for Bikaner. The minimum amount of rainwater that can be harvested is < 25000 liters with an area of 0-500 m^2 in Bikaner.	[19]
Junagadh Agricultural University Campus, Gujarat/India	Estimating the roof rainwater harvest potential of the campus and evaluating the demand supply analysis.	• Roof areas of campus buildings, • Average monthly precipitation.	• Google Earth • Quantum GIS (QGIS) • Gould and Nissen-Petersen formula	On the campus with a total roof area of 1,04,012 m^2, the monthly roof water harvesting potential of all 81 buildings is based on kilolitres; 16797.94 for June, 30236.29 for July, 18566.14 for August and 12289.02 for September. It has been determined that the total amount of rainwater for 4 months that can be harvested from the campus buildings is 77889.39 kilo liters.	[20]
Eskisehir Technical University İki Eylül Campus, Türkiye	Determining the capacity to collect rainwater harvesting from the roof.	• Total roof area, • Average annual precipitation (mm), • Flow coefficient.	• ESRI ArcGIS software • Gould and Nissen-Petersen formula	The annual amount of water consumed on the campus, which has a roof area of 113718.3654 m^2 is 1,530,543 m^3. The annual rainwater capacity is 37,109.9 m^3, and it has been concluded that it only covers 2.4246% of the water consumed in a year.	[21]
A savannah area covering the Blue Nile and Sinar states, Sudan	Determination of surface rainwater harvesting areas and capacities based on remote sensing data for agricultural areas.	• SRTM90 DEM data, • Harvesting area (km^2), • Minimum amount of precipitation (mm).	• QGIS • Remote Sensing (RS)	It revealed that conventional systems in residential and agricultural areas can detect rainwater harvesting sites with 82 and 8 times the drainage capacity, respectively.	[22]
RK University, India	Roof rainwater harvesting system design.	• Roof area (m^2), • Rainfall (mm), • Flow coefficient, • The number of people in the buildings,	• QGIS • Google Earth • Gould and Nissen-Petersen formula	Considering the rainy months, the total amount of rainwater that can be harvested is calculated as 3088514,6 liters. In the study area, it has been proven that it is possible to meet the drinking water need with the roof harvesting system all year round. The 20x10x10 m storage tank was designed to store water.	[23]

		• Rainfall duration, • Water consumption.			
Haqlan Valley, Iraq	Identifying suitable areas for rainwater harvesting.	• Flow depth, • Slope, • Soil structure, • Drainage, • Land use.	• ArcGIS • Remote Sensing (RS) • Analytical Hierarchy Process (AHP)	Total suitable area for rainwater harvesting constitutes 28% of the study area. 21% of the region is moderately suitable.	[24]
Wadi Nisah/Saudi Arabia	Creating maps of potential flood hazards and suitable locations for rainwater harvesting.	• For the flood hazard; flow depth, drainage, density, elevation, slope, topographic wetness index and curve number. • For a place suitable for rainwater harvesting; precipitation, land cover, slope, flow pattern and linear density.	• ArcGIS 9.3 • Remote Sensing (RS) • Multi-Criteria Decision Making Model (MCDM) • Analytical Hierarchy Process (AHP)	It was concluded that 15% of the study area has a very high rainwater harvesting potential. Based on the rainwater potential map, two possible impoundage locations are proposed.	[25]
Downstream side of Wadi Al-Lith, Saudi Arabia	To map suitable sites for rainwater harvesting.	• Soil, • Slope, • Slope number, • Alluvium, • Drainage density, • Proximity to streams, • Precipitation distribution, • Flow depth.	• ArcGIS 10.2 • Remote Sensing (RS) • Analytical Hierarchy Process (AHP)	It is emphasized that the developed suitability maps will provide useful information to the decision maker to be used in water management.	[26]
Giresun University Güre and Gazipaşa campus areas, Türkiye	Calculating the amount of rainwater collection in the roof areas of buildings.	• Total roof area, • Average annual precipitation (mm), • Flow coefficient.	• ArcGIS • Gould and Nissen-Petersen formula	The study area has a total roof area of 44017.918 m^2. The annual amount of rainwater to be harvested from the roofs is calculated as 43185058.22 liters. Three different ways have been proposed for the use of harvested rainwater. The first is that approximately 8637011.644 m^2 area meets irrigation water if all of them are used for irrigation of green areas. Secondly, if all of them are used in toilets, it can meet the water needs of approximately 878 people for one year. The last recommendation is that if all of them are used in car washes, they should be used to clean approximately 431.850 vehicles.	[27]

Green infrastructure is a network of green area that aims to restore the ecosystem and ecological processes that have been destroyed by urbanization. In terms of sustainability, rainwater management provides numerous advantages [30, 31]. Green infrastructure applications can help to reduce the need for costly gray rainwater drainage systems as well as the impact of rainwater flow on infrastructure [29]. Natural hydrological cycle activities such weld point infiltration, evapotranspiration, and other losses in rainwater management are advantageous for green infrastructure applications [28]. Humanity's excessive and unconscious consumption of resources has caused global warming. As a result of global warming, climate change has occurred [8]. Changes in precipitation regimes are observed in line with global warming and climate change [8, 32]. Rainwater harvesting systems, one of the green infrastructure applications, are regarded as important adaptation mechanisms for communities affected by climate change [4]. These systems are based on various methods of collecting rainwater. Collected water can be used for agriculture, household usage, drinking water after treatment, and groundwater discharge [3].

Rainwater is a safe and dependable source in locations where industrial and transportation pollution are not as prevalent [4]. Rainwater harvesting is a widely used method of harvesting and storing water for a variety of applications, including irrigation and household use [33]. The water that is available in rainwater collection systems is acceptable for non-drinking applications including toilet flushing, landscape watering, and untreated car washing. With a straightforward treatment, this rainwater, which is reasonably clean compared to other sources, can also be transformed into a potable supply [4].

The methods for harvesting rainwater are examined under the main two systems, passive and active [34]. Rainwater harvesting from the roof, which is one of the active systems and preferred in areas with dense structures, is the process of collecting runoff from impermeable surfaces in or near buildings during rains, storing them in waterproof containers and then using them. A simple rooftop rainwater harvesting system is provided in Figure 1, mainly consists of a collection area, transmission structure, filtering, tank and distribution structure [35].

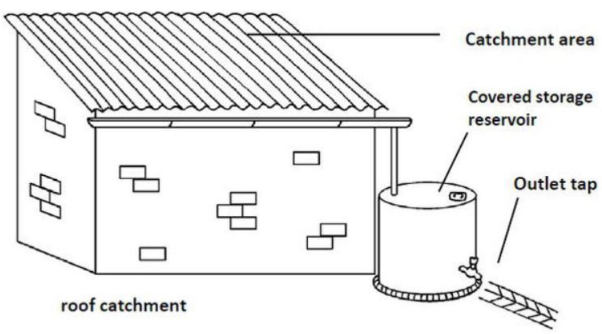


Figure 1. Roof type rainwater harvesting system [35]

As a field of study, industrial areas have an important share in the development plans of countries and water is a basic requirement of processes and products [36]. 19% of all freshwater is used by industry and energy worldwide. However, this section contains a variety of water sources, such as a well provided solely by factories located outside of the mains water supply. As a result, the actual used by the industry is even higher [9]. According to the concept of green growth, businesses can benefit both financially and environmentally by implementing sustainable strategies such as rainwater collection rather than conventional water management [36].

Besides graphical data, additional textual information describing object properties is also needed. In this context, it is important to use more effective systems that combine graphical and textual data [37]. In recent years, the management of water resources has become more interested in geographical information systems (GIS) and remote sensing (RS) technologies. The reasons for this situation are that it provides advantages for many detailed options such as high-resolution spatial data acquisition, processing of the obtained data, mapping, detailed analysis, reporting and modeling [38–42]. This interdisciplinary approach is preferred because it allows quick decision-making of options without going on the field in many studies [39, 40]. The identification and mapping of ecological networks is a critical area of green infrastructure research [44]. Table 1 summarizes studies that associate the potential for rainwater harvesting with the Geographic Information System (GIS) and Remote Sensing (RS) and investigate the possibilities for use within green infrastructure. These studies have gained speed with the effects of global climate change.

Within the scope of the literature examined, it was seen that no work was done on industrial areas. This work for industrial areas will be pioneering. This study was analyzed using open-source GIS software and Google Earth software, a free application for experts in various trade branches of rainwater harvesting in the industrial region, the industriallist, and researchers who want to research in this area to do so quickly and easily. When seen from this angle, it is clear that the work has original value in the subject and contributes significantly to the literature. In addition, this work contributes directly to the sustainable development goals of "Clean water and Sanitation" and "Climate Action".

The study's goal is to identify the possibility for rainwater harvesting in industrial zones (Eskisehir Organized Industrial Zone (EOIZ), Baksan Industrial Site, Matbaacılar Site, ESTIM Wholesalers site, Auto Gallery, EMKO Furniture and Woodworks, Teksan Industrial Site, Auto Industrialists and Small Industry, Craft Industrial Site, New Organized Industrial Zone Development Area and Small and medium-sized enterprises (SMEs)) with high water use and concentrated impermeable areas. In this context, the amount of rainwater accumulated in impermeable regions was calculated using GIS and RS to reduce the rainwater load that accumulated or reached the wastewater treatment plant with wastewater manholes. The study will directly contribute to the uncovering of the green water footprint originating from industrial impermeable areas.

2. Method

The escalating water demand exerted on current water supplies will result in significant challenges in the future. The potential water shortage can be mitigated through the effective administration of rainwater with high levels of purity [45]. The investigation utilized open-source software. Figure 2 displays the flow chart for the investigation.

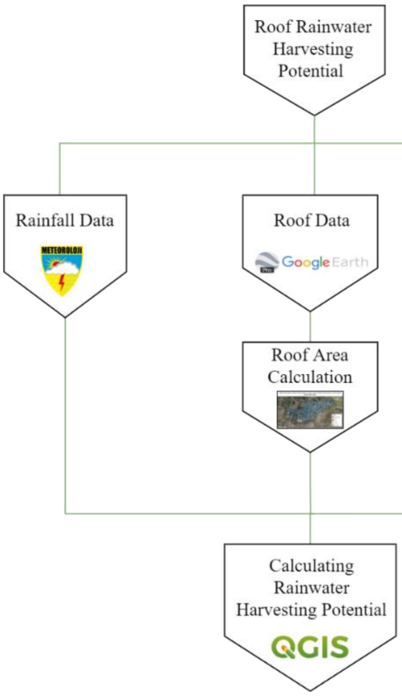


Figure 2. Study flow chart

Gould and Nissen-Petersen formula [19] were used to calculate the potential for rain water harvesting in industrial areas (Eq 1).

$$Q = C \times i \times A \quad (1)$$

Where; Q (m^3) rainwater harvesting potential,
C run-off coefficient,
i (mm) mean annual precipitation and
A (m^2) roof top collecting area.

The runoff coefficients (C) determined according to the type of roof in this formula are given in Table 2.

In Eskişehir, the mean of the rainfall falling to square meters for 2021 is 452 mm [46]. The monthly rainfall amounts of the province are given in Table 3.

The measurement of the roof area is a crucial piece of information in the context of roof rainwater harvesting. This data was generated using the open-source software Google Earth Pro. The roofs of factories are converted into kmz format using Google Earth Pro and then measured using the "area calculator" tool in the open source QGIS program. Roof types are recorded in the GIS software database to calculate the area and estimate the suitable runoff coefficient for each digitized building. The roofing kinds are determined using the Google Earth Pro software and by doing on-site observations. The annual capacity for rainwater collection is automatically estimated by considering the roof areas of each building.

Table 2. Runoff coefficients by roof type [47, 48]

Roof Type	Runoff coefficients
Concrete	0.70
Metal	0.75
Plastic	0.85
Tile	0.85

Table 3. Eskişehir monthly rainfall data (2021) [46]

Months	Precipitation/Rainfall (mm)
January	48
February	47
March	57
April	53
May	49
June	37
July	12
August	14
September	16
October	36
November	35
December	54

2.1. Study Area

The industry has played a significant role in the development of Eskişehir. Eskişehir's industrial areas cover a total of 13,652 km^2. Machine Manufacturing Industry leads the way with 23.1% of the total number of companies. The Chemical and Plastic Products Industry ranks second with 12.4%, followed by the Food Industry with 11.6% and the Metal Goods Industry in third place. Founded in 1969, Eskişehir Organized Industrial Zone is important for the city's industry. The region, which currently has 32,406,000 m^2 fields, is one of Türkiye's largest organized industry zones [49]. In addition to the EOIZ, Baksan Industrial Site, Matbaacılar Site, ESTIM Wholesalers Site, Car Dealers, EMKO Furniture and Woodworks, Teksan Industrial Site, Auto Industrialists and Small Industry, Small and medium-sized enterprises (SMEs), Craft Industrial Site and New Development Area are the main industrial areas of the province and are located within the study area [40]. Universities play an important role in the development of Eskişehir's industry, in addition to its geographical location, workforce, and transportation advantages [49]. Eskişehir province and the study area are given in Figure 3.

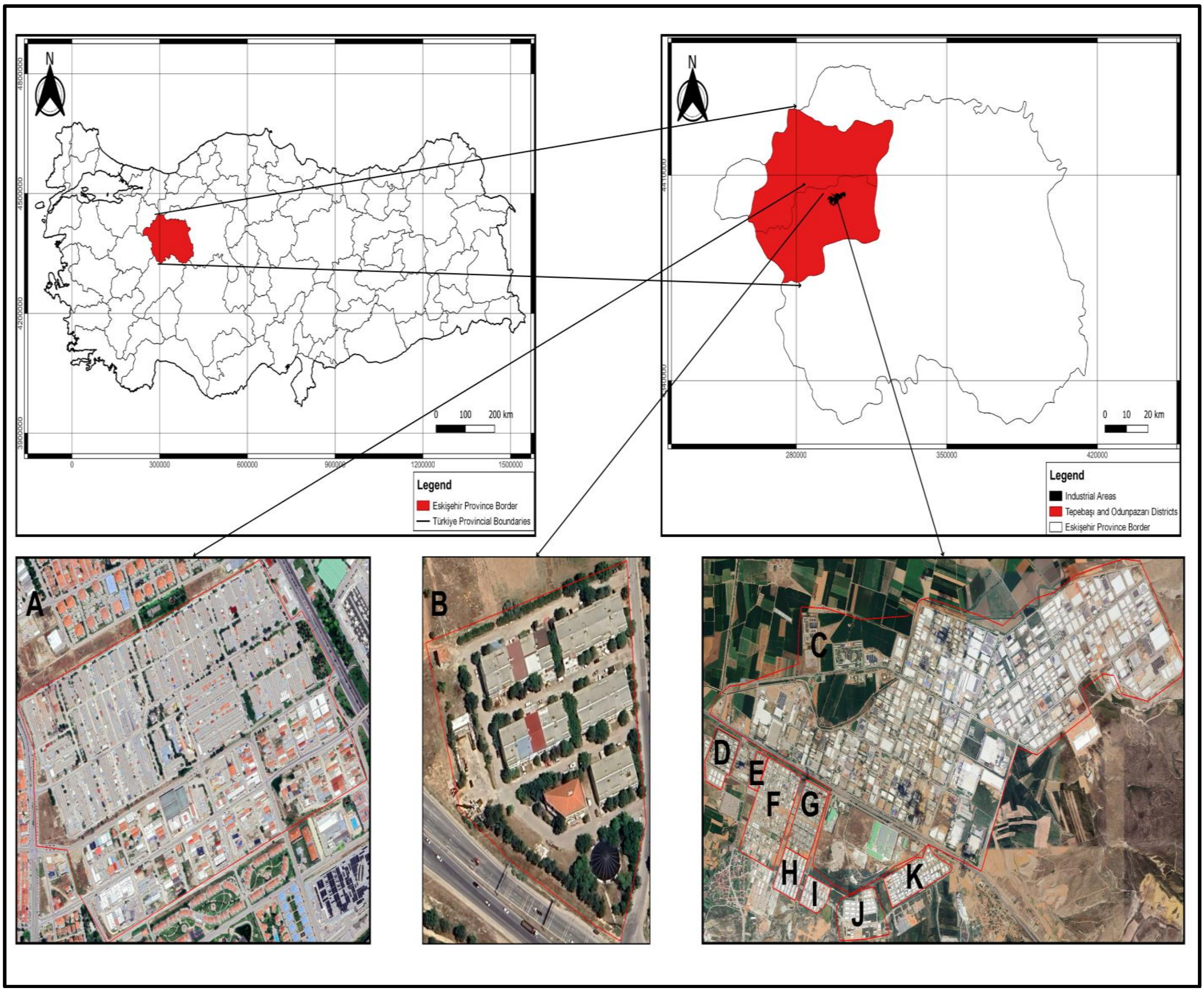


Figure 3. Study area (A: Baksan Industrial Site, B: Matbaacılar Site, C: Eskisehir Organized Industrial Zone, D: ESTIM Wholesalers Site, E: Auto Gallery, F: EMKO Furniture and Woodworks, G: Teksan Industrial Site, H: Auto Industrialists and Small Industry, I: Sm all and medium-sized enterprises (SMEs), J: Craft Industrial Site, K: New Organized Industrial Development Area)

3. Results

This work involves the creation of themed maps specifically for industrial locations that exhibit high levels of water usage. Site-specific legends have been created to account for the variations in roof area sizes and the possibility for rainwater collection in different industrial zones. The labels of the maps for the specified numerical parameters were classified using quantile (equal count) at Baksan Industrial Site and Matbaacılar Site. The process of natural fragmentation is employed to generate maps of the EOIZ and other industrial regions. Furthermore, the data on the type of roof for all fields is categorized as nominal. The size of the roof directly impacts the quantity of rainwater that may be collected from it. As the roof area expands, the potential amount of gathered rainwater also increases. The figures provided display the maps illustrating the sizes of the roof areas for Baksan Industrial Site (Figure 4), Matbaacılar Site (Figure 5), EOIZ, and other industrial sites (Figure 6). The charts indicate that the minimum roof area in industrial regions is 4 square meters, while the maximum roof area measures 119.124 square meters.

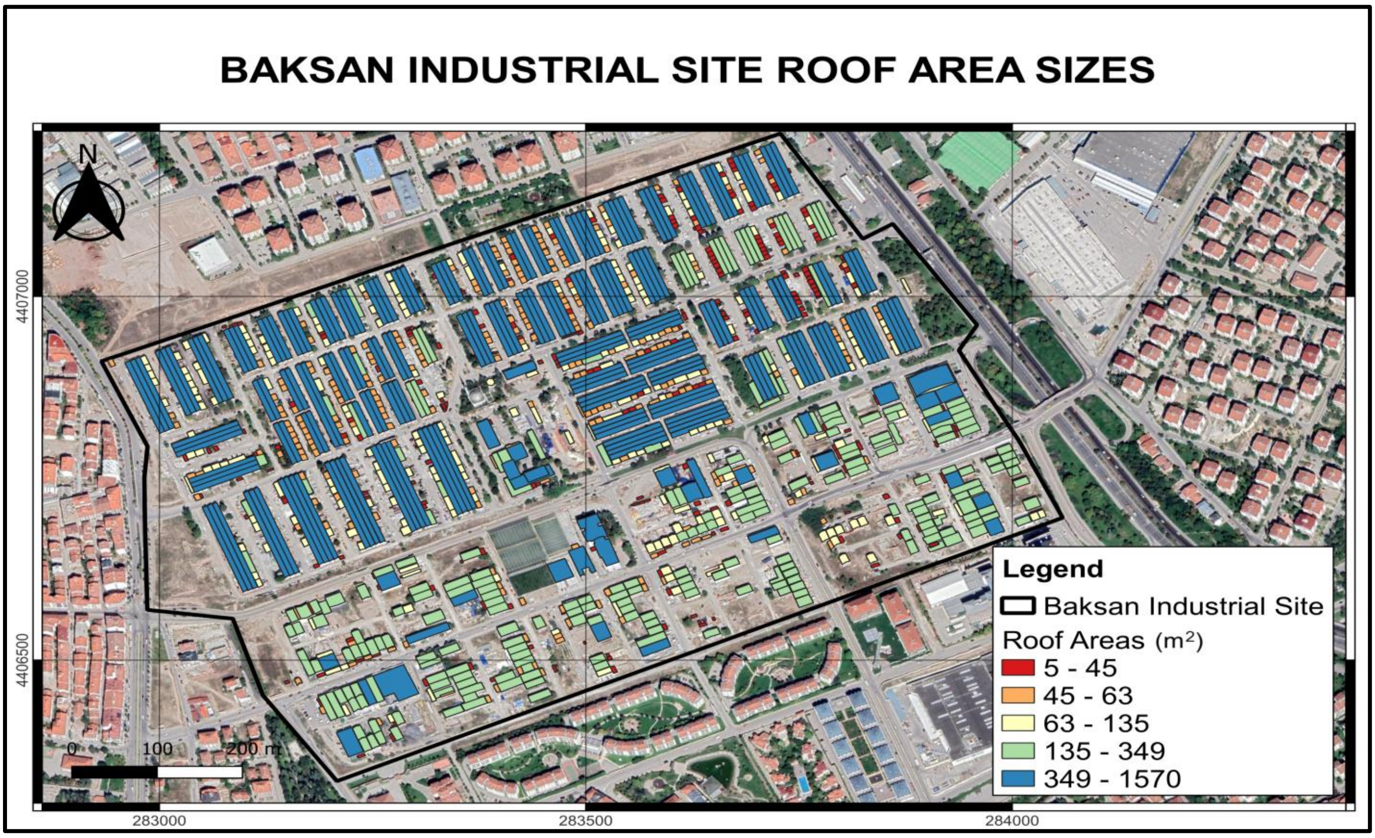


Figure 4. Baksan Industrial Site roof area

The Baksan Industrial Site has a minimum roof area of 5 m² and a maximum roof area of 1570 m². The roof area predominantly spans a range of 349 to 1570 m², as depicted in Figure 4. The roofs within this range account for 56% of the total number of roofs at the Baksan Industrial Site.

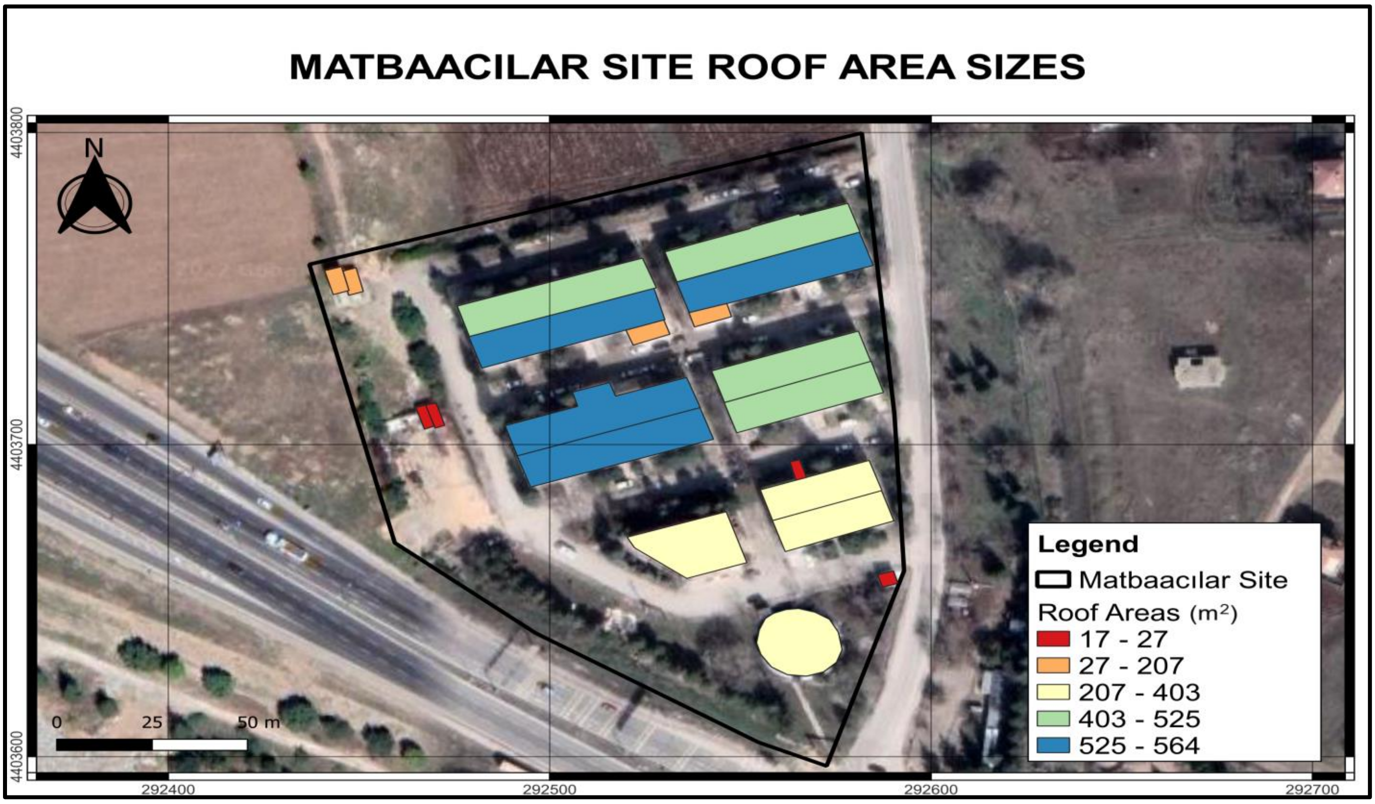


Figure 5. Matbaacılar Site roof area

When looking at the roof areas of the Matbaacılar Site, the smallest roof area is 17 m². The largest roof area the site has is 564 m². 38% of the roofs on the site are in the range of 525-564 m² (Figure 5).

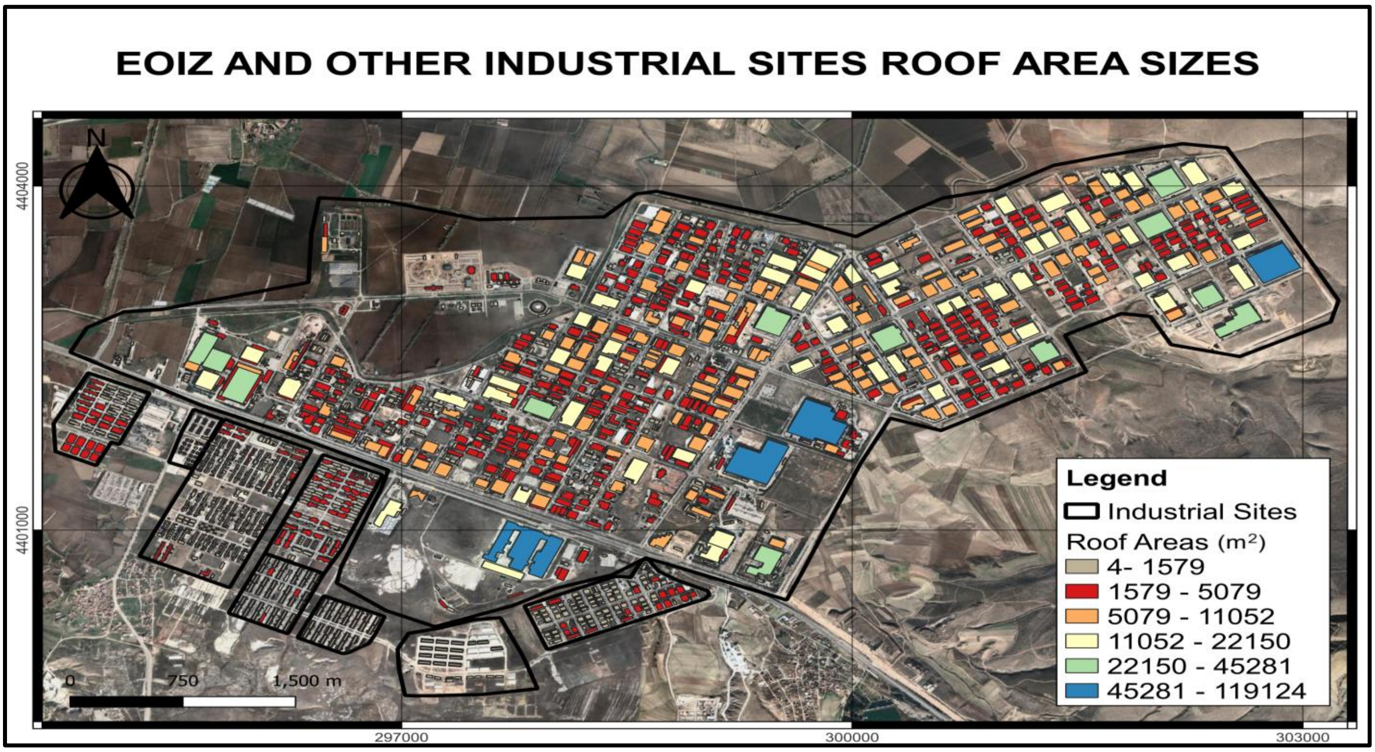


Figure 6. EOIZ and other sites roof area

The Eskişehir Organized Industrial Zone and the adjacent industrial regions have the largest roof area in the research area, as shown in Figure 6. 24% of the roofs in the specified area have an area of less than 1579 m^2. 20% of the values fall within the range of 5079-11052 m^2, and 26% are between 1579 and 5079 m^2. The roofs have an area of 16% between 11052-22150 m^2, while a tiny fraction of them, specifically 7%, have an area between 22150-45281 m^2. The total area of roofs greater than 45281 m^2 is 8% of the whole amount. Roof types have been identified in order to ascertain the runoff coefficient. The roof types maps for the Baksan Industrial Site, Matbaacılar Site, EOIZ, and other industrial sites are provided in Figure 7, Figure 8, and Figure 9, respectively. The predominant roof materials in Eskişehir's industrial zones are concrete, metal, tile, and plastic. The metal roof type is the most favored among these options, as depicted in the figures.

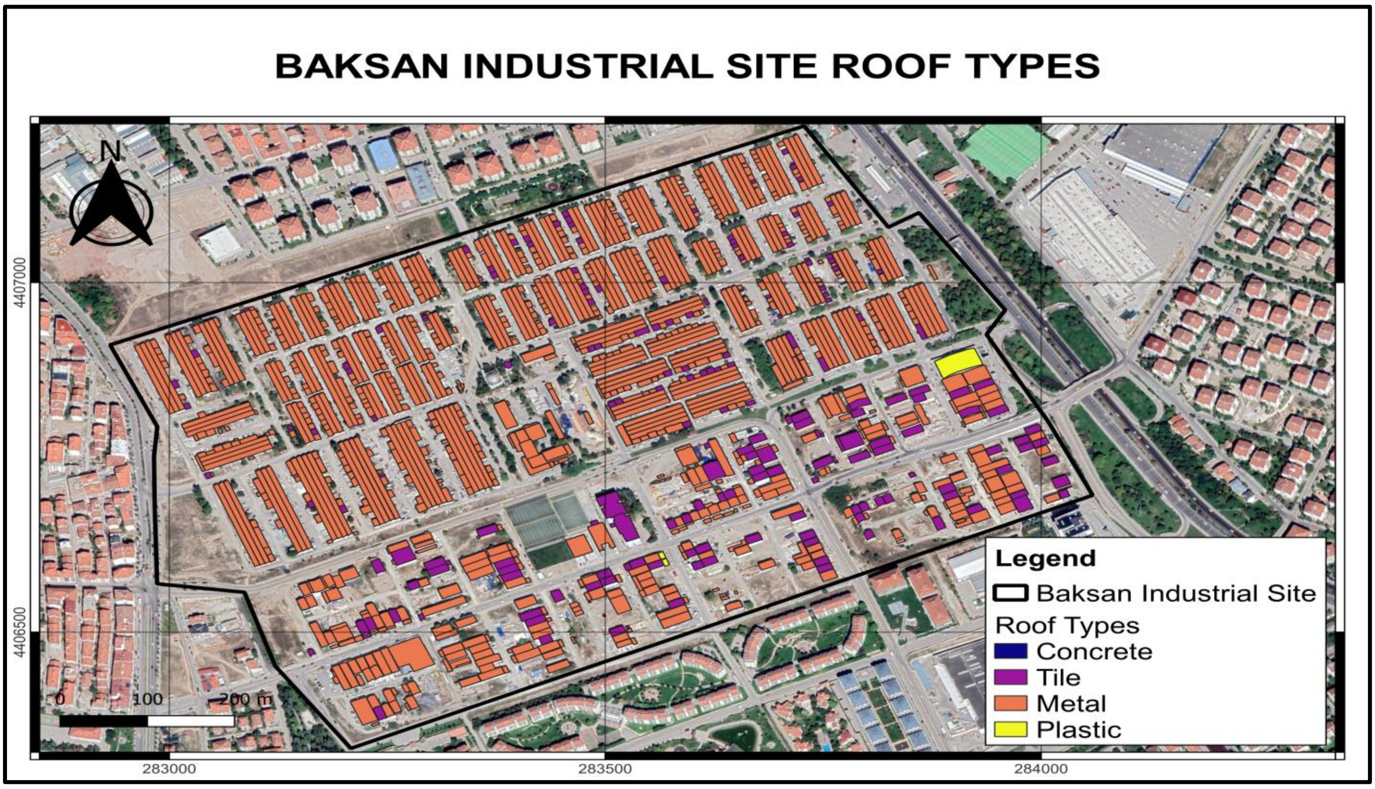


Figure 7. Baksan Industrial Site roof types

The Baksan Industrial Site is primarily characterized by the prevalence of metal roofs, accounting for 81.27% of the area (Figure 7). The plastic roof is the least common type of roof, accounting for only 0.50% of all roofs. Furthermore, the proportion of concrete roofs amounts to 1.83%, while the proportion of tile roofs stands at 16.40%.

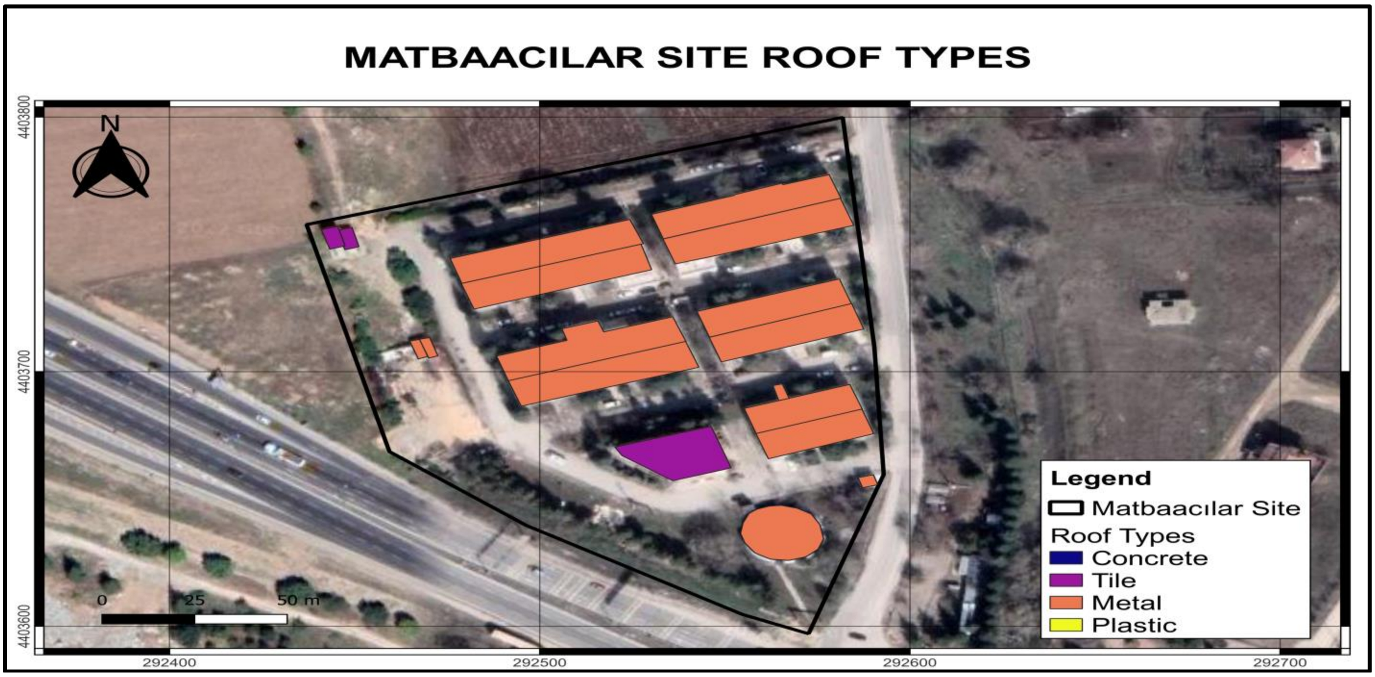
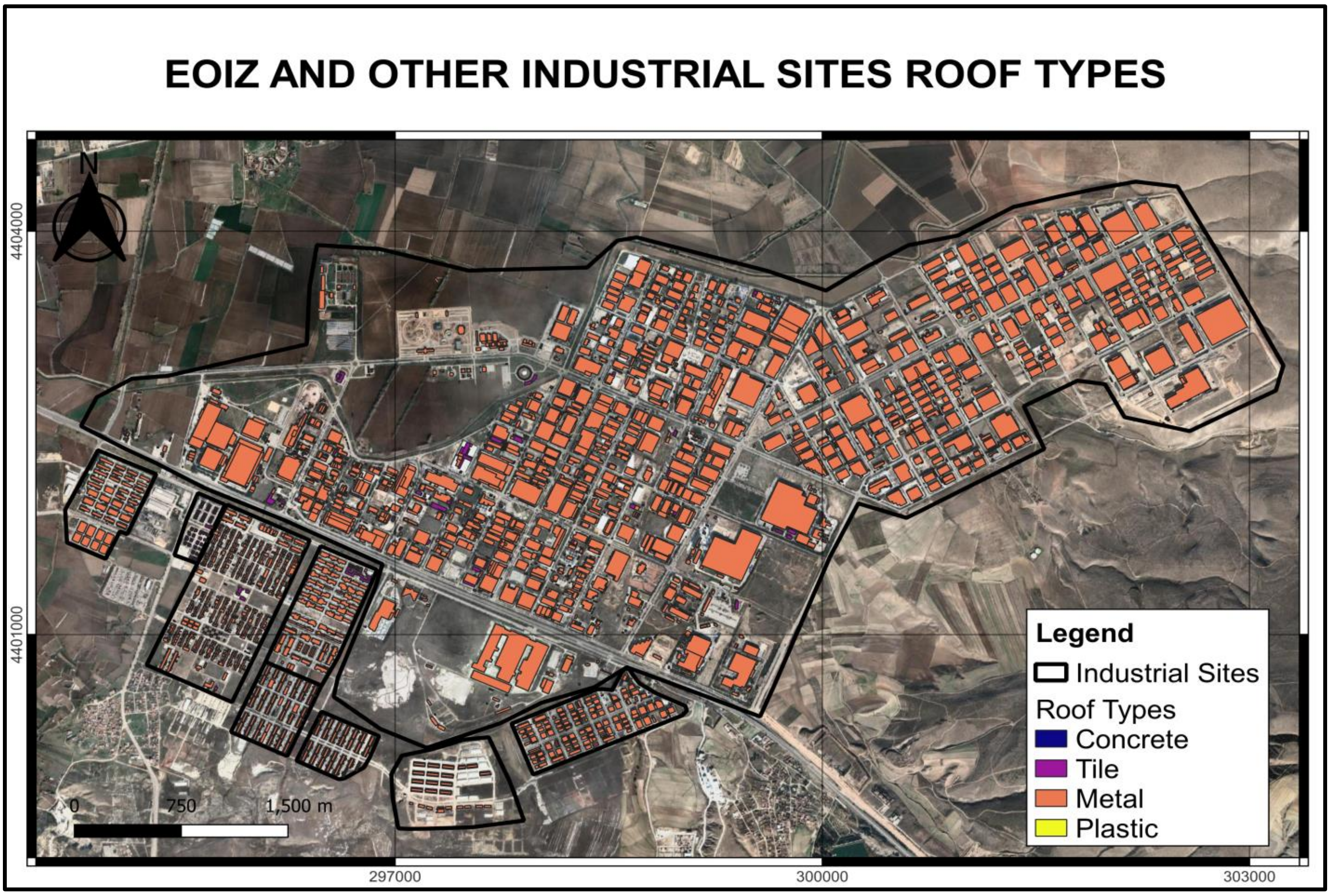


Figure 8. Matbaacılar Site roof types

According to Figure 8 of the Matbaacılar Site, there was no plastic roof found. The percentage of concrete structures with the smallest roof type is 10%. Typical metal roofs have a ratio of 75%. The proportion of roofs that are tiled is 15%.



Şekil 9. EOIZ and other sites roof types

Figure 9 depicts the prevailing variety of metal roof. The percentage of metal roofs specified is 93.96%. The predominant roofing material in the area is plastic, accounting for 0.13% of the total. The proportion of concrete roofs is 0.27% and the proportion of tile roofs is 5.64%. The inclusion of rain data in 2021 into the existing database has resulted in the generation of roof rainwater collection potential maps for industrial sites in Eskişehir. The minimum amount of rainwater that can be captured from these places is 1 cubic meter, while the maximum amount is 40383 cubic meters. The potential maps for Baksan Industrial Estate, Matbaacılar Site, EOIZ, and other Industrial Sites are provided in Figure 10, Figure 11, and Figure 12, respectively. The Eskişehir Organized Industrial Zone exhibits the greatest potential.

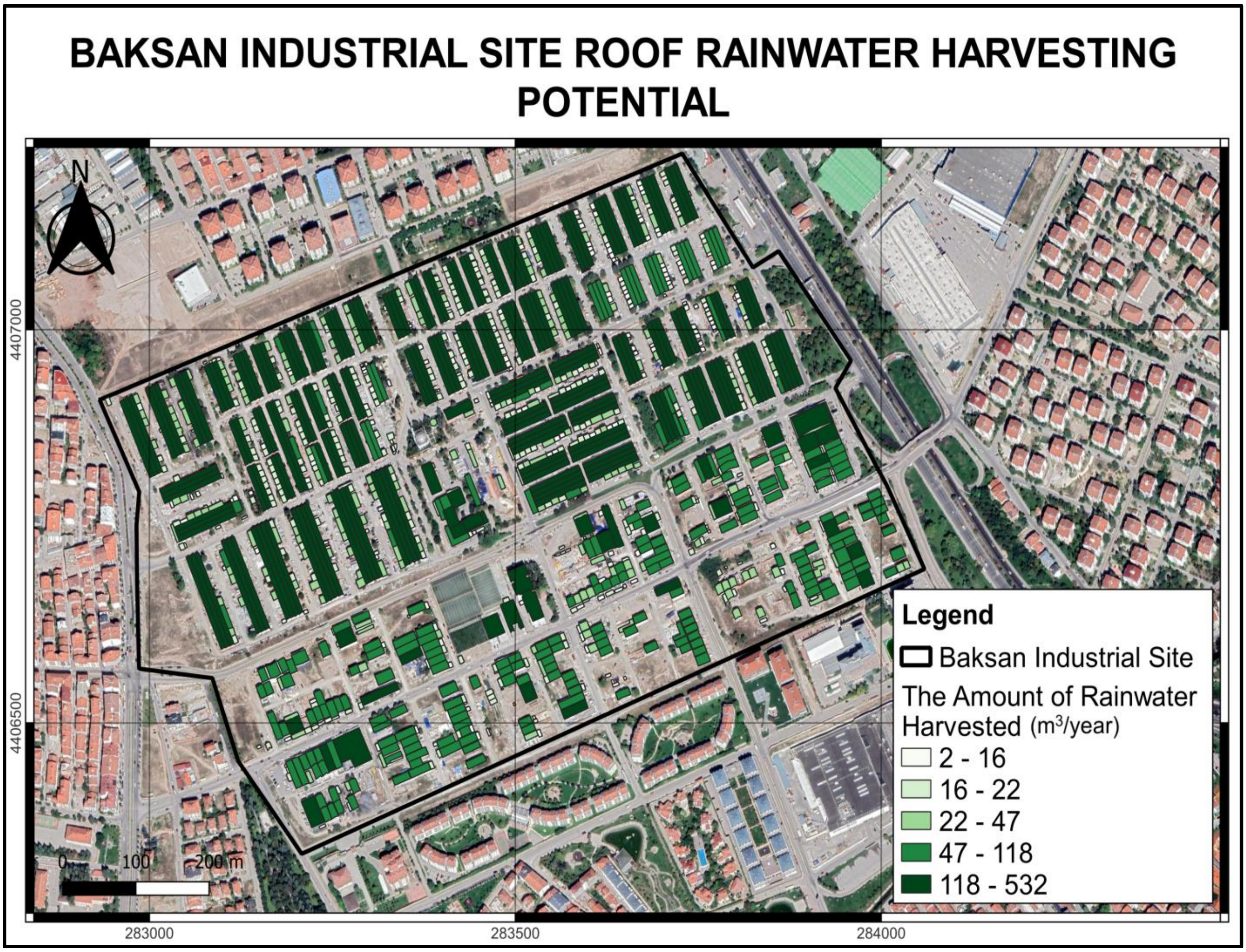


Figure 10. Baksan Industrial Site roof rainwater harvesting potential in 2021

The Baksan Industrial Site (Figure 10) can collect a minimum of 2 m^3 and a maximum of 532 m^3 of water each year from its roof. Roofs with a rainwater harvesting capacity of less than 16 m^3 account for 3%. For the harvests between 16-22 m^3, the roofs that are appropriate have a capacity of 6%, while the roofs capable of harvesting between 22-47 m^3 have a capacity of 10%. Approximately a quarter of roofs have the capacity to collect rainwater within the range of 47 to 118 cubic meters. The remaining 56% exhibits potential within the range of 118-532 cubic meters.

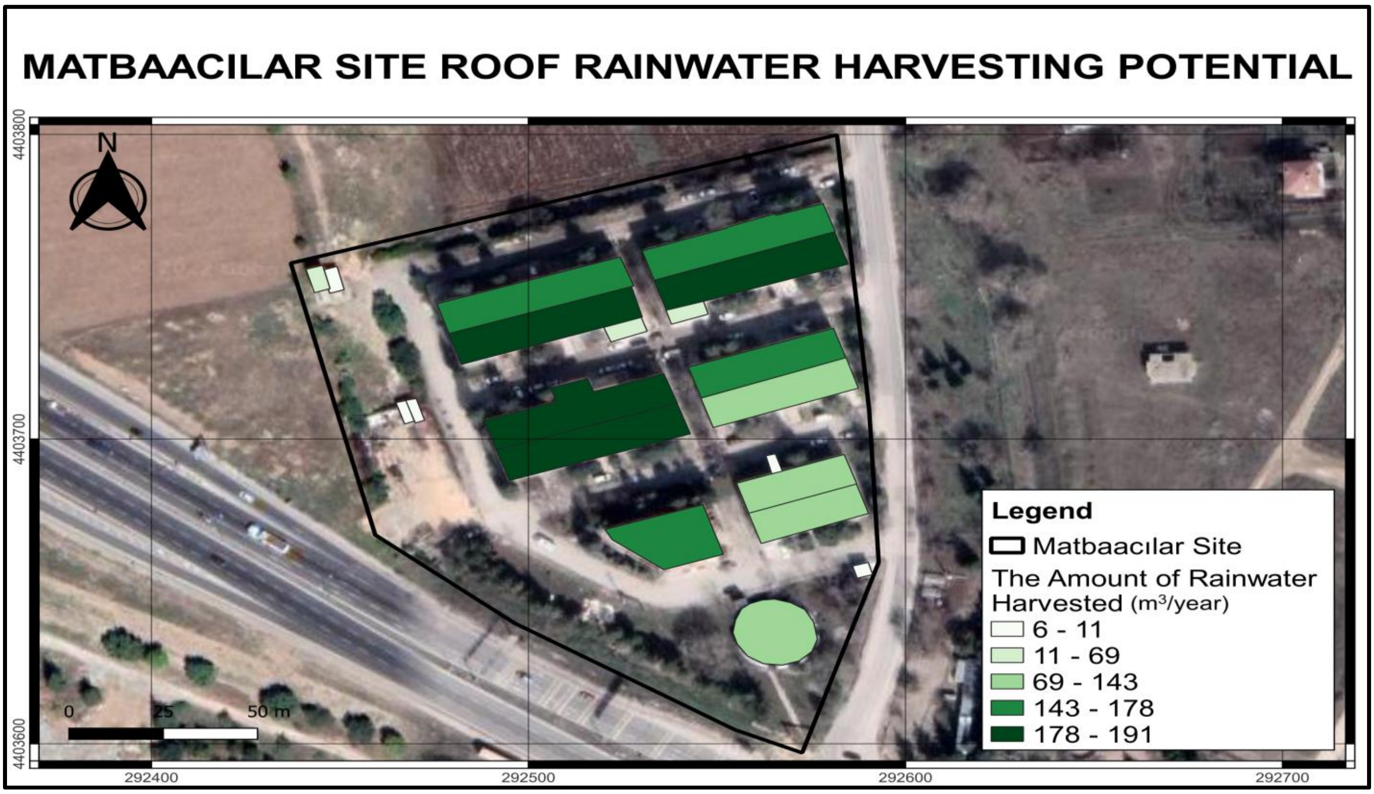


Figure 11. Matbaacılar Site roof rainwater harvesting potential in 2021

The minimal quantity of water that can be collected from a roof in the Matbaacılar Site (Figure 11) is 6 cubic meters. The land has a maximum rainwater harvesting capacity of 191 cubic meters. The amount of rooftops having the capability for rainwater collection ranges from 6 to 11 cubic meters, or 1% of the total. Only 3% of the roofs have the capacity to collect between 11 and 69 cubic meters of rainwater. Roofs with a capacity between 69-143 m^3 make up 17% of the total, while roofs capable of collecting rainwater between 143-178 m^3 account for 40%. The maximum capacity for rainwater harvesting in the industrial sector ranges from 178 to 191 cubic meters, with 38% of the roof area contributing to this range.

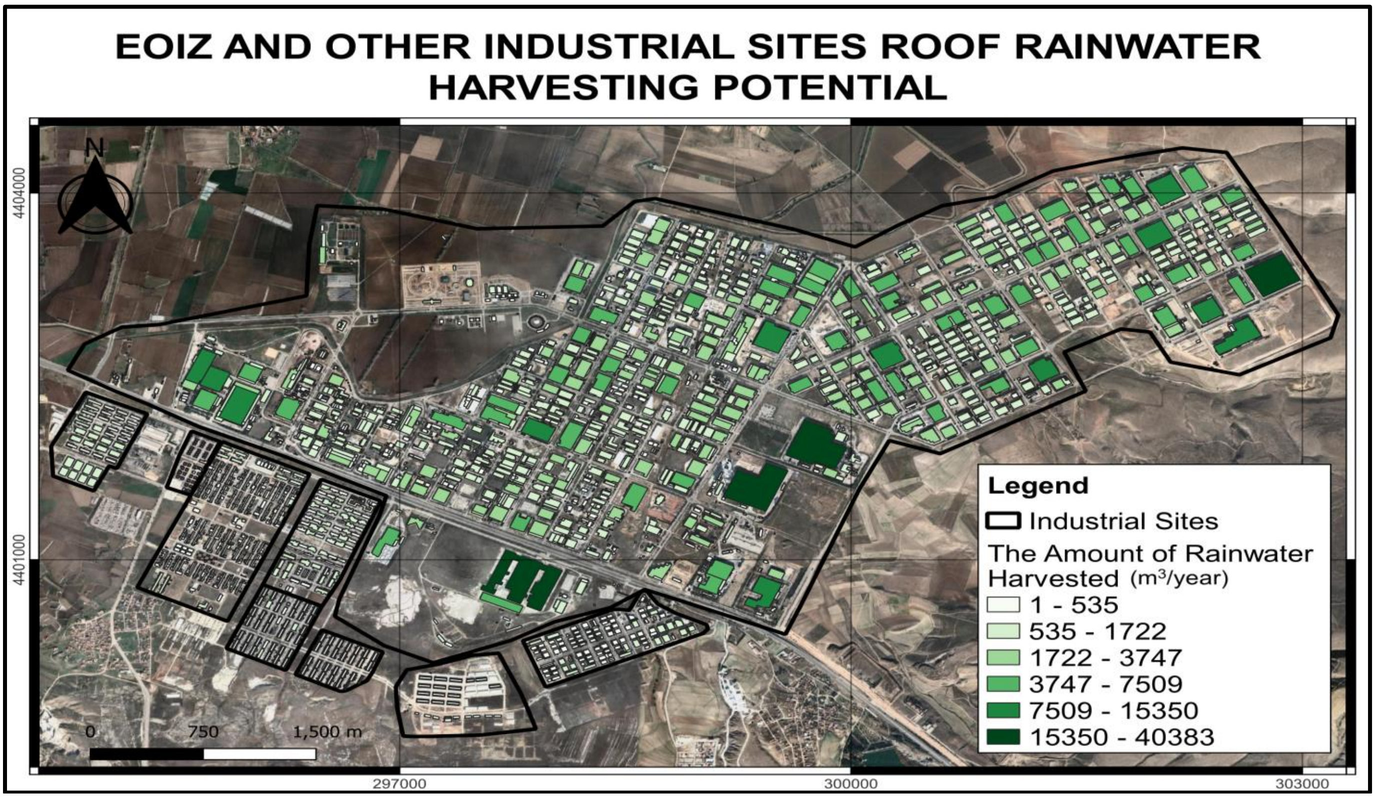


Figure 12. EOIZ and other industrial sites roof rainwater harvesting potential in 2021

Figure 12 displays a potential map of the EOIZ and other industrial sites that can be used for roof rainwater gathering. Approximately 24% of roofs in these areas had a water collection capacity of less than 535 cubic meters. The part representing 26% of the whole shows promising prospects within the range of 535 to 1722 cubic meters. Within the range of 1722-3747 m^3, roofs capable of collecting rainwater account for a 19% proportion. Approximately 16% of the roofs in the area have a capacity for harvesting between 3747 and 7509 cubic meters of water. The volume between 7509-15350 m^3 represents 7%. Roofs with a capacity of more than 15350 m^3 of rainwater make about 8% of the total.

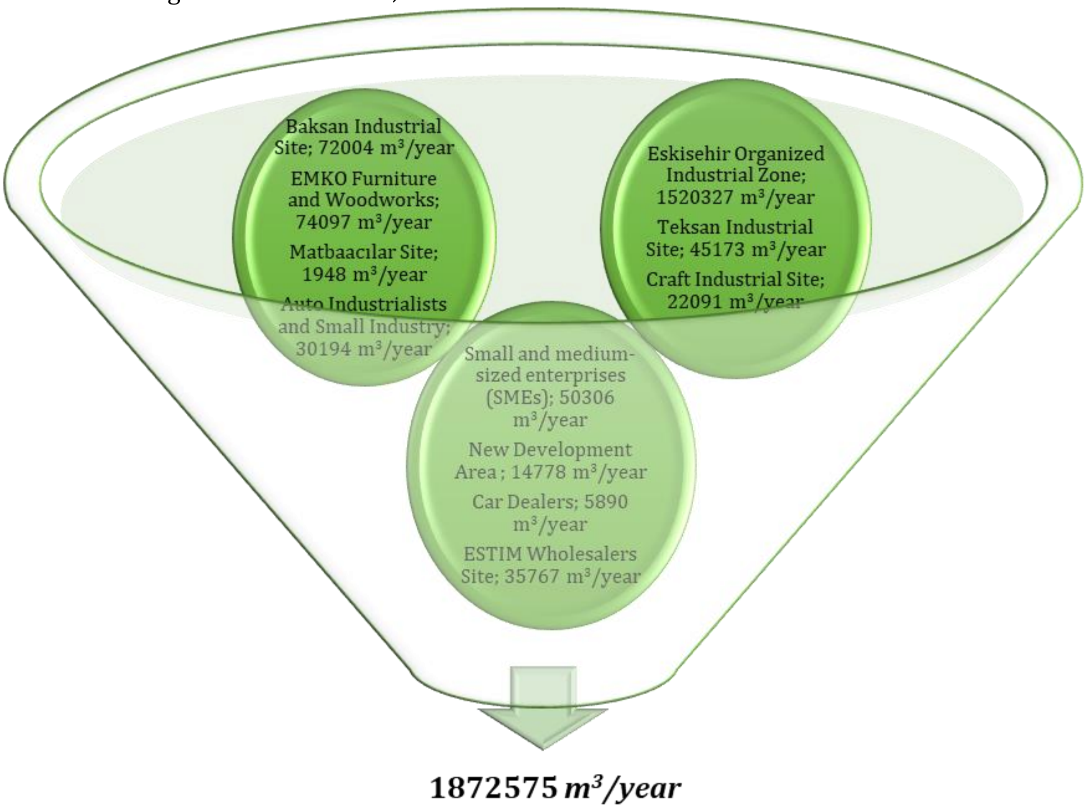


Figure 13. Potential for roof rainwater harvesting in industrial areas (m^3/year)

4. Discussion

Due to the rise in impermeable surfaces and population, there has been a corresponding increase in the amount of precipitation that collects or enters the wastewater treatment plant via wastewater manholes. The conventional approaches to rainwater management are inadequate. The reflections of this phenomenon disrupt the balance of the water cycle and manifest themselves in the form of floods and inundations. In addition, the energy spent during the transportation and treatment of water/wastewater between the plant and the consumer increases carbon emissions. When considered economically, high water withdrawal and consumption also bring high bills. In line with the green growth approach, implementing approaches with low installation and operating costs, such as rooftop rainwater harvesting systems, compared to traditional water management provides businesses with financial and environmental advantages. Sustainable practices that will reduce carbon footprint and disaster risk should be adopted in rainwater management for adaptation to climate change.

Based on the conclusions of the analysis, which are presented in Figure 13, it can be deduced that the total amount of rainwater that may be collected from the rooftops of all industrial zones in Eskişehir in the year 2021 is 1,872.575 cubic meters. EOIZ, boasting the most expansive roof area among all industrial areas, possesses significant untapped potential. The Matbaacılar Site has the lowest potential in terms of area. When assessing the potential for roof rainwater harvesting, it is important to consider various elements, including the current climate conditions, evaporation losses, roof slope, wind speed, and the parameters being studied. In order to achieve more dependable and precise outcomes, it is advisable to utilize precipitation data on a weekly, daily, or hourly basis [50].

EOIZ consumed a total of 7.084 cubic meters of water in 2021, as indicated in Figure 14. Rainwater harvesting, an exemplification of green infrastructure applications, has the capacity to yield 1,520.327 cubic meters of water for this specific region, based on the data from 2021. The quantity of water delivered is 215 times greater than the amount that was utilized (Figure 14). Excess water can be effectively controlled by utilizing gardening techniques like irrigation. Moreover, in regions characterized by a high concentration of impermeable surfaces, it is plausible that precipitation does not infiltrate the aquifers. Unused rainwater can be released into aquifers. Consequently, it has been demonstrated that the water requirements of industrial regions can be fulfilled using a sustainable approach.

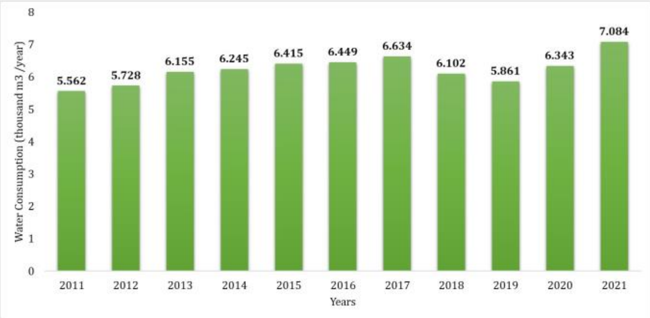


Figure 14. Eskişehir Organized Industrial Zone Water Consumption [51]

5. Conclusion

Rainwater harvesting studies are led by the German DIN 1989-100:2022-07 standard, as well as the "Regulation On Rainwater Collection, Storage And Discharge Systems" in Türkiye and the "Rainwater Harvesting Guide Document" published by the General Directorate of Water Management of the Ministry of Agriculture and Forestry in 2022. Furthermore, the revisions implemented by the Ministry of Environment, Urbanization, and Climate of the Republic of Türkiye have modified the previously published Fields Imar Regulation, as stated in the Official Gazette dated January 23, 2021. These changes will serve as a significant reference for present and future projects, particularly in relation to the requirement of incorporating a rainwater collection system in structures exceeding an area of 2000 m^2. Istanbul, the metropolis of Türkiye, has introduced a legal regulation for green roof and rainwater harvesting works with the "Istanbul Zonıng Regulatıon". In order to raise awareness on this issue, a total of four rainwater collection ponds have been built in Konya so far, while projects are ongoing in metropolitan cities such as Izmir and Ankara. The municipalities continue to implement education and projects on the subject. At this point, the work done can be a resource for the administrations in planning new projects. Furthermore, rainwater collection makes a direct and significant contribution to achieving the "Clean Water and Sanitation" and "Climate Action" objectives outlined in the sustainable development goals established by the United Nations.

In this study, utilized open-source QGIS and Google Earth Pro applications to assess the rain harvesting potential and utilization opportunities for industrial districts in Eskişehir, a significant water consumer. The collection of yearly rainwater harvesting data holds significance for both the environment and the economy in these industrial regions. This study, which reveals the potential of rainwater that can be harvested through the replanning of the existing infrastructure in the region and new construction, has shown that by integrating rainwater harvesting systems as a part of the green infrastructure, industrial zones in Eskişehir may fulfill their water needs by using rainwater collected from roofs within the framework of green infrastructure.

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Author contributions

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Conflicts of interest

The authors declare no conflicts of interest.

References

1. Karaca, M., Yağmur, N., & Balçık, F. (2022). Determining the temporal change of İstanbul Terkos Lake using Google Earth Engine. Geomatik, 7(3), 235-242. https://doi.org/10.29128/geomatik.975714
2. Kaynarca, M., Demir, N., & San, B. T. (2020). An Approach for Modeling of Ground Water Sources Using Remote Sensing and GIS Techniques: Kırkgoz Catchment (Antalya). Geomatik, 5(3), 241-245. https://doi.org/10.29128/geomatik.649221
3. Kılıç, M., Abuş, M. N. (2018). Rain Water Harvesting in a Garden House Sample. International Journal of Agriculture and Wildlife Science (IJAWS), 4(2), 209-215.
4. Norman, M., Shafri, H. Z. M., Mansor, S. B., & Yusuf, B. (2019). Review of remote sensing and geospatial technologies in estimating rooftop rainwater harvesting (RRWH) quality. International Soil and Water Conservation Research, 7(3), 266-274. https://doi.org/10.1016/j.iswcr.2019.05.002
5. Jamil, M., Mahmood, S., Hussain, S., & Saad, M. (2024). Assessing the impact of drought on groundwater resources using geospatial techniques in Balochistan Province, Pakistan. Advanced Remote Sensing, 4(1), 11-27.
6. Yalılı Kılıç, M., & Adalı, S. (2022). Rainwater Harvesting in a Shopping Mall Example. Uludağ University Journal of The Faculty of Engineering, 29-40. https://doi.org/10.17482/uumfd.1034275
7. General Directorate of State Hydraulic Works, Soil-Water Resources. (2023). https://www.dsi.gov.tr/Sayfa/Detay/754
8. Yiğit, A. Y., Orhan, O., & Ulvi, A. (2020). Investigation of The Rainwater Harvesting Potential at the Mersin University, Turkey. Mersin Photogrammetry Journal, 2(2), 64-75.
9. United Nations Educational, Scientific and Cultural Organization (2022). The United Nations World Water Development Report 2022. Paris.
10. Siraj, M., Mahmood, S., & Habib, W. (2023). Geo-spatial assessment of land cover change in District

Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan. Advanced Remote Sensing, 3(1), 1-9.
11. Bellot, J., Bonet, A., Peña, J., & Sánchez, J. R. (2007). Human Impacts on Land Cover and Water Balances in a Coastal Mediterranean County. Environmental Management, 39(3), 412-422. https://doi.org/10.1007/s00267-005-0317-9
12. Göksel, Ç., & Bozkaya Karip, G. (2017). Modeling Of Land Use /Land Cover Change Detection Of Igneada Protecting Zone Using Markov Chain. Geomatik, 2(2), 94-105. https://doi.org/10.29128/geomatik.303890
13. Arnold, C. L., & Gibbons, C. J. (1996). Impervious Surface Coverage: The Emergence of a Key Environmental Indicator. Journal of the American Planning Association, 62(2), 243-258. https://doi.org/10.1080/01944369608975688
14. Yamak, B., Yagci, Z., Bilgilioglu, B. B., & Comert, R. (2021). Investigation of the effect of urbanization on land surface temperature example of Bursa. International Journal of Engineering and Geosciences, 6(1), 1-8. https://doi.org/10.26833/ijeg.658377
15. Müftüoğlu, V., & Perçin, H. (2015). The Rain Garden Within Sustainable Urban Stormwater Management. Inonu University Journal of Art and Design, 5(11), 27-37.
16. Patil, M., Saha, A., Pingale, S. M., Rathore, D. S., & Goyal, V. C. (2023). Identification of potential zones on the estimation of direct runoff and soil erosion for an ungauged watershed based on remote sensing and GIS techniques. International Journal of Engineering and Geosciences, 8(3), 224-238. https://doi.org/10.26833/ijeg.1115608
17. Avdan, Z., Yıldız, D., & Çabuk, A. (2015). Yağmur Suyu Yönetimi Açısından Yeşil Altyapı Sistemlerinin Değerlendirilmesi. II. International Sustaınable Structure Symposıum, Ankara, 733-740.
18. Bakir, M., & Xingnan, Z. (2008). GIS and Remote Sensing applications for rain water harvesting in the Syrian Desert (Al-Badia). In Proceedings of the 12th International Water Technology Conference (pp. 73-82).
19. Dadhich, G., & Mathur, P. (2016). A GIS based analysis for rooftop rain water harvesting. Int. J. Comput. Sci. Eng. Technol, 7(4), 129-143.
20. Pandya, P. A., Bhanderi, H. M., Chauhan, N. K., & Garala, P. J. (2017). Roof Water Harvesting Quantity Estimation Usıng GIS. AGRES – An International e. Journal, 6(2), 226-230.
21. Yükselir, H., Ağaçsapan, B., & Çabuk, A. (2019). CBS tabanlı çatıların yağmur suyu toplama kapasitesinin hesaplanması. GSI Journals Serie C: Advancements in Information Sciences and Technologies, 1(2), 16-26.
22. Gar Al-Nabi, M. (2020). Remote Sensing Data Based Rainwater Harvesting Approach for Remote Rural Areas - A Case Study, Blue Nile Area, Sudan. Journal of Scientific Research and Reports, 26(7), 75-82. https://doi.org/10.9734/jsrr/2020/v26i730286
23. Gohel, J., Bhatu, H., Kapupara, P., & Barath, R. (2020). Designing rooftop rainwater harvesting system at RK University. Journal of Pharmacognosy and Phytochemistry, 9(2S), 351-353.
24. Sayl, K. N., Mohammed, A. S., & Ahmed, A. D. (2020). GIS-based approach for rainwater harvesting site selection. In IOP Conference Series: Materials science and engineering (Vol. 737, No. 1, p. 012246). IOP Publishing.
25. Abd-el-Kader, M., Elfeky, A., Saber, M., & AlHarbi, M. (2021). Designating Appropriate Areas for Determining Potential Rainwater Harvesting in Arid Region Using a GIS-based Multi-criteria Decision Analysis.
26. Balkhair, K. S., & Ur Rahman, K. (2021). Development and assessment of rainwater harvesting suitability map using analytical hierarchy process, GIS and RS techniques. Geocarto International, 36(4), 421-448. https://doi.org/10.1080/10106049.2019.1608591
27. Kalıpcı, E., Başer, V., & Nihal, G. E. N. Ç. (2021). Evaluation of Rainwater Harvest Using Geographic Information System: Giresun University Campus Example. Gaziosmanpasa Journal of Scientific Research, 10(1), 49-58.
28. Nickel, D., Schoenfelder, W., Medearis, D., Dolowitz, D. P., Keeley, M., & Shuster, W. (2014). German experience in managing stormwater with green infrastructure. Journal of Environmental Planning and Management, 57(3), 403-423. https://doi.org/10.1080/09640568.2012.748652
29. Li, C., Peng, C., Chiang, P.-C., Cai, Y., Wang, X., & Yang, Z. (2019). Mechanisms and applications of green infrastructure practices for stormwater control: A review. Journal of Hydrology, 568, 626-637. https://doi.org/10.1016/j.jhydrol.2018.10.074
30. Benedict, M. A., & McMahon, E. T. (2022). Green Infrastructure: Smart Conservation For The 21st Century. Renewable Resources Journal, 20(3), 12-17.
31. Dhakal, K. P., & Chevalier, L. R. (2017). Managing urban stormwater for urban sustainability: Barriers and policy solutions for green infrastructure application. Journal of Environmental Management, 203, 171-181. https://doi.org/10.1016/j.jenvman.2017.07.065
32. Alptekin, A., & Yakar, M. (2020). Determination of pond volume with using an unmanned aerial vehicle. Mersin photogrammetry journal, 2(2), 59-63.
33. Memduhoğlu, A. (2023). Identifying impervious surfaces for rainwater harvesting feasibility using unmanned aerial vehicle imagery and machine learning classification. Advanced GIS, 3(1), 01–06.
34. Sert, E. (2013). Rain Water In The Energy Efficient Urban Landscape Design (Master's Thesis). Istanbul Technical University, Istanbul.
35. Çelik, M. Ö., & Yakar, M. (2023). Arazi kullanımı ve arazi örtüsü değişikliklerinin uzaktan algılama ve cbs yöntemi ile izlenmesi: Mersin, Türkiye örneği. Türkiye Coğrafi Bilgi Sistemleri Dergisi, 5(1), 43-51..
36. Jayasooriya, V. M., Ng, A. W. M., Muthukumaran, S., & Perera, C. B. J. (2020). Optimization of Green Infrastructure Practices in Industrial Areas for Runoff Management: A Review on Issues, Challenges and Opportunities. Water, 12(4), 1024. https://doi.org/10.3390/w12041024
37. Önder, M. ., Güntel, A., & Kaya, Özgür Y. (2022). A geographical information systems (GIS) perspective

on European green deal and sustainability. Advanced GIS, 2(1), 33–37.

38. Alfaloji, M. (2022). Water budget estimation using remote sensing observations and GLDAS-CLSM for Limpopo River Basin. *Advanced Remote Sensing*, *2*(2), 85–93.
39. Çabuk, A., Çabuk, K.M., Aksoy, T., Şimşek, B., Güney, Y., Avdan, U., Uyguçgil, H., Çömert, R. (2018). Coğrafi Bilgi Sistemlerine Giriş. Eskişehir: Anadolu Üniversitesi. E-ISBN 978-975-06-2496-4
40. Sağlam Doğan, B. (2020). Determination In Urban Areas Carbon Emissions And Land Use Relationship Using Remoe Sensing And Georaphic Information Systems: A Case Study Of Eskisehir Povince (Master's Thesis). Eskişehir Technical University, Eskişehir.
41. Başaran, N., Küçük Matcı, D., & Avdan, U. (2022). Using multiple linear regression to analyze changes in forest area: the case study of Akdeniz Region. International Journal of Engineering and Geosciences, 7(3), 247-263. https://doi.org/10.26833/ijeg.976418
42. Polat, Z. A., Kırtıloğlu, O. S., & Kayalık, M. (2023). Evolution and future trends in global research on geographic information system (GIS): a bibliometric analysis. *Advanced GIS*, *3*(1), 22–30.
43. İşcan, F., & Ilgaz, A. (2017). Analysis Of Geographic/Urban Information System Web Presentations Of Local Goverments In Turkey. International Journal of Engineering and Geosciences, 2(3), 75-83. https://doi.org/10.26833/ijeg.317088
44. Tülek, B., & Ersoy Mirici, M. (2019). Green Infrastructure and Ecosystem Services on Urban Systems. Peyzaj, 1(2, 1-11).
45. Che-Ani, A., N, S., & Sairi, A. (2009). Rainwater Harvesting as an Alternative Water Supply in the Future. European Journal of Scientific Research, 34.
46. Ünel, F. B., Kuşak, L., Yakar, M., & Doğan, H. Coğrafi bilgi sistemleri ve analitik hiyerarşi prosesi kullanarak Mersin ilinde otomatik meteoroloji gözlem istasyonu yer seçimi. Geomatik, 8(2), 107-123.
47. Biswas, B. K. B. K., & Mandal, B. H. (2014). Construction and Evaluation of Rainwater Harvesting System for Domestic Use in a Remote and Rural Area of Khulna, Bangladesh. International Scholarly Research Notices, 2014, 1-6. https://doi.org/10.1155/2014/751952
48. Doğangönül, Ö., & Doğangönül, C. (2009). Küçük ve Orta Ölçekli Yağmursuyu Kullanımı. Ankara: Teknik Yayınevi.
49. Eskisehir Chamber of Industry 2024-2027 Strategic Plan. (2024). https://www.eso.org.tr/stratejik-plan
50. Hımat, M. A. (2018). Province-Based Assessment Of Rooftop Rainwater Harvesing Potential In Turkey (Master's Thesis). Selcuk University, Konya.
51. Eskisehir Industrial Zone. (2021). Water Consumption. https://www.eosb.org.tr/analiz/su_tuketimleri_bin_m_yil_7.html