water

MDPI

Article

Geospatial Approaches to Improve Water Availability through Demand Assessment in Agriculture Based on Treated Wastewater: A Case Study of Weinstadt, Baden-Württemberg

Sourav Karmaker [1,*], Sanchalita Bandyopadhyay [2] and Sonja Bauer [3]

1 Faculty of Computer Science, Mathematics and Geoinformatics, Stuttgart University of Applied Sciences (HFT Stuttgart), 70174 Stuttgart, Germany
2 TELUS International Europe, 45127 Essen, Germany; sanchalita1994@gmail.com
3 Department of Electrical Engineering, Media and Computer Science, Ostbayerische Technische Hochschule Amberg-Weiden, 92224 Amberg, Germany; s.bauer@oth-aw.de
* Correspondence: souravkm021@gmail.com

Abstract: The sustainable management of water scarcity is a globally crucial issue. Germany has established efficient water management systems, but the agricultural sector still struggles with water scarcity as the demand surpasses the available water supply. In this work, the primary aim was to establish a framework for making water accessible for irrigation and additional use in households through the effective utilization of recycled water from wastewater treatment facilities. The research inquiries were focused on evaluating the changes in the CROPWAT agricultural irrigation model, determining the spatial distribution of zonal severity, estimating the capacity of urban roof catchments, and evaluating the economic value addition of retreated water from the existing wastewater treatment plant supply. According to the findings, the annual amount of water required for agriculture in the designated study location is approximately 2.9 million m^3. Although there is no initial need for irrigation water, the demand for irrigation water increases during the development, active growth, and mature stages of maize, winter wheat, and wine grapes, reaching around 189 mm, 223 mm, and 63 mm, respectively. According to our observations, the annual water supply in Weinstadt is around 4 million m^3. On the other hand, the compensated volume of water to the current water supply calculated from the urban roof rainfall is estimated to be 0.8 million m^3, which is considered valuable from an economic standpoint. This economically efficient volume of water would reduce the current treated water supply, which indicates an opportunity for enhanced agricultural irrigation.

Keywords: water scarcity; irrigation water; roof catchment; CROPWAT; Germany

check for updates

Citation: Karmaker, S.; Bandyopadhyay, S.; Bauer, S. Geospatial Approaches to Improve Water Availability through Demand Assessment in Agriculture Based on Treated Wastewater: A Case Study of Weinstadt, Baden-Württemberg. *Water* **2024**, *16*, 704. https://doi.org/10.3390/w16050704

Academic Editor: Tammo Steenhuis

Received: 23 January 2024
Revised: 20 February 2024
Accepted: 21 February 2024
Published: 28 February 2024

1. Introduction

Water scarcity is growing as a concerning issue in many regions, which makes water a vital resource that must be managed sustainably. The United Nations Sustainable Development Goal 6 "Clean Water and Sanitation" is dedicated to water and aims to significantly increase global water recycling and safe reuse by 2030. Irrigation water reuse practices have been established in different countries, i.e., the USA, Israel, African nations such as Namibia, Windhoek very long years ago and some projects implemented among the EU nations as well. But, in 2012, the European Union recognized the potentiality of water reuse as a solution to the problems of water scarcity and drought [1].

Germany is one of the countries in Europe with a higher water availability compared to other European countries because it is surrounded by oceans and seas, with numerous rivers and lakes running through it. Agriculture still has greater effects on water bodies through substance emissions and alterations to their physical structure. The use of agricultural fertilizers leads to excessive nutrient discharges into water bodies and contributes significantly to nitrate pollution and over-enrichment of nutrients (eutrophication) in rivers, lakes, and seas [2]. Due to this reason, Germany and other EU countries have made outstanding advances in managing their hydraulic resources to meet the needs of the agriculture, industrial, and tourism sectors, as well as the needs of a rising population.

From June 2023 onwards, treated wastewater would be used for irrigation purposes and excess water would be supplied to households. In this regard, a new regulation on the minimum treated water requirements will be imposed to encourage water use in agricultural irrigation and reduce the water scarcity brought about by climate change in the European Union and enable the deployment of water reclamation while promoting the circular economy, protecting the safety of human health and the environment as well [3].

Germany has several large-scale water treatment plants that provide clean and safe drinking water to its residents. Undoubtedly, traditional wastewater treatment systems have improved the quality of life in urban areas and lowered environmental stress [4]. For better reusability of water, the most considerable concern is to know the potentiality of wastewater treatment plants and also consider the urban roof water harvesting for how it adds economic value to the water users [5]. Nevertheless, with the potential for recycling wastewater and the nutrients it contains, the goal of improving sustainable resource management in wastewater treatment has become increasingly important [4].

Different prior research provided a detailed study of water availability, highlighting the depiction of irrigation water requirements, urban water harvesting, and the potential of wastewater treatment plants in assessing water stress scenarios. For addressing the water scarcity issue, a Geographic Information System (GIS)-based study was conducted to determine the potential volume of treated wastewater and afterwards the water quality standardized for suitable irrigation [6]. To meet the rising water needs in the EU, Jodar-Abellan et al. [7] proposed a conceptual model that compared to the present situation in several municipalities where the primary source of increased water requirements is clearly agriculture and urban expansion. Jia et al. [8] focused on the application of GIS techniques to assess the potentiality of wastewater reclamation in different urban land use scenarios in Beijing. Ramirez et al. [9] employed the water–energy–food nexus approach to analyze the impact of capturing, treating, and repurposing wastewater for irrigation. Jaramillo and Restrepo [10] presented a discussion on the positive and negative impacts of using treated wastewater and proposed “end of ripe” conventional solutions so that the irrigation purposes can be improved. To address this concern, Moseki et al. [11] utilized the CROPWAT model to determine the reference evapotranspiration rate (ETo), actual evapotranspiration (ETc), irrigation water requirements (IWR), and the effect of irrigation on yield. According to the study of Bilibio and Hensel [12], water scarcity situations in Germany were analyzed using the FAO-CROPWAT model to calculate the effective precipitation, crop evapotranspiration, actual evapotranspiration, and water deficit from 2014 to 2016. Consequently, Surendran et al. [13] studied the crop water requirements of different paddy varieties by using the CROPWAT model to estimate the climatic water balance and proposed projected water future demand for irrigation, industrial and domestic purposes. The crucial factor in designing irrigation systems is usually determining the effective rainfall to assess the amount of water that should be supplied through irrigation. Bokke and Shoro [14] compared various rainfall models using small-scale weather data and found that the USDA-SC method resulted in the lowest net irrigation water requirements in water-scarce regions, whereas the dependable rain method resulted in the highest net irrigation water requirements in water-sufficient regions.

After the estimation of the IWR in CROPWAT, some of the research articles demonstrated the geo-spatial distribution and some research took remote-sensing techniques for analyzing the crop water demand. Feng et al. [15] applied spatial distribution techniques for planning and managing maize cultivation at various stages of development on irrigated farmlands. Al-Najar [16] demonstrated the Gaza Strip’s spatial distribution results of irrigation water needs for citrus, almonds, date palm, and grapes based on data from eight weather stations. Bhardwaj et al. [17] observed the Land Use Land Cover (LULC) analysis for evapotranspiration differentiation from the district-level collected data. But Adamala et al. [18] assessed the Normalized Difference Vegetation Index (NDVI) and LULC for the calculation of crop evapotranspiration. The actual evapotranspiration (ETc) of the wheat crop was estimated using the crop coefficient (Kc) that has relationship with the NDVI outcome maps and the reference evapotranspiration (ETo). Machine learning and multicriteria analysis were used for the modeling and evaluation of reference evapotranspiration. The study by Kadkhodazadeh et al. [19] employed six machine learning techniques, namely multiple linear regression (MLR), multiple non-linear regression (MNLR), multivariate adaptive regression splines (MARS), model tree M5 (M5), random forest (RF) and least-squares boost (LSBoost). In urban areas, roofs are often the primary choice for collecting rainwater. Farreny et al. [20] established guidelines for selecting roofs that would optimize the amount and quality of the collected rainwater on four types of roofs: clay tiles, metal sheet, polycarbonate plastic, and flat gravel. Maqsoom et al. [21] examined a Building Information Modeling (BIM)-based approach considering the water scarcity that created a 3D building model based on the average roof area and population. The water demand in the nearby city of Ludwigsburg of this proposed study area was evaluated using a method that can precisely predict the pressure on local water resources in Germany on a single building level and can also be scaled to a regional level while maintaining detail [22].

Therefore, the primary goal of this research is to create a context for the availability of water for irrigation and household use, estimating the potential of water recycling from wastewater treatment plants in Weinstadt Municipality of Baden Württemberg, Germany. Thus, it is necessary to gather the required factors, environmental derivers, and workflow for building a wastewater reuse framework to fulfill the goals. The main research questions are as follows:

- What is the extent of the agriculture irrigation water requirement (IWR) varied according to agro-climate variable in the CROPWAT model at different crop life stages?
- How can the definition of the urban roof catchment surface yield the volume of the water-retaining capacity for each roof type?
- How to economically compensate the agriculture irrigation and current water supply from the WWTP (wastewater treatment plant) by the urban roof catchment harvesting capacity?

The following section provides a detailed description of the water requirements, including the collection and preparation of data, the use of the CROPWAT model to determine irrigation water requirements, the calculation of urban water requirements, and the estimation of economic value.

2. Materials and Methods

This research consisted of several phases of water requirement calculations (Figure A1). The 1st phase described the datasets collection, preparation, and data types. The 2nd phase described the data processing in CROPWAT (CropWat 8.0 is a decision support tool that has a semantic model for agriculture cropping pattern authentication and irrigation scheduling calculation based on soil, climate, and crop datasets) and spatial integration for agricultural water requirements. The 3rd phase presented the urban water requirement analysis. The 4th phase showed the estimation of economic value and visualizations.

2.1. Study Area

The study area is Weinstadt, a town in Baden Württemberg, Germany. Weinstadt means “wine city”, which is located in the Rems-Murr region, with an area of 31.7 km^2. As suggested by its name, Weinstadt is well renowned for its wineries and vineyards. By focusing on the biggest wine grape production area in the southern region and considering the other agriculture crop plantation (maize, winter wheat, etc.), the quantity of irrigation water usage has soared already as well as indeed required more. Nevertheless, the goal of this study is to utilize additional harvested water for irrigation in the form of recycled water from the WWTP, for which the local wastewater treatment facility should also be considered as well. That is why Weinstadt was chosen as the research area (Figure 1).

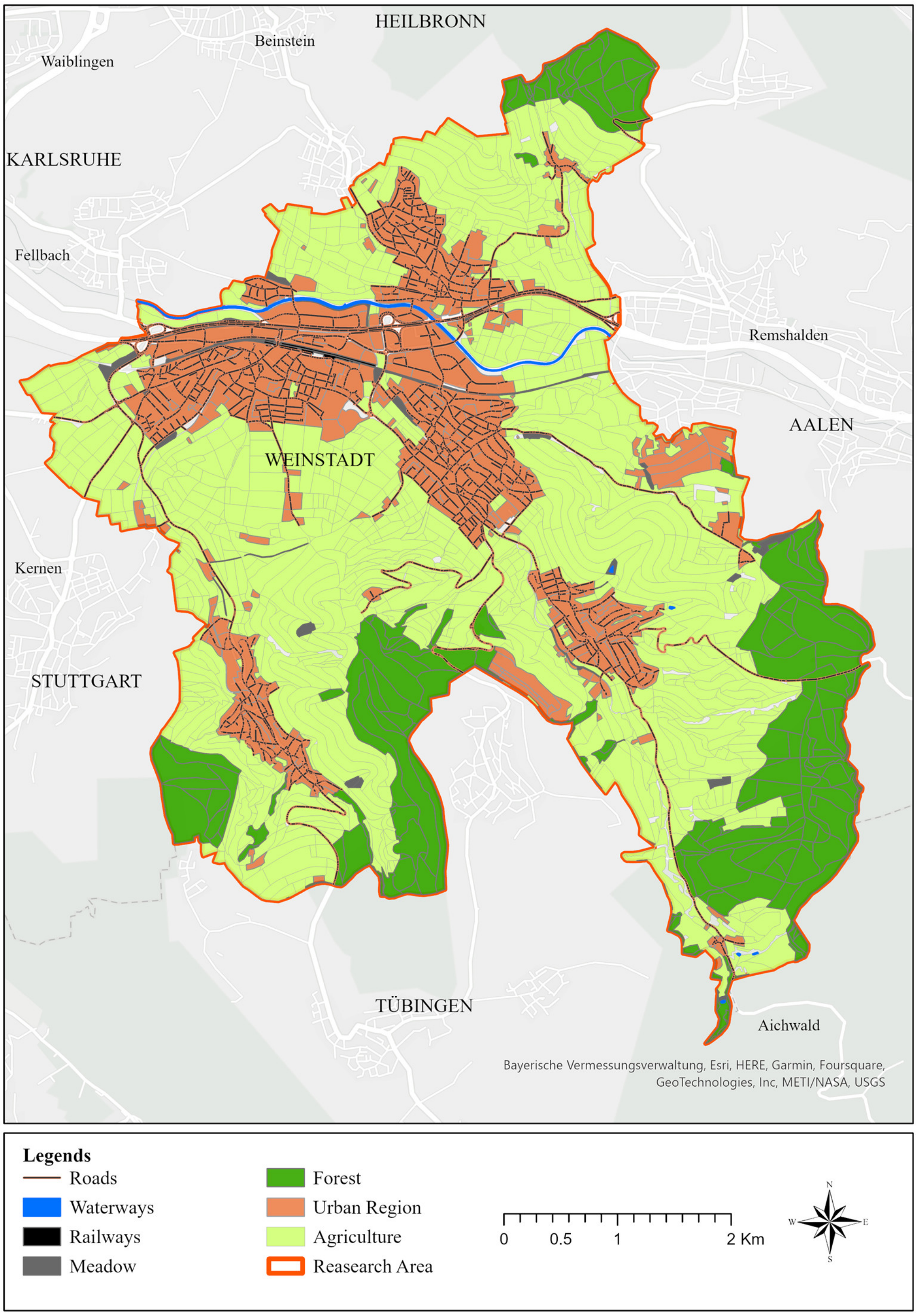


Figure 1. Research area: Weinstadt, Baden-Württemberg.

2.2. Datasets

The most important complexity of this research is the collection and processing of different kinds of datasets. As this research is fully focused on the water requirement issue of Weinstadt Municipality in Baden-Württemberg, the authority of the city planning office has provided the datasets containing the urban point clouds, digital elevation model, digital land use model, digital terrain model, true orthophotos, building level of details (LOD2)—Citygml 2.0 (a file format for virtual 3D city model), ALKIS 2500 land parcel group datasets (ALKIS stands for Liegenschaftskatasterinformationssystem, which contains information about the real estate cadastre), WWTP yearly water yield and topographic maps. It is possible to set up predefined weather stations of Germany by using ClimWat 2.0

weather station datasets. But these stations are very far away from each other. However, the availability of the historic 30-year dataset and nearby distance of 5 cities are selected for manual weather stations, for which the spatial analysis has being carried off. The main climate indicators are considered the minimum and maximum temperatures, precipitations, humidity, average sunshine hours and wind speed for the cities of Karlsruhe, Fellbach, Heilbronn, Aalen and Tübingen. The temperature, humidity, rainfall, and sunshine hours are collected from an international climate database [23]. Here, all the datasets are rendered from the European Centre for Medium-Range Weather Forecasts (ECMWF) data. These historic monthly climatic variables, such as temperature, humidity, precipitation, are collected between 1991 and 2021. Yet, the sunshine hours are recorded from 1999 to 2019. Though the historic monthly wind speed was not available in the previous site, this dataset is collected from an international weather database for the same previous cities [24]. The wastewater treatment plant (Klärwerk Weinstadt) is one of the biggest water treatment plants in the Stuttgart region. This WWTP has a yearly average volume of water 4000,000 m^3 purified. In Weinstadt, three agricultural crops, i.e., winter wheat, wine grapes and maize, are frequently practiced but another crop plantation is less practiced. According to the soil map BGR geoportal of Germany, Stuttgart lies in the region of brown soil with sandy clay rocks [25]. Rinaldi et al. [26] proposed that red wine production is better on loam soils. So, medium soil texture like loam soil is considered for the agriculture water requirement calculation for this research.

2.3. Determination of Agriculture Water Requirements

2.3.1. Reference Evapotranspiration

The amount of solar radiation that reaches the topsoil surface is the key factor affecting how much moisture evaporates from cropped soil. When the crop is very young, soil evaporation accounts for the majority of the water loss, but after the crop is mature and completely covers the soil, transpiration takes over as the primary mechanism [27]. The CROPWAT model calculates the crop water requirements and develops the irrigation schedule, which will help with the proper simulation of the water supply. So, CROPWAT windows used the FAO Penman–Monteith method for reference evapotranspiration and radiation with the help of measured weather data (Equation (1)) [15,28].

$$\mathrm{ETo} = \frac{0.408\Delta(\mathrm{Rn} - \mathrm{G}) + \frac{900}{\mathrm{T}+273}\mathrm{u}_2(\mathrm{e_s} - \mathrm{e_a})}{\Delta + \gamma(1 + 0.3442)} \tag{1}$$

where ETo = Reference evapotranspiration; Rn = Net radiation ($MJ/m^2/day$); G = Soil heat flux density ($MJ/m^2/day$); T = Mean daily air temperature at 2 m height (°C); u_2 = Wind speed at 2 m height (m/s); $e_s - e_a$ = Vapor pressure deficit of the air (kPa); Δ = Slope of the vapor pressure (kPa $°C^{-1}$); γ = Psychometric constant (kPa $°C^{-1}$).

2.3.2. Effective Rainfall

The crops may receive this water from irrigation, rainfall, or a mix of irrigation and precipitation. Though there is some rainfall, it is not enough to meet the crop's water demands. Effective rainfall is the portion of precipitation that is retained in the soil profile and aids in crop development [28]. In this study, the dependable rain (FAO/AGLW Formula) method is employed (Equation (2)) because Bokke and Shoro [14] proposed that the dependable rain method is preferable for the water sufficient area and implemented for small-scale irrigation as well.

$$\begin{gathered}\mathrm{Peff} = 0.6 \times \mathrm{P} - 10 \text{ for Pmonth} \leq 70 \text{ mm} \\ \mathrm{Peff} = 0.8 \times \mathrm{P} - 24 \text{ for Pmont} > 70 \text{ mm}\end{gathered} \tag{2}$$

where P = Precipitation; Peff = Effective Precipitation in in mm/month.

2.3.3. Irrigation Water Requirement (IWR)

The irrigation water requirement (IWR) is the quantity of water required to meet the crop's water needs following any significant rainfall, for a disease-free crop growing in substantial fields with distortive soil and water conditions and with sufficient nutrients [29]. So, the final irrigation water requirement is determined by calculating the reference evapotranspiration (ETo) and actual evapotranspiration (ETc). Afterwards, the ETc is combined with the decade of crop lifecycle for the final estimation of the irrigation water requirement of every life stage of the crop. This process is a sequential workflow in CROPWAT. Equation (3) is used to determine the actual evapotranspiration, and it is represented by the rate of ETc in mm/day.

$$\mathrm{ETc} = \mathrm{Kc} \times \mathrm{ETo} \tag{3}$$

where ETc = Crop water requirements; Kc = Crop coefficient; ETo = Reference evapotranspiration.

2.3.4. Spatial Distribution of Agricultural Water Requirements

The spatial distributions of winter wheat, wine grapes and maize are performed in two stages. The most used methods that build and maintain a digital elevation model (DEM—replicates the terrain surface of earth landscape [30]) use the Inverse Distance Weighted (IDW) approach, which is demonstrated in this research for the spatial distribution of crop irrigation water requirements (IWRs). The IDW settings for this study are output cell size 5 m, power 2, and search radius "variable", and the cell size projection method is also selected as the preserve resolution. The whole process is performed in the ArcGIS Pro 3.1 mapping environment. In the first stage, the DEM and GIS-assisted method is deployed to calculate the spatial distribution of ETo, ETc, and effective rainfall [15]. Again, with the same interpolation settings, the IDW approach is performed based on the monthly water requirement for the crop cultivation stage like initial, development, middle, late and whole crop growth water. Standard symbology followed the highest values in red color; medium values identified in yellow color and lowest values are in deep sky-blue, with the 10 classes considered for proper IWR visualization. In the second stage, it is very certain that knowing of the specific agriculture area is for each crop. The test ALKIS dataset of Baden-Württemberg clearly defined the ground space and cultivable lands are considered as agricultural lands. So, the agriculture areas for winter wheat and maize are considered green open spaces and current cultivation lands. But separately, there is the indication of wine garden areas. In line with the cultivation practices, it is expected that 70% of areas are defined as the winter wheats area because this crop has the mass production and one of the major crops in Germany than maize. On the contrary, 30% of the area is covered by maize. This estimated area defines the spatial distribution of the irrigation water demand with the calculated IWR from the CROPWAT model.

2.3.5. Agriculture Water Requirements Zonal Model

The zonal model is made to describe which area has more water required and accordingly less water required areas for agriculture irrigation. The ArcGIS model builder tool is used for this water variability processing in different zones of Weinstadt (Figure A2). The primary variable is the land parcel of the agriculture area of cultivation land and wine grounds. From the entire irrigation water requirements (IWRs), interpolation obtained the crop water requirements values, which would be necessary to extract for analysis. Afterwards, data normalization was performed for obtaining the dataset value of the water requirement in a simplified form of 0 to 5 scale (Equation (4)). Moreover, 0 is the lower water required area and, continuously, 5 indicated the higher water required area. So, a weighted parameter index is utilized between the winter wheat area and maize area because same area chosen for the both crops so that all the corps' water requirement lies in a specific percentile in between 100% [31]. Finally, merged all the outputs corresponding to land parcels with the purpose of effectively symbolizing the vulnerable zonal area of Weinstadt according to the zonal severity of the water required situations.

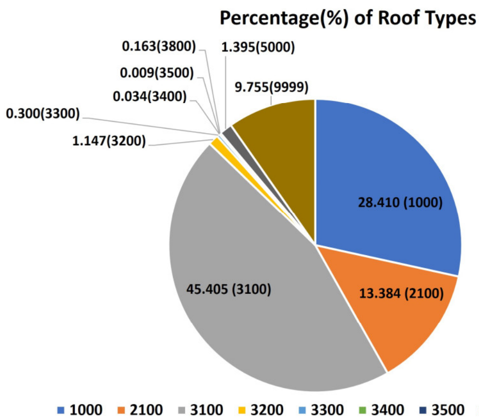
$$Zi = \frac{X - X_{min}}{X_{max} - X_{min}} \times SR \tag{4}$$

where, Zi = Normalized attribute; X = Value attribute; X_{min} = Minimum of value attribute; X_{max} = Maximum of value attribute; SR = Severity scale ranges (0 to 5); Weighted index (cultivable lands) = 70% × [Winter Wheat] + 30% × [Maize].

2.4. Urban Roof Water Harvesting

2.4.1. Roof Type Definition

For this analysis, monthly average rainfall datasets were used as the primary water source. The urban roof water harvesting technique is taken under the building information management (BIM) process. In the building level of details dataset, ten types of roofs are identified. The roof types are basically defined by the roof code (standardized roof ID by Open Geospatial Consortium) that each roof has (Figure 2) [32]. These datasets are processed in the ArcGIS pro workspace. Actually, the data interoperability plugin is used by using the quick import tools, which can read the 3D building surface and can be also worked in an attribute table.



Roof Code	Roof Description
1000	Flat
2100	Pent
2200	Offset pent
3100	Pitched
3200	Hip
3300	Half-hipped
3400	Mansard
3500	Pyramid Hip
3600	Cone
3700	Dome
3800	Shed
3900	Arch
4000	Tower/Hexagonal
5000	Mixed form
9999	Miscellaneous

Figure 2. Percentage of building roof types.

2.4.2. Urban Water Catchment Area

The roof area is the major element of roof water harvesting for every roof type. However, some buildings have flat roofs, and some have sloped roofs. To calculate this inclined area, this study used the sloped area calculation by area calculator tool in the FME (Feature Manipulation Engine) Workbench and wrote it as the .csv format to be joined with the CityGML 2.0 building ID. Therefore, the following Figure 3 shows the FME workbench working schema.

Figure 3. FME (Feature Manipulation Engine) Workbench workflow for sloped area calculation.

2.4.3. Roof Runoff Coefficient

The roof runoff coefficient (RC) is the vital factor used to calculate the roof water harvesting volume. The runoff coefficient is a dimensionless figure that calculates the amount of rainfall that actually becomes runoff after accounting for leakage, spills, soaking of the catchment surface, and evaporation losses. To ensure that the water collection is as effective as possible, the RC must be considered while choosing roof types that have only been evaluated from the CityGML datasets and additional roof types, i.e., green roofs are not taken under analysis. The runoff coefficient is divided into two types. One, sloping roofs, which can be concrete/asphalt, metal and aluminum. Two, flat roofs with bituminous, gravel and level cement. In the Weinstadt area, most of the flat roofs are covered with gravel and the sloped roofs are made with concrete/asphalt. Table 1 has the description of the runoff coefficient.

Table 1. Runoff coefficient [33] (reproduced with permission).

Roof		RC	Reference
Sloping Roof	Concrete/Asphalt	0.9	[34]
	Metal	0.95	[34]
		0.81–0.84	[35]
	Aluminum	0.7	[36]
Flat Roof	Bituminous	0.7	[36]
	Gravel	0.8–0.85	[34]
	Level Cement	0.81	[35]

2.4.4. Catchment Water Volume

The urban roof catchment water volume calculation is the method that will serve the water shortage situations and have economic benefits as well [32]. For this progression, the monthly average rainfall, surface catchment area and the run runoff coefficient area had the relationship to operate for main water volume calculation (Equation (5)).

$$\text{Roof Water Volume} = \text{P} \times \text{A} \times \text{RC} \tag{5}$$

where P = Average precipitation (m); A = Roof catchment area (m^2); RC = Runoff co-efficient.

2.5. Economic Value Assessment

To summarize the final analysis, an economic value assessment has been made, which is the important socio-economic factor in the research. This value assessment is similar to the beneficial part for the municipality, which is performed on the basis of reduction for the current water supply so that the deducted amount of water can be used for future extreme situations. This process was performed by subtracting between the current volume of water supply from the wastewater treatment plant and the calculated harvested water from different roof types. The following Equation (6) shows the economic value estimation.

$$\text{EV} = \text{Ws} - \text{Whp} \tag{6}$$

where EV = Economic value; Ws = Water supply from WWTP; Whp = Harvested water potential.

2.6. Visualization Workflow

Visualization is very vital to show the outcomes of the agriculture and urban water demand. All the layers used in the analysis are in 2D and 3D formats. So, the ArcGIS visualization API is an appropriate platform where all the 2D and 3D layers are deployed as contents. ESRI shapefiles are generally uploaded. But CityGML 3D building objects are converted into scene layer packages (.slpk) file formats with the purpose of being readable by the ArcGIS online application. An application dashboard is customized with viewer controls, layer appearance and legends. All the parcels of the 2D layers of the agriculture water demand and 3D buildings of the rainfall harvesting showed the pop-up tables constructed on their attribute values (Figures 4 and A2).

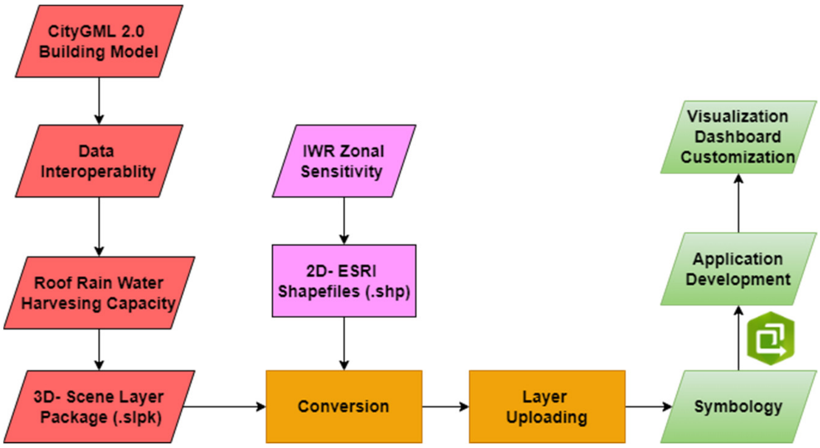


Figure 4. Visualization workflow for all the geospatial layers.

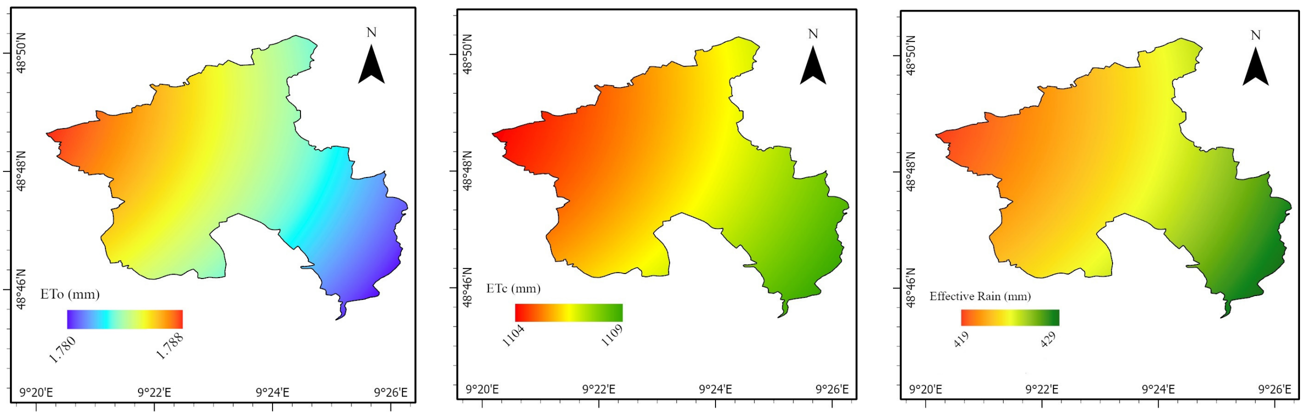
3. Results

Initially, the described results showed the agricultural IWR analysis for the CROPWAT model development outputs and several stages of crop development in various stages. The following stage is the urban roof water harvesting from the perspective of the monthly rainfall. Afterwards, there was included a description of how economic values were added by considering the present water supply.

3.1. Agriculture Water Requirements

3.1.1. Spatial Distribution of Calculated CROPWAT Model Parameters

The spatial distribution in Weinstadt for the water deficit parameters, i.e., ETo (reference evapotranspiration), effective rainfall and ETc (actual evapotranspiration) by which the IWR is defined. The spatial distribution considered the empirical distributions of the calculated CROPWAT model parameters. After performing the Digital Elevation Model (DEM)-based calculations of the spatial distribution procession, the ranges of the reference evapotranspiration values lie between 1.780 and 1.788 (Figure 5a). The highest value for the crop water requirements (actual evapotranspiration) is 1109 mm and the lowest value is 1104 mm (Figure 5b). The effective rainfall value that is calculated from the CROPWAT model for Weinstadt ranged between 419 mm and 429 mm yearly (Figure 5c).



(**a**) (**b**) (**c**)

Figure 5. Estimated spatial distribution of (**a**) reference evapotranspiration; (**b**) crop water requirements and (**c**) effective rainfall in Weinstadt Municipality. This figure is the different observations of the CROPWAT model parameters.

3.1.2. Irrigation Water Requirements (IWR) for Maize

Weinstadt's irrigation water demand for maize is estimated from the CROPWAT model. The result is the clipped IWR values of maize in the active growth stage, development stage, maturity stage, and whole stages after the spatially distributed from five cities. Initially, no irrigation water was required in the month of May. The variation in irrigation water requirements in the development stage is very less. The average IWR value is 28 mm in June. In the active growth stage of maize, the irrigation water variation is a very smaller amount in the month of July. Among the 10 classes of the maize active growth stage, higher and lower values range between 113 mm and 115 mm. In the mature stage (starting middle of August and ending in September), the total values ranged between 47 mm and 48 mm. Eventually, a total of 188 mm to 191 mm water is required for the maize in Weinstadt.

3.1.3. Irrigation Water Requirements (IWR) for Wine Grapes

The spatial distribution of wine grapes' IWR has three stages—namely, active growth stage, mature stage, and whole period (cultivation to harvesting). Primarily, no water is required in the initial and development stages from August to the first week of February, because enough water stayed in the ground surface. In the active growth stage, which starts from the mid-term of February and lasts to the late mid-term of June, in that period the volume of irrigation water requirement lies between 40 mm and 42 mm. In the mature stage (late June to July), the ranges of the IWR are 21 mm to 22 mm. So, the total irrigation required water for wine grapes in Weinstadt is about 59 mm to 63 mm.

3.1.4. Irrigation Water Requirements (IWR) for Winter Wheat

The total ranching period of winter wheat is an entire year of time, which starts in September and lasts up to August. The spatial distribution of the winter wheat irrigation water requirement is taken under the four stages, i.e., initial, development, active growth, and fully matured stage. In the initial stage (beginning of September) and early stage of development (till the end of February), no water is needed for irrigation because of the availability of enough precipitation. Therefore, the IWR in the late development stage ranged between 23 mm and 27 mm from March to the mid-term of April. The active growth started immediately after the development stage, which lasted until July and the value of the IWR ranges between 151 mm and 153 mm. The mature stage irrigation water requirement values lie between 49 mm and 50 mm in the months of July and August. Finally, in the whole period of winter wheat cultivation, the total value of the IWR ranges between 221 mm and 226 mm for Weinstadt.

3.1.5. Agriculture Irrigation Water Requirements

Figure 6 has portrayed the varied stages of the IWR for maize, wine grape and winter wheat. Though there was no initial IWR, only wine grapes had no IWR in the development stage and all three crops had higher water requirements in the mature stages. In fact, winter wheat and maize required more water compared to wine grapes. The final mature stage had a much less amount of water required for all the crops.

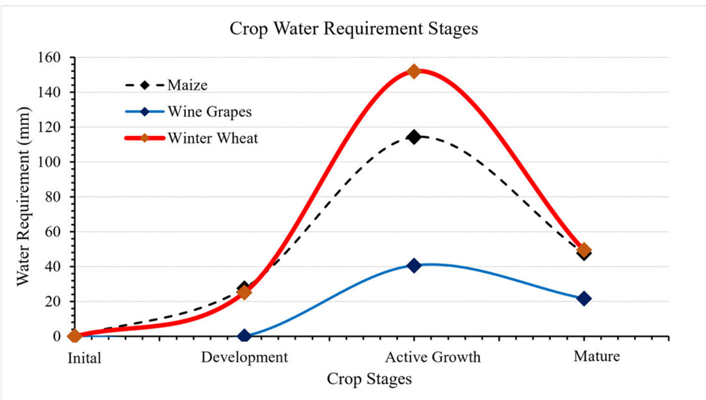
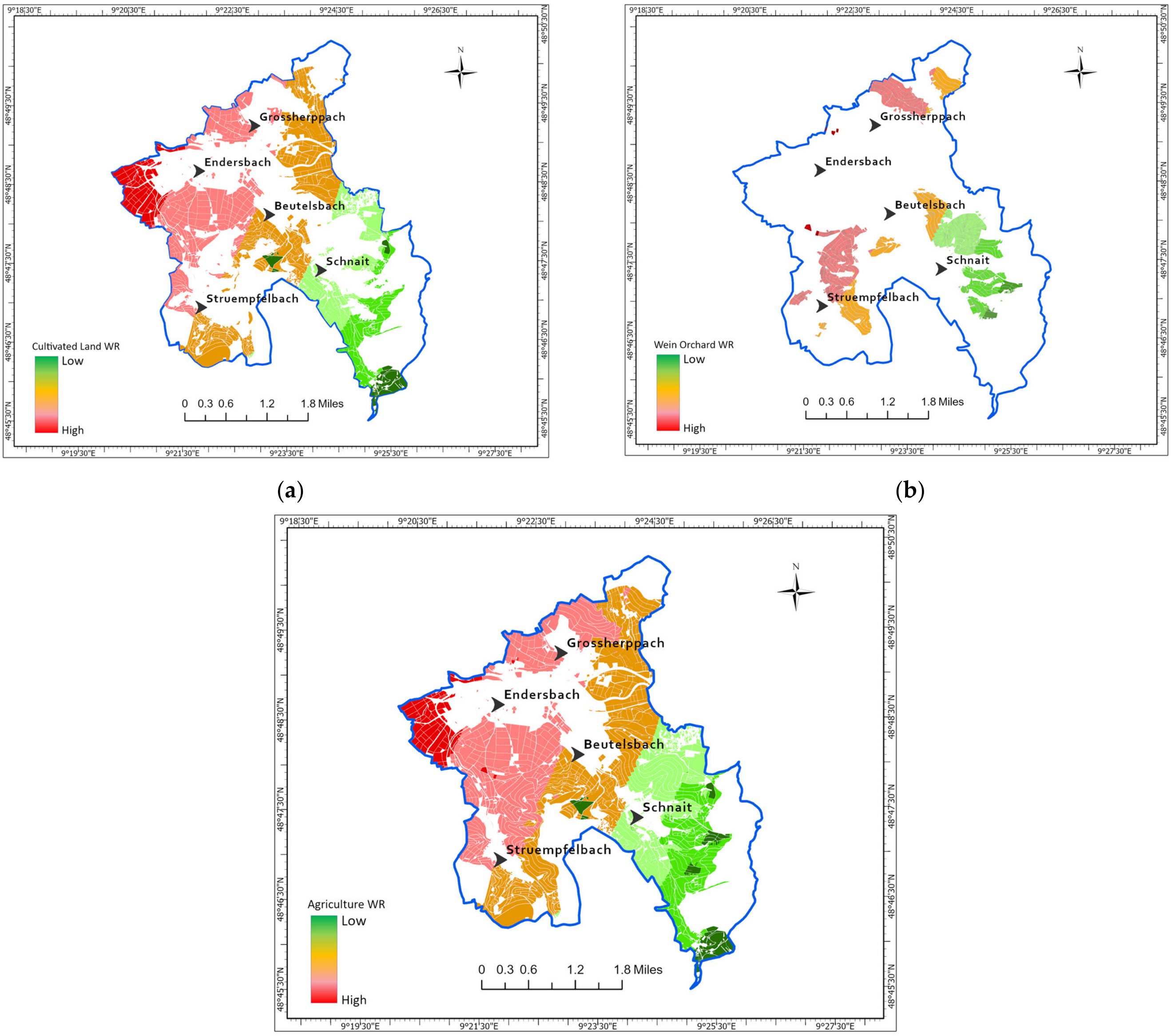


Figure 6. Agriculture water requirement from the CROPWAT model: variation of the irrigation water requirement in the crop lifecycle.

3.1.6. Zonal Severity for IWR

Figure 7a–c show the zonal severity, which generally described the required water of irrigation with spatial merging with the CROPWAT model outputs. The western part Endersbach of Weinstadt has extremely high irrigation water needed for crop cultivation. But the western parts of Grossherppach and Struempfelbach have moderate IWR severity. Although the eastern parts of Struempfelbach, Beutelsbach, and Schnait have medium and lower irrigation water requirements. Because the eastern parts have forest area, that is why the irrigation water requirement is very marginal.



(**a**) (**b**) (**c**)

Figure 7. Zonal IWR severity—(**a**) cultivated lands for maize and winter wheat; (**b**) wine orchards and (**c**) final agriculture IWR zonal severity.

By focusing on the zonal severity area, the total volume of required water has been calculated (Table 2). So, the maize total area assumed here is 375 $\times$ 10^3 m^2 and the calculated IWR is 70.8 $\times$ 10^3 m^3. Similarly, winter wheat is having an area of 875 $\times$ 10^3 m^2 with a total required yearly water of 195.3 $\times$ 10^3 m^3. Wine grapes have 28.6 $\times$ 10^3 m^3 of required water for the area 470 $\times$ 10^3 m^2. Definitively, the total volume of agriculture water required is 294.7 $\times$ 10^3 m^3 in Weinstadt Municipality.

Table 2. Volume of total required water in the agricultural fields of Weinstadt.

Crop Name	Area (10^3 m^2)	Potential Irrigation Water Requirement (mm)	Total Water Requirement (10^3 m^3)
Maize	375	189.0	70.8
Winter Wheat	875	223.3	195.3
Wine Grapes	470	60.92	28.6
Total			**294.7**

3.2. Urban Rainfall Water Harvesting

The urban water harvesting from rainfall is mainly carried out by calculation of the roof area. There are other factors, i.e., runoff coefficient, average rainfall. Figure 8 shows the monthly chart and detailed harvested water volume for different roof types. In flat roofs, the yearly rainwater harvested is one of highest roof types, where the value is about 25.1×10^3 m^3. The pent roof has a harvested water volume of 5.7×10^3 m^3. But the pitched roof type collected the highest volume of 38.9×10^3 m^3 water. The roof types like hipped, half-hipped, shed, mixed and miscellaneous have retained the volume of water of 1.2×10^3 m^3; 0.3×10^3 m^3; 0.6×10^3 m^3; 2.2×10^3 m^3 and 12.1×10^3 m^3. In contrast, the mansard and pyramid roof types have a very little amount of rainwater harvested (0.02×10^3 m^3 and 0.005×10^3 m^3). Eventually, the total amount of 86×10^3 m^3 is harvested in different roof types in Weinstadt.

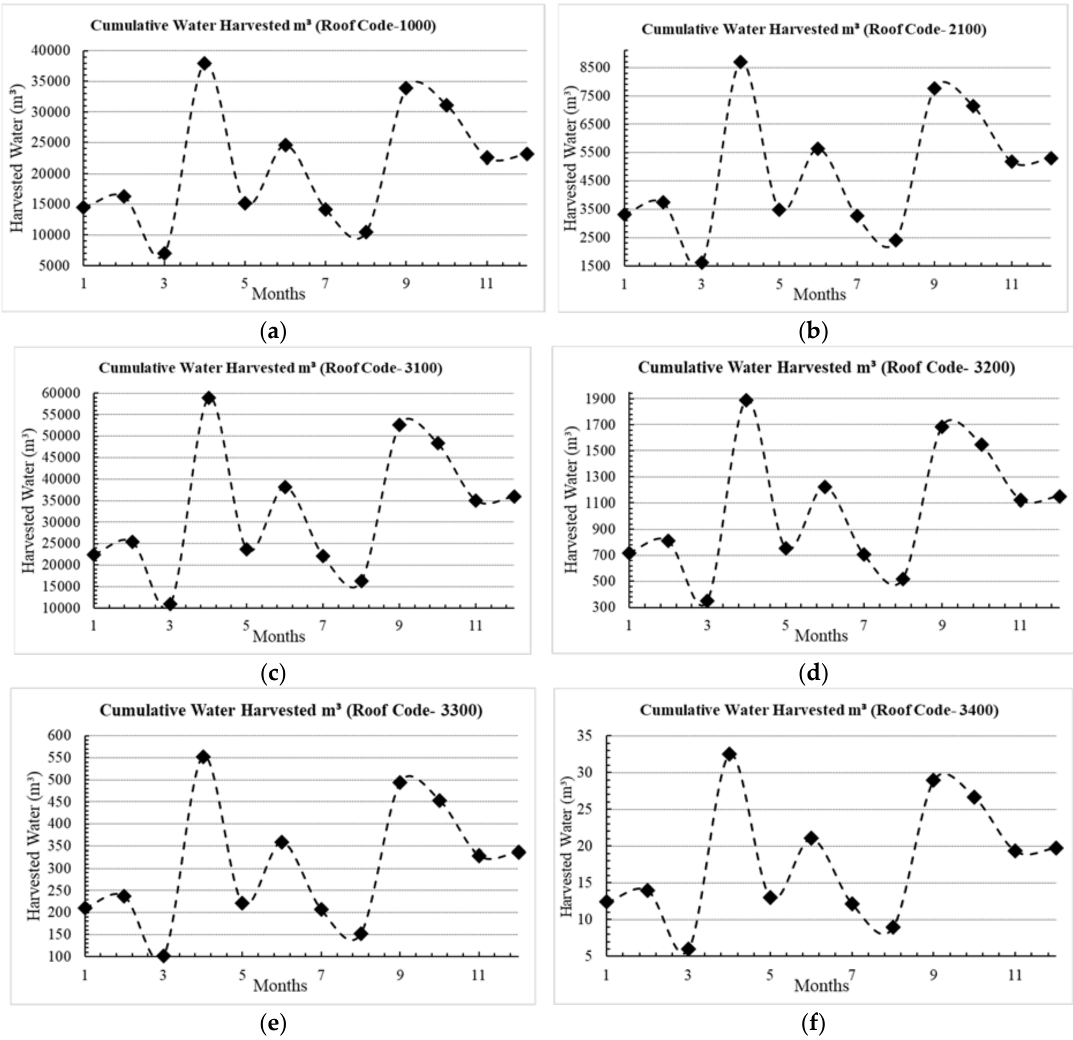


Figure 8. *Cont.*

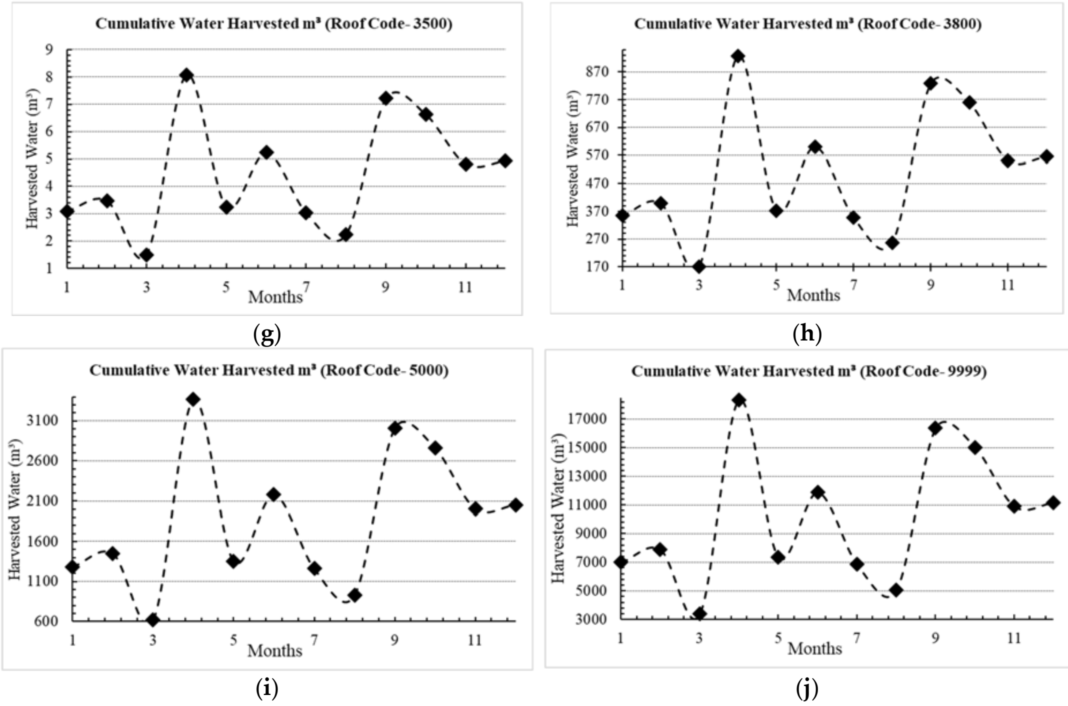


Figure 8. Volume of harvested water in different roof types. (**a**) flat roof; (**b**) pent roof; (**c**) pitched roof; (**d**) hip roof; (**e**) half-hipped roof; (**f**) mansard roof; (**g**) pyramid roof; (**h**) shed roof; (**i**) mixed form roof; and (**j**) miscellaneous roof.

Figure 9 shows the different building groups based on the higher to lower water harvesting capacity. The roof categories half hipper, mansard, pyramid and shed (3300, 3400, 3500 and 3800) have very lower rainwater harvesting capacity because they are very less in numbers and in areas as well (Figure 9a). But the roof types like pent, hipped, mixed and other types (2100, 3200, 5000, 9999) have more water harvesting category (Figure 9b,c). But the highest group of rainwater harvesting roof types are the pitched roofs (3100) (Figure 9e). These buildings have pitched roofs in residential areas as well as being greater in areas. However, the flat roof types (1000) also have more capacity compared to the other roofs but not other than pitched roofs (Figure 9d).

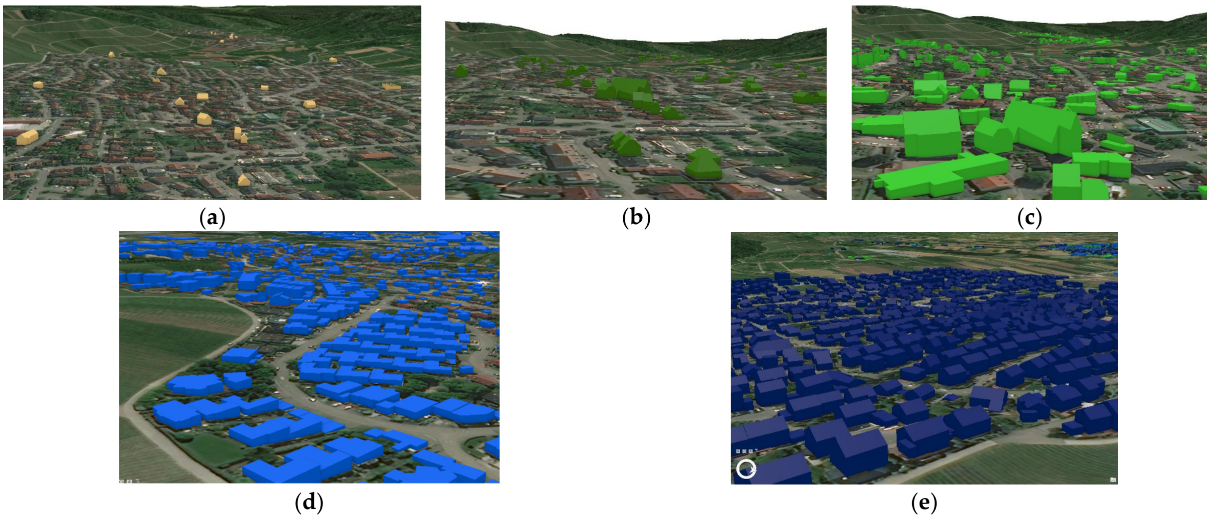


Figure 9. Symbology of roof types with their rainfall water harvesting capacity. (**a**) very less water harvesting group; (**b**) less water harvesting group; (**c**) moderate water harvesting group; (**d**) high water harvesting group; and (**e**) extremely high-water harvesting group (source of basemap: Esri Web Map).

3.3. Economic Impact of Water Efficiency

In this research, economic value addition is taken to estimate the potential reduced water that would be saved or used for future use purposes. Though this measured amount of water is not possible to calculate in the factual currency value because some factors, including water quality, ecological value and sustainable management, are also interrelated. However, the output of the total yearly rainfall water harvested from different roof types is about 86 $\times$ 10^3 m^3. But the total supply chain volume is about 380 $\times$ 10^3 m^3 in the year 2022. After comparison between the datasets, the reduced usage amount of potential water is about 294 $\times$ 10^3 m^3. So, from this perspective, the rainfall water harvested amount can be the potential water amount of economic values calculated for Weinstadt Municipality. Figure 10 and Table A1 show the total monthly variability of different economic value-induced parameters, i.e., urban catchment water volume, WWTP water volume and economic valued water. All three parameters are correlated to each other. However, the month of April has the highest rainfall as well as the urban roof harvested water quantity is higher in 2022, and the precipitation and water supply from the wastewater treatment plant are also greater. That is why the potential reduced water volume is also higher. Simultaneously, the other months, September, October, November, have a higher water supply from the wastewater treatment plant, but September to February has a higher declining amount of water that would be saved because of urban rainfall water harvesting.

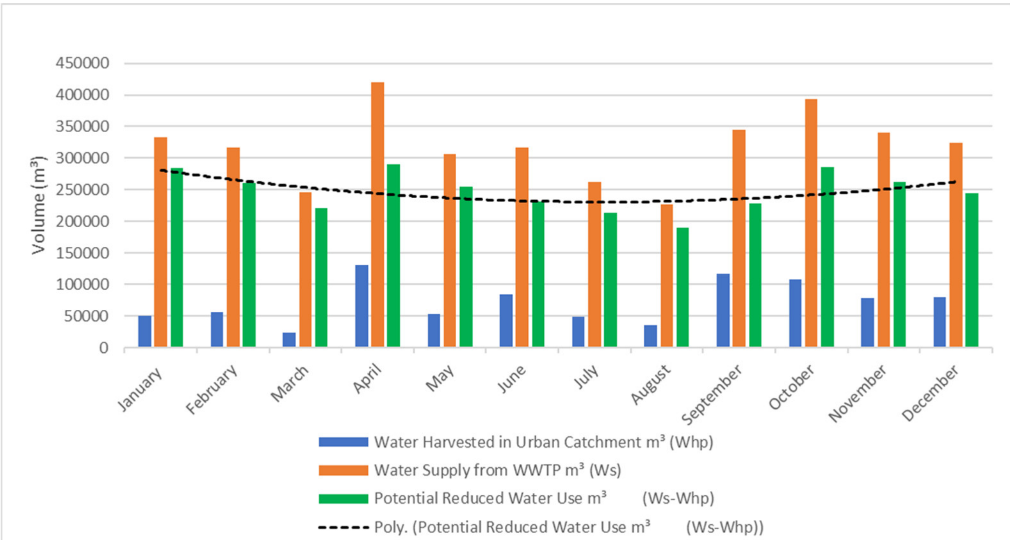


Figure 10. Potential economic irrigation water value.

4. Discussion

The agricultural irrigation water demand is very important to partially estimate the current water scarcity situation. To calculate the exact irrigation water requirement in the selected study area of Weinstadt, the empirical CROPWAT model is employed for different crop types. In the processing of stages, the reference evapotranspiration, effective rainfall, crop water requirements and final irrigation water requirements are measured for every specific crop (Figure 5). Afterwards, the results of the IWR for specific crops like winter wheat, maize and wine grapes have been spatially distributed by implementing a DEM-based approach (IDW) with the closest weather station datasets. In this way, the agricultural water volume is calculated, which is spatially modeled for zonal suitability by defining the multicriteria evaluation (Figure 7). In this research, there is another objective describing the assessments of roofs' ability to retain water depending on the kinds of roofs achieved regarding the urban rainfall water harvesting. The most valuable element for this stage is to understand the CityGML roof categories and to calculate the roof exact area, whether it is sloped or flat. By knowing the various roof runoff coefficients, a very effective volume of harvested water is calculated according to the different roof groups. Among all the roof categories, the residential areas have enormous quantities of runoff catchments and the larger areas calculated as well as the higher harvested volume of water identified (Figure 9). Water scarcity can be eradicated by the reliability of the economic analysis using urban rainfall harvesting. In addition, an economic water economic value estimation is performed by differentiating between the yearly current water supply to the municipality and the measured harvested rainwater. The is the best way to analyze the water supply assessment potentiality of the wastewater treatment plant.

4.1. Comparative Overview with Related Research

Numerous researchers have obtained the agricultural water requirement, urban rainwater availability and economic values in a visualization platform separately. But it is very unusual to find related research that is combined with all the above-mentioned three outputs. So, this study was carried out to overcome the real-life urban agriculture problem by doing similar, which helps to increase the potentiality of water use in an efficient way. The following Table 3 is the optimal description of the water availability analysis with the other methodologies and outputs.

Table 3. Parameters and outputs comparison with previous research.

References	Datasets and Time Frame	Methodological Philosophy	Research Methods	Findings	Study Regions
[37]	Wastewater treatment plant nominal flow rate, soil textures and depth, land use, DEM; Time period: 2009/2010 (Landsat TM imagery), 2000 (Google Earth data and land use map)	Analytical hierarchical process for geospatial integration	Study area characterization by classification, standardizing the sub criteria, sensitivity analysis and cross validation	31% of the aquifer is fitting for irrigation, GIS sensitivity ranking cases 1–5.	Tunisia
[28]	Agro climatic data, crop data showing and harvesting; Time period: 2017–2021 (agroclimatic data)	Irrigation water requirement (IWR) and irrigation scheduling for cultivated crops	CROPWAT model for calculation of Eto and effective rainfalls, calculation of evapotranspiration	IWR: 3108.0 mm-sugarcane, 1768.5 mm—banana, 1655.7 mm—cotton, 402.5 mm—wheat	Pakistan
[13]	Ago-ecological datasets, crop data; Time periods: Not defined	Total water requirement in various agro-ecological zone in order to estimate ground water balance	CROPWAT model 8.0 used for calculation of evapotranspiration	Net irrigation requirement: Paddy: 442 to 1483 mm; water demand: 1146 mm^3	India
[16]	CROPWAT station dataset and crop data; Time period: Not defined	Irrigation water requirement estimation for spatial modeling	CROPWAT model for crop water requirement and water qualitative measurements	IWR: 763 mm/year-citrus, 722 mm/year-almonds, 1083 mm/year-date palm, 591 mm/year-grapes.	Palestine
[15]	Meteorological data; Time period: 1961 to 2001	Spatial distribution of crop water requirement	CROPWAT model for irrigation water requirement and irrigation scheduling, DEM based methods	Spatial distribution of ETc of spring maize 324.57–500.55 mm; water deficit ratio up to 40%	China

Table 3. *Cont.*

References	Datasets and Time Frame	Methodological Philosophy	Research Methods	Findings	Study Regions
[21]	Daily rainfall, 2D and 3D model of building; Time period: January 2014–December 2018 (daily rainfall)	Rainwater harvesting assessment through Building Information Modeling (BIM)	Calculation of potential roofing catchment size, rainwater harvesting potential and fixing of tank capacity	Collected harvested rainfall water volume: 8190 L/yr to 103,300 L/yr	Pakistan
[22]	CityGML building models; Time period: Not defined	Urban water demand assessment	Implementation of water analysis workflow of SimStadt, log-log model for water demand assessment	Industrial water demand: 397 to 579 m^3 and Predicted precipitation: 248 mm by 2030	Germany
Our Proposed Methodology	Climate dataset, wastewater treatment Plant water supply volume, ALKIS maps Time period: 1991–2021 (temperature, humidity, rainfall), 1991–2019 (sunshine hours), 2022 (wind speed), 2021–2022 (WWTP supply), 2021 (ALKIS maps)	Agriculture water demand assessment by using the potentiality of urban rainwater harvesting and wastewater treatment plant supply	Employment of CROPWAT model for IWR, zonal severity analysis, urban roof catchment area measurement, economic value.	IWR estimation: 189 mm-maize, 223.3 mm-winter wheat, 60.92 mm for wine grapes, spatial volume of IWR 294.7×10^3 m^3/yearly. Sensitivity phases 0–5. Rainfall water harvested volume: 86×10^3 m^3/yearly	Germany

4.2. Influence on Agriculture and Urban Water Demand

From the modeling outcomes of CROPWAT and the spatial distribution, it is understood that a huge amount of cubic meter water is needed to irrigate in Weinstadt's agriculture area. Most of the agricultural lands are in medium high to severe water required regions. Extremely severe and other classes of lands are very less in percentage. But still every land parcel has water demand. So, Figure 11 shows the consequences of the IWR zonal severity. Most of the irrigation water sources in Germany are natural sources. The main source of irrigation water is ground water. In Germany, approximately 77% of the irrigation water utilized is blue water (the proportion of irrigation water that is attributed to the imported agricultural crops) [2], while 11% comes from surface water and the public or private supply networks, spring water makes up the majority [38]. The amount of ground water or water from rivers and lakes utilized in the production of a product is referred to as blue water. In the production of agricultural crops, this refers to the amount of extra irrigation that is used [2]. Between 80 and 150 mm (mm) or 425 and 800 million cubic meters (m^3) of irrigation water are used annually [39]. According to the federal statistics office of Germany, 364 billion m^3 water was supplied, including irrigation water, from 1961 to 2020. Beyond this huge amount of water supply nationally, the present demand for irrigation water is estimated in this study. If the percentage of the blue water supply is assumed static confronting the irrigation demand, the harvested urban water can repay the rest of the amount or be used for future use when the water supply would be very low. Hence, with the calculated reduced potential, the amount of water will be distributed in urban areas. The rest of the economically valued water will be helped to recharge the ground water in the summer seasons. The outcomes of this study not only improve the subsequent water resources but also explicate the climate change impacts on water resource management.

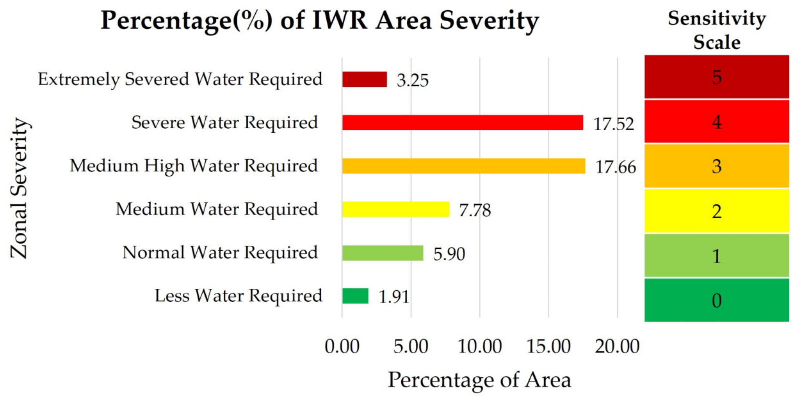


Figure 11. Percentile of zonal agriculture land sensitivity.

5. Conclusions

To conclude, this research on agriculture and urban water availability is very significant for the whole regional system. All three objectives are analyzed in a very scientific way to evaluate the ultimate benefit of encountering future water stress situations as a pilot study for all over Germany.

The agriculture water demand simulation in the CROPWAT model evaluation showed that the irrigation water demand is very high in Weinstadt Municipality all the year round 2022. The comparative aspects of the results, such as the irrigation water requirements, are much higher in the south–western region surrounding the study areas. In addition, the results from the spatial distribution between the crop studies are varied considerably based on their showing to harvesting periods. Wine grapes needed a very lower amount of irrigation water because of the elevated terrain cultivation and substantial amounts of water owing to the grounds. In this regard, winter wheat is the highest irrigation water required crop and maize is the medium conditions in both of their active growth stages. The zonal severity of the IWR is also very effective for this region because this analysis distinguishes the environmental effects. The western part of the study area is more like the urban regions, that is why the water demands in agricultural lands are very severe. Sequentially, when the IWR severity is directed to eastern parts of Weinstadt, lower sensitive areas are observed due to having the green areas.

Another objective signifies the urban water potentiality calculation so that it can be compared with present sources of water supply reductions. Basically, there are 10 types of LOD 2 building roof types observed. In this study, the primary source of urban water harvesting is considered only rainfall, which varied in different roof types. The pitched and flat roofs have the most harvested capacity linked to other types of roofs that have medium or less harvesting capacity. This harvested volume of water is potential water, which reduced the present supply volume from the WWTPs. This study referred to it as the economic value for the IWR. In addition to the outcomes of the analysis, water framework development has been proposed for the municipality and users to be followed. To do so, a visualization application is developed so that the total idea of protecting future scarcity-induced water availability is disseminated easily to the user levels in a very interactive manner. Apart from these above-mentioned analyses, there are many crucial factors to be taken care of in the future, such as database management and decision clarification. These are as follows:

- A comparative analysis can be performed using various methods in the CROPWAT model. In the depth of effective rainfall, other methods would be checked in CROPWAT models for the water sufficient region like Germany.
- The snowfall as a water harvesting source could add the more reduced amount of water, which will improve the more proficient amount of potential economic water values.

- The proper survey data on the degree of sloping, roof materials and roof covering can have huge impacts on the urban water availability potentials.

Author Contributions: S.K.: Conceptualization, methodology, visualizations, writing—original draft preparation; S.B. (Sanchalita Bandyopadhyay): Conceptualization, methodology, analysis—article reviewed; S.B. (Sonja Bauer): Conceptualization, methodology, analysis—article reviewed and supervision. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: The work presented in this paper was developed in the master's thesis project by Sourav Karmaker at Stuttgart University of Applied Sciences (HFT Stuttgart), Germany. The authors express their sincere gratitude to Weinstadt Town Planning Department and Klärwerk Weinstadt authority for providing the geodatasets and supporting this project.

Conflicts of Interest: Sanchalita Bandyopadhyay was employed by TELUS International Europe. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Appendix A

Table A1. Potential economic impact estimation.

Months	Water Harvested in Urban Catchment (Whp) 10^3 m^3	Water Supply from WWTP (Ws) 10^3 m^3	Potential Reduced Water Use (Ws − Whp) 10^3 m^3
January	4.9	33.3	28.3
February	5.6	31.7	26.1
March	2.4	24.5	22.1
April	13	42	28.9
May	5.2	30.6	25.4
June	8.4	31.6	23.1
July	4.8	26.2	21.4
August	3.6	22.6	19
September	11.6	34.4	22.8
October	10.7	36.6	25.8
November	7.7	34	26.2
December	7.9	32.4	24.4
Total	**86**	**380**	**294**

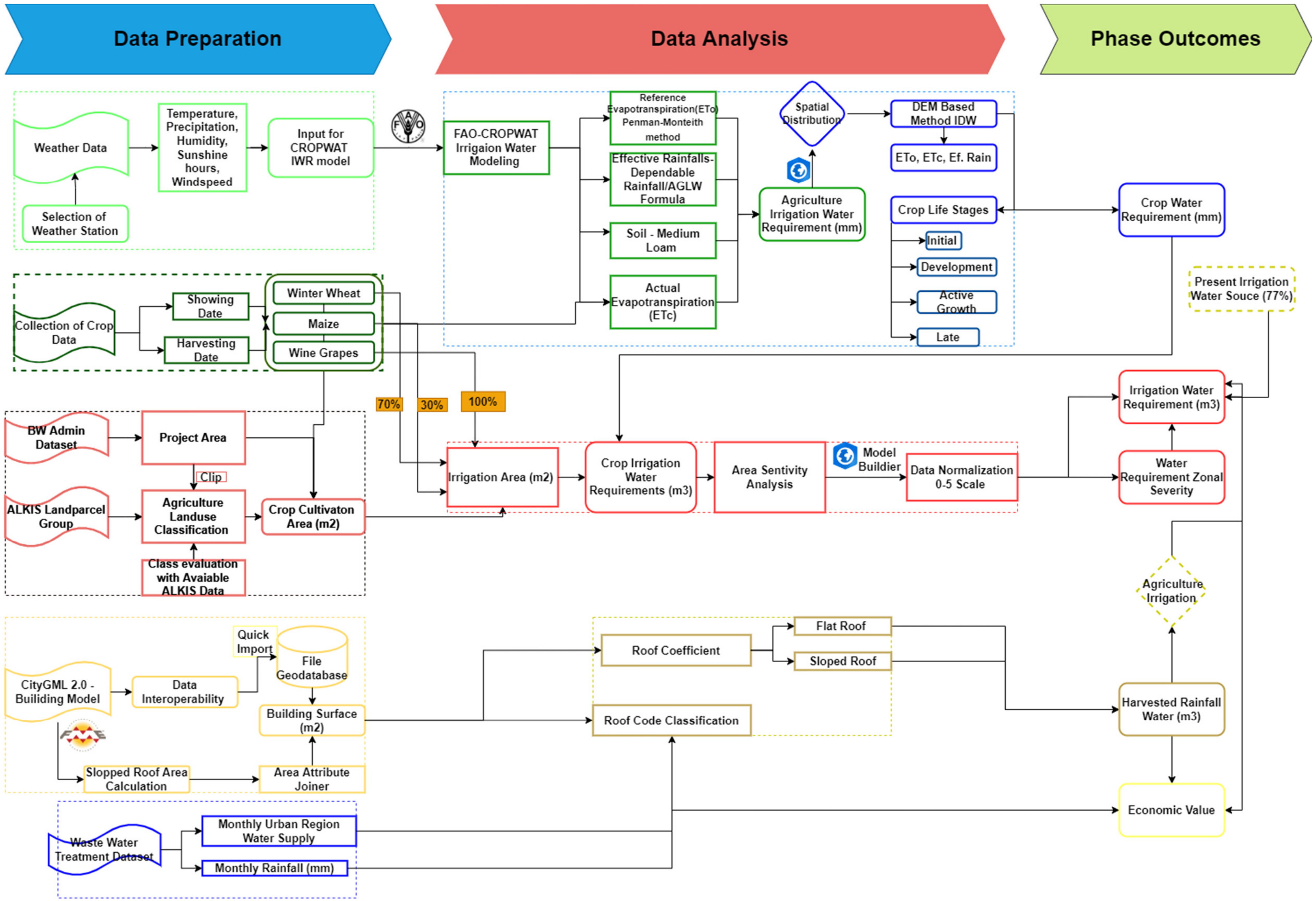


Figure A1. Proposed conceptual IWR framework.

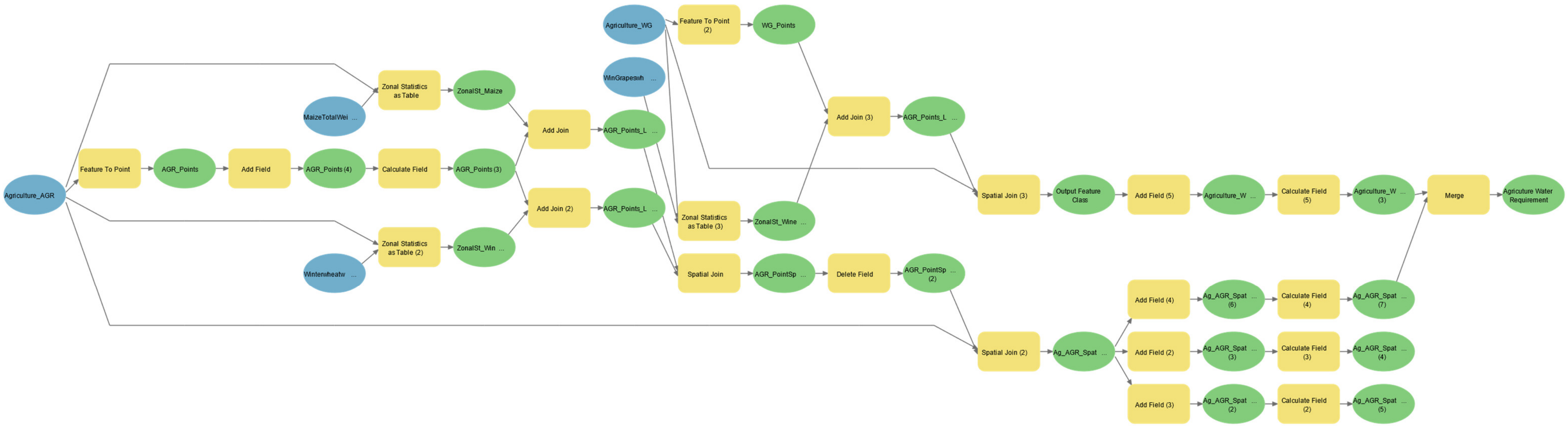


Figure A2. Agriculture water requirement zonal severity model.

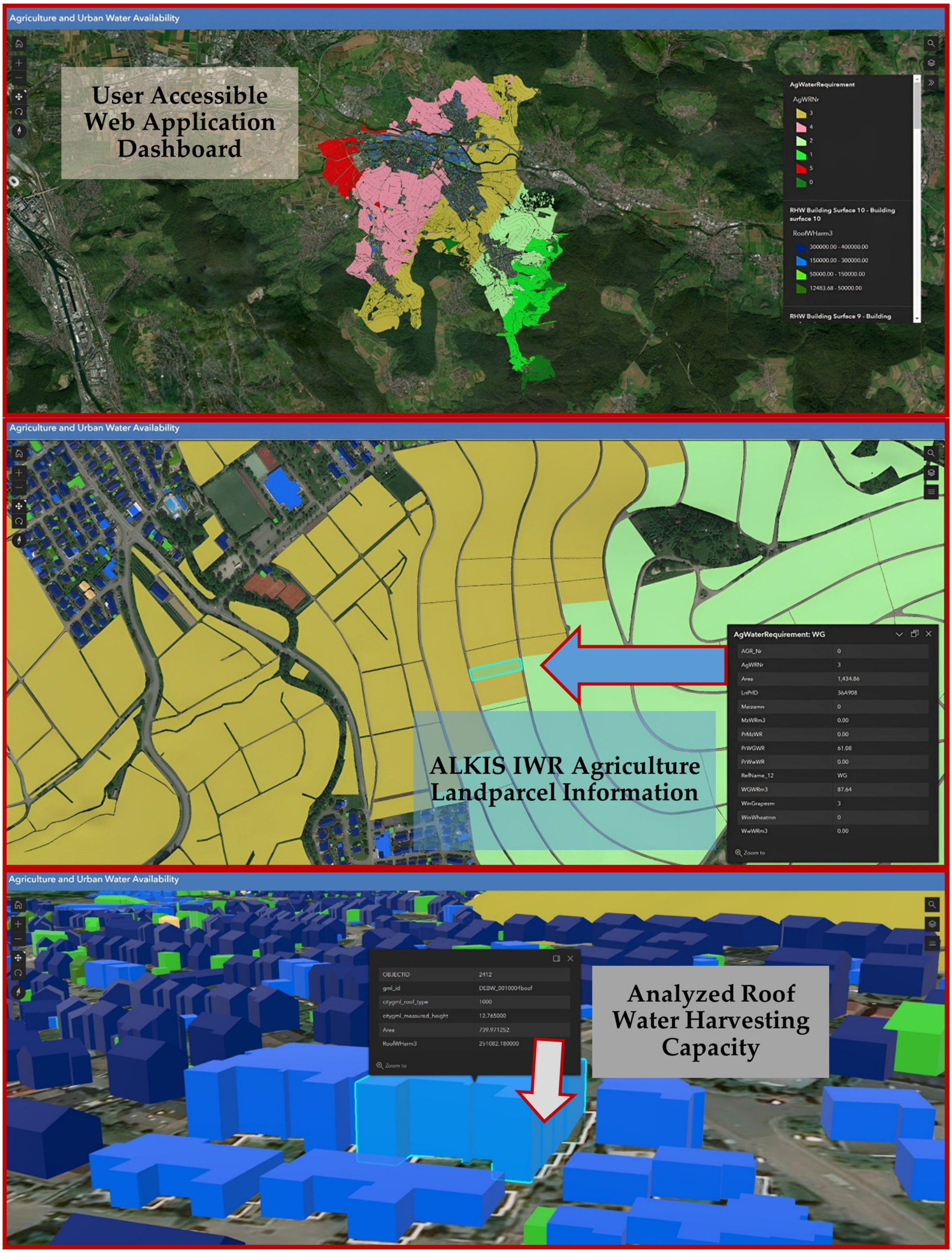


Figure A3. User accessible web application.

References

1. Helmecke, M.; Fries, E.; Schulte, C. Regulating water reuse for agricultural irrigation: Risks related to organic micro-contaminants. *Environ. Sci. Eur.* **2020**, *32*, 4. [CrossRef]
2. Stoll, J. Water Resource Management in Germany. Umweltbundesamt. 2018. Available online: https://www.umweltbundesamt.de/publikationen/water-resource-management-in-germany (accessed on 3 February 2023).
3. Schiller, A. Umweltbundesamt. New EU Regulation on Minimum Requirements for Water Reuse. 2021. Available online: https://www.umweltbundesamt.de/en/topics/water/water-resource-management/water-reuse/new-eu-regulation-on-minimum-requirements-for-water (accessed on 26 September 2022).
4. Maaß, O.; Grundmann, P. Governing Transactions and Interdependences between Linked Value Chains in a Circular Economy: The Case of Wastewater Reuse in Braunschweig (Germany). *Sustainability* **2018**, *10*, 1125.
5. Inter3. Wasserwiederverwendung in Deutschland Ermöglichen. Available online: https://www.inter3.de/aktuelles/meldungen (accessed on 6 September 2022).
6. Barbagallo, S.; Cirelli, G.L.; Consoli, S.; Licciardello, F.; Marzo, A.; Toscano, A. Analysis of treated wastewater reuse potential for irrigation in Sicily. *Water Sci. Technol.* **2012**, *65*, 2024–2033. [CrossRef] [PubMed]
7. Jodar-Abellan, A.; Fernández-Aracil, P.; Melgarejo-Moreno, J. Assessing Water Shortage through a Balance Model among Transfers, Groundwater, Desalination, Wastewater Reuse, and Water Demands (SE Spain). *Water* **2019**, *11*, 1009. [CrossRef]
8. Jia, H.; Guo, R.; Xin, K.; Wang, J. Research on wastewater reuse planning in Beijing central region. *Water Sci. Technol.* **2005**, *51*, 195–202. [CrossRef]
9. Ramirez, C.; Almulla, Y.; Fuso Nerini, F. Reusing wastewater for agricultural irrigation: A water-energy-food Nexus assessment in the North Western Sahara Aquifer System. *Environ. Res. Lett.* **2021**, *16*, 044052. [CrossRef]
10. Jaramillo, M.; Restrepo, I. Wastewater Reuse in Agriculture: A Review about Its Limitations and Benefits. *Sustainability* **2017**, *9*, 1734. [CrossRef]
11. Moseki, O.; Murray-Hudson, M.; Kashe, K. Crop water and irrigation requirements of *Jatropha curcas* L. in semi-arid conditions of Botswana: Applying the CROPWAT model. *Agric. Water Manag.* **2019**, *225*, 105754. [CrossRef]
12. Bilibio, C.; Hensel, O. The Water Deficit of Evapotranspiration Covers on Potash Tailing Piles Using CropWat. *Agric. Eng. Int. CIGR J.* **2021**, *23*, 75–91.
13. Surendran, U.; Sushanth, C.M.; Mammen, G.; Joseph, E.J. Modelling the Crop Water Requirement Using FAO-CROPWAT and Assessment of Water Resources for Sustainable Water Resource Management: A Case Study in Palakkad District of Humid Tropical Kerala, India. *Aquat. Procedia* **2015**, *4*, 1211–1219. [CrossRef]
14. Bokke, A.S.; Shoro, K.E. Impact of effective rainfall on net irrigation water requirement: The case of Ethiopia. *Water Sci.* **2020**, *34*, 155–163. [CrossRef]
15. Feng, Z.; Liu, D.; Zhang, Y. Water requirements and irrigation scheduling of spring maize using GIS and CropWat model in Beijing-Tianjin-Hebei region. *Chin. Geogr. Sci.* **2007**, *17*, 56–63. [CrossRef]
16. Al-Najar, H. The integration of FAO-CropWat Model and GIS Techniques for Estimating Irrigation Water Requirement and Its Application in the Gaza Strip. *Nat. Resour.* **2011**, *2*, 146–154. [CrossRef]
17. Bhardwaj, R.K.; Sharma, S.; Kumar, D. Impact of LULC Dynamics on Evapotranspiration using GIS: Case Study of Uttarakhand. *J. Mater. Environ. Sci.* **2022**, *13*, 631–639.
18. Adamala, S.; Rajwade, Y.A.; Krishna Reddy, Y.V. Estimation of wheat crop evapotranspiration using NDVI vegetation index. *J. Appl. Nat. Sci.* **2016**, *8*, 159–166. [CrossRef]
19. Kadkhodazadeh, M.; Valikhan Anaraki, M.; Morshed-Bozorgdel, A.; Farzin, S. A New Methodology for Reference Evapotranspiration Prediction and Uncertainty Analysis under Climate Change Conditions Based on Machine Learning, Multi Criteria Decision Making and Monte Carlo Methods. *Sustainability* **2022**, *14*, 2601. [CrossRef]
20. Farreny, R.; Morales-Pinzón, T.; Guisasola, A.; Tayà, C.; Rieradevall, J.; Gabarrell, X. Roof selection for rainwater harvesting: Quantity and quality assessments in Spain. *Water Res.* **2011**, *45*, 3245–3254. [CrossRef]
21. Maqsoom, A.; Aslam, B.; Ismail, S.; Thaheem, M.J.; Ullah, F.; Zahoor, H.; Musarat, M.A.; Vatin, N.I. Assessing Rainwater Harvesting Potential in Urban Areas: A Building Information Modelling (BIM) Approach. *Sustainability* **2021**, *13*, 12583. [CrossRef]
22. Bao, K.; Padsala, R.; Thrän, D.; Schröter, B. Urban Water Demand Simulation in Residential and Non-Residential Buildings Based on a CityGML Data Model. *ISPRS Int. J. Geo-Inf.* **2020**, *9*, 642. [CrossRef]
23. Climate-Data. Available online: https://en.climate-data.org/ (accessed on 5 October 2022).
24. Weater-Data. Available online: https://weatherspark.com/ (accessed on 7 October 2022).
25. BGR Geoportal. Available online: https://www.bgr.bund.de/ (accessed on 10 October 2022).
26. Rinaldi, S.; Bonamente, E.; Scrucca, F.; Merico, M.; Asdrubali, F.; Cotana, F. Water and Carbon Footprint of Wine: Methodology Review and Application to a Case Study. *Sustainability* **2016**, *8*, 621. [CrossRef]
27. Choudhary, D. Methods of Evapotranspiration. 2018. Available online: http://rgdoi.net/10.13140/RG.2.2.14533.76007 (accessed on 23 January 2023).
28. Solangi, G.S.; Shah, S.A.; Alharbi, R.S.; Panhwar, S.; Keerio, H.A.; Kim, T.W.; Memon, J.A.; Bughio, A.D. Investigation of Irrigation Water Requirements for Major Crops Using CROPWAT Model Based on Climate Data. *Water* **2022**, *14*, 2578. [CrossRef]

29. Alemayehu, Y.A.; Steyn, J.M.; Annandale, J.G. FAO-type crop factor determination for irrigation scheduling of hot pepper (*Capsicum annuum* L.) cultivars. *S. Afr. J. Plant Soil.* **2009**, *26*, 186–194. [CrossRef]
30. Lakshmi, S.E.; Yarrakula, K. Review and critical analysis on digital elevation models. *Geofizika* **2019**, *35*, 129–157. [CrossRef]
31. Rabbi, S.E.; Shant, R.; Karmakar, S.; Habib, A.; Kropp, J.P. Regional mapping of climate variability index and identifying socio-economic factors influencing farmer's perception in Bangladesh. *Environ. Dev. Sustain.* **2021**, *23*, 11050–11066. [CrossRef]
32. Repository.De. Index of /Schemas/Adv/Citygml/Codelisten/. Available online: https://repository.gdi-de.org/schemas/adv/citygml/Codelisten/ (accessed on 25 January 2023).
33. Ugai, T. Evaluation of Sustainable Roof from Various Aspects and Benefits of Agriculture Roofing in Urban Core. *Procedia Soc. Behav. Sci.* **2016**, *216*, 850–860. [CrossRef]
34. Lancaster, B. *Rainwater Harvesting for Drylands and Beyond*; Rainwater Harvesting for Drylands and Beyond; Rainsource Press: Tucson, Arizona, 2006; Volume 1.
35. Liaw, C.; Tsai, Y. Optimum Storage Volume of Rooftop Rain Water Harvesting Systems for Domestic Use1. *J. Am. Water Resour. Assoc.* **2004**, *40*, 901–912. [CrossRef]
36. Ward, S.; Memon, F.A.; Butler, D. Harvested rainwater quality: The importance of appropriate design. *Water Sci. Technol.* **2010**, *61*, 1707–1714. [CrossRef] [PubMed]
37. Anane, M.; Bouziri, L.; Limam, A.; Jellali, S. Ranking suitable sites for irrigation with reclaimed water in the Nabeul-Hammamet region (Tunisia) using GIS and AHP-multicriteria decision analysis. *Resour. Conserv. Recycl.* **2012**, *65*, 36–46. [CrossRef]
38. Schoenwiese, G. Umweltbundesamt. WW-R-1: Water Use Index. 2021. Available online: https://www.umweltbundesamt.de/en/topics/climate-energy/climate-impacts-adaptation/impacts-of-climate-change/monitoring-report-2019/indicators-of-climate-change-impacts-adaptation/cluster-water-regime-water-managementmarine-coastal/ww-r-1-water-use-index (accessed on 20 September 2022).
39. Germany, Federal Republic of. Available online: https://www.icid.org/i_d_germany.pdf (accessed on 3 February 2023).