hydrology

MDPI

Article

Investigating the Performance of Green Roof for Effective Runoff Reduction Corresponding to Different Weather Patterns: A Case Study in Dublin, Ireland

Arunima Sarkar Basu [1], Bidroha Basu [2], Francesco Pilla [1,*] and Srikanta Sannigrahi [1]

1 School of Architecture Planning and Environmental Policy, University College Dublin, D14 E099 Dublin, Ireland; arunima.sarkar@ucdconnect.ie (A.S.B.); srikanta.sannigrahi@ucd.ie (S.S.)
2 Civil, Structural and Environmental Engineering, Munster Technological University Cork, T12 P928 Cork, Ireland; bidroha.basu@mtu.ie
* Correspondence: francesco.pilla@ucd.ie

Abstract: This article aims to analyse the performance of green roof in runoff reduction. A case study has been conducted through a deployed green roof at the custom house quay building in Dublin, Ireland. Modular green roofs have been deployed which have IoT scales associated to it for measuring the effective reduction in runoff. Hydro-meteorological variables such as rainfall, temperature, relative humidity and wind speed values were corresponded to the amount of runoff reduction by means of a regression-based relationship. Comparison of the observed runoff reduction from a modular green roof and that estimated based on the developed regression relationship yielded a R^2 value of 0.874. Through this research, a pattern was identified which established that longer records and better weather variables data have the potential to improve the performance of the regression model in predicting the amount of runoff reduction corresponding to different rainfall and weather patterns. In general, performance of green roof was found to be highly positively correlated to the amount of rainfall received; however, low correlation between rainfall and the percentage of runoff reduction indicate that saturated soil in green roofs considerably deteriorates the performance in runoff reduction. Overall, this study can help in identification of locations where installation of green roofs can help mitigate floods at a city scale.

Keywords: green roof; Dublin CHQ building; real-world monitoring of green roofs; multiple linear regression

check for updates

Citation: Basu, A.S.; Basu, B.; Pilla, F.; Sannigrahi, S. Investigating the Performance of Green Roof for Effective Runoff Reduction Corresponding to Different Weather Patterns: A Case Study in Dublin, Ireland. *Hydrology* **2022**, *9*, 46. https://doi.org/10.3390/hydrology9030046

Academic Editor: Abdullah Gokhan Yilmaz

Received: 31 December 2021
Accepted: 2 March 2022
Published: 9 March 2022

1. Introduction

Urban sprawl has resulted in substantial reduction in soil permeability since impervious surfaces have started rising due to urbanization [1]). The flood peak magnitudes, flood frequency and runoff volume have increased, resulting in increased urban flooding [2–4]. The urban development of catchment has affected the hydrological response of surface runoff and infiltration, bringing forward the importance of urban stormwater management [5]. Previous urban stormwater management studies have shown that when more than ten percent of the watershed becomes impervious, the runoff discharge rises rapidly; as a result, the stream's natural quality starts deteriorating [6]. Further studies researched on the evolution of floods in urban areas and the sources of flood variability were based on geographic properties location of site [7,8]. The urban sewers and drainage systems in many cities are dealing with limited capacity; hence, there is risk of flooding in urban areas [9]. The green roof has been recommended extensively as a sustainable urban drainage system [10]. The green roof has reduced stormwater runoff compared to conventional roofs because of the additional capacity for water volume retention and evapotranspiration [11,12]. Various experimental sites showed that annual runoff from green roof performance improved by 15–35% for intensive roofs, whereas 20–75% for extensive roofs for the total annual rainfall in Germany [13]. The observed green roof retention capacity improvement is 46% of annual precipitation in Sweden [14]. The green roof retention capacity improvement is 50% in England [15], 60% improvement in Michigan, 66% in Auckland, 78% in Georgia [16–18]. Previous literature has proposed the outcome of predicting the hydrological performance of green roofs and the design based on performance indicators to make the green roof performance better [19]. For example, the Hydrus model when used for estimating the performance of green roof has shown difficulties when converging the weather conditions of dry and wet conditions and also in model simulations where precipitation is variable with the duration and depths [20]. Various urban drainage models have shown the impact of large-scale green roofs on hydrological fluxes [21]. Other literatures have predicted runoff retention performance of modular green roof (Shushunova et al., 2021). Previous simulation study of green roof performance assessment suggested that reduction in runoff has been implicated through the green roof on those days where greater than 50 mm, 40 mm, 30 mm, 20 mm, and 10 mm precipitation were obtained in terms of percentage [12].

The overall performance of the green roof system is evaluated by observing the following characteristics of the hydrological processes: (i) prolonging the runoff initiation; (ii) reduction of the volume of runoff; and (iii) extension of the runoff process via slow releases of excess substrate pore water [12]. Modular green roofs are gaining popularity as they have been successfully installed in many high-density urban areas, resulting in solving problems of not encroaching green spaces and urban lands [22]. In big cities where the availability of land surface is a challenge, modular green roof can serve as a key growth strategy to improve the livability of cities [23]. The stormwater retention performance of green roof focuses on the phenomenon of evaporation, transpiration and infiltration of engineered soil like substrate and vegetation to reduce the overland flow achieved through peak rainfall events [24].

The efficiency of storage stormwater runoff has been well demonstrated by Villarreal et al. [25] through a case study conducted in an inner city in Sweden. A detailed spatial analysis and modelling has been shown through green roofs, where imperviousness has been shown to be reducing and stormwater storage solutions were shown effective as a result of deployment of green roof [26]. Empirical equations as well as conceptual process-based models have shown an impact on estimating the model performance of green roof retention and runoff [27].

Modular green roof is gaining popularity over conventional green roofs in the recent years. A 248 sq. m. modular green roof was installed in 2 September 2009 on a public plaza at the University of Connecticut in Storrs, USA. The green roof consisted of 334 extensive GreenGrid® modules installed by Weston Solutions Inc., West Chester, PA, USA. The size of each green roof panel was 1.2 m long, 0.6 m wide, and 10.2 cm thick, and the panels covered 81% of the 307 sq. m. roof top area [19].

Another modular green roof was installed on the Maracanã Campus of the Rio de Janeiro State University, Rio de Janeiro, Brazil. The city exhibits tropical monsoon climate with extreme rainfall events. The deployed modular green roof units consisted of green roof tray modules installed in boxes made of waterproof board supported on metal benches with inclinable surfaces. There was also a control unit consisting of a corrugated fibre-cement roofing sheet. The modules consist of substrate of unvegetated agricultural compost [28].

Another pilot modular green roof system was installed at University of Hawaii at Manoa with three different module depths: 10 cm, 15 cm, and 20 cm. The three modules had drainage openings at 1.27 cm above the bottom. Water content of the growth media near the surface (integrated over depth: 0–5 cm) was collected with time domain reflectometry sensors [20].

A meteorological central unit was setup along with the anchor unit to measure the hydrological variables (rainfall and temperature). The runoff is indirectly measured in terms of weight difference of the modular green roof units. The weight of each modular green roofs is measured through IOT scale before runoff and after runoff and the weight difference is calculated as the runoff. The modular units are 80 cm wide and 105 cm long having a surface area of 1 sq. m., whereas the sides of each unit are 15 cm high and made of 8 mm thick slabs of waterproof material. During precipitation, some water will be intercepted by leaves and the remainder will leave the system as surface overflow when precipitation rate exceeds the rate of infiltration. The main advantages of modular green roof are that they are easy to install and can be installed in small areas, especially in urban areas where there are considerable space constrictions.

The aim of this study was to investigate the performance of green roof in reducing the runoff by considering the influence of important weather variables such as rainfall, temperature, relative humidity and windspeed.

2. Materials and Methods

A brief description of the study area, data details and the techniques used for the analysis has been provided in this section below.

2.1. Study Area and Materials

Dublin is the capital city of Ireland and is located in the eastern part of the country. Dublin exhibits a variety of weather patterns throughout the year. The monthly average temperature in Dublin ranges from 5 °C to 16 °C, with the highest temperature records in July and the lowest temperature in January. The average yearly rainfall is 760 mm. Precipitation is minimum in the months between February and April and maximum in the months between August and November. In order to understand the monthly variation in the rainfall pattern in Dublin, hourly rainfall data were collated from Dublin Airport from 1 January 1992 to 31 December 2021. The mean monthly rainfall and the standard deviation for each of the 12 months were estimated based on the hourly rainfall data measured at the airport covering 30 years (Figure 1). The figure indicates that the mean rainfall in Dublin is high for August, October and November, moderate in January, June, July, September and December, while low from February to May. The monthly standard deviation also follows a similar pattern as that of the mean, indicating that the variability of the rainfall is high in months exhibiting high rainfall. To understand the extreme rainfall pattern, the percentage of times the hourly rainfall exceeded 5 mm/h intensity for each month were estimated based on 30 years of data. The results indicate that August has exhibited maximum rainfall events, followed by October and November. However, the mean rainfall is highest in November, indicating that the number of rainy days is highest in November. Based on the rainfall pattern, it can be concluded that the majority of the flooding can be expected to occur between August and November in Dublin and the surrounding areas.

Due to high urbanization, presence of several waterbodies, and relatively high rainfall and storm events, the city is susceptible to flooding at several locations. In order to explore the effectiveness of green roofs in flood mitigation, this study has deployed modular green roofs at the Custom House Quay (CHQ) Building. The location of the CHQ building is shown in Figure 2. The CHQ Building is located in a high-density urban area. The location of the building is extremely significant as it is based in the inner part of Dublin city and is in close vicinity to the Dublin docklands and port area. The Dublin dockland area is served by the river Liffey and hosts the business hub of Dublin named the International Financial Services Centre (IFSC).

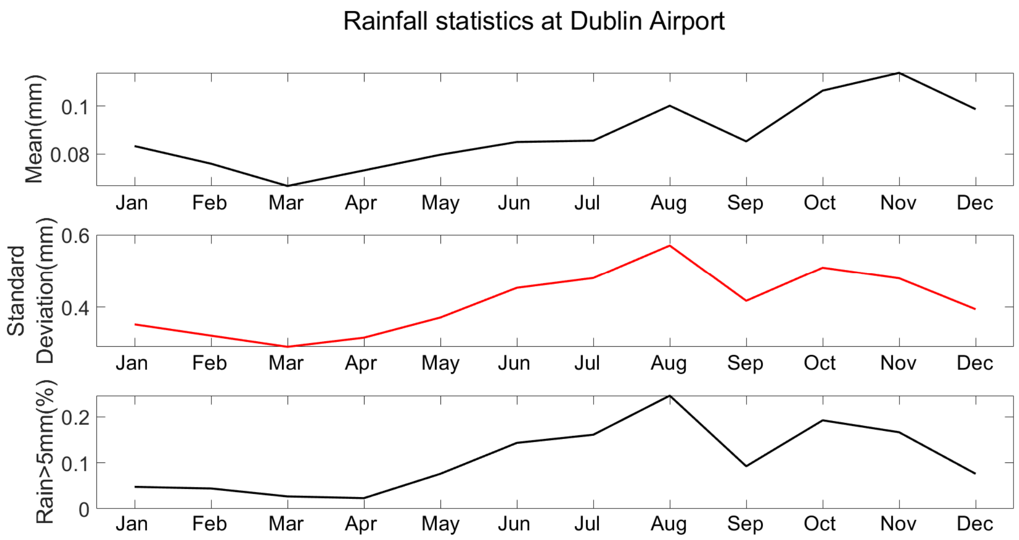


Figure 1. Statistics of rainfall in Dublin based on hourly rainfall data obtained from Dublin Airport, Ireland, for the period of 30 years.

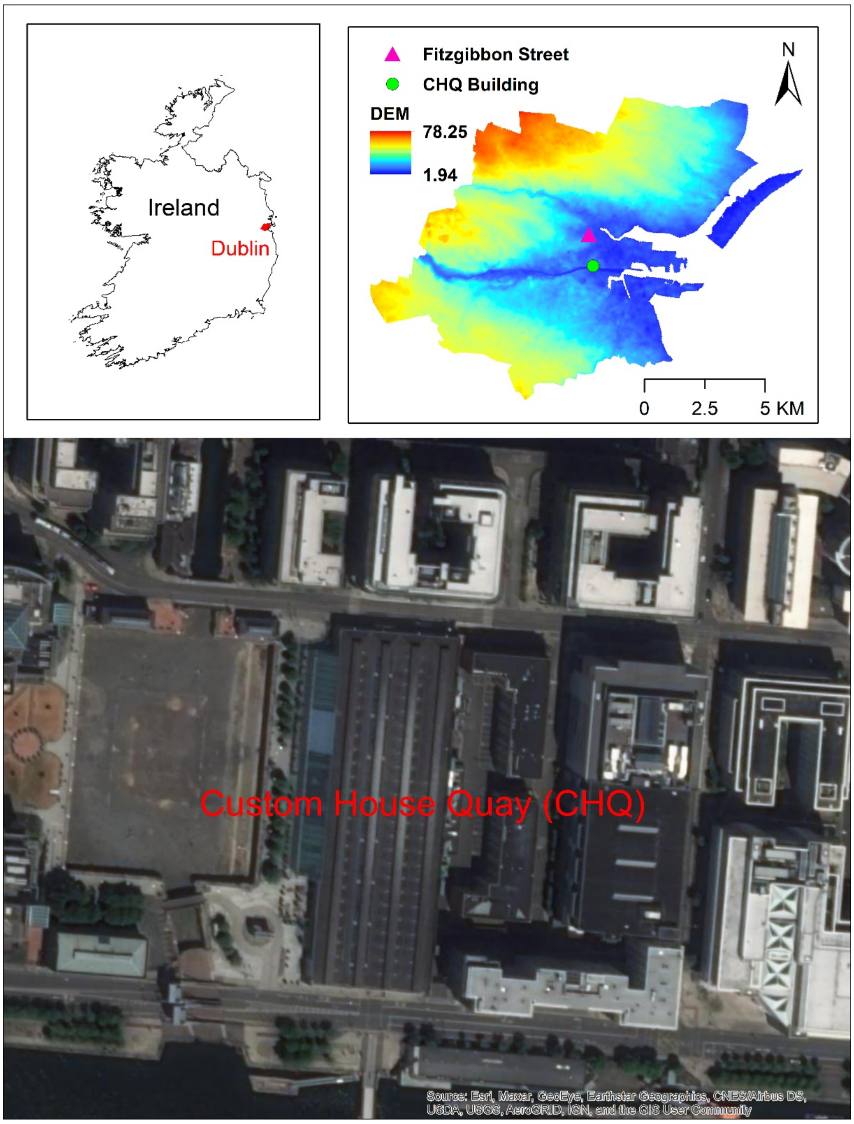


Figure 2. Location of Custom House Quay in Dublin, Ireland.

2.2. Data Collection and Modelling

The runoff data from the modular green roof were acquired into the Aquaroot Control System (ARCS), which is dedicated to data acquisition, data storage and representation in autonomous distributed Internet of Things (IoT) sensor networks. Each modular green roof is equipped with IoT scales, which monitor the weight of the modular green roof continuously. Images of the modular green roofs and sensors are shown in Figure 3.

Figure 3. Green roofs and sensors in the CHQ building.

The experimental setup of the green roof consists of an anchor unit frame, four weighing cradles, four bio-grow bags of modular green roofs, one rain gauge and one temperature gauge. Each of the four modular green roofs were placed in a modular tray made of waterproof flat board, which is supported through metal platforms. A combination of different recyclable materials has been used as the substrate of the modular green roofs. The primary materials used are wool, wood shavings, and hemp. Wool substrate was locally sourced, is extremely affordable and sustainable as well as biocompostable within a year. Wool due to its property has meshed support and is responsible for slow release of water. Biocompostable hemp and wood shavings have also been used due to low density, elasticity and permeability. Hemp promotes excellent properties for maintaining soil moisture, minimizes soil erosion, suppresses weed growth and helps in seed germination. Furthermore, hemp helps in insulating the substrate from heat and cold winter, and especially protects the plants in a frost environment. The hemp layer also helps to retain the soil moisture for a longer time period.

The green roof at the CHQ building was deployed in February 2021. However, due to prevalence of COVID-19, strict restrictions were imposed to access the CHQ building premises. Hence, only a limited experiment was conducted and data for short and intermittent period were collated from the green roofs. Once the COVID restrictions were relaxed in July 2021, the system of sensors was installed for monitoring the green roof data at continuous interval, and those sensors were connected to the wifi network to obtain the monitored data in real-time.

Time series data of IoT weight, precipitation and temperature were measured using the Aquaroot sensors from 23 July 2021 to 20 January 2022 at the Custom House Quay (CHQ) building. Data were measured at four modular green roof units located at the roof of the CHQ building. Corresponding to each modular green roof unit, the weight of the entire modular unit along with the vegetation, soil and the tray were measured along with the volume of the precipitation in mL every minute over the entire duration stated above. The temperature was considered to be the same at all four modular green roof locations, which can be considered a realistic assumption since those units are located on the same roof. Details on the data collection process are provided as a flowchart in Figure 4. The data were initially recorded from the modular green roof through a set of autonomous distributed IoT sensor networks, called EcoMet stations. The data were then forwarded to the Aquaroot Control Systems (ARCS), which is a supervisory control system used for real-time data acquisition and monitoring. The specialty of the ARCS is that it follows the mechanism of multi-tier client server architecture, where different layers of data are presented for processing and application on different processors. The ARCS work on LAN and its performance is based on ethernet standards. The technology has the following components: data acquisition (DAQ) server, real-time database, user interface, web-server and security system. The web pages produced by the ARCS web server contain a lot of dynamic elements such as indicators, graphs and tables.

Since the performance of the green roofs depends not only on the amount of rainfall received and the temperature, but also on other meteorological variables such as relative humidity and wind speed, those two data were also considered in this study. As relative humidity and wind speed were not measured at the CHQ building, data from another weather station located at Fitzgibbon Street (Figure 2), Dublin, were considered. It can be noted that this weather station is located at a distance of 1.8 km from the CHQ building. However, the area between those two locations does not exhibit considerable changes in the elevation. The ground elevation of the CHQ building is 8.35 m, while that for the weather station at Fitzgibbon Street is 14.6 m. Since the two places are located nearby without exhibiting considerable changes in the topography, the relative humidity and wind speed values measured at the Fitzgibbon Street weather station can be considered to be the same as for the CHQ building. The weather data at the Fitzgibbon Street weather station were measured at 5 min time intervals.

The relationship between the reduction in runoff from the green roof and four meteorological variables (rainfall, temperature, relative humidity and wind speed) was developed by using the multiple linear regression (MLR) approach, where the parameters of the model were estimated by using ordinary least square (OLS). The MLR-OLS model can be expressed in matrix notation as,

$$[\boldsymbol{y}]_{n\times 1} = [X]_{n\times p}[\boldsymbol{a}]_{p\times 1} + [\varepsilon]_{n\times 1} \quad (1)$$

where $\boldsymbol{y} = [y_1, y_2, \cdots, y_n]^T$ and $y_i, i = 1, \cdots, n$ is the amount of runoff reduction on a chosen period i; n is the number of data points; $X = \begin{bmatrix} 1\, x_{11} & \cdots & x_{1p} \\ 1\, x_{21} & \cdots & x_{2p} \\ 1\, \vdots & \ddots & \vdots \\ 1\, x_{n1} & \cdots & x_{np} \end{bmatrix}$ is the set of meteorological variables and p is the number of meteorological variables considered for developing the regression relationship; and ε is the regression model error terms. In this study, four meteorological variables, rainfall, temperature, relative humidity and wind speed, were considered.

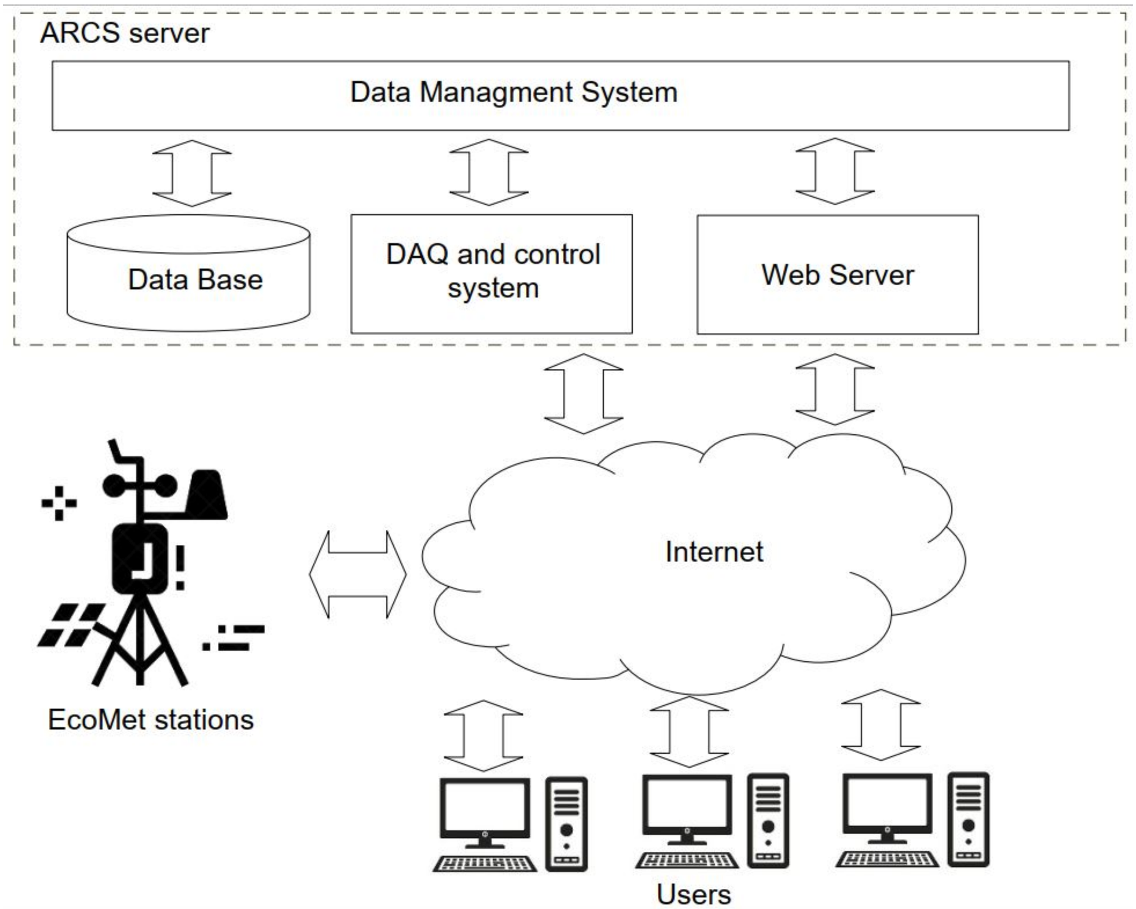


Figure 4. Data collection process from the green roof using Aquaroot sensors and ARCS server.

3. Results and Discussion

The analysis of the green roof performance was performed at an hourly time scale in this study. For this purpose, all the weather variables (the cumulative rainfall and average temperature, relative humidity and wind speed) were estimated at an hourly scale from the data measured at 5 min time intervals. The time series plot of each of those variables at the hourly scale is provided in Figure 5.

The reduction in runoff from the green roof can be estimated indirectly as the changes in the weight of the modular green roof unit. An increase in weight of the unit in an hour indicates that the modular unit has held that amount of water and reduced the surface runoff, while a reduction in weight indicates that the unit is releasing the stored water via draining and evapotranspiration. It can be noted that during a prolonged dry period, there will be no changes in the weight of the modular units, while an increase in weight will occur during a rainfall event and a reduction is expected after a rain event.

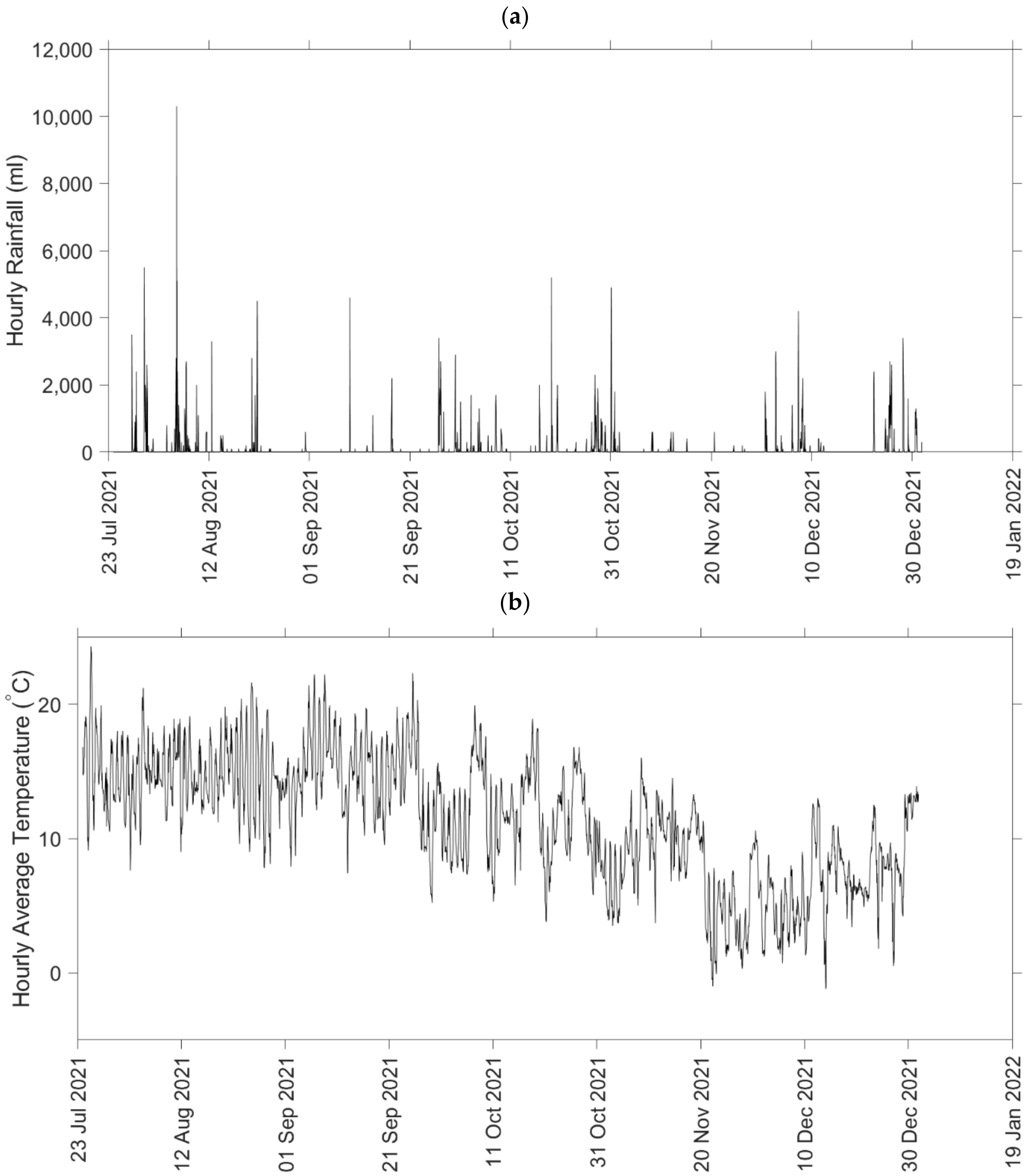
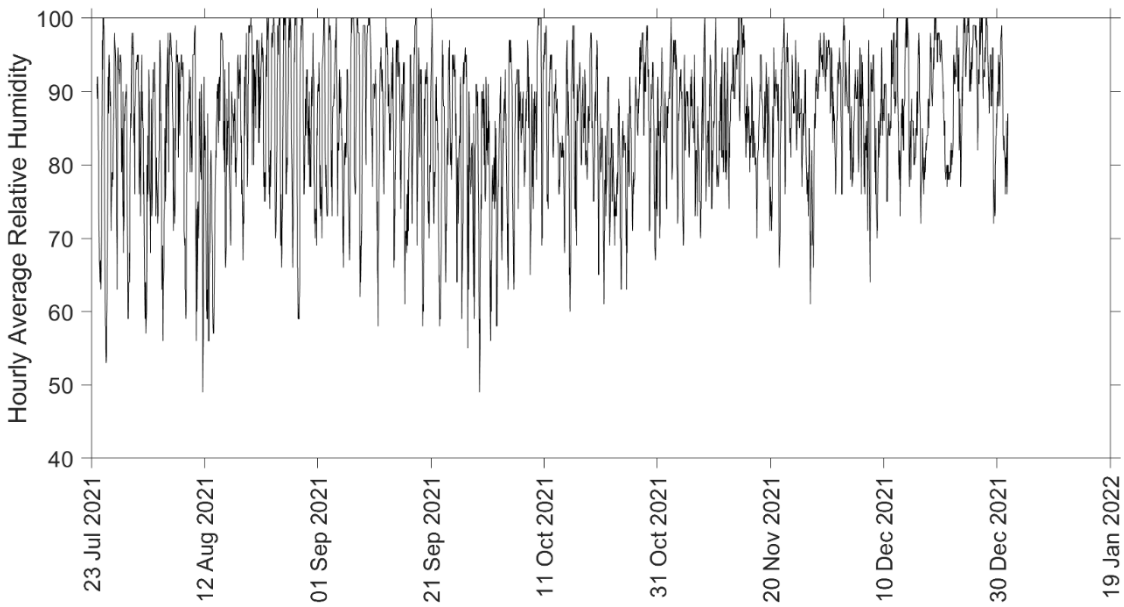


Figure 5. *Cont.*

(**c**)



(**d**)

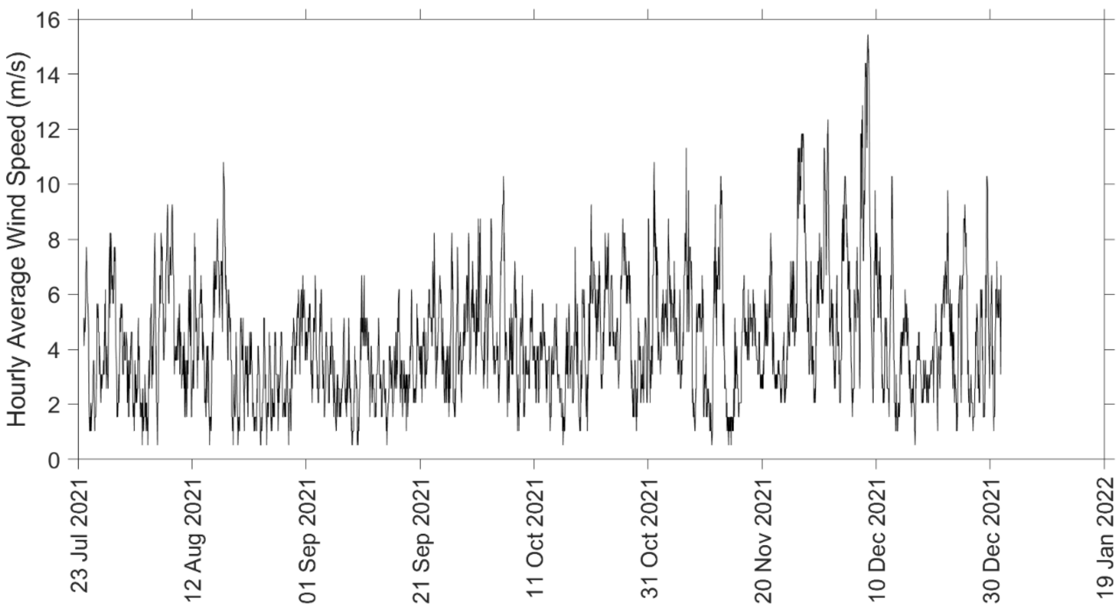


Figure 5. Time series plot of (**a**) hourly total rainfall, (**b**) hourly average temperature, (**c**) hourly average relative humidity, and (**d**) hourly average wind speed used in the study.

The objective of this research is to relate the amount of runoff reduction with the amount of rainfall received, and the temperature, relative humidity and wind speed. For this purpose, the correlation between those variables with the amount of runoff reduction was estimated (Table 1). The values indicate that the amount in runoff reduction is highly correlated to the total amount of rainfall received (0.93). This is expected as a high amount of rainfall will lead to a high volume of runoff reduction. However, it needs to be noted that in situations where the amount of rainfall is considerably high, the soil in the modular green roof will become fully saturated and entire excess rainfall will be converted to surface runoff. This phenomenon can be noted from the scatterplot between the rainfall and the reduction in runoff in Figure 6a. The figure indicates that, beyond a certain rainfall value, the amount of runoff reduction does not increase with an increase in the rainfall amount. Furthermore, the correlation between the percentage of runoff reduction and received rainfall (Table 1) was found to be 0.257, indicating that the percentage of runoff reduction does not necessarily increase with an increase in the received rainfall on a green roof. The correlation between temperature and the amount of runoff reduction as well as the percentage of runoff reduction was found to be low. The scatterplot (Figure 6b) between temperature and amount of runoff reduction indicates that the relationship might be nonlinear, leading to a low correlation value. A positive correlation between the relative humidity and amount of runoff reduction is expected, as higher relative humidity indicates a higher chance of rainfall. On the other hand, higher relative humidity reduces the percentage of runoff reduction, as high relative humidity leads to a reduction in evapotranspiration. High wind speed leads to extreme storm events and extreme rainfall, during which the amount of runoff reduction reaches a saturation value. In general, higher windspeed increases evapotranspiration, and slightly increases the percentage of runoff reduction, as evident from the correlation value of 0.069.

Table 1. Correlation between the amount and percentage of runoff reduction due to a green roof with a set of weather variables.

Correlation	Weather Variables			
	Rainfall (mL)	Temperature (°C)	Relative Humidity	Wind Speed (m/s)
Amount of runoff reduction (mL)	0.931	0.043	0.070	0.069
Percentage of runoff reduction (%)	0.258	0.026	−0.207	0.064

(**a**)

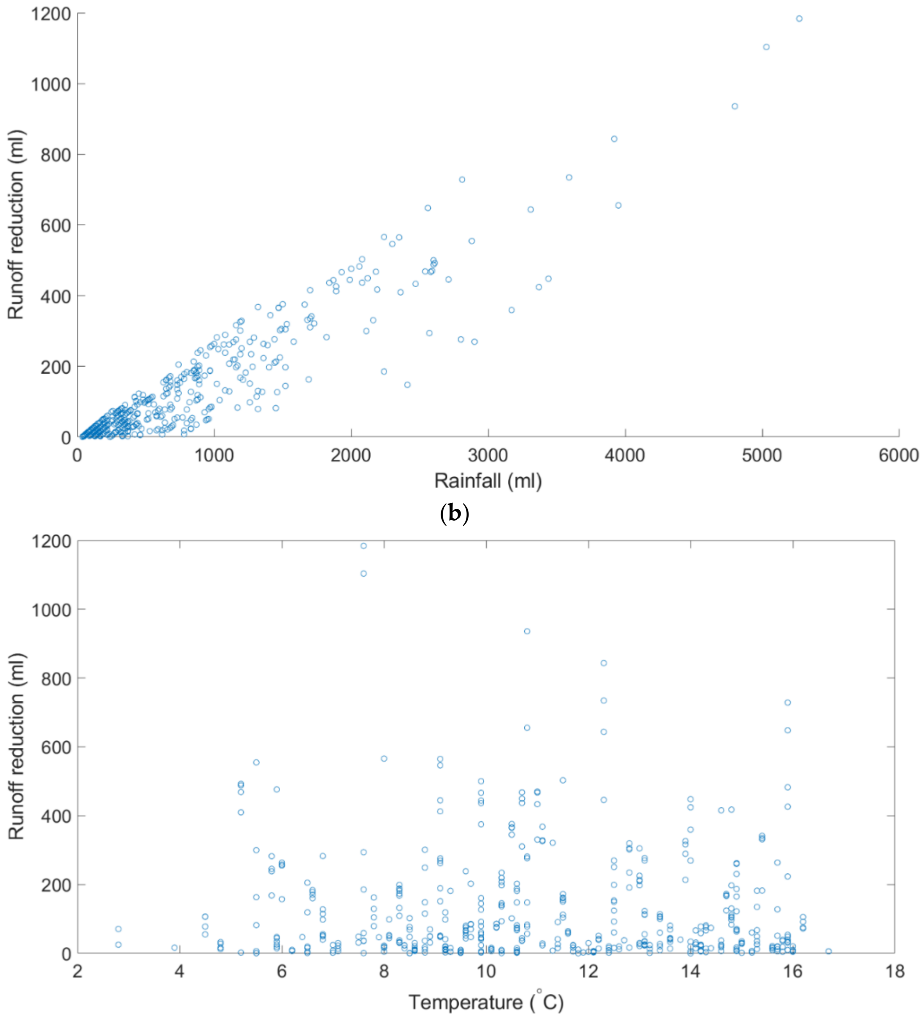


Figure 6. *Cont.*

(**c**)

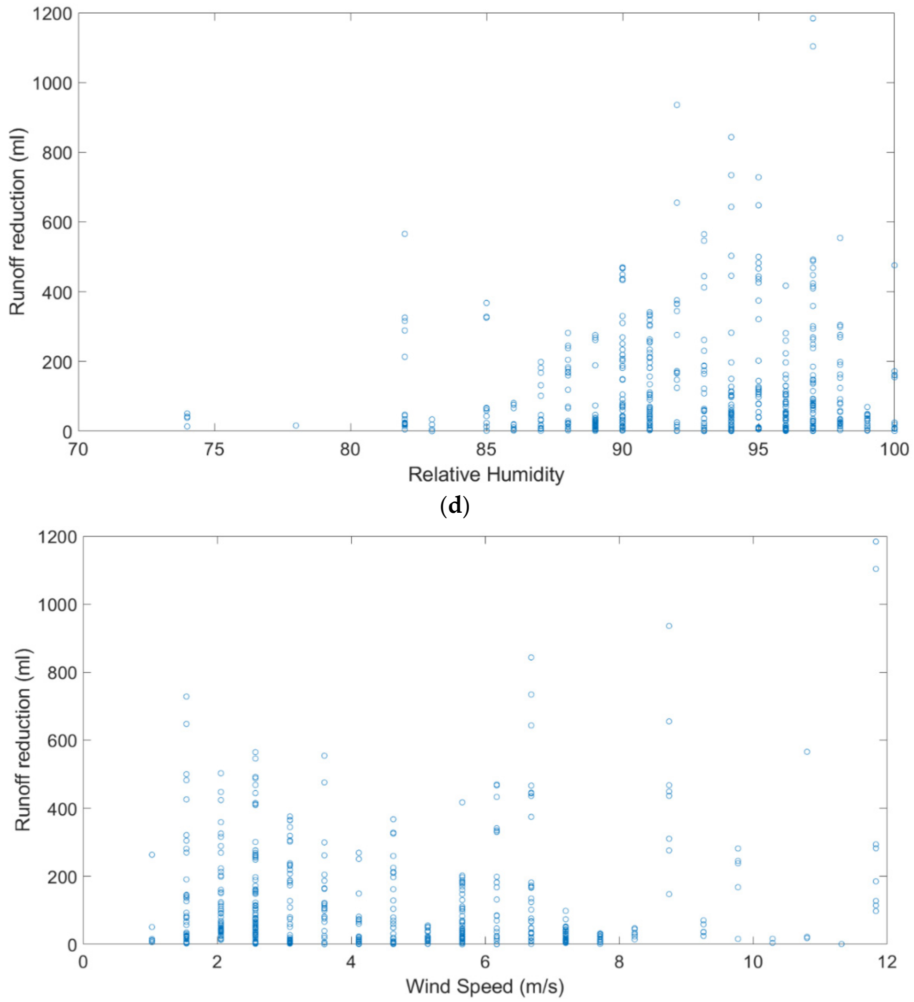


Figure 6. Scatterplot between the weather variables (**a**) hourly total rainfall, (**b**) hourly average temperature, (**c**) hourly average relative humidity, and (**d**) hourly average wind speed and the amount of runoff reduction.

One point to be noted is that, in general, performance of the green roofs in runoff reduction needs to be estimated for each season over an entire calendar year. In this study, however, data ranging from July 2021 to January 2022 were used for analysis. Continuous measurement from the deployed green roof is ongoing, and the analysis needs to be extended when a longer date will be made available. However, the rainfall pattern in Dublin over the past 30 years indicates that the majority of high-to-extreme rainfall occurred between August and November, and the time period has been covered in the current analysis.

A multiple linear regression model has been developed between the amount of runoff reduction in mL (predictand) and the four predictor weather variables (rainfall, temperature, relative humidity and wind speed). The regression relationship can be expressed as:

$$\begin{aligned} \text{Amount of Runoff} \quad & \text{reduction (mL)} \\ &= a_0 + a_1 \times \text{Rainfall(mL)} + a_2 \times \text{Temperature}(^\circ\text{C}) \\ &+ a_3 \times \text{RelativeHumidity} + a_4 \times \text{WindSpeed}(\text{m/s}) \end{aligned} \quad (2)$$

The model parameters $(a_0, a_1, a_2, a_3, a_4)$ are provided in Table 2 along with the p-value statistic.

Table 2. Regression relationship between the amount of runoff reduction (mL) with rainfall (mL), temperature (°C), relative humidity and wind speed (m/s).

Regression Parameters	Estimate	*p*-Value
a_0	136.930	1.46×10^{-6}
a_1	0.194	0
a_2	2.378	0.061
a_3	−3.403	1.41×10^{-7}
a_4	1.951	0.113

The performance of the multiple linear regression model has been provided based on the R^2 value and scatterplot between the observed amount of runoff reduction and the model predicted runoff reduction, as shown in Figure 7. The R^2 value was found to be 0.874. It can be noted from the figure that the model sometimes is overestimating as well as underestimating the amount of runoff reduction. It needs to be noted that the model has been developed based on data collected for a period of 6 months. Furthermore, two important weather variables (relative humidity and wind speed) were available at a station located 1.8 km from the location of the green roofs. Longer records and better weather variables data have the potential to improve the performance of the regression model in predicting the amount of runoff reduction corresponding to different rainfall and weather patterns. Furthermore, the two major factors that reduce the runoff from a green roof are the soil/substrate moisture content (SMC) and the evapotranspiration. Due to practical difficulties in measuring the evapotranspiration from the green roof, the evapotranspiration was usually estimated based on a conceptual model. The most commonly used approaches are the FAO Penmann–Monteith [29] and the Priestley–Taylor equation [30], which require different weather variables such as temperature, relative humidity, wind speed and solar radiation to estimate evapotranspiration. This study investigated the effect of three weather variables: temperature, relative humidity and wind speed in reduction in runoff from the green roof. The other important factor is the soil/substrate moisture content. The same amount of rainfall can lead to considerable differences in runoff reduction from a green roof based on the soil/substrate moisture content. In situations where the soil is dry, the runoff reduction will be higher, whereas for completely saturated soil, the runoff reduction from the green roof will occur solely due to evapotranspiration. Measurement of substrate moisture content and including it in the regression model can improve the model performance and the understanding of the performance of green roofs.

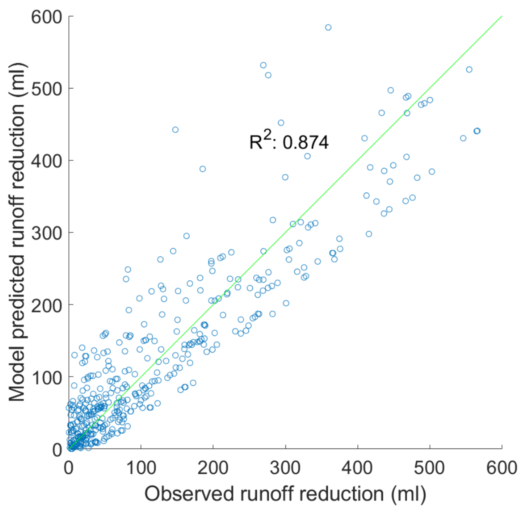


Figure 7. Scatterplot between observed and regression model predicted amount of runoff reduction from a green roof.

4. Conclusions

This research focuses on the performance of a green roof in reducing runoff using real-world observed data. A set of modular green roofs has been deployed at the CHQ building in Dublin, the capital of Ireland. Reduction in runoff from the deployed green roofs has been measured indirectly by using an IoT weight scale in this study. A regression relationship has been developed to predict/estimate the amount of runoff reduction corresponding to different rainfall, temperature, relative humidity and wind speed values. The model performance yields an R^2 value of 0.874, indicating the potential of the modelled approach. Longer data have the potential to improve the performance of the developed regression model in predicting runoff reduction from green roofs. Ongoing research focuses on recording longer records from the installed green roof, as well as collecting substrate moisture content, relative humidity, wind speed and solar radiation data from the green roof at CHQ building. The advantage of the approach is that the developed model can be used to predict the amount of runoff reduction from the green roofs corresponding to different climatic conditions. This information can be further used to identify potential locations for the installation of new green roofs and create a flood mitigation system at a city scale. Research is underway in collaboration with the Dublin City Council to achieve this goal in the near future.

Author Contributions: Conceptualization: A.S.B. and B.B.; methodology: A.S.B. and B.B.; validation: A.S.B. and B.B.; formal analysis: A.S.B. and B.B.; investigation: A.S.B. and B.B.; data curation: A.S.B. and S.S.; writing—original draft preparation: A.S.B., B.B. and F.P.; writing—review and editing: F.P.; supervision: F.P.; funding acquisition: F.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the European Community's H2020 Programme, grant number 776848.

Data Availability Statement: The weather data at the Fitzgibbon Street can be accessed from https://www.wunderground.com/weather/ie/fitzgibbon-street/IFITZGIB2, accessed on 30 December 2021.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. McGrane, S.J. Impacts of urbanisation on hydrological and water quality dynamics, and urban water management: A review. *Hydrol. Sci. J.* **2016**, *61*, 2295–2311. [CrossRef]
2. Ogden, F.L.; Raj Pradhan, N.; Downer, C.W.; Zahner, J.A. Relative importance of impervious area, drainage density, width function, and subsurface storm drainage on flood runoff from an urbanized catchment. *Water Resour. Res.* **2011**, *47*, 1–12. [CrossRef]
3. Smith, J.A.; Baeck, M.L.; Morrison, J.E.; Sturdevant-Rees, P.; Turner-Gillespie, D.F.; Bates, P.D. The regional hydrology of extreme floods in an urbanizing drainage basin. *J. Hydrometeorol.* **2002**, *3*, 267–282. [CrossRef]
4. Smith, J.A.; Baeck, M.L.; Meierdiercks, K.L.; Nelson, P.A.; Miller, A.J.; Holland, E.J. Field studies of the storm event hydrologic response in an urbanizing watershed. *Water Resour. Res.* **2005**, *41*, 1–15. [CrossRef]
5. Niehoff, D.; Fritsch, U.; Bronstert, A. Land-use impacts on storm-runoff generation: Scenarios of land-use change and simulation of hydrological response in a meso-scale catchment in SW-Germany. *J. Hydrol.* **2002**, *267*, 80–93. [CrossRef]
6. Sohn, W.; Kim, J.H.; Li, M.H. Low-impact development for impervious surface connectivity mitigation: Assessment of directly connected impervious areas (DCIAs). *J. Environ. Plan. Manag.* **2017**, *60*, 1871–1889. [CrossRef]
7. Pour, S.H.; Abd Wahab, A.K.; Shahid, S.; Asaduzzaman, M.; Dewan, A. Low impact development techniques to mitigate the impacts of climate-change-induced urban floods: Current trends, issues and challenges. *Sustain. Cities Soc.* **2020**, *62*, 102373. [CrossRef]
8. Whitfield, P.H. Floods in future climates: A review. *J. Flood Risk Manag.* **2012**, *5*, 336–365. [CrossRef]
9. Djordjević, S.; Butler, D.; Gourbesville, P.; Mark, O.; Pasche, E. New policies to deal with climate change and other drivers impacting on resilience to flooding in urban areas: The CORFU approach. *Environ. Sci. Policy* **2011**, *14*, 864–873. [CrossRef]
10. Li, W.C.; Yeung, K.K.A. A comprehensive study of green roof performance from environmental perspective. *Int. J. Sustain. Built Environ.* **2014**, *3*, 127–134. [CrossRef]
11. Locatelli, L.; Mark, O.; Mikkelsen, P.S.; Arnbjerg-Nielsen, K.; Jensen, M.B.; Binning, P.J. Modelling of green roof hydrological performance for urban drainage applications. *J. Hydrol.* **2014**, *519*, 3237–3248. [CrossRef]

12. Basu, A.S.; Pilla, F.; Sannigrahi, S.; Gengembre, R.; Guilland, A.; Basu, B. Theoretical Framework to Assess Green Roof Performance in Mitigating Urban Flooding as a Potential Nature-Based Solution. *Sustainability* **2021**, *13*, 13231. [CrossRef]
13. Mentens, J.; Raes, D.; Hermy, M. Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? *Landsc. Urban Plan.* **2006**, *77*, 217–226. [CrossRef]
14. Bengtsson, L.; Grahn, L.; Olsson, J. Hydrological function of a thin extensive green roof in southern Sweden. *Hydrol. Res.* **2005**, *36*, 259–268. [CrossRef]
15. Stovin, V.; Vesuviano, G.; Kasmin, H. The hydrological performance of a green roof test bed under UK climatic conditions. *J. Hydrol.* **2012**, *414*, 148–161. [CrossRef]
16. VanWoert, N.D.; Rowe, D.B.; Andresen, J.A.; Rugh, C.L.; Fernandez, R.T.; Xiao, L. Green roof stormwater retention: Effects of roof surface, slope, and media depth. *J. Environ. Qual.* **2005**, *34*, 1036–1044. [CrossRef] [PubMed]
17. Monterusso, M.A.; Rowe, D.B.; Rugh, C.L.; Russell, D.K. Runoff water quantity and quality from green roof systems. *Acta Hortic.* **2002**, *639*, 369–376. [CrossRef]
18. Carter, T.L.; Rasmussen, T.C. Hydrologic behavior of vegetated roofs 1. *JAWRA* **2006**, *42*, 1261–1274. [CrossRef]
19. Gregoire, B.G.; Clausen, J.C. Effect of a modular extensive green roof on stormwater runoff and water quality. *Ecol. Eng.* **2011**, *37*, 963–969. [CrossRef]
20. Li, Y.; Babcock, R.W. A simplified model for modular green roof hydrologic analyses and design. *Water* **2016**, *8*, 343. [CrossRef]
21. Lamera, C.; Becciu, G.; Rulli, M.C.; Rosso, R. Green roofs effects on the urban water cycle components. *Procedia Eng.* **2014**, *70*, 988–997. [CrossRef]
22. Korol, E.; Shushunova, N. Benefits of a modular green roof technology. *Procedia Eng.* **2016**, *161*, 1820–1826. [CrossRef]
23. Nguyen, T.T.; Ngo, H.H.; Guo, W.; Wang, X.C.; Ren, N.; Li, G.; Ding, J.; Liang, H. Implementation of a specific urban water management-Sponge City. *Sci. Total Environ.* **2019**, *652*, 147–162. [CrossRef] [PubMed]
24. Palla, A.; Gnecco, I.; Lanza, L.G. Hydrologic restoration in the urban environment using green roofs. *Water* **2010**, *2*, 140–154. [CrossRef]
25. Villarreal, E.L.; Semadeni-Davies, A.; Bengtsson, L. Inner city stormwater control using a combination of best management practices. *Ecol. Eng.* **2004**, *22*, 279–298. [CrossRef]
26. Barnhart, B.; Pettus, P.; Halama, J.; McKane, R.; Mayer, P.; Djang, K.; Brookes, A.; Moskal, L.M. Modeling the hydrologic effects of watershed-scale green roof implementation in the Pacific Northwest, United States. *J. Environ. Manag.* **2021**, *277*, 111418. [CrossRef]
27. Stovin, V.; Poë, S.; Berretta, C. A modelling study of long term green roof retention performance. *J. Environ. Manag.* **2013**, *131*, 206–215. [CrossRef]
28. Loiola, C.; Mary, W.; da Silva, L.P. Hydrological performance of modular-tray green roof systems for increasing the resilience of mega-cities to climate change. *J. Hydrol.* **2019**, *573*, 1057–1066. [CrossRef]
29. Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M. *Crop Evapotranspiration-Guidelines for Computing Crop Water Requirements*; FAO Irrigation and Drainage Paper 56; FAO: Rome, Italy, 1998; 300p.
30. Priestley, C.H.B.; Taylor, R.J. On the assessment of surface heat flux and evaporation using large-scale parameters. *Mon. Weather Rev.* **1972**, *100*, 81–92. [CrossRef]