CC-GRMAS: A Multi-Agent Graph Neural System for Spatiotemporal Landslide Risk Assessment in High Mountain Asia

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Introduction

Landslides, driven by climate change, pose significant risks to life and economic stability, particularly in **High Mountain Asia**, where complex topography, active seismicity, and shifting precipitation patterns amplify vulnerability. More than **1.5 billion people** depend on the glaciers and rivers of the HMA, making the impacts of these hazards particularly severe

Current Challenges:

1. Weak spatial modeling and data integration
2. Fragmented disaster response mechanisms
3. Limited real-time monitoring capabilities
4. Poor coordination among stakeholders

Dataset

Table 1: Graph Database Node Type Distribution

Node Type	Count	Percentage	Description
Event	1,558	61.1%	Core landslide event records
Source	440	17.2%	Information sources and references
GazetteerPoint	331	13.0%	Geographic reference points
LandslideProfile	223	8.7%	Landslide characterization profiles
Total	**2,552**	**100.0%**	**Complete node inventory**

Table 2: Landslide Event Record Attributes

Category	Attribute	Description
Temporal	event_date	Date of landslide occurrence
	submitted_date	Record submission date
Spatial	latitude	Geographic coordinate
	longitude	Geographic coordinate
	location_description	Textual location description
	location_accuracy	Coordinate precision assessment
Impact	fatality_count	Confirmed fatalities
	injury_count	Reported injuries
Descriptive	event_title	Brief event identifier
	event_description	Detailed event narrative

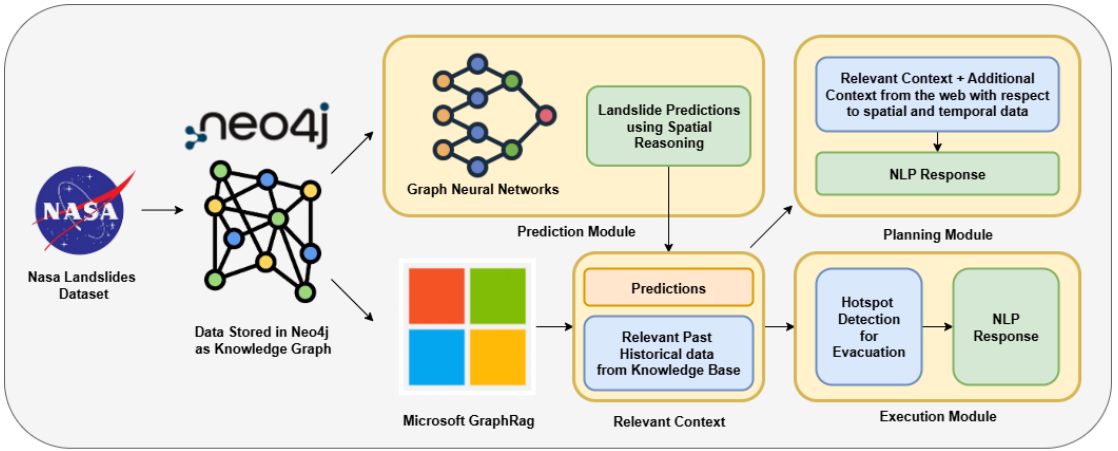
NASA Global Landslide Catalog (GLC)

Coverage: 2007-2020 | Events: 1,558 (HMA region)

Sources: News Articles, Scientific literature, Government reports

Provider: NASA Goddard/GPM mission

Methodology



Prediction Agent

Graph Neural Networks with **attention** mechanisms

Models **spatial dependencies** between landslide events

42.7K parameters - **99.9% reduction** vs traditional CNNs

Dynamic **proximity graphs** for enhanced risk modelling

Planning Agent

Large Language Models with **GraphRAG** integration

Context aware risk analysis and climate impact assessment

Vector embeddings for **semantic search** across knowledge graph

Comprehensive assessment of **temporal** and geographic patterns

Execution Agent

Automated hotspot detection via grid based spatial sampling

Coordinates predictions with **contextual** analysis

Generates **spatially** aware response recommendations

Real time intervention for vulnerable communities

Results

Table 3: Performance comparison of baseline models and U-Net for landslide forecasting.

Approach	Method	F1-Score	Precision	Recall	Params (M)
Nepal Study [26]	RF	0.56	0.47	**0.70**	< 0.1
Nepal Study [26]	XGB	0.54	0.45	0.67	< 0.1
Nepal Study [26]	GB	0.56	0.49	0.65	< 0.1
Nepal Study [26]	U-Net	**0.79**	**0.91**	0.69	31.0
CC-GRMAS (Ours)	**Spatial GNN**	**0.7981**	**0.8062**	**0.7928**	**<0.1**

Table 4: Semantic Coherence Metric Components for GraphRAG Evaluation

Component	Score	Description
Overall Semantic Coherence	0.751	Composite metric measuring retrieval quality and answer relevance averaged across all HMA countries
Average Similarity	0.814	Mean cosine similarity between retrieved nodes and ground truth across all retrieved results
Weighted Similarity	0.821	Position weighted similarity emphasizing higher ranked retrieval results
Maximum Similarity	0.840	Best single node match indicating peak retrieval accuracy
Minimum Similarity	0.797	Weakest node match showing lower bound of retrieval quality
Diversity Score	0.143	Measure of information variety across retrieved nodes balancing relevance with coverage

Key Advantages:

1. Faster training and inference
2. Lower memory requirements
3. Scalable to larger geographic regions
4. Interpretable spatial relationships
5. Suitable for resource constrained deployment in HMA

Summary and Outlook

Scan Here for the code

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CC-GRMAS provides an efficient, interpretable, and scalable multi-agent framework for climate resilient disaster preparedness in vulnerable mountain regions.