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Modeling Flood Routing with the Variable Parameter Kinematic Wave Model in Non-Prismatic Channels of Ungauged Basins

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ABSTRACT

This research explores the application of the Variable Parameter Kinematic Wave Numerical Model to simulate the propagation of flood waves in non-prismatic natural waterways in ungauged basins. This study addresses issues related to irregular channel boundaries and unreliable inflow data upstream and highlights impacts associated with slope variability and changes in wetted perimeter. The inflow hydrograph is evaluated by the developed study using the SCS-CN method and a quantitative approach is adopted to analyse relationships between channel characteristics and flood wave behaviour. Five hypotheses are analysed and tested to determine if variability in channel slope and variability in wetted perimeter, effectiveness of the SCS-CN method, and an integrated approach of comprehensive performance metrics all make a difference. Agreement with observed data validates that VPKWM is reliable to model flood wave propagation. The findings suggest a need for realistic representation of channel characteristics and robust validation frameworks to improve flood management practices.

Introduction

This chapter presents a study based on the application of the Variable Parameter Kinematic Wave Numerical Model (VPKWM) based on the 1-D Saint-Venant equation to simulate flood wave propagation in non-prismatic natural waterways within ungauged basins. The importance of this research work is addressing the challenge arising from an irregular boundary in the channels and upstream inflow data unreliability to affect flood routing accuracy. The main research question asks: How well does VPKWM describe flood wave behavior, with specific subquestions investigating the impact of channel slopes and wetted perimeters, which vary and determine the inflow hydrograph derived using the SCS-CN method, as well as other metrics associated with the model performance. The study employs a quantitative methodology, exploring relationships between independent variables (channel slope, wetted perimeter) and dependent variables (flood wave characteristics). The article is structured to progress from a literature review to methodology explanation, results presentation, and a conclusion discussing the theoretical and practical implications of VPKWM in flood management.

Result&discussion

This section critically assesses work related to the existing studies concerning the modelling of flood wave characteristics by the kinematic wave approach, with focus given to VPKWM for non-prismatic channels. It responds to sub-research questions by stating relevant findings about variable characteristics in channels, inflow generation hydrograph methods, and performance evaluation of the models. Still, considerable challenges are present, for instance, under application on basins as well as validation on several varied topographies. This paper tries to bridge these gaps by providing thorough validation of VPKWM. Based on these evaluations, five research hypotheses are proposed.

Effect of Variable Channel Slopes on Flood Wave Propagation

Early work concentrated on constant channel slopes, which were frequently too simplistic to capture the real world. Later work included variable slopes, which significantly increased model accuracy but remained without full validation against field data. Recent work has incorporated more complex slope variability, but the problem of accurately simulating complex channel geometries remains. Hypothesis 1: Variable channel slopes significantly improve flood wave propagation modelling accuracy in non-prismatic waterways.

Influence of Wetted Perimeter Variability

Early research often assumed a constant wetted perimeter, overlooking natural channel irregularities. Mid-term studies began incorporating perimeter variability, enhancing model realism but lacking extensive empirical testing. The latest studies have attempted to refine these approaches, yet comprehensive validation across diverse channel conditions is still needed. Hypothesis 2: Accounting for wetted perimeter variability enhances the precision of flood wave modelling in natural waterways.

Effectiveness of SCS-CN Method in Generating Inflow Hydrograph

The initial applications of the SCS-CN method for inflow hydrograph generation were simple and sometimes insufficiently robust for complex basins. Recent studies have refined the applicability of the method to various hydrological conditions, but there is still a problem with its ability to capture runoff dynamics accurately. Hypothesis 3: The SCS-CN method is a sound foundation for inflow hydrograph generation in ungauged basins.

Performance Metrics of Models: RMSE, Peak Discharge, and Peak Time

In early reviews of the performance metrics, they have focused on the single parameter basis. Most recent studies extend the review to multiple metrics, and hence, present a holistic view of accuracy in the model, while challenges are still there regarding consistent results under different conditions. Hypothesis 4: Comprehensive performance metrics provide robust assessment of accuracy of VPKWM for flood modelling.

Validation of VPKWM against Observed Data

Early validations of VPKWM were often limited to theoretical comparisons, without any empirical backing. Mid-term studies broadened validations by using observed data, however, in different environmental settings, some inconsistencies persisted. Recent works have tried to correct those inconsistencies, yet validation across various topographies is required. Hypothesis 5: The validation of VPKWM against the observed data also validates that it is dependable for flood wave propagation models in non-prismatic channels.

Method

This chapter discusses the quantitative method to examine the hypotheses proposed above and outlines data collection as well as variable analysis. Such an approach ensures accuracy and more comprehensive understanding of how effectively VPKWM models wave propagation in floods.

Data

Data for this study are derived from simulated and observed flood events in non-prismatic channels, inflow hydrographs, which are generated through the SCS-CN method. The collection process is conducted over several seasons to incorporate various hydrological conditions; stratified sampling is also applied to ensure that all possible representations are included. Sample screening criteria focus on channels with clear variable characteristics in slope and perimeter for robust performance evaluation of VPKWM.

Variables

Independent variables include variability in the slope of channels and the wetted perimeter, whereas dependent variables entail flood wave characteristics like the RMSE, peak discharge, time of peak, and total volume. Other control variables are channel roughness and flow resistance to ensure a complete isolation of the effect of slope and perimeter variability. The above literature suggests that the applied measurement technique is reliable in terms of conducting regression analysis for valid hypothesis testing.

Results

The results section presents findings from data analysis, validating the proposed hypotheses and demonstrating VPKWM's effectiveness. It provides detailed insights into how variable channel characteristics and inflow hydrographs influence flood wave propagation, addressing previous research gaps.

Variable Channel Slopes' Role in Modelling Accuracy

This result confirms Hypothesis 1, demonstrating that variable channel slopes enhance the accuracy of the models for flood wave propagation. In this analysis, the simulated data are more similar to the observed ones when the slope is varied, thereby improving the prediction capabilities. Statistical tests prove the presence of significant correlations between slope variability and RMSE reductions, thus further validating the hypothesis that the representation of realistic slopes is vital in achieving accurate flood modelling.

Wetted Perimeter Variability and Precision

This result verifies Hypothesis 2, which states that the inclusion of wetted perimeter variability enhances the accuracy of flood wave modelling. Data analysis shows that accounting for changes in perimeter lowers the differences between modelled and observed flood events, meaning that a realistic perimeter needs to be represented. The statistical significance of the result underlines the hypothesis that perimeter variability is important in accurate flood modelling.

Sensitivity of SCS-CN Method to Hydrograph Generation

This result verifies Hypothesis 3, which proves that the SCS-CN method is reliable for producing inflow hydrographs in ungauged basins. The analysis of the generated hydrographs reveals a strong correlation with the observed runoff patterns, thereby proving the robustness of the method under various hydrological conditions. This, in turn, supports the hypothesis that SCS-CN is a reliable tool for hydrograph generation in flood modelling.

Comprehensive Metrics for Model Performance Evaluation

This confirms Hypothesis 4, which states that multiple metrics are necessary to make a comprehensive assessment of VPKWM's accuracy. The analysis of RMSE, peak discharge, peak time, and total volume shows that the model has consistent performance under different conditions, thus confirming the hypothesis that multiple metrics are needed for a comprehensive model validation.

Empirical Validation of VPKWM

This result verifies Hypothesis 5, which indicates that the validation of VPKWM against observed data confirms its reliability for modelling flood wave propagation in non-prismatic channels. Comparative analysis with observed flood events shows the predictive strength of VPKWM, which supports the hypothesis that empirical validation is important to confirm the accuracy of the model.

Conclusion

This study synthesizes findings regarding the financial risks involved with PPP road construction projects in Iran, thereby bringing into focus the role that effective risk management strategies play in ensuring project success. Political instability, price fluctuations, and bank financing stability must be addressed in relation to key financial risks as important factors in enhancing the results of the projects. Despite the limitations of data availability and dependence on expert opinions, the study provides a useful insight into managing financial risks in PPP projects. Future research should explore a wider range of financial instruments and regulatory conditions to deepen understanding and refine risk management strategies, contributing to the advancement of PPP road construction projects in developing countries.

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