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:

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

Dataset

Table 1: Graph Database Node Type Distribution

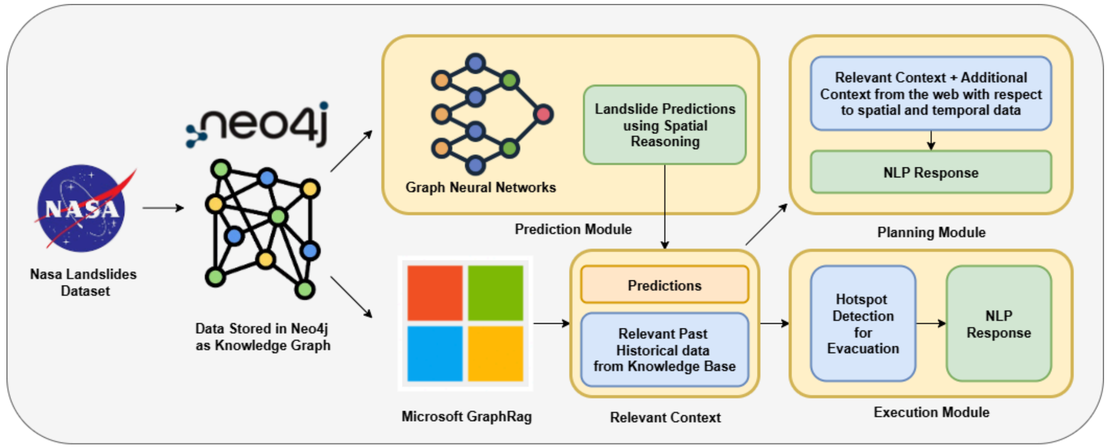
Node Type	Count	Percentage	Description
Event	1,558	61.1%	Core landslide event records
Source	440	17.2%	Information sources and references
GazetteerPoint	331	13.0%	Geographic reference points
LandslideProfile	223	8.7%	Landslide characterization profiles
Total	**2,552**	**100.0%**	**Complete node inventory**

NASA Global Landslide Catalog (GLC)
Coverage: 2007-2020 | Events: 1,558 (HMA region)
Sources: News: News Articles, Scientific literature, Government reports
Provider: NASA Goddard/GPM mission

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

Methodology



Prediction Agent

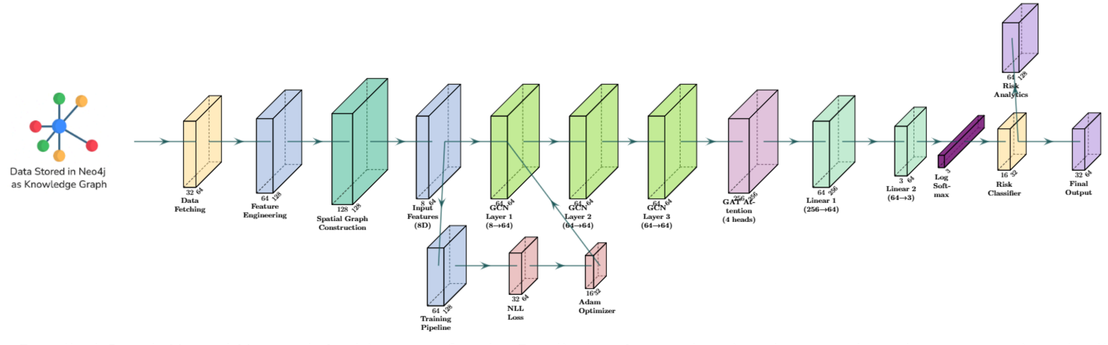
- Graph Neural Networks with **attention** mechanisms
- Models **spatial dependencies** between landslide events
- 42.7K parameters - **99.9% reduction** vs traditional CNNs
- Dynamic **proximity graphs** for enhanced risk modelling

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



Detailed Graph Neural Network Architecture for the Prediction Agent showing the complete data processing pipeline from raw landslide data through feature engineering, spatial graph construction, GCN and GAT layers, to final risk classification output.

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**

Key Advantages:

- Faster training and inference
- Lower memory requirements
- Scalable to larger geographic regions
- Interpretable spatial relationships
- Suitable for resource constrained deployment in HMA

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 of nodes
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

Summary and Outlook

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

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