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Red Relief Image Maps to Visualize Landslide Risks in Master-Planned Storage-Type Hydropower Projects in Nepal Using a Free and Open-Source GIS Approach

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Abstract: The development of storage-type hydropower projects is crucial for enhancing energy security and managing water resources in Nepal. However, these projects often face significant challenges related to terrain stability, particularly in landslide-prone regions of the Nepal Himalayas. This study presents an innovative approach to terrain visualization using Red Relief Image Maps (RRIM) generated through free and open-source GIS tools. This article presents RRIM visualization techniques developed entirely with free and open-source GIS tools, such as QGIS and Topographic Openness. The selection criteria for these techniques prioritize simplicity and speed of implementation while ensuring their suitability for effective visualization. The study focuses on the application of these techniques to Nationwide Master Planned Storage-type Hydropower Projects in Nepal. By generating and analyzing several RRIM, the article demonstrates how these tools can aid in visualizing terrain features and identifying potential risks associated with deep-seated landslides distribution. The RRIM has been prepared for all 20-master planned storage-type hydropower, diversion and multipurpose projects of Nepal. Additionally, the integration of 3D map visualization of the RRIM enhances the understanding of the terrain's topography and landform. The findings highlight the effectiveness of RRIM and open-source GIS tools in enhancing geohazard assessment and planning for sustainable infrastructure development in future.

Keywords: ***ALOS PALSAR, Deep-seated Landslides, Landslide Risks, Open-Source GIS Tools, QGIS, Red Relief Map, RRIM, Remote Sensing, Storage-type Hydropower, Topographic Openness, 3D Terrain Visualization***

Introduction

Government of Nepal intends to develop the hydropower potential of Nepal in an economically efficient and sustainable manner to meet the growing power demand in the country. In the line with the hydropower development policy Government of Nepal intends to carryout Feasibility Studies and Environmental studies of hydropower projects under Hydropower Project Study Program utilizing Nepal Government's resources. In this regards, Government of Nepal (GoN), Department of Electricity Development (DoED) conducting the Feasibility and Environmental Impact Assessment (EIA) Study of different storage-type hydropower projects. These projects are listed in the Nationwide Master Plan Study on Storage-Type Hydropower Projects conducted by the Nepal Electricity Authority in 2014. This master plan provides a strategic framework for developing storage-type hydropower projects across Nepal.

Landslides, particularly in deep-seated landslide areas, frequently damage infrastructure, leading to major economic losses and public suffering every year in Nepal (Bhandary et al. 2011). In the Himalayan region, where many of these projects are planned, it presents unique challenges due to its complex terrain and susceptibility to natural hazards such as landslides. Traditional methods of terrain analysis may not fully address these challenges, necessitating advanced visualization techniques to improve understanding and risk assessment. Large-scale landslide inventory mapping in the Lesser Himalaya has demonstrated that the spatial distribution of landslides is strongly influenced by terrain morphology, geological structures, and slope conditions, underscoring the effectiveness of GIS-based methodologies for comprehensive hazard assessment (Timilsina et al. 2017).

This article introduces an innovative approach to terrain visualization using Red Relief Image Maps (RRIM), generated with free and open-source GIS tools such as QGIS and Topographic Openness. These tools are chosen for their simplicity, speed of implementation, and effectiveness in providing detailed visualizations. By applying these techniques to master-planned storage-type hydropower projects in Nepal, this study demonstrates how RRIM can enhance the 3D visualization of terrain features and identify potential risks, especially related to deep-seated landslides distribution in the reservoir area.

Most of the small-scale landslides are found to occur on the large-scale landslide or deep-seated landslide topography (Dahal, 2015). Identifying such risks is crucial for ensuring the stability of the reservoir and surrounding infrastructure. Deep-seated landslides can trigger waves or reservoir tsunamis, leading to damage or even failure of dam structures. They can also contribute to excessive sedimentation, reducing water storage capacity and increasing maintenance costs. Additionally, landslides may affect access roads, tunnels, and other key infrastructure, posing risks to long-term operations. These hazards can also lead to the displacement of communities and have significant ecological impacts. Early identification of these risks allows for proactive mitigation strategies, ensuring cost-effective and safe project execution.

This study focuses on 20-master plan storage-type hydropower, diversion and multipurpose projects across Nepal, analyzing their terrain characteristics and associated risks. The findings of this study aim to support the GoN's efforts in developing sustainable infrastructure in the challenging mountainous terrain, improving the planning and risk management of future storage- type hydropower projects.

The Government of Nepal has prioritized the sustainable and economically viable development of its hydropower potential to meet the country's increasing energy demands. In alignment with national hydropower development policies, the Department of Electricity Development (DoED) is conducting feasibility studies and Environmental Impact Assessments (EIA) for various storage-type hydropower projects identified in the Nationwide Master Plan Study on Storage-Type Hydroelectric Projects prepared by the Nepal Electricity Authority (NEA and JICA, 2014). These projects are predominantly located in the Himalayan region, characterized by complex terrain and a high susceptibility to geohazards, particularly landslides.

Landslides, especially deep-seated ones, have caused significant damage to infrastructure in Nepal, resulting in economic losses and public safety concerns (Bhandary et al. 2011 and Dahal 2015). Moreover, small-scale landslides often occur within broader zones of deep-seated instability (Dahal, 2015), increasing the risk to hydropower infrastructure. This study introduces an advanced terrain visualization method using Red Relief Image Maps (RRIM), generated through open-source GIS platforms such as QGIS and Topographic Openness. Applied to 20 master plan storage-type and multipurpose hydropower projects, this approach enhances the identification of potential landslide-prone zones. The findings aim to improve planning and hazard mitigation strategies, thereby supporting the safe and sustainable development of hydropower infrastructure in Nepal's mountainous regions.

Study area

The study area includes 20 storage-type hydropower, diversion and multipurpose projects as shown in Table 1, identified in the Nationwide Master Plan Nationwide Master Plan Study on Storage-Type Hydropower Projects conducted by the Nepal Electricity Authority (NEA) and some of them being under Feasibility Study & Environmental Impact Assessment (EIA) Study are conducting by the Department of Electricity Development (DoED), Department of Water Resources & Irrigation (DWRI). Figure 1 shows the geographic distribution of these projects across Nepal.

Table 1, List of Master planned Storage-type Hydropower, Diversion and Multipurpose Projects of Nepal

S.N.	Project Name	Geographic Location	Geo-tectonic Location	Administrative location		FSL (masl)	Reservoir area (km^2)
				Province	District		
1	Budhigandaki Hydropower Project	Central Nepal	Lesser Himalaya	Gandaki and Bagmati	Gorkha and Dhading	540	63
2	Bharbung Storage Hydropower Project	Western Nepal	Higher Himalaya	Karnali	Dolpa	3350	8.20
3	Dudh Koshi Storage Hydropower Project	Eastern Nepal	Lesser Himalaya	Koshi	Khotang, Okhaldhunga and Solukhumbu	640	20.01
4	Kaligandaki Storage Hydropower Project	Western Nepal	Lesser Himalaya	Gandaki and Lumbini	Parbat, Baglung and Gulmi	750	21.06
5	Kaligandaki-2 Storage Hydropower Project	Western Nepal	Lesser Himalaya	Gandaki and Lumbini	Syanja, Palpa, Nawalparasi (East) and Tanahu	370	92.12
6	Kankai Multipurpose Project	Eastern Nepal	Siwaliks	Koshi	Ilam and Jhapa	200	48.88
7	Khimti Those Siwalaya Storage Hydropower Project	Eastern Nepal	Lesser Himalaya	Bagmati	Dolakha and Ramechhap	1885	9.00
8	Kokhajor Storage Hydropower Project	Central Nepal	Siwaliks	Bagmati	Sindhuli and Kabhrepalanchok	460	6.17
9	Kulekhani Hydropower Project	Central Nepal	Lesser Himalaya	Bagmati	Makawanpur	1530	2.2
10	Lower Badigad Storage Hydropower Project	Western Nepal	Lesser Himalaya	Lumbini	Gulmi	700	17.53
11	Madi Siti Storage Hydropower Project	Western Nepal	Lesser Himalaya	Gandaki	Kaski and Lamjung	640	8.74
12	Manahari Multipurpose Project	Western Nepal	Lesser Himalaya	Bagmati	Makawanpur	540	5.95
13	Mugu Karnali Hydropower Project	Far Western Nepal	Lesser Himalaya	Karnali and Sudurpaschim	Bajura, Mugu and Humla	1350	40.66
14	Nalgad Storage Hydropower Project	Western Nepal	Lesser Himalaya	Karnali	Jajarkot	1580	7.66
15	Naumure Storage Hydropower Project	Western Nepal	Siwaliks	Lumbini	Argakhanchi and Pyuthan	524	19.73
16	SR-6 Storage Hydropower Project	Far Western Nepal	Lesser Himalaya	Sudurpaschim	Doti and Achham	603	50.80
17	Sun Koshi 3 Storage Hydropower Project	Eastern Nepal	Lesser Himalaya	Bagmati	Kabhrepalanchok, Sindhupalchok and Ramechhap	700	53.38
18	Sunkoshi Marin Diversion Multipurpose Project	Central Nepal	Lesser Himalaya	Bagmati	Sindhuli and Ramechhap	476	3.44
19	Tamor Storage Hydropower Project	Eastern Nepal	Lesser Himalaya	Koshi	Panchthar, Terhathum and Taplejung	550	39.02
20	Tanahu Hydropower Project (Upper Seti)	Western Nepal	Lesser Himalaya	Gandaki	Tanahu	417	8.27

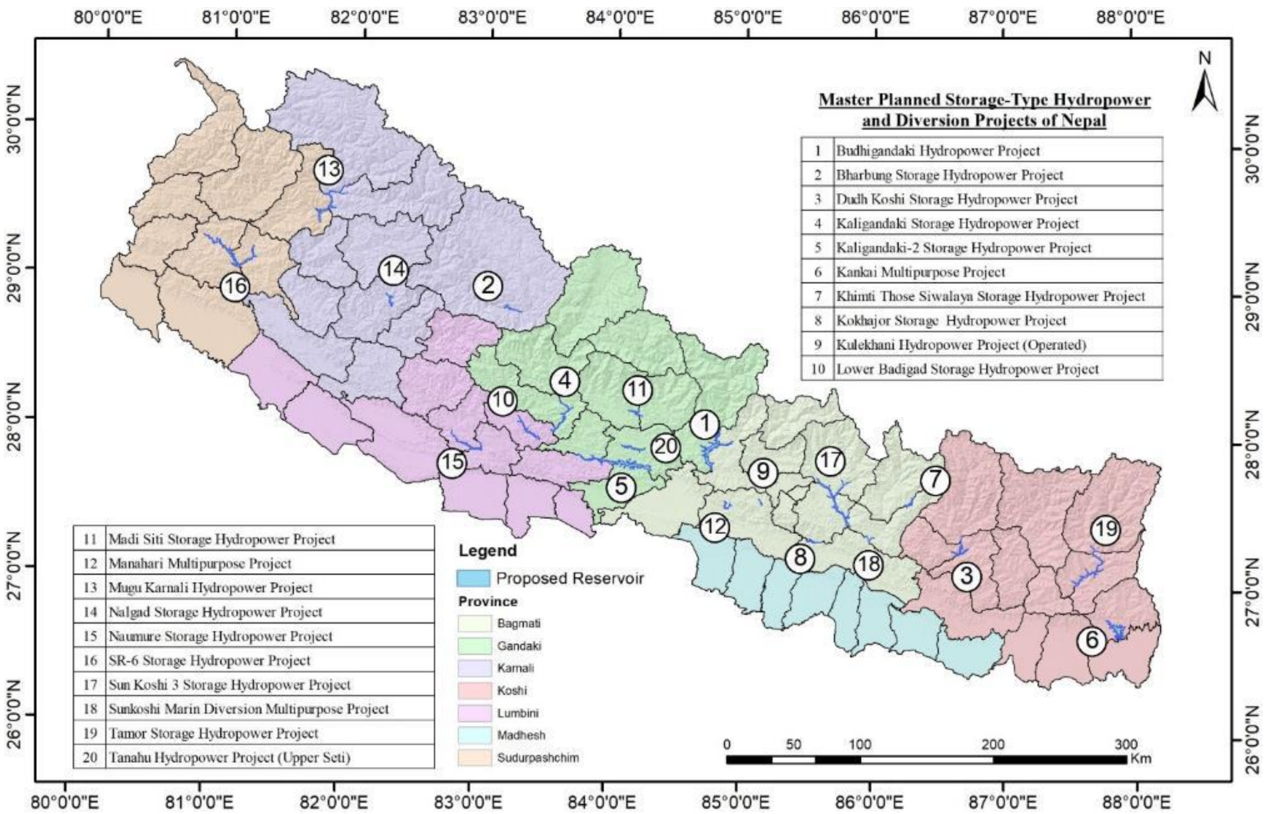

Figure 1, Location map of the 20-master planned storage-type projects of Nepal.

Methodology

The main concept of RRIM from DEMs is based on Topographic Slope and Topographic Openness i.e., Positive Openness (Op), Negative Openness (On). Positive and negative openness were defined by Yokoyama et al. (2002). Positive openness represents convexity of the surface and Negative openness represents surface concavity of the surface. Positive openness represents higher values such as ridges, peaks and crests while negative openness takes higher value such as valley, gully, pit, landslides and inside of craters. Figure 2 is a conceptual diagram of positive and negative openness. The Op and On are shown schematically for values less than 90 degrees. L is radial limit of calculation for chosen points (P1 and P2) on a DEM. Chiba et al. (2008) calculated a new parameter called differential openness from Op and On like below,

Differential Openness = (Positive Openness - Negative Openness)/2

$$\text{i.e., } I = \frac{(Op-On)}{2} \qquad -(1)$$

Where, Op is positive openness and On is negative openness. The Op and On are shown schematically for values less than 90 degrees. I is a ridge and valley index. In RRIM, index is expressed by gray-scale image layer and topographic slope is red color layer.

According to Chiba et al. (2008), that red color has the richest tone for human eyes, especially under computer-oriented color spaces. RRIM effectively represents large-scale land features as well as fine structure at the same time in a wide variety of topographic situations. This dual representation is invaluable for understanding terrain characteristics and identifying potential instability risks. Figure 3 is a sample color diagram of RRIM method. Topographic slope is shown as Chroma value of red (y axis) and (Op-On)/2 is shown as brightness (x axis). As a result, the top of ridges is shown as white, bottom of valleys is shown as black, steep slopes are shown as bright red and flat surfaces are shown as gray in RRIM.

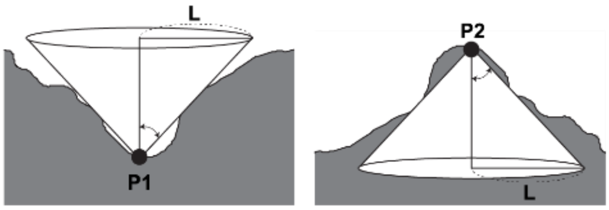

Figure 2, Conceptual diagram of positive openness and negative openness.

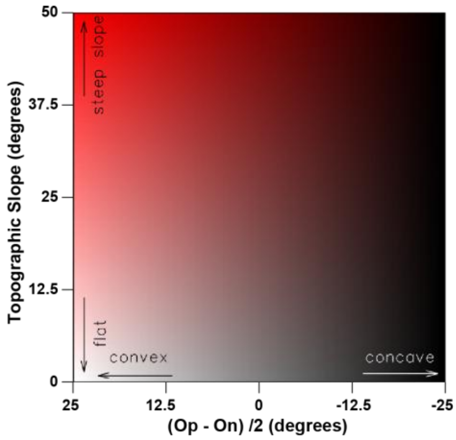

Figure 3, Color diagram of RRIM (example).

Preparation RRIM by using Digital Elevation Model (DEM)

All the raster maps are readily determined in the QGIS tool based on the DEM retrieved and analyzed by using the model as shown in Figure 4 for RRIM.

Data Acquisition and Processing in QGIS

The primary data source in this study is the ALOS PALSAR Digital Elevation Model (DEM) with a resolution of 12.5 x 12.5 meters and obtained from Alaska (2024).

The open-source software QGIS can be downloaded from its home page (https://www.qgis.org/). This powerful Geographic Information System (GIS) tool allows users to visualize, analyze, and manage spatial data effectively. Additionally, we provide a step-by-step tutorial for the preparation of a Red Relief Image Map (RRIM) in Appendix-I. This supplementary guide covers each step of the procedure, from data import to visualization, enabling you to create effective terrain analyses.

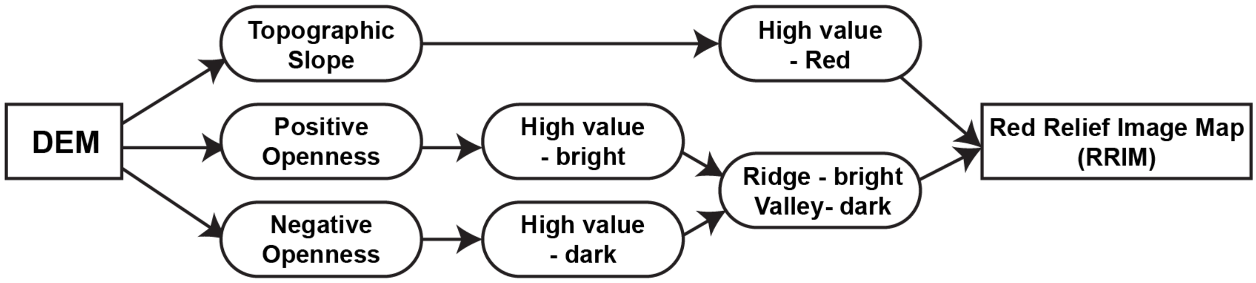

Figure 4, Model of preparation the Red Relief Image Map by using DEM.

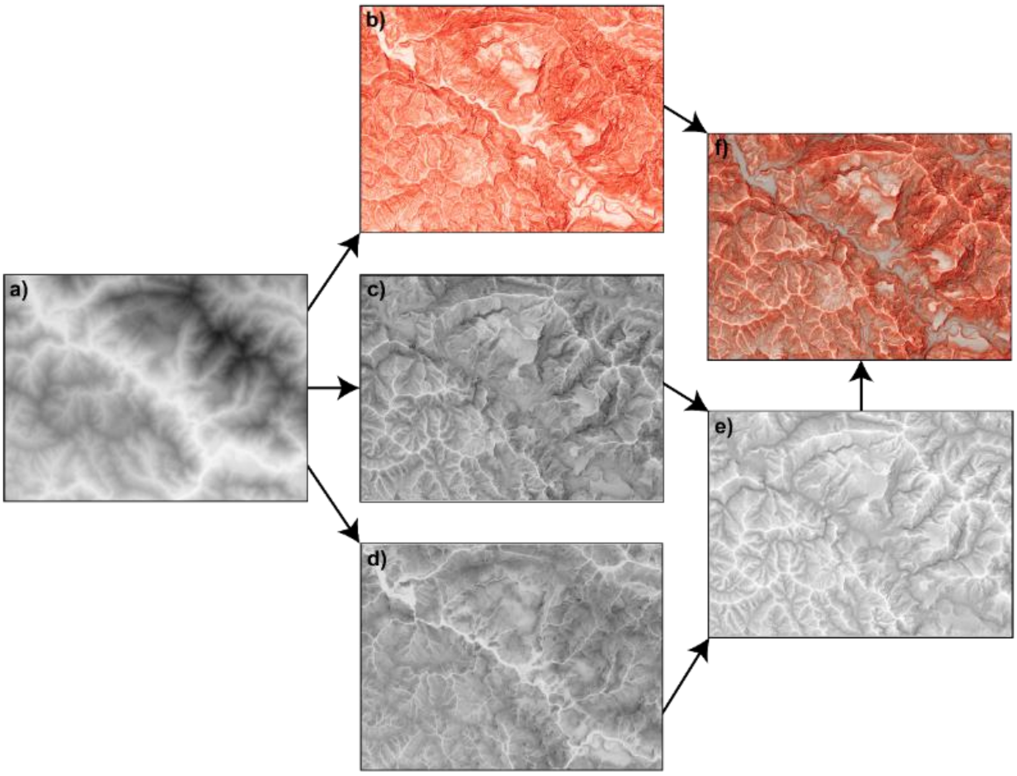

Figure 5, Flow of preparation RRIM. a) DEM, b) Slope, c) Positive Openness, d) Negative Openness, e) Differential Openness, and e) Final Red Relief Image Map.

Results and Discussion

The RRIM has been prepared for all 20-master plan storage-type hydropower, diversion and multipurpose projects of Nepal as shown in Figure 6. The resulting RRIM successfully enhanced the identification of deep-seated landslides distribution at the study area and proved to be an effective tool for illustrating the complexity of the terrain and highlighting areas susceptible to deep-seated landslides. The distinct red color of the slope layer, combined with the grayscale representation of openness, facilitates a clear visualization of critical terrain features. In contrast, the normal hill shade technique, while beneficial for providing an overview of the topography, falls short in emphasizing the underlying landslide hazards. This technique tends to obscure important details related to the concavity and convexity of the terrain, which are crucial for assessing landslide hazard risks.

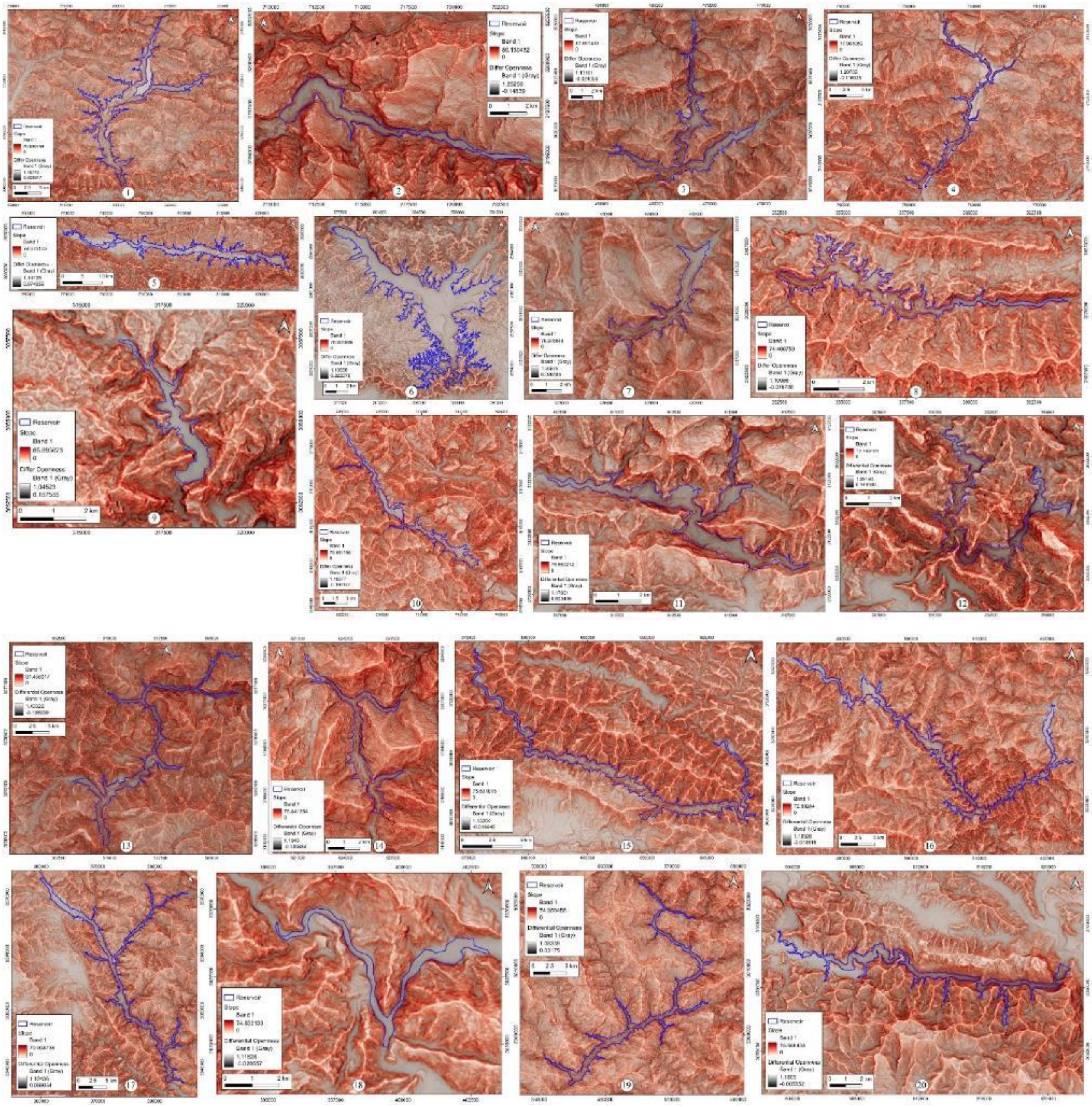

Figure 6, RRIM map of all 20-master plan storage-type projects.

Case study: Lower Badigad Storage Hydropower Project

This case study focuses on the geomorphic features and terrain analysis conducted for the Lower Badigad Storage Hydropower Project, located in a highly landslide-prone area, which presents significant relevance for this study, specifically emphasizing the identification and visualization of deep-seated landslides using both the RRIM and normal hill shade techniques. Various geological and geomorphological evidence has been found to trace the Badi Gad Fault in the region (Timalsina and Paudyal 2018). However, there have been very few studies on the fault's existence and its extent. Figure 7, RRIM map showing marked both old and recent landslides in the Lower Badigad Storage Hydropower Project area.

Comparison of Visualization Techniques

The primary objective of this study was to visualize terrain morphology in a way that traditional hill shade or satellite imagery may not reveal. Figure 8 presents a comparative analysis and field verification of a landslide event within the study area. Figure 8a displays the landslide as captured by Sentinel-2 (Copernicus, 2024) imagery using a false-color combination, which enhances vegetation and soil contrast, making the landslide scar more distinguishable from the surrounding terrain. The landslide-affected area appears as a distinct light-toned zone, indicating the exposed soil and debris. Figure 8b provides a field photograph taken during the site visit, confirming the presence and characteristics of the landslide observed in the satellite imagery. Visible features such as slope failure, exposed bedrock, and displaced materials validate the remote sensing interpretation. Figure 8c includes the Google Earth image of the same location, offering a visual context with high-resolution optical imagery for cross-verification of landslide extent and surrounding features. This multi-source comparison enhances the reliability of landslide identification and supports the integration of remote sensing and field-based approaches in RRIM mapping and validation. Figure 9a illustrates the RRIM, with landslides clearly marked, highlighting the spatial distribution of these hazards in relation to the proposed dam site and the reservoir area. The enhanced visibility of risk zones in the RRIM allows for more informed decision-making during the planning and risk management phases of project development. Conversely, Figure 9b presents the normal hill shade for comparative analysis. While it provides a general overview of the landform, it lacks the detailed depiction of deep-seated landslide distribution, which is also not apparent in the Google Earth imagery shown in Figure 10b.

Additionally, the integration of 3D map visualization of the RRIM enhances the understanding of the terrain's topography and the spatial relationships between various landform features. The 3D representation provides an immersive perspective, allowing stakeholders to visualize the landscape more intuitively. Figure 11 demonstrates the 3D RRIM visualization, which can significantly aid in identifying critical areas for potential landslide occurrences and assessing their impacts on storage type hydropower project planning.

Importantly, while Yokoyama et al. (2002) and Chiba et al. (2008) have previously developed RRIM techniques in Japan, the present study represents the first application of these methodologies in the mountainous terrain of Nepal. The resulting maps not only provide effective visualization of terrain features and geomorphological aspects but also contribute to a deeper understanding of landslide dynamics in this challenging region. This study is grounded in a completely free and open-source GIS approach, promoting accessibility and sustainability in geospatial analysis.

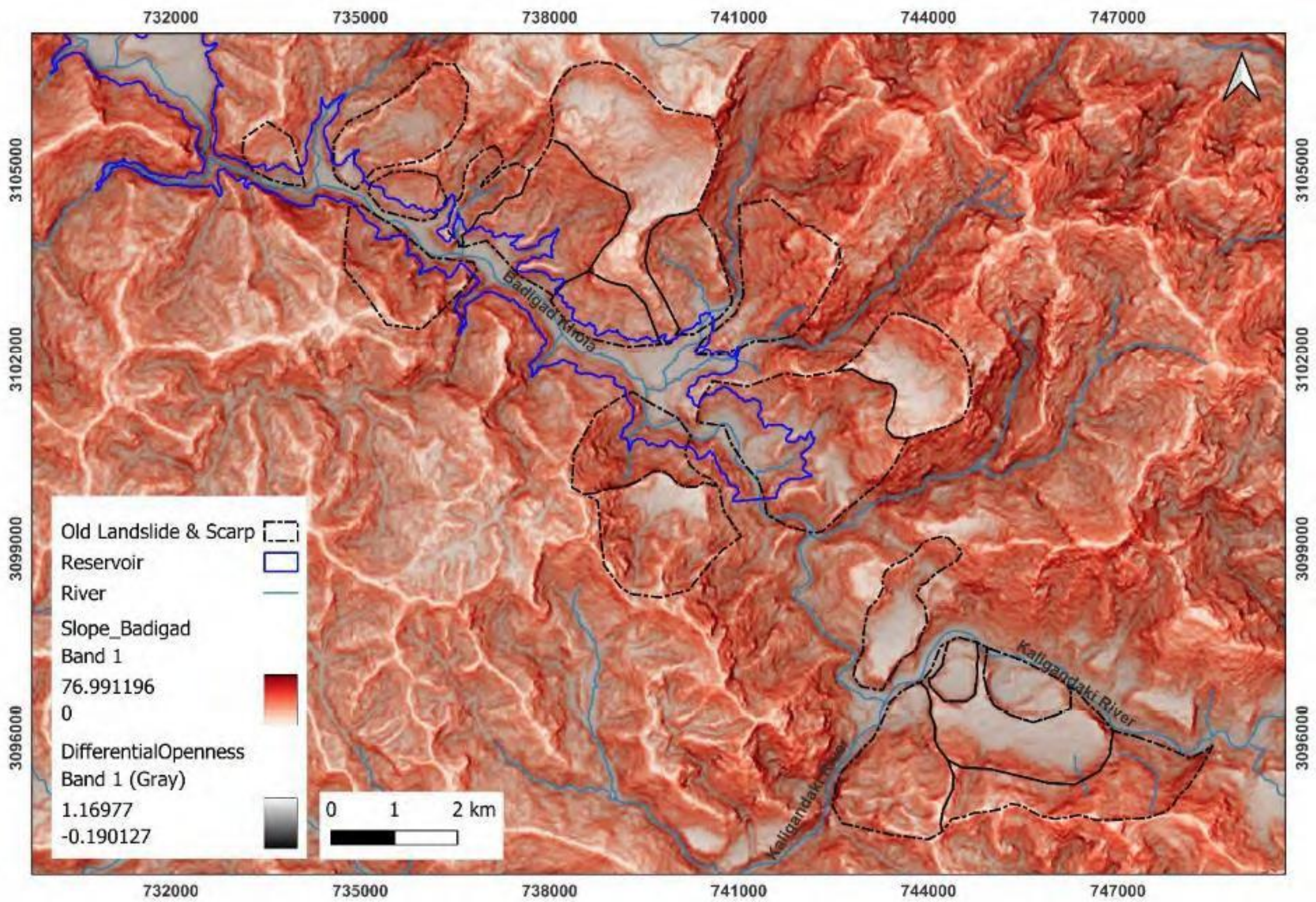

Figure 7, RRIM map showing marked deep-seated landslides within the Lower Badigad Storage Hydropower project area.

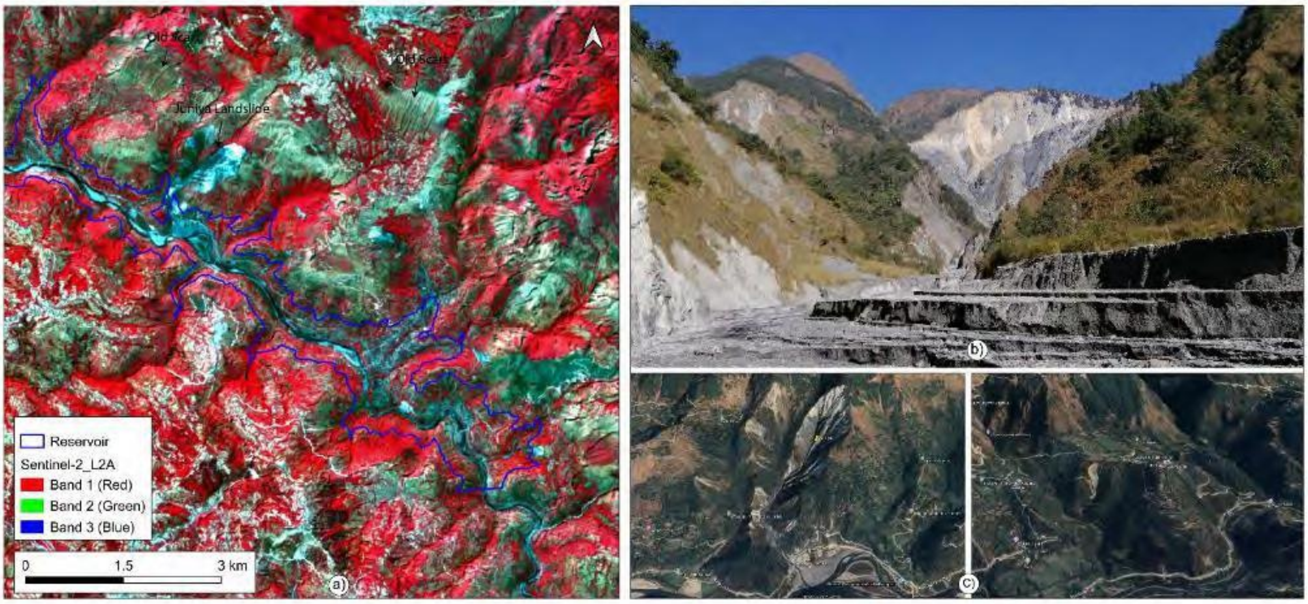

Figure 8, Comparisons and field verifications: a) Landslide as captured by Sentinel-2 imagery in false color combination, b) corresponding field photograph, and c) imagery from Google Earth.

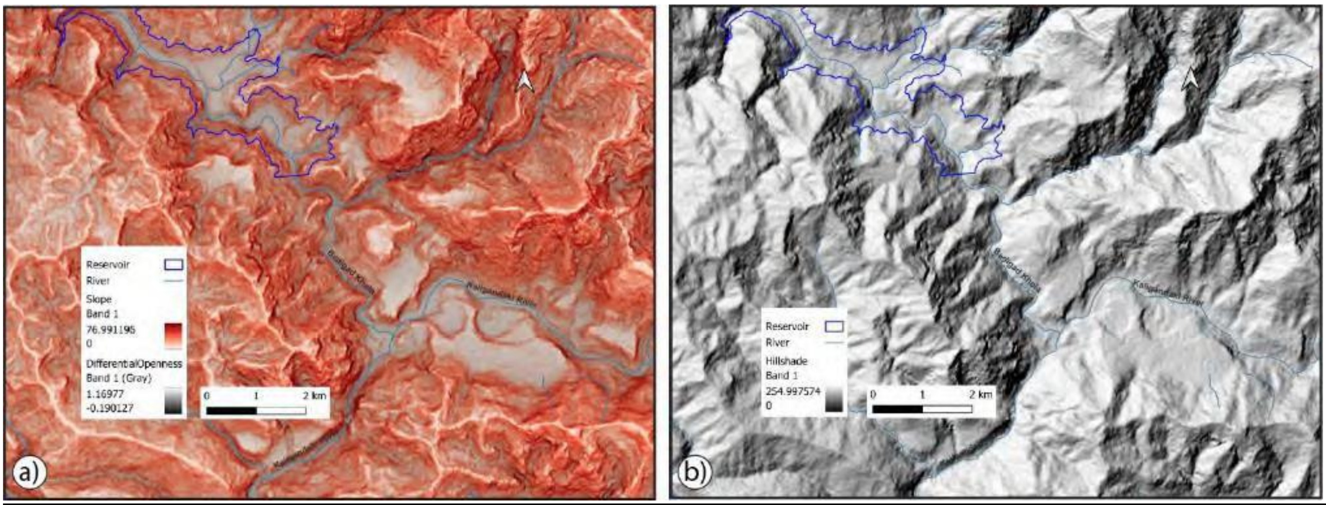

Figure 9, Comparisons between RRIM and normal Hill shade, a) RRIM and b) Hill shade.

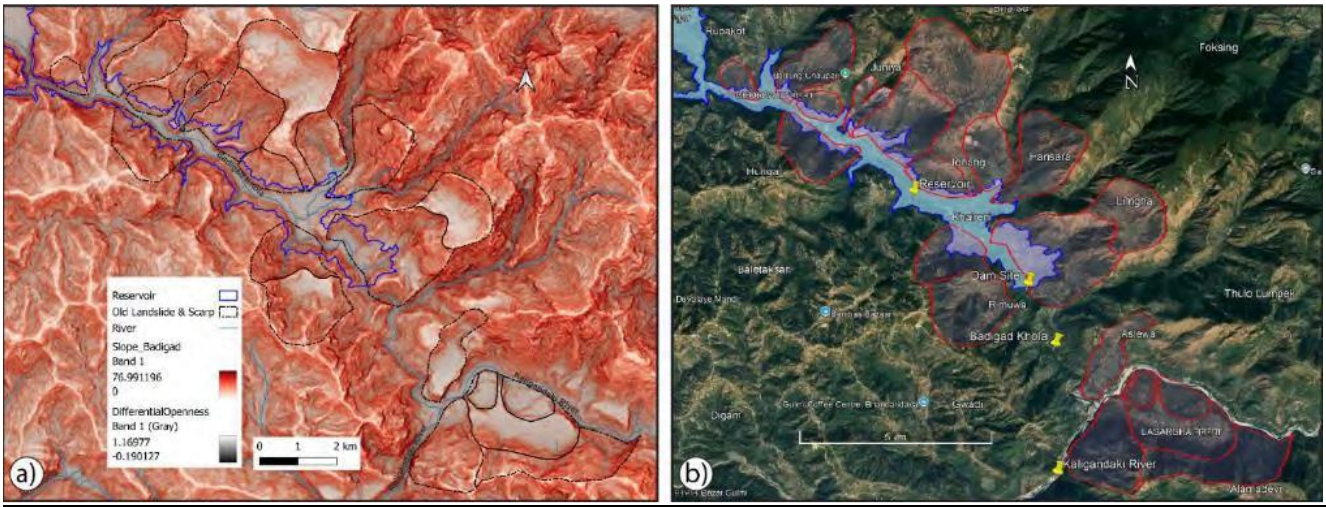

Figure 10, Comparisons between RRIM and Google Earth imagery, a) RRIM, and b) Google Map.

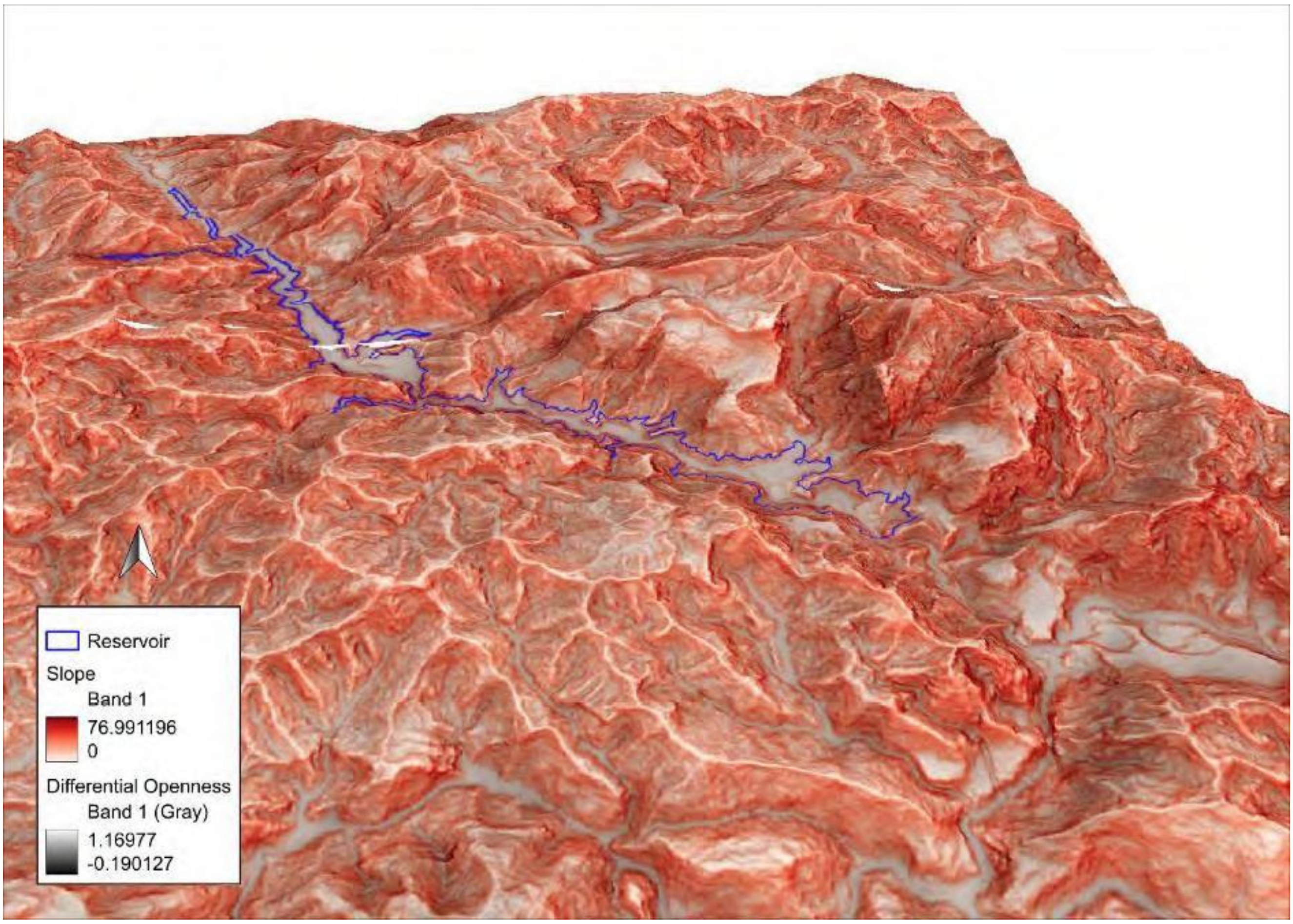

Figure 11, 3D Red Relief Image Map (3D RRIM) Visualization.

Implications for Risk Assessment in storage type Hydropower Projects

The findings from this analysis underscore the importance of utilizing advanced visualization techniques, such as 3D RRIM, in the planning and development of storage type hydropower projects situated in landslide-prone areas. By providing clearer insight into potential landslide risks, these tools can assist stakeholders in making more informed decisions concerning site selection, design modifications, and mitigation strategies. Integrating RRIM and 3D visualizations into feasibility studies and environmental assessments is vital for ensuring the safety and sustainability of hydropower infrastructures, particularly in challenging terrains like the Himalayan region.

Challenges and Limitations

A key limitation in this study is the resolution of 12.5 m x12.5 m pixels DEM data used for the preparation of RRIM. Although this dataset was the most accessible, it is recognized that using higher-resolution data, such as LiDAR or airborne surveys, would yield significantly better results, especially in complex mountainous regions and provide more reliable risk assessments.

Figure 12 illustrates an RRIM generated from high-resolution LiDAR survey data, showcasing its effectiveness in detailed topographic representation. The RRIM technique enhances subtle terrain features by combining slope and openness, allowing for clearer visualization of surface morphology, including landslide scars, ridge lines, drainage patterns, and fault traces. The use of LiDAR data significantly improves the accuracy of elevation models, especially in densely vegetated or rugged terrain, making RRIM a valuable tool for geomorphological analysis and landslide susceptibility assessment. This example demonstrates the superior capability of LiDAR-derived RRIM in detecting micro-topographic variations that are often missed in conventional DEM-based visualizations.

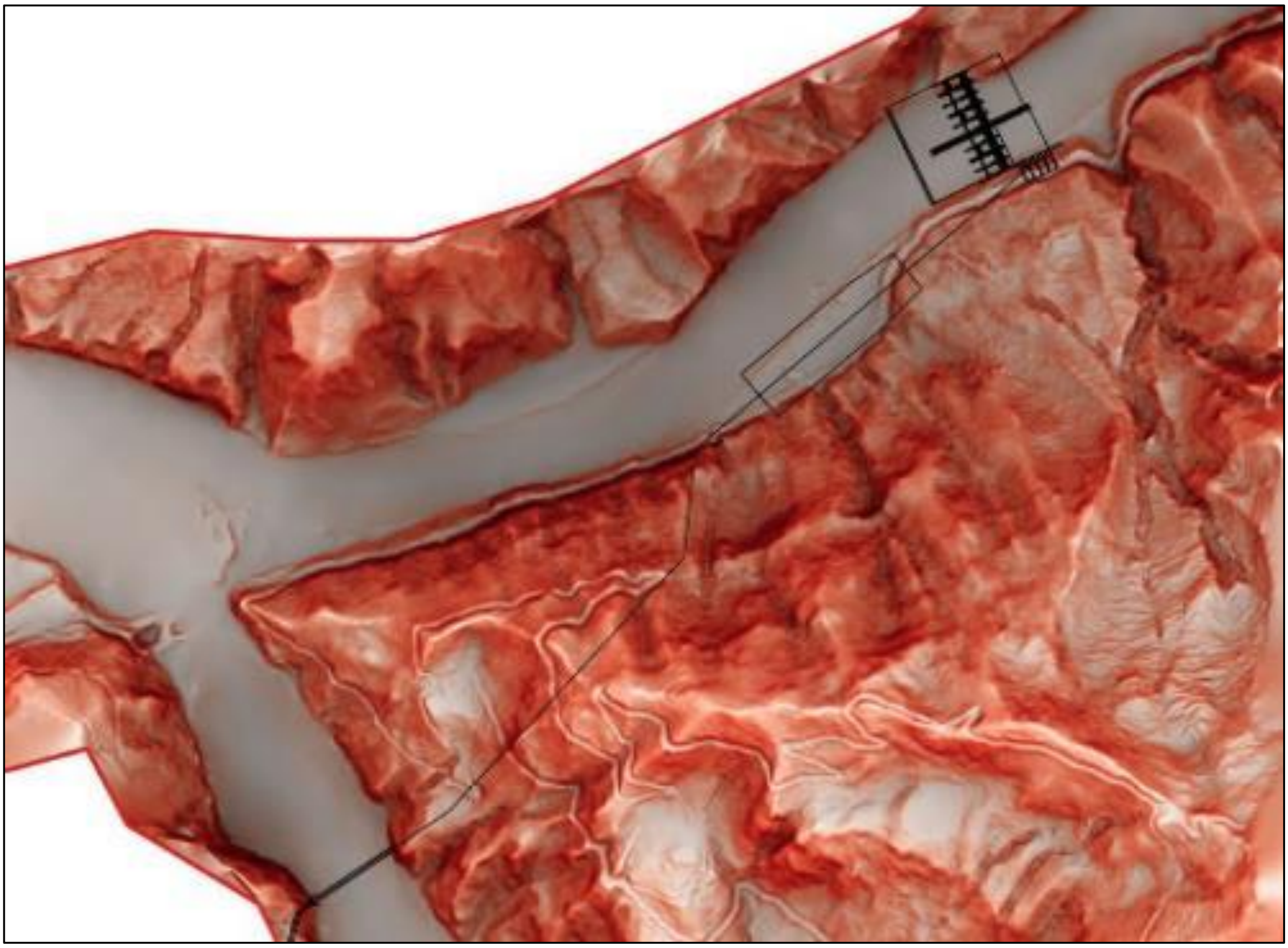

Figure 12, Example of a RRIM generated from LiDAR survey data.

Conclusions and Future Works

In conclusion, the RRIM has been prepared for all 20-master planned storage-type hydropower, diversion and multipurpose projects of Nepal. This study demonstrates the advantages of employing RRIM for terrain analysis in landslides prone area. Illustrating the complexity of the terrain and highlighting areas susceptible to deep-seated landslides. The addition of 3D visualization techniques further enriches the analysis, offering a more comprehensive understanding of the terrain. Future research should prioritize incorporating additional datasets, such as geological and hydrological information, along with reservoir slope stability and modeling approaches, to enhance the understanding of landslide dynamics and advance risk assessment methodologies. To further refine this technique, it is recommended that future projects incorporate higher-resolution DEM data, such as LiDAR or airborne surveys, to enhance the accuracy of the RRIM. Furthermore, the identification of deep-seated landslides should be verified through InSAR analysis or other suitable remote sensing techniques. This should be combined with field surveys to validate the results and ensure that critical terrain features are accurately captured. Moreover, expanding the use of this approach across the broader hydropower sector, particularly in evaluating reservoir slope stability, addressing potential slope failures during impoundment or rapid drawdown, and supporting mitigation planning, will contribute significantly to improved project design, safety and risk management.

Supplementary Data

Appendix -I: A step-by-step tutorial for the preparation Red Relief Image Map (RRIM) using QGIS. Attached with the paper.

Appendix -II: Full format Red Relief Image Map of all 20 Master Plan Storage-Type Hydropower, Diversion and Multipurpose Projects of Nepal. Attached with the paper.

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Data Availability Statement: All data sources utilized in this study are publicly available and have been clearly described within the article. No proprietary or restricted datasets were used.

The data supporting the findings of this study are available within the article and its supplementary materials.

Conflicts of Interest: The authors declare no conflict of interest.

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Supplementary Data

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Red Relief Image Maps to Visualize Landslide Risks in Master-Planned Storage-Type Hydropower Projects in Nepal Using a Free and Open-Source GIS Approach

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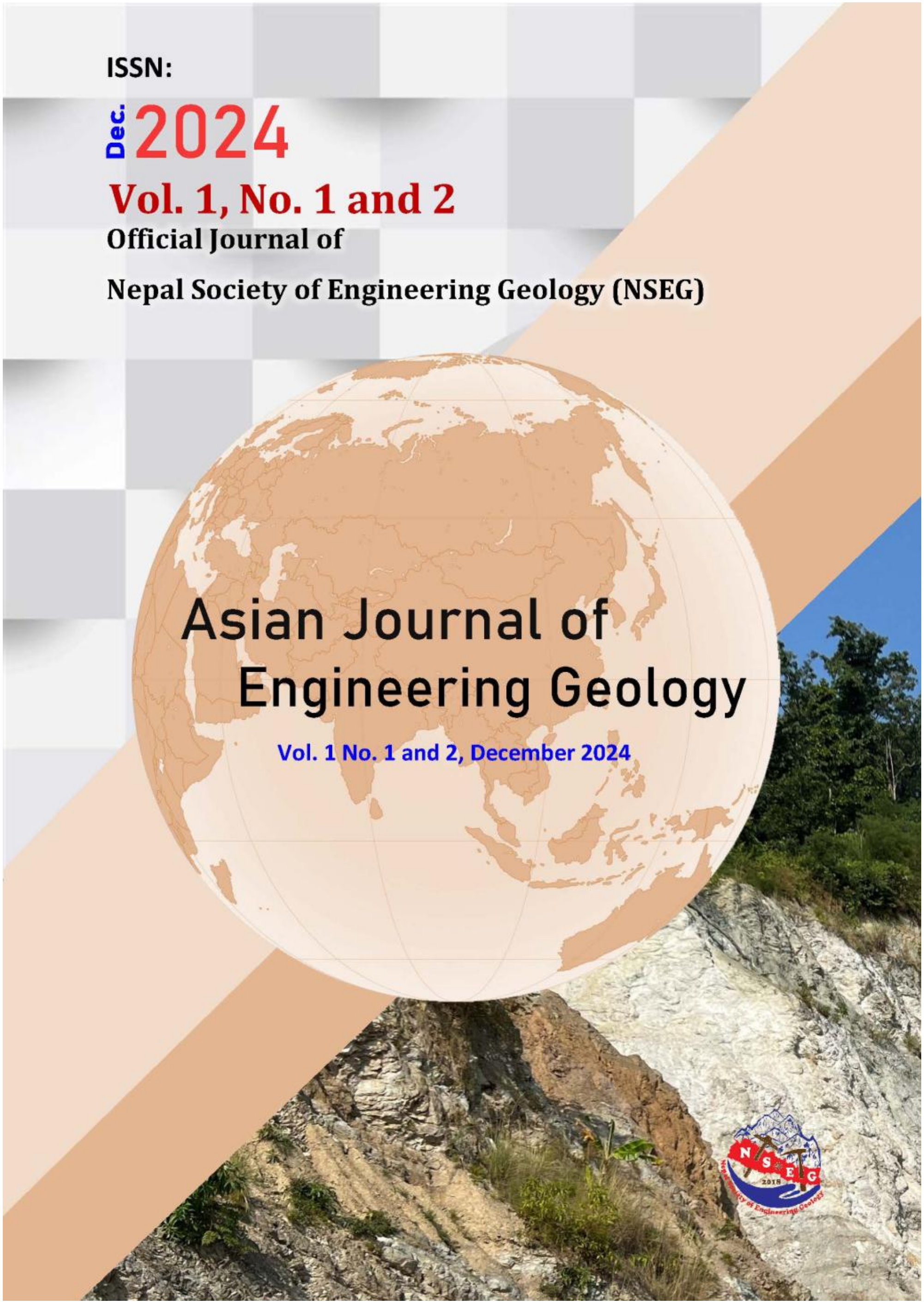
Appendix - 1: A step-by-step tutorial for the preparation Red Relief Image Map (RRIM) using QGIS.

Appendix - 2: Full format Red Relief Image Map of all 20 Master Plan Storage-Type Hydropower, Diversion and Multipurpose Projects of Nepal



Appendix – 1

A step-by-step tutorial for the preparation Red Relief Image Map (RRIM) using QGIS.

Step 1: Add the DEM

First, we must add the DEM, either by dragging and dropping the raster file from its folder into the map window, or by clicking Layer - Add Layer - Add Raster Layer (Figure Sup 13).

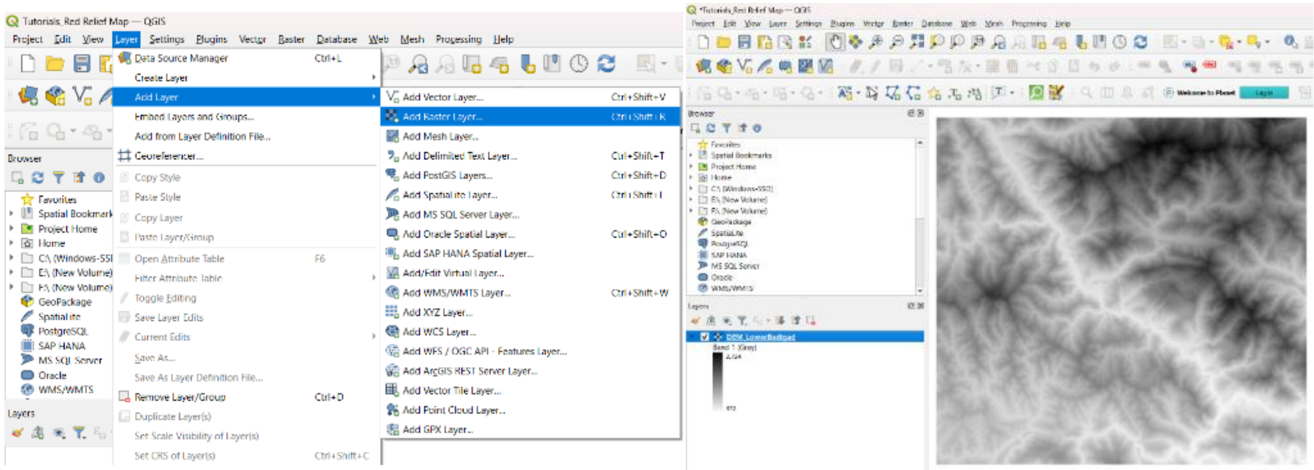


Figure Sup 13, Add Raster Layer.

Step 2: Calculating the Slope angle

For the calculation of slope angle, Search for the 'Slope' in the Processing Toolbox and click on it. Then 'Slope' window opens.

- Select required DEM as the elevation layer and click run (Figure Sup 14).

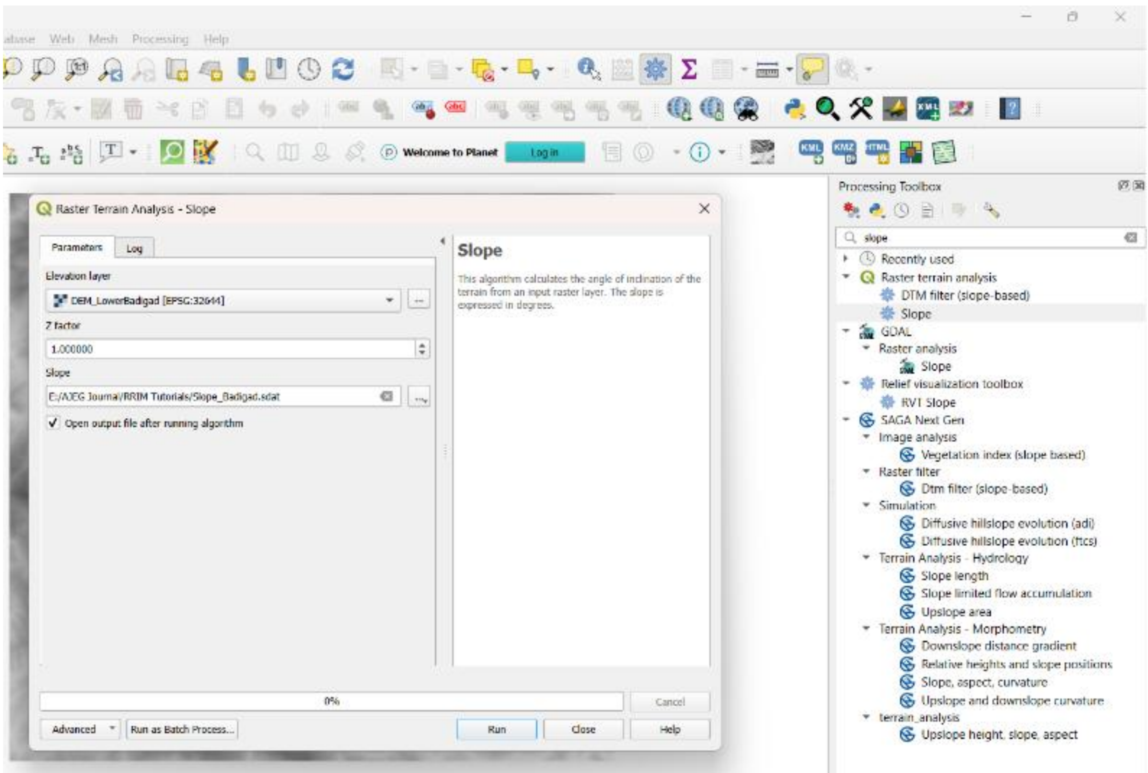


Figure Sup 14, Calculating the Slope angle.

- Changing the rendered colors of Slope map
- Click on Symbology in layer properties of slope map (Figure Sup 15).
- Render type – Single band gray to Single band pseudocolor
- Change the color ramp to 'Reds'
- Layer rendering – Blending mode – 'Multiply' – Click apply.

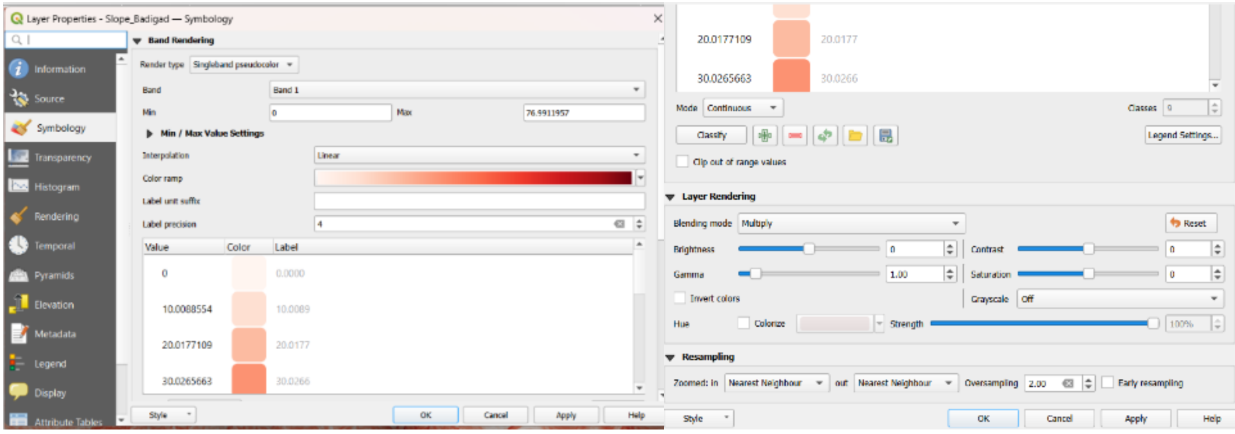


Figure Sup 15, Symbology and layer rendering of Slope map.

The slope map looks like to Figure Sup 16.

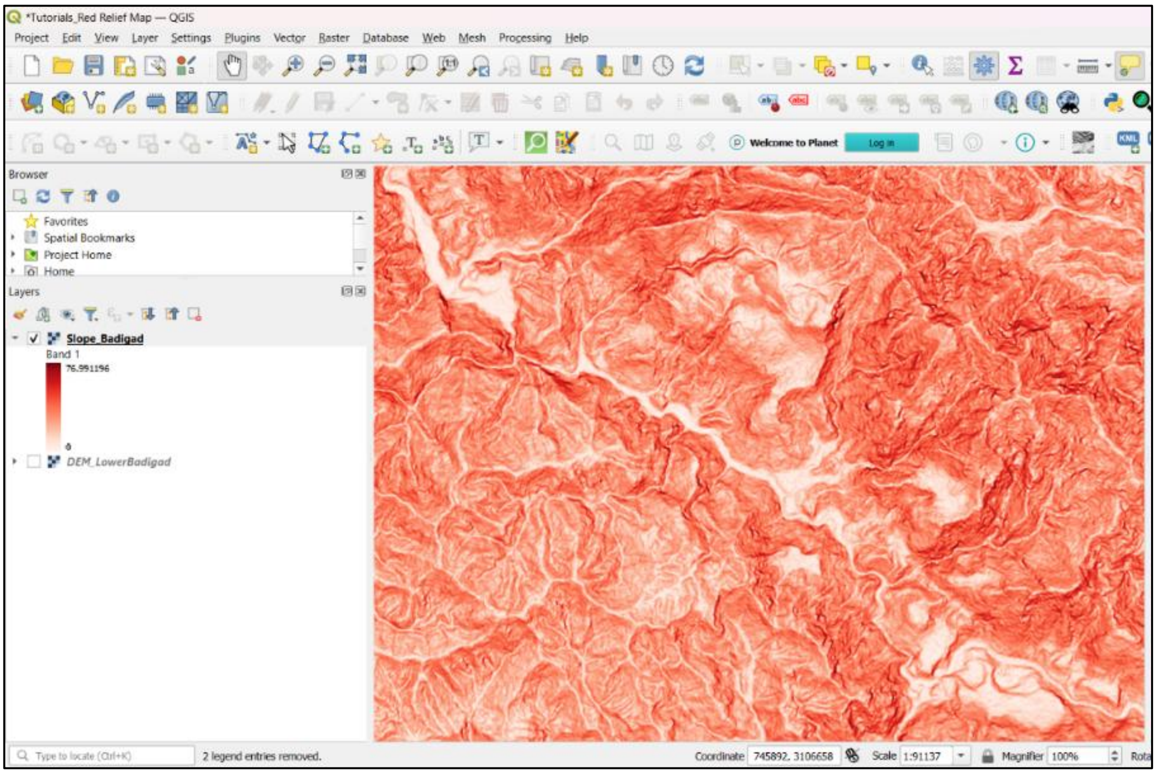


Figure Sup 16, Slope map.

Step 3: Generating positive and negative openness maps

First of all, make sure that the SAGA –'System for Automated Geoscientific Analyses' plugin installed or not, if not, firstly download and install all the necessary modules as well as SAGA GIS and all its calculating algorithms as required computer operating system. If you are using latest versions of QGIS, you have to download SAGA GIS separately from official website of SAGA GIS (https://saga-gis.sourceforge.io/en/index.html)

For generate the positive openness and negative openness map, in the processing toolbox, search for 'Openness' and click on "Topographic Openness" or Go to SAGA next gen-Terrain analysis lighting-Topographic openness (Figure Sup 17).

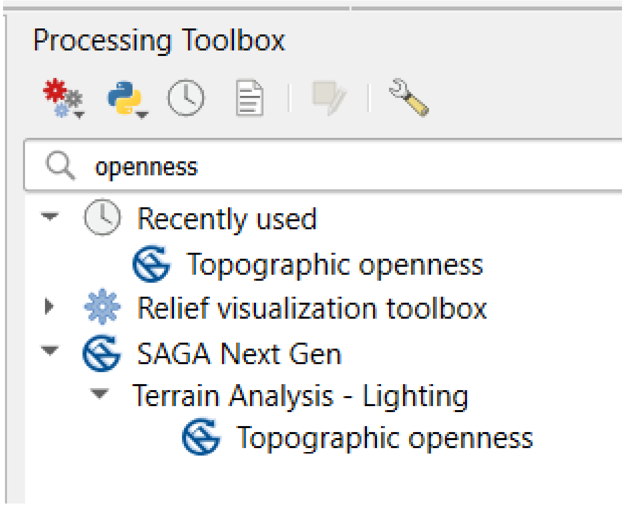


Figure Sup 17, Processing Toolbox for Topographic openness.

This will open the Topographic openness module window, where you can choose certain parameters (Figure Sup 18, Figure Sup 19 and Figure Sup 20).

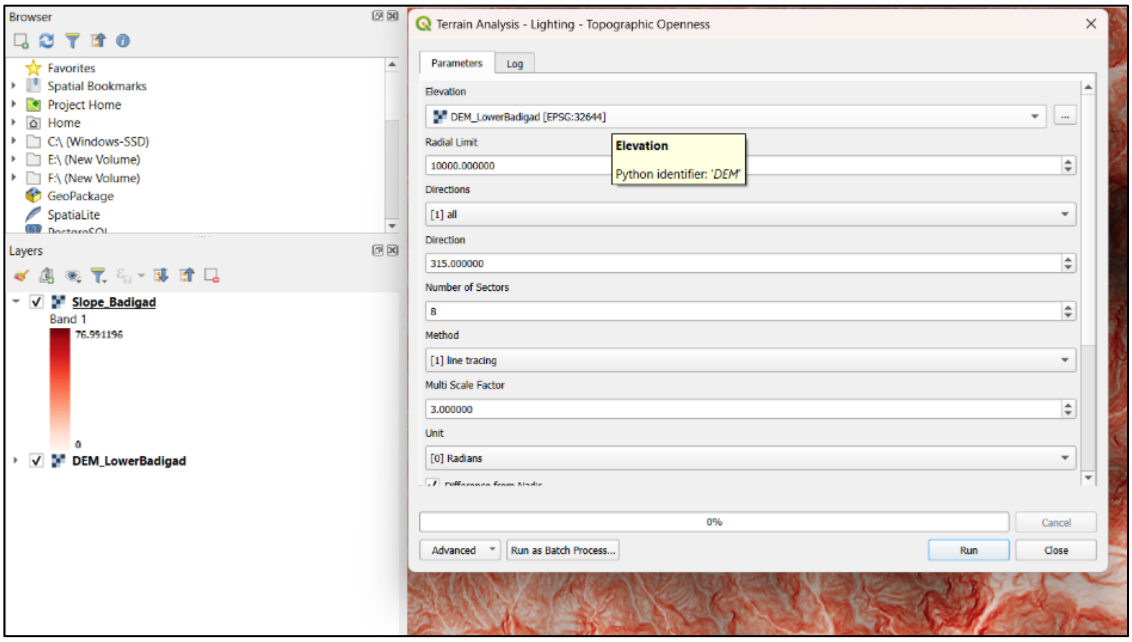


Figure Sup 18, Topographic openness module window.

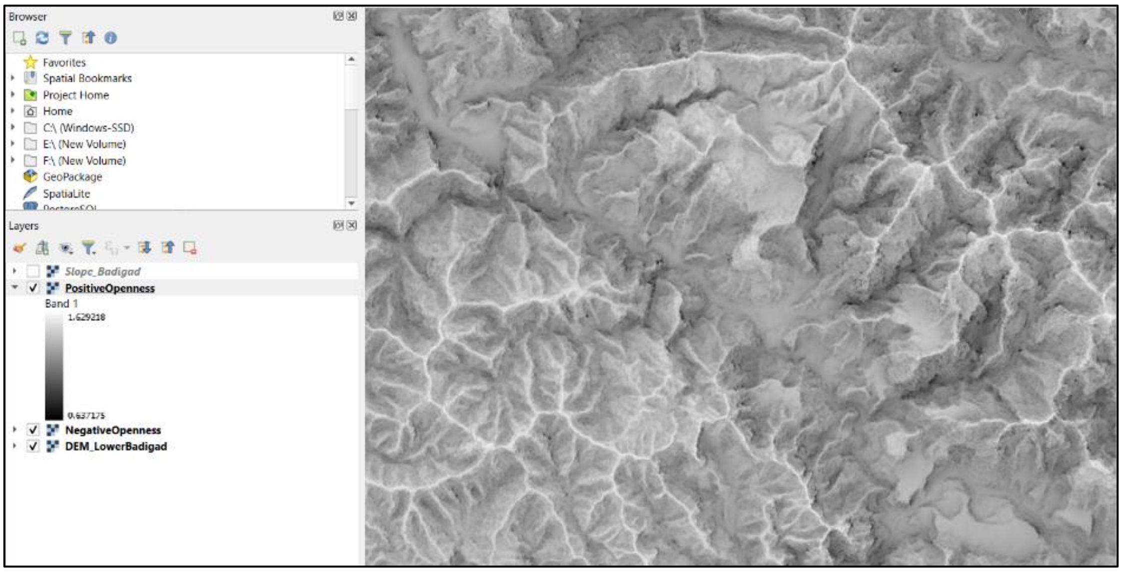


Figure Sup 19, Positive openness raster map.

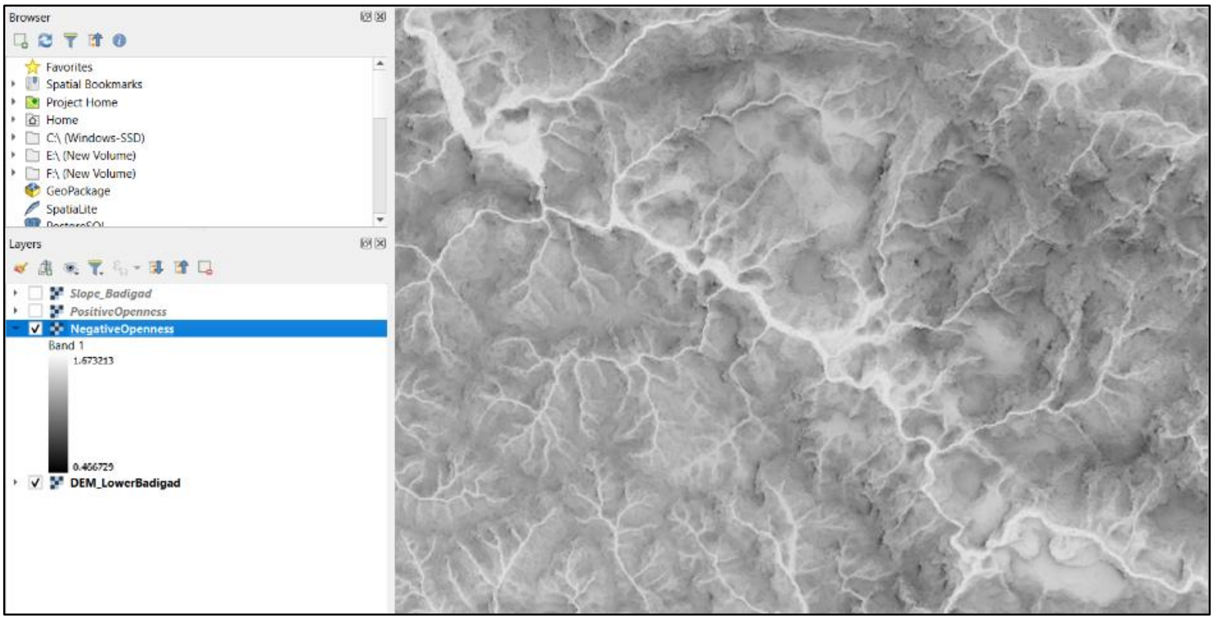


Figure Sup 20, Negative openness raster map.

Step 4: Calculating the Differential Openness raster

After generating the positive and negative openness raster, the raster calculator (Raster - Raster calculator) is used to calculate the differential openness raster as according to the formula (Figure Sup 21),

(Positive Openness – Negative Openness)/2

i.e. (Op-On)/2

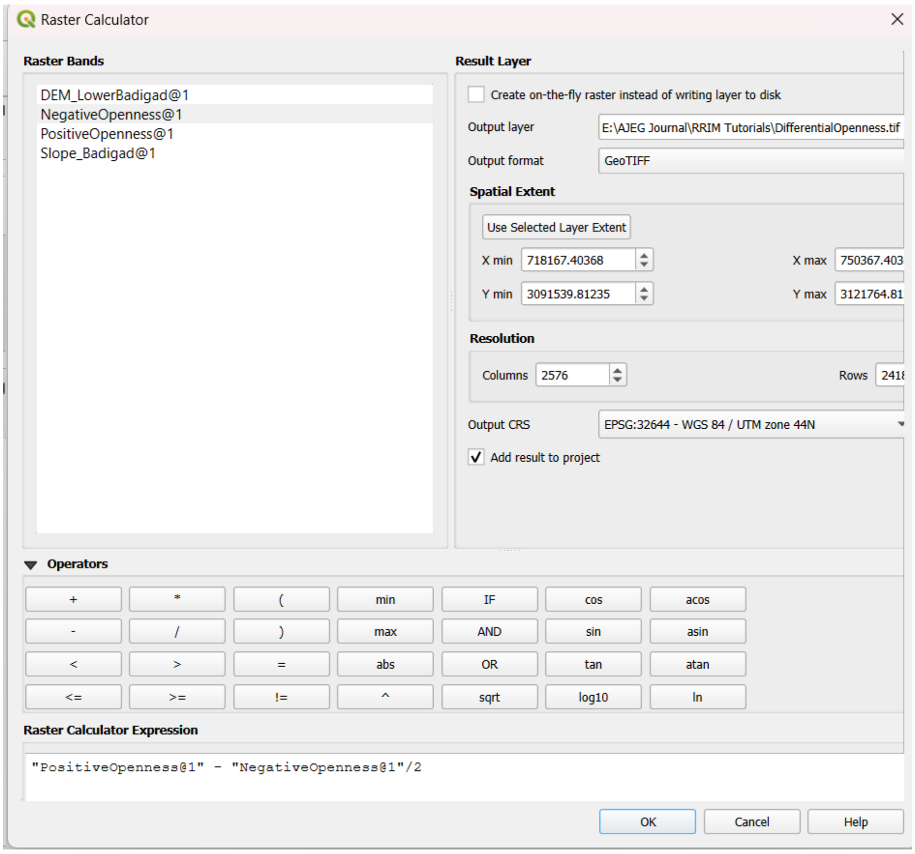


Figure Sup 21, Raster calculator module window.

Step 5: Enhancing the Differential Openness raster

After calculation, differential openness map should be enhanced to improve contrast for better visualization.

- Double click on the differential openness raster

- Click on Symbology in layer properties of raster.
- Contrast enhancement is set to Min/Max value settings (you can select several options depending on what should be highlighted) and click apply.

The result map looks like Figure Sup 22.

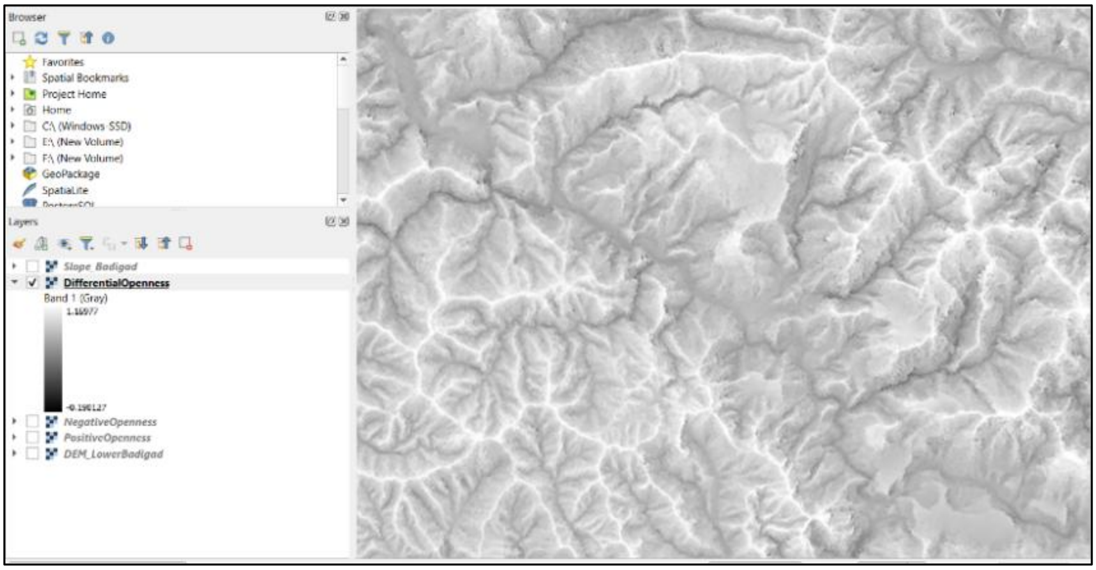


Figure Sup 22, Differential openness raster map.

At the last, first make sure that the slope raster is placed on top of the differential openness raster. The final RRIM map looks like to Figure Sup 23.

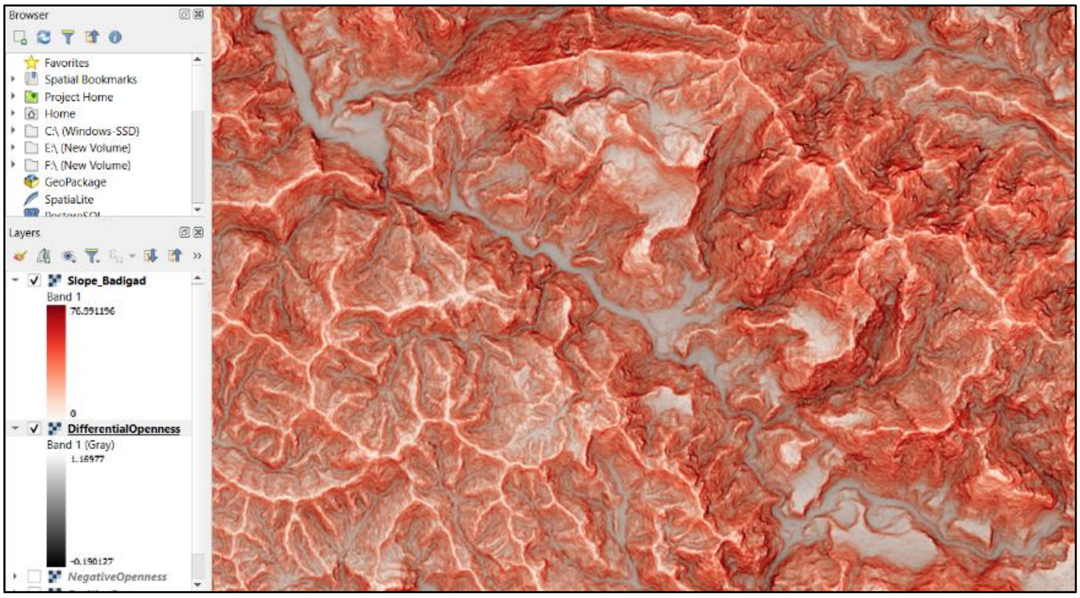


Figure Sup 23, Final Red Relief Image Map.

Step 6: 3D RRIM visualization

Worked on QGIS 3.x (e.g., 3.28, or newer)

1. Open the 3D Map View
   - In QGIS main window, go to the top menu bar.
   - Click View → New 3D Map View.
   - A new panel or window will appear with the 3D canvas.
2. Configure 3D Settings
   - Click the cogwheel icon ⚙ (top-right of the 3D Map View).
   - Under Terrain tab:

- Choose your DEM layer under "Elevation".
- Set a vertical scale factor to exaggerate the terrain for better visualization.

3. Apply RRIM as Surface Texture
   - In the same 3D configuration window:
   - Under "Surface" → "Map texture", choose your RRIM raster layer.
   - This overlays the RRIM onto the DEM in 3D.
4. Adjust Visualization Options
   - Pan, tilt, and zoom using mouse controls.
   - Adjust lighting and shading for enhanced terrain perception:
   - Settings → Lighting → Enable directional light or ambient light.

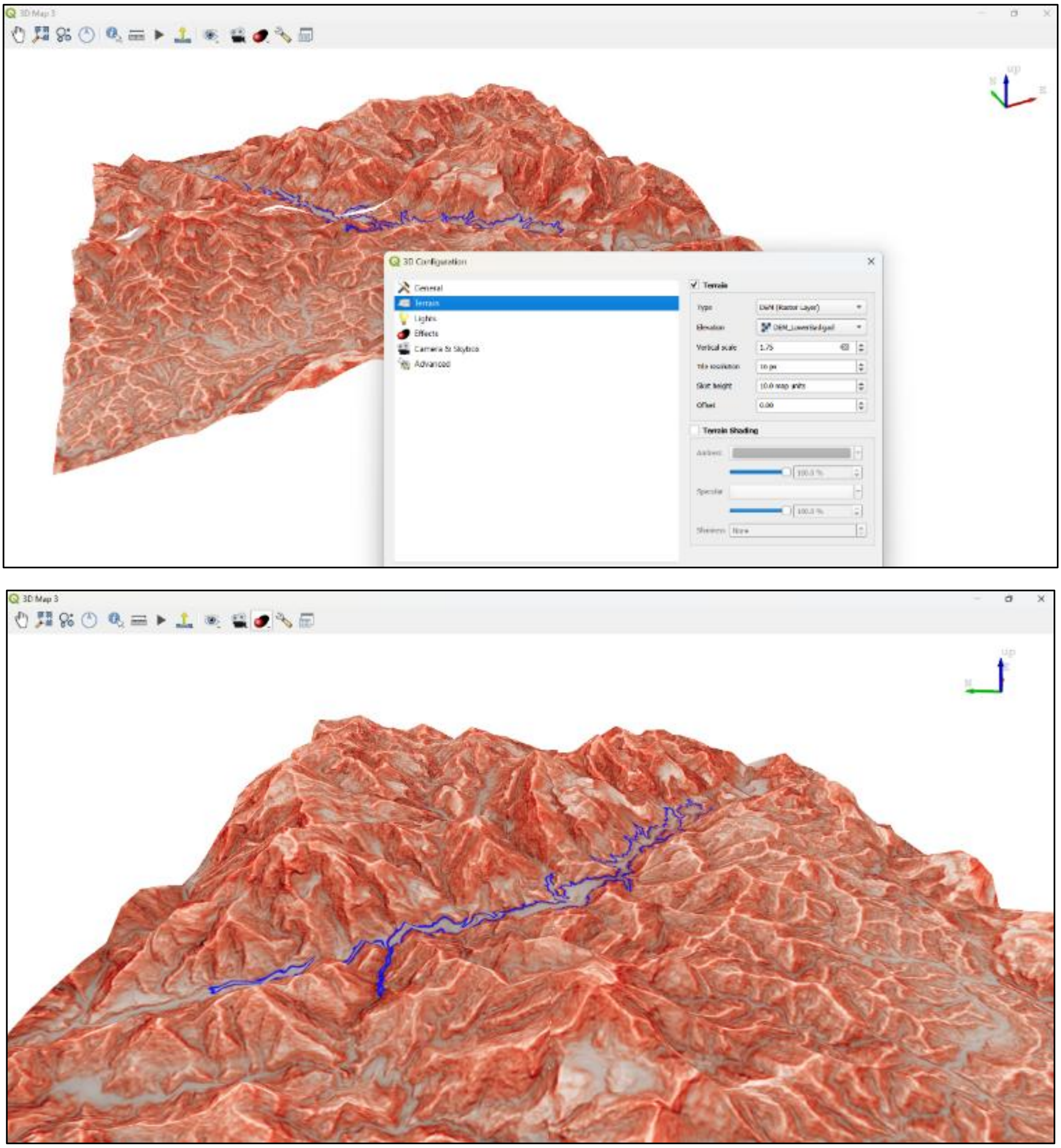


Figure Sup 24, 3D configuration window in QGIS.

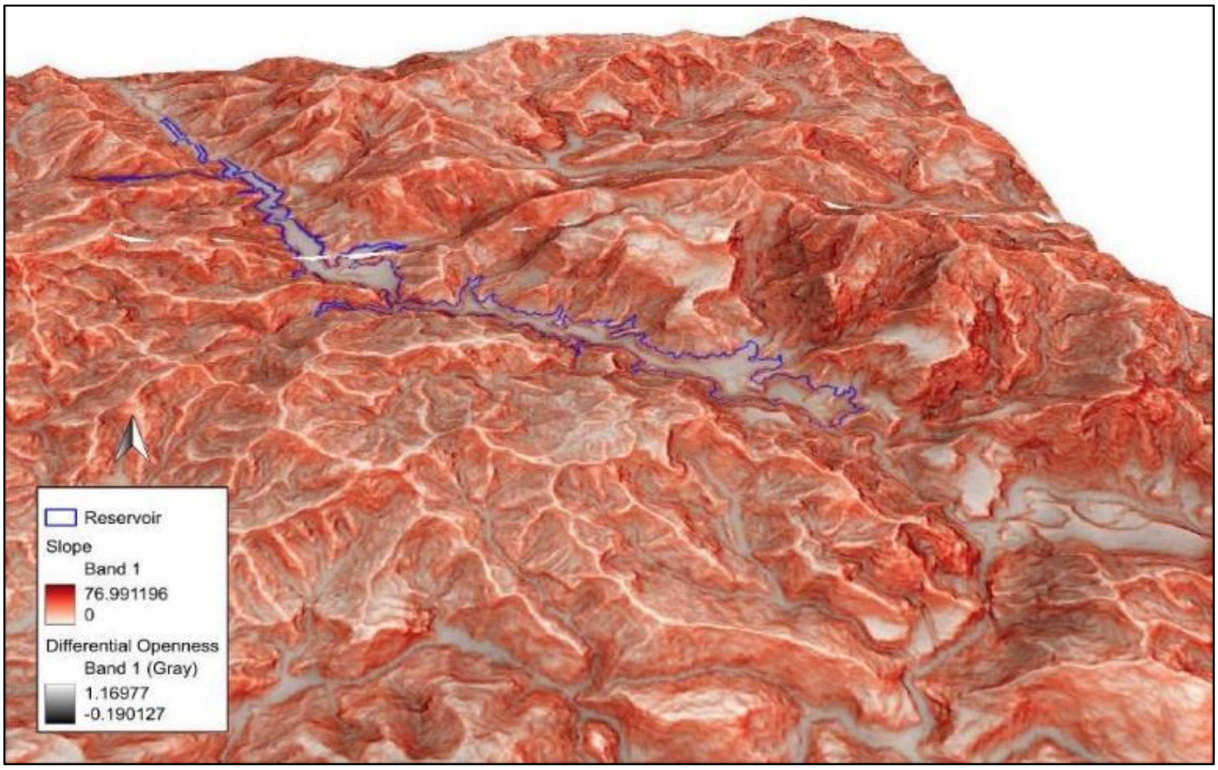


Figure Sup 25, 3D Red Relief Image Map (3D RRIM).

Appendix – 2

Full format Red Relief Image Map of all 20 Master Plan Storage-Type Hydropower, Diversion and Multipurpose Projects of Nepal

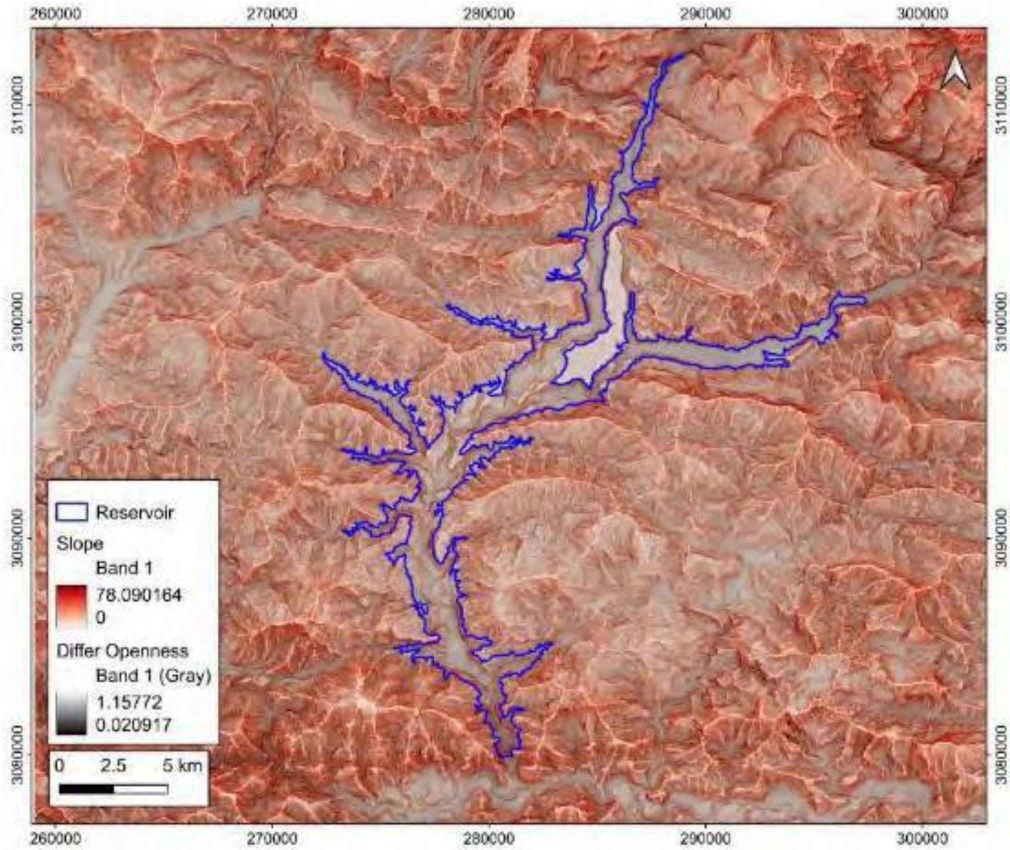


Figure Sup 26, Red Relief Image Map of Budhigandaki Hydropower Project.

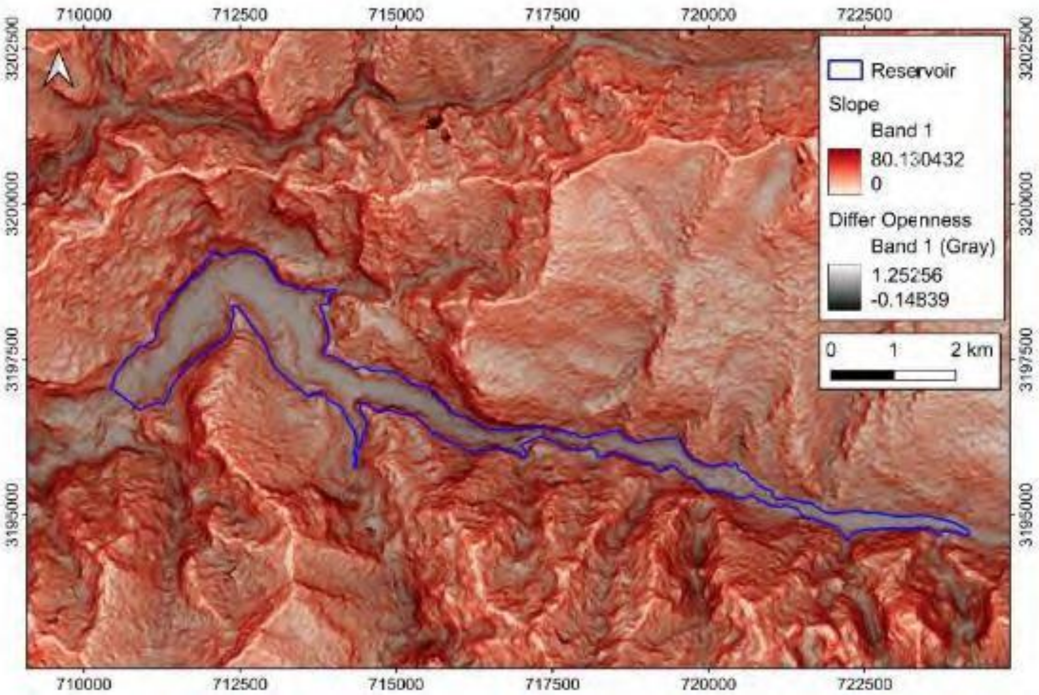


Figure Sup 27, Red Relief Image Map of Bharbung Storage Hydropower Project.

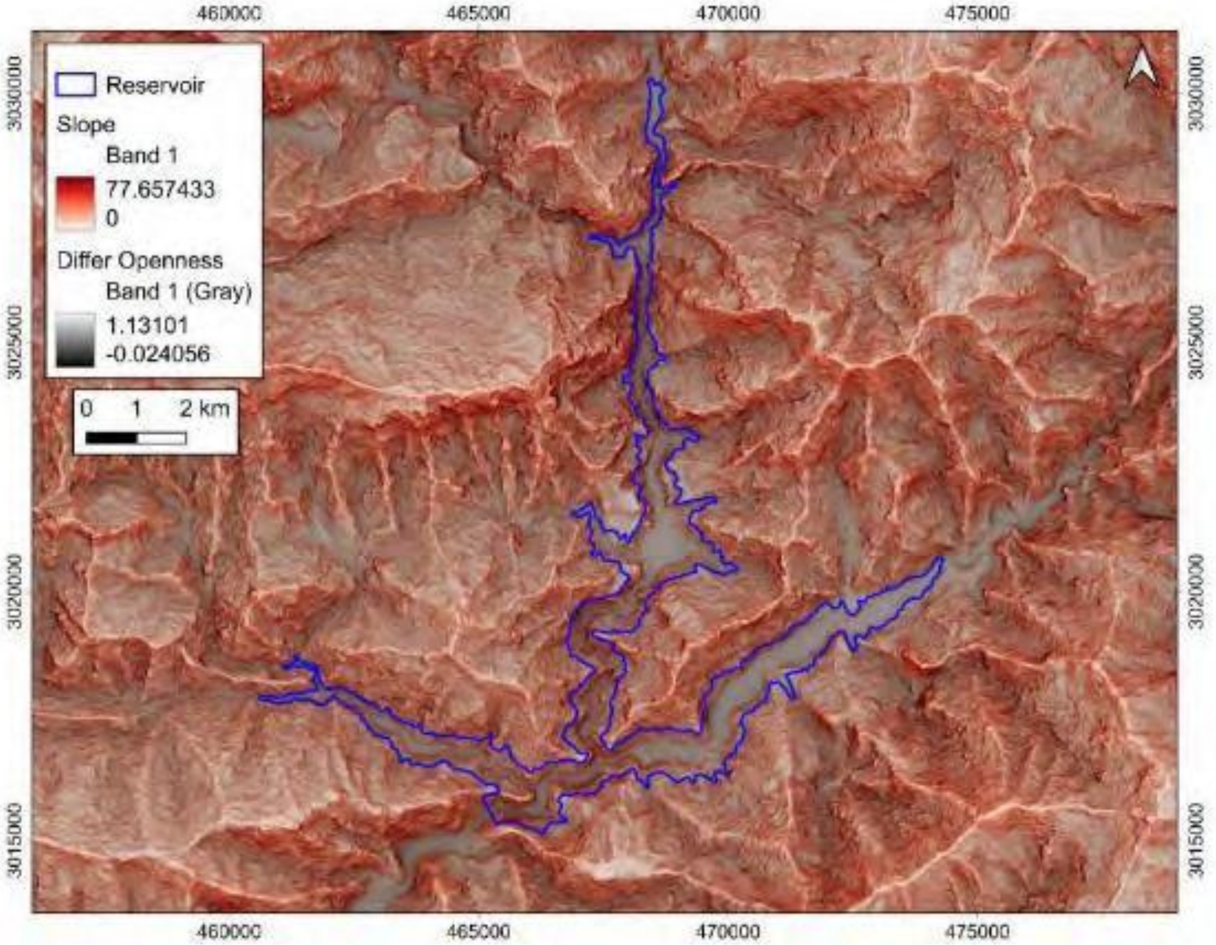


Figure Sup 28, Red Relief Image Map of Dudh Koshi Storage Hydropower Project.

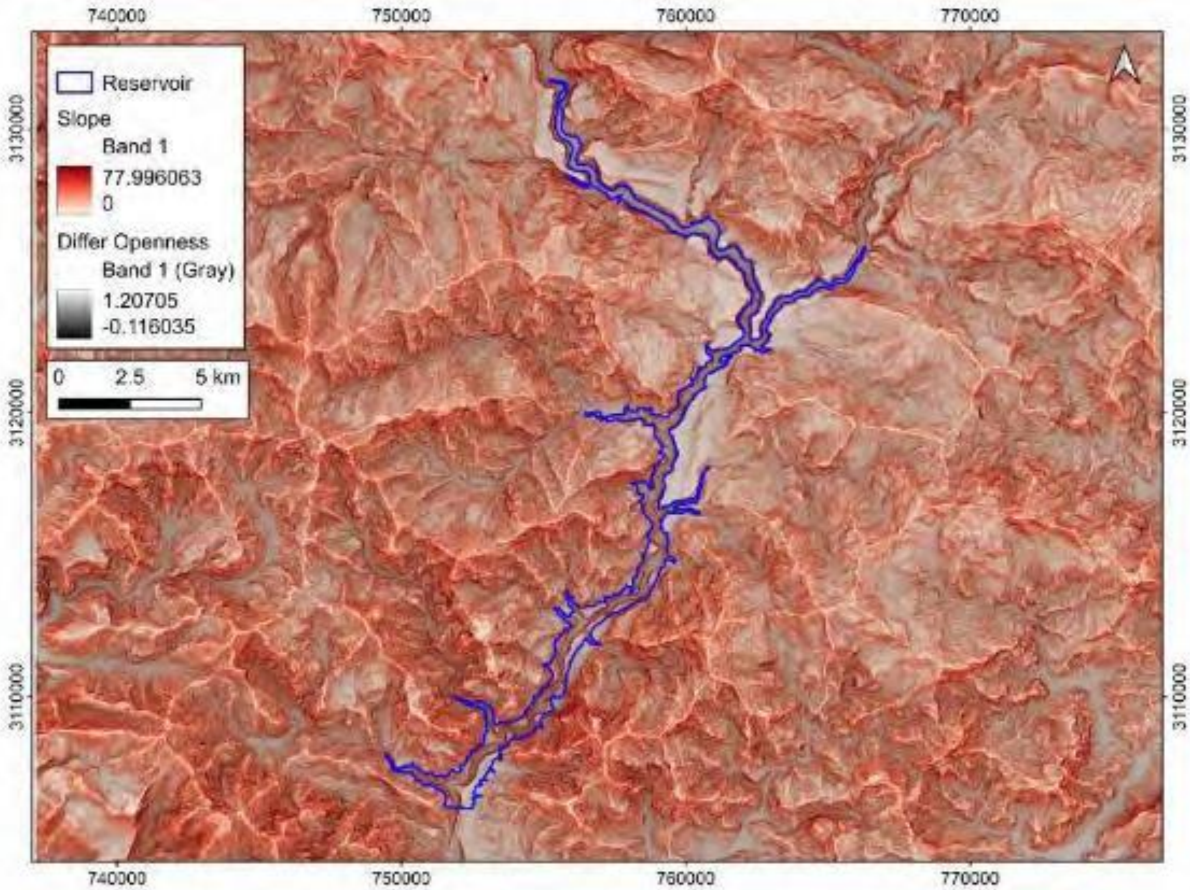


Figure Sup 29, Red Relief Image Map of Kaligandaki Storage Hydropower Project.

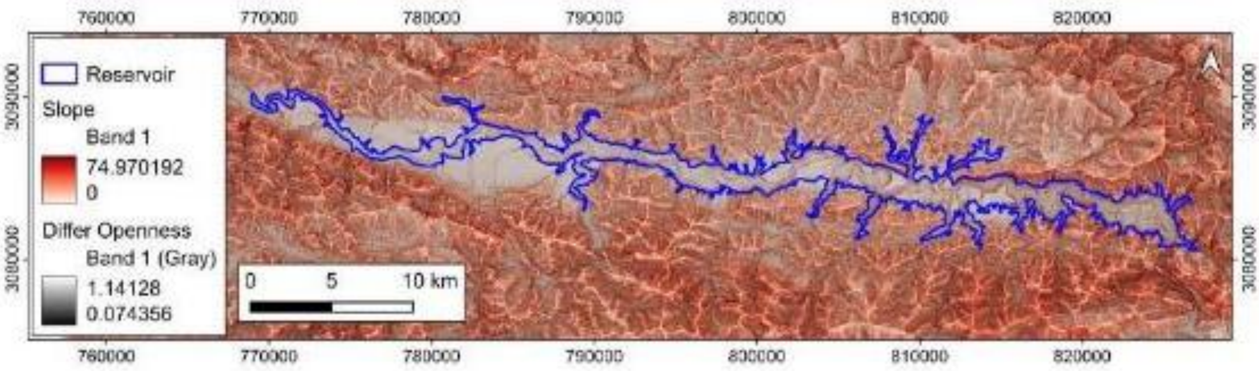


Figure Sup 30, Red Relief Image Map of Kaligandaki-2 Storage Hydropower Project.

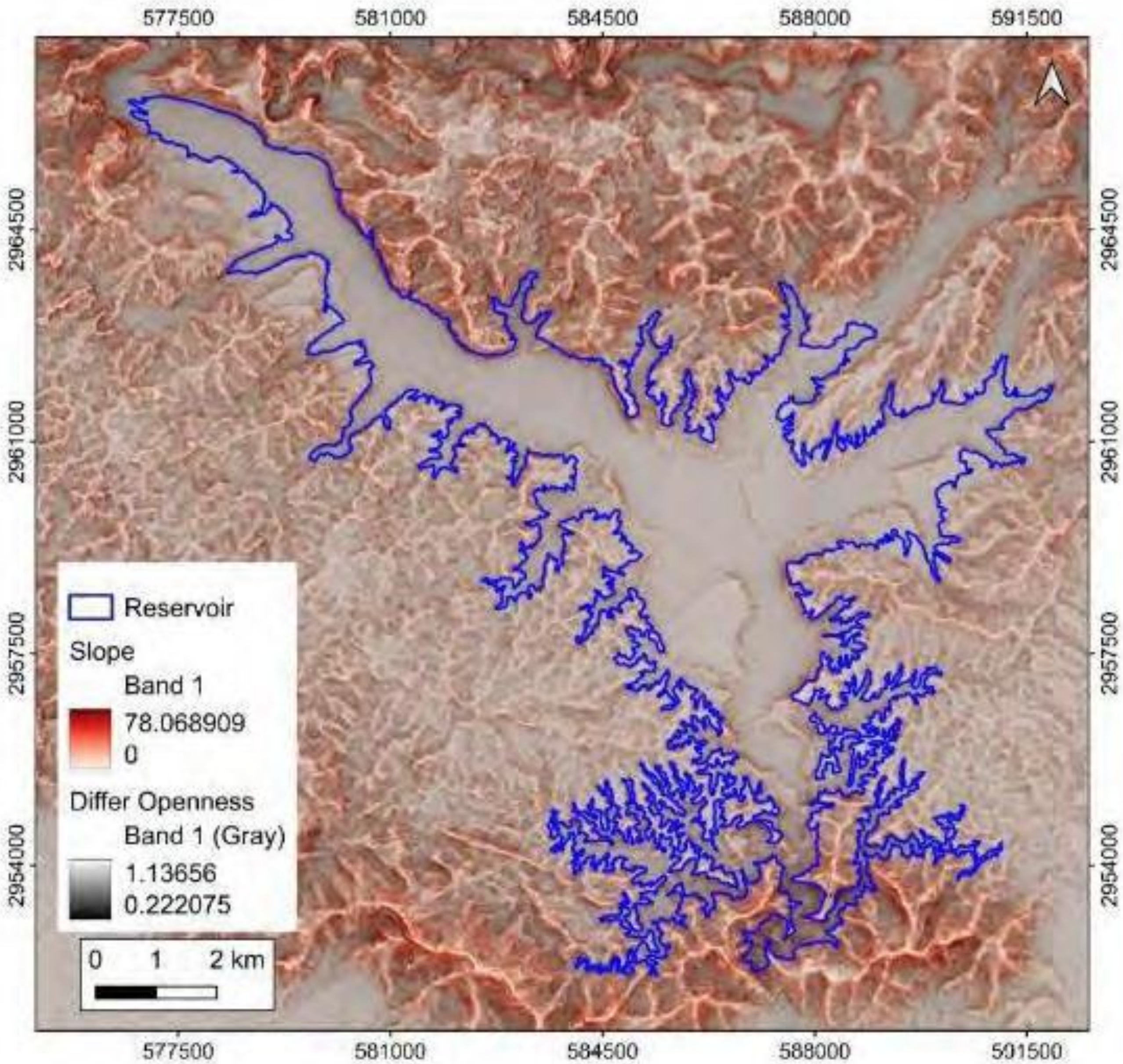


Figure Sup 31, Red Relief Image Map of Kankai Multipurpose Project.

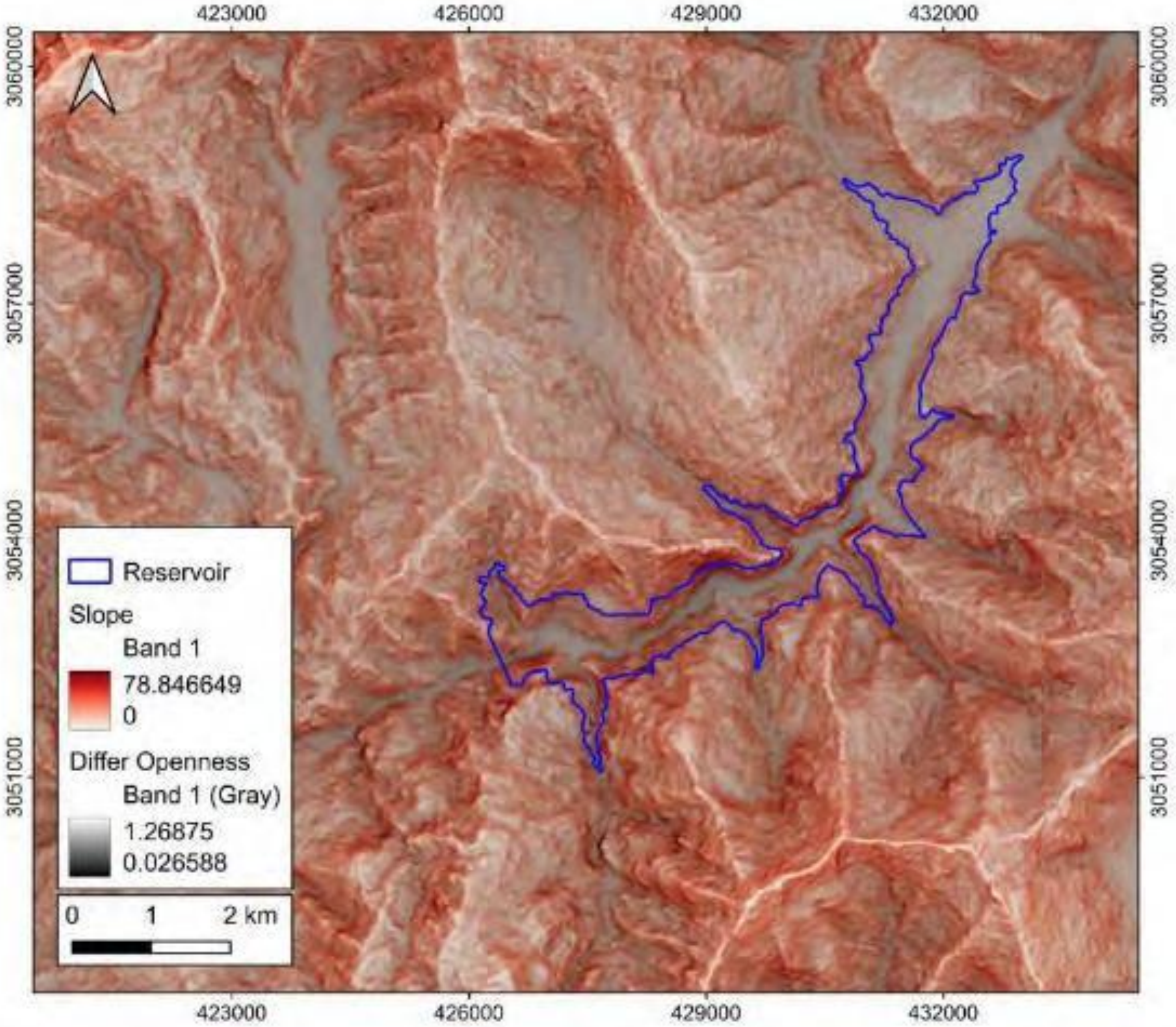


Figure Sup 32, *Red Relief Image Map of Khimti Those Siwalaya Storage Hydropower Project.*

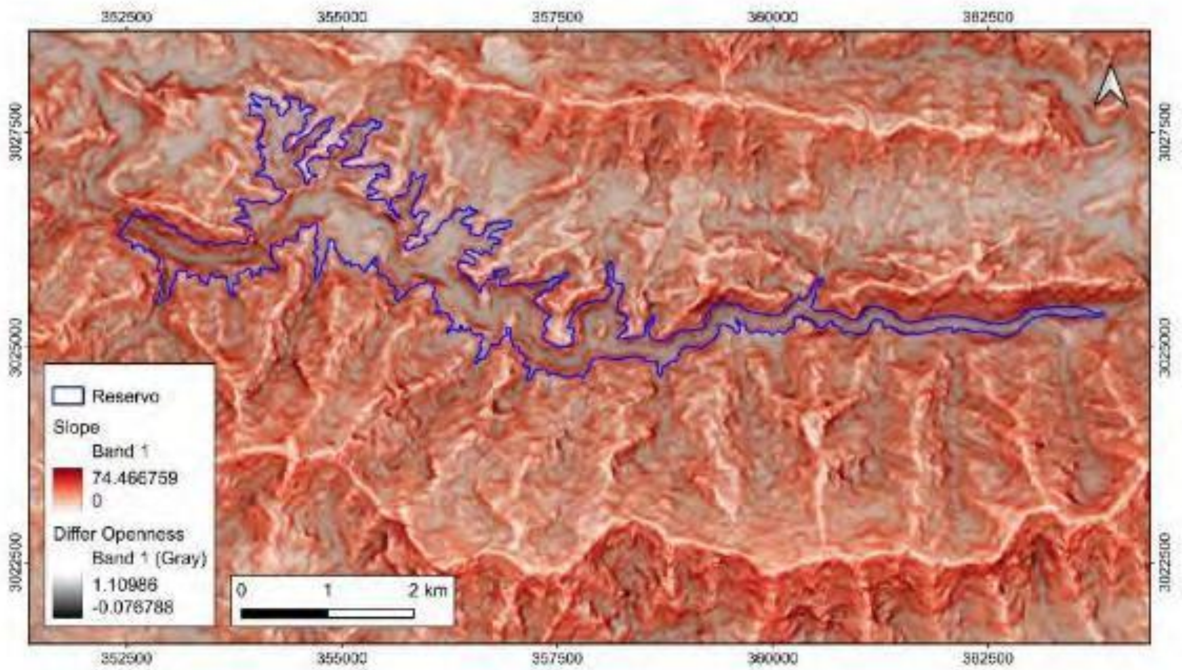


Figure Sup 33, *Red Relief Image Map of Kokhajor Storage Hydropower Project.*

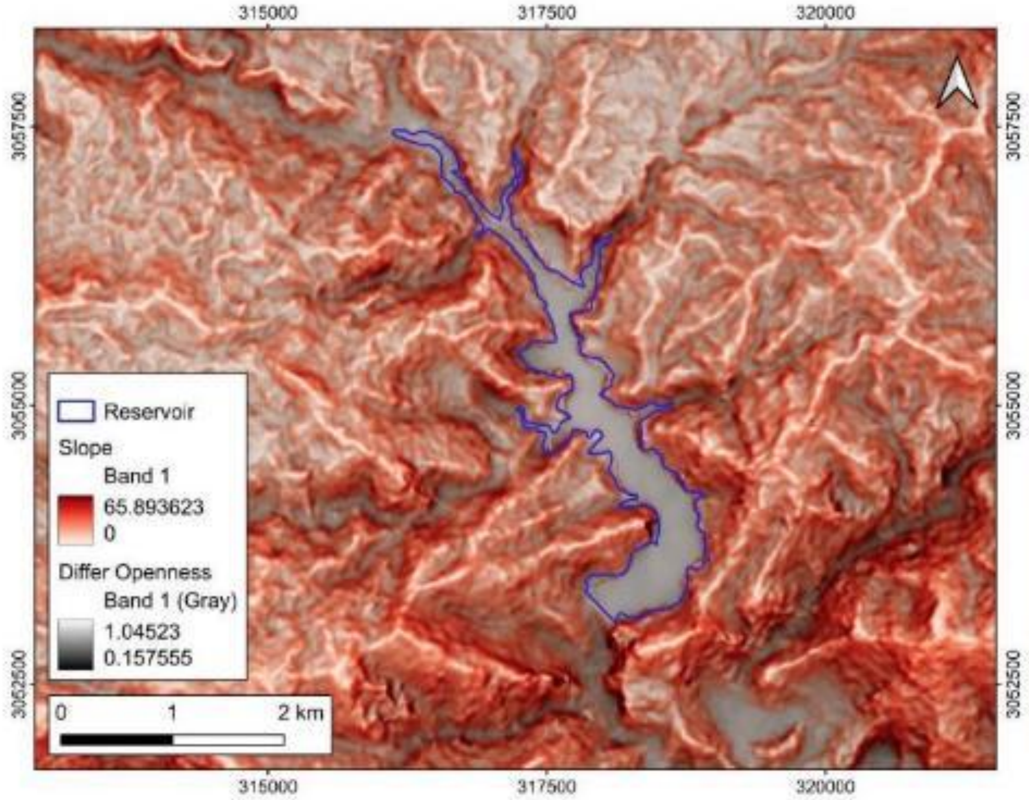


Figure Sup 34, Red Relief Image Map of Kulekhani Hydropower Project (Operated).

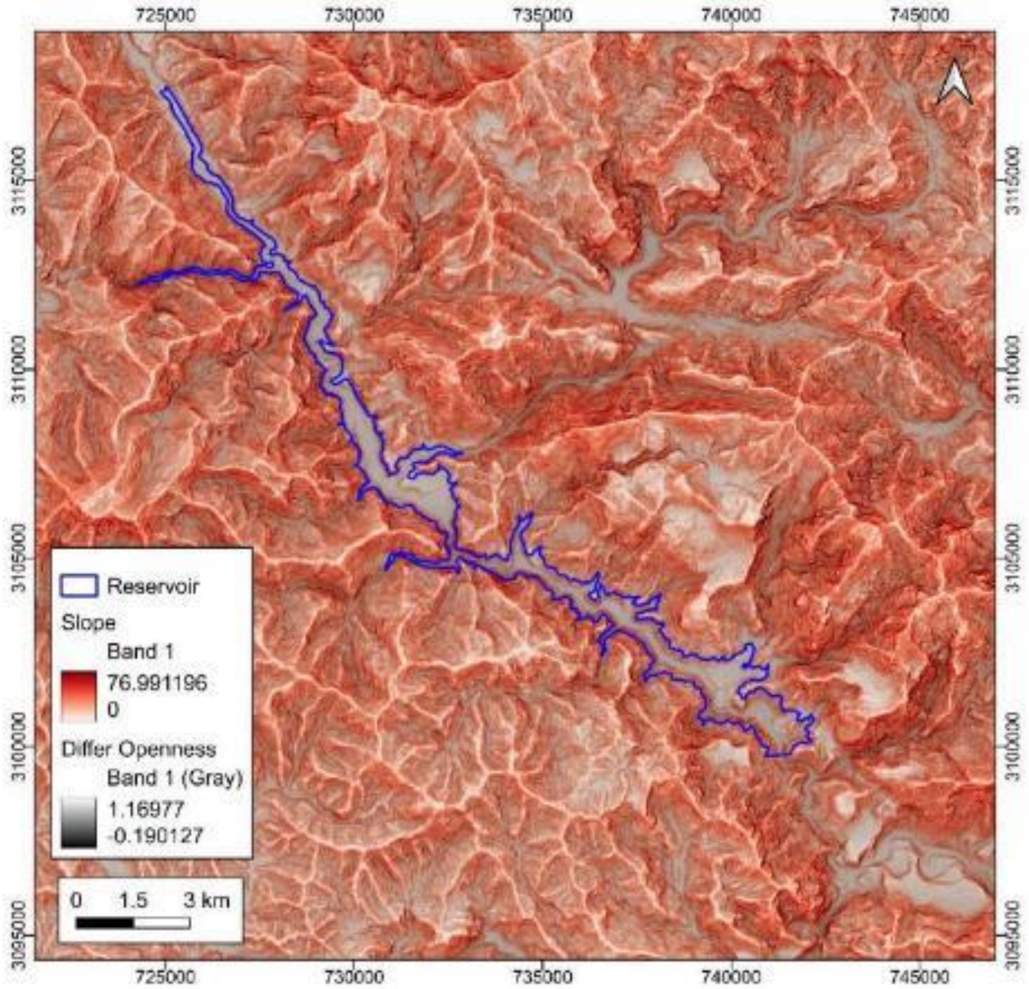


Figure Sup 35, Red Relief Image Map of Lower Badigad Storage Hydroelectric Project.

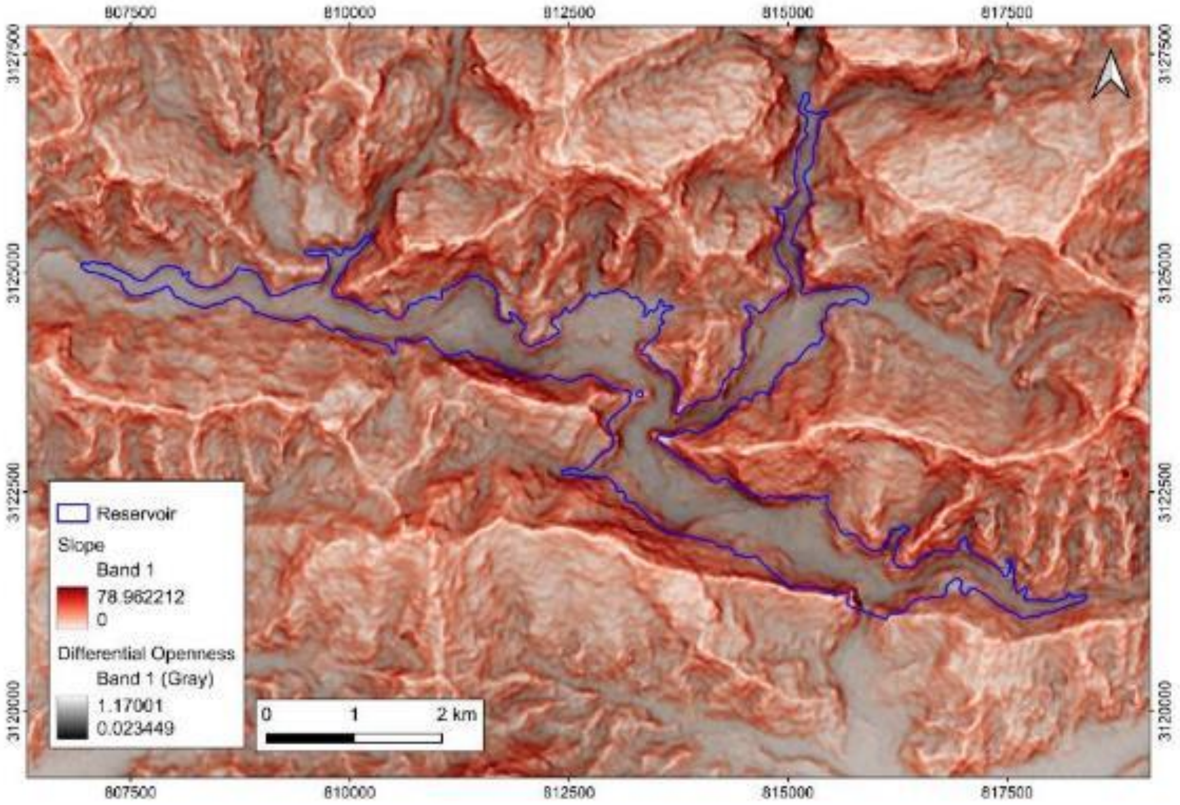


Figure Sup 36, *Red Relief Image Map of Madi Siti Storage Hydropower Project.*

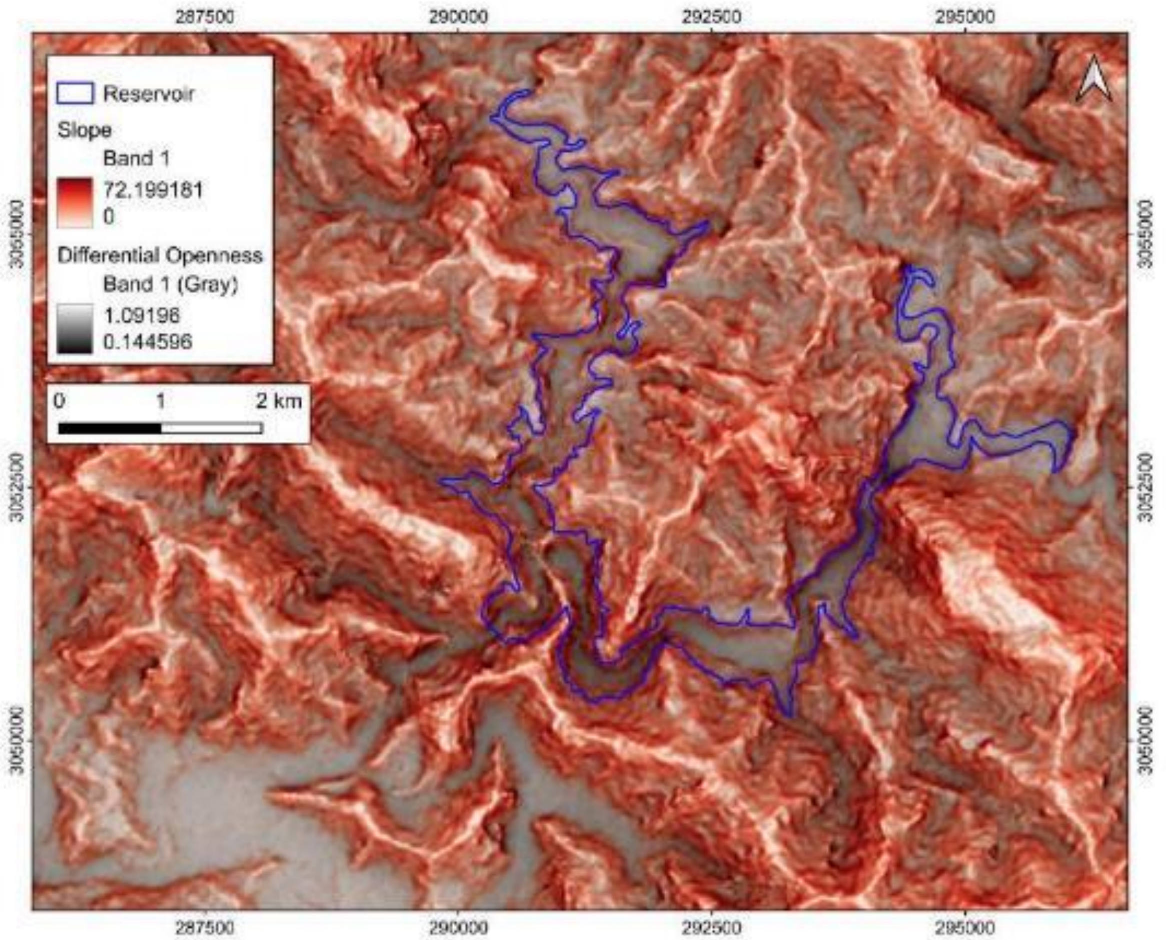


Figure Sup 37, *Red Relief Image Map of Manahari Multipurpose Project.*

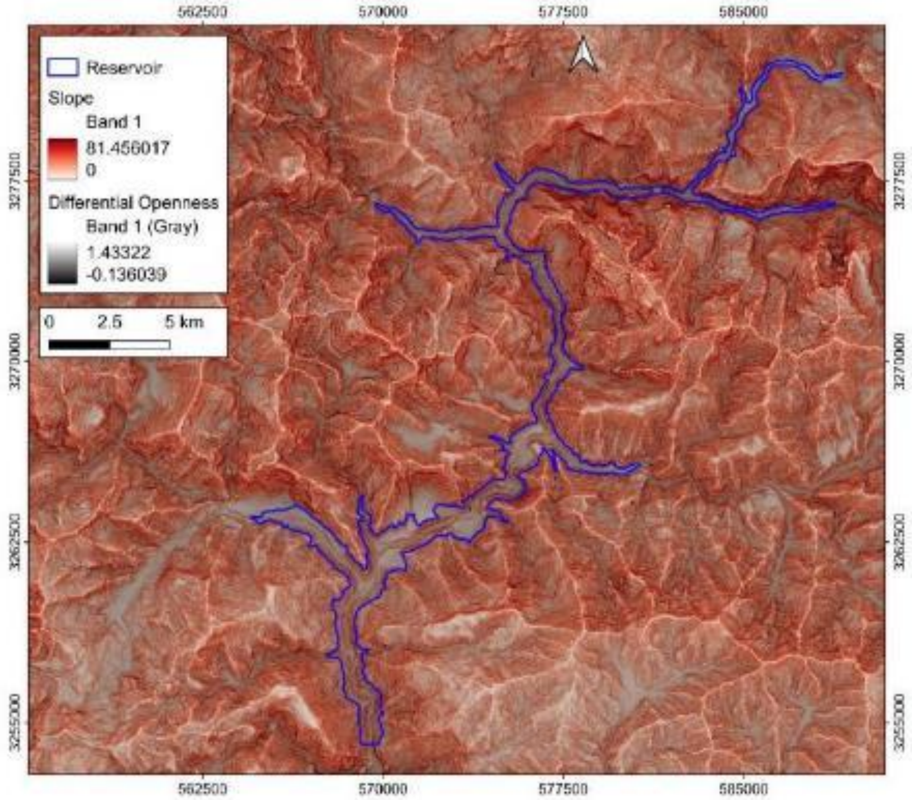


Figure Sup 38, Red Relief Image Map of Mugu Karnali Hydroelectric Project.

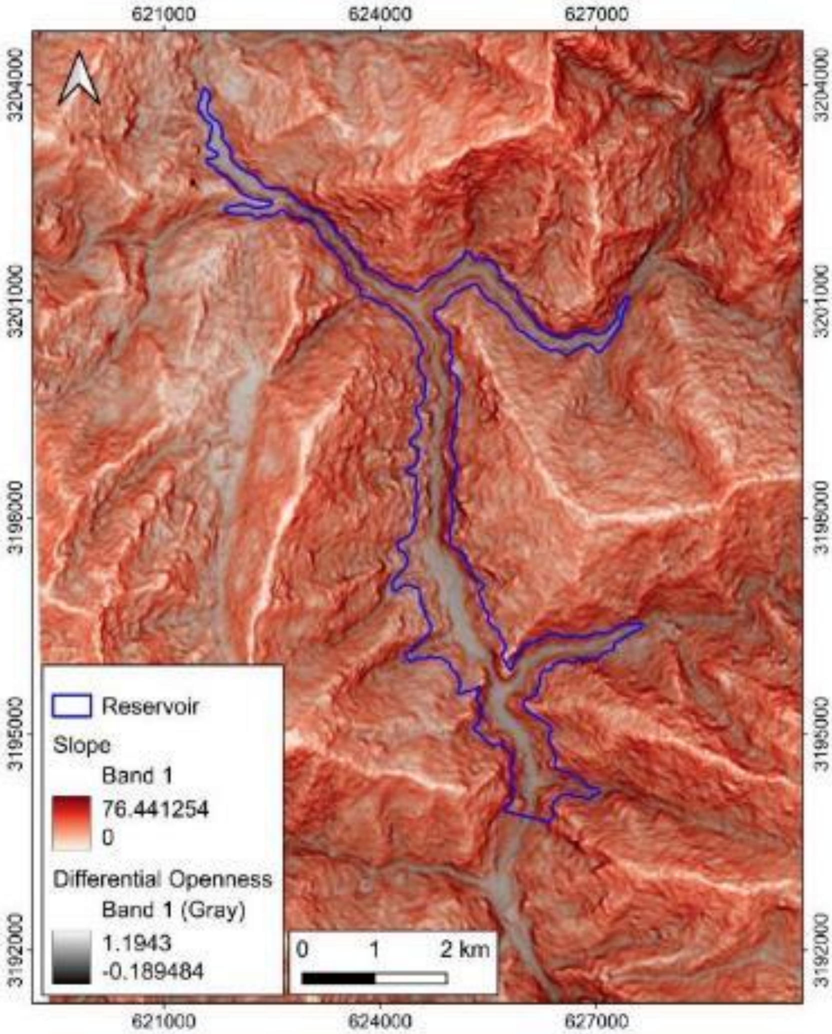


Figure Sup 39, Red Relief Image Map of Nalgad Storage Hydropower Project.

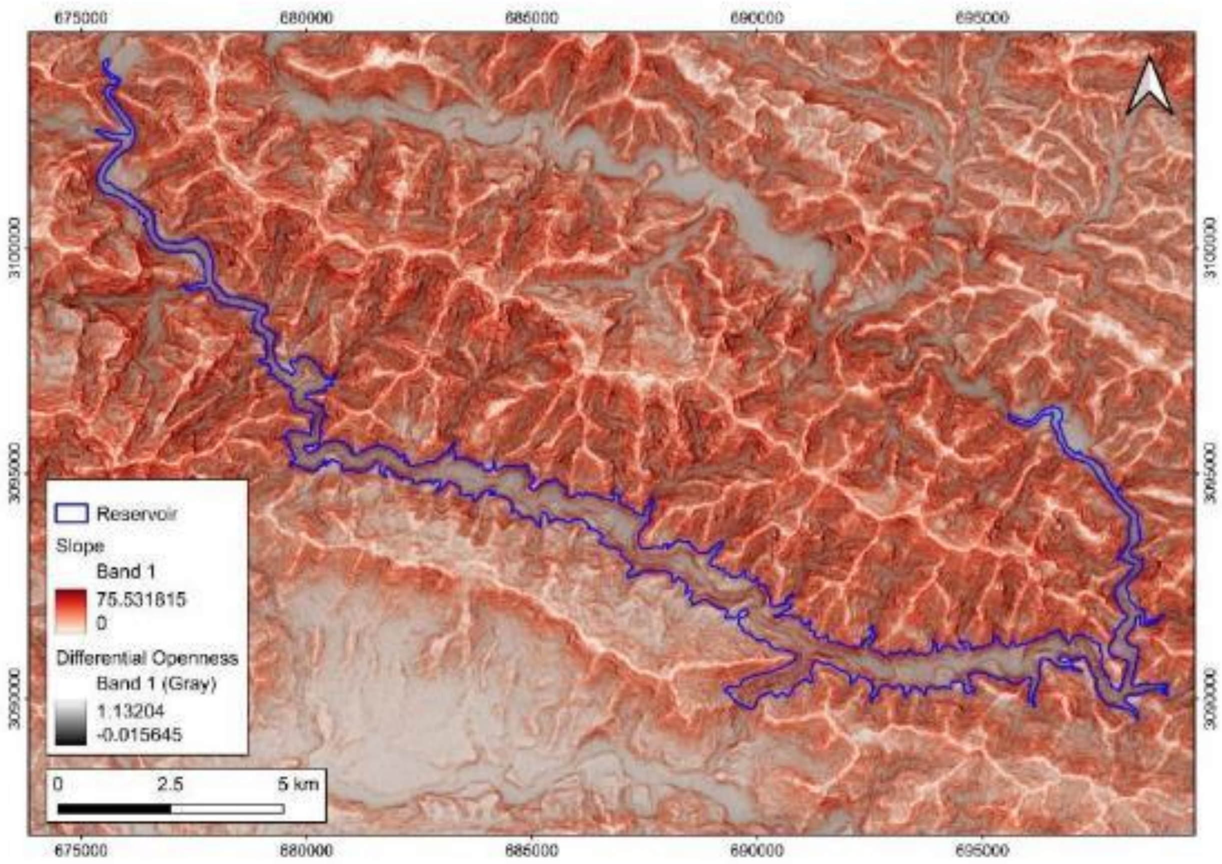


Figure Sup 40, Red Relief Image Map of Naumure Storage Hydropower Project.

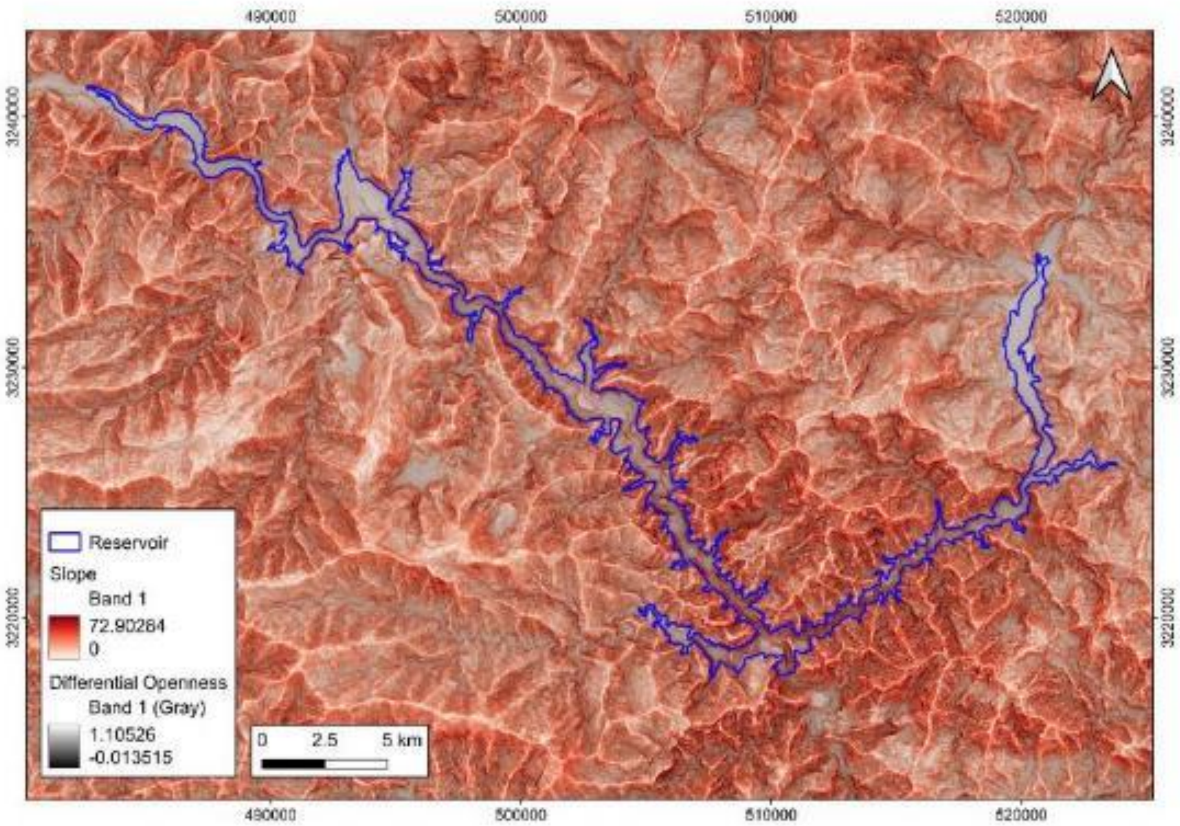


Figure Sup 41, Red Relief Image Map of SR-6 Storage Hydropower Project.

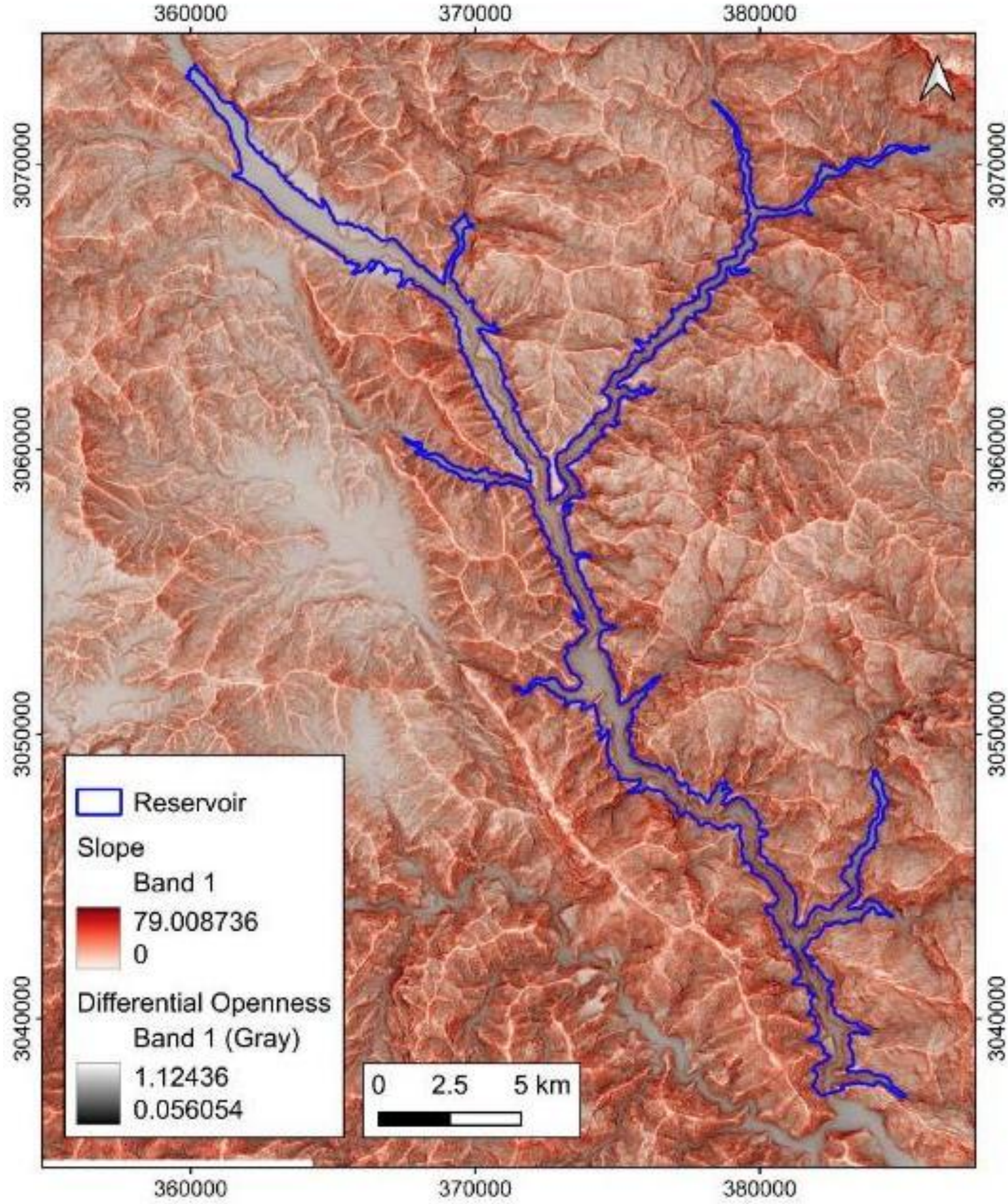


Figure Sup 42, Red Relief Image Map of Sun Koshi 3 Storage Hydropower Project.

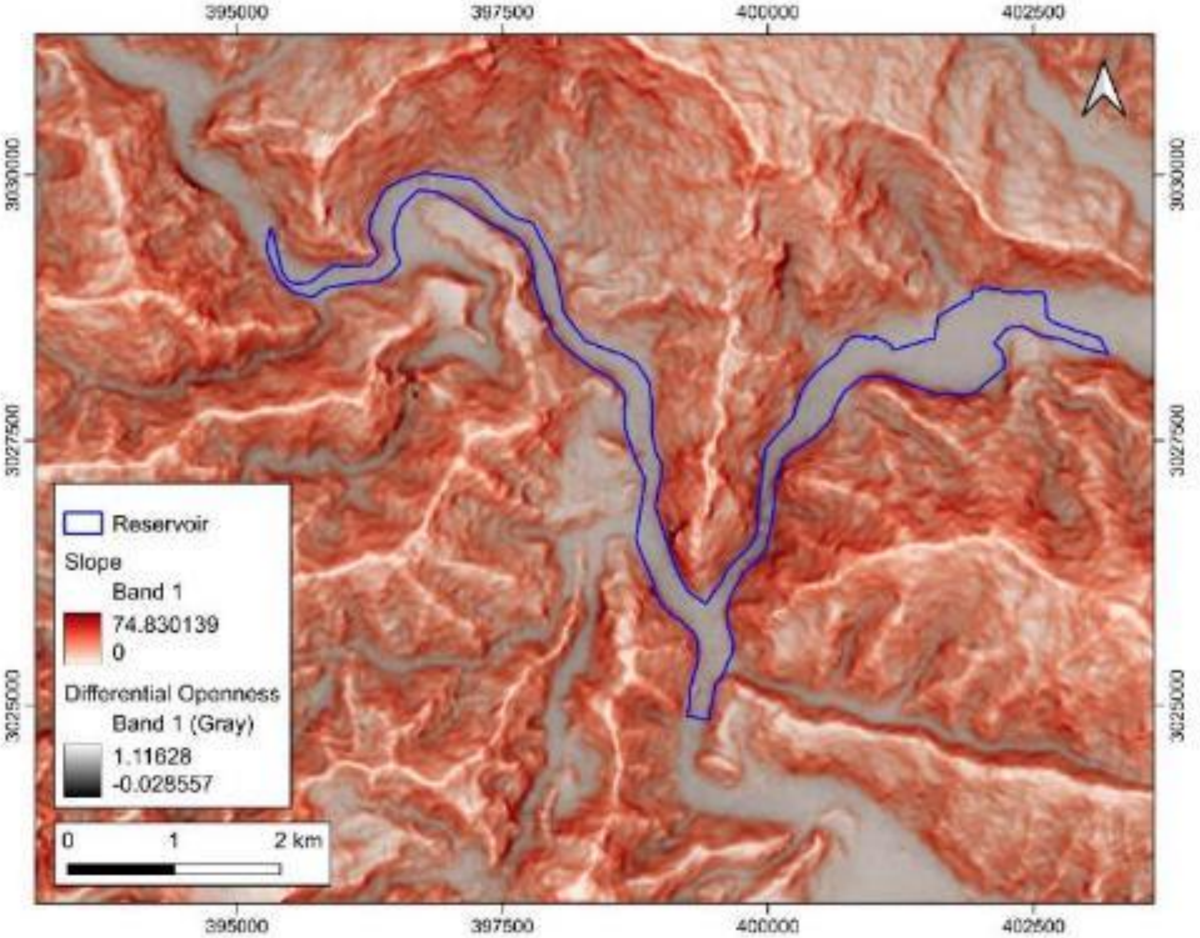


Figure Sup 43, Red Relief Image Map of Sunkoshi Marin Diversion Multipurpose Project.

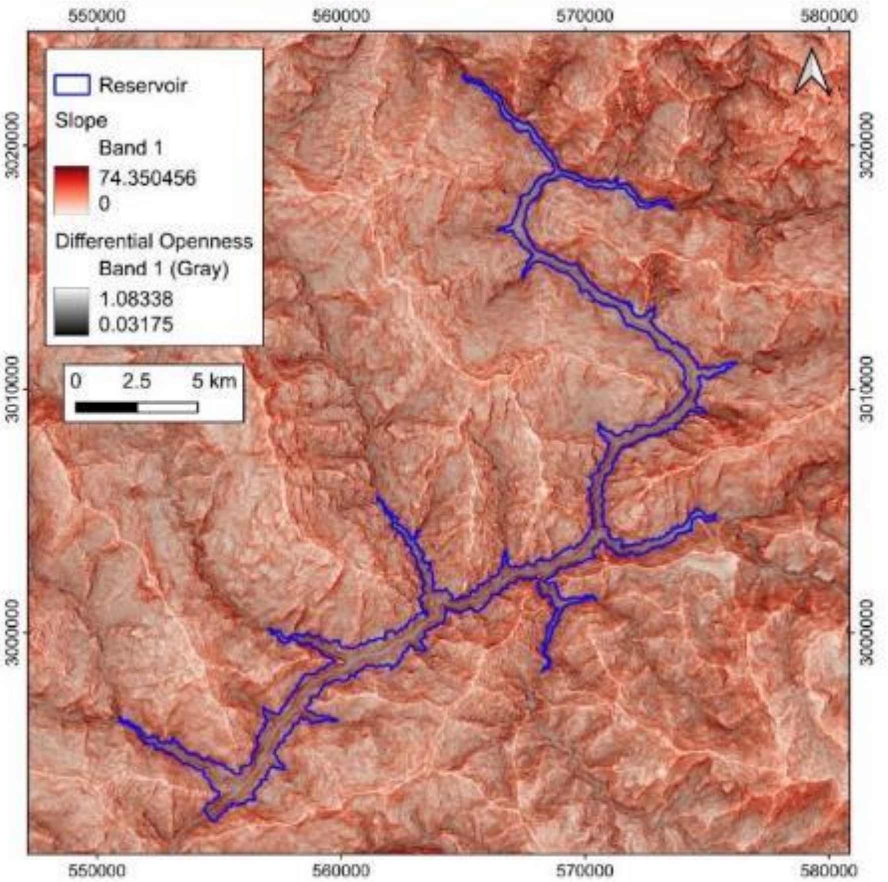


Figure Sup 44, Red Relief Image Map of Tamor Storage Hydropower Project.

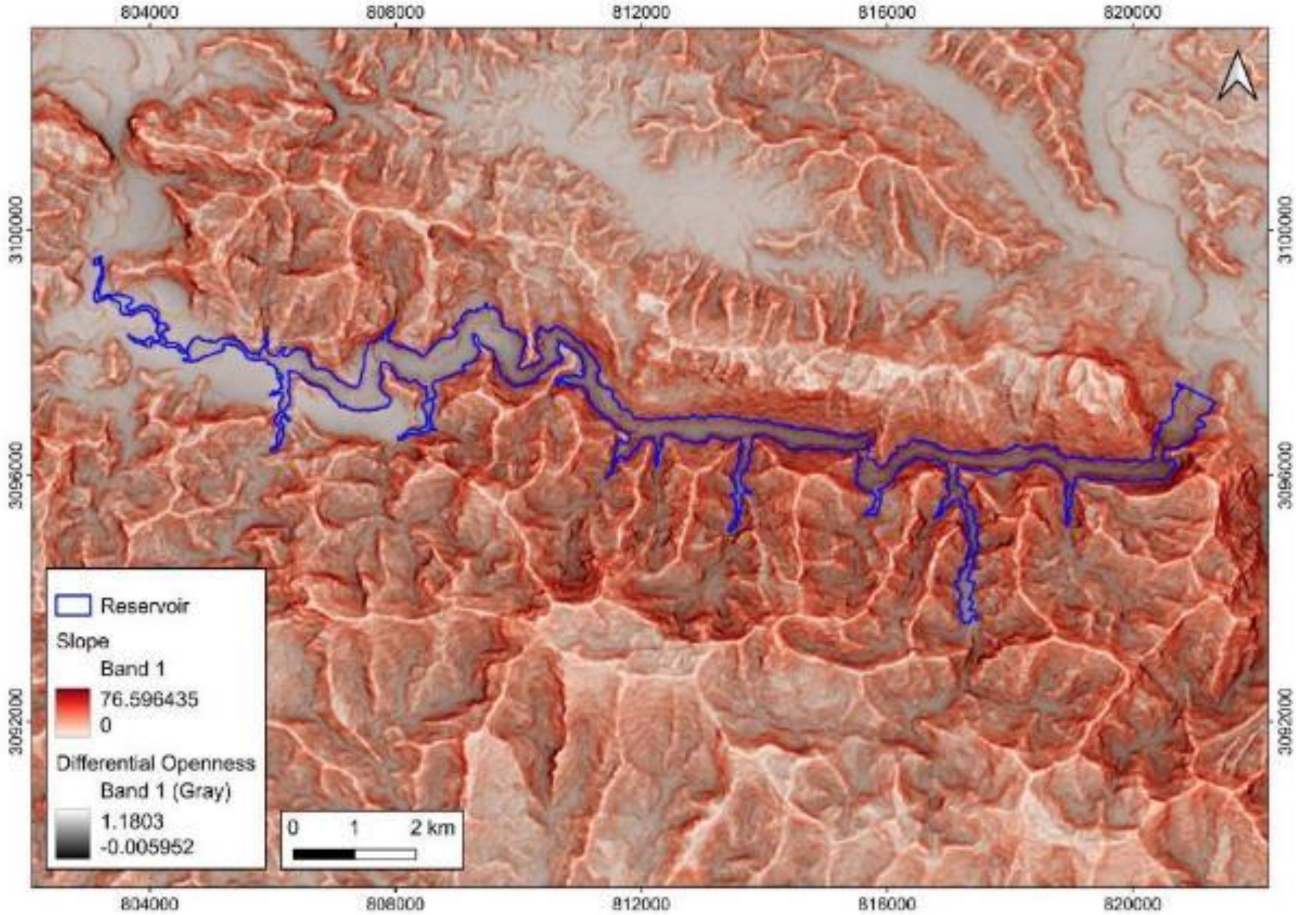


Figure Sup 45, Red Relief Image Map of Tanahu Hydropower Project (Upper Seti).