ABSTRACT

Rivers carrying high discharges and heavy sediment loads often experience severe bank erosion, channel shifting, and deposition, leading to reduced discharge capacity and increased flood risk. Spur dikes are widely used as a river-training structure, deliberately to modify flow, and achieve desired hydraulic and morphological conditions. However, their hydraulic performance is strongly influenced by local scour and complex flow-sediment interaction near spur dike heads. This research comprehensively examines river planform dynamics and hydraulic-morphodynamic processes across field and laboratory scales. The novelty of the research lies in combining field-based river morphological assessment, detailed experimental investigation of flow-sediment interactions around a series of spur dikes, artificial intelligence-machine learning (AI-ML) modelling of temporal and spatial scour dynamics, and the development of an empirical equation for predicting temporal scour evolution and maximum scour depth.

At the field scale, morphological changes in a 92.4 km reach of the Gandak River were analysed for the period 1989–2022 using remote sensing and GIS techniques. Riverbank erosion and accretion, channel migration, sinuosity, and braiding characteristics were quantified using river waterbody extraction based on the Modified Normalized Difference Water Index (MNDWI). At the laboratory scale, experiments were conducted in a 15 m long rectangular flume using a series of non-submerged repelling spur dikes inclined 60° upstream. The effects of constriction ratio, flow depth, and discharge on scour evolution, bed morphology, and flow characteristics were investigated. Sediment topography and scour depth were measured using laser profiling and a point-gauge, while three-dimensional velocity components were recorded using an Acoustic Doppler Velocimeter (ADV). In addition, AI–ML models were developed and evaluated for predicting temporal and spatial scour characteristics.

The field investigation revealed significant riverbank instability driven by channel shifting, braiding, and meander migration, indicating the need for effective bank protection measures. Therefore, an experimental study was carried out, and the results demonstrated that spur dikes substantially alter local flow structures and sediment transport processes, resulting in the formation of scour holes, recirculation zones, wake vortices, and downstream deposition regions. Turbulence characteristics, vortex dynamics, Reynolds shear stress, turbulent kinetic energy, and drag behavior showed progressive variations along successive spur dikes, highlighting the influence of flow interaction and energy dissipation. Scour analysis indicated

that a minimum channel width of approximately three times the spur dike length is required to minimize outer-bank effects. Among the AI–ML models examined, the XGBoost–PSO model provided the most accurate prediction of both spatial and temporal scour characteristics. Furthermore, an empirical equation was successfully developed to estimate temporal scour evolution and maximum scour depth at the spur dike head. The findings contribute to a better understanding of spur dike hydraulics and provide practical tools for the design and management of river-training structures.