MODELLING IMPACTS OF LAND USE LAND COVER AND CLIMATE CHANGES ON RUNOFF AND SEDIMENTATION IN THE UPPER JHELUM BASIN

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By

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I dedicate this dissertation to my beloved late mother

Mrs. Gulshana Banoo

CERTIFICATE

This is to certify that the thesis entitled **"Modelling Impacts of Land Use Land Cover and Climate Changes on Runoff and Sedimentation in the Upper Jhelum Basin"** being submitted by **Mr. Shahid Ul Islam** to the **Indian Institute of Technology Delhi**, for the award of the **degree of Doctor of Philosophy** is a record of the original bonafide research work carried by him under my guidance and supervision. The thesis work, in my opinion, has reached the requisite standards, fulfilling the requirement for the **Degree of Doctor of Philosophy.**

The results contained in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma.

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Shahid Ul Islam

Abstract

Changes in Land Use Land Cover (LULC) patterns and climate variability significantly impact the hydrological processes and sediment dynamics within river basins. In the Himalayan region, the Upper Jhelum Basin has experienced rapid LULC modifications due to urbanization and deforestation, highlighting the need for an integrated analysis of hydrology and sedimentation. The Indicators of Hydrologic Alteration (IHA) framework was applied in this study to evaluate flow pattern variations from 1960 to 2022. The Soil and Water Assessment Tool (SWAT) was utilized to model the impacts of LULC changes and climate variability on runoff and sediment yield. Historical and projected LULC datasets were analyzed to evaluate their influence on runoff coefficients and hydrological responses. Rainfall erosivity (R) was evaluated using outputs from six General Circulation Models (GCMs) within the (Coupled Model Intercomparison Project) CMIP6 framework under two Shared Socioeconomic Pathways: SSP245 and SSP585. GIS-based modeling techniques and the Revised Universal Soil Loss Equation (RUSLE) were employed to estimate soil erosion patterns and specific sediment yield (SSY). Spatial and temporal variations of RUSLE parameters were analyzed alongside climate projections, and the sediment delivery ratio (SDR) was calculated to evaluate sediment transport dynamics across the watershed. Additionally, SWAT modeling was used to simulate hydrological processes, providing a comprehensive assessment of runoff and sedimentation patterns under future climate and LULC scenarios. The findings indicate a significant increase in soil loss from 2020 to 2090, with peak erosion rates reaching 71.67 t/ha/yr under the SSP585 scenario. SWAT simulations demonstrate that rapid urbanization has led to increased runoff and altered hydrological flow regimes, intensifying flood risks and sediment deposition. The estimated sediment yield trends suggest a progressive increase in sedimentation, significantly affecting water resource management and reservoir storage capacity. Both mid-term (2050) and long-term (2100) projections highlight escalating erosion risks, pointing out the urgent need for sustainable watershed management strategies. This study introduces a comprehensive framework that combines climate variability, LULC transitions, and hydrological modeling to generate critical insights for managing flood risks and controlling sedimentation in the Upper Jhelum Basin. The results provide a scientific foundation for policymakers and water resource planners to develop adaptive strategies to address the effects of climate change and LULC changes on regional hydrology. This study is the first in-depth investigation focused on the Jhelum Catchment.

सार

भूमि उपयोग भूमि आवरण (एलयूएलसी) में परिवर्तन तथा जलवायु परिवर्तन नदी बेसिनों में जल-चक्र प्रक्रियाओं और तलछट गतिकी पर महत्वपूर्ण प्रभाव डालते हैं। हिमालयी क्षेत्र में स्थित अपर झेलम बेसिन में शहरीकरण और वनों की कटाई के कारण एलयूएलसी में तीव्र परिवर्तन हुआ है, जिससे जल-चक्र और अपक्षय पर एक समेकित विश्लेषण की आवश्यकता महसूस की गई। इस अध्ययन में, १९६० से २०२२ तक प्रवाह प्रतिरूप में आए परिवर्तनों का मूल्यांकन करने के लिए जल-वैज्ञानिक परिवर्तन संकेतक (आईएचए) रूपरेखा का प्रयोग किया गया। भूमि उपयोग और जलवायु परिवर्तन के प्रभावों का मॉडलिंग करने के लिए सॉइल एंड वॉटर असेसमेंट टूल (SWAT) का उपयोग किया गया।

ऐतिहासिक और भावी एलयूएलसी डेटासेट का विश्लेषण कर, रनऑफ गुणांक और जल-वैज्ञानिक प्रतिक्रियाओं पर उनके प्रभाव का अध्ययन किया गया। वर्षा अपरदनता (R) का आकलन छह सामान्य परिसंचरण मॉडलों (GCMs) के सीएमआईपी६ ढांचे के तहत दो साझा सामाजिक-आर्थिक मार्गों (SSP245 और SSP585) के परिदृश्यों में किया गया। भू-स्थानिक मॉडलिंग तकनीकों और संशोधित सार्वभौमिक मृदा अपरदन समीकरण (RUSLE) का प्रयोग कर मृदा अपरदन तथा विशिष्ट तलछट उत्पादन (SSY) का अनुमान लगाया गया। आरयूएसएलई मापदंडों के स्थानिक और कालिक भिन्नताओं का विश्लेषण जलवायु पूर्वानुमानों के साथ किया गया, और तलछट वितरण अनुपात (SDR) की गणना कर अपवाह गतिशीलता का अध्ययन किया गया।

इसके अतिरिक्त, एसडब्ल्यूएटी मॉडलिंग द्वारा जल-वैज्ञानिक प्रक्रियाओं का अनुकरण किया गया, जिससे भविष्य के जलवायु और एलयूएलसी परिदृश्यों के अंतर्गत रनऑफ और तलछट संचयन प्रतिरूपों का व्यापक आकलन किया गया। अध्ययन से पता चला कि २०२० से २०९० तक मृदा अपरदन में महत्वपूर्ण वृद्धि हुई, जिसमें SSP585 परिदृश्य के अंतर्गत अधिकतम अपरदन दर ७१.६७ टन/हेक्टेयर/वर्ष तक पहुंच गई।

एसडब्ल्यूएटी सिमुलेशन ने प्रदर्शित किया कि तीव्र शहरीकरण के कारण अपवाह में वृद्धि और जल-प्रवाह प्रतिरूपों में बदलाव हुआ है, जिससे बाढ़ के जोखिम और तलछट संचयन की घटनाओं में वृद्धि हुई है। अनुमानित तलछट उत्पादन प्रवृत्तियाँ जल संसाधन प्रबंधन और जलाशयों की भंडारण क्षमता पर प्रतिकूल प्रभाव को दर्शाती हैं।

मध्यावधि (२०५०) और दीर्घावधि (२१००) पूर्वानुमान बढ़ते मृदा अपरदन जोखिमों को रेखांकित करते हैं, जिससे स्थायी जलग्रहण क्षेत्र प्रबंधन रणनीतियों को अपनाने की तत्काल आवश्यकता सामने आती है। यह अध्ययन जलवायु परिवर्तन, भूमि उपयोग परिवर्तन और जल-वैज्ञानिक मॉडलिंग का समन्वित ढांचा प्रस्तुत करता है, जो अपर झेलम बेसिन में बाढ़ जोखिम प्रबंधन और तलछट नियंत्रण हेतु आवश्यक नीतिगत निर्णयों के लिए एक महत्वपूर्ण वैज्ञानिक आधार प्रदान करता है। यह अध्ययन झेलम बेसिन पर केंद्रित पहला गहन विश्लेषणात्मक कार्य है।

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ANN –	Artificial Neural Network
C –	Crop Factor
CMIP6 –	Coupled Model Intercomparison Project Phase 6
DEM –	Digital Elevation Model
FAO –	Food and Agriculture Organization
GBM –	Ganges-Brahmaputra-Meghna
GCM –	General Circulation Model
GEE –	Google Earth Engine
GIS –	Geographic Information System
IFC –	Irrigation and Flood Control Department
IHA –	Indicators of Hydrologic Alteration
IMD –	India Meteorological Department
IMDAA –	Indian Monsoon Data Assimilation and Analysis
INVEST –	Integrated Valuation of Ecosystem Services and Tradeoffs
K –	Soil Erodibility Factor
LULC –	Land Use Land Cover
LS –	Slope Length and Steepness Factor
MUSLE –	Modified Universal Soil Loss Equation
P –	Support Practice Factor
QGIS –	Quantum Geographic Information System
R –	Rainfall Erosivity Factor
RUSLE –	Revised Universal Soil Loss Equation
SCP –	Semi-Automatic Classification Plugin
SDR –	Sediment Delivery Ratio
SRTM –	Shuttle Radar Topography Mission
SSP –	Shared Socioeconomic Pathway
SSY –	Specific Sediment Yield
SWAT –	Soil and Water Assessment Tool
USLE –	Universal Soil Loss Equation