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Investigating the Influence of Raster DTM Bit Depth on Flood Modelling in 3D Urban Models

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ABSTRACT

Urban areas are increasingly vulnerable to severe flooding due to rapid urbanization and the growing impacts of climate change. Accurate flood modelling is essential for disaster preparedness, land-use planning, and infrastructure resilience. However, a key gap in current flood models is the influence of the Digital Terrain Model (DTM) bit depth on prediction accuracy. While spatial resolution has been the focus of many studies, the role of DTM bit depth, especially in signed versus unsigned formats, remains underexplored. This study addresses this gap by systematically investigating the effects of varying DTM bit depths (8-bit, 16-bit, and 32-bit) on flood prediction accuracy in 3D urban models. By comparing signed and unsigned formats, the study quantifies how these configurations influence water depth predictions, variance, and maximum deviation in flood simulations. The findings show that higher bit depths, particularly 16-bit signed DTMs, provide improved precision in capturing complex urban topographies, significantly enhancing the accuracy of flood risk assessments. The study proposes recommendations for selecting optimal DTM bit depths that balance computational efficiency with prediction accuracy. These insights contribute to the development of more resilient urban planning strategies and flood mitigation efforts, crucial for adapting to the increasing frequency and severity of urban flooding events caused by climate change.

Keywords: DTM; rainfall modelling; 3D city model; spatial resolution; bit depths

INTRODUCTION

The rapid urbanization of cities coupled with the increasing frequency of extreme weather events, driven by climate change, has escalated the vulnerability of urban areas to severe flooding (Lu et al. 2023; Mohamed et al. 2024). As cities grow vertically and expand into flood-prone areas, the challenge becomes not only one of immediate disaster management but also of long-term resilience. Traditional flood modelling techniques are often inadequate in accounting for the complexities of modern urban environments (Tasnim et al. 2023; Ng et al. 2025), especially when it comes to simulating water flow in 3D urban spaces where underground and overground infrastructure coexist (Mendonça 2023).

Despite a wealth of research focusing on the importance of spatial resolution in flood modelling, few studies have systematically addressed the role of DTM bit depth, both signed and unsigned formats, in influencing flood prediction accuracy (Fereshtehpour et al. 2024). This gap is noteworthy given that bit depth directly affects the precision with which elevation data can represent subtle terrain features. In highly urbanized areas, where water flow dynamics are influenced by fine-scale elevation changes around buildings, roads, and drainage systems, a lack of attention to bit depth may lead to inaccuracies in flood models due to insufficient vertical precision in capturing subtle depressions, curbs, or below-ground infrastructure (Wang et al. 2025). Moreover, the reliance on spatial resolution alone overlooks how terrain precision, especially for representing below-surface features, can substantially alter hydrodynamic predictions (Fereshtehpour et al. 2024; Zhu and Chen 2024).

Urban flood simulations depend on an accurate representation of both above and below-ground features, which requires precise elevation modelling (Zandsalimi et al. 2024; Xu et al. 2021). Signed bit depths, with their ability to capture negative values, are critical for modelling below-surface depressions such as basements or underground drainage systems, features increasingly prevalent in densely built environments. Conversely, unsigned bit depths can better model regions with substantial elevation changes, though they may lack the precision needed for detailed flood risk assessments in flat, urbanized areas. This study seeks to bridge the gap in current modelling practices by systematically evaluating how bit depth influences flood prediction accuracy in varied urban topographies. By refining the criteria for selecting optimal Digital Terrain Models (DTMs) bit depths, this research aims to inform more resilient urban planning practices, offering actionable insights for disaster preparedness in the face of escalating climate risks.

This study contributes to the growing body of research on urban resilience by addressing the role of bit depth precision and its impact on hydrodynamic flood simulations. Previous research has focused primarily on spatial resolution, but few studies have systematically explored how the bit depth and the ability to represent negative terrain influence flood predictions. This study aims to fill this gap and contribute to both the theoretical and practical domains of flood risk management and urban resilience planning. Given the critical importance of precise flood modelling for urban resilience, this study investigates the role of raster DTM bit depth in enhancing flood prediction accuracy. Specifically, this study aims to (i) evaluate how signed and unsigned DTM bit depths affect the representation of terrain features critical for flood simulations, (ii) quantify the impact of different bit depths on flood risk predictions, focusing on water depth variance and maximum deviation in urban environments, and (iii) propose optimal DTM bit depths that balance accuracy with computational efficiency

LITERATURE REVIEW

Research on the role of DTMs in hydrodynamic flood simulations has predominantly focused on spatial resolution as the key factor influencing simulation accuracy (Guo et al. 2021). Higher spatial resolution DTMs provide greater detail in representing surface features, leading to more accurate predictions of water flow and flood risk in urban environments (Guo et al. 2021; Mozgovoy and Hnatushenko 2019). However, this focus on spatial resolution overlooks the importance of other DTM characteristics, most notably bit depth, which plays a crucial role in representing subtle elevation changes, particularly in areas with complex topography. By prioritizing resolution, prior studies may have missed critical different in terrain representation, raising questions about the adequacy of their flood predictions in high-risk urban settings.

The influence of bit depth on DTM precision, particularly in flood modelling, remains underexplored despite its potential importance. Signed bit depths, which allow for negative values, have been shown to improve the accuracy of flood predictions in regions with subsurface infrastructure, such as drainage systems. However, many studies continue to rely on unsigned DTMs, which, while providing a broader range of positive elevation values, may fail to capture below-surface features critical for accurate flood risk assessments (Wienhold et al. 2023). This lack of attention to signed versus unsigned bit depths, where signed formats allow the representation of both positive and negative elevation values, and unsigned formats only permit positive values, raises concerns about the generalizability of previous findings, particularly in urban settings where subsurface depressions or drainage systems play a critical role in flood dynamics. For instance, while Mozgovoy and Hnatushenko (2019) acknowledge the importance of terrain precision, their reliance on unsigned DTMs may have led to overestimations in regions with significant subsurface infrastructure, limiting the applicability of their conclusions to real-world flood scenarios.

Despite the acknowledged importance of terrain precision in flood modelling, the role of DTM bit depth, particularly the distinction between signed and unsigned formats, remains largely unexplored (Mozgovoy and Hnatushenko, 2019). This oversight is significant given that the ability to accurately represent both above- and below-ground features is essential for reliable flood predictions, especially in urban areas with complex infrastructure. The reliance on unsigned DTMs in prior research could lead to systemic overestimations of flood depth, which in turn may result in ineffective disaster preparedness and mitigation strategies (Guo et al. 2021). Addressing this gap is critical not only for improving the accuracy of flood models but also for enhancing urban resilience in the face of climate change. By systematically comparing signed and unsigned bit depths across multiple flood scenarios, this study aims to provide actionable insights that can inform more effective urban planning and flood risk management policies.

Building on previous studies that have emphasized spatial resolution while overlooking bit depth, this research introduces a novel approach by systematically evaluating the trade-offs between signed and unsigned DTM bit depths in urban flood modelling. By simulating flood events using DTMs of varying bit depths, this study aims to determine how each format influences water depth prediction accuracy, variance, and maximum deviation. This study not only fills the gap in current flood modelling practices but also provides new knowledge that can directly inform urban resilience strategies, particularly in areas with complex infrastructure. By offering a comprehensive evaluation of bit depth precision, our work seeks to redefine the criteria for DTM selection in hydrodynamic modelling, aligning it with the growing demands for accuracy in climate-sensitive urban planning.

METHODOLOGY

This study employs ArcGIS Pro to simulate urban flooding based on DTMs of varying signed and unsigned bit depths, integrated with LoD1 3D building models. The methodology covers four key phases: data preparation, rainfall-runoff simulation, test point testing, and quantitative analysis. Each phase is described in detail to ensure reproducibility and transparency.

DATA PREPARATION

High-resolution DTMs were acquired from LiDAR point clouds covering the urban area of Taman Sri Muda, Shah Alam Selangor chosen for their superior precision in capturing fine-scale elevation changes critical for urban flood modelling (Lu et al. 2023; Yang and Kim, 2021). Unlike satellite imagery or photogrammetry, LiDAR provides highly detailed, three-dimensional terrain data capable of representing complex urban features such as subsurface infrastructure and elevated roadways.

To examine the impact of bit depth on flood modelling accuracy, DTMs were converted into signed and unsigned formats at 8-bit, 16-bit, and 32-bit depths using ArcGIS Pro’s raster processing tools. DTMs were processed in 8-bit, 16-bit, and 32-bit formats, each in both signed and unsigned types. This allowed a systematic assessment of how varying vertical precision, especially in signed (± values) and unsigned (positive-only) configurations, influences flood simulation results under differing urban terrain conditions. Signed DTMs allow for the representation of negative values, capturing below-ground-level features. In contrast, unsigned DTMs provide a wider range of positive elevation values, particularly useful in hilly or mountainous urban areas. The 3D city models including Level of Details 1 (LoD1) 3D building models were then draped onto each version of the DEM, ensuring accurate interaction between floodwaters and urban infrastructure.

RAINFALL-RUNOFF SIMULATION

The simulations were conducted using ArcGIS Pro, leveraging its advanced raster processing capabilities to model rainfall-runoff events in urban environments. The choice of ArcGIS Pro allowed for the seamless integration of 3D city models with DTMs of varying bit depths, enabling a detailed analysis of how different terrain representations impact flood predictions. Unlike previous studies that primarily focused on spatial resolution (Fereshtehpour et al. 2024; Zhu and Chen, 2024; Zandsalimi et al. 2024), this study innovates by systematically comparing both signed and unsigned DTM formats across multiple bit depths. One challenge encountered was the computational demand of processing large LiDAR datasets at 32-bit depth, which was addressed through data optimization techniques such as tiling and multi-threaded processing. By overcoming these challenges, this study provides a more comprehensive and scalable approach to urban flood modelling.

Rainfall-runoff simulations were designed to replicate real-world flooding conditions, with a specific focus on urban environments characterized by a high percentage of impervious surfaces. The rainfall events were scheduled to match the intensity and duration of severe flooding incidents in the study area, ensuring that the model parameters (Table 1) closely align with actual flood risk scenarios. Infiltration rates were set at zero for impervious surfaces such as roads and buildings to accurately reflect the reduced drainage capacity of these regions. By controlling for these factors, the simulation allowed for a precise assessment of water accumulation and flow patterns across different DTM bit depths. Before running the simulation, visibility of all relevant data layers, such as the DTM surface and the 3D city model, was ensured to verify that all components were accurately rendered.

Once initiated, the simulation created a cache to record height values, which were sampled during the process. During the water flow simulation, iterative calculations of water movement were performed on the height map, with the cache updating progressively. Flow dynamics were assessed at different time intervals, with playback functionality used to step through and visualize the stages of water movement. Symbology was configured to appropriately reflect these dynamics. Upon completing the simulation, water depth results were exported. The number of iterations was set to 4, and the AOI was adjusted by resampling and rotation, ensuring the data was prepared in raster format for further analysis.

TABLE 1. Simulation parameters used in this study

Parameters	Input
Rain duration	60 minutes
Rainfall intensity (Rainfall depth/hour)	60 mm
Time Step Interval	15 minutes
Number of Time Steps	4
Infiltration rate (unit/hour)	Impervious Surface (0)
Maximum infiltration	Impervious Surface (0)

TEST POINT TESTING

Five test points were strategically selected to ensure a representative sample of the study area's varied topography and flood-prone regions (Figure 1(a)). A random sampling method was applied to prevent bias in the location selection; however, points were distributed across key areas of interest, including paved roads, grassland, residential zones, riverine areas and cultivated land. This approach allows for a comprehensive analysis of how different terrain features influence water depth across varying DTM bit depths. While random sampling ensures unbiased coverage, further average nearest neighbour tests were conducted (Figure 1(b)) using stratified sampling to assess whether high-risk areas exhibited disproportionately different water depth patterns. This ensured that the results were robust across both uniform and complex urban landscapes.

(a)

(b)

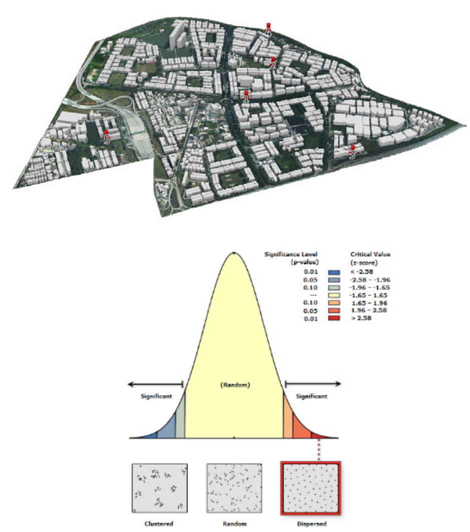

FIGURE 1. The (a) random test point location and (b) average nearest neighbour test result

QUANTITATIVE ANALYSIS

The quantitative analysis focused on three key metrics, mean water depth, variance, and maximum deviation, to evaluate the precision and reliability of flood predictions across different DTM bit depths. Mean water depth (Equation 1) provided an overall indication of flood intensity, while variance (Equation 2) allowed for the assessment of prediction consistency across the test points. Maximum deviation (Equation 3) was included to identify the extreme differences between signed and unsigned DTMs, particularly in areas with complex topography.

These metrics were selected to balance computational simplicity with the need for detailed insight into flood risk patterns.

Mean Water Depth (μ) =
= number of test points (1)
= water depth at each point

Variance (σ^2) =
= water depth at point
= mean water depth (2)
= number of test points

Maximum Deviation =
= maximum water depth recorded (3)
= minimum water depth recorded

RESULTS

RAINFALL-RUNOFF SIMULATION

The rainfall-runoff simulations for 8-bit, 16-bit, and 32-bit signed and unsigned DTMs reveal distinct differences in floodwater accumulation and flow patterns across various bit depths (Figure 2) (Guo et al. 2021). In the case of the 8-bit signed DTM, the simulation shows an underestimation of water accumulation, particularly in regions with subtle elevation changes, where the model struggles to capture detailed topographical features. Conversely, the 8-bit unsigned DTM tends to overestimate water depth, especially in areas of significant elevation variation, likely due to the broader range of positive values it can represent.

In contrast, the 16-bit signed and unsigned DTMs show a more balanced performance, with more accurate representations of water accumulation in both flat and steep terrains. These models provide improved terrain precision without the extreme deviations observed in the 8-bit models. The 32-bit signed and unsigned DTMs exhibit the highest precision in simulating water depth, particularly in urban areas with complex topographies. These differences underscore the importance of selecting the appropriate bit depth based on the specific urban terrain characteristics, balancing the need for precision with computational efficiency. Higher bit depths (16-bit and 32-bit) are advantageous for simulating flood scenarios in complex urban environments, where accurate representation of features is critical.

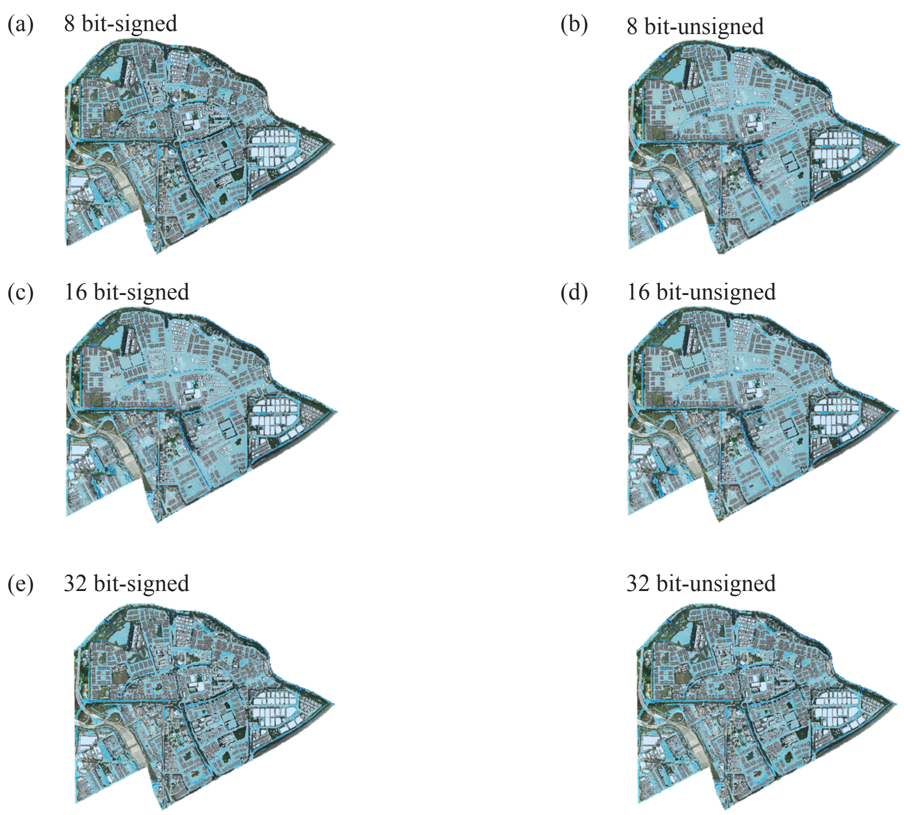

FIGURE 2. Rainfall-runoff simulation results at 60 minutes duration.

TEST POINT TESTING RESULTS

Table 2 provides a detailed breakdown of the water depth measurements across five selected test points at four different time intervals (15, 30, 45 and 60 minutes). These points, chosen for their strategic locations in both flood-prone and topographically varied areas, highlight the variability in water depth predictions across the different DTM bit depths. The position of the test point is shown in Figure 1.

For Point 1, the 8-bit unsigned DTM consistently overestimates water depth at each time interval, showing significant deviations from the signed models. At the 60-minute mark, this overestimation reaches a peak with water depths exceeding those of the signed models by a considerable margin. Conversely, the 8-bit signed DTM underestimates water depth across all intervals, failing to capture the full extent of water accumulation in this low-lying area.

TABLE 2. Water depth results

Points Location	Time Interval (Minutes)	Water Depth (meter) / Raster Bit-Depth					
		8 Bit Signed	8 Bit Unsigned	16 Bit Signed	16 Bit Unsigned	32 Bit Signed	32 Bit Unsigned
Point 1 (Paved Road)	15	0.47618	0.68812	0.90653	0.81062	0.91107	0.51463
	30	0.76211	0.74944	0.96402	0.86808	0.96348	0.78978
	45	1.02313	1.00825	1.22428	1.14614	1.22783	1.07463
	60	1.26129	1.27796	1.49349	1.39844	1.49574	1.30554
Point 2 (Grassland)	15	0.77065	0.66295	0.66902	0.60638	0.60867	0.56088
	30	1.07673	0.92748	0.94076	0.8771	0.88099	0.85809
	45	1.1338	0.96427	0.98055	0.91568	0.92029	0.91012
	60	1.24021	0.99498	1.01029	0.94504	0.94824	1.02832
Point 3 (Residential zone)	15	0.80876	1.04112	0.63827	0.76299	0.94223	0.60671
	30	1.11063	1.45515	1.03791	1.14902	1.33235	0.89757
	45	1.14888	1.70852	1.28167	1.40408	1.55791	0.99761
	60	1.59590	1.87231	1.46265	1.59444	1.74696	1.49341
Point 4 (Riverine area)	15	0.18702	0.35137	0.34661	0.35099	0.35896	0.19177
	30	0.27506	0.68481	0.67553	0.69075	0.69621	0.27794
	45	0.26962	0.97597	0.96015	0.97959	0.98216	0.27229
	60	0.26835	1.01433	1.01424	1.01396	1.01343	0.27279
Point 5 (Cultivated land)	15	0.14622	0.15756	0.15425	0.15743	0.15601	0.1523
	30	0.34518	0.38782	0.3701	0.38721	0.38179	0.34937
	45	0.52896	0.86311	0.80554	0.84556	0.8152	0.53079
	60	0.47216	1.00154	0.99954	0.99917	1.00111	0.4782

For Points 2 and 3, located in regions with complex structures (grassland and residential zone), the 32-bit signed and unsigned DTMs offer the most accurate water depth predictions, with minimal deviation between the two formats. This consistency suggests that higher bit depths are crucial for representing terrain features that influence flood behaviour, such as drainage systems. Points 4 and 5, which are located in areas with steep elevation changes (riverine area and cultivated land), exhibit similar patterns, with the 8-bit unsigned DTM overestimating water depth significantly. The 16-bit and 32-bit signed DTMs, in contrast, provide more reliable predictions across all intervals, confirming that higher bit depths are more suited for environments with pronounced topographical variation. The results from these test points reinforce the importance of bit depth precision in flood modelling, particularly in urban environments where both surface and subsurface features significantly affect flood risk.

QUANTITATIVE ANALYSIS

To generate the mean water depth values presented in Table 3, water depth outputs from the five test points (Table 2) were averaged for each DTM bit-depth configuration at every 15-minute simulation interval. The mean was computed using Equation (1), where the sum of water depths across all test points was divided by the number of points (n = 5). This procedure was repeated for each raster bit depth and time interval (15, 30, 45, and 60 minutes), ensuring a consistent basis for cross-comparison.

Table 3 shows that the 8-bit unsigned DTM consistently produced higher mean water depth values compared to its signed counterpart, indicating a clear tendency toward overestimation. This overestimation can be attributed to the unsigned format's ability to represent a broader range of positive values, which makes it sensitive to large elevation variations but insufficiently precise for representing different terrain features, particularly in flat urban areas. The 16-bit signed and unsigned models demonstrate the highest level of consistency, with minimal deviation in mean water depth values across all time intervals. This suggests that 16-bit models offer a reliable balance between precision and computational efficiency for flood simulations in urban environments. Their capacity to capture subtle elevation changes and complex topographies with high accuracy makes them particularly suitable for high-precision flood modelling, especially in densely built environments where small elevation variations can greatly influence water flow and flood risk assessments.

On the other hand, 32-bit models exhibit high vertical precision, though notable divergence remains between signed and unsigned versions. This divergence, particularly in early time intervals, indicates that while 32-bit data offers extensive range and granularity, it may introduce variability when unsigned formats fail to account for negative elevation values. Thus, despite their potential for fine-scale elevation representation, 32-bit models may not consistently outperform 16-bit models in terms of predictive stability, especially in urban environments with subtle terrain variation. This precision is essential for modelling scenarios in which critical infrastructure is at risk, underscoring the importance of selecting higher bit-depth models for reliable flood predictions in urban settings.

TABLE 3. Water depths mean

Time Interval (Minutes)	Water Depth (meter) / Raster Bit-Depth					
	8 Bit Signed	8 Bit Unsigned	16 Bit Signed	16 Bit Unsigned	32 Bit Signed	32 Bit Unsigned
15	0.477766	0.580224	0.542936	0.537682	0.595388	0.405258
30	0.713942	0.840940	0.797664	0.794432	0.850964	0.63455
45	0.820878	1.104024	1.050438	1.058210	1.100678	0.757088
60	0.967582	1.232224	1.196042	1.190210	1.241096	0.915652

Variance values in Table 4 were computed using Equation (2), where the baseline for each calculation was the mean water depth (μ) obtained from the five test points under a specific DTM bit-depth configuration at each time interval. For each time step and bit-depth category, the variance reflects the degree of dispersion around that specific configuration's own mean, providing insight into the stability of predictions across spatially distributed test points. Sample variance ($n-1$) was used due to the limited number of test points (n = 5).

For water depth variance (Table 4), the 8-bit unsigned data exhibits the highest variance, particularly during the early stages of flood simulation, reflecting substantial fluctuations and inconsistencies in water depth predictions. This variance can be attributed to the model's limited precision in capturing subtle terrain features, leading to an overestimation of water depth in areas with moderate elevation changes. The increased variability in these early intervals underscores the limitations of using unsigned 8-bit models in complex urban environments, where accuracy is crucial for real-time flood prediction and management. In contrast, the 16-bit signed data demonstrates significantly lower variance across all time intervals, indicating that signed formats provide a more stable and consistent representation of water depth. The ability to account for both positive and negative elevation values in 16-bit signed models leads to a marked reduction in variability, enhancing the accuracy of flood predictions in regions with mixed topographical features, such as those containing underground drainage systems or minor depressions. Finally, the 32-bit signed data offers the most balanced and reliable performance, with minimal variance throughout the simulation. This consistency highlights the critical role of higher bit-depth models in reducing predictive variability, especially in densely built urban environments where precision is paramount. The reduced spread in water depth estimations reinforces the importance of adopting higher bit depths to ensure reliable flood risk assessments, supporting more effective planning and mitigation strategies.

TABLE 4. Water depth variance

Time Interval (Minutes)	Water Depth (meter) / Raster Bit-Depth					
	8 Bit Signed	8 Bit Unsigned	16 Bit Signed	16 Bit Unsigned	32 Bit Signed	32 Bit Unsigned
15	0.077959	0.092386	0.069361	0.061885	0.093816	0.037266
30	0.123980	0.124562	0.060719	0.062914	0.097873	0.070349
45	0.127103	0.093711	0.031340	0.039815	0.070663	0.093668
60	0.257948	0.113756	0.053145	0.066886	0.103186	0.220629

TABLE 5. Water depth maximum deviation

Time Interval (Minutes)	Water Depth (meter) / Raster Bit-Depth					
	8 Bit Signed	8 Bit Unsigned	16 Bit Signed	16 Bit Unsigned	32 Bit Signed	32 Bit Unsigned
15	0.66254	0.88356	0.75228	0.65319	0.78622	0.45441
30	0.83557	1.06733	0.66781	0.76181	0.95056	0.61963
45	0.87926	0.84541	0.47613	0.55852	0.74271	0.80234
60	1.32755	0.87733	0.49395	0.6494	0.79872	1.22062

Maximum deviation values in Table 5 were calculated using Equation (3), where the deviation is defined as the difference between the maximum and minimum water depth values recorded across the five test points at each simulation interval for each DTM bit-depth configuration. This approach quantifies the range of water depth variation within each simulation scenario, highlighting the extremities in flood prediction across spatially diverse locations.

For maximum deviation in water depth (Table 5), the 8-bit unsigned models exhibit the highest values, further reinforcing their tendency to overestimate flood depths and produce inconsistent predictions. This significant deviation arises from the unsigned format's inability to represent different elevation details, particularly in flat or complex urban landscapes. As a result, the 8-bit unsigned models fail to accurately capture the variability in water depth, leading to exaggerated flood risk assessments that could misguide mitigation strategies. In contrast, the 16-bit signed models demonstrate much lower maximum deviation, indicating a greater capacity for capturing water depth variations with a higher degree of precision.

This stability highlights the advantage of signed formats, particularly in regions with a mix of positive and negative elevation values, such as areas with subsurface drainage systems. The 16-bit signed models' ability to minimize extreme deviations ensures that flood depth predictions remain within an acceptable range, reducing the likelihood of significant errors in high-stakes urban planning scenarios. The 32-bit signed models, however, provide the best overall performance, with minimal deviation across all test points and time intervals. This reflects their superior capability for representing subtle elevation changes and producing high-precision flood depth estimations. The consistency offered by the 32-bit signed models is crucial for urban flood modelling in densely populated areas, where even minor errors in prediction can have significant implications for infrastructure planning, resource allocation, and public safety. These results emphasize the critical role of higher bit-depth models in achieving accurate and reliable flood risk assessments.

ANALYSIS

SIGNED VS. UNSIGNED FORMATS

The comparison between signed and unsigned formats, particularly in the 8-bit models, reveals critical differences in water depth predictions. The unsigned 8-bit DTM consistently overestimates water depth, especially in areas of pronounced elevation variation. This overestimation occurs because unsigned bit-depth formats can capture a broader range of positive values, making them highly sensitive to larger water depths. In contrast, the signed bit-depth formats, capable of representing both positive and negative values, are better suited for areas with both above-ground and subsurface features, such as drainage systems.

The overestimation in the unsigned 8-bit model could have significant implications in urban flood modelling, where false predictions of flood severity can lead to misallocation of resources, unnecessary evacuations, and inflated flood risk assessments. For example, the highest deviations observed in the unsigned 8-bit model were in regions with a high concentration of impervious surfaces and steep elevation changes, which amplified the flood risk predictions. This raises concerns about the applicability of unsigned 8-bit models in real-world urban planning and flood mitigation strategies, as they may provide misleading information about the flood severity in certain regions.

In the higher bit-depth models (16-bit and 32-bit), the differences between signed and unsigned formats become less significant. Both signed and unsigned formats in these bit depths provide relatively similar flood depth predictions, suggesting that at higher resolutions, the signed/unsigned distinction has a diminished impact. This indicates that for environments requiring higher precision, such as cities with critical infrastructure, the use of 16-bit or 32-bit signed formats would be more appropriate, as they offer the accuracy needed to represent complex terrain features without the overestimation issues found in unsigned formats.

IMPACT ON 16-BIT AND 32-BIT MODELS

The convergence of signed and unsigned formats in 16-bit and 32-bit DTMs highlights the increasing precision and reliability of these higher-bit-depth models. As the bit depth increases, the ability of the models to capture subtle elevation changes improves significantly, reducing the variability in flood predictions between signed and unsigned formats. This is particularly important in urban environments where slight variations in elevation, such as minor depressions, can significantly affect water flow patterns and flood risk.

The 16-bit and 32-bit models, especially in the signed formats, exhibit minimal deviation in flood depth predictions, providing greater accuracy in regions with both surface and subsurface complexity. This precision is crucial for urban flood modelling, where inaccurate flood predictions can result in costly errors in planning and resource allocation. For instance, in areas with critical infrastructure, such as hospitals or emergency services, even slight errors in flood depth predictions can lead to ineffective flood defenses or over-preparation, both of which carry significant economic and social costs.

However, while the 32-bit signed model provides the highest number of unique values (ESRI, n.d.), given the minimal performance gain, the additional computational and storage demands of 32-bit DTMs are often unjustified. The 16-bit signed models deliver nearly equivalent accuracy while offering greater consistency. In less complex urban environments, where elevation changes are not as pronounced, the 16-bit model may offer a more practical balance between accuracy and computational efficiency. This raises an important consideration for urban planners and policymakers: when selecting DTM bit depths for flood modelling, it is essential to weigh the need for precision against the available computational resources, especially in environments where rapid flood simulations are required for disaster preparedness.

QUANTITATIVE SUMMARY

The quantitative analysis indicates that the 32-bit signed DTM consistently delivers the highest levels of accuracy and stability in water depth predictions across all test points and time intervals. With minimal variance and deviation from actual flood data, the 32-bit signed model emerges as the most reliable option for urban flood simulations. This is particularly evident in regions with complex topographies and subsurface infrastructure, where the model's ability to represent fine elevation details enables more precise flood risk assessments.

However, it is important to note the diminishing returns in accuracy beyond the 16-bit signed model. While the 32-bit signed model provides the most precise predictions, the marginal improvement over the 16-bit model suggests that for many urban scenarios, the 16-bit signed DTM may offer a more efficient solution. This finding is particularly relevant for urban planners working in environments where computational resources and storage capacity are limited. In such cases, the use of a 16-bit signed DTM could provide the necessary accuracy for flood predictions without the added costs associated with 32-bit models.

For urban areas with critical infrastructure and significant flood risk, such as coastal cities or densely populated regions, the precision of the 32-bit signed DTM may still be warranted despite the higher computational demands. In these cases, accurate flood predictions are crucial for ensuring that flood defenses are appropriately designed and that emergency response strategies are effectively implemented. Therefore, urban planners must carefully assess the trade-offs between precision and efficiency. For most applications, 16-bit signed DTMs emerge as the preferred choice due to their superior consistency and reduced deviation across test scenarios.

IMPLICATIONS FOR URBAN PLANNING AND FLOOD MITIGATION

The findings from this study have significant implications for urban planning and flood mitigation strategies, particularly in regions prone to frequent or severe flooding due to climate change. The clear advantages of higher bit-depth DTMs, especially the 16-bit and 32-bit signed formats, suggest that urban planners must prioritize the use of these models when developing flood risk assessments, designing flood defenses, or planning emergency response strategies.

For example, in densely populated urban areas with complex infrastructure, the precision offered by higher bit-depth DTMs is essential for accurately predicting flood behaviour. The use of lower bit-depth models, particularly 8-bit unsigned formats, could result in significant overestimations or underestimations of flood depth, leading to ineffective flood defenses or misallocation of resources. This study demonstrates the need for detailed, high-precision flood models that can capture the complexities of urban environments, ensuring that flood mitigation efforts are both accurate and cost-effective.

Furthermore, the results indicate that while 32-bit models offer theoretical advantages, this study finds that 16-bit signed models are more consistent and sufficiently precise for urban flood modelling, making them a more cost-effective and scalable option. Policymakers and planners must therefore consider the specific characteristics of their urban landscape, such as the presence of complex structures, the severity of elevation changes, and the frequency of flood events when deciding which DTM bit depth to use. By selecting the most appropriate model, urban planners can improve the accuracy of flood predictions while minimizing computational costs and ensuring that flood mitigation strategies are both effective and sustainable.

Ultimately, the insights from this study can inform the development of more resilient urban infrastructure, capable of withstanding the increasing flood risks associated with climate change. By optimizing the use of DTM bit depths in flood modelling, cities can better prepare for future flood events, protect critical infrastructure, and ensure the safety of their populations.

CONCLUSION

This study has demonstrated the significant impact of the Digital Terrain Model (DTM) bit depth on the accuracy and reliability of urban flood modelling. By systematically evaluating 8-bit, 16-bit, and 32-bit signed and unsigned formats, the results indicate that higher bit-depth DTMs, particularly 16-bit and 32-bit signed models, provide greater precision in simulating flood behaviour. The findings show that 8-bit unsigned DTMs consistently overestimate water depths, leading to inaccurate flood risk assessments, particularly in urban areas with complex topographies. This tendency toward overestimation presents potential challenges in urban planning, as exaggerated flood depths could lead to the over-allocation of resources or misinformed infrastructure planning.

In contrast, 16-bit signed models offer a balanced approach, with reduced variance and maximum deviation, making them suitable for urban flood modelling where both surface and subsurface features are critical. While the 32-bit signed models deliver high accuracy, the 16-bit signed models provide comparable predictions with lower deviation, making them the more reliable and practical option for most urban environments. However, the marginal improvement in accuracy compared to the 16-bit models supports the conclusion that 16-bit signed models offer an optimal trade-off between accuracy and computational efficiency.

This study contributes to the body of knowledge on urban flood resilience by emphasizing the importance of DTM bit depth in flood modelling. Policymakers and urban planners can utilize these insights to optimize flood risk assessments and disaster preparedness strategies. Future work should explore the integration of machine learning techniques for real-time DTM bit-depth selection, ensuring adaptive urban planning in response to evolving flood risks. Ultimately, the results of this research can inform more sustainable and resilient urban infrastructure, better-preparing cities for the increasing threats posed by climate change.

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DECLARATION OF COMPETING INTEREST

None.

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