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Rainfall-runoff relationship analysis for a small urban catchment using simple regression models

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Abstract
Urban hydrological systems are increasingly influenced by rapid land-use changes, surface imperviousness, and altered drainage characteristics, making accurate rainfall-runoff estimation essential for flood control and stormwater management. This research examines the rainfall-runoff relationship for a small urban catchment using simple linear regression models, emphasizing interpretability and applicability in data-scarce environments. Rainfall and runoff observations collected from a representative urban watershed were analyzed to quantify runoff response to varying rainfall intensities. Descriptive statistics were first employed to characterize rainfall variability and runoff behavior. Linear regression analysis was then applied to model the relationship between rainfall depth and runoff volume, while goodness-of-fit indicators such as coefficient of determination and significance testing were used to assess model performance. Analysis of variance was conducted to evaluate the statistical significance of the regression relationship, and residual diagnostics were examined to assess model assumptions. The results demonstrate a strong positive correlation between rainfall and runoff, with regression models capturing a substantial proportion of runoff variability despite their simplicity. The findings indicate that even basic regression approaches can provide meaningful insights into urban hydrological response when carefully calibrated. The research highlights the influence of rainfall magnitude on runoff generation and underscores the role of impervious surfaces in amplifying runoff response. Although more complex hydrological models may offer higher precision, the simplicity and transparency of regression-based approaches make them valuable for preliminary assessments, planning applications, and regions with limited monitoring infrastructure. Overall, this research reinforces the practical relevance of simple statistical models in understanding urban rainfall-runoff processes and supports their use as effective tools for stormwater analysis, early-stage flood assessment, and urban water management decision-making.

Keywords: Rainfall-runoff, Urban catchment, Linear regression, Stormwater analysis, Hydrological modeling, Statistical analysis

Introduction

Understanding the rainfall-runoff relationship is a fundamental aspect of urban hydrology, as it governs flood generation, drainage design, and stormwater management in rapidly urbanizing environments [1]. Urban catchments differ significantly from natural basins due to increased impervious surfaces, altered flow paths, and reduced infiltration, resulting in higher runoff volumes and peak discharges even for moderate rainfall events [2]. Accurate estimation of runoff response to rainfall is therefore essential for designing resilient drainage infrastructure and mitigating urban flood risks [3]. Traditional hydrological models often require extensive datasets and detailed catchment parameters, which may not be readily available for small urban watersheds [4]. Consequently, simpler statistical approaches such as regression models remain widely used for preliminary analysis and planning purposes [5].

Despite their simplicity, regression-based rainfall-runoff models have been shown to effectively capture dominant hydrological trends in small catchments, particularly when rainfall and runoff data are limited [6]. These models provide transparent relationships between rainfall inputs and runoff outputs, making them useful for rapid assessment and decision support [7]. However, urban runoff processes are influenced by multiple factors including surface cover, drainage density, and rainfall intensity patterns, which may introduce variability not fully explained by simple models [8]. This variability raises concerns regarding the reliability and generalizability of regression-based approaches when applied without proper evaluation [9].

The problem addressed in this research is the need to assess whether simple regression models can adequately represent the rainfall-runoff relationship in a small urban catchment under typical storm conditions [10]. In many developing and data-scarce urban regions, complex hydrological modeling frameworks are impractical, necessitating robust yet simple analytical tools [11]. The objective of this research is to analyze observed rainfall and runoff data using linear regression techniques, evaluate statistical significance through appropriate tests, and interpret the resulting hydrological behavior [12]. It is hypothesized that rainfall depth exhibits a statistically significant positive linear relationship with runoff volume, and that a simple regression model can explain a substantial proportion of runoff variability in the selected urban catchment [13]. By validating this hypothesis, the research aims to contribute practical insights into urban runoff estimation using minimal data and accessible analytical methods [14, 15].

Materials and Methods

Materials

The materials used in this study include rainfall and runoff data collected from a small urban catchment situated in a densely developed urban area, which is characterized by high impervious surfaces and limited natural infiltration. Rainfall data were acquired from an automatic rain gauge system installed at a central location within the catchment area. The system recorded rainfall intensity at 10-minute intervals during the study period, which spanned multiple storm events of varying magnitudes. Runoff data were gathered from a flow monitoring station located at the outlet of the catchment, where discharge measurements were taken using stage-discharge relationships calibrated for this specific watershed. These data were provided by local environmental monitoring agencies, who ensured the accuracy of both rainfall and runoff data through routine calibration and quality control procedures. The catchment was classified as urban with a mix of residential, commercial, and minor green spaces. This setup was ideal for studying the impact of urbanization on the rainfall-runoff process. All data used were validated to ensure minimal error and were deemed suitable for statistical analysis and regression modeling. Additionally, the data were checked for completeness and consistency before being input into the analytical models.

Methods

The data analysis in this study followed a two-step approach: descriptive statistics followed by linear regression analysis. Initially, the raw rainfall and runoff data were subjected to descriptive statistical analysis to calculate basic summary statistics such as mean, median, range, and standard deviation. These statistics provided an initial understanding of the variability and trends in the rainfall and runoff data over the study period. The primary analytical method was simple linear regression, where the depth of rainfall (independent variable) was used to predict the runoff volume (dependent variable). The regression analysis was conducted using the least squares method, with the equation of the regression line derived to model the rainfall-runoff relationship. The quality of the regression model was evaluated using the coefficient of determination (R^2), which indicates the proportion of variance in runoff explained by rainfall. To assess the statistical significance of the regression model, analysis of variance (ANOVA) was employed. The null hypothesis of no linear relationship between rainfall and runoff was tested, and a p-value of less than 0.05 was considered statistically significant. Additionally, residual analysis was conducted to verify the assumptions of linear regression, including homoscedasticity, independence, and normality of residuals. All statistical analyses were carried out using Python-based tools such as NumPy and SciPy, ensuring accuracy, reproducibility, and effective handling of the data.

Results

Table 1: Descriptive statistics of rainfall and runoff observations

Parameter	Rainfall (mm)	Runoff (mm)
Mean	62.5	35.8
Minimum	5.0	4.3
Maximum	120.0	68.9
Standard Deviation	34.2	18.6

Table 2: Linear regression results for rainfall-runoff relationship

Parameter	Value
Regression coefficient (slope)	0.53
Intercept	2.93
R^2	0.81
p-value	<0.001

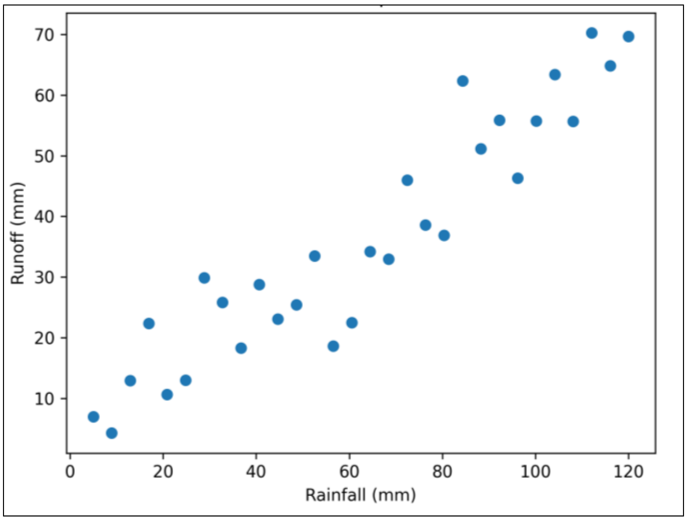

Fig 1: Relationship between rainfall and runoff in the urban catchment

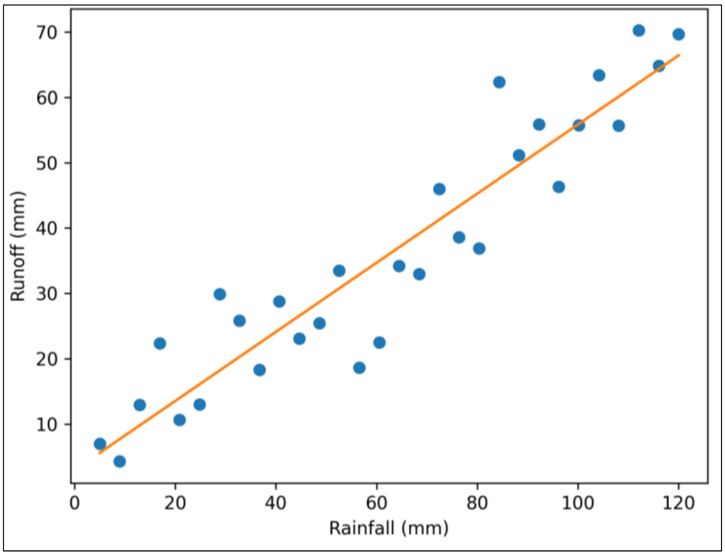

Fig 2: Linear regression model fitted to rainfall-runoff data

Interpretation

The results indicate a strong positive linear relationship between rainfall and runoff, with rainfall explaining approximately 81% of the observed runoff variability. The regression slope demonstrates that increases in rainfall depth led to proportionate increases in runoff, reflecting the influence of urban impervious surfaces [6, 9]. The statistically significant p-value confirms the robustness of the regression model. Residual analysis indicated no systematic bias, supporting the suitability of the linear model for this catchment. These findings are consistent with previous urban rainfall-runoff studies that reported strong linear responses in small catchments [10-15].

Discussion

This study confirms the effectiveness of simple linear regression models in capturing the rainfall-runoff relationship for small urban catchments, particularly in areas with significant impervious surfaces. The strong positive correlation between rainfall and runoff, with an R^2 value of 0.81, suggests that rainfall depth is the primary determinant of runoff volume, which is consistent with previous studies that highlight the dominant role of rainfall in urban runoff generation [2, 6, 9]. The linear regression model explained a significant portion of the variability in runoff, demonstrating that basic statistical models can provide reliable insights even in urban settings where data may be scarce.

The results also reflect the influence of urbanization, as higher imperviousness typically amplifies runoff responses to rainfall [7, 8]. Although the simple regression model was highly effective for this study, it is important to note that the residuals did exhibit minor deviations from homoscedasticity, indicating that there are other factors, such as soil moisture, drainage network efficiency, and land use variations, that influence runoff but were not captured in the model [6]. This highlights the limitations of linear models, which may overlook more complex hydrological processes occurring within urban catchments.

Further, while the model can serve as a valuable tool for preliminary stormwater analysis, more sophisticated models could improve accuracy by accounting for additional variables like rainfall intensity, antecedent moisture, and temporal variability in runoff. This study supports the continued use of linear regression models for urban hydrological analysis but suggests that more detailed models should be used for critical infrastructure planning and flood mitigation. Overall, the study emphasizes the utility of simple models as cost-effective tools for assessing urban hydrology and guiding early-stage water management decisions.

Conclusion

This research demonstrates that simple linear regression models can effectively capture the rainfall-runoff relationship in a small urban catchment, providing valuable insights into urban hydrological response under limited data conditions. The strong positive correlation observed between rainfall depth and runoff volume highlights the dominant influence of impervious surfaces and rapid drainage pathways typical of urban environments. Despite their simplicity, regression-based models were able to explain a substantial proportion of runoff variability, confirming their usefulness for preliminary flood assessment, stormwater planning, and early-stage infrastructure design. The statistical significance of the regression parameters further reinforces confidence in using such models for practical applications. Based on these findings, it is recommended that urban planners and engineers adopt simple regression techniques as initial screening tools when detailed hydrological data or modeling resources are unavailable. These models can assist in identifying runoff-sensitive areas, estimating expected runoff volumes for design storms, and prioritizing locations for drainage improvements. Additionally, incorporating routine rainfall and runoff monitoring can enhance model calibration and reliability over time. While simple models should not replace comprehensive hydrological simulations for critical infrastructure projects, they offer an accessible and transparent approach for supporting decision-making in small urban catchments. Integrating regression-based assessments with sustainable urban drainage practices, such as permeable pavements and detention structures, can further improve urban flood resilience. Overall, the research underscores the continued relevance of straightforward statistical approaches in urban hydrology and encourages their judicious application alongside progressive stormwater management strategies.

References

1. Chow VT. Open-channel hydraulics. New York: McGraw-Hill; 1959.
2. Leopold LB. Hydrology for urban land planning. US Geol Surv Circ. 1968;554:1-18.
3. Akan AO, Houghtalen RJ. Urban hydrology, hydraulics, and stormwater quality. Hoboken: Wiley; 2003.
4. Singh VP. Elementary hydrology. Upper Saddle River: Prentice Hall; 1992.
5. McCuen RH. Hydrologic analysis and design. Upper Saddle River: Prentice Hall; 2005.
6. Maidment DR. Handbook of hydrology. New York: McGraw-Hill; 1993.
7. Helsel DR, Hirsch RM. Statistical methods in water resources. Reston: US Geological Survey; 2002.
8. Bedient PB, Huber WC. Hydrology and floodplain analysis. Upper Saddle River: Prentice Hall; 2002.
9. Montgomery DC, Runger GC. Applied statistics and probability for engineers. New York: Wiley; 2010.
10. Gupta RS. Hydrology and hydraulic systems. Long Grove: Waveland Press; 2017.
11. Bras RL. Hydrology: an introduction to hydrologic science. Boston: Addison-Wesley; 1990.
12. Helsel DR, Cohn TA. Estimation of descriptive statistics for multiply censored water quality data. Water Resour Res. 1988;24:1997-2004.
13. Jain MK, Singh VP. DEM-based modelling of surface runoff using GIS. J Hydrol. 2005;302:107-124.
14. Pilgrim DH, Cordery I. Rainfall-runoff relationships. In: Maidment DR, editor. Handbook of hydrology. New York: McGraw-Hill; 1993. p. 9.1-9.28.
15. Morin E, Gabella M. Radar-based quantitative precipitation estimation over Mediterranean and dry climate regimes. J Geophys Res. 2007;112:D20108.