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Fractal Dimension and Multiscale Analysis in Geomorphological Parameter Assessment and Hydrological Modeling

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Spatial scaling and the reconditioning of Digital Elevation Models (DEMs) are fundamental to hydrological modeling, as they directly affect the accuracy of geomorphological parameters and runoff simulation results. This study analyzes two basins, the Po River (Europe) and the Tugela River (Africa), using base DEMs with a resolution of 30 m, scaled to resolutions of 200, 500, 1000, 2500, and 5000 m. The DEMs were reconditioned using the AGREE method (both locally and globally) to evaluate variations in parameters such as flow direction, flow accumulation, slope, and hillslope and river network flow velocity. These variations were analyzed in the hydrological modeling of a precipitation event using TETIS v9.1 software, under the assumption of impermeable soil and reproducing the unit hydrograph principle. In addition, an exploratory analysis of the fractal dimension (FD) was conducted. To identify patterns in the scalar interactions of the results, primarily using the Box Counting methodology. Recognizing the notion that fractal dimension can be mathematically interpreted as regressions of data sets, FD was estimated by clustering sets of 2, 3, 4, 5, and 6 data points for each of the study scenarios, focusing on variables such as the total basin area, the area covered by the drainage network, the network length, and the drainage density.

The results indicate that the total area of the basins increases with scaling: from 28,955 km² to 31,225 km² for Tugela, and from 67,021 km² to 95,925 km² for Po. Flow direction alterations were observed at intermediate scales (1000 and 2500 m) reaching up to 60%, while the percentage of unaltered flow velocity decreased to 0% for scales between 500 and 1000 m . The slope exhibited a substantial decrease, from mean values of 1.84 and 3.16 to 0.07 and 0.11 for Tugela and Po, respectively. In the modeling, scale variations could amplify simulated peak flows by up to 10% or reduce them by up to 26%, while simulated peak times could be delayed by up to 12% or advanced by up to 20%. Regarding FD, it was observed that the variable "area covered by the drainage network" exhibited a tendency to converge at a value of 1.0 when the dataset corresponded to two fine scales. Conversely, when the dataset corresponded to two coarse scales, the results exhibited a tendency to approach a value of 2.0. Finally, the analysis indicated that clustering 6 data points minimizes uncertainty in the regressions. For instance, the mean values for the "area covered by the drainage network" converged to 1.17, while for total area, network length, and drainage density, the mean values were 1.97, 0.14, and 0.17, respectively.

In conclusion, each spatial scale requires specific adjustments to achieve precise calibration in hydrological modeling. These adjustments are essential to ensure that the results are consistent and reliable, allowing the model to accurately reflect the actual basin conditions and flow dynamics.