Ministry of Internal Affairs and Law, Bagmati Province, Nepal

Multi Hazard Assessment and Vulnerability Mapping of Sindhupalchowk District

FINAL REPORT

Environment and Engineering Research Centre Pvt.Ltd
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Title:

Multi Hazard Assessment and Vulnerability Mapping of Sindhupalchowk District

Report submitted to:

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Makawanpur Hetauda, Nepal

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हेटौडा, मकवानपुर

मन्तव्य

नेपालको संविधानले विपद् व्यवस्थापनलाई राज्यको जिम्मेवारीको रूपमा तीनवटै सरकारको साझा अधिकार क्षेत्रको रूपमा सूचीकृत गरेको छ । विपद् जोखिम न्यूनीकरण तथा व्यवस्थापन ऐन, २०७४ ले विपद् व्यवस्थापनको क्षेत्रमा विश्वव्यापी रूपमा विकास भएका अवधारणा र नेपालले विगतमा गरेका अनुभव समेतको आधारमा नेपालको विपद् जोखिम व्यवस्थापनको राष्ट्रिय संचरना तथा सबै तहको काम, कर्तव्य र अधिकार तोकेको छ। विपद् जोखिम न्यूनीकरण तथा व्यवस्थापन राष्ट्रिय नीति, २०७५ र विपद् जोखिम न्यूनीकरण राष्ट्रिय रणनीतिक कार्ययोजना २०१८ -२०३० ले विपद् जोखिम न्यूनीकरण गर्दै उत्थानशील राष्ट्र निर्माणका लागि स्पष्ट लक्ष्य र निदिष्ट गन्तव्य सहित प्राथमिकता प्राप्त क्षेत्र र रणनीतिक क्रियाकलापहरू तय गरेको छ। विपद् सम्बन्धी बुझाईलाई पहिलो प्राथमिकतामा राखेर प्रकोप अनुसारको विपद् जोखिम लेखाजोखा र नक्शांकनलाई यस कार्ययोजनाले तय गरेका १८ वटा मुख्य प्राथमिकता प्राप्त कार्यहरूमध्ये पहिलोमा राखेको छ। बागमती प्रदेश सरकारले प्रदेश विपद् व्यवस्थापन ऐन २०७५ तर्जुमा गरी प्रदेश सरकारले गर्ने विपद् व्यवस्थापन सम्बन्धी कानूनी प्रवन्धलाई व्यवस्थित गरेको छ।

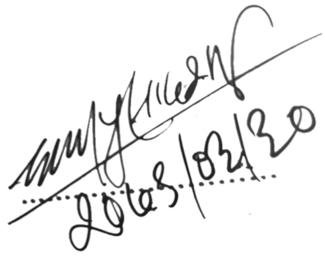
बागमती प्रदेश बहु-प्रकोपको उच्च जोखिममा रहेको छ। प्रदेशको संकटसन्नता तथा सामाजिक आर्थिक संवेदनशीलताले गर्दा यस प्रदेशमा विपद्‌बाट धेरै नोक्सानी हुने गरेको छ। सिन्धुपाल्चोक विभिन्न विपद्‌हरूबाट लगातार रूपमा प्रभावित हुँदै आइरहेको जिल्ला हो। भूकम्प, पहिरो, बाढी, आगलागी र चट्याङ यस जिल्लामा बारम्बार दोहोरि रहने प्रमुख विपद्‌हरु हुन्। भूकम्प, पहिरो र चट्याङबाट यस जिल्लामा धेरै मानवीय क्षति हुने गरेको छ। प्रकोप, संकटसन्नता र जोखिम अध्ययन र नक्शाङ्‌कन लाई विपद् जोखिम बुझ्ने महत्वपूर्ण कार्यको रूपमा लिएर प्रथमिकताको आधारमा प्रदेशका सबै जिल्लाहरूको प्रकोप संकटासन्नता तथा विपद् जोखिम लेखाजोखा र नक्शाङ्‌कन गर्ने नीति प्रदेश सरकारले लिएको छ।

सम्भावित विपद् जोखिम न्यूनीकरणको दीर्घकालीन आधार भनेको जोखिम संवेदनशील भू-उपयोग योजना तर्जुमा र यसको प्रभावकारी कार्यान्वयन हो। जिल्लाका सबै स्थानीय तहले बहुप्रकोप लेखाजोखा र नक्शाङ्‌कनको

आधारमा जोखिम संवेदनशील भूउपयोग योजना बनाई जोखिम सुसूचित विकासको अभ्यासलाई कार्यान्वयनमा ल्याउनु पर्दछ। बहुप्रकोपको उच्च जोखिमयुक्त क्षेत्रमा बस्ती तथा पूर्वाधार विकासलाई निषेध गर्ने, मध्यम जोखिमयुक्त क्षेत्रमा नियन्त्रण गर्ने र न्यून जोखिमयुक्त क्षेत्रमा मात्र बस्ती तथा पूर्वाधार विकासलाई प्रवर्धन गर्ने नीति लिएर यसको कार्यान्वयन गर्न जरुरी छ।

सिन्धुपाल्चोक जिल्लाको बहु-प्रकोप लेखाजोखा गरी संकटासन्नता तथा जोखिम नक्शाङ्कन कार्यको प्राविधिक सहयोगको लागि इन्भाइरोनमेन्ट एण्ड इन्जिनियरिङ रिसर्च सेन्टर र यस कार्यमा संलग्न विज्ञ टोलीका सदस्यहरूलाई धन्यवाद दिन चाहन्छु । यसरी नै बाँकी जिल्लाहरूको अध्ययन गर्दै जाने र अध्ययनले सिफारिस गरेका योजनाहरूको कार्यान्वयन गर्न स्थानीय तहहरूसँग समन्वय, सहकार्य र सहजीकरण गर्दै विपद् जोखिम न्यूनीकरणको लागि प्रदेश सरकारले नेतृत्वदायी भूमिका निर्वाह गर्ने छ भन्ने कुरामा विश्वास दिलाउन चाहन्छु।

धन्यवाद।



सचिव

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ABBREVIATIONS

AHP - Analytic hierarchy process

DEM – Digital Elevation Model

DHM - Department of Hydrology and Meteorology

DRRM- Disaster Risk Reduction and Management

EM – DAT – Emergency Events Database

EWS – Early Warning System

FBT - Frontal Back Thrust

FEMA – Federal Emergency Management Agency

FR – Frequency Ratio

GIS – Geographical Information System

GLOF - Glacial Lake Outburst Flood

GoN – Government of Nepal

GPS – Geographical Positioning System

IDW - Inverse Distance Weighted

INGOs – International Non - Government Organizations

KII – Key Informant Interview

LDOF – Landslide Dam Outburst Flood

LSI – Landslide Sensitivity Index

LST - Land Surface Temperature

MBT – Main Boundary Thrust

MCT - Main Central Thrust

MFT – Main Frontal Thrust

MHRA – Multi Hazard Risk Assessment

MoHA – Ministry of Home Affairs

NBC - National Building Code

NDVI – Normalized Difference Vegetation Index

NGOs – Non-Government Organizations

SFDRR – Sendai Framework for Disaster Risk Reduction

TWI – Topographic Wetness Index

UNDRO – Office of the United Nations Disaster Relief Co-coordinator

UNDRR – United Nations Office for Disaster Risk Reduction

कार्यकारी सारांश (EXECUTIVE SUMMARY)

- हिमालय पर्वतको मध्य भागमा अवस्थित नेपाल, यसको भौगर्भिक अवस्थिति, भौगोलिक अवस्था र जलवायुको विषेशताका कारण बहुप्रकोपको उच्च जोखिममा रहेको मुलुक हो । भूकम्प, बाढी, पहिरो आगलागी, चट्याङ, हावाहुरी, हिमपहिरो, असिना, महामारी र दुर्घटना यहाँ बारम्बार दोहोरिने र जन-धनको क्षति गर्ने प्रमुख प्रकोप हुन् । यस प्रकारका विपद्बाट मानवीय क्षति तथा सम्पत्तिको नोक्सानी हुनको साथै भौतिक पूर्वाधारहरूको क्षति र आर्थिक विकासको गति समेत अवरूद्ध हुने गरेको छ । नेपालले विभिन्न समयमा विभिन्न ठूला विपद्का घटनाहरु बेहोर्दै आइरहेको छ । वि. सं. १९९० सालको भूकम्प, २०३८, २०४४ र २०७२ सालको भूकम्प; वि. सं. २०५१, २०६५, २०७१, २०७२ र २०७४ सालको बाढी, विगत सय वर्षमा नेपालमा भएका ठूला विपद्का घटनाहरु हुन् । नेपालको ८० प्रतिशत जनसङ्ख्या बहुप्रकोपको जोखिमयुक्त क्षेत्रमा बसोबास गर्दछन् ।

- बागमती प्रदेश बहुप्रकोपको उच्च जोखिममा रहेको छ । सिन्धुपाल्चोक जिल्ला पछिल्लो दशकमा बहुप्रकोपबाट अत्यन्त प्रभावित जिल्लाको रूपमा रहेको पाइएको छ । वि. सं. २०७२ सालको भूकम्पको केन्द्रविन्दु गोरखा भएतापनि सबैभन्दा बढी क्षति र नोक्सानी सिन्धुपाल्चोक, दोलखा र रसुवा जिल्लामा भएको थियो । त्सयसैगरी २०७१ सालको जुरे पहिरो २०७३ सालमा भोटेकोशीमा आएको बाढी, २०७७ सालको लिदी पहिरो, २०७८ को मेलम्चीको बाढी र पहिरो यस जिल्लामा विगत दशकमा भएका विपद्का प्रमुख घटनाहरु हुन् । यस प्रकार एकपछि अर्को निरन्तर विपद्का घटनाहरूले जिल्लाको कमजोर भूभौतिक परिस्थिति र बहुप्रकोपको उच्च जोखिमलाई दर्साउँछ ।

- नेपालको संविधानले विपद् व्यवस्थापनलाई तीनवटै तहका सरकारको अधिकार बाँडफाँट सम्बन्धी साझा तथा एकल अधिकार सूचीमा सूचीकृत गरेपछि यसको कार्यान्वयनको लागि विपद् जोखिम न्यूनीकरण तथा व्यवस्थापन ऐन, २०७४; विपद् जोखिम न्यूनीकरण राष्ट्रिय नीति, २०७५; र विपद् जोखिम न्यूनीकरण राष्ट्रिय रणनीतिक कार्ययोजना, २०१८ – २०३०; नेपालको विपद् व्यवस्थापन सम्बन्धमा बनेका प्रमुख कानूनी तथा नीतिगत प्रवन्धहरू हुन् । यी दस्तावेजहरूले बहुप्रकोप जोखिम लेखाजोखा र नक्शाङ्कनलाई विपद् जोखिम बुझ्ने मुख्य आधारको रूपमा लिइएको छ । विपद् जोखिम न्यूनीकरण राष्ट्रिय रणनीतिक कार्ययोजना २०१८ -

२०३० ले विपद् सम्बन्धी बुझाई लाई पहिलो प्राथमिकतामा राखेर प्रकोप अनुसारको विपद् जोखिम लेखाजोखा र नक्शाङ्कनलाई यस कार्ययोजनाले तय गरेका १८ वटा मुख्य प्राथमिकता प्राप्त कार्यहरूमध्ये पहिलोमा राखेको छ। साथै रणनीतिक कार्ययोजनाले प्रकोप संकटसन्नता र जोखिम अध्ययनलाई जोखिम संवेदनशील भूउपयोग योजनाको मुख्य आधारको रूपमा लिइएको छ। संभावित विपद् जोखिम न्यूनीकरणका लागि जोखिम संवेदनशील भूउपयोग योजनाको कार्यान्वयन पहिलो शर्त हो।

- विगत दशकमा सिन्धुपाल्चोक जिल्ला विभिन्न विपद्हरूबाट लगातार रूपमा प्रभावित हुँदै आएको छ। विगत ११ वर्षमा यस जिल्लामा विभिन्न आठ प्रकारका विपद्का २६७ वटा घटनाहरु भए र यी घटनाहरूबाट ३७४२ जनाले ज्यान गुमाए। भूकम्प, पहिरो, बाढी, आगलागी, चट्याङ हावाहुरी, भारी बर्षा र वन्यजन्तु प्रकोप विगत ११ वर्षमा भएका प्रमुख विपद्हरु हुन्। आगलागी, पहिरो र चट्याङ यस जिल्लामा बारम्बार दोहोरि रहने प्रमुख तीनवटा प्रकोप हुन्। मानवीय क्षतिका हिसावले भूकम्प, पहिरो र चट्याङ यस जिल्लामा बढी मानवीय क्षति गर्ने प्रमुख तीनवटा विपदमा पर्दछन्। त्यसैगरी पहिरो, बाढी र भूकम्प मानिस बेपत्ता पार्ने प्रमुख विपद् हुन्। साथै भूकम्प, पहिरो र बाढी यस जिल्लामा सबैभन्दा बढी भवन तथा संरचना क्षति गर्ने प्रमुख तीनवटा विपद् हुन्।

- विगतमा भएका विपद्को घटनाहरूको रेकर्ड एवं विपद्बाट भएको क्षति तथा नोक्सानीको विवरणले सिन्धुपाल्चोक जिल्ला बहुप्रकोपको उच्च जोखिममा रहेको देखाउँछ। भूकम्प तथा पहिरो ल्याउने भूकम्पीय प्रकोप; बाढी, पहिरो, चट्याङ तथा हावाहुरी ल्याउने जलवायुजन्य वा जलउत्पन्न प्रकोप र आगलागी, दुर्घटना जस्ता मानवीय कारणबाट हुने प्रकोपहरू यस जिल्लामा बारम्बार दोहोरिने गरेको पाइन्छ। वि. सं. २०७१ सालको जुरे पहिरो, २०७२ सालको भूकम्प, २०७३ सालको भोटेकोशीको बाढी र पहिरो, २०७७ सालको लिदी पहिरो र २०७८ सालकको मेलम्चीको बाढी पहिरो विगत दशकमा सिन्धुपाल्चोकमा भएका विपद्का प्रमुख घटनाहरु हुन्। यस प्रकार वर्षेनी हुने विपद्का घटनाले सिन्धुपाल्चोक जिल्ला विपद्को "हट स्पट" को रूपमा देखिएको छ।

- मेन सेन्ट्रल थ्रस्ट (MCT) र मेन बाउण्डरी थ्रस्ट (MBT) जस्ता भौगर्भिक चिराहरु तथा दरारहरू सिन्धुपाल्चोक जिल्लामा पूर्व पश्चिम फैलिएर रहेका छन्। यस प्रकार यो जिल्ला भौगर्भिक चिराहरूबाट

घेरिएको छ । जिल्लाको बलेफी, बाह्रबीसे र तारामाराङ क्षेत्र मेन सेन्ट्रल थ्रस्ट (MCT) को आसपास पर्दछ । विगतका भूकम्पहरूको केन्द्रविन्दु र त्यसको घनत्वलाई समेत हेर्दा सिन्धुपाल्चोक जिल्ला सक्रिय भूकम्पीय गतिविधिहरूको क्षेत्रमा अवस्थित छ । यसकारण यस जिल्लामा भौगर्भिक प्लेटहरूको गतिशीलता, भौगर्भिक अवस्था र उच्च रूपमा हुने भू-आकृतिको परिवर्तनले भूकम्प, पहिरो, बाढी, भूक्षय जस्ता भूभौतिक प्रकोपहरु उत्पत्ति हुनमा सहयोग पुगेको छ । यस भन्दा बाहेक जलवायु परिवर्तनका कारण उच्च दरमा हिमनदी पग्लिने क्रम र हिमाली क्षेत्रमा हुने असरका कारण हिमताल फूट्ने खतरा बढेको र बाढी पहिरोको जोखिम बढाएको छ ।

- बहुप्रकोपको जोखिमयुक्त क्षेत्रमा धेरैवटा प्रकोपका घटना एकैसाथ हुने तथा एउटा प्रकोपले अर्को प्रकोप ल्याउने समेत गर्दछन् । उदाहरणको लागि २०७२ सालको भूकम्प पछि भूकम्पको कारण धेरै पहिरोका घटनाहरु भए । २०७३ सालमा भोटेकोशी जलाधारको तिब्वतीय क्षेत्रमा हिमताल विष्फोट हुँदा भोटेकोशी र सुनकोशीमा बाढी आयो । २०७८ मा भ्रेमाथाङ हेलम्बुमा गएको पहिरो र कटानले मेलम्चीमा लेदो सहितको बाढी आयो । जलवायु परिवर्तन तथा बढ्दो शहरीकरण र पूर्वाधार निर्माणको विस्तारले हिमाली तथा पहाडी भूगोलमा बहुप्रकोपको जोखिमलाई अझ बढाएको छ । सडक निर्माण गर्दा पानीको प्राकृतिक बहावलाई अवरोध गरेर सही तरीकाले व्यवस्थापन नगरिँदा पहाडी क्षेत्रहरुमा पहिरोका घटना बढिरहेका छन् । यस प्रकार एउटा र अर्को प्रकोपबीच सम्बन्ध हुने र एउटा प्रकोपले अर्को प्रकोप निम्त्याउने हुनाले बहुप्रकोप लेखाजोखा र अध्ययन एकैसाथ गरिनु आवश्यक हुन्छ ।
- सिन्धुपाल्चोक पहाडी तथा उच्च हिमाली भूगोलमा अवस्थित जिल्ला भएकोले यहाँको जमिनको ढाल अत्यन्त भिरालो छ । यस जिल्लाको ८० प्रतिशतभन्दा बढी जमिन उच्च ढालयुक्त छ । उच्च भिरोपन भएको भूभागमा सानो घटनाले मात्र पनि यसको गुरूत्वाकर्षण सन्तुलनमा फरक पर्ने वित्तिकै पहिरो तथा भूक्षयको जोखिम बढ्ने गर्दछ । जमिनको भिरालोपनसँगै माटोको किशिम, बर्षाको प्रवृत्त तथा र सघनता र नदी-नालाहरूको घनत्वले त्यस क्षेत्रको प्रकोप संकटासन्नता निर्धारण गर्दछ । त्यसैगरी मानव निर्मित बस्ती, सडक तथा भू-उपयोगको अभ्यासले प्राकृतिक पद्धतिलाई परिवर्तित गर्दछ । त्यस क्षेत्रमा बसोबास गर्ने जनसंख्या तथा पूर्वाधार संरचनाहरूको प्रकोप सम्मुखता बढ्छ र विपद् जोखिम बढाउँछ । खासगरी सिन्धुपाल्चोक

जिल्लाको उत्तरी क्षेत्र पहिरोको उच्च प्रकोपयुक्त क्षेत्र हो। जुगल, पाँचपोखरी र हेलम्बु गाउँपालिका पहिरोको उच्च जोखिम क्षेत्रको रूपमा देखिएको छ।

- यस अध्ययनको मुख्य उद्देश्य सिन्धुपाल्चोक जिल्लामा बहु प्रकोपको अवस्था को विश्लेषण गर्न GIS प्रविधिको प्रयोग गरि उत्पन्न हुन सक्ने संकट र त्यसको सम्भावनालाई मापन गर्ने हो। यस अध्ययनमा विभिन्न प्रकोप हरुको अध्ययन गर्न मिश्रित प्रबिधि प्रयोग गरि निर्णय मुखी नक्शांकन गर्न सहज भएको छ जसले प्रकोप अनुसारको संकटासन्नता नक्शा निर्माण गर्न सम्भब भएको छ। यस्तो नक्शांकनले एक प्रकोप को संकटासन्नता तथा बहु प्रकोपको संकटासन्नता पहिचान गर्न मद्दत गरेको छ। जसले गर्दा प्रकोप को क्षति न्यूनीकरण गर्न आवस्यक नीति निर्माण गर्न मार्गदर्शन गर्दछ।

- सिन्धुपाल्चोक जिल्लाको संकटासन्नता नक्शाङ्कन गर्न थुप्रै आधार र सूचकहरू लिइएको छ। यसको आधारमा हेर्दा जिल्लाको ११ प्रतिशत क्षेत्र बाढीबाट अति उच्च संवेदनशील, ५६ प्रतिशत क्षेत्र उच्च संवेदनशील, ३१ प्रतिशत क्षेत्र मध्यम संवेदनशील र १.४ प्रतिशत क्षेत्र मात्र कम संवेदनशील देखिएको छ।त्यसैगरी पहिरोको लागि ६.४६ प्रतिशत क्षेत्र अति उच्च संवेदनशील, ३४.४९ प्रतिशत उच्च संवेदनशील, ५०.६९ प्रतिशत क्षेत्र मध्यम संवेदनशील र ८.३४ प्रतिशत क्षेत्र न्यून संवेदनशील पाइएको छ भने आगलागीको हिसावले जिल्लाको ४.९२प्रतिशत क्षेत्र अति उच्च, ४६.७७ क्षेत्र उच्च, ३२.७० प्रतिशत क्षेत्र मध्यम र १५.५९ न्यून संवेदनशील देखिएको छ।

सिन्धुपाल्चोक जिल्लाको बहु-प्रकोपिय संकटासन्नता	
बाढी	
संकटासन्नता	प्रतिशत
न्युन	१.४५
मध्यम	३१.०२
उच्च	५६.०१
अति उच्च	११.५०
पहिरो	
न्युन	८.३४
मध्यम	५०.६९
उच्च	३४.४९
अति उच्च	६.४६

आगलागी	
न्युन	१५.५९
मध्यम	३२.७०
उच्च	४६.७७
अति उच्च	४.९२

- जिल्लाको बहुप्रकोपको अवस्थालाई अति उच्च, उच्च, मध्यम र न्यून संवेदनशील क्षेत्रमा विभाजन गरिएको छ। यसको आधारमा जुगल, हेलम्बु, पाँचपोखरी र भोटेकोशी गाउँपालिकाको धेरै भाग पहिरोको अति उच्च र उच्च जोखिमयुक्त क्षेत्रमा पर्दछ। त्यसैगरी बलेफी, बाह्रबीसे, चौतारा साँगाचोकगढी, मेलम्ची, त्रिपुरासुन्दरी र सुनकोशीका धेरै भूभाग बाढीको अति उच्च र उच्च जोखिमयुक्त क्षेत्रमा पर्दछन् भने चौतारा साँगाचोकगढी आगलागीको समेत उच्च जोखिममा रहेको छ।
- सिन्धुपाल्चोक जिल्ला विगतदेखिनै बहुप्रकोपबाट प्रभावित हुँदै आइरहेको छ। २०७२ सालको भूकम्प, त्यसपछिका पहिरो र २०७८ सालको मेलम्ची बाढीलाई हेर्दा यो जिल्ला कमजोर भूगर्भ र कमजोर भूस्वरूपमा अवस्थित रहेको देखिन्छ। बहुप्रकोप संकटासन्नताको अवस्था विद्यमान रहेको र जलवायु परिवर्तनको असर तथा विकास निर्माण कार्यले आगोमा घिउ थप्ने काम गरिरहेकोले भविष्यमा पनि यस प्रकारका प्रकोपका घटनाहरू हुन सक्ने सम्भावना पनि पनि उत्तिकै उच्च रहेको छ र भविष्यमा यस प्रकारका प्रकोपका घटना भइहालेमा त्यसको असर तथा प्रभाव पनि उच्च हुने देखिन्छ।
- सिन्धुपाल्चोक जिल्लामा पहिरो एक प्रमुख प्रकोपको रूपमा रहँदै आएको छ। पहिरोको विकास हुनमा दुइटा कुराहरू आवश्यक हुन्छ; पहिलो, पहिरो जानको लागि त्यस ठाउँको भूस्वरूप तथा भूगर्भ लगायतका संकटासन्नता वा विद्यमान संवेदनशीलता र दोस्रो, त्यसलाई बल पुऱ्याउने भारी बर्षा जस्ता तात्कालिक परिस्थिती। यसर्थ पहिरोको जोखिम लेखाजोखा गर्दा तथा पहिरो जोखिम न्यूनीकरण र नियन्त्रण सम्बन्धी योजना बनाउँदा वा कार्यान्वयन गर्दा यी दुइटा पक्षहरूलाई ख्याल गरिनु पर्दछ। यसकारण जमीनको भिरालोपना, नदी-नालाहरुको बहाव ढाँचा, घनत्व र सघनता, भूउपयोग अभ्यास , वन जंगलले ढाकेको क्षेत्र र भौगर्भिक स्थितिलाई प्रमुख आधार तथा सूचकको रूपमा लिएर सानो भौगोलिक क्षेत्र, गाउँपालिका वा नगरपालिका तथा वडा तहमा पहिरो जोखिमको विस्तृतमा अध्ययन लेखाजोखा र नक्शाङ्कन गर्न जरूरी छ।

- सिन्धुपाल्चोक जिल्ला सक्रिय भूकम्पीय दरार र चिराहरुले घेरिएको छ र सिंगो जिल्ला नै भूकम्पको उच्च जोखिममा रहेको छ । गाउँ वा नगर पालिका तथा वडा तहमा विस्तृत रूपमा भूकम्पीय माइक्रो जोनेसन र नक्शाङ्कन गरी भूकम्पको उच्च, मध्यम र न्यून जोखिमयुक्त क्षेत्र छुट्याएर यसका आधारमा मात्र बस्ती तथा पूर्वाधार एवं संरचना निर्माण योजना तर्जुमा र यसको कार्यान्वयन गरिनु पर्दछ ।

- सुनकोशी, भोटेकोशी, बलेफी, इन्द्रावती तथा मेलम्ची नदीका किनार क्षेत्र आकस्मिक रूपमा आउने बाढी तथा हिमताल विष्फोट भएर आउनसक्ने बाढीको उच्च जोखिममा छ । यो जोखिमयुक्त क्षेत्रमा सडक, जलविद्युत, खानेपानी लगायतका थुप्रै पूर्वाधारहरू र ठूलो बस्ती समेत रहेकोले बाढीबाट धेरै क्षति हुनसक्ने सम्भावना छ । यसकारण सम्बन्धित स्थानीय तहले विस्तृत रूपमा बाढी प्रकोप तथा जोखिम नक्शाङ्कन गरी प्रमुख नदीहरुमा बाढी पूर्वसूचना प्रणालीको विकास र विस्तार गर्नुपर्ने देखिन्छ ।

- सम्भावित विपद् जोखिम न्यूनीकरणको दीर्घकालीन आधार भनेको जोखिम संवेदनशील भू-उपयोग योजना तर्जुमा र यसको कार्यान्वयन हो । यसकारण जिल्लाका सबै स्थानीय तहले बहुप्रकोप लेखाजोखा र नक्शाङ्कनको आधारमा जोखिम संवेदनशील भू-उपयोग योजना बनाई जोखिम सुसूचित विकासको अभ्यासलाई कार्यान्वयनमा ल्याउनु पर्दछ । बहुप्रकोपको उच्च जोखिमयुक्त क्षेत्रमा बस्ती तथा पूर्वाधार विकासलाई निषेध गर्ने, मध्यम जोखिमयुक्त क्षेत्रमा नियन्त्रण गर्ने र न्यून जोखिमयुक्त क्षेत्रमा मात्र बस्ती तथा पूर्वाधार विकासलाई प्रबर्धन गर्ने नीति लिनु पर्दछ ।

- नेपालको संविधान तथा विपद् जोखिम न्यूनीकरण तथा व्यवस्थापन सम्बन्धी विद्यमान कानूनी व्यवस्थाले विपद् व्यवस्थापनलाई तीनबटै तहका सरकारको साझा अधिकारको रूपमा राखेकोले स्थानीय सरकारले प्रकोप, संकटासन्नता तथा जोखिमको लेखाजोखा गर्ने, आवश्यक नीति रणनीति तथा योजनाहरू तयार गरी कार्यान्वयन गर्ने, स्थानीय तह र समुदायको विपद् जोखिम व्यवस्थापन क्षमता सुदृढीकरण गर्ने र विपद् प्रतिकार्यका लागि आवश्यक पूर्वतयारीका कार्यहरू गर्न सक्दछन । आफ्नो क्षेत्रको प्रमुख प्रकोपहरूको आधारमा प्राथमिकता निर्धारण गरी आवश्यक नीति तथा कार्यक्रमहरु तर्जुमा गरेर कार्यान्वयन गर्ने तथा आफ्नो क्षेत्र बाहिर वा ठूलो स्केलका विपद्को लागि माथिल्लो र तल्लो जलाधार क्षेत्रमा रहेका स्थानीय तह तथा समुदायबीच समन्वय र संचारको संयन्त्र स्थापना गर्ने एवं जिल्ला, प्रदेश तथा संघीय सरकार सँगको

समन्वय र सहयोगबाट विपद् जोखिम न्यूनीकरण र पूर्वतयारीका कार्यहरूलाई प्राथमिकतामा राखेर कार्यान्वयनमा जानुपर्ने देखिन्छ । त्यसका लागि प्राथमिकताको आधारमा गर्नुपर्ने केही गतिविधिहरूको योजना समेत यस प्रतिवेदनमा सिफारिस गरिएको छ ।

- यस अध्ययनको क्रममा पहिचान भएका मुख्य पाँच चुनौतिहरु यसप्रकार छन् : १) भौगोलिक तथा भौगर्भिक तथ्यांक को कमि, २) नेपालको सानो क्षेत्रमा धेरै भौगोलिक विभिधता हुने हुनाले Digital Elevation Model को गुणस्तरमा थप सुधार हुन आवश्यक, ३) भौगोलिक तथ्यांक अध्ययन गर्न आवश्यक सबल प्रबिधि हरुको कमि, ४) जल तथा मौसम बिभागले मापन गर्ने मौसम सम्बन्धि तथ्यांकमा हुने अपूर्णता, तथा ५) नदीको बहाव मापन गर्न आवस्यक मापन केन्द्र हरुको कमि । यसले बैज्ञानिक तथा प्राबिधिक प्रबिधि लाई सिमित गर्दछ र यसको सुधार गर्न सके भविष्यमा गरिने बहु प्रकोपिया संकटासन्नता सम्बन्धि अध्ययन हरुमा उच्च सफलता हासिल गर्न सकिन्छ जसले सटिक विश्लेषण तथा सहि नीति निर्माण गर्न मद्दत गर्दछ ।

1 INTRODUCTION

1.1 Background

Nepal has a diverse topography, complex geology and highly varying climate, and is exposed to multiple natural and human-induced hazards. Located in the central Himalayas, Nepal is among the most disaster-prone countries in the world due to its geology, topography and climatic condition. Earthquakes, landslides, floods, fire, and thunderbolts are the major disaster events that caused damage in the past, weakening the fragile ecosystem of the country. Nepal ranks 4th in terms of climate risk according to the Global Climate Risk Index which assesses the impacts of meteorological events in relation to economic losses and human fatalities (Eckstein et al., 2020). According to the Central Bureau of Statistics, 2018, Nepal's population has surpassed 29 million people, of which almost 80% depend on agriculture-based livelihoods. Limited domestic economy, geographically scattered population, as well as diverse ethnic and indigenous communities, adds social vulnerability to disasters. More than 80% of the population is exposed to the multi hazard risk (MoHA, 2017). Economic Vulnerability Analysis shows that Nepal exhibits the huge losses due to large exposure at risk and the high level of hazards. These phenomena not only cause loss of lives and properties, but also pose severe threats to physical infrastructure, and disrupt economic development.

Nepal is situated in the central part of the Himalayas covering an area of 147,516 km2 and an elevation range from 58 m. to 8848.86 m. above sea level. Nepal has diverse climates due to the large variation in elevation. The climate varies from humid tropical type in the tropical lowlands in the south to alpine cold semi-desert type in the trans-Himalayan zone (Wangda & Ohsawa, 2006). The average annual rainfall is around 1000 – 2000 mm, but sometimes it exceeds 3000 mm in some lower parts of the country (Karki et. al., 2017). Nepal has a diverse geography that ranges from permanent snow and ice-covered very rugged Himalayan Mountains in the north to the tropical alluvial plains in the south. Due to variation in climate and topography, Nepal is classified into five physiographic zones i.e., Terai, Siwalik, middle Mountain, high Mountain, and Himalaya (Shrestha et al., 2010). About 75% of the total land area of 147,516 km2 is made up of mountains and hills. As a mountainous country, Nepal is most susceptible to precipitation extremes and related hazards, including severe floods, landslides, and droughts that cause huge losses of life and property, impact the Himalayan environment, and hinder socio-economic development of the country (Karki et al., 2017).

Nepal is exposed to most disaster types including earthquakes, floods, landslides, droughts, storms, avalanches, hailstorms, fires, lightning, road accidents, epidemics, and ecological hazards. A wide range of physiological, geological, ecological, meteorological, and demographic factors contribute to the vulnerability of the country to disasters. Major factors contributing to disasters are rapid population growth, slow economic development, a high degree of environmental degradation, fragility of the land mass and high elevation of the mountain slopes. Nepal is facing the fury of natural and human induced disasters with greater frequency and intensity. People in Nepal live with hazards, accepting them as their way of life. Disasters are so penetrative in every Nepalese geographic and societal framework that the people are constantly under the threat of a multitude of natural disasters. The earthquake of 1934, 1980, 1988, 2015 and the flood of July 1993, 2008, 2013, 2014 and 2017 are the most devastating disasters which not only caused heavy losses to human lives and physical properties but also adversely affected the development process of the country. The lessons of the 1988 earthquake and 2015 Gorkha Earthquake, 1993 flood and landslide, 2008 Koshi floods and 2013 floods and landslide in Far Western Region, 2014 flood and landslide in Mid-Western Region and 2017 floods and landslides in Eastern and Central Region have brought about a shift of attitude on the part of planners, government, development partners, NGOs and INGOs towards the need for a coordinated disaster preparedness and response mechanism. Fire is another disaster which occurs on a regular basis and wildfires are damaging to already severely depleted forests and biodiversity of Nepal which results in economic loss, land degradation and environmental pollution. Hence, Nepal is considered as the “hot spot” of disasters. If we analyse the disaster data of Nepal, we can perceive that the human and property losses are in increasing trend. This is basically due to the low level of preparedness (GoN, 2018).

Water induced disasters are the most devastating disaster in Nepal in terms of the number of deaths that occur and the damages they cause; and mostly Terai of Nepal faces most devastation due to flooding because of degraded Siwaliks and Hilly areas. Risk reduction that integrates interventions for reducing land degradation, flood, erosion control in upstream, inundation control in the downstream and early warning systems through the communication between upstream and downstream communities through upstream downstream linkage can be the better options for the reduction of the impact of water induced disasters: flood and landslide (Dhakal, 2013).

Bagmati Province in Nepal has faced multiple disasters that indicate the high vulnerability of the region. Although the epicenter of the 2015 Earthquake was at Gorkha, the biggest damage was recorded in Sindhupalchowk, Dolakha and Rasuwa. Multiple disasters in Sindhupalchowk including the Jure landslide in 2014, the earthquake of April 2015, Bhotekoshi flood 2016, Lidi Landslide in 2020 and

Melamchi Flood in 2021 have indicated a highly fragile landscape and high multi hazard risk of the district.

Increasing frequency of such disasters has created huge concerns as it causes huge loss of life and infrastructures. To safeguard the lives and infrastructure it is utmost urgent to understand the nature and risks of disasters that are susceptible in the province. As per Sendai framework, it requires all governments to equally engage in pre-disaster assessment to post-disaster responses for resilient societies, but adequate understanding of pre-disaster assessment is lacking. Due to this, understanding the disaster risk in a local context has been challenging.

1.2 Disaster Risk Reduction and Management Policy Frameworks

The Constitution of Nepal, 2015 embarked on a revised structure of governance and shifted to a federal system. It has created three tiers of government at the federal, province and local levels with significant authority of decision making, resources management and service delivery systems to provincial and local level. Over the years, the Government of Nepal (GoN) has made efforts to shift its focus from a reactive to a proactive approach to Disaster Risk Reduction and Management by strengthening legal frameworks, policy, strategy, planning, institutional capacities, and multi-stakeholder partnerships for DRRM. The Disaster Risk Reduction and Management (DRRM) Act, 2017; National DRR Policy, 2018; and National DRR Strategic Action Plan, 2018-2030 are the major legal and policy frameworks that are guiding proactive approach for multi hazard assessment and mapping in line with Sendai Framework for DRR (SFDRR). The DRRM Act, 2017 entails various provisions thereby providing new requirements for DRRM of the country in the recent global and national context. The DRRM Act has the provision of multi hazard and disaster assessment, mapping, planning and its implementation under the jurisdiction of the DRR Executive Committee. The DRRM policy has the provision of developing disaster risk assessment and multi hazard mapping systems.

The DRR National Strategic Action Plan presents a new roadmap for Nepal till 2030 and sets 32 targets, 18 priority actions, and more than 270 activities to strengthen the country's overall disaster risk assessment, risk reduction, disaster response and management capacity. The DRR National Strategic Action Plan, 2018 – 2030 has incorporated several activities related to risk assessment and hazard mapping. Hazard wise risk assessment is the first priority action out of the eighteen priority actions of the DRR national strategic action plan. Several strategic activities related to hazard wise risk assessment and mapping are incorporated in the strategic action plan including earthquake risk, epidemic, landslide, flood, road accident and other climatic risks. The strategic action plan has provisioned to consider the hazard, risk and vulnerability as a base for land use planning, to avoid settlement and infrastructure development in the high-risk areas, control moderate risk areas and promote settlement and infrastructure development only in low-risk areas.

The Bagmati province has endorsed the province disaster management act, 2018 that has the provision of province DRM council and province DRM executive committee. The province DRR executive committee has the role and responsibility of identification of disaster risk prone areas, hazard assessment and mapping.

1.3 The Context

Nepal has always been one of the most landslide-prone countries in Asia. "Between 1950 and 2009, the frequency of fatal landslides was highest in China, followed by Indonesia, India, the Philippines, Japan, Pakistan and Nepal," FAO, 2011 report says that "Those seven countries accounted for 87 percent of the 17,830 landslide-related fatalities reported in Asia between 1950 and 2009, and 82 percent of the 267 reported landslides." Even so, the frequency of landslides in Nepal has been constantly increasing. Many factors led to greater frequency of landslides mainly in hilly and mountainous regions. "Nepal is in the middle of the Himalayan region that is still in the making. Our landform is evolving so it is always vulnerable to landslides".

Rainfall variability (unequal rainfall in time and space), slope (Steep Mountain and flat Terai), Deforestation (decreasing vegetative cover) are the major factors contributing to the landslide and floods in Nepal. Nepal lies on the tectonically active zone and has a fragile geological structure are more susceptible for seismic hazards. Moreover, our current development practice does not factor in geological engineering and scientific surveys. Climate change is also causing more frequent and intense rainfall, triggering landslides in high hills and mountains of Asia.

Sindhupalchowk is especially vulnerable to the disasters. Among the numerous reasons contributing to landslides, include the prevalence of thrusts beneath the earth's surface—Main Boundary Thrust (MBT) and Frontal Back Thrust (FBT)—vegetation type, topography, culture and tradition of building construction in the sloped terrains in the hills, the earthquakes and the frequency of heavy rainfall are the major causes.

The earthquakes of 2015 have led the landmass to develop several fault lines, where the rainwaters seep through, making the soil loose and porous, and causing landslides. But besides that, road networks and their unsustainable approach to constructing these infrastructures without conducting proper technical research has contributed to the district being more prone to natural disasters in the last decade. A lack of proper drainage system is another reason for soil erosion in hilly terrains leading to frequent landslides.

1.4 Review of Past Disasters of Sindhupalchowk District

In the last decade Sindhupalchowk district was badly affected by a series of hazards. In the last 11 years from 2011 to 2021, a total 267 disaster incidents of different 8 disasters happened in the Sindhupalchowk district. Earthquake, landslide, flood, fire, thunderbolt, windstorm, heavy rainfall and animal incident are recorded as frequently repeated disasters in the district. In the total incident numbers fire, landslide and thunderbolt are the top three frequently repeated disasters. In terms of human casualty, the earthquake, landslide, and thunderbolt rank in top three devastative disasters. Similarly, the landslide, flood and earthquake rank in top three disasters for missing people. Earthquake, landslide and flood are major three disasters causing building damage.

Table 1: Disaster loss and damage in last 11 years (2011 – 2021) in Sindhupalchowk district

SN	Disaster Incident	No. of Incident	Total Death	Missing People	Affected Family	Injured	Govt. Houses Damaged	Private House Damaged
1	Earthquake	1	3570	8		1569	747	92635
2	Landslide	66	128	161	684	95	0	274
3	Thunderbolt	33	17	0	20	63	0	2
4	Fire	120	13	0	115	15	0	81
5	Flood	30	11	24	230	8	2	571
6	Windstorm	8	3	0	31	3	0	27
7	Animal Incidents	2	0	0	2	2	0	0
8	Heavy Rainfall	7	0	0	12	1	0	4
	Total	**267**	**3742**	**193**	**1094**	**1756**	**749**	**93594**

Data source: http://www.drrportal.gov.np/

The past disaster events and loss and damage data shows that the earthquake, landslide, flood, fire and thunderbolt are major top five disasters in the Sindhupalchowk district. It also shows that the district is prone to the multi hazards; seismic hazards (earthquake and landslide), hydro meteorological and climatic hazards (flood, landslide and thunderbolt), human induced hazards (fire). The Jure landslide 2014, Gorkha earthquake 2015, Bhotekoshi Flood 2016, Tatopani Bhotekoshi flood and landslide; and Lidi

Landslide 2020; and Melamchi flood 2021 are the major disaster events of the last decade in Sindhupalchowk. Similarly fire and thunderbolt are the frequently repeated disasters in the district.

1.4.1 Jure landslide 2014

On Aug. 2, 2014, a landslide occurred after heavy rain about 16 km downstream of the powerhouse on the Sunkoshi River, at Jure. The landslide was situated on the right bank from river level at El. 795 m to the top of the scarp at El. 1500 m and was 1.3 km long and 850 m wide at its base. The rapid slope failure of soil and rock flowed downslope and across the valley and up onto the opposite bank, damming the river. The Jure landslide had an estimated volume of 6 million m3. The landslide dam created was about 400 m long (east-west), 105 m at the base, and 30 to 35 m high, which created a lake 3 km long and about 200 m in width, with a volume of 8.6 million m3. The devastation caused by the landslide and damming of the river led to at least 156 fatalities. The Jure landslide killed 145 people and injured 15. It had swept away 113 houses and affected 319 families. The same year, landslide of Jalbire Khamare on August 25, 2014, killed five people and buried 18 houses.

Figure 1: Landslide in Mankha village, (Jure) Sindhupalchowk 2014 (Sources: Online News)

1.4.2 Gorkha Earthquake 2015

Sindhupalchowk is one of the worst-affected districts by the 2015 Gorkha earthquake. The entire district has faced high earthquake impact. The district suffered major damages in the earthquakes of 1988 and 2015. The earthquake of 2015 had caused the loss of 3,557 lives and injured 1,569 people, and INSEC had documented damage of 67,383 households. While the initial epicenter of the earthquake was in Gorkha district, the highest magnitude (6.7) aftershock took place in Sindhupalchowk district 17 km south of Kodari (USGS 2015). Based on government reporting on damaged houses as of 6th May an estimated 109,000 people (Ministry of Home Affairs 7th May) are affected (40% of district population as per the 2011 Census). Around 90,000 people have been identified as in need of assistance based on reporting at the VDC level.

Figure 2: Sindhupalchowk Earthquake 2015 (Source Online News Agencies)

1.4.3 Bhotekoshi Flood 2016

The district has also been affected by floods frequently. A flood in Bhotekoshi on July 5, 2016, had caused major damage to physical property, swept away three people and damaged different sections of the

Kodari Highway to Nepal's border with China. After three months of opening the Nepal-China border, floods swept away the road from Barhabise to Liping. It had also swept away 98 houses and damaged 945 houses. The flooding resulted from several natural factors and was exacerbated by human-made factors such as haphazard construction of infrastructure and unscientific road construction.

During the 2016 flood, the BhoteKoshi River peaked at about 3.5 m above the top of the Bhotekoshi dam and at about 1.7 m above the powerhouse yard. The river discharge may have peaked at about 2,576 m3/s based on measurements made in the river basin upstream of the head works. The debris-laden flood occurring in July 2016 cascaded over the Upper Bhotekoshi dam and head works after failure of the desanding basin. Sindhupalchowk continues to get battered by natural disasters every year. More than 400 households across the district were displaced by the disasters in a week during July 2020, rendering them homeless and in immediate need of rehabilitation. Thirty-six houses were swept away by floods and landslides in Jambu, Khagdal, and Barkute on July 9, 2020, where 3 dead bodies were recovered whereas 20 went missing in the flooded Bhotekoshi River.

Figure 3: Damaged dam of the Upper Bhotekoshi Hydropower Project after flooding on 5 July 2016 on the Bhotekoshi River in Sindhupalchok district and flood caused in the downstream. (Sources: News Media)

In August 2020, a massive landslide struck Lidi village, destroying 17 houses and damaging 37 others. As many as 39 villagers' perished and 135 families were displaced in the disaster. At least 11 people died, and 20 others were missing when a landslide caused by heavy rainfall swept 22 houses in Gumthang, Bahrabise Municipality Ward No 7, Sindhupalchowk, on September 12, 2020.

1.4.4 Recent Landslides

Other landslides that have occurred in the district include one at Melamchi Bazar on August 3, 2020, which killed nine workers and buried a house. Another at Baruwa of Thampal Rural Municipality on August 3 had killed two and damaged five houses. Similarly, 32 houses were affected by the landslide in Thumpakhar of Sunkoshi Rural Municipality on August 30. Another landslide at Barhabise Municipality on August 30, 2020, had killed 17, injured nine, buried 14 people, and swept away 27 houses. The land at all locations mentioned above have deep fractures and is still fragile. However, people continue to live in those areas for a lack of proper management of the people who were affected.

Sindhupalchowk is one of the hardest-hit districts by natural disasters. As many as 73 people died in different landslides in Bahrabise Municipality, Melamchi Municipality, Bhotekoshi Rural Municipality and Jugal Rural Municipality in 2021 alone; forty-two people went missing in those landslides. In 2021, landslides destroyed 130 houses and displaced 3,290 people in the district.

Figure 4: Bhremathang Landslide in Helambu 2021 (Sources: social media)

1.4.5 Melamchi Flash Flood 2021

On 15 June, the Melamchi faced heavy flash flood from two tributaries – the Melamchi and Indrawati rivers – which resulted in 5 deaths and 20 missing persons along with heavy damage to the Melamchi water supply project in Helambu damaging infrastructures and destroying lives while cutting off road access to several villages. On 15 June, a massive flood wreaked havoc on towns and cities along the Melamchi River in central Nepal's Sindhupalchowk district, 40 kilometres northeast of capital Kathmandu. At least six people were killed and 20 more were missing. Hundreds of houses were washed away.

Figure 5: Aftermath of Flash flood in Melamchi 2021 (Sources: Online news media)

Sindhupalchowk is one of the hardest-hit districts by natural disasters. As many as 73 people died in different landslides in Bahrabise Municipality, Melamchi Municipality, Bhotekoshi Rural Municipality and Jugal Rural Municipality in 2021 alone; forty-two people went missing in those landslides. In 2021, landslides destroyed 130 houses and displaced 3,290 people in the district.

1.5 Objective of the Study

The main objective of this assignment is to conduct multi-hazard and vulnerability assessment and hazard mapping of Sindhupalchowk District, Bagmati Province to provide a basis from which local government, policy makers, other agencies and responders can create or update the regional emergency plan, allocate resources for risk mitigation, enhance community preparedness, and prepare budgets for cost-effective, on-going emergency planning. The specific objective of this assignment is follows:

1) To conduct multi hazard and vulnerability assessment and hazard mapping for identifying, prioritizing and allocating resources to vulnerable populations in high-risk areas for risk reduction, safe evacuation, rescue, relief and rehabilitation activities.
2) To prepare the multi hazard maps based on the hazard assessment of the rural/urban municipalities in Sindhupalchowk district.
3) To identify high multi hazard risk zones based on disaster susceptibility mapping using GIS and RS based models.
4) To measure socio-economic vulnerability of the population based on hazards and susceptibility.
5) To prepare an indicative disaster management plan to guide local and provincial governments.

2 Study Area: Sindhupalchowk District

Sindhupalchowk district is one of the districts of Bagmati province located in the northern part of the province. Sindhupalchowk district is divided into 12 local levels including 3 municipalities and 9 rural municipalities. Chautara is the headquarters of the district. Sindhupalchowk is the biggest district in regard to area with 2,542 km2 in the Central Development Region among 19 districts and it has covered 1.73% area of Nepal. This district is situated 86 kilometres from Kathmandu in east/north direction. The district has been distributed from 746 meter (2,450 feet: Sunkoshi riverbank of Chautara Sangachowk municipality) above from sea level to 7,083 (23,238 feet: Langpoghyan peak) altitude and the altitude of the district headquarter- Chautara is 1,418 meter. The average east-west width of the district is 49.38 km; whereas, the north-south length is 53.06 meter. The district is bounded by Dolakha District and Tibet in east; Nuwakot and Rasuwa Districts in west; Rasuwa District and Tibet in north and Kavrepalanchowk, Kathmandu and Ramechhap Districts in south.

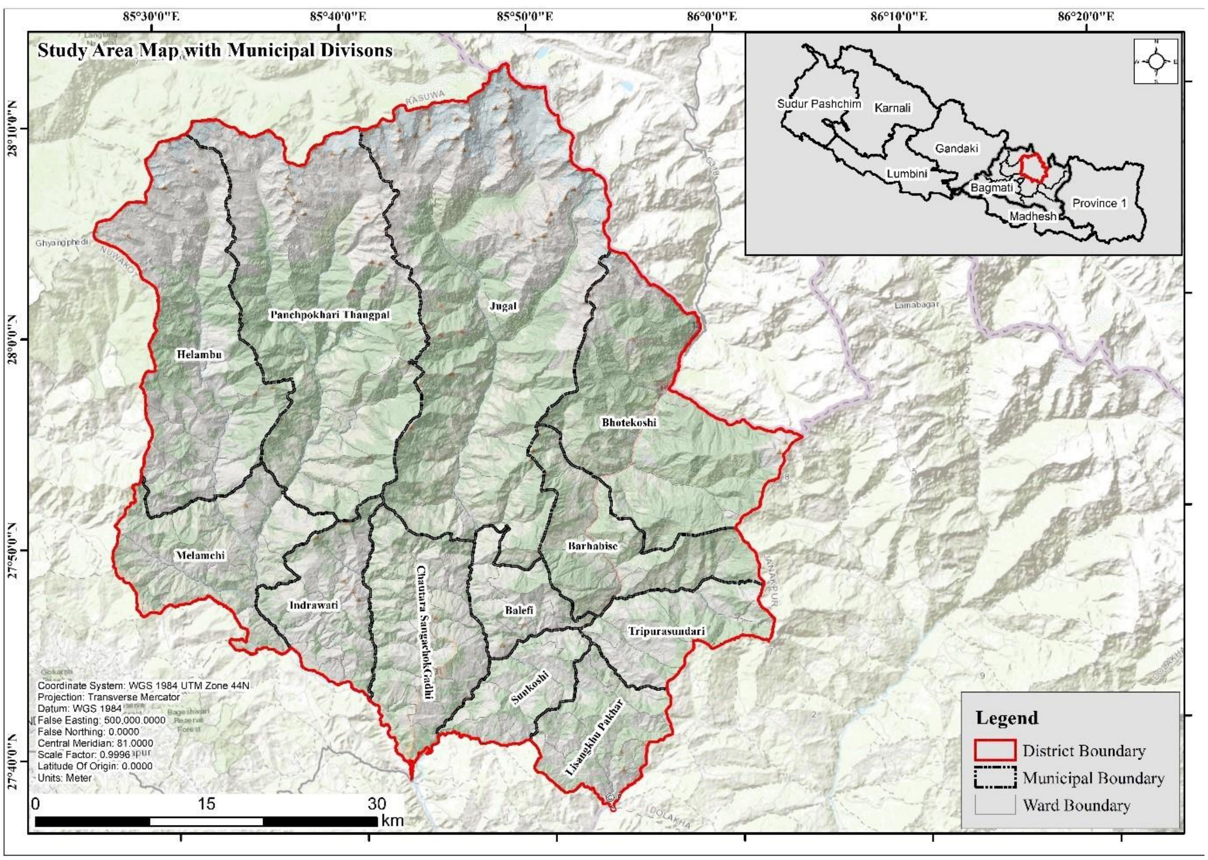


Figure 6: Map of Sindhupalchowk District

2.1 Geophysical Environment

2.1.1 Geology of the district

The Himalayas are considered one of the most active yet fragile mountain ranges because it still rises through moving Indian Plate and Tibetan blocks and its rocks are geologically weak. The frequent seismic movement and monsoon rainfall make it even more prone to disasters. Based on geographical structure of this district, it can be classified in 4 groups: 1) Himalayan region (16,000 to 23,238 feet), 2) Mountain region (7,000 to 16,000 feet), 3) Hilly region (5,000 to 7,000feet) and 4) lowland plain region (2,450 to 5,000 feet). As Himalayan and high mountains are in the northern part of the district, those areas have less possibility of agriculture. In regard to the land slope situation of this district, the maximum area has been covered by 20–30-degree slope (37.5%), and in accordance with, 24.6% by 30-40 degree slope, 22.5% by 10-20. Geologically young and tectonically active Himalayan Range is characterized by highly elevated mountains and deep river valleys.

Geologically, Himalayas consist of several physiographic units including Terai (part of Indo-Gangetic plain), Bhavar Tract, Siwalik Range/Chure (outer Himalaya), Dun/Inner Terai, lesser Himalaya/Mahabharat Lek, Midland Valley Region, Greater or High Himalayas, High Himalayan Valleys and Trans-Himalaya (Tibetan Tethys zone). The Sindhupalchowk district includes lesser Himalaya/Mahabharat Lek, Midland Valley Region, and Greater or High Himalayas. Each of the geological zones is characterized by diverse lithology, tectonics, structures, and geological history. These all-tectonic zones are separated from each other by the thrust faults viz. Main Frontal Thrust (MFT), Main Boundary Thrust (MBT) and Main Central Thrust (MCT).

Geologically the area is recognized as the central Nepal geological zone that includes the area between Dudhkoshi River in the east and Marsyangdi River in the west. Especially, main tectonic zones of this district include the following units from north to south.

- The higher Himalayas are composed of crystalline rocks.

- The lesser Himalayas are composed of low-grade meta-sedimentary, autochthonous to allochthonous rock units. This zone includes the midlands and Mahabharat ranges.

The geology of the Central Nepal around and north-east of Kathmandu was first studied by Medlicott (1875). The other geologists who studied the geology of the area profoundly are Auden (1935), Hagen (1951, 1969), Hashimoto (1959, 1973), Stocklin & Bhattarai (1977), Stocklin (1980) etc.

Due to weak geological formations of Lesser Himalayan rocks, Active Mountain, rugged topography, torrential rainfall, landslides and debris flow are common phenomena in the major river's catchment area in the district, causing severe loss of lives and property from time to time. In addition to their direct impact, landslides and debris flows trigger flooding. If large amounts of material from landslides or debris flows reach a river, they can temporarily block its flow, creating a reservoir in the upstream reach. This phenomenon has also been seen in Jure landslide; however fortunately timely management of debris has made it safe to the downstream part. The recent flood in the Melamchi River was a flash flood that lost many people, houses and other important infrastructures. As the reservoir level rises due to river flow and overtops the dam crest, sudden erosion of the dam can cause an outburst. Overtopping can also be caused by secondary landslides falling into the reservoir. Internal instability of the dam might trigger an outbreak even without overtopping. Outburst events are generally random and cannot be predicted with any precision. Such a flood, commonly known as a landslide dam outburst flood (LDOF), scrapes out beds and banks causing heavy damage to the riparian areas and huge sedimentation in downstream areas.

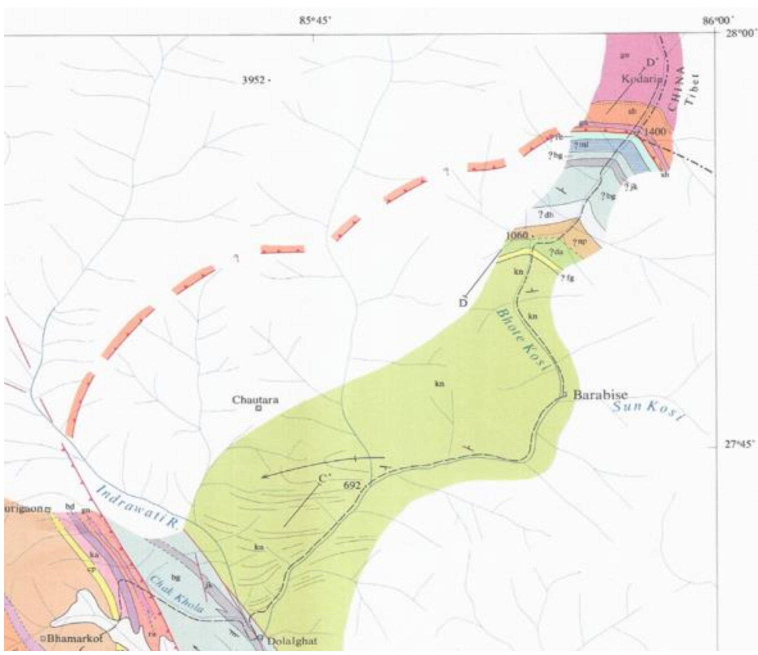


Figure 7: Geological Map of the North-Eastern area of Sindhupalchowk District (Source: Department of Mines and Geology, Govt. of Nepal)

As geology of the district lies in the Lesser Himalayan and Higher Himalayan Zones, the district almost surrounded by the Main Central Thrust (MCT) as the district area is existed as window as geological terms "clippe" form. The regional geology indicates that northern areas are in crystalline rocks with higher proportions of schists in the southern section and gneiss. The area is characterized by the rocks around the MCT mainly consisting of dark gray feldspathic schist and banded gneiss with garnet and kyanite. The moderately (35°–50°) northwest dipping Main Central Thrust passes through Majhitar, south of the Sindhu Khola, and crosses the Indrawati River in the south. The thrust is characterized by an approximately 50 m thick granitic–chlorite schist zone that rests over a 25 m thick fine-grained white quartzite band underlain by the Benighat slates of Lesser Himalaya. The garnet–chlorite schists are followed upwards by the kyanite– garnet schists, belonging to the northern part of the MCT.

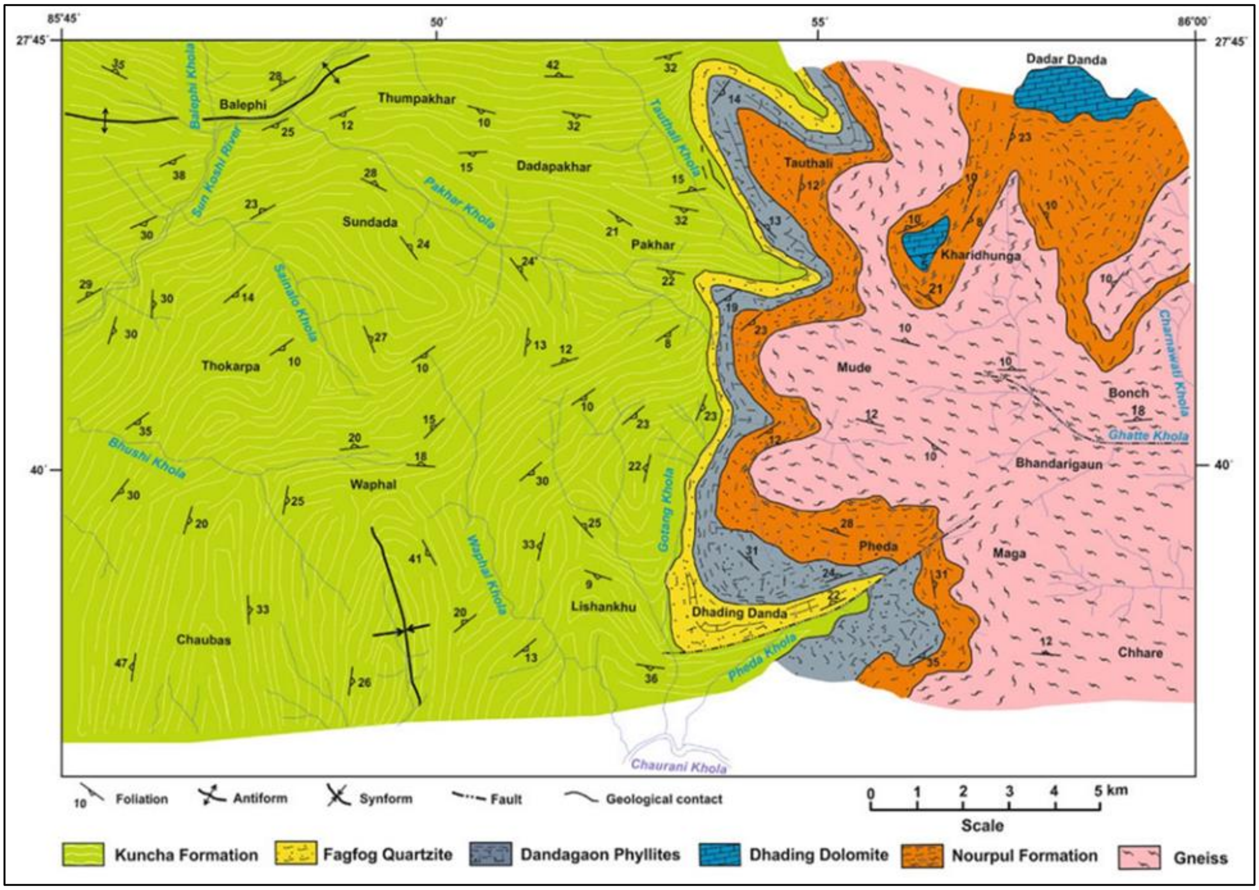


Figure 8: Geological Map of (Eastern area of the district) Kharidhhunga Area (Dahal and Adhikari 2001)

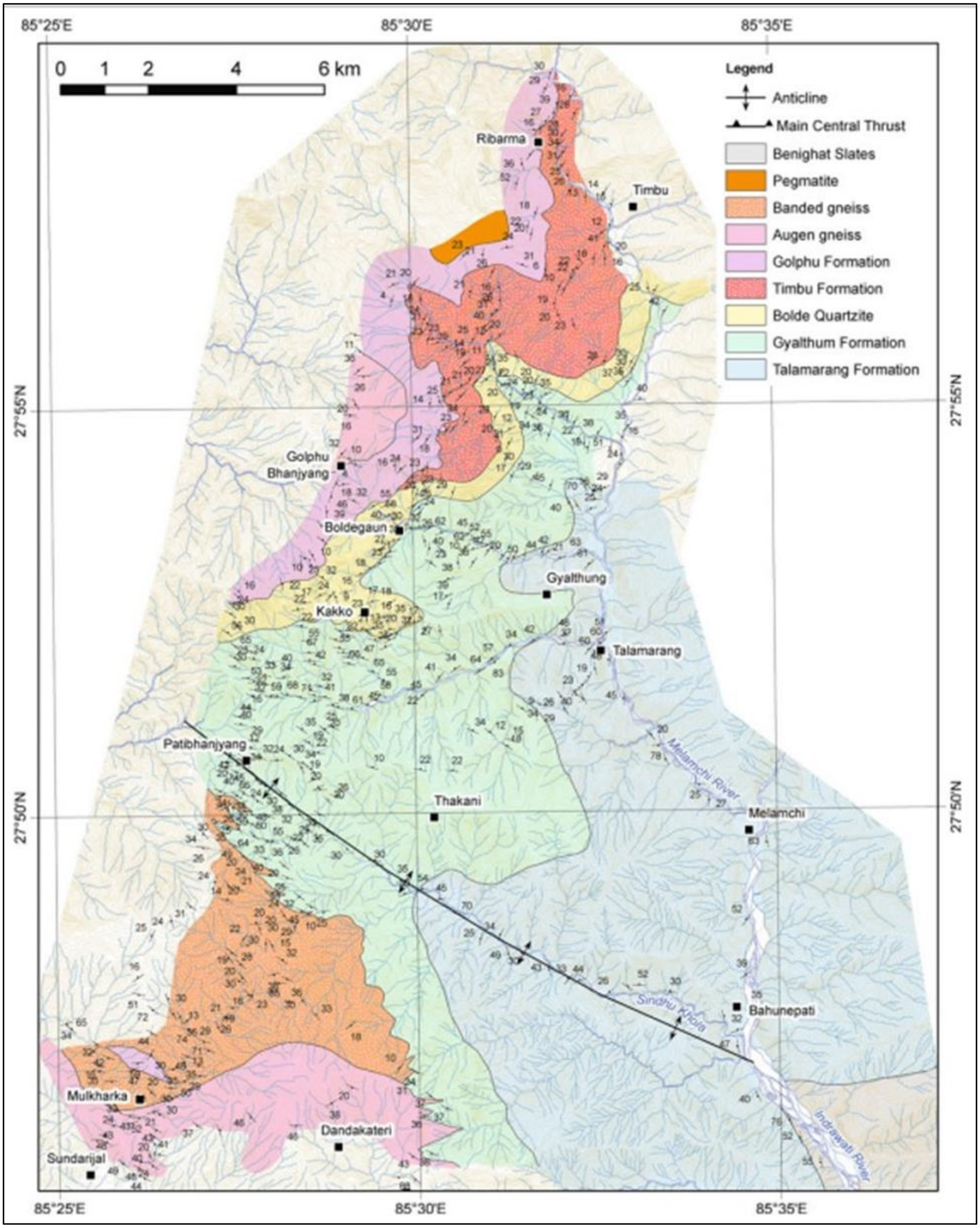


Figure 9: Geological Map of Kathmandu-Melamchi area

There are rock exposures in and around the district. Most rock exposures are noticed along the Sunkoshi, Indrawati, Balephi and Melamchi rivers and other tributaries and gullies of southern and northern facing slopes. The rocks around the study area are weathered to be fresh metamorphic with major three sets of discontinuities. The soil in the project site comprises colluvium, residual, and alluvium. The thickness of the soil around the area is about 1-4 m, followed by the weathered rock after the regolith. The geological features and conditions within the district area are reflected in the geomorphological characteristics. Geological structures and lithology control the main geomorphic features of the area. Steep slopes are observed along the river and streams. The gentle slopes with smooth ridges are seen in the thick colluvial debris deposits and residual soil deposits. The major geomorphic features of the area include residual soils, talus deposits, active gullies, and colluviums. The Sunkoshi, the Indrawati, the Balephi and the Melamchi rivers and their tributaries are the major drainages of the area, and the dendritic drainage pattern is the most common in the area.

Table 2: Slide potential of Rock of Nepalese Mountains (source Krahenbunl J. and Wagner A., 1983)

Group	Rock Type of Nepal	Lithological Slide Potential
I	Slate, phyllite and schist, closely interbedded respected with calc-slate, clac schist, lime stone, dolomite and dolomitic quartzite.	Very High (LCPS 16)
II	**Slates, phyllites and schists**	**High (LCPS 10)**
III	**Slates, phyllites and schists closely interbedded respect with quartzite and gneiss**	**Medium (LCPS 5-10)**
IV	Gneiss	Medium to Low (LCPS 1-5)
V	Quartzite	Low (LCPS 1)
VI	Massive Lime stone and dolomite	Very Low (LCPS 0-1)

2.1.2 Faults

The active faults are the major trigger to develop the landslides because of its movement during the seismic event and plate tectonic movement. The major geological unit separators are the thrusts; these are the low-angle reverse faults. During the time of the formation of the Himalayas in the northern part of Nepal, two fault lines were formed in the district and they are

1. Main Central Thrust (MCT)

2. Main Boundary Thrust (MBT)

There is a long fault line that has created anticline and syncline in around the Balephi river area and Barhabise area, Taramarag area, and upper part of the Barhabise area falls in Main Central Thrust. The dynamics of plate movements together with diverse geological conditions and a high degree of topography change in the district have contributed to the evolution of geological hazards, most prominently earthquakes, landslides, floods, soil erosion, and debris flow. Apart from this, the high rate of glaciers melting due to global warming has posed a serious threat to Glacial Lake outbursts as well. However, the amount of risk of all these hazards is not the same throughout the district.

Besides these major thrusts, there are few active faults as shown in Figure above, Northern side of the district in Higher Himalayas zones and few on western part and the eastern part of the district. The continuation length of these faults varies from 25 km to 150 km. Most of the active faults extended towards east-west direction except few north-south extensions. These fault lines exhibit the probability of landslides if a driver or trigger event has occurred. Mainly MCT lies in the district. This fault line exists in East West Direction crosses in the northern region of the district which makes this district prone to earthquakes.

2.2 Lithology and Landform

The area is entirely covered with residual, colluvium and alluvial soils with exposure of weathered to fresh rocks. The geological features and conditions within the area reflect the geo-morphological characteristics. The main geomorphic features of the area are controlled by geological structures and lithology. Steep slopes are observed along the slate, semi-schist, sandstone, phyllitic quartzite and gneiss cliffs and the cut bank of the streams and gullies. The gentle slopes with smooth ridges are seen on the thick colluvial debris deposits and residual soil deposits area. The major geomorphic features of the area include talus deposits, active gullies and rills. The few major streams and its tributaries are the major drainages of the area, and the dendritic drainage pattern is the most common in the area.

The study area comprises mostly residual soil, colluviums with little alluvial. The most of land that has settled is made up of residual soil and colluvium underlain by highly to moderately weathered metamorphic rock. The rock type is meta-sandstone and phyllite with northeast dipping rock faces. The area comprises the yellowish gray coloured residual soil with little rock fragments of 0.1-5 m of thickness as overburden soil underlain by regolith and weathered rock. The most encountered rocks are phyllite, metasandstone, slates and carbonates with different geomorphic structures. Slide potential classification (Krahenbunl & Wagner, 1983) of Rock for Nepalese Mountains also shows the area lies on Group II, II and III as per the composition of the rock. The represented groups have medium to high lithological slide potential. In addition, the unstable and stable lands can be classified based on geological structures, existing physical condition and the types of the rocks. Therefore, the chances of the potential slide are considered as different as in location-by-location cases.

In most of the rock exposure, slightly to moderately weathered rock with three sets of joints are observed. The road along the colluvial deposit has many small slides due to the toe cutting on newly constructed and existing roads and trails. As a result, boulder gravelly soil with little fines are the contents of the sliding debris on the toe of the landslide (debris slide). The rock fragments on the slide material also vary in sizes from silt to boulder.

2.2.1 Major rivers and fluvial geomorphology

The Sunkoshi including Bhotekoshi, Melamchi, Indrawati and Balephi are the major rivers in the district. The Sunkoshi is a trans-boundary river that originates in Tibet Autonomous Region and is part of the Koshi or Saptakoshi River system in Nepal. In Nepali language, the word "sun" means gold and golden; and the word "kosi " means river.

The Sunkoshi's headwaters are located in the Zhangzangbo Glacier in Tibet. Its upper course, the Bhote Koshi, is known as Poiqu in Tibet. The catchment area of the Sunkoshi basin is about 19,000 Km2. The Sunkoshi River originates in the mountain range east of Barhabise called Kalinchowk, and flows in a westerly direction with steep river gradients of 1:10 to meet the Bhotekoshi at Barhabise. The Bhotekoshi originates from a glacier on the south slope of Mt. Xixabangma Feng, in the southern part of the Himalayan range in the Tibetan plateau. The catchment area at the confluence point is about 2,375 km2 of which about 2000 km2 lies in Tibet. The average gradient in the upper reach is 1:8, while in the lower reach it is about 1:31.

The Sunkoshi flows in a south-east direction up to Dolalghat, the confluence point of the Sunkoshi with the Indrawati River, with an average gradient of 1:130. The Indrawati River, one of the main tributaries of the Sunkoshi River, originates in the Himalayan range and flows in a south, south-east direction to meet with the River Sunkoshi at Dolalghat. The average gradient of this river is about 1:34 in the upper reach and 1:194 in the lower reach. The total catchment area of the Indrawati at the confluence with the Sunkoshi River is about 1,175 km2. The Sunkoshi River, after the confluence with Indrawati River, flows in a south-east direction with an average gradient of 1:450.

2.3 Geography and Land use

The Himalayas are among the highest mountain ranges on earth. It is considered one of the most active yet fragile mountain ranges because it still rises through moving Indian Plate and Tibetan blocks and its rocks are geologically weak. The frequent seismic movement and monsoon rainfall make it even more prone to landslides. Thus, Nepal, including the mountain region, is extremely vulnerable to the disasters.

Based on geographical structure of this district, it can be classified in 4 groups: 1) Himalayan region (16,000 to 23,238 feet), 2) Mountain region (7,000 to 16,000 feet), 3) Hilly region (5,000 to 7,000 feet) and 4) lowland plain region (2,450 to 5,000 feet). As Himalayan and high mountains are in the northern part of the district, those areas have less possibility of agriculture. In regard to the land slope situation of this district, maximum area has been covered by 20–30-degree slope (37.5%), and in accordance

The total land area of Sindhupalchowk is about 2542 sq.km, out of which agricultural land is 737.10 Sq. km (29.0%). Similarly, snow covered land, forest, grazing land, barren, bush cover land, water bodies and others are 47.00 Sq. Km (1.85%), 775.67 Sq. km. (30.51%), 118.23 Sq. km (4.65%), 456.15 Sq. km (17.94%), 2.34 Sq. km (0.10%), 322.53 Sq. km (12.69%), and 53.91 Sq. km (2.12%) respectively.

2.4 Climate

Sindhupalchowk lies partly in the Mid-Hill and partly in the High-Hills/Mountain. The lowest point of Sindhupalchowk is Banditar/Majhigaun Sunkoshi basin 747 m in Sanghachok and the highest peak is Langpoghyang 7085 m from mean sea level. On the basis of altitude, the district is classified in 4 types of climate as follows; a) Semi-tropical climate (2,450 to 7,000 feet), b) Subtropical climate (7,000 to 13,000 feet), c) Alpine climate (13,000 to 16,000 feet) and d) Nival/Himalayan (Himali) climate (above 16,000 feet). The rainy season is generally from June to August, and the average annual rainfall in Sindhupalchowk District is 1,615 millilitres; whereas, maximum average temperature is 32.5 degree Celsius and minimum average temperature is 5 degree Celsius.

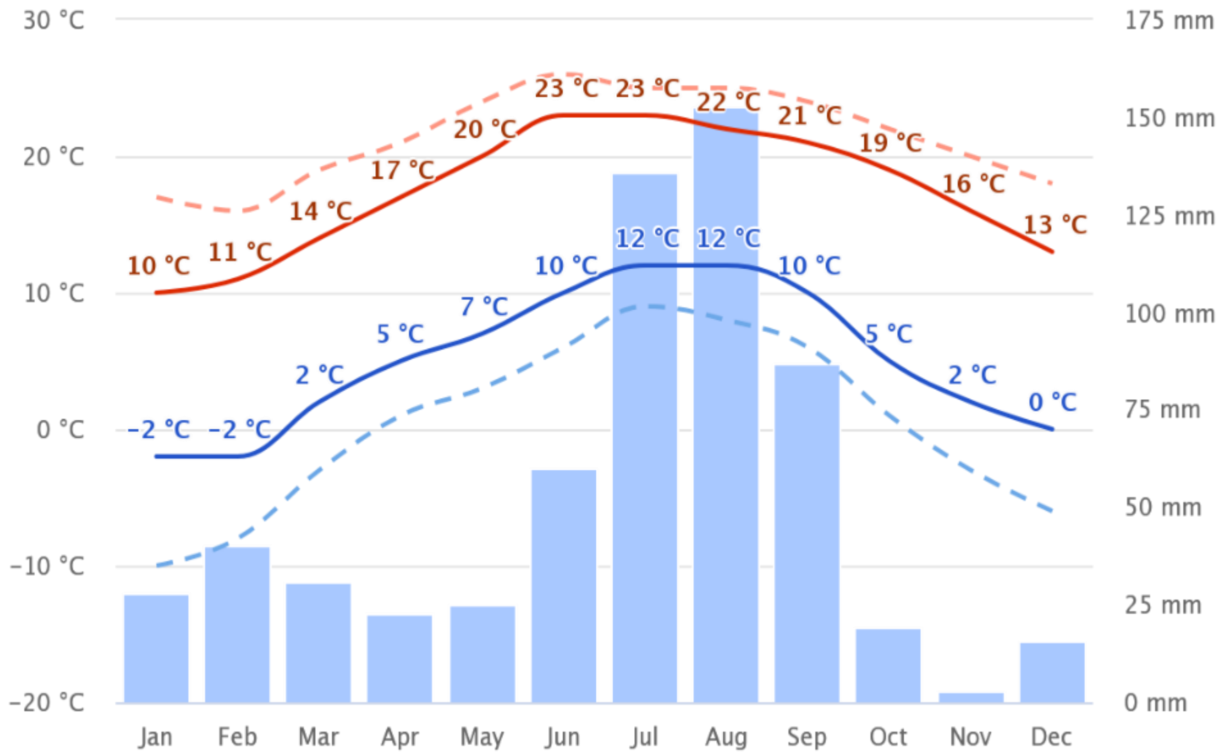


Figure 9: Temperature Scenario of Sindhupalchowk District

The "mean daily maximum" (solid red line) shows the maximum temperature of an average day for every month for Sindhupalchowk. Likewise, "mean daily minimum" (solid blue line) shows the average minimum temperature. Hot days and cold nights (dashed red and blue lines) show the average of the hottest day and coldest night of each month of the last 30 years. Blue Columns show the Average Daily Precipitation which increases from June till September with peak during July and August during the monsoon season.

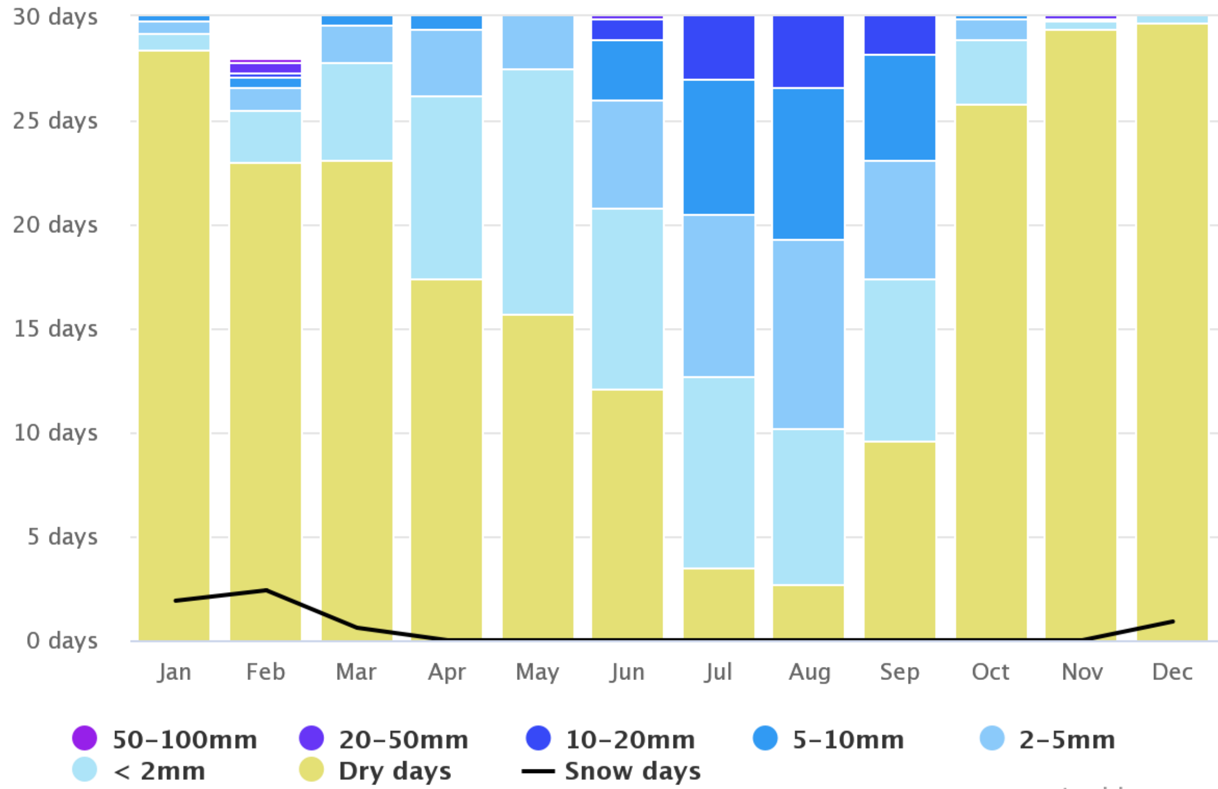
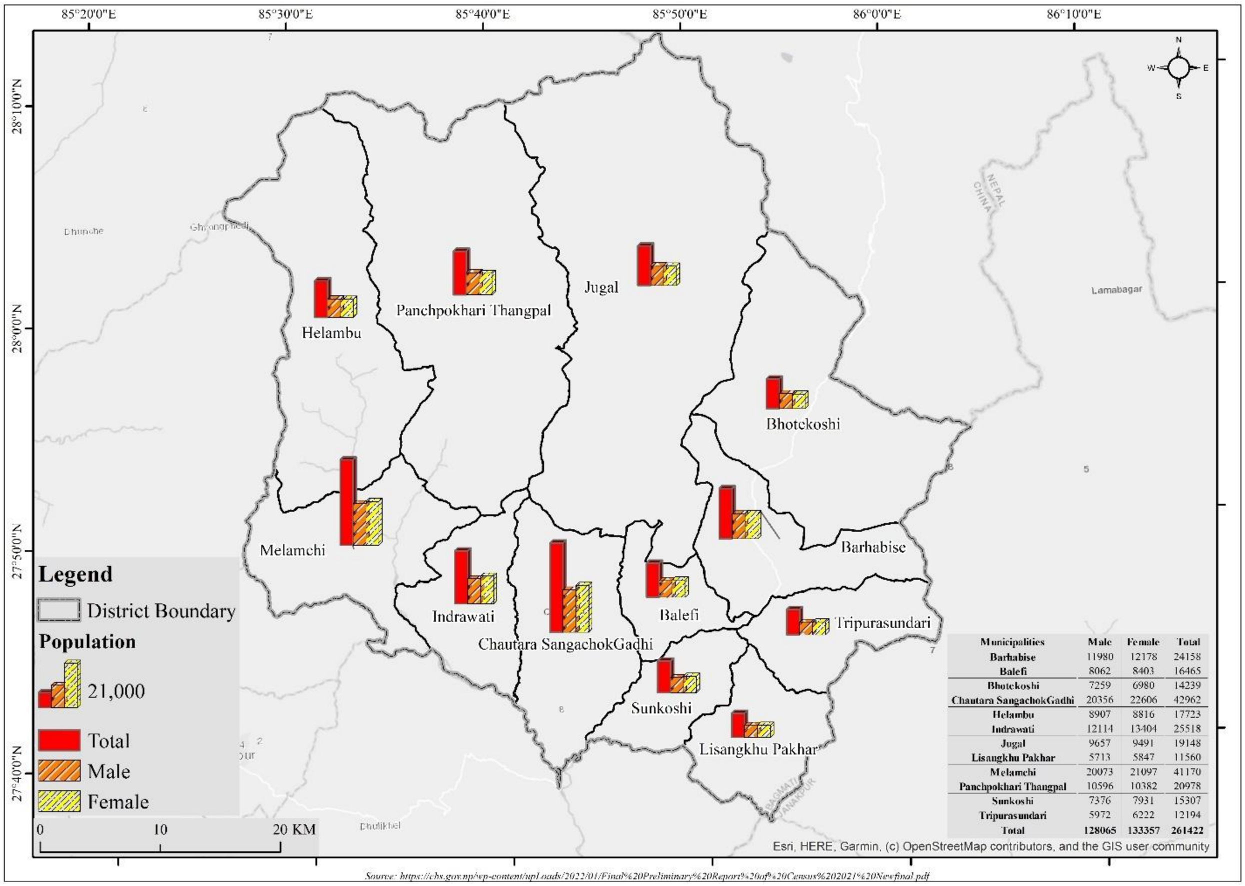


Figure 10: Precipitation distribution Diagram for 12 months in Sindhupalchowk

As per the chart of precipitation distribution, monsoon season has above 20 days of wet days per month with more than 10 mm of precipitation. This is when the peak rainfall arrives sometimes reaching above 150 mm of rain per day mainly during June to September.

2.5 Socio-Economic and Development Profile of the District

Sindhupalchowk is the largest district of the Bagmati province. The district has 2542 Sq. km area and the district is divided into 12 local levels. There are 3 municipalities and 9 rural municipalities and are further divided into 110 wards. The Census 2011 estimated that the population of Sindhupalchowk District is about 288,000 while the population of male and female is about 138,000 and 149,000. The household number is 66,635 and the number of people per household is 4.32. According to the Census 2011, the forecasted population of Sindhupalchowk District in 2021 is about 295,000 and in 2031 is forecasted to increase to 307,000.



Municipalities	Male	Female	Total
Barhabise	11980	12178	24158
Balefi	8062	8403	16465
Bhotekoshi	7259	6980	14239
Chautara SangachokGadhi	20356	22606	42962
Helambu	8907	8816	17723
Indrawati	12114	13404	25518
Jugal	9657	9491	19148
Lisangkhu Pakhar	5713	5847	11560
Melamchi	20073	21097	41170
Panchpokhari Thangpal	10596	10382	20978
Sunkoshi	7376	7931	15307
Tripurasundari	5972	6222	12194
Total	**128065**	**133357**	**261422**

Source: https://cbs.gov.np/wp-content/upLoads/2022/01/Final%20Preliminary%20Report%20of%20Census%202021%20New final.pdf

Figure 11: Population Distribution Map (Census 2011)

Tatopani, Barhabise, Khadichaur, Chautara, Melamchi are the main trading centres and Chaku, Lamosangu, Mude, Balephi, Jalbire, Syaule, Sanghachok, Nawalpur, Talamarang, Bahunepati, Tipeni, Gyalthum, Chanaute etc. are other market centres.

The average family size is 4.32. Life expectancy of the people is 62 years. The average literacy rate is about 59.58% (51.88% female and 67.97% male). Sindhupalchowk has a multi ethnic composition with Tamang, Chhetri, Brahman, Newar, Bishwokarma, Sanyasi, Sherpa, Darji/Pariyar, Majhi, Magar, Gurung, Hyolmo, Thami, Mijar/Sarki, Danuwar, Pahari, Ghale and others. The dominant language is Nepali (55.31%) followed by Tamang (31.26%), Newari (6.71%), Sherpa (2.86%), Hyolmo (2.11%), Thami (0.99%) and others (0.76%).

Approximately 77.3% of the active populations are involved in the agricultural sector. Subsistence agriculture farming and small scale livestock rearing is the major source of livelihood of the majority of the population, with 79% of the population active in this sector. Due to insufficient agricultural production, most households face acute food shortages for a long duration of the year.

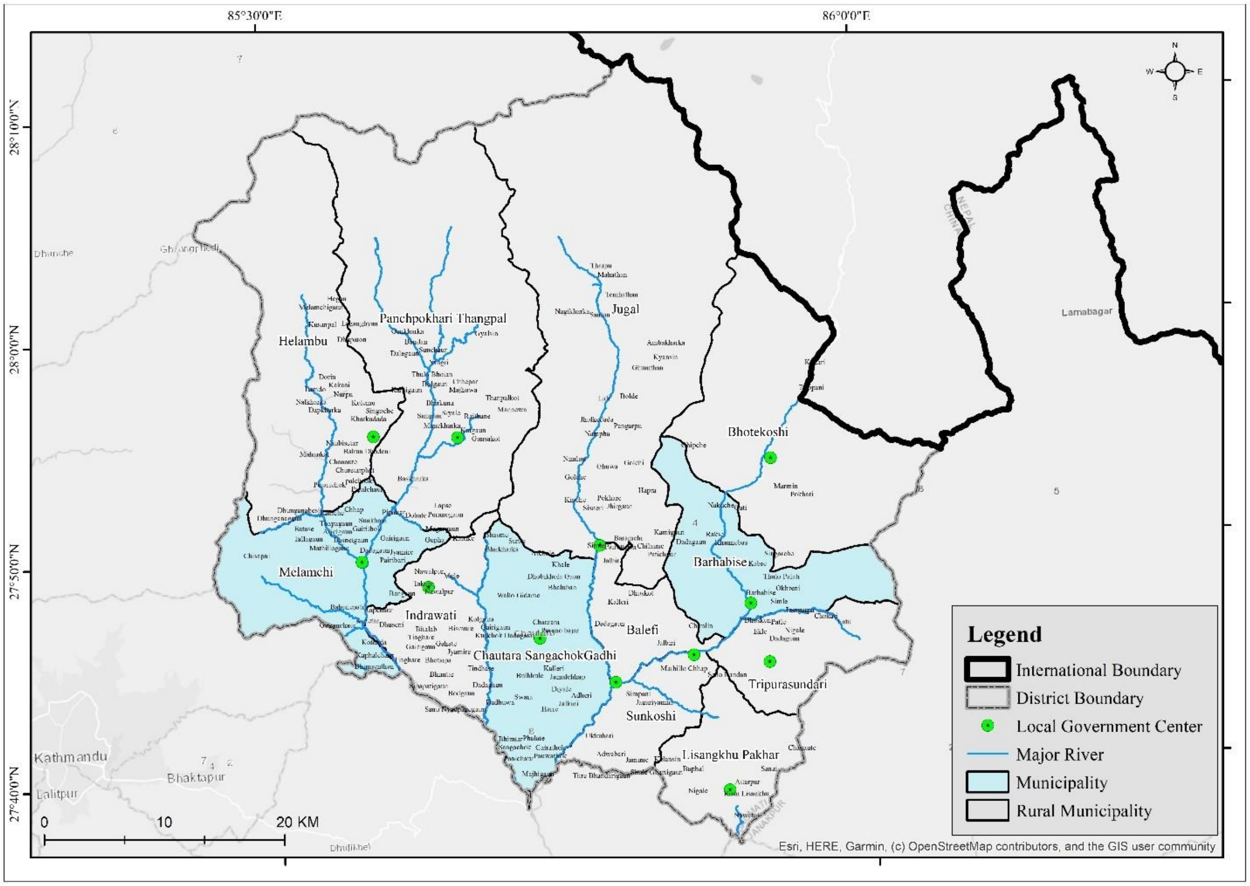


Figure 12: Local Administrative map of Sindhupalchok district

The headquarters Chautara is linked with a strategic road from Araniko highway at Bandeu/Dolalghat. The strategic road networks are (1) Araniko Highway (H03), (2) Panchkhal-Helambu feeder road (F30), (3) Bandeu/Dolalghat-Chautara feeder road (F31), and (4) Lamosanghu-Tamakoshi-Manthali feeder road (F32), plays crucial role to Sindhupalchowk in connectivity and transportation. The strategic roads are either black topped or gravel standard maintained by the Department of Road. The part of Mid-Hill highway (under construction) will run from Dhandkhola to Chisapani (border with Nuwakot). The western part of Sindhupalchowk is growing up its commercial and developmental efforts due to implementation of Melamchi Water Supply Project which targets to supply water to Kathmandu valley.

Sindhupalchowk is rich in tourism resources. Cultural heritages like Gaurati Bhimeshwor temple, Tauthali Mai Temple, Sunkoshi Kafeshwor Mahadev Temple, Kshemadevi Temple, Larke Ghyang are the popular pilgrimages in the district. Sunkoshi and Bhotekoshi are the world-famous rafting rivers which are flowing via this district. Bhairav Kundaand Panch Pokhari are popular trekking destinations which have religious and cultural importance. Bungy Jump over the Bhote Koshi River is another attraction of Sindhupalchowk. Tatopani (Hot Water Spring) near Nepal China border is popular as a pilgrimage place. Besides these, there are so many attractions that are still behind the flash. Hill stations like Tamche, Hunde, Yangima Danda have high probability for tourism.

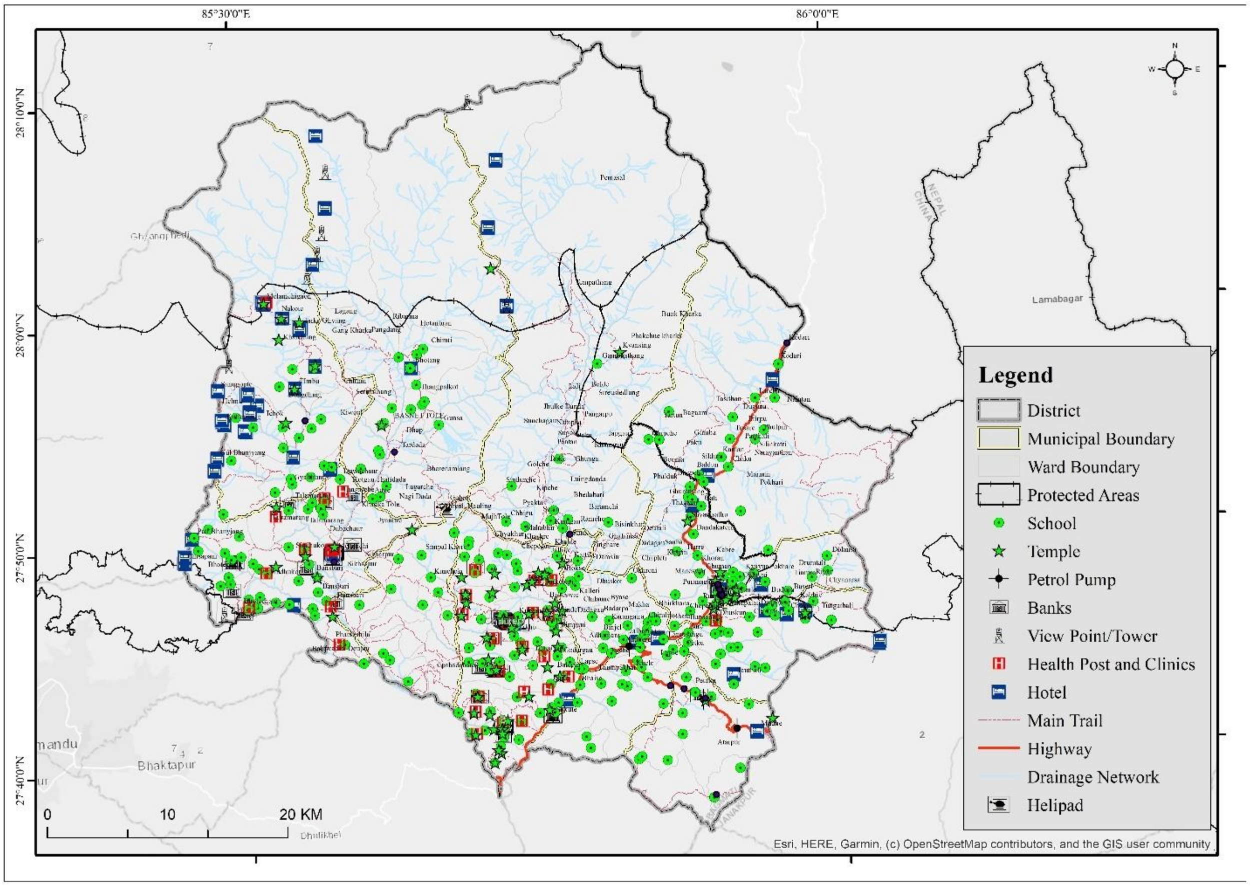


Figure 13: Socio-Economic Map of Sindhupalchowk District

3 APPROACHES AND METHODOLOGY

3.1 Approaches to Hazard, Vulnerability and Risk Assessment

When a hazard event (such as a drought, flood, landslide, and earthquake) occurs and causes a loss of life and damage to infrastructure, it highlights the reality that society and its assets are vulnerable to such events. When discussing disaster risk management, a disaster can highlight the following in a community:

- The geographical area where the community is settled is exposed to such a hazard.
- The society (including individuals) and its infrastructure, assets and other processes - as well as services which may have experienced damage or destruction - are vulnerable.

Hazard is defined as "a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation".

Exposure is defined as "the situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas". As stated in the UNDRR glossary, "measures of exposure can include the number of people or types of assets in an area.

Vulnerability is defined as "the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards".

Disaster risk is defined as "the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity. In the technical sense, it is defined through the combination of three terms: hazard, exposure and vulnerability.

3.1.1 Risk Assessment

Risk is a function of hazard exposure, vulnerability and coping capacity as shown below.

Risk = (Hazard Exposure X Vulnerability) / Coping capacity

The stages in a multi-hazard risk assessment take each factor in turn to provide an overview of the risks.

The risk assessment starts with the identification of potential hazards occurring in the study area based on past records and history. Not all hazards need to be considered in the study and this study focuses on the major hazards that need special attention for disaster preparedness and response.

3.1.2 Hazard identification

Hazard identification is used to identify which kinds of natural hazards influence a given area and summarize the spatial distribution of these hazards (Bell and Glade, 2004; Schmidt et al., 2011). Spatial distribution decides which pattern of hazard-response is needed in a given area. Below, some commonly used methods for hazard identification are discussed. These methods are used in assessment of risk from both single- and multiple- hazards.

3.1.3 Historical data analysis

Historical data is past-periods data, collected from historical texts, newspaper reports, diaries, and maps. Historical data describes the past, but planning involves the future. Therefore, historical data analysis is an approach of analysing what happened in the past to discover patterns or relations which are useful in projecting the future value of significant variables.

Many studies make use of this approach to analyse the spatial distribution of hazards (Munich Re, 2003; UNDP, 2004). Spatial distribution of natural hazards can be summarized by analysing the influence situation of each hazard in the past. However, this approach relies on extensive historical data (at least 20 years), which is hard to obtain for some areas. Additionally, because the occurrence of hazard is a random event, historical data may not contain all the possible hazard situations, especially as some hazards have a long return period (e.g., volcanic eruption).

3.1.4 Social survey

In the absence of historical data, social surveys can be used to collect the relevant data. Systematic social survey is used to collect data from people living in a specific geographic, cultural, or administrative area. The social survey is one of the best known and most widely used investigative approaches in the social sciences, most manifested as a questionnaire or interview. Researchers use this approach to collect information on the hazard situation during past years from residents, then summarize the spatial distribution of these hazards. Survey generally only applies on a local scale because the social survey is resource intensive in terms of time and human resources. Furthermore, it generally relies upon respondents living in the surveyed area for 20 years or more, with an even spatial distribution in the study area (Ge et al., 2008). In addition, the data collected by social surveys also face the same problem as historical data. The data may not contain all the possible hazard situations, especially as some hazards have a long return period.

Therefore, the significant gap in hazard identification is that the data collected may not reflect all the possible hazard situations due to some hazards having long return periods. This problem is exacerbated in the case of MHRA which must address multiple and interacting hazards (see below) where return periods of hazard interactions may be longer than single hazards.

3.1.5 Hazard analysis

Hazard analysis, that is magnitude-frequency analysis, analyses the probability of hazard occurrence of different magnitudes in each area (Petak and Atkisson, 1982; UNDRO, 1991). As mentioned in section 2.1.2.2, there is a strong nonlinear relationship between magnitude and frequency. According to the magnitude-frequency rule, there will be many small events and few large ones over a sufficient interval of time (Wolman and Miller, 1960). Hence, the average return period of small-magnitude hazards is short and that of big-magnitude hazards is long (Alexander, 1993). The mathematical statistics method is the commonly used method (Section 2.6.2) with both parametric and nonparametric methods used to estimate the required hazard occurrence probabilities. The existing research on hazard analysis mainly relies on the historical disaster data (FEMA, 2004; Grünthal et al., 2006). However, many disaster databases tend to record loss data rather than the magnitude data, e.g., EM-DAT (2015). Hence, the lack of hazard magnitude data is the main gap in hazard analysis.

3.1.6 Hazard interaction analysis

The existing research on hazard interaction in MHRA mainly focuses on the domino effect, introduced in Section 2.6.3, with hazard matrix and event tree the commonly used methods (Marzocchi et al., 2012; Gill and Malamud, 2014; Eshrati et al., 2015). They analyse hazard interaction beginning with given information about the primary hazard, which triggers another or increases the probability of others occurring. However, the interaction between different natural hazards is complex and dynamic, and the domino effect is not enough to cover all situations. For example, two hazards may occur independently without evident common cause, but in proximity, spatially, temporally, or both. Hence the relationships between different natural hazards need a systematic classification to facilitate improved MHRA.

3.2 Exposure analysis

Exposure analysis is used to analyse the spatial distribution of people, infrastructure or other valued assets at risk. There are three methods to exposure analysis in a risk area: official statistics analysis (Dilley et al., 2005; Schmidt-Thomé, 2006a), on-site survey (Khatsu and Van Westen, 2005) and remote sensing image analysis (Wang et al., 2008). Any combinations of these methods can be applied in exposure analysis to meet the data requirements. Official statistical data can be obtained easily, but data collection units are mainly based on government administrative division which may not map well to hazard zones. On-site surveys can produce more detailed and targeted data, but it generally applies only on a local scale as it is time and resource intensive to collect. Remote sensing image provides wide area coverage, but that raster format (i.e., an image) means that the information conveyed is more limited in scope.

3.3 Vulnerability Assessment

Vulnerability assessment is used to measure the possible loss for a given exposure, under conditions caused by hazard of varying degree, and to reflect how these conditions (including physical, social, economic and environmental indicators) influence the possible loss (Cutter, 1996; Villagran, 2006). The assessment methods fall into two types based on the development of either a vulnerability index or vulnerability curve (fragility curve). Vulnerability Assessment is important to

a) Identify who are the most exposed and vulnerable populations to potential hazards.

b) Identify what assets are most exposed to potential hazards.

c) Assess the nature and factors contributing to their vulnerability; and

d) Estimate the susceptibility to hazards.

The poorest people often live-in hazardous places, for example on the steep slopes of hillsides or rivers and so are at higher risk of harm from landslides and floods. Vulnerability will vary by age, gender, and ethnic group. In earthquake zones it is not always the poorest who are the most vulnerable as urban middle-class areas may be poorly built. But assets, such as utilities and critical infrastructure (roads, ports, airports) should also be considered. Mapping where the most vulnerable live and scenario planning potential impacts and fatalities is useful for emergency preparedness and contingency planning.

The factors contributing to vulnerability could stem from a range of different issues, including the extent to which building standards and codes have been followed, the quality and strength of infrastructure, accessibility of basic services, the scale of poverty and income opportunities, land tenure and the level of financial protection.

3.4 Landslide Hazard Assessment

Landslide hazard assessment can be a vital tool to understand the basic characteristics of the terrains that are prone to failure especially during extreme climatic events. Landslide hazard zonation is defined as the mapping of areas with an equal probability of occurrence of landslides within a specified period (Varnes 1984; Crozier and Glade 2005). Moreover, intrinsic (bedrock geology, geomorphology, soil depth, soil type, slope gradient, slope aspect, slope convexity and concavity, elevation, engineering properties of the slope material, land use pattern, drainage pattern) and extrinsic (rainfall, earthquakes, and volcanoes) variables are used to determine landslide hazard in an area (Siddle 1991; Wu and Siddle 1995; Atkinson and Massari 1998; Dai et al. 2001; Çevik and Topal 2003). The extrinsic variables are site specific and possess temporal distribution. Moreover, they are difficult to estimate because of lack of information about the spatial distribution. Hence, in landslide hazard assessment practice, the term "landslide susceptibility mapping" is addressed without considering the extrinsic variables in determining the probability of occurrence of a landslide event (Dai et al. 2001; Dahal et al. 2008a, b). In 2008, JTC-1 (Joint International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE), International Society of Rock Mechanics (ISRM) and International Association of Engineering Geology (IAEG) Technical Committee on Landslides and Engineered Slopes) prepared the guidelines and defined landslide susceptibility and hazard in the prospect of interaction between intrinsic and extrinsic variables as well as frequency of occurrence of the events (Fell et al. 2008). According to the JCT-1 definition, landslide susceptibility is a quantitative or qualitative assessment of the classification, volume (or area), and spatial distribution of landslides which exist or may potentially occur in an area. Landslide susceptibility zoning requires an inventory map of landslides that occurred in the past together with assessment of the areas with the potential to occurrence of landslides in future but with no assessment of frequency (annual probability) of occurrence (Cascini 2008). Landslide susceptibility map includes landslides which have their source in the area or may have their source outside the area but may travel through the area or return into the area (Fell et al. 2008; Cascini 2008; Frattini et al. 2010).

A region is susceptible to landslides when the terrain conditions at that site are comparable to those in the region where a slide has occurred (van Westen 2000). The integrated analysis of all intrinsic variables in relation to the spatial distribution of landslides has gained enormous success by the introduction of Geographic Information Systems (GIS), the ideal tool for the analysis of parameters with a high degree of spatial variability. For a landslide hazard assessment, the assumption is made that conditions, which led in the past to landslides, will also result in potential unstable conditions in the present. Thus, a landslide inventory mapping, differentiating according to type, activity, dimensions and so on is primary data for landslide hazard or susceptibility zonation.

The inventory map also needs to cover information of time span-based landslide distribution as far as possible. When mapping intrinsic parameters or causal factors, emphasis should be given to the most relevant terrain parameters related to the occurrence of landslides. Generally, it is true that the selection of intrinsic parameters takes the nature of the study area and the data availability into account. But in a GIS-based technique, it is also necessary to be sure that any selected factor is functional (has a certain degree of affinity with previous occurrences of landslides), complete (is reasonably represented all over the study area), no uniform (remarkable spatial variation), measurable (can be expressed by nominal, ordinal, interval, ratio scales), and non-redundant, i.e., outcome of selected factors should not account for double effects in the final result (van Westen 2000; Yelcin 2008). Geomorphological hazard mapping and analysis of landslide inventories are two basic expert knowledge-based qualitative landslide hazard mapping techniques. Geomorphological mapping of landslide hazard is a direct, qualitative method that relies on the ability of the investigator to estimate actual and potential slope failures. The basic idea is to use the information in combination with geo-environmental conditioning factors to extract the level of detail offered by the landslide data itself for determining landslide susceptibility in the study area. In this study, a bivariate statistical method called the Frequency Ratio (FR) was applied to derive a landslide susceptibility map for Sindhupalchowk district. FR was chosen for this research as a basic analysis for a preliminary probabilistic assessment, the mathematical simplicity, and data extraction in a limited time period (rapid assessment).

3.5 Study Methods

This study will include GIS tools to conduct Multi Hazard Assessment and Vulnerability Analysis.

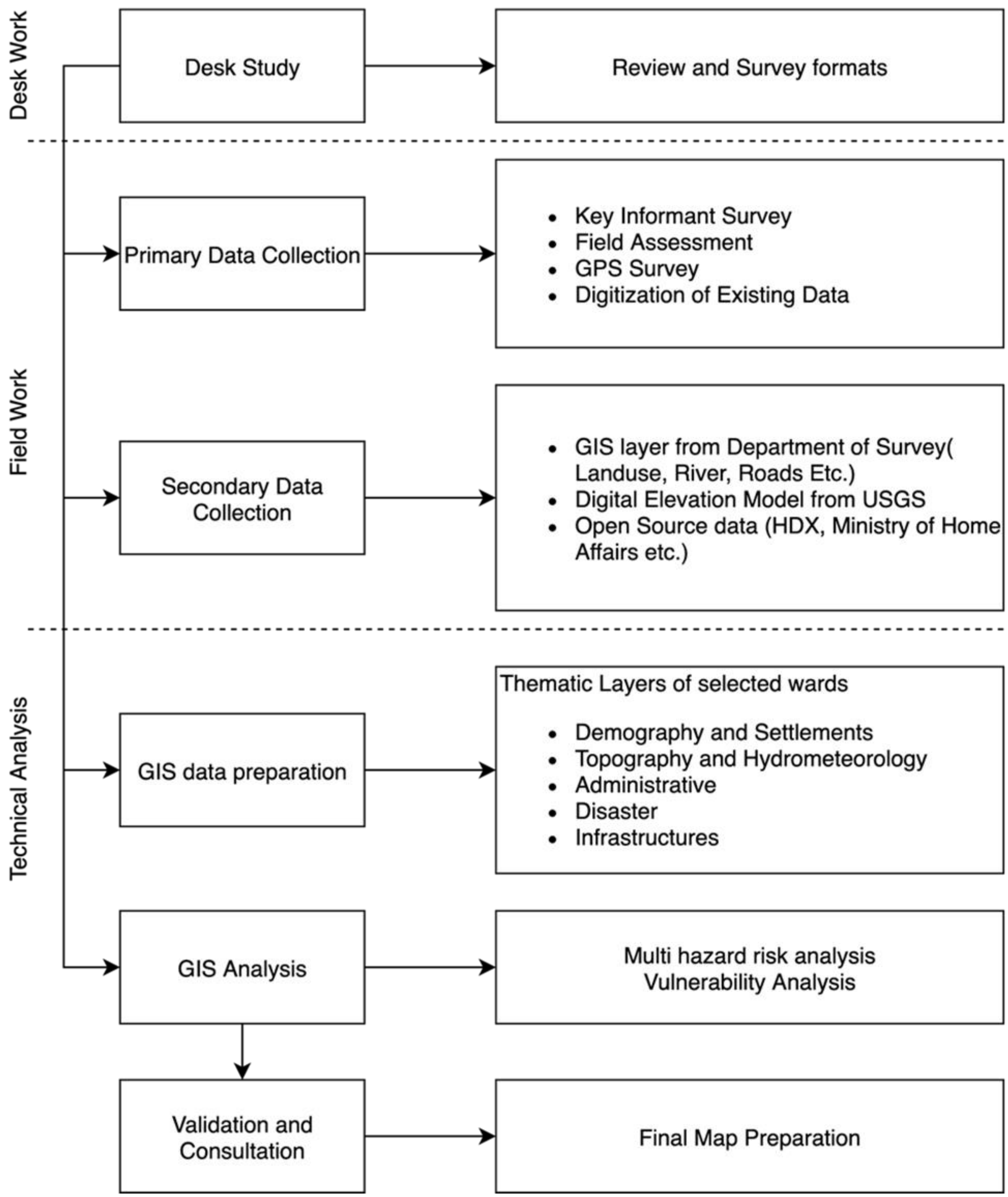


Figure 14: Methodological Framework

3.5.1 Desk Study

Review of existing data and information at district and municipalities including resource map, socio economic profile and data related to Disaster Risk Management. Review of existing plan, planning process, infrastructure development, demography of proposed study area. Preparation of survey format for data collection.

3.5.2 Primary Data Collection

Collection of Primary data will be based on Key informant survey, field assessment, GPS survey and digitization of existing data. Data from multiple open mapping sources like Open Street Map, existing geocodes, and other relevant data portal if exists will be acquired and prepared as an integrated geo-database. This will also involve digitizing available hard copy maps and identifying the gaps in existing maps including accumulated risk areas. Satellite images including Sentinel archive, Landsat archive and Google earth images are used for the recent year from 2015 to 2022 for digitization of identified hazards and risks.

3.5.2.1 Key Informant Interview (KII)

KII will cover past disaster information on hazards, demography, risk-population and capacity for disaster risk reduction and emergency response. It will also include capacities of municipality, authorities and communities.

Field Assessment will cover physical, social and economic vulnerability of the population. This will include field assessment of identified sites like Jure Landslides, Lidi Landslide, Melamchi Flood and other specific areas based on consultation and field exploration.

GPS Survey will cover geo-location information of infrastructures, hazard areas, settlements, transition settlements, and temporary shelters to prepare thematic layers for GIS mapping.

Digitization of existing data will cover the preparation of digital layers from existing thematic ward maps, municipality maps, disaster maps, that are only available in hard copies archives.

3.5.3 Secondary Data Collection

GIS layers and maps from the department of the survey, Digital elevation model from USGS, open-source data from online sources like humanitarian data portal (hdx), and other relevant sources like Open Street Map, existing geocodes, Sentinel archive, Landsat archive, and Google earth images. Other sources include BIPAD Portal, Des-Inventar, and Global Landslide Database (https://data.nasa.gov/Earth-Science/Global-Landslide-Catalog/), EMDAT Database (https://public.emdat.be/) will be used as a secondary source for the disaster data.

3.5.4 GIS Data Preparation and Analysis

Dataset`	Data format	Data Description/Processing	Resolution
Distance from Fault	Line	Derived from geo-referencing and digitizing	_
Slope	Spatial Grids	Extracted from Digital Elevation Model (DEM)	30*30 m
Aspect	Spatial Grids	Extracted from Digital Elevation Model (DEM)	30*30 m
Elevation	Spatial Grids	Extracted from Digital Elevation Model (DEM)	30*30 m
Curvature	Spatial Grids	Extracted from Digital Elevation Model (DEM)	30*30 m
NDVI	Spatial Grids	Landsat Imagery	30*30 m
TWI	Spatial Grids	Extracted from Digital Elevation Model (DEM)	30*30 m
Distance from River	Line	Extracted from OSM and Buffering	-
Distance from River	Line	Extracted from DEM using Hydrology tool box and buffering	-
Land Use	Spatial Grids	Classification of Landsat imagery by providing signature values	30*30 m
Rainfall	Excel data	Rainfall data from 13 rainfall station which were interpolated	-
Geology	image	Derived from geo-referencing the map from DMG and digitizing	-
Soil	Polygon	Extracted from Soil and Terrain	-

		Database (SOTER)	
Drainage Density	Spatial Grids	Extracted from DEM	30*30 m
Epicenter	Points	Extracted from the USGS earthquake catalogue database	-
Settlement	Points/Polygon	Extracted from OSM	-
Land Surface Temperature	Spatial Grids	Extracted from MODIS	-

3.6 GIS for Disaster Risk Mapping

Disaster risk mapping requires gathering specific information on the capacity, vulnerability, and disaster risks of the community. This includes historical records of disaster, damage and loss, continuity of the disaster, and exposure of the population, infrastructure, and natural resources to future disasters. Disaster risk mapping is a tool generally used by local governments and communities to identify risks, vulnerabilities, and disaster risk management capacities. GIS provides mapping tools that can be effective in compiling various thematic layers at different scales and overlaying them together to understand the exposure and risk of infrastructures, population, and natural resources.

Base maps such as Land Use, Rivers, Roads, settlements, etc. help the local people, stakeholders, and the authorities to understand the spatial extent of the information which helps in the planning process.

3.6.1 Hazard Inventory

Individual hazard inventory mapping is a basic requirement of multi-hazard mapping. Mapping of hazardous events is important to understand the spatial relationship between the location of hazards and their predisposing factors. Inventory mapping in this study was performed by aerial photo interpretation in Google Earth pro, survey, historical data, and literature review. The inventory was cross-validated with the help of pilot field observations.

This assessment is based on both primary and secondary sources. Both quantitative and qualitative methods are used to determine hazard ratings for the area of interest for identifying multi-hazard high risk zones.

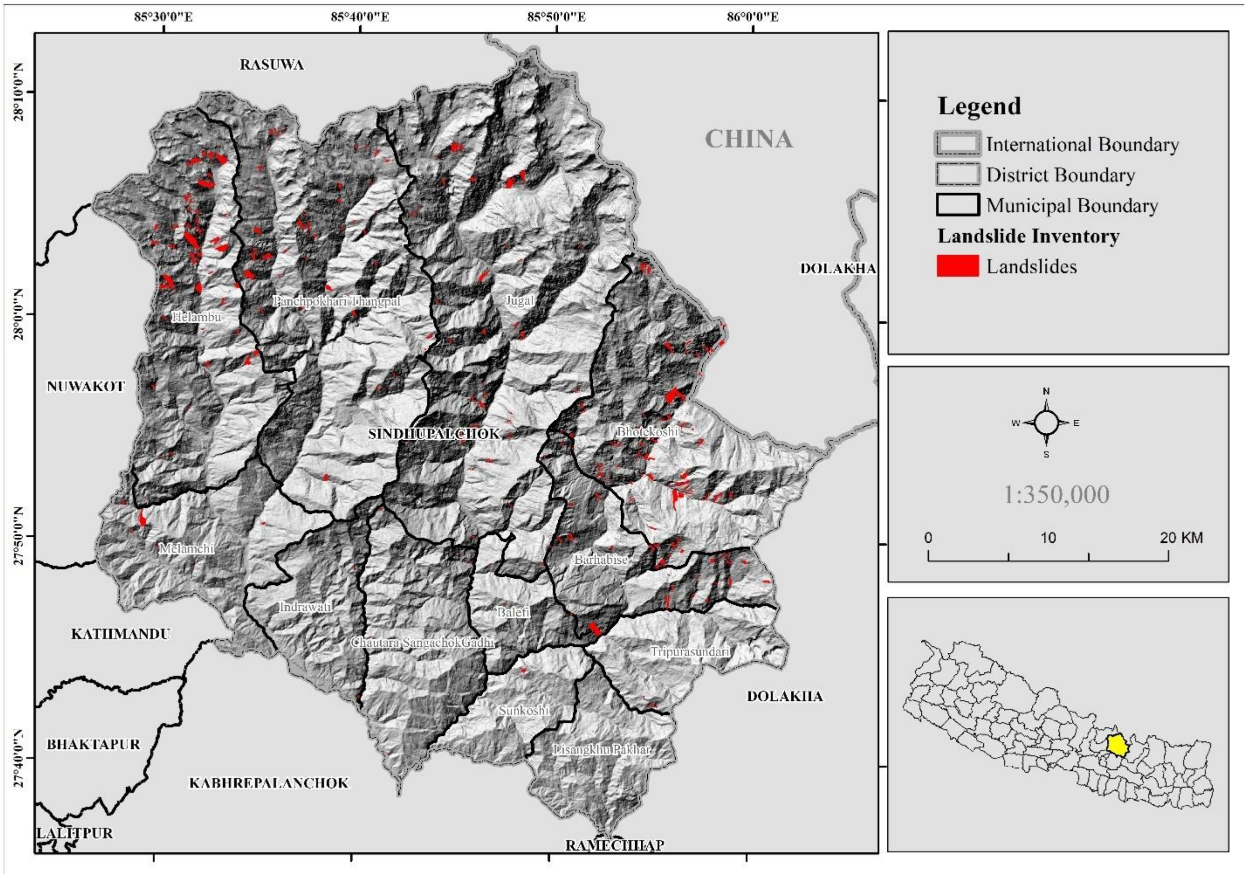


Figure 15: Landslide Inventory Map of Sindhupalchowk District

3.6.2 Open-Source software - QGIS

Quantum Geographic Information System, also known as QGIS is open-source software. QGIS can support most of the basic functions of GIS software including: data management, reading many data formats, editing and publishing maps, exporting - importing data and spatial analysis functions which are applied for developing disaster risk maps.

Topographic analysis, Climate data analysis, and analysis of hazard and vulnerability will be conducted in QGIS software.

Thematic layers based on primary and secondary data for the study area will be prepared in QGIS software. This includes all local municipalities and watersheds in the Sindhupalchowk district.

3.6.3 GIS map preparation

Standard Layout map preparation was conducted in QGIS and high-quality printable maps are prepared.

3.6.4 Field Verification and Consultation

Review and validation of the digitized maps, as well as prepared thematic layers, will be based on field verification and consultation meetings with ward level and municipality level.

3.7 Frequency Ratio Method

The relationship between the landslide occurrence area and the landslide causative factors can be inferred from the relationship between the non-slippery area and the landslide causative factors. To determine how close their relationship is, a simple statistical technique was applied to infer it with the frequency ratio approach. In addition, the FR model has become valuable for ranking preferred causal factors based on their ability to control landslides (Kannan et al. 2013), as FR can describe clearly the difference of each score between the landslide causative factors in the class and the landslide occurrence. Therefore, the number of pixels where landslide occurred on the area must be combined between causal factors. Then, the rate for each factor was calculated by dividing the landslide occurrence rate by the proportion of each class in the causal factors (Lee and Thalib 2005). The scale value in each class shows how strongly the attribute of certain factors is related between landslide occurrences, and where a ratio greater than one indicates a stronger correlation, a ratio less than one showed a weaker correlation (Lee et al. Pradhan 2006).

The calculation steps for an FR for a class of the landslide-influencing factors are below

$$\text{FR}=\frac{A/B}{C/D}$$

where, A is the number of pixels with landslide for each element, B is the total number of landslide points in the study area, C is the number of pixels in the layer area of the element, D is the total number of pixels in the area of study and FR is the frequency ratio of a class to the factor.

Scale values obtained using FR are assigned as weighted values to the layers of each factor map to generate weighted, overlaid and detailed factor thematic maps using a raster calculator to generate a Landslide Sensitivity Index (LSI) map.

$$\text{LS}=\sum FR$$

The calculated values of FR for each pixel of the LSI indicate the relative susceptibility to the occurrence of landslides. The high pixel values of the LSI are most sensitive to landslides and the lower pixel values are the least sensitive.

3.8 AHP Method

Analytic hierarchy process (AHP) is one of the most common and widely used multi-criteria methods. This technique integrates the process of evaluating alternatives and aggregating them to find the most relevant alternatives. This technique is used to rank a set of choices or to choose the best from a set of choices. Ranking / selection is based on the overall purpose, which is categorized into several criteria. Decisions are usually based on the perception of the person who is supposed to make the final decision, and evaluate priorities, emphasizing the importance of the consistency and correlation of alternatives compared throughout the decision-making process (Satty, 1980).

The AHP procedure is very flexible because it provides an easy way to find the relationship between criteria and alternatives. Using this method, you can break down complex problems into specific hierarchies and include both quantitative and qualitative aspects of the problem in your analysis. The AHP connects all levels of the hierarchy. This allows you to see how changing one standard affects other standards and alternatives.

4 MULTI HAZARD ASSESSMENT

Multi Hazard Assessment is a holistic approach to understand and explain all hazards that exist in a certain area so that preventive measures can reduce multiple types of threats. Multi hazards risk assessment aims for a more comprehensive view of the total effects or impacts by assessing and mapping expected loss due to the occurrence of various natural hazards on the social, environmental, and economic settings in a given area. The basic components of MHRA include hazard identification, hazard analysis, hazard interaction analysis, exposure analysis and vulnerability analysis (Marzocchi et al., 2009; Komendantova et al., 2014). Multi hazards risk assessment allows the identification of the most endangered areas and suggests where further detailed studies must be carried out. A focus on multi-hazards does not contradict the need to reduce the risk associated with individual hazards; instead, a multi-hazard approach is an opportunity to align risk reduction measures to avoid tradeoffs and find synergies. Interaction between multiple hazards needs to be studied to explore the accumulated risks and it is vital to address the integrated hazards. Without causing another hazard directly, one hazard can worsen the effects of another, such as 2020's widespread forest fires in Nepal that denuded hillsides, making the slopes more prone to landslides, mudflows, and flooding.

Hazards in the Himalaya do not queue up politely to occur one at a time. More often, they occur together and, when they do, their cumulative effect is greater than the sum of their parts. When floods and landslides happen at once, for instance, the impact of each is intensified by the other. Still, it remains common to approach risk reduction for each hazard individually. In Nepal, and the wider Himalayan region, the coincidence of multiple hazards necessitates a multi-hazard approach to disaster risk reduction. At best, considering one hazard at a time is wishful thinking. At worst, single-hazard approaches reduce the risk of one hazard only to increase the risk from others. To avoid these tradeoffs, a multi-hazard approach manages the connections between hazards to reduce overall risk. Since many people in the Himalaya live in multi-hazard environments, managing one hazard at a time could have disastrous consequences. Importantly, adopting a multi-hazard approach does not mean making things more complicated. Instead, it can identify synergies to address them together, while providing a basis for collaboration for aligning single hazard management and governance practices that could otherwise conflict.

A multi-hazard approach is relatively new, but multi-hazards themselves are already here. They can take many forms. Sometimes, one hazard causes another: In 2015, the Mw 7.8 Gorkha earthquake caused thousands of landslides and claimed thousands of lives (Rusk, J., 2021). Adopting a multi-hazard approach may increase resource demand but in the face of ongoing climate change and urbanization, effective disaster risk reduction in fragile environments in the mountainous regions necessitates a multi-hazard approach. The hazard assessment should begin with the identification of what natural hazards can be expected and how they might change in the short and medium term. This could include earthquakes, floods, landslides, thunderstorms, wildfire, drought, and epidemics. Consideration should be given to both extensive (frequent, low impact) and intensive (occasional, high impact) events.

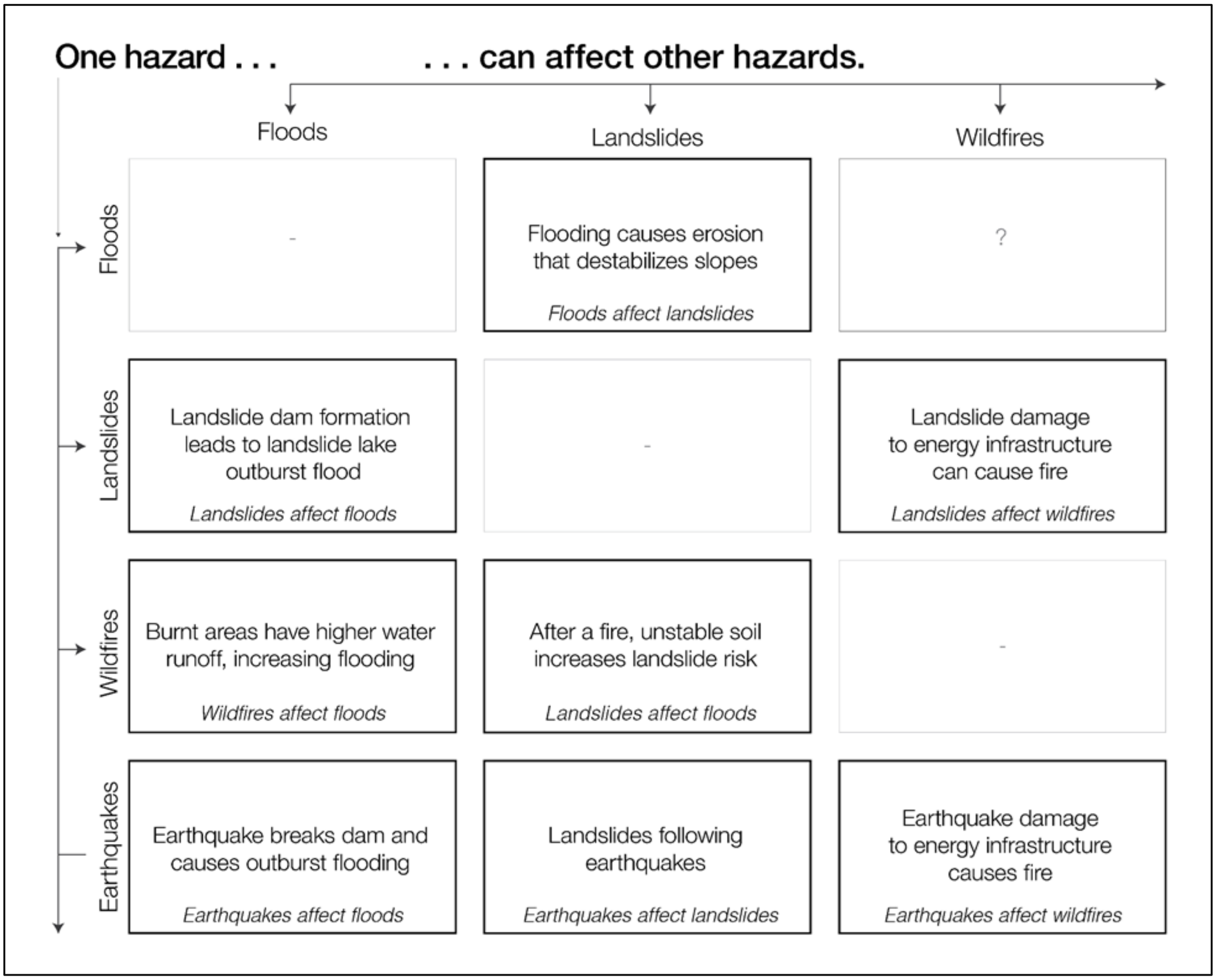


Figure 16: Multi Hazard Interactions (Rusk, J., 2021)

4.1 Factors Influencing Multi-Hazards

There are many factors that contribute to the occurrence of hazardous phenomena, which are either related to the environmental setting (topography, geomorphology, geology, soils etc.) or to anthropogenic activities (e.g., deforestation, road construction, tourism). Although these factors contribute to the occurrence of the hazardous phenomena and therefore should be taken into account in the hazard and risk assessment, they are not directly triggering the events. For these we need triggering phenomena, which can be of meteorological or geophysical origin (earthquakes, Heavy rainfalls, or landslides).

The type and source of data used in landslide, flood, fire, earthquake, and multi-hazard mapping are summarized in Table below. Seventeen influencing factors were selected based on the available information. The thematic maps for the factors considered for flood, landslide, fire, and earthquake hazard assessment are depicted in Figures in the following sub-headings.

Table 3: Factors Used for Preparation of Hazard Map

Factors	Earthquake	Landslide	Flood	Fire
Slope	—	✓	✓	✓
Aspect	—	✓	—	—
Curvature	—	✓	✓	—
Distance From Road	—	✓	—	—
Distance from river	—	✓	✓	—
Geology	—	✓	—	—
Normalized Difference Vegetation Index (**NDV**I)	—	✓	—	✓
Topographic Wetness Index **(TWI**)	—	✓	✓	—
Soil	—	—	✓	—
Fault	✓	—	—	—
Epicenter	✓	—	—	—
Elevation	—	✓	✓	✓
Rainfall	—	✓	✓	
Settlement	✓	—	—	✓
Land Use	—	✓	✓	—
Drainage Density	—	—	✓	—
Land Surface Temperature	—	—	—	✓

4.1.1 Slope:

Slope has significant importance in terms of the formation, development, and susceptibility to landslides and is defined as an input parameter in susceptibility studies by many researchers, and it is the expression of the rate of the vertical distance to the horizontal distance between two specified points with the tangent angle. Slope is the measurement of surface steepness and is measured as a degree. It has a range of 0-90 degrees, where 0 represents a horizontal area and 90 represents a vertical area (Yılmaz et al., 2012). In broader terms, slope is the angle between each surface section and horizontal reference point that measures the speed of change in height and that supports the flow of water and other materials in the direction of slope in terms of the steepest drop in slope for elevation (Dehnavi et.al., 2017)

Sindhupalchowk is a mountain district having much of its area under rugged topography with high mountains and deep river valleys. As shown in slope map below, only 9.73 % of its area lies under 15 degrees of slope while 40.95% under 15-30 degrees, 38.15% in 30-45 degrees, 10.21% in 45-60 degrees and 0.96% above 60 degrees shows that the district has more than 85% of its land in a high slope terrain. This already increases the risk for all kinds of mass movements existing under gravity. A small trigger can create mass movement in such terrain with high slopes.

Slope	Percent
<15	9.73
15 - 30	40.95
30 - 45	38.15
45 - 60	10.21
60 <	0.96

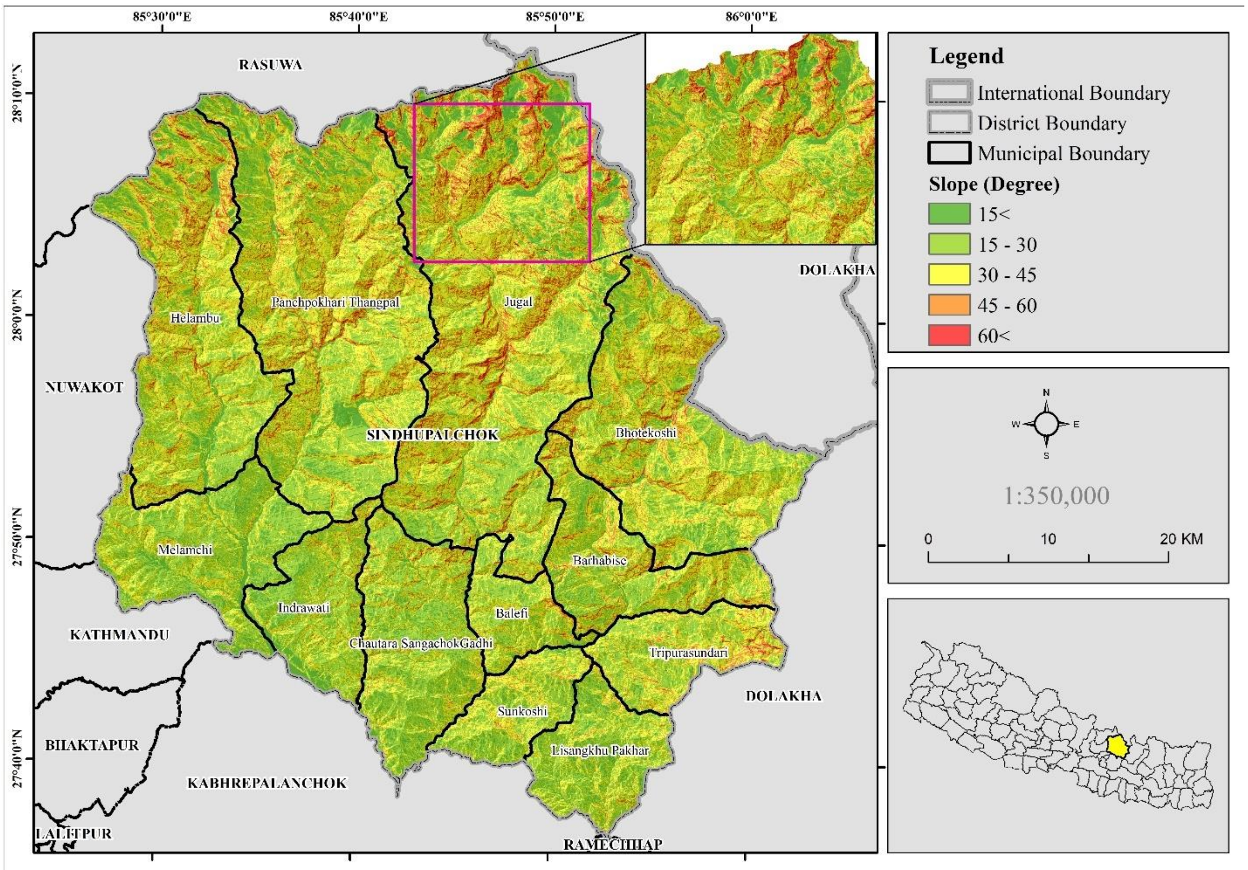


Figure 17: Slope Map of Sindhupalchowk District

4.1.2 Aspect:

An aspect map shows both the direction and grade of a terrain at the same time. Therefore, it is an important factor in the analysis and production of landslide susceptibility maps. Studies have suggested a strong relationship between aspect and landslide as it also explains the underlying factors and action of external factors like rainfall in a specific terrain. Not all faces of the terrain face the same amount of rainfall, wind and other forces. Similarly, aspect has stronger relation with the thawing of frost in the soil as well as drying of moisture. In mountainous terrain the role of aspect is even more important to

understand the effects of local climate. The aspect factor is controlled by the climate process. Elevation and slope angle are also effective factors on this parameter. On the other hand, there are processes controlled by the aspect factor. The most important of these is plant ecology. As Sindhupalchowk district has a northern range of mountains and snowmelt in the mountains can affect hazards in the lower valleys, study of aspects becomes important to understand the disasters going on in the terrain. https://www.intechopen.com/online-first/78441

Aspect	Percent	Aspect	Percent
Flat	0.204561		
N	10.224091	S	13.815954
NE	10.610087	SW	15.904306
E	11.654917	W	13.777271
SE	12.807844	NW	11.000969

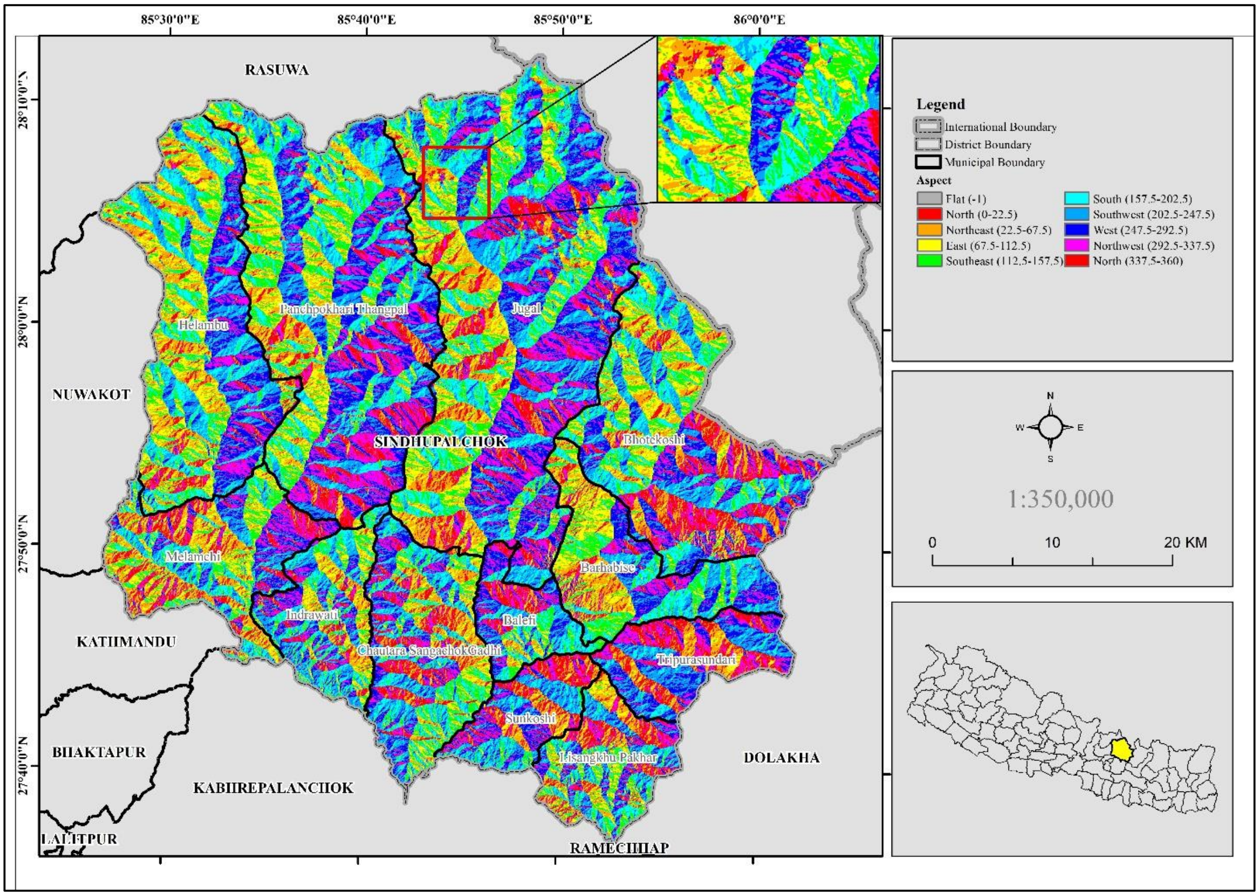


Figure 18: Aspect Map of Sindhupalchowk District

4.1.3 Curvature:

Profile curvature influences the driving and resisting stresses in the direction of mass movement. The profile curvature in this study was extracted from the DEM and is classified into (i) convex (<-0.5), (ii) flat (-0.5–0.5), and (iii) concave (>0.5) as shown in Figure below, which is used for landslide hazard assessment. Normally, convex slopes are well built as they dispense the runoff equally down the slope while concave slopes are regarded as potentially unstable as they concentrate water at the lowest point and contribute to the build-up of adverse hydrostatic pressure.

Curvature	Percent
Convex	14.310517
Flat	72.676301
Concave	13.013183

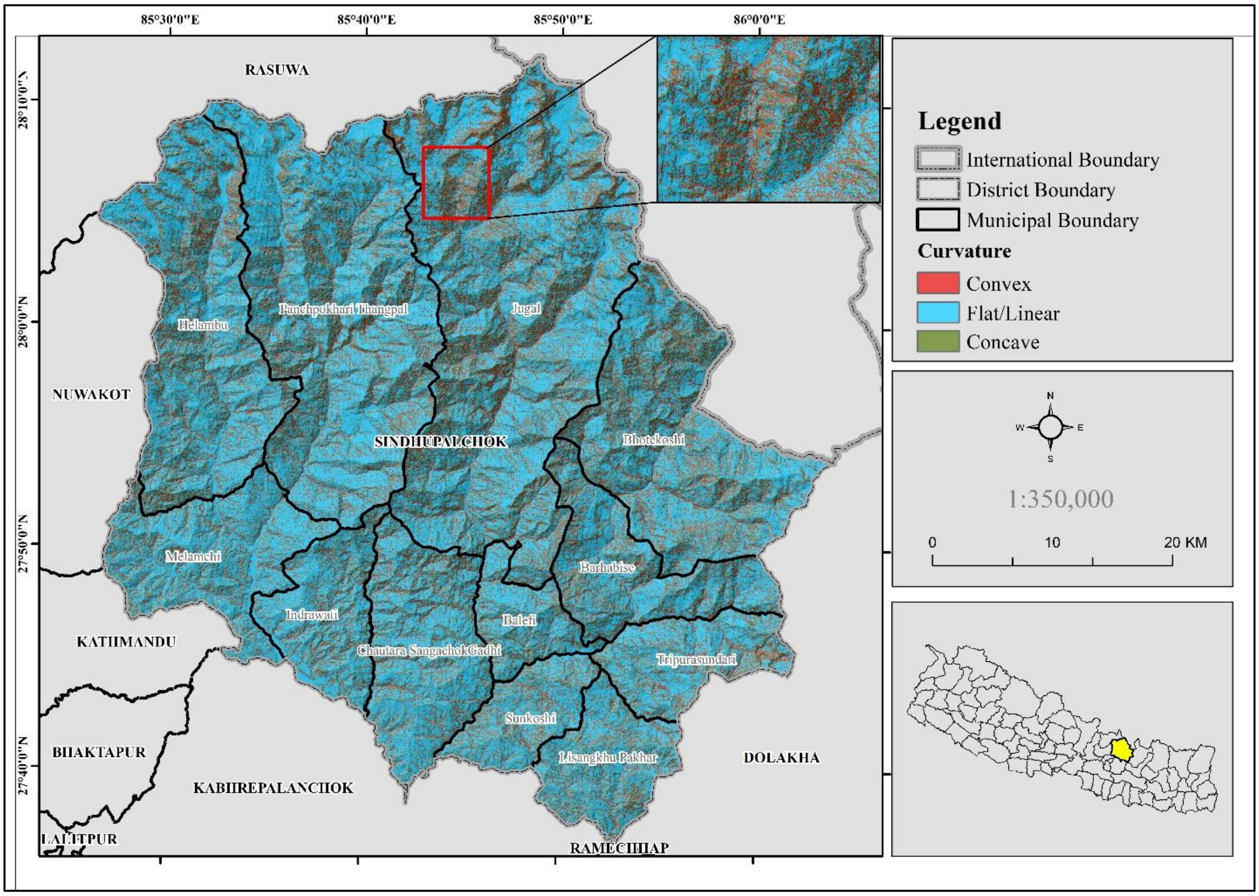


Figure 19: Curvature Map of Sindhupalchowk District

4.1.4 Distance from Road

Road is the anthropogenic factor that is a result of human construction. As roads are extensively built in the terrain this affects the stability of slopes. Road alters the gully drainage and can affect the local hydrology and exposes cuts for seepages that can trigger slope failures. Movement in roads can trigger small but continuous shakes that can affect the existing cracks in geology. Further road has a unique role in reducing the impact of disaster by improving access.

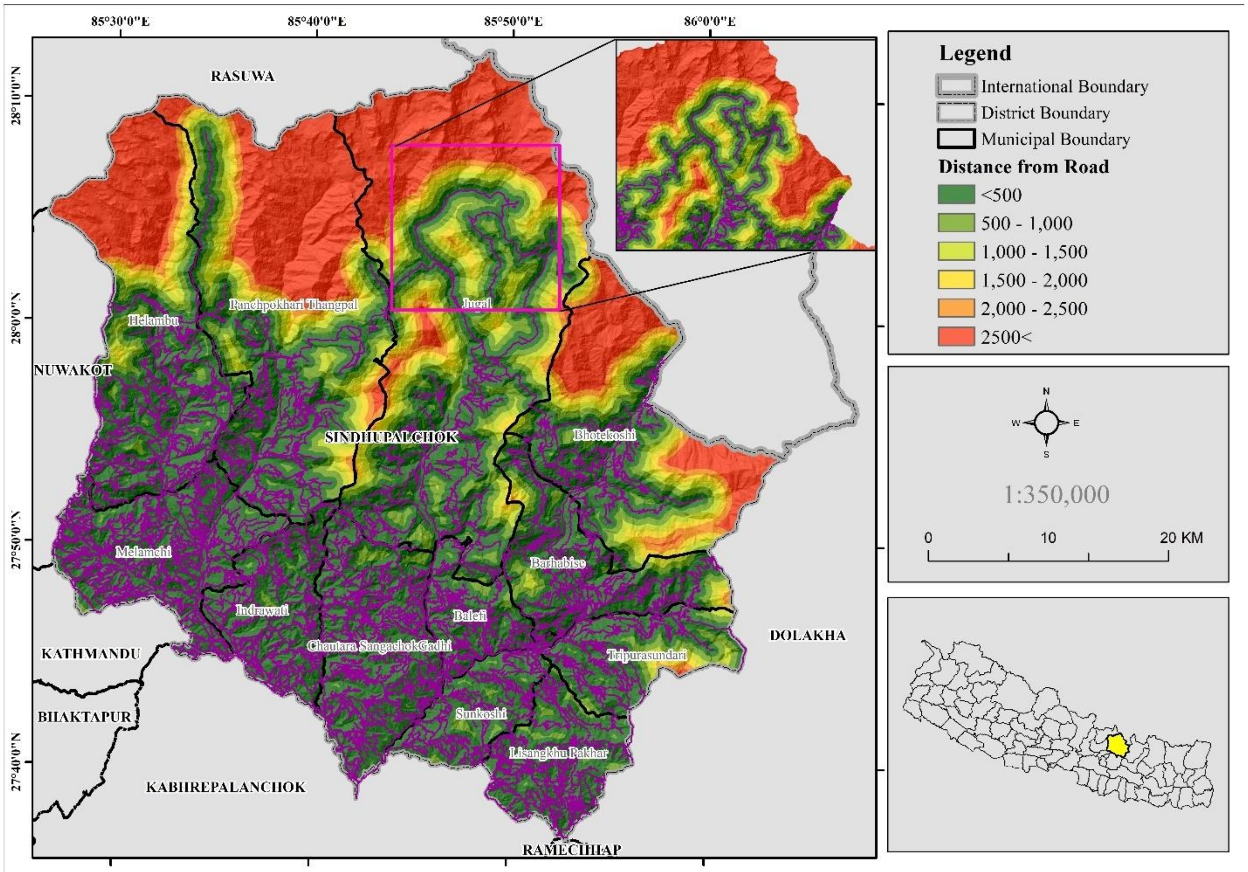


Figure 20: Distance from Road Map of Sindhupalchowk District

4.1.5 Distance from River:

The stability of a slope depends on the degree of saturation of the material on the slope, and proximity to streams is considered to be an aggravation factor due to its contribution in saturation. Proximity to the stream can be negatively correlated with the stability of slopes because it triggers the potential of slope erosion due to saturation of the lower part of the material. Precipitation results in the rise of river discharge that causes sediment deposition in the neighbouring areas of the river and may lead to flooding. Six buffer zones were created to assign different levels of proximity as (i) <500 m, (ii) 500–1000 m, (iii) 1000–1500 m, (iv) 1500–2000 m, (v) 2000–2500 and (vi) >2500 m for landslide and flood hazard assessment as shown in map below.

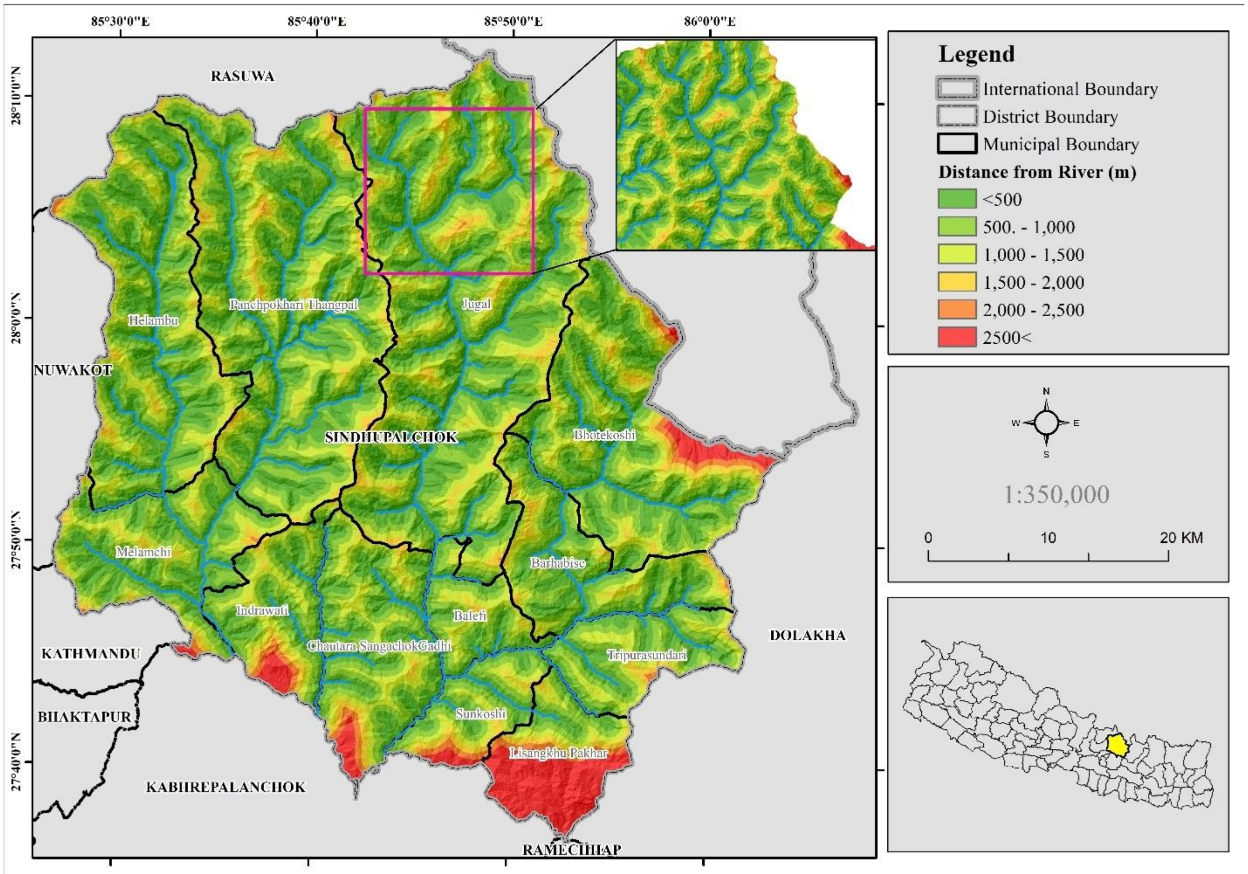


Figure 21: Distance from River Map of Sindhupalchowk District

4.1.6 Geology:

Geologically, the area comprises two geological zones rocks, the mid and southern part is made of Lesser Himalayan zone rock that has low to medium metamorphic rocks and Higher Himalayan zone with crystalline metamorphic rocks. Amongst all rock types, phyllite dominant formation (Kuncha formation) of lesser Himalaya zone has occupied most of the district area and that exhibits most of the district area is landslide hazards prone area. The other formation that has rock limestone has also potential of instability of the slopes because of high weathering and the thick soil depth on the moderate to high gradient slopes. Therefore, the geological map shows the instability that potential for the landslide is almost covering the districts especially along the newly constructed roads, and the rivers & streams.

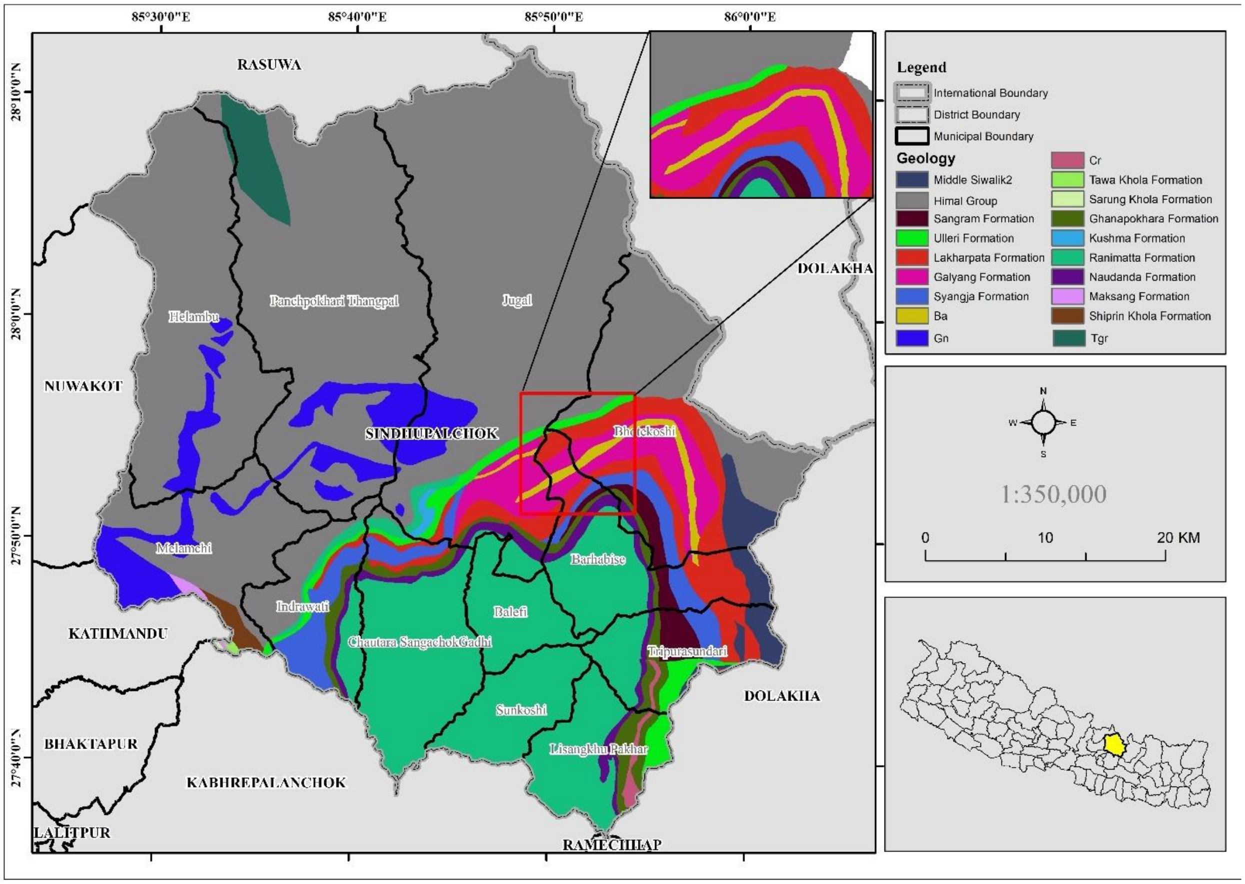


Figure 22: Geology Map of Sindhupalchowk District

4.1.7 Normalized Difference Vegetation Index (NDVI):

The NDVI was used to examine the presence of vegetation cover by measuring surface reflectivity. Vegetation provides both hydrological and mechanical effects that increase the stability of slopes by anchoring roots with soil and hence contribute to reducing speed of rainfall/run-off movement by creating a barrier. The NDVI was calculated from Landsat 8 image and was classified into five categories as (i) -1 - -0.25 (ii) -0.24 - 0.082, (iii) 0.083–0.22, (iv) 0.23–0.61, and (v) 0.62–1, which were used in landslide hazard assessment. These NDVI values represents that as the NDVI values increases the vegetation cover also increases accordingly. The NDVI value is inversely correlated to landslide susceptibility while it also affects fire incidence.

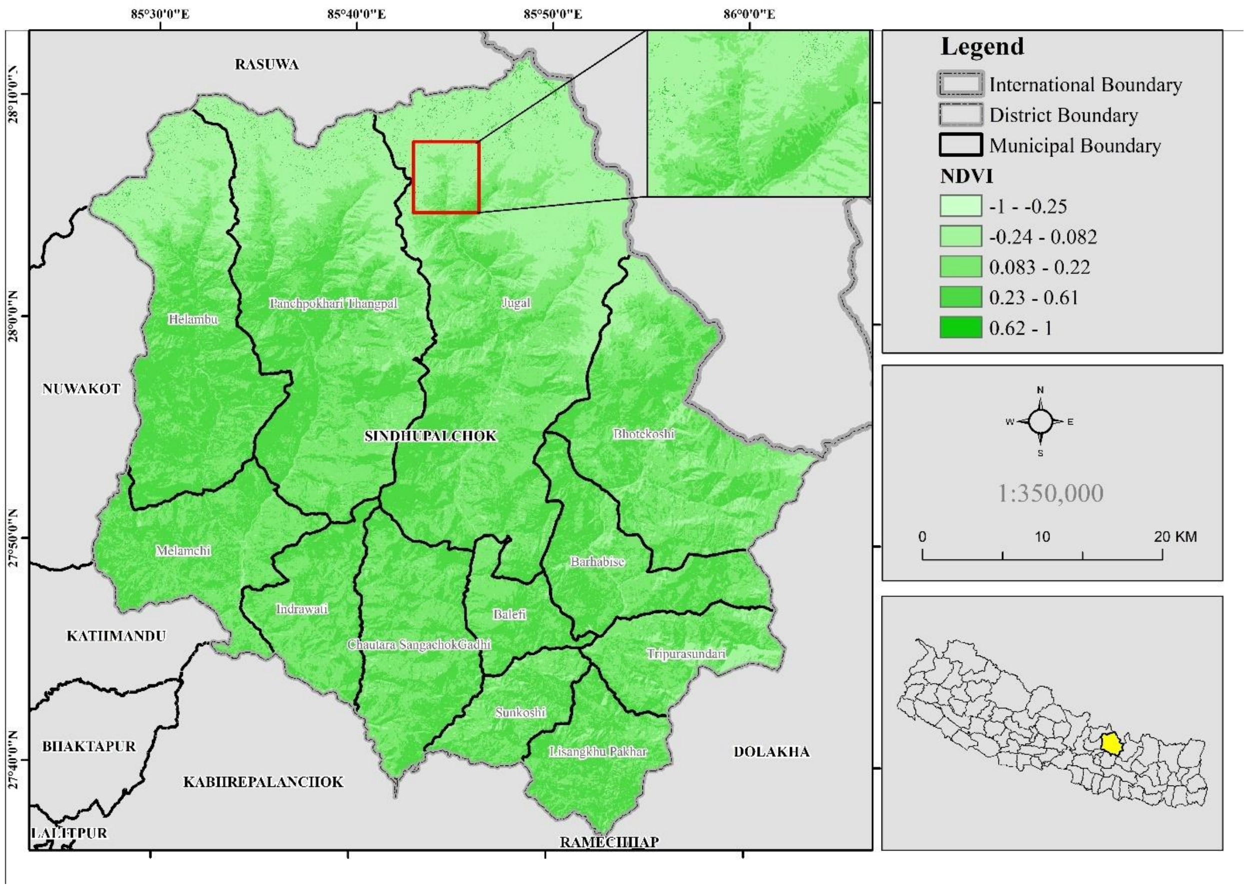


Figure 23: NDVI Map of Sindhupalchowk District

4.1.8 Topographic Wetness Index (TWI):

The topographic wetness index (TWI), also known as the compound topographic index (CTI), is a steady state wetness index. It is commonly used to quantify topographic control on hydrological processes. The index is a function of both the slope and the upstream contributing area per unit width orthogonal to the flow direction. Accumulation numbers in flat areas will be very large, so TWI will not be a relevant variable. The index is highly correlated with several soil attributes such as horizon depth, silt percentage, organic matter content, and phosphorus. Methods of computing this index differ primarily in the way the upslope contributing area is calculated.

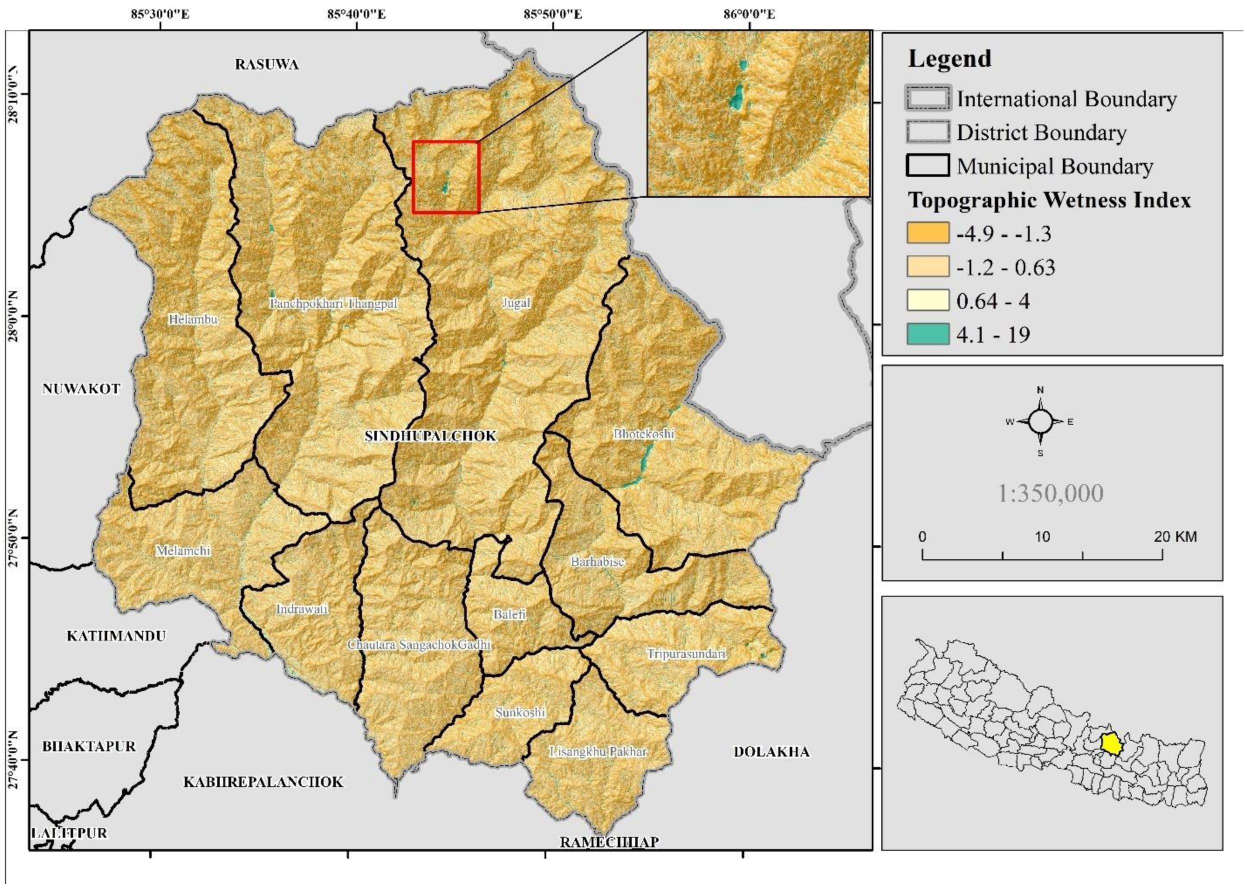


Figure 24: TWI Map of Sindhupalchowk District

4.1.9 Soil:

Soil type has a crucial role in determining the terrain characteristics, slope failure, mass movement and effect of rainfall, irrigation, flood, earthquake and human factors like construction. Soil categories for Sindhupalchowk district were prepared as shown in the map below. Sindhupalchowk has a range of parent soils that differs from north to south and is also extended towards north in river valleys showing relation with the elevation factor.

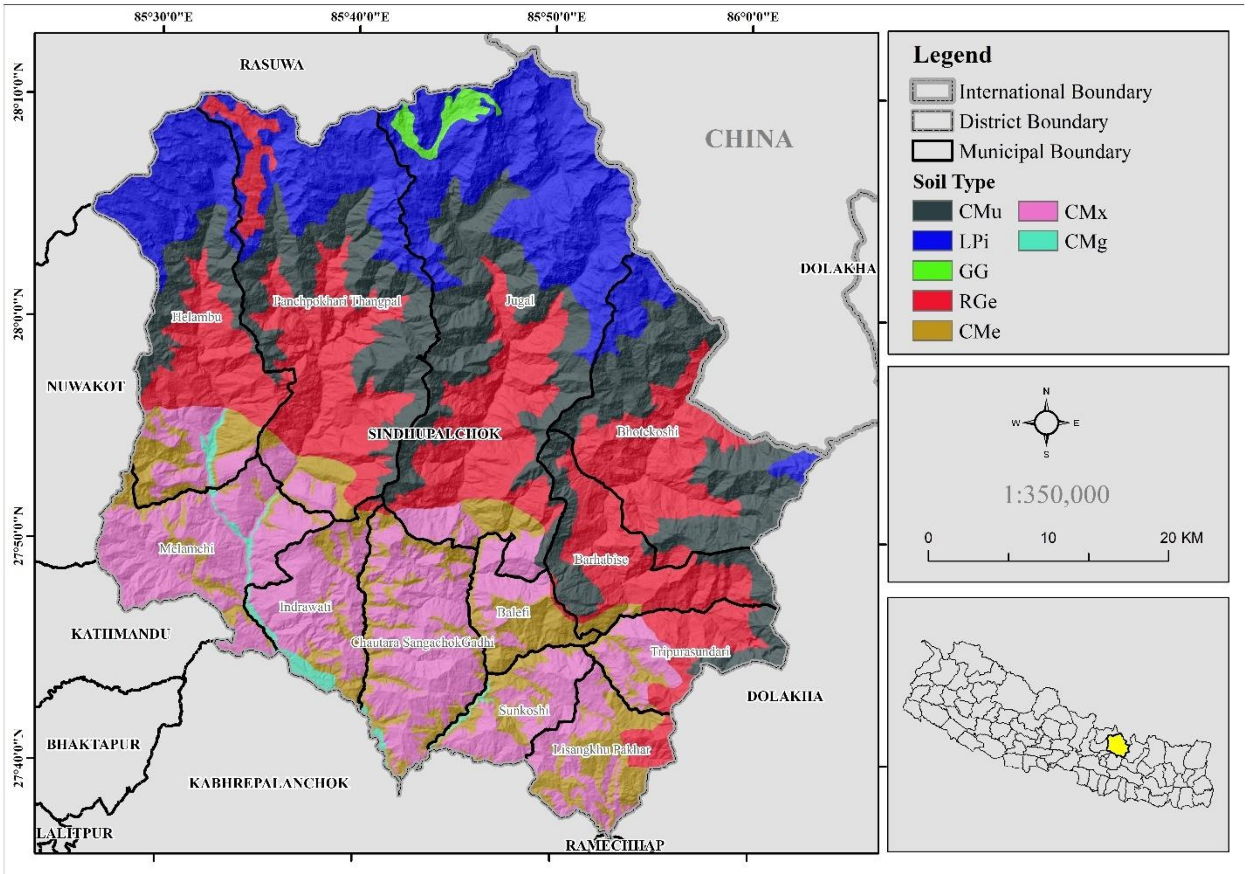


Figure 25: Soil Map of Sindhupalchowk District

4.1.10 Fault:

Fault is the major cause of damage by seismic event. The fault Earthquakes occur on faults - strike-slip earthquakes occur on strike-slip faults, normal earthquakes occur on normal fault and thrust earthquakes occur on reverse or thrust faults. When an earthquake occurs on one of these faults, the rock on one side of the fault slips with respect to the other. The fault surface can be vertical, horizontal, or at some angle to the surface of the earth. The slip direction can also be at any angle.

Many faults are mapped as individual segments across district. These fault segments are crossed along the East-West direction with different lengths. Fault has several different dip directions from vertical to unspecified, and fault type from exposed to conceal. Basically, all these faults are associated with the Main Central Thrust (MCT) and recent epicenter area that may have created a new fault line during the seismic event. The map indicates the district is surrounded by fault lines. Amongst them, the central and northern part of the district is more vulnerable to the seismic activity that may create more disaster.

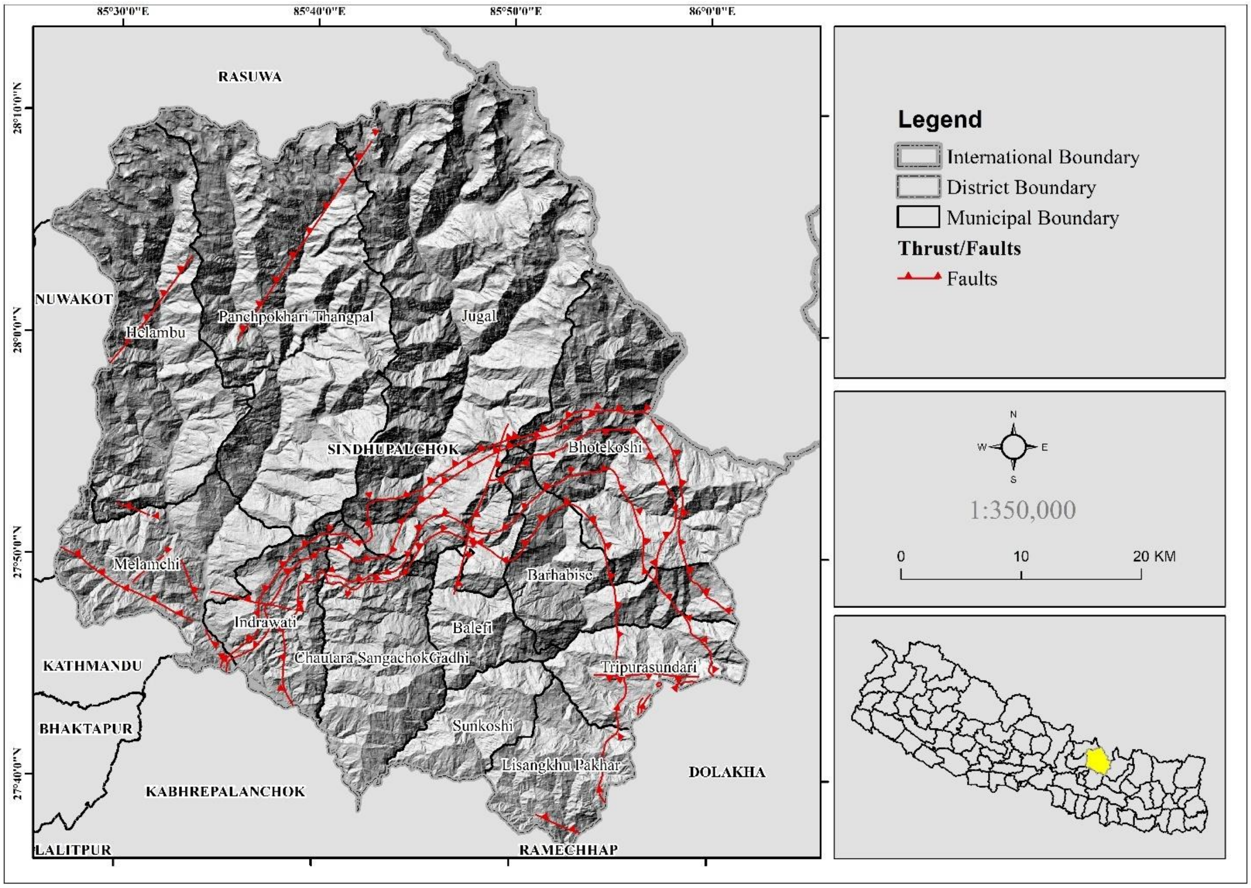


Figure 26: Fault Map of Sindhupalchowk District

4.1.11 Epicenter:

The District Earthquake Epicenters map shows epicenters of the earthquakes that occurred in and around most of the area. The earthquake, its epicenter, and its magnitude are illustrated on the map with legend. The points are also symbolized by the magnitude of the earthquake with small circle. The density of the epicenters is more in the middle part of the area from east to west; it can be correlated to the fault lines. Moreover, the more density (concentration of epicenters) is in the south-eastern part of the district.

The epicenter points in the figure also indicate that earthquakes are aligned parallel to the surface traces of the previously mapped principle other faults as well as MCT and the surrounding region. It can also be observed that the overwhelming majority of the recorded seismic events in the district and the surrounding region are aligned roughly in east northwest trending direction and concentrated near the surface trace of Main Central Thrust (MCT). Moreover, epicenters of a great majority of strong events ($Ms \geq 6.0$) are spatially located at small distance from the previously mapped major faults in Nepal and the surrounding area.

Basically, the earthquakes with a magnitude of 5 and above should be taken as seriously. On the Richter scale, earthquakes above 5 can be felt by everyone and can cause slight damage to all buildings. In this regard, the about 5 in Richter scale is only one at the boarder of Dolakha district.

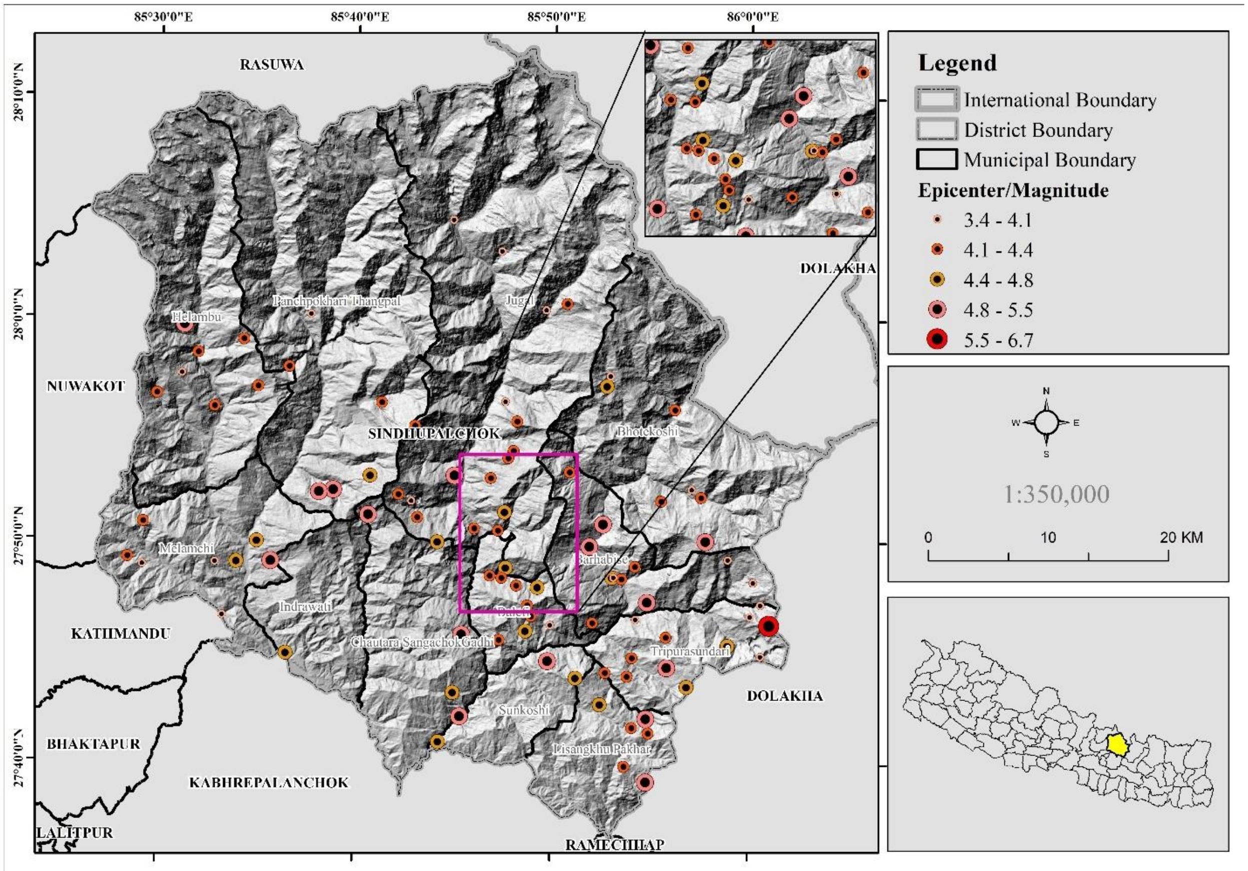


Figure 27: Epicenter Map of Sindhupalchowk District

4.1.12 Elevation:

Elevation was considered for landslide hazard because it is affected by geological processes. It commands the spatial disparity of hydro-meteorological condition and slope stabilities. It is also an influencing factor for flood as it affects runoff direction, moisture, temperature, wind direction, and the extent and the depth of the flood. The DEM of 30 m spatial resolution was used to derive the elevation classes of (i) <2500 m, (ii) 2500-3500 m, (iii) 3500-4500 m, (iv) 4500 - 5500 m, and (v) >5500 m up to 6962m which is the highest elevation in the district as shown in map below.

Elevation	Percent
<2500	57.01839
2500 - 3500	19.53263
3500 - 4500	12.88848
4500 -5500	8.971347
5500 <	1.589148

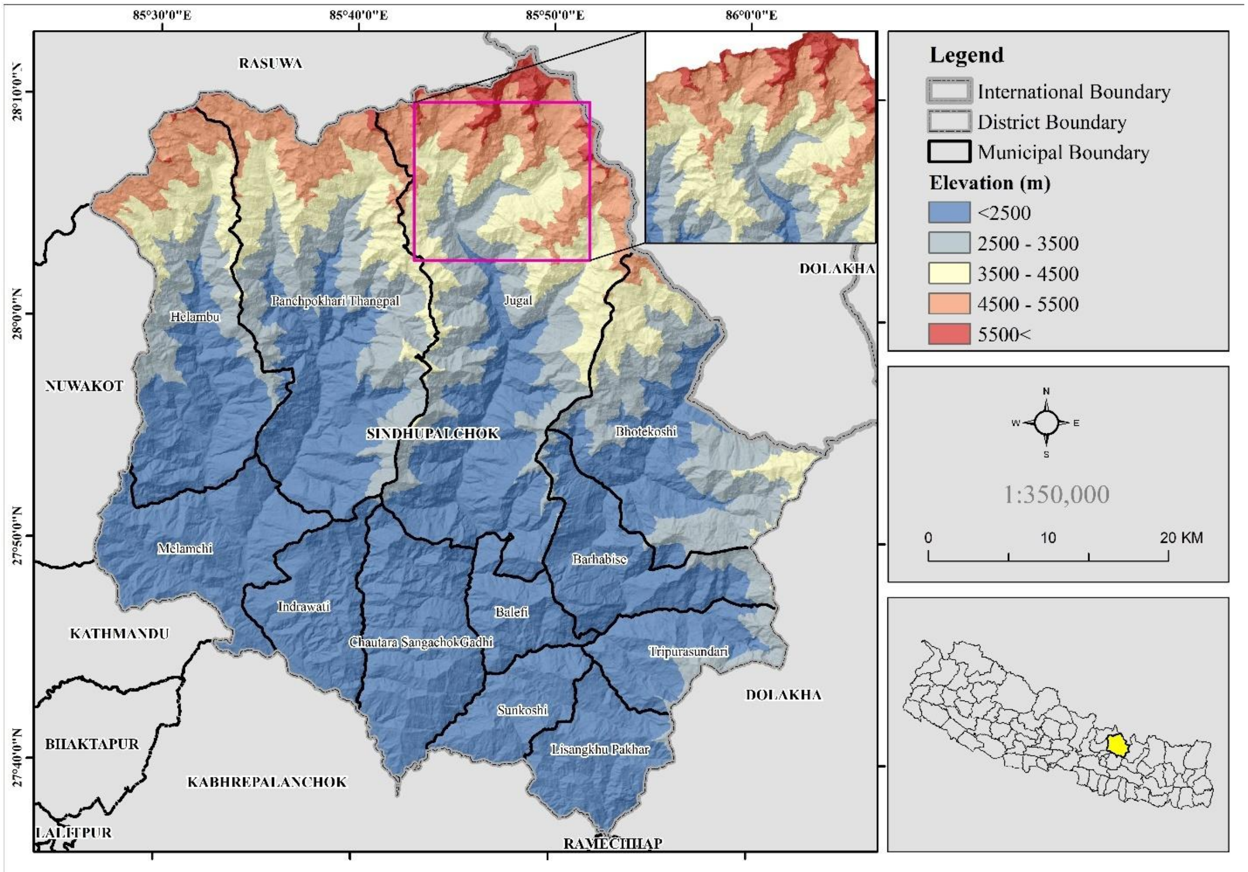


Figure 28: Elevation Map of Sindhupalchowk District

4.1.13 Annual Precipitation:

Heavy rainfalls trigger floods and landslides. Floods occur not only due to intensity and pattern of precipitation but also due to the moisture stored in the watershed basin, which is contributed by the previous hydrological process over a long time. The inverse distance weighted (IDW) interpolation approach was applied to create the five buffer zones of rainfall as (i) <2500 mm, (ii) 2500-3000 mm, (iii) 3000-3500 mm, (iv) 3500-4000 mm, and (v) 4000< mm as shown in map below. As per the interpolated map, it is obvious that northern part of the district receives more than double rainfall each year compared to the southern part which intensifies towards northwest.

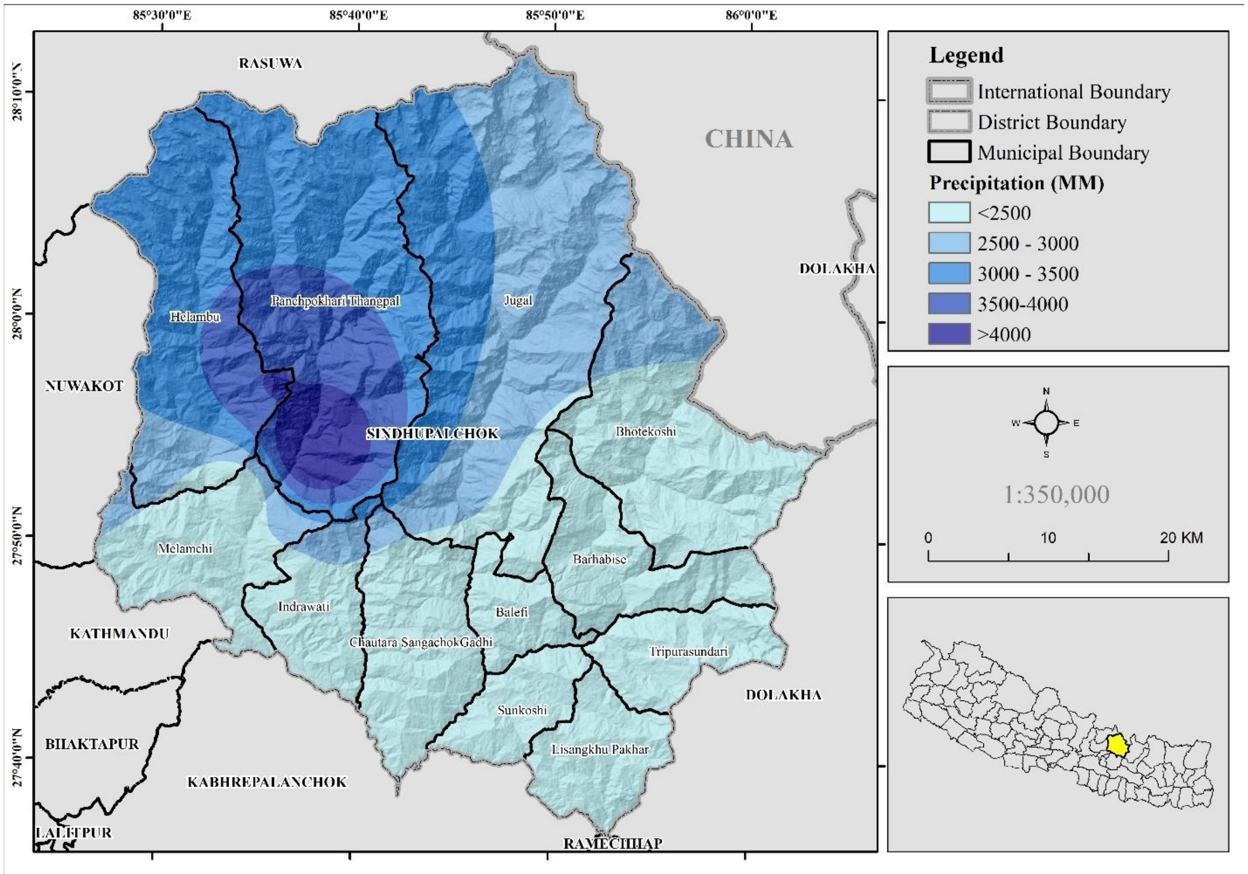


Figure 29: Precipitation Map of Sindhupalchowk District

4.1.14 Settlement:

Dense settlements increase the exposure to natural as well as anthropogenic hazards. There lies a positive correlation between the population density and the potential number of casualties and property damaged by earthquakes and urban fire hazard. The high population density and clustered settlements result in challenges for response and evacuation during fire, landslide, and earthquake hazards. Settlement map was prepared below showing major settlements while scattered settlements with low population density are abundant in the terrain except northern region. Elevation above 2500m is normally not settled due to harsh conditions.

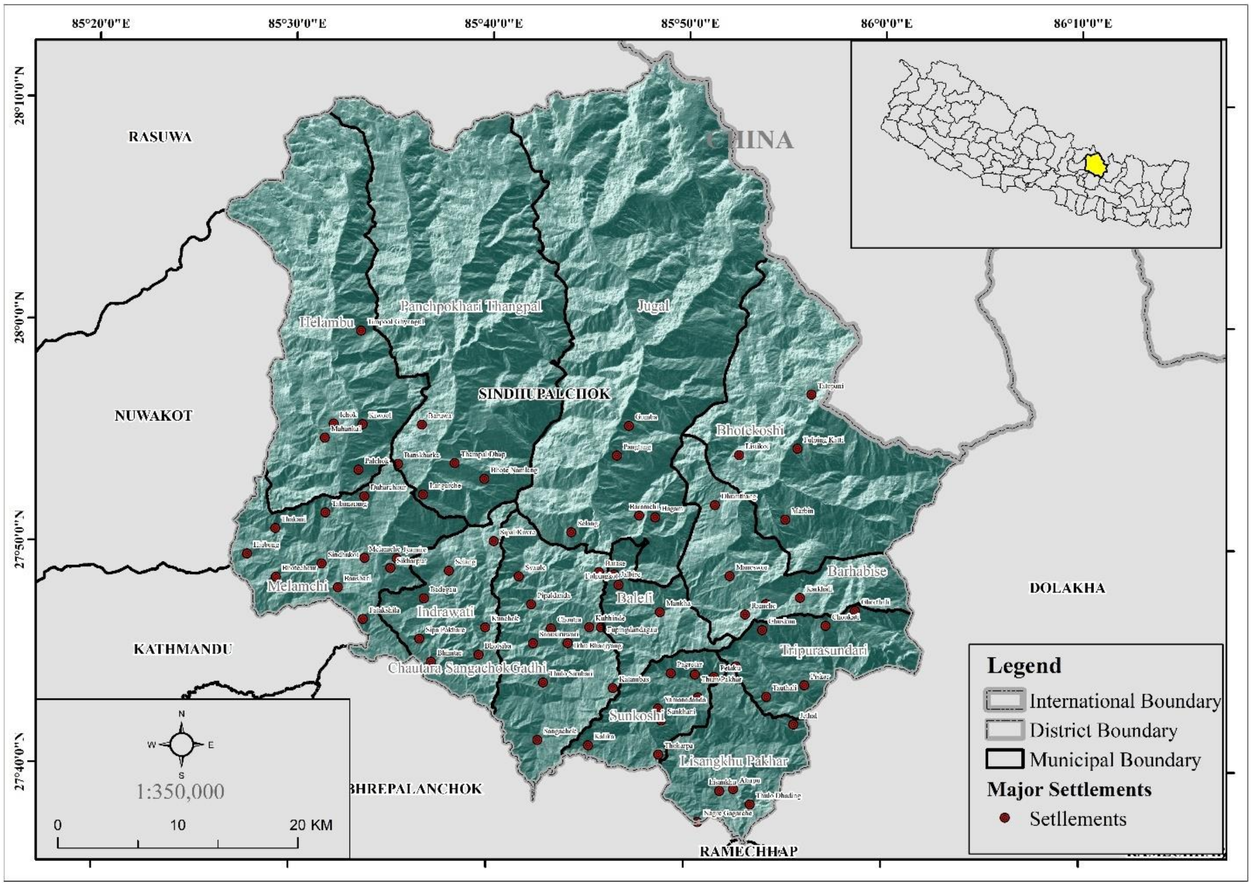


Figure 30: Settlement Map of Sindhupalchowk District

4.1.15 Land use:

The land use influences all four hazards considered in this study. It directly or indirectly affects some hydrological processes such as surface runoff, evapotranspiration, and infiltration and physical infrastructures such as open space, building stock, road and transport infrastructure, and critical facilities. For landslide hazard assessment, the agricultural land with shallow rooted nature of most of the agricultural crops and the lack of proper drainage system compared to natural forest areas have different actions. The presence of the built-up area creates the favourable environment for fire, flood, and earthquake hazard mostly due to exposure and the underlying vulnerabilities of constructed facilities. The land uses were classified as Water, Forest, Grassland, Cropland, Shrub land, Built-up, Bare and Snow areas. Mainly forest covers around 82% of the land use while 3.8 percent under snow cover has a significant role in creating mountain hazards.

Class	Percent
Water	0.208
Forest	55.813
Grassland	13.278
Cropland	13.726
Shrub land	4.333
Built-up Area	0.267
Bare Area	3.972
Snow/Ice Area	8.404

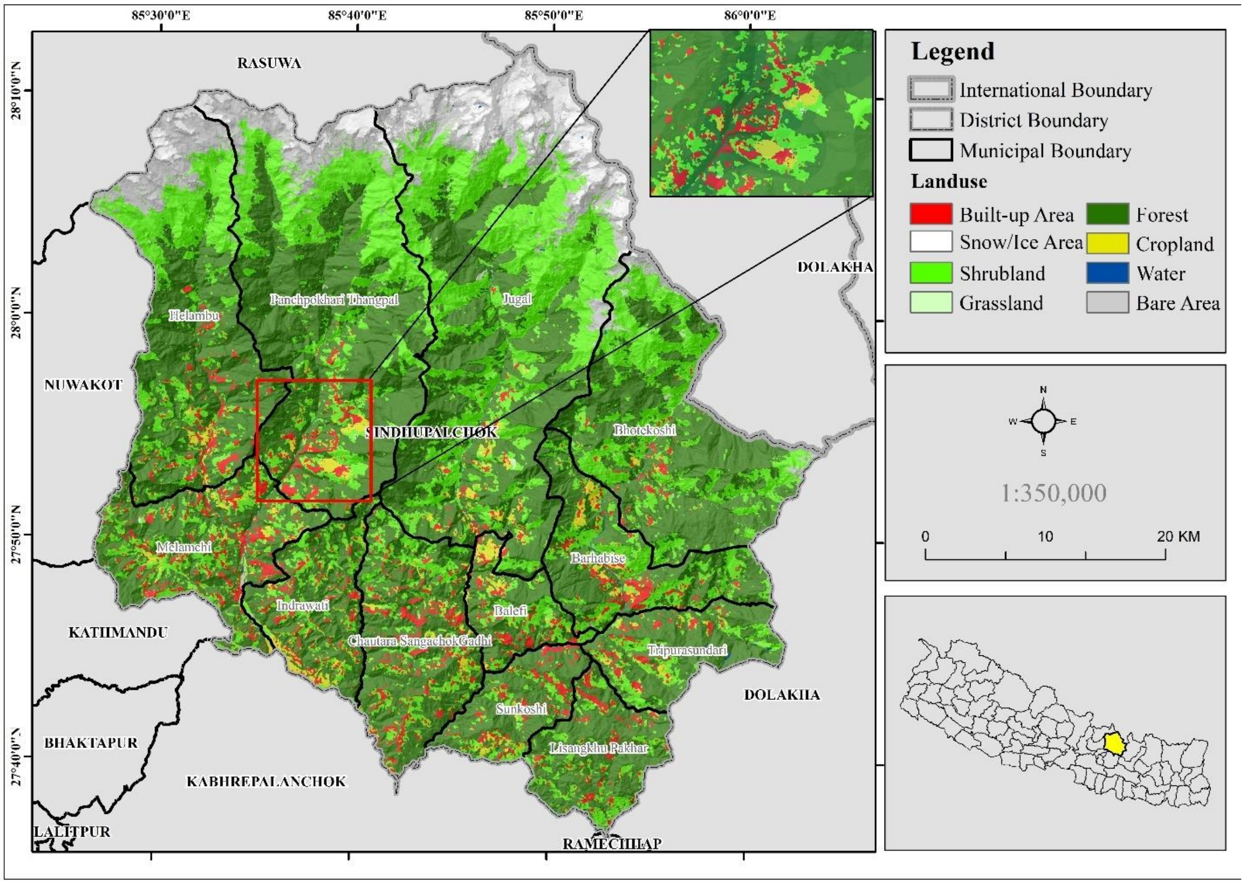


Figure 31: Land use Map of Sindhupalchowk District

4.1.16 Drainage Density:

Drainage density is indicative of infiltration and permeability of a drainage basin, as well as relating to the shape of the hydrograph. Drainage density depends upon both climate and physical characteristics of the drainage basin. Drainage density depends upon both climate and physical characteristics of the drainage basin. Soil permeability (infiltration difficulty) and underlying rock type affect the runoff in a watershed; impermeable ground or exposed bedrock will lead to an increase in surface water runoff and therefore to more frequent streams. Rugged regions or those with high relief will also have a higher drainage density than other drainage basins if the other characteristics of the basin are the same.

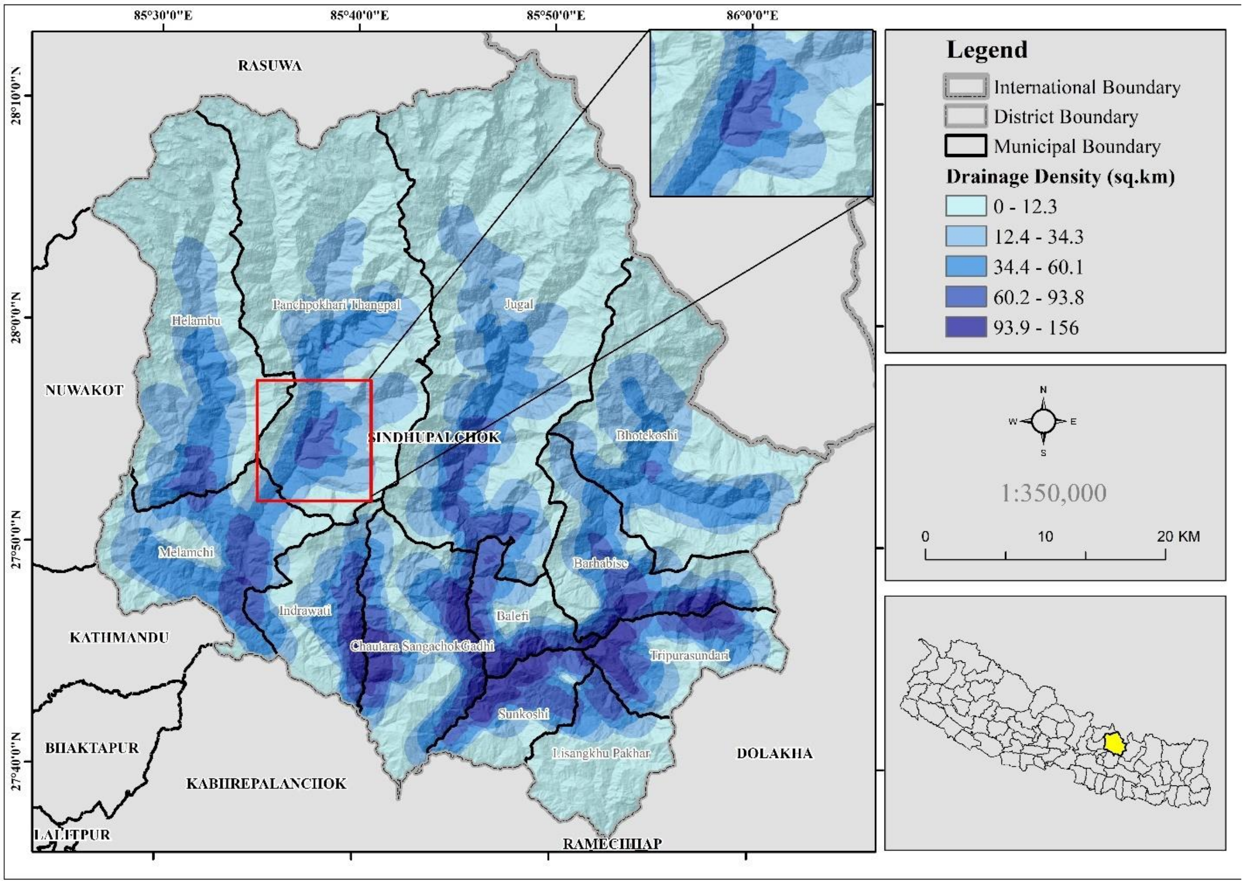


Figure 32: Drainage Density Map of Sindhupalchowk District

4.1.17 Land Surface Temperature (LST):

The Land Surface Temperature (LST) is one of the key climatic variables that establish an interaction between land surface and atmosphere. LST is the radiative skin temperature of the land derived from solar radiation. In as simple meaning, LST is the degree of hotness the surface of earth is felt when touched (Donlon et.al., 2012). Effective radiating temperature from the Earth's surface is used to evaluate the LST as surface of earth is responsible for controlling the heat and water exchange with the atmosphere (Yuan and Bauer, 2007).

The spatial distribution of LST for Sindhupalchowk district is shown in Fig. The figure shows that the surface temperature of Sindhupalchowk has risen above 30°C. The maximum LST is estimated to be 30.17ºC. Areas with population density and infrastructure also appear to have higher LST values than areas with lower population density. This is due to rapid urbanization, which means that the land cover has been replaced by impervious soil surfaces such as concrete layers.

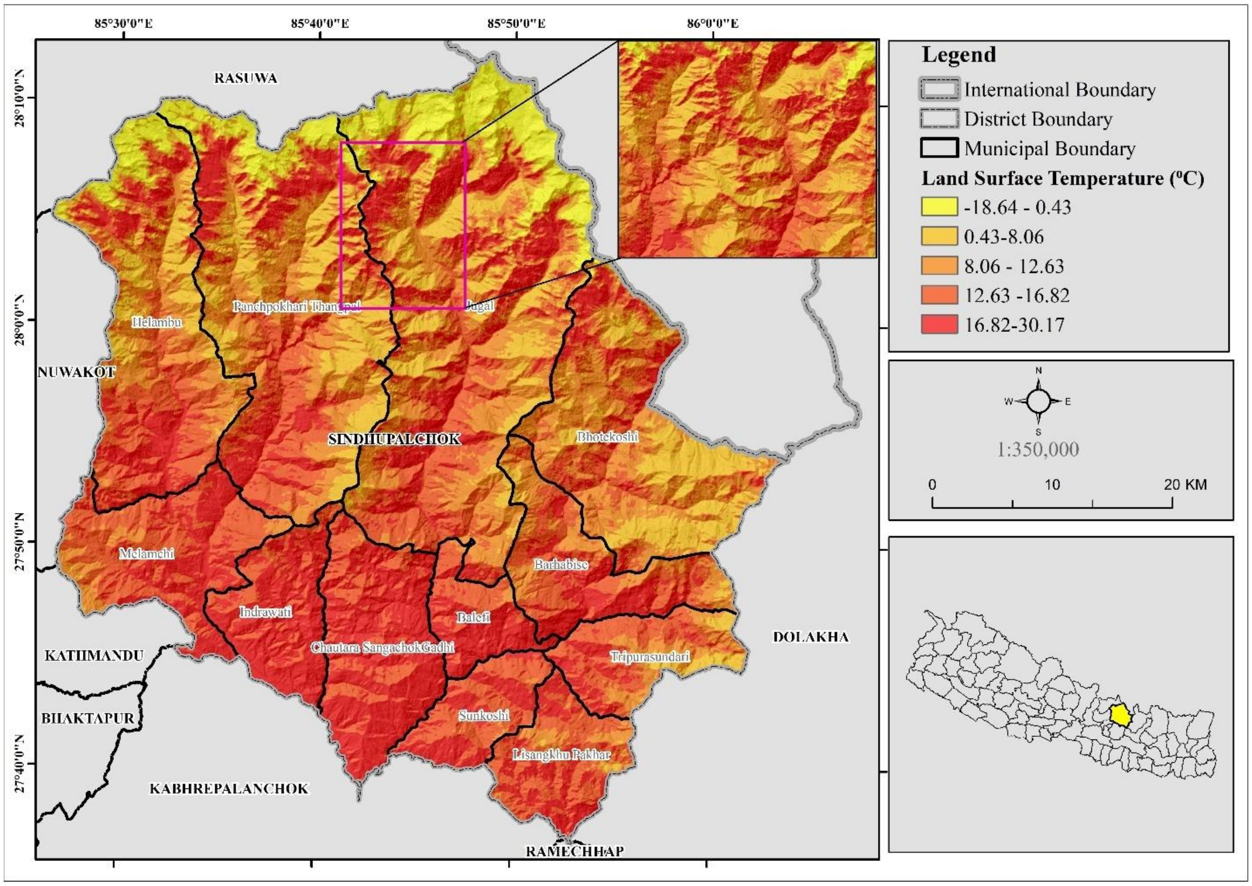


Figure 33: LST Map of Sindhupalchowk District

4.2 Hazard Assessment

The first step of hazard assessment involves individual hazard mapping based on the selected influencing factors. Thereafter, all hazard maps are superimposed based on their weights to generate a multi-hazard risk map for Sindhupalchowk district. The details of individual as well as multi-hazard mapping are explained as follows

4.2.1 Earthquake Hazard Assessment and Mapping

An earthquake is caused by a fault that suddenly slides across, like when you snap your finger. Faults allow the blocks to move relative to each other. This movement may occur rapidly, in the form of an earthquake - or may occur slowly, in the form of creep. Faults may range in length from a few millimetres to thousands of kilometres. Just as you snap your fingers with the whole area of your fingertip and thumb, earthquakes happen over an area of the fault, called the rupture surface.

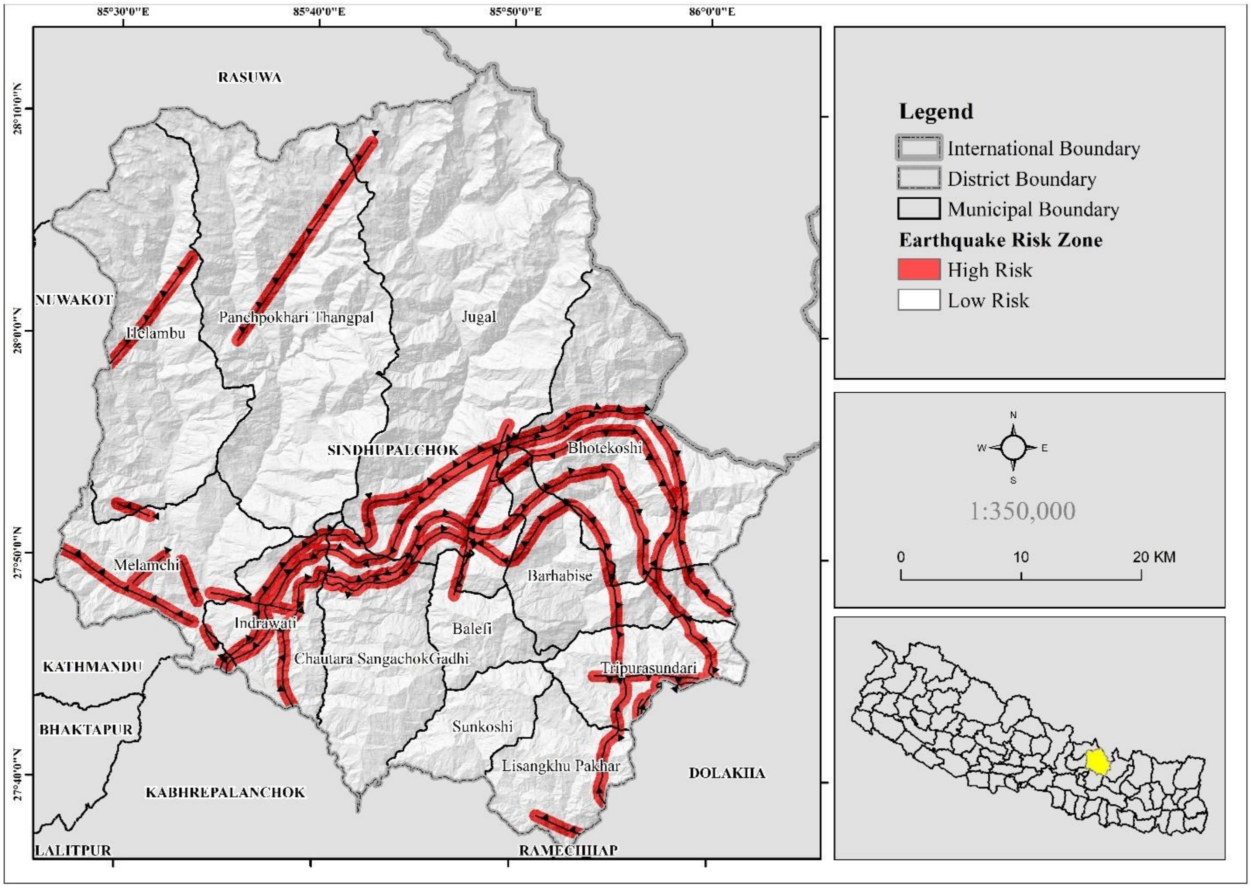


Figure 34: Earthquake Hazard Map of Sindhupalchowk District

An earthquake is one of the most destructive hazards in Nepal. Earthquakes are caused mostly by tectonic movement in the earth's crust; thus, the distribution of earthquakes tends to follow crustal plate boundaries. Seismic waves are produced when some form of energy stored in Earth's crust is suddenly released, usually when masses of rock straining against one another suddenly fracture and "slip." Earthquakes occur most often along geologic faults, narrow zones where rock masses move in relation to one another. The major fault lines of the world are located at the fringes of the huge tectonic plates that make up Earth's crust.

Nepal on a regular interval witnesses' earthquake along the major active faults in the east-west alignment. Historical data and ongoing seismological studies have clearly indicated that the entire region of Nepal is prone to earthquakes, and it lies in the active seismic zone V. It is evident that the seismic pattern has geographically divided into three clusters of events; viz: western, central, and eastern Nepal. It has also been pointed out that Siwalik, the lesser Himalaya, and the frontal part of the Higher Himalaya are the most vulnerable zones. Historical data has shown that the country witnessed three major earthquakes in the 20th century namely the Bihar-Nepal earthquake (1934), Bajhang earthquake (1980), Udayapur earthquake (1988), and Gorkha earthquake (2015). According to Global Report on Disaster Risk, Nepal ranks 11th position in terms of earthquake risk as earthquakes have often occurred in Nepal.

The Nepal earthquake of 2015, also called the Gorkha earthquake, was a severe earthquake that struck near the city of Kathmandu in central Nepal on April 25, 2015. About 9,000 people were killed, many thousands more were injured, and more than 600,000 structures in Kathmandu and other nearby towns were either damaged or destroyed. The earthquake was felt throughout central and eastern Nepal, much of the Ganges River plain in northern India, and north-western Bangladesh, as well as in the southern parts of the Plateau of Tibet and western Bhutan.

The initial shock, which registered a moment magnitude of 7.8, struck shortly before noon local time (about 06:11 AM Greenwich Mean Time). Its epicenter was about 21 miles (34 km) east-southeast of Lamjung and 48 miles (77 km) northwest of Kathmandu, and its focus was 9.3 miles (about 15 km) underground. Two large aftershocks, with magnitudes 6.6 and 6.7, shook the region within one day of the main quake, and several dozen smaller aftershocks occurred in the region during the succeeding days. On May 12, a magnitude-7.3 aftershock struck some 76 km (47 miles) east-northeast of Kathmandu, killing more than 100 people and injuring nearly 1,900.

Another potential geo hazard is seismic hazards. Based on the recent earthquakes (Nepal earthquake 2015) and the epicenter of the aftershocks indicate the zone is very sensitive to potential of the seismic hazards. The frequent seismological event and higher density of the epicenter locations are the major challenges to keep the district safe from the seismic geo hazards.

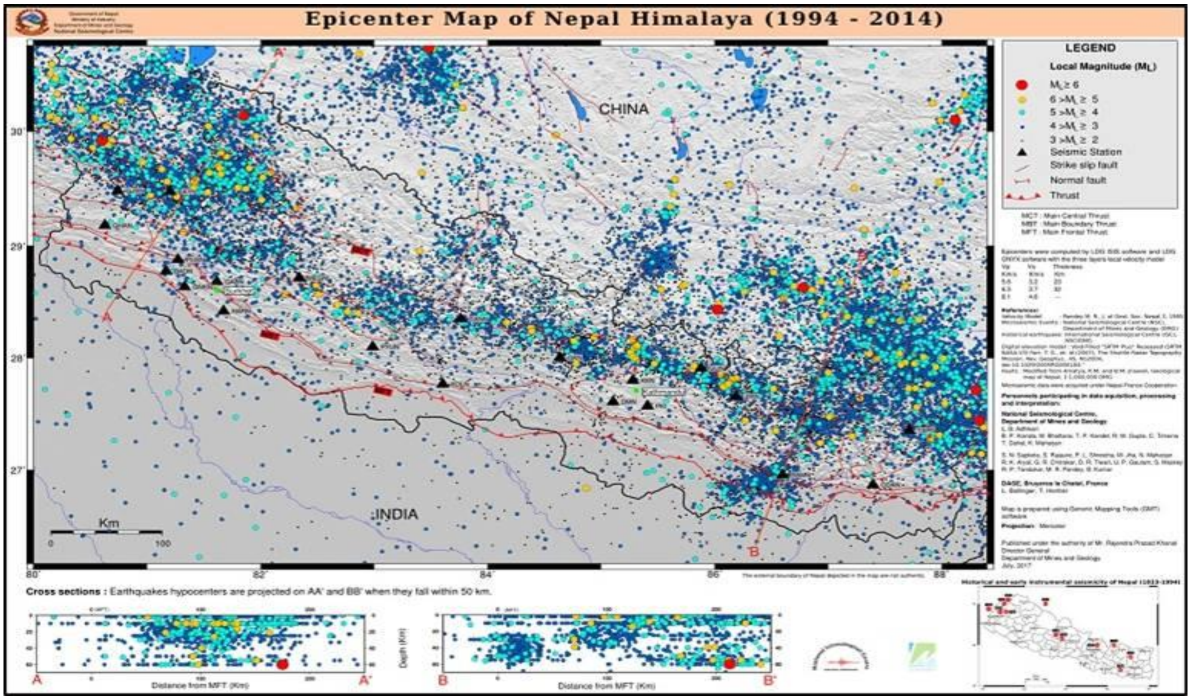


Figure 35: Epicenter Map of Nepal (Source: Department of Mines and Geology)

The epicenter map clearly shows the higher frequency of the earthquake in the whole district. That means the triggering factor from earthquakes is high potential for the occurrence of other consequences of geo hazards like landslides, landslide dams, flash floods and debris flow.

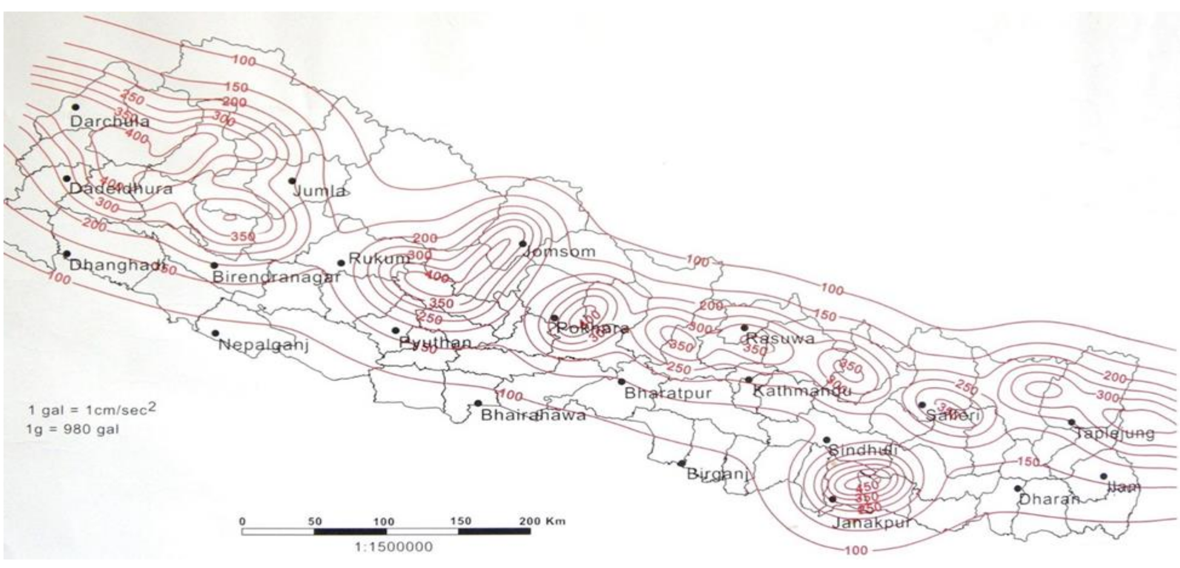


Figure 36: Seismic Hazard map of Nepal and Road Location (Source: Nepal Seismological Center, Department of Mines and Geology)

The study area is located in between the area having Seismic Zoning Factor, Z, equal to 0.9 and 1 according to the Nepal National Building Code (NBC 105: 1994) and within 150-to-350-gal acceleration of seismic hazard according to Nepal Seismological centre, Department of Mines and Geology.

Seismic point of view, the area lies under seismic prone area as according to the seismic map that was published by mines and geology. The map indicates M 3.5 to 5.0 in Richter scale is more frequent than the major one except the 2015 Gorkha and Dolakha earthquakes and 1934 Udaypur earthquake.

ZONE FACTORS FOR SELECTED MUNICIPALITIES

MANICIPALITY	FACTOR.Z	MUNICIPALITY	FACTCR.Z
Shadrapur	0.93	Dharan	1.00
Bharatpur	0.99	Dipayal	1.10
Bidur	1.00	Gaur	0.82
Birendra Nagar	1.02	Ilam	0.97
Biratnagar	0.93	Janakpur	0.89
Birganj	0.85	Kathmandu	
Butwal	0.90	Valley Towns	1.00
Byas	1.00	Mahendra	0.91
		Nagar	
Damak	0.96	Nepalganj	0.91
Dhanagadi	0.90	Pokhara	1.00
Dhanakuta	1.00	Tulsipur	1.00

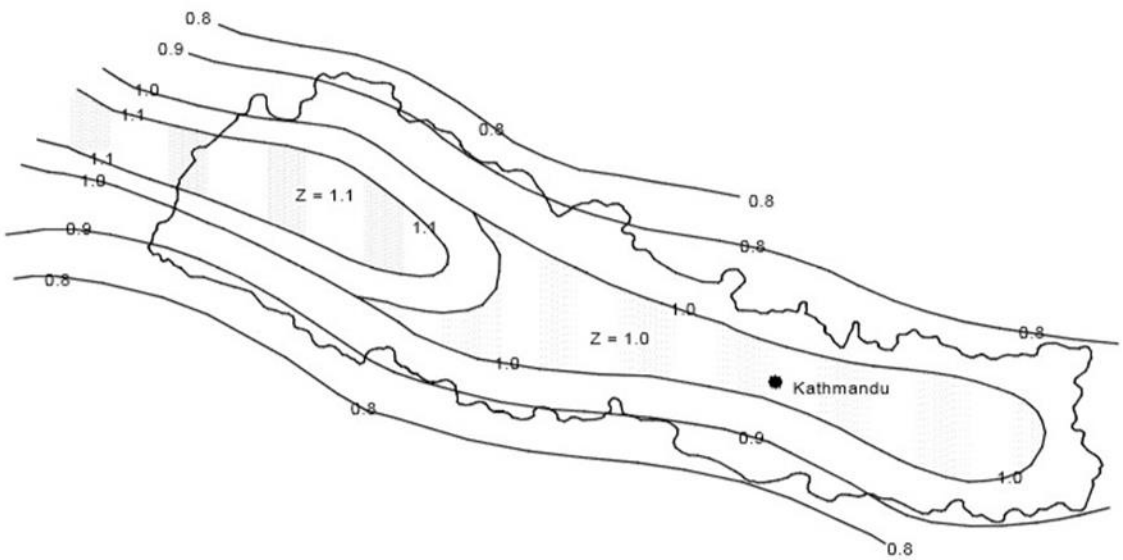


Figure 37: Zone Factor Map

Similarly, the seismic zone factor map shown by Nepal National Building Code (NBC, 1994) has indicated the project area zone lies in between 0.9 to 1.0.

4.2.2 Landslide Hazard Assessment

Landslide is the movement down slope of a mass of rock, debris, earth, or soil (soil is a mixture of earth and debris). Landslides occur when gravitational and other types of shear stresses within a slope exceed the shear strength (resistance to shearing) of the materials that form the slope. Shear stresses can be built up within a slope by a number of processes. These include overstepping of the base of the slope, such as by natural erosion or excavation, and loading of the slope, such as by an inflow of water, a rise in the groundwater table, or the accumulation of debris on the slope's surface. Short-term stresses, such as those imposed by earthquakes and rainstorms, can likewise contribute to the activation of landslides. Landslides can also be activated by processes that weaken the shear strength of a slope's material.

Landslides are one of the common natural hazards in the hilly region of Nepal. Both natural and human factors such as steep slopes, fragile geology, and high intensity of rainfall, deforestation, and unplanned human settlements are the major causes of landslides. The risk of landslides is further exacerbated by anthropogenic activities like improper land use, encroachment into vulnerable land slopes and unplanned development activities such as construction of roads and irrigation canals without proper protection measures in the vulnerable mountain belt. The hilly districts of Nepal located in the Siwalik, Mahabharat range, Mid-land, and also fore and higher Himalayas are more susceptible to landslides because of steep topography and fragile ecosystem.

Landslides present a threat to life and livelihood throughout the world, ranging from minor social disruption to huge economic catastrophe. Most work on landslide hazard assessment has been site-based and driven by development projects and engineering concerns (Crozier and Glade 2005). The study of landslides has drawn worldwide attention mainly due to increasing awareness of the socio-economic impact of landslides, as well as the increasing pressure of urbanization on the mountain environment. The local geology and slope of the area also have a significance on landslides. To minimize the loss due to landslides, landslide-prone areas should be identified.

This study covers multi-hazard risk assessment including landslide and maps the same for the district by using state of the art methods. This is achieved by integrating methods used with a geographic information system (GIS) and Remote Sensing. The blending of the different methods in GIS enhances the decision-making process with better illustration and mapping capabilities to facilitate the development of hazard maps. Such mapping helps to identify the highly susceptible areas for single hazard as well as multi-hazards that can play a significant role to address disaster risk reduction and also provide a guide for policymakers.

The degree of landslide hazard present is considered relative since it represents the expectation of future landslide occurrence based on the conditions of that particular area. Another area may appear similar but, in fact, may have a differing landslide hazard due to a slightly different combination of landslide conditions. Thus, landslide susceptibility is relative to the conditions of each specific area, and it cannot be assumed to be identical for a similar appearing area.

Even with detailed investigation and monitoring, it is extremely difficult to predict landslide hazards in absolute terms. Sufficient understanding of landslide processes does exist, however, to be able to make an estimation of landslide hazard potential. The planner can use this estimation to make certain decisions regarding site suitability, type of development, and appropriate mitigation measures. Thus, the planner is determining acceptable risk.

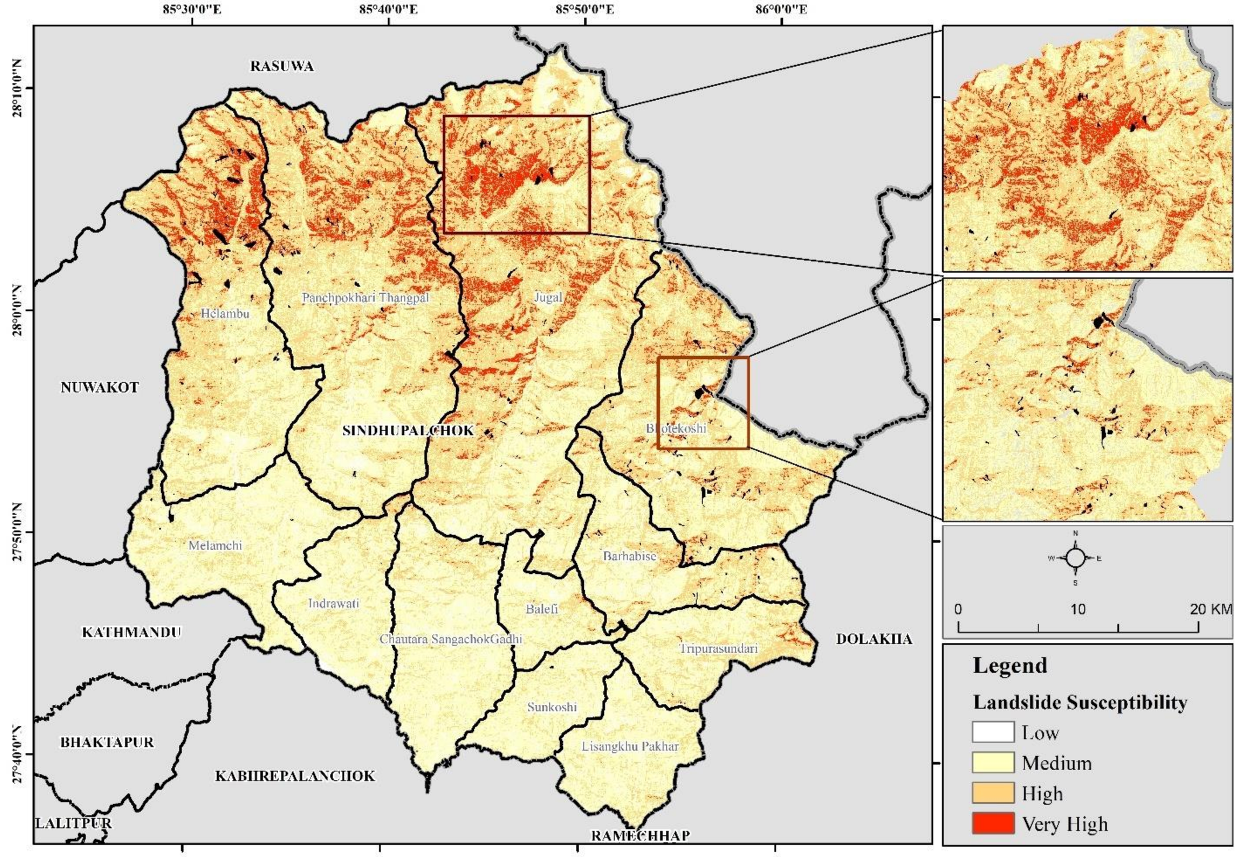


Figure 38: Landslide Susceptibility Map of Sindhupalchowk district

Determining the extent of landslide hazard requires identifying those areas which could be affected by a damaging landslide and assessing the probability of the landslide occurring within some time period. In general, however, specifying a time frame for the occurrence of a landslide is difficult to determine even under ideal conditions. As a result, landslide hazard is often represented by landslide susceptibility (Brabb, 1985). Like the concept of flood-prone areas, landslide susceptibility only identifies areas potentially affected and does not imply a time frame when a landslide might occur. To simplify these concepts, landslide susceptibility will be referred to as landslide hazard. Comparing the location of an area of proposed development to the degree of landslide hazard present enables the planner to estimate the landslide risk. This can be used to define land use capability and identify appropriate mitigation measures. Empirical evidence and past studies on Landslide Hazard in Sindhupalchowk shows the concentration of the landslides and high potential areas that are prone to landslides are the northern area of Jugal, Panchpokhari and Helambu rural municipalities. However, in Jugal municipality the high potential area has extended to the western middle part of the municipality.

The table below shows the factors that were combined to prepare the landslide susceptibility map with their frequency ratio value (FR) and the prediction rate of each factor.

Table 4: FR and PR Value for Selected Factors for Landslide Hazard Assessment

S.N	Type	Class	Class Pixels	% Class Pixels	Landslide Pixels	% Landslide Pixels	FR	PR
1	Elevation	614-1610	805082	29.103	2174	14.107	0.003	2.362
		1611-2506	778186	28.131	4623	29.998	0.006	
		2507-3527	540354	19.533	4357	28.272	0.008	
		3528-4597	379820	13.730	3632	23.568	0.010	
		4598-6962	262878	9.503	625	4.056	0.002	
2	Slope	<17	373108	13.527	342	2.221	0.001	4.125
		17-26	772016	27.988	1741	11.304	0.002	
		26-35	823245	29.846	3936	25.557	0.005	
		35-46	555604	20.143	5680	36.881	0.010	
		46<	234371	8.497	3702	24.037	0.016	
3	Aspect	Flat (-1)	1459	0.053	2	0.013	0.001	2.407
		North (0-22.5 & 337.5-	281221	10.195	309	2.006	0.001	

		360)						
		Northeast (22.5-67.5)	302754	10.976	586	3.805	0.002	
		East (67.5-112.5)	327544	11.875	1716	11.142	0.005	
		Southeast (112.5-157.5)	331013	12.000	3756	24.388	0.011	
		South (157.5-202.5)	387272	14.040	4754	30.868	0.012	
		Southwest (202.5-247.5)	428847	15.547	3154	20.479	0.007	
		West (247.5-292.5)	391092	14.179	787	5.110	0.002	
		Northwest (292.5-337.5)	307142	11.135	337	2.188	0.001	
4	Curvature	Convex	487029	17.606	4025	26.118	0.008	1.804
		Flat	1752070	63.336	8031	52.112	0.005	
		Concave	527221	19.059	3355	21.770	0.006	
5	TWI	–4.9 – –1.3	1292611	46.862	7904	51.321	0.006	4.534
		–1.2 – 0.63	991876	35.959	4811	31.238	0.004	
		0.64-4	381812	13.842	2197	14.265	0.002	
		4.1-19	92045	3.337	489	3.175	0.000	
6	NDVI	–1– –0.25	12145	0.439	47	0.305	0.004	2.092
		–0.24– 0.082	598898	21.649	4273	27.732	0.007	
		0.083- 0.22	1128372	40.788	8636	56.049	0.008	
		0.23 - 0.61	1017670	36.786	2427	15.752	0.002	
		0.62 - 1	9354	0.338	25	0.162	0.003	
7	Land use	Water	7691	0.278	28	0.182	0.004	3.218
		Forest	1466663	53.017	2333	15.140	0.002	
		Grassland	4362	0.158	4	0.026	0.001	
		Cropland	54220	1.960	80	0.519	0.001	

		Shrub land	821105	29.681	10392	67.437	0.013	
		Built up	141215	5.105	417	2.706	0.003	
		Bare Area	163798	5.921	2112	13.705	0.013	
		Snow/ice area	107372	3.881	44	0.286	0.000	
8	Distance from River	<200	455501	16.465	2965	19.242	0.007	1.000
		200-400	410898	14.853	2848	18.483	0.007	
		400-600	384523	13.900	2707	17.568	0.007	
		600-800	346362	12.520	2203	14.297	0.006	
		800-100	319636	11.554	1971	12.791	0.006	
		1000<	849530	30.708	2715	17.620	0.003	
9	Distance from Road	<200	1129655	40.633	3233	20.859	0.003	1.039
		200-400	375167	13.494	2217	14.304	0.006	
		400-600	181945	6.544	1260	8.130	0.007	
		600-800	114641	4.124	974	6.284	0.008	
		800-100	90153	3.243	1030	6.646	0.011	
		1000<	888587	31.962	6785	43.777	0.008	
10	Geology	Himal Group	1535566	55.877	10935	70.914	0.007	1.885
		Gn	140929	5.128	102	0.661	0.001	
		Ulleri Formation	46719	1.700	36	0.233	0.001	
		Lakharpata Formation	117037	4.259	1179	7.646	0.010	
		Galyang Formation	85256	3.102	1173	7.607	0.014	
		Ba	19975	0.727	108	0.700	0.005	
		Syangja Formation	80178	2.918	300	1.946	0.004	
		Ranimatta Formation	504343	18.352	672	4.358	0.001	

		Sangram Formation	31060	1.130	447	2.899	0.014	
		Gahanapokhara Formation	54663	1.989	191	1.239	0.003	
		Naudanda Formation	41726	1.518	38	0.246	0.001	
		Middle Siwalik	46318	1.685	163	1.057	0.004	
		Cr	7170	0.261	9	0.058	0.001	
		Tgr	37170	1.353	67	0.435	0.002	
11	Rainfall	1640-2439	1165878	42.144	4776	30.995	0.004	2.99
		2440-2940	557981	20.170	1939	12.584	0.003	
		2941-3427	702736	25.402	6940	45.039	0.010	
		3428-4063	287339	10.387	1654	10.734	0.006	
		4064-5092	52512	1.898	100	0.649	0.002	

4.2.3 Avalanche

Avalanches are a rapid movement of snow and debris flowing down through the slope or flanks of mountains. It can be triggered by natural factors like slopes, thickness of snow or human activity. They have the capacity to carry massive masses of snow and associated debris that make them one of the most destructive elements of hazards. The high mountainous region having the rugged and steep slopes topographically is susceptible to avalanche. A number of cases of avalanche with destructive nature have been reported in Nepal. Unexpected Seti River Flood of 5th may, 2012 at Kaski district could be an example of this type of hazard.

Landslides are the common problems of mountainous terrains of tropical, subtropical and temperate regions and are demonstrated in a variety of processes. Landslides pose serious threats to settlements, and structures that support transportation, natural resources management and tourism. They cause considerable damage to highways, railways, waterways and buildings. Potential sites that are particularly prone to landslides should therefore be identified in advance to reduce disaster damages.

4.3 Flood Hazard Assessment

Flood, a high-water stage in which water overflows its natural or artificial banks onto normally dry land, such as a river inundating its floodplain. Floods can happen during heavy rains, when ocean waves come on shore, when the snow melts quickly, or when dams or levees break. Damaging flooding may happen with only a few inches of water, or it may cover a house to the rooftop. Floods can occur within minutes or over a long period and may last days, weeks, or longer. Floods are the most common and widespread of all weather-related natural disasters. The effects of floods on human well-being range from unqualified blessings to catastrophes.

Flood is a common cause of disaster in the rainy season in Nepal and has been the most frequent, highly damaging and widespread natural hazard. It is estimated that more than 6,000 rivers and rivulets are in Nepal flowing from north to south. Among these, snow-fed rivers, such as the Koshi, Narayani, Karnali, and Mahakali, are perennial rivers. They originate from the Himalayas and snow-capped mountains and pass through the hills to the Terai plains. During the monsoon (June-September), these rivers swell and cause damage to the villages, crops lands, and people and livestock remain within the river basins. Historical data has shown that Nepal witnessed major floods in the Tinau basin (1978), Koshi River (1980), Tadi River Basin (1985), Sunkoshi Basin (1987), and a devastating cloud burst in the Kulekhani area (1993) which alone claimed the lives of 1336 people.

Recent flash floods in the Melamchi River and old flood in the Sunkoshi River are severe flood events that occur with little or no warning. They can be triggered by intense rainfall ('cloudbursts'), failure of natural or artificial dams, and outbursts of glacial lakes. The frequent occurrence of flash floods within the district poses a severe threat to lives, livelihoods, and infrastructure, both within the mountains and downstream. Vulnerable to lives and properties– are often the hardest hit. Flash floods pose a greater risk to human life and livelihoods than the regular riverine floods, which build up over days when there is heavy rainfall upstream. Flash floods tend to carry with them much higher amounts of debris and, as a result, cause more damage to hydropower stations, roads, bridges, buildings, and other infrastructure Flash flood damage can be reduced by establishing a proper flood control management structure or organ to manage flood events and reduce their negative effects. The benefits of precautionary steps, measures, and actions will bring communities, agricultural land, infrastructure, and livelihoods in flash flood-prone areas to safety with the help of government management. Risk assessment forms the core of the disaster risk management process and results in identifying potential risk-reduction measures. Risk assessment integrated into the development planning process can identify actions that meet development needs and reduce risk. Risk assessment is an essential part of flash flood risk management during the decision-making process. Due to weak geological formations of Himalayan rocks, active mountains, rugged topography, torrential rainfall, landslides, and debris flow are common phenomena in the district's major river catchment area, causing severe loss of lives and property from time to time. In addition to their direct impact, landslides and debris flows trigger flooding. If large amounts of material from landslides or debris flows reach a river, they can temporarily block its flow, creating a reservoir in the upstream reach. This phenomenon has also been seen in Jure, fortunately, timely management of debris made the downstream part safe. The recent flood in the Melamchi River was a flash flood that lost many people, houses and other important infrastructures. As the reservoir level rises due to river flow and overtops the dam crest, sudden erosion of the dam can cause an outburst. Overtopping can also be caused by secondary landslides falling into the reservoir. Internal instability of the dam might trigger an outbreak even without overtopping. Outburst events are generally random and cannot be predicted with any precision. Such a flood, commonly known as a landslide dam outburst flood (LDOF), scrapes out beds and banks, causing heavy damage to the riparian areas and huge sedimentation in downstream areas.

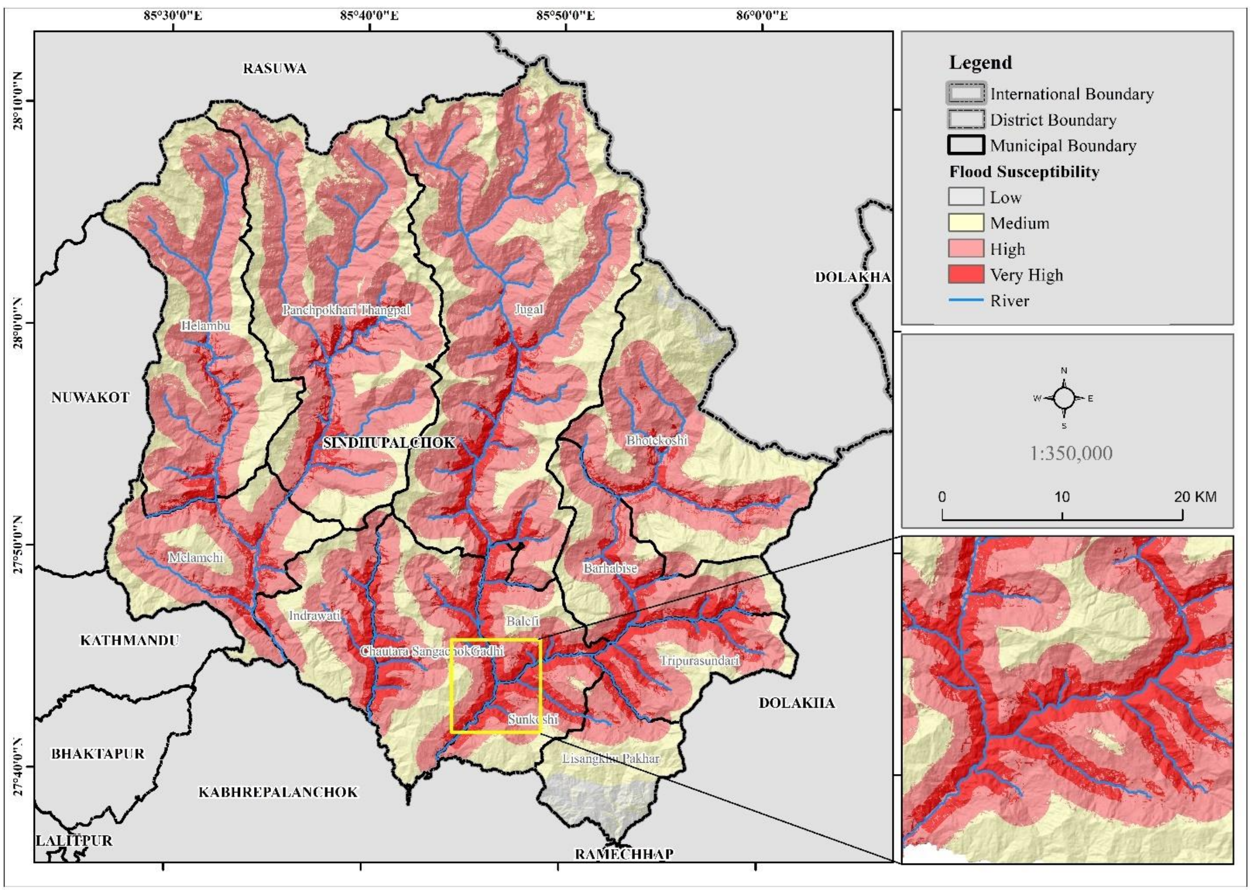


Figure 39: Flood Susceptibility Map of Sindhupalchowk district

A hydrological model can be used to evaluate flood peaks, depths, and volumes, and to generate flood hazard mapping. However, calibrating these models requires intensive data based on meteorological, hydrological, and geomorphological information. Many developing countries including Nepal lack such data at the watershed scale. Thus, a GIS based flood hazard analysis was employed to assess the flood hazard in Sindhupalchowk district.

The table below shows the factors that were combined to prepare the Flood susceptibility map with their Weightage and Susceptibility range using AHP method.

Table 5: Assigned Weight and Rank Score for Flood Hazard Assessment

Flood Causative Criterion	Class	Susceptibility Class Ranges	Susceptibility Class Rating	Weight %
Distance From River	<200	Very High	5	42
	200-400	High	4	
	400-600	Medium	3	
	600-800	Low	2	
	800<	Very Low	1	
Flow Accumulation	0-42401	Very Low	1	9
	42401-186418	Low	2	
	186418-420353	Medium	3	
	420353-761103	High	4	
	761103-1386336	Very High	5	
Drainage Density(sq.km)	0-12.3	Very Low	1	11
	12.4-34.3	Low	2	
	34.4-60.1	Medium	3	
	60.2-93.8	High	4	
	93.9-156	Very High	5	
Soil (Clay Content %)	4-8	Low	2	4

	8-10	Medium	3	
	10-12	High	4	
	12-16	Very High	5	
	16-27	High	3	
Land use	Snow/Ice Area	Very Low	1	6
	Forest	Low	2	
	Grassland	Medium	3	
	Bare Area	High	4	
	Water	Very High	5	
Rainfall (mm)	1640-2439	Very Low	1	18
	2440-2940	Low	2	
	2941-3427	Medium	3	
	3428-4063	High	4	
	4064-5092	Very High	5	
Slope	<17	Very Low	5	10
	17-26	Low	4	
	326-35	Medium	3	
	35-46	High	2	
	46<	Very High	1	

For each of the factor and the weightage provided to each factor the Consistency ratio is 0.1 which means that the matrix of each considered factor has an acceptable consistency

4.4 Fire Hazard Assessment

With the global climate change and the impact of human activity, the forest area reduces rapidly, while the forest fire results in most of the reduction. Because it is uncontrolled fire that occurs in the countryside or a wilderness area, forest fire usually causes life and property loss and does harm to the ecology and environment of a region.

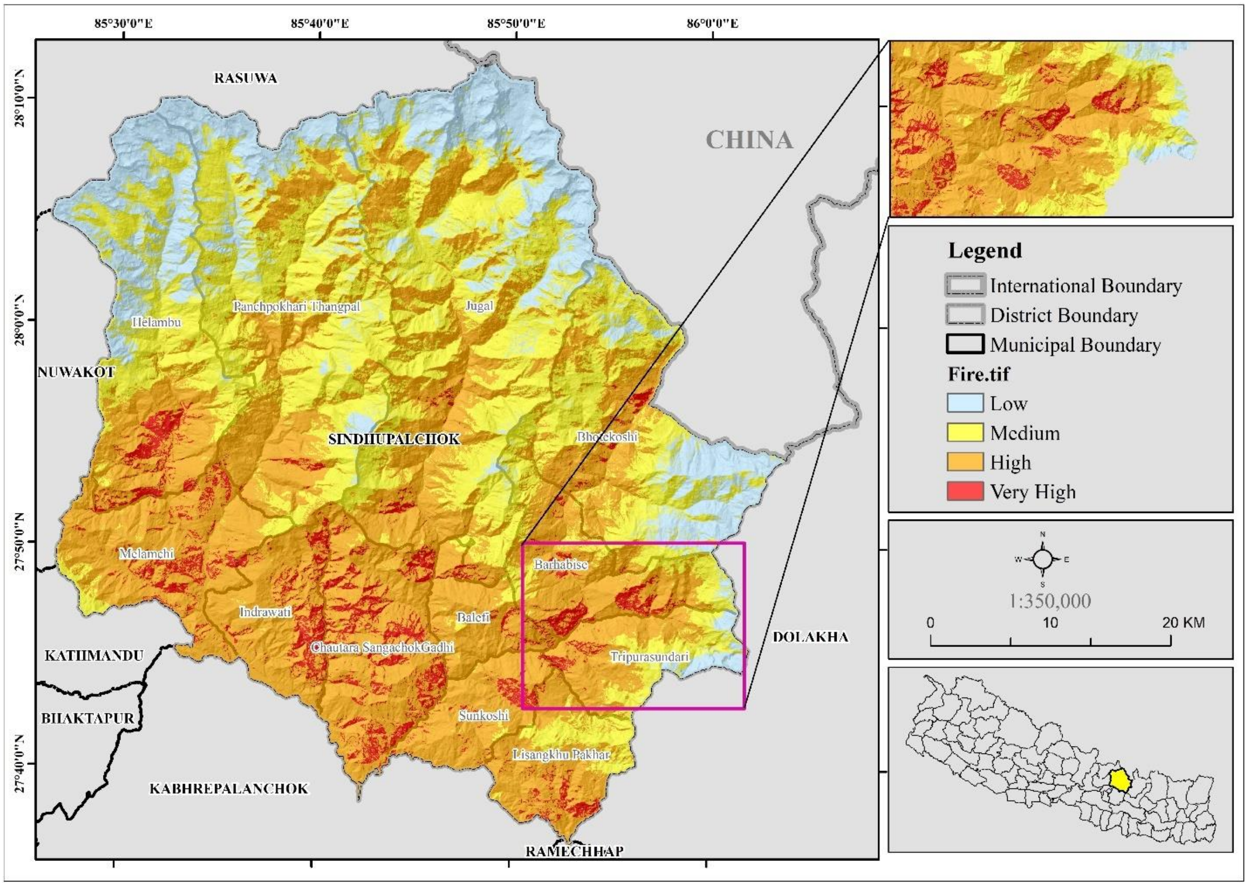


Figure 40: Fire Susceptibility Map

Of the total households of the country, nearly 78 percent households are agro-based households. In the rural areas thus, about 86 percent of the population lives in houses made of earthen wire, stone and wood. In Nepal, houses for residential purposes are developed on a cluster basis which are more susceptible to catching fire and spreading over there immediately due to close connectivity, especially in the dry season. Wildfire is another cause of natural disaster which usually occurs during dry season, especially in the mid hill areas. In the Terai region, fire, including the wildfire occurs mainly in the dry season.

The table below shows the factors that were combined to prepare the Fire susceptibility map with their Weightage and Susceptibility range using AHP method.

Table 6: Assigned Weight and Rank Score for Fire Hazard Assessment

Flood Causative Criterion	Class	Susceptibility Class Ranges	Susceptibility Class Rating	Weight %
Land Surface Temperature	–18.64 – (–0.43)	Very Low	1	40
	–0.43 – 8.06	Low	2	
	8.06 – 12.63	Moderate	3	
	12.63 – 16.82	High	4	
	16.82 – 30.17	Very High	5	
Slope	<17	Very Low	1	8
	17 – 26	Low	2	
	26 – 35	Moderate	3	
	35 – 46	High	4	
	46<	Very High	5	
Distance from Fire Hotspot	<2000	Very High	5	20
	2000 – 4000	Moderate	4	
	4000 – 6000	High	3	
	6000 –8000	Moderate	2	
	8000<	Low	1	
NDVI	–1 – (–0.25)	Very Low	1	21
	–0.26 – 0.082	Low	2	
	0.083 – 0.22	Moderate	3	
	0.23 – 0.61	High	4	
	0.61 – 1	Very High	5	
Elevation	614 – 1610	Very High	5	1
	1610 – 2506	Moderate	4	

	2506 – 3527	High	3	
	3527 – 4597	Moderate	2	
	4597 – 6962	Low	1	
Settlement	<1000	Very High	5	10
	1000-3000	Moderate	4	
	3000 – 6000	High	3	
	6000 – 9000	Moderate	2	
	9000<	Low	1	

4.5 Drought Hazard Assessment

A drought is a period of time when an area or region experiences below-normal precipitation, with characteristics and impacts that can vary from region to region. Drought is a low-onset natural hazard with effects that accumulate over a considerable period (weeks to months). The frequency and intensity of extreme climate events like drought have increased significantly. Since extreme climate events tend to be more abnormal, unexpected, unpredictable, and sensitive to climate change, they are considered the main source of terrestrial ecosystem instability and have a substantial impact on sustainable development of both ecosystems and human economy.

Drought is a frequently happening hazard in Nepal. This is mainly caused by uneven and irregular low monsoon rainfall. Some parts of Terai, mid-land and Trans-Himalayan belts of Nepal are prone to drought. The lack of irrigation facilities further exacerbates the effect of drought causing enormous loss of crops production leading to the shortage and insecurity of food. The droughts that happened in 1972 and 1979 were the most seriously damaging and harmful to the people, livestock and crops. In 1994 Nepal witnessed the worst drought in its history that affected 35 districts of western hilly and Terai regions.

4.6 GLOF Hazard Assessment

Melting of glaciers is one of the major effects of recent atmospheric warming in the Himalayas which results in the development of supraglacial lakes that coalesce to form proglacial lakes. Large volumes of water in these lakes are considered dangerous due to its unstable surrounding geomorphology. Most of the proglacial lakes are moraine-dammed and breaching of such moraine due to some triggering events may give rise to rapid release of water and sediment, often termed as Glacial Lake Outburst Floods (GLOFs).

GLOFs represent catastrophic phenomena of the Himalaya and pose a risk to downstream communities and infrastructure.

Glacial lakes are located in high-altitude areas particularly in the foothill of mountains. The lakes are formed due to damming by moraines. These lakes contained huge volumes of water; melting of glaciers may lead to an outbreak of the lakes, called a glacial lake outburst flood (GLOF) with substantial capacity to cause great damage downstream. 2,315 glacial lakes have, in total, been identified in Nepal and 14 GLOFs were recorded to have occurred between 1935 and 1991 in Nepal. At this background, 15 glacial lakes are found substantially dangerous in Nepal.

A glacial lake outburst flood (GLOF) in Tibet was responsible for the destructive Bhotekoshi river flood of July 2016, the Department of Hydrology and Meteorology (DHM) found out recently from the latest satellite images of the Himalayan bioregion taken by Google Earth. DHM discovered the GLOF in Nepal-China border. The glacial lake, roughly 9,000 sq.m in area, had eroded its moraine, issuing tsunami-like floods downstream that swept clean at least two dozen riverside homes and parts of the Araniko Highway on July 5. GLOFs can cause significant disaster of lives and properties.

4.7 Lightning

Lightning is a giant spark of electricity in the atmosphere between clouds, the air, or the ground. In the early stages of development, air acts as an insulator between the positive and negative charges in the cloud and between the cloud and the ground. When the opposite charges build up enough, this insulating capacity of the air breaks down and there is a rapid discharge of electricity that we know as lightning. The flash of lightning temporarily equalizes the charged regions in the atmosphere until the opposite charges build up again. Lightning can occur between opposite charges within the thunderstorm cloud (intra-cloud lightning) or between opposite charges in the cloud and on the ground (cloud-to-ground lightning). Lightning is one of the oldest observed natural phenomena on earth. It can be seen in volcanic eruptions, extremely intense forest fires, surface nuclear detonations, heavy snowstorms, in large hurricanes, and obviously, thunderstorms.

4.8 Multi Hazard Vulnerability Assessment

Various factors have been combined to map the vulnerability of Sindhupalchowk district, which is classified into four susceptibility ranges as low, medium, high and very high. Of the total area of Sindhupalchowk district, 56.01% of the districts are highly sensitive, 31.02% are moderately sensitive, 11.50% are very highly sensitive and 1.45% are low sensitive to flood risk. Similarly, 50.69% of districts are moderately sensitive, 34.49% highly sensitive, 6.49% very highly sensitive and 8.34% sensitive to low landslide susceptibility range. Regarding fire, 46.77%, 32.70%, 15.59% and 4.92% of districts have high, medium, low and very high fire risk.

The details of each element are illustrated in the table below:

Table 7: Multi hazard Vulnerability of Sindhupalchowk District

Multi hazard Vulnerability for Sindhupalchowk District	
Flood	
Susceptibility Range	Percentage
Low	1.45
Medium	31.02
High	56.01
Very High	11.50
Landslide	
Low	8.34
Medium	50.69
High	34.49
Very High	6.46
Fire	
Low	15.59
Medium	32.70
High	46.77
Very High	4.92

5 SOCIO-ECONOMIC VULNERABILITY ANALYSIS

5.1 Vulnerability Scenarios

Sindhupalchowk district demonstrates high vulnerability in terms of disasters like flood, landslide, and earthquake. Socio-economic vulnerabilities are increased when infrastructures and population are distributed in proximity of such disasters. Infrastructure will be affected by environmental and climate risks, including disasters. When planning investment, these climate and disaster risks need to be understood over the full lifespan of the infrastructure. Moreover, the impact and interactions of the structure in wider infrastructure systems needs to be reviewed with a resilience lens, and decision making harmonized with related strategic and spatial planning decisions reflecting broader societal needs.

These requirements relate not just to new structures, but also to maintenance, upgrade and management of existing infrastructure. Crucially this understanding depends on the availability of risk information (including knowledge of its accuracy and uncertainty) and a clear interpretation of these risks to inform the infrastructure investment decision. Infrastructure decisions must be informed by an understanding of the likely frequency and magnitude of climate events and how they are likely to change in the future. It is important to try to understand what the possible future changes might be – that unpredictable disasters, slow onset impacts or reoccurring seasonal events. This requires an understanding of climate and disaster risk, and an understanding of current weather patterns. Climate change models predict significant changes worldwide in temperature, precipitation (rainfall) patterns, storm surges, increases in sudden and catastrophic weather events, and in sudden changes in mountain environment.

5.1.1 Highly Vulnerable Areas are populated

Lack of plan for settlement and land use has resulted in haphazard settlement in hill slopes and river valleys without proper understanding of underlying hazards and future risks. With development of highways and Roads, settlement has increased along the road corridor which is a general tendency of communities towards improved access to infrastructures, facilities, and services. Due to this many new settlements have emerged along the roads. Mainly the emerging towns along the riverbank of Sunkoshi, Bhotekoshi, Brahmayani (Balephi) and Indrawati have expanded exponentially during last few decades. These emerging towns are already threatened by the disasters like flood and landslides every year. Moreover, 2015 earthquake has caused huge loss in these areas, mainly due to unplanned development and inadequate infrastructures.

5.1.2 Infrastructures increase Risk

In context of Nepal, construction of infrastructure is mostly compromised for low cost which increases the exposure to hazards. As an example, most of the road construction are done along river corridors, due to low-cost construction but the proximity to the river always results it in a flood and landslide hazard zone. Such infrastructures mainly road and bridges attract commercial activities and small markets emerge around road and bridges. These markets gradually grow inviting large buildings without proper reinforcement and end up increasing exposure in flood zones like Melamchi bazar, Bhotekoshi bazar, Balephi bazar, Sunkoshi bazar, Dolalghat, Khadichaur, Bahrabise etc. Such areas are under risk of annual floods and periodic landslides while increasing risk to fire hazard.

5.1.3 Hazard Zones are used to build Infrastructures

Lack of land availability is a major factor which encourages illegal encroachment of public land mainly along the river banks. These lands are captured temporarily or permanently through hefty corruptions and are used to build private buildings and markets. Such hazard zones are intentionally used for construction which falls under high flood risk zones.

5.1.4 Flood Zones are Encroached

With expansion of road development along the river corridors, people move from hill slopes to the roadside and easily available flood zones are encroached. Usually, flat lands along the riverbanks are used for cultivation due to irrigation convenience and reach of flood water. Most of these lands are converted to settlement and encroached towards the river which is seen along most of the riverbanks in Sindhupalchowk. This increases the risk of such settlements, agriculture as well as human beings settled their.

5.1.5 Government Standards are not implemented

Government has implemented policies to avoid construction in hazard prone areas. Melamchi Municipality enforced 100m right of way standards for construction of private houses. This is crucial to safeguard private properties during high floods. After 2015 earthquake, it was observed that people were not abide by the government laws and construction was carried along the rivers without maintaining the safe distance. This was the major cause of huge damage during 2021 Flood as most of the damaged houses were built in the flood zone which is not allowed as per the government law.

5.1.6 Post-Earthquake reconstruction couldn’t address the planned settlement

Post-earthquake reconstruction was an opportunity to provide safe shelter to the communities reducing their exposure to risks such as landslides, flood, thunderstorm, earthquake and fire. Due to lack of space, government was not able to implement planned settlement in recommended areas. This was coupled by the people constructing houses in haphazard sites without considering the underlying risks. Planned settlement is essential to reduce risk and at the same time provide essential services to the people including immediate responses in times of disasters.

5.1.7 Windstorm/ Thunderstorm are not managed

Windstorm and thunderstorms are huge risks in the hilly and mountain areas. There is no proper understanding of occurrence of such hazards and preparation is lacking. Even basic interventions required to manage thunderstorms and windstorms are not implemented which increases the risk of such hazards.

5.1.8 Communities’ perceptions are undermined

Many communities in Sindhupalchowk have reported their experience of risk with the request to resettlement plan. None of it was addressed in timely manner and many communities have faced disaster within this period. Landslide in Lidi is one example where communities were unheard, and this caused high number of human casualties.

5.2 Multi Hazard Interaction

In previous Chapter, we have explained that multiple hazards are existing in Sindhupalchowk district with variety of risk factors. Sindhupalchowk has been affected by major multi hazards in past decade. It in one of the severely affected districts by Earthquake, Landslide and Flood. Jure Landslide, 2015 earthquake and Melamchi Flood all have clearly revealed that Sindhupalchowk has one of the weakest topography and geology. In this situation, it is likely that future disasters and its impact will be of same scale in the district. The most alarming recent disaster of Melamchi flood has revealed that mountain terrain in the district is much fragile which could be possibly due to the impact of earthquake. Heavy rainfall event during June 15, 2021, was observed as one of the rare meteorological conditions which triggered cascading disasters of landslides and floods. In this scenario, it is likely that future extreme events might trigger similar consequences. A hypothetical interaction model of multi hazard is generated based on empirical understanding of the environment.

Table 8: Multi hazard interaction in Sindhupalchowk District

	Triggered Events			
Pre-Event		**Landslide**	**Flood**	**GLOF**
	Likelihood			
Earthquake	*Once in a decade*	Earthquake of 2015 created cracks in the terrain is susceptible to landslides with common triggers		Glaciers and Glacier lakes are increasingly at risk after 2015 earthquake and may show signs of breaching in coming years
Heavy Rainfall	*Every Year*	Earthquake created cracks receiving heavy rain can easily cause slope failure	Heavy Rainfall is likely to increase flood events every year	Heavy rainfall in higher mountains can cause GLOF event
Landslides			Landslides damming can amplify the flood event	Landslides above Glacier lakes are risk for GLOF

Flood		Undercutting by flood causes landslides every year, mainly in Sunkoshi along Tatopani		Flood in the mountain can cause breaching
GLOF	*Warming climate can cause breaching of glaciers*	GLOF has been observed as major factor behind mass movement in Melamchi flood and similar event are increasing	GLOF event in mountain areas can trigger extreme floods in the downstream.	
Warming temperature	*Every year*	Reduces soil moisture and increases slope failure	Flood events are increasing with increased extreme meteorological events due to effect of climate change	Glaciers and Glacial lakes are at high risks due to warming temperature

5.3 Multi Hazard Vulnerability in Municipalities

Natural disasters are always a serious threat to life and property worldwide. While disasters cannot be prevented, their impacts can certainly be minimized by developing preparedness plans and appropriate mitigation measures. A guiding principle behind these mitigation plans is the school of thought that risk reduction plans should be compatible with multiple hazards, rather than being disaster specific. Such an aggregated approach not only minimizes duplication efforts and computational costs, but also eliminates the possibility of risky substitution.

For preparing multi-hazard maps, different methods such as the frequency ratio method have been used to map landslide susceptibility, while to map other hazards, the AHP method was used. The hazard zoning map was created by classifying the district into four hazard zones as shown in the figure. The spatial distribution of landslides shows that landslide occurrence frequency seems to be higher in Helambu Rural municipality, Jugal Rural municipality and Panchpokhari Thangpal Rural municipality as explained in Table 9. Usually, the low frequency of landslides occurs at very high and very low altitudes because slopes are usually rocky with high shear resistance at very high altitudes and a milder slope at very low elevations, while the slope at intermediate altitudes causing instability, more prone to landslides (Dai & Lee, 2002).

Table 9: Hazard Susceptibility for Each Municipality

	Landslide susceptibility (%)				Flood susceptibility (%)				Fire susceptibility (%)			
Municipality	**Low**	**Medium**	**High**	**Very High**	**Low**	**Medium**	**High**	**Very High**	**Low**	**Medium**	**High**	**Very High**
Balefi	15.67	66.56	17.32	0.45	–	18.51	43.43	38.06	–	5.37	89.83	4.8
Barhabise	10.72	58.18	29.47	1.63	–	28.28	50.62	21.1	2.01	25.01	64.01	8.97
Bhotekoshi	4.47	48.79	41.99	4.75	2.84	44.53	46.09	6.54	23.61	44.41	30.83	1.15
Chautara Sangachwok Gadhi	17.86	67.66	14.24	0.23	–	28.75	46.94	24.31	–	0.32	77.47	22.21
Helambu	4.77	40.55	43.26	11.42	–	32.25	62.47	5.27	32.44	35.96	26.71	4.89
Indrawati	16.39	67.65	15.65	0.31	–	32.07	50.64	17.29	–	0.49	83.93	15.57
Jugal	4.67	38.89	44.83	11.61	–	28.4	64.66	6.94	23.6	43.25	32.52	0.62
Lisangkhu Pakhar	15.55	70.54	13.86	0.05	28.84	45.82	20.13	5.21	0.01	24.34	69.4	6.25
Melamchi	16.37	69.64	13.94	0.05	–	31.03	57.68	11.3	0.01	6.52	83.06	10.4
Panchpokhari Thangpal	4.34	42.54	43.67	9.45	–	28.6	65.94	5.46	16.97	51.84	30.82	0.37
Tripurasundari	10.35	61.56	26.78	1.3	–	20.54	47.98	31.49	12.63	31.58	52.7	3.08
Sunkoshi	17.61	71.11	11.27	0.01	–	23.9	41.7	34.4	–	1.44	89.97	8.59

As per the table 9, multi hazard susceptibility in each rural/ municipalities is in range of Low, Medium, High and Very High and the majority of rural/municipalities have large percentage of medium and high susceptibility. Moreover, as per landslide, Bhotekoshi, Helambu, Jugal and Panch pokhari have large percentage of its area under **very high susceptibility**. Similarly, as per flood susceptibility, all rural/ municipalities have majority of area under medium susceptibility whereas Balefi, Bahrabise, Chautara, Indrawati, Melamchi, Tripurasundari and Sunkoshi have large areas under **very high susceptibility**.

Similarly, as per fire hazard, most of the rural/ municipalities show high susceptibility whereas Chautara shows largest percentage i.e., 22% under highest susceptibility. This measure of vulnerability is based on area under all classes of susceptibility. But to address the risk, hazards cannot be generalized as per the range of susceptibility, but spatial distribution of the hazard and risk should be understood. For this, multi hazard maps of each municipality are presented in sub-headings below.

Understanding the susceptibility:

Rank	Susceptibility class	Descriptions / Result
	Low	There is low risk.
	Medium	There is medium risk. Requires understanding
	High	There is high risk. Identified as High-Risk Zones
	Very High	There is Very High risk. Identified as High-Risk Zones

5.3.1 Balefi Rural Municipality

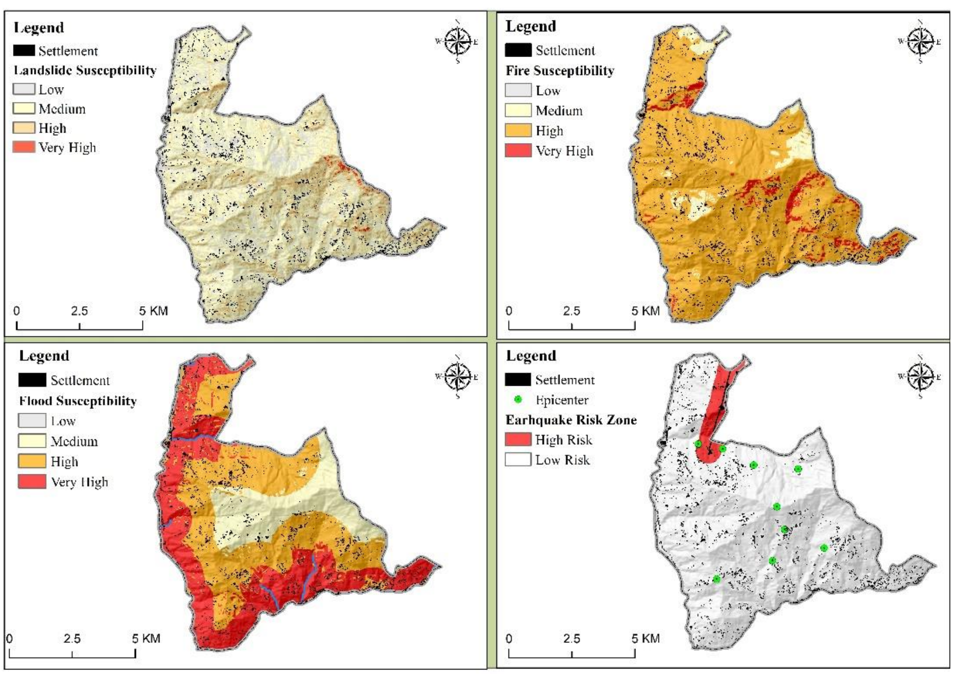


Figure 41: Multi-Hazard susceptibility map for Balephi Rural Municipality

5.3.2 Bahrabise Municipality

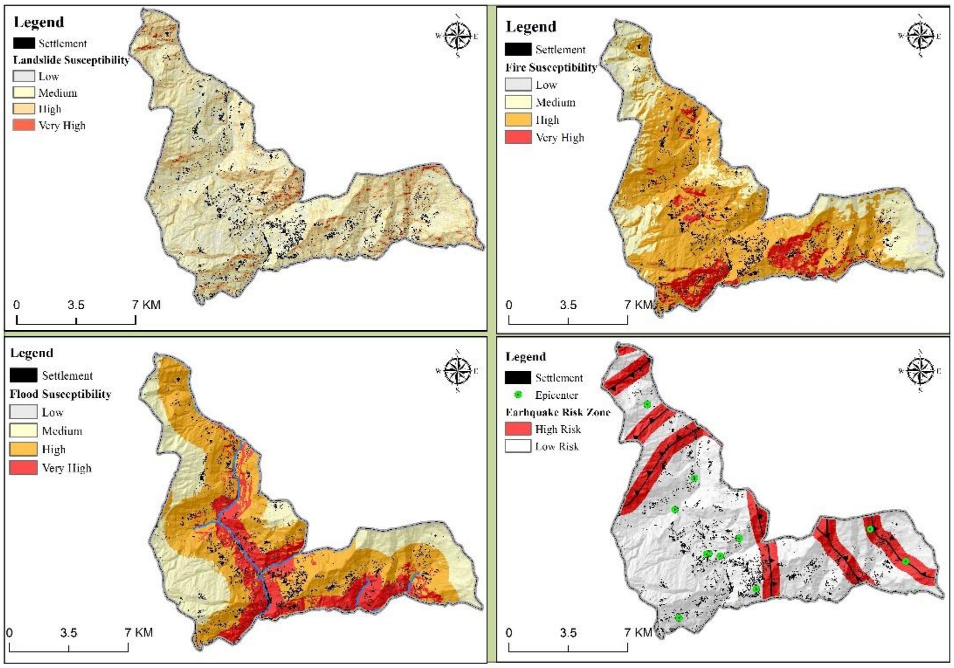


Figure 42: Multi-Hazard susceptibility map for Bahrabise Municipality

5.3.3 Bhotekoshi Rural Municipality

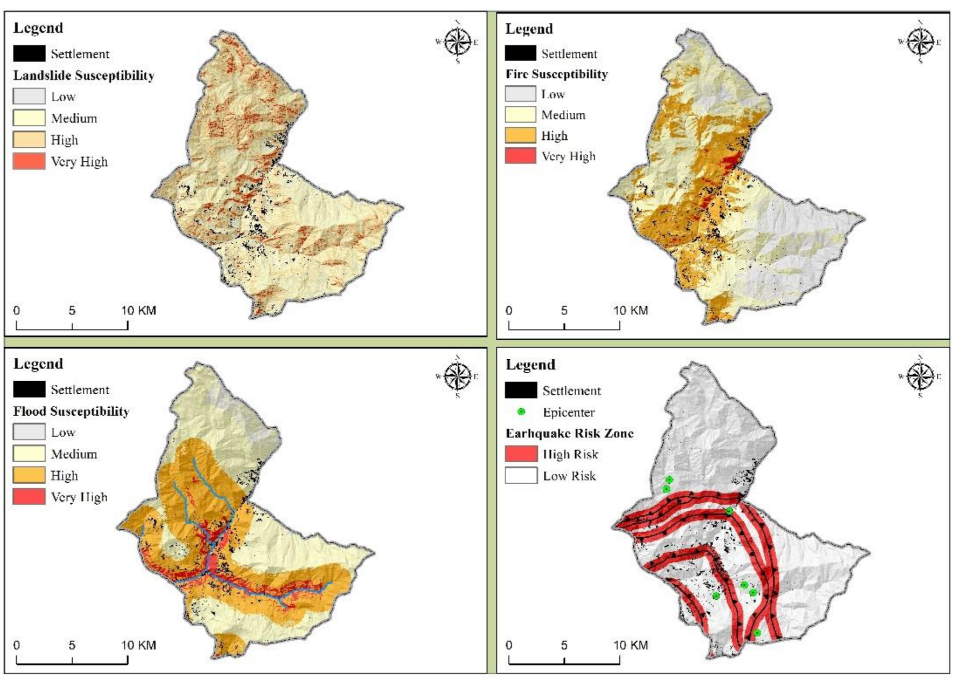


Figure 43: Multi-Hazard susceptibility map for Bhotekoshi Rural Municipality

5.3.4 Chautara Sangachwokgadhi Municipality

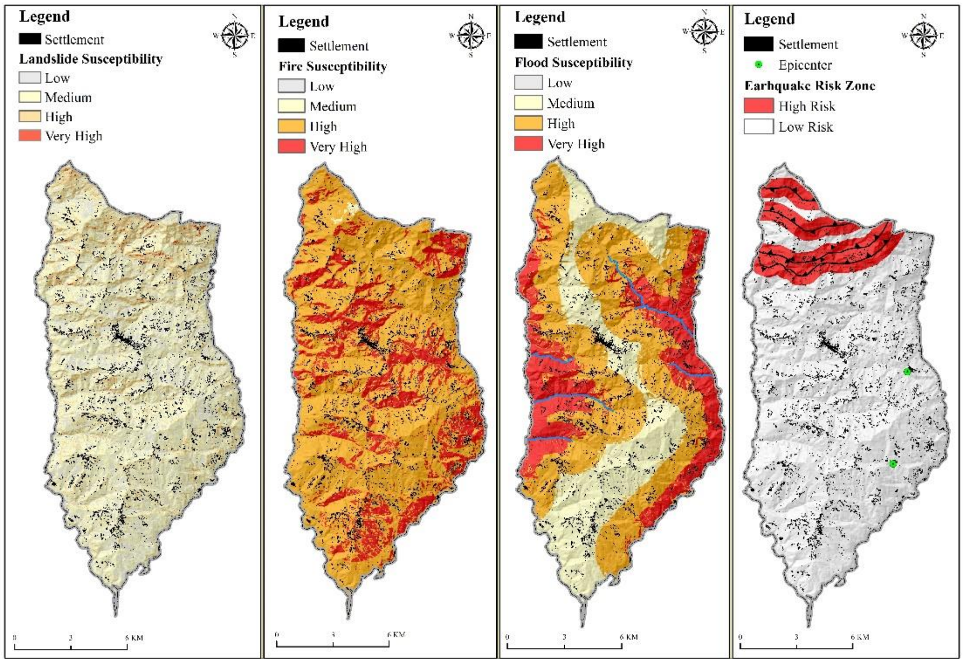


Figure 44: Multi-Hazard susceptibility map for Chautara Sangachowkgadhi Municipality

5.3.5 Helambu Rural Municipality

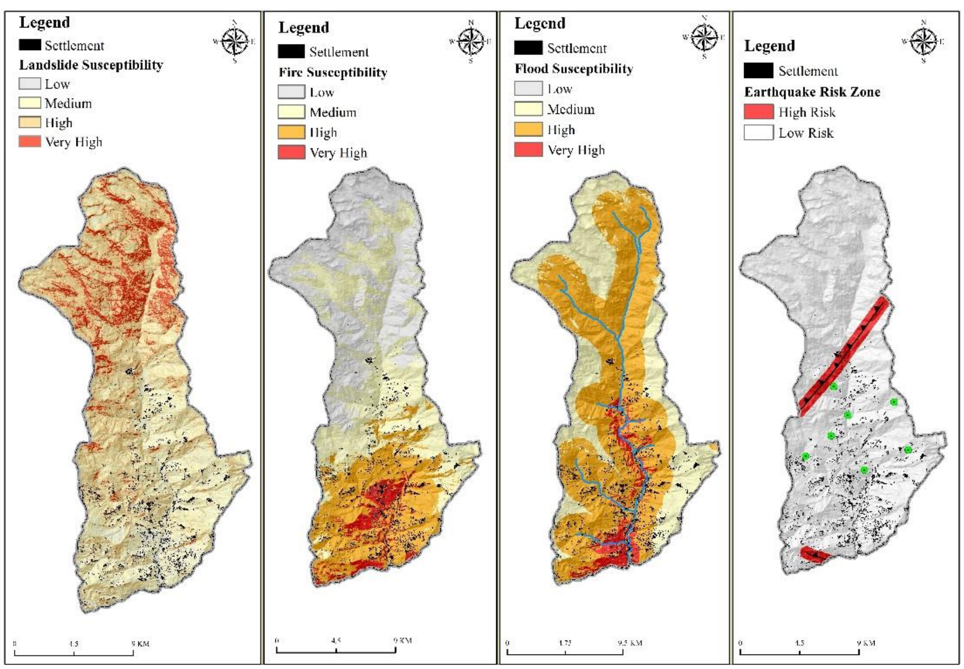


Figure 45: Multi-Hazard susceptibility map for Helambu Rural Municipality

5.3.6 Indrawati Rural Municipality

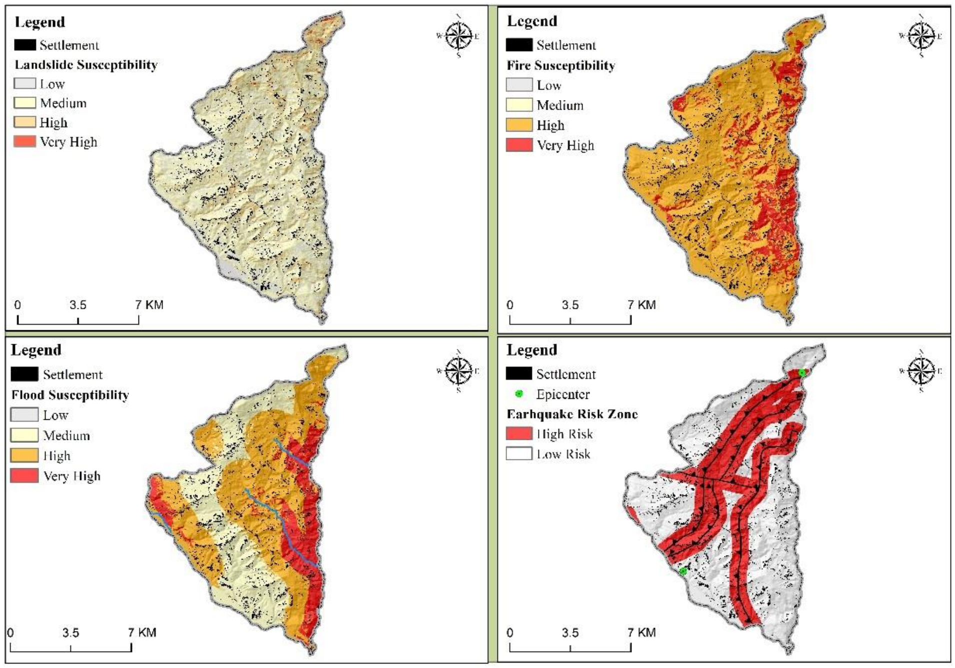


Figure 46: Multi-Hazard susceptibility map for Indrawati Rural Municipality

5.3.7 Jugal Rural Municipality

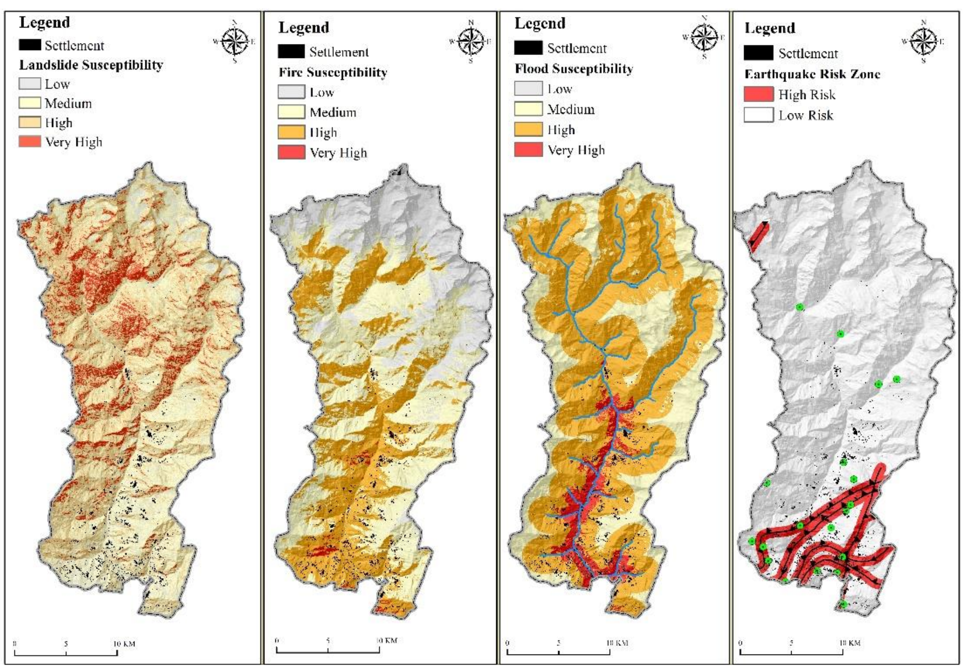


Figure 47: Multi-Hazard susceptibility map for Jugal Rural Municipality

5.3.8 Lisankhu Pakhar Rural Municipality

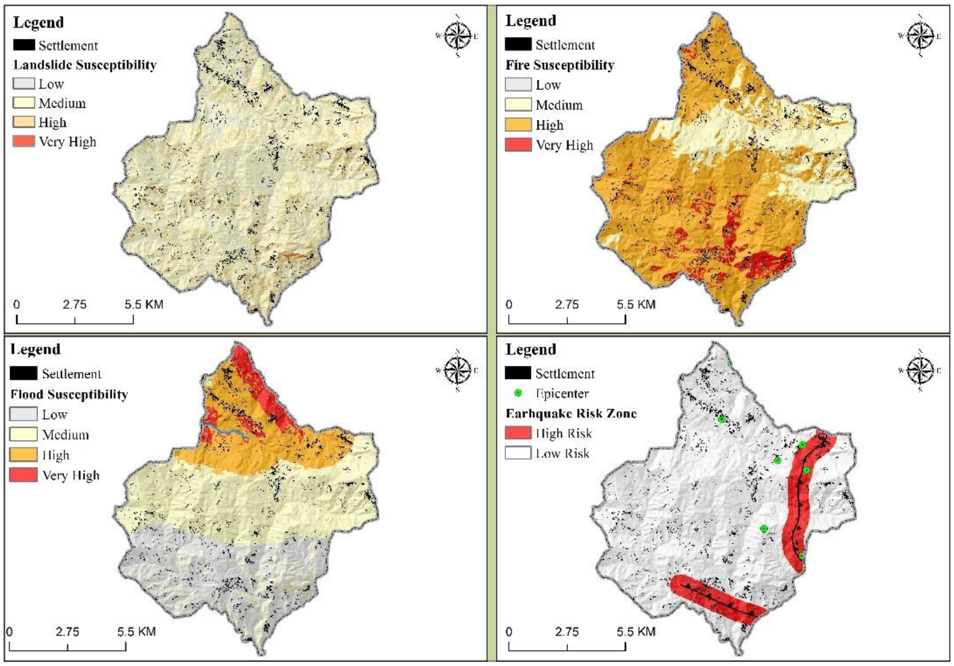


Figure 48: Multi-Hazard susceptibility map for Lisankhu Pakhar Rural Municipality

5.3.9 Melamchi Municipality

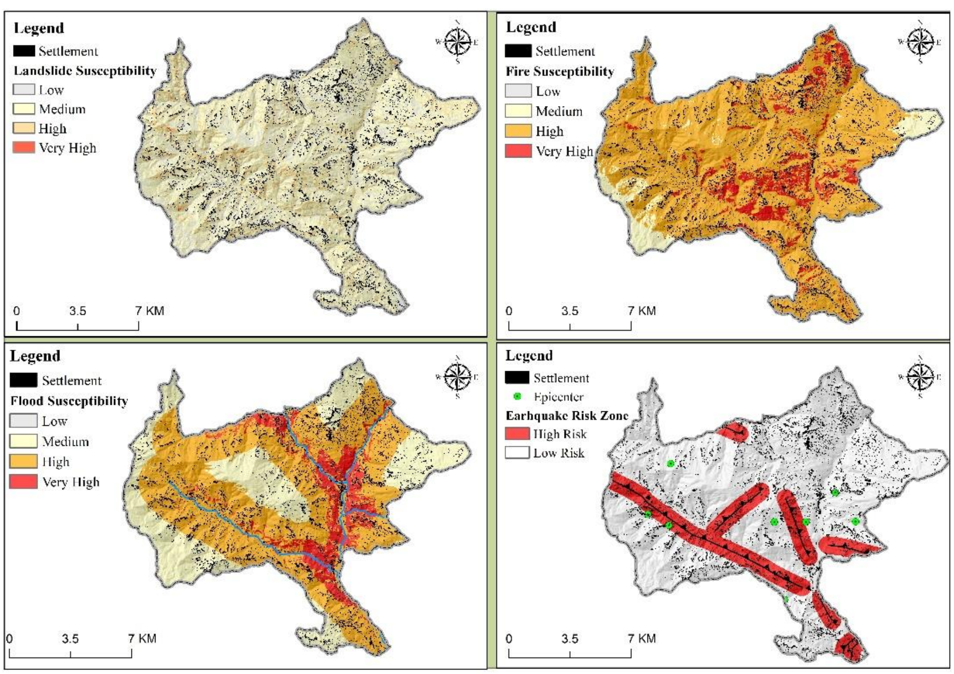


Figure 49: Multi-Hazard susceptibility map for Melamchi Municipality

5.3.10 Panchpokhari Thangpal Rural Municipality

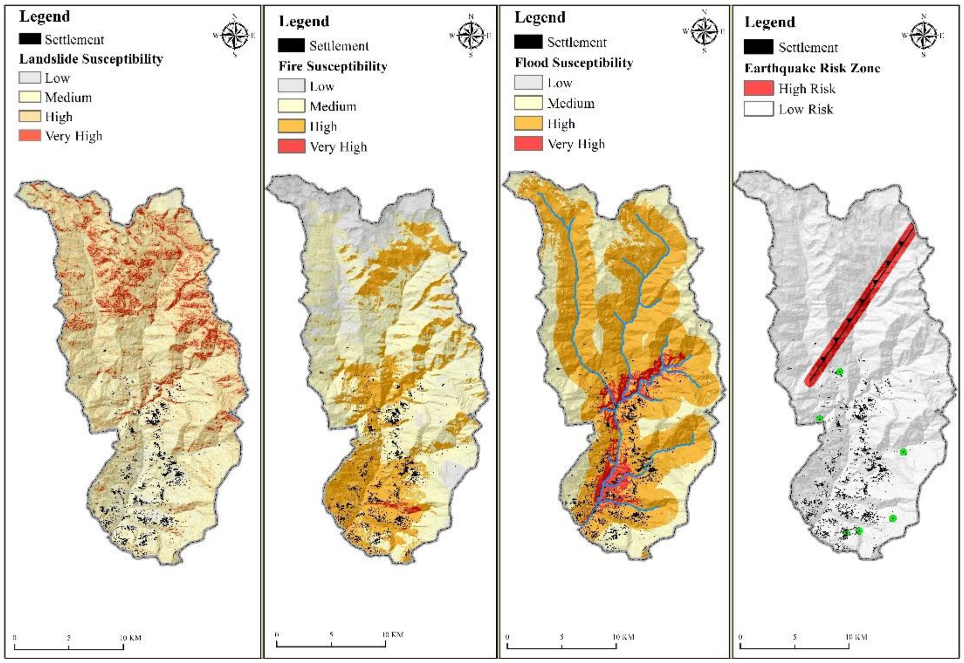


Figure 50: Multi-Hazard susceptibility map for Panchpokhari Thangpal Rural Municipality

5.3.11 Tripurasundari Rural Municipality

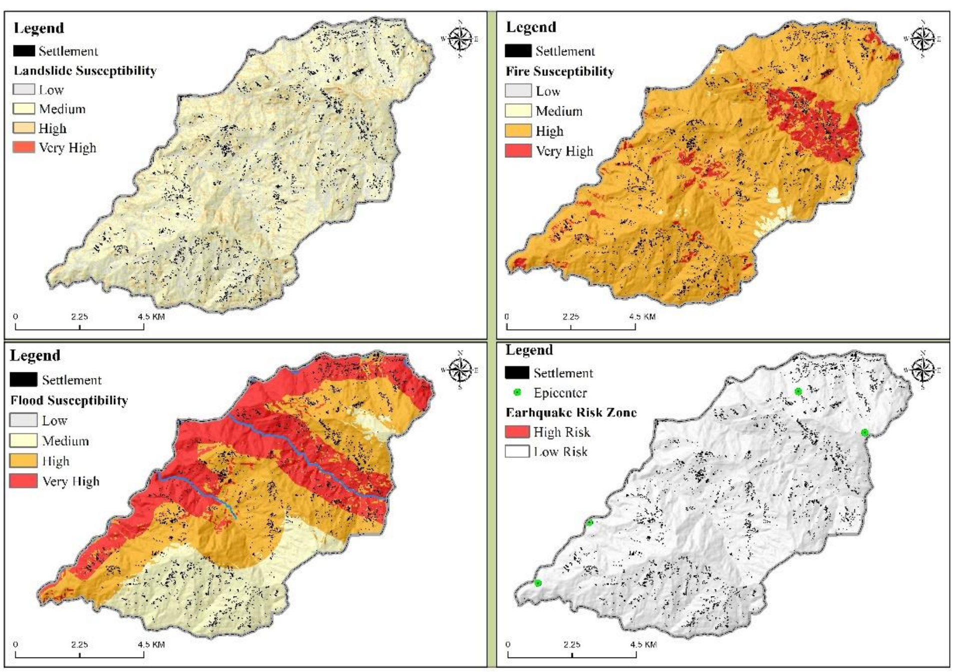


Figure 51: Multi-Hazard susceptibility map for Tripurasundari Rural Municipality

5.3.12 Sunkoshi Rural Municipality

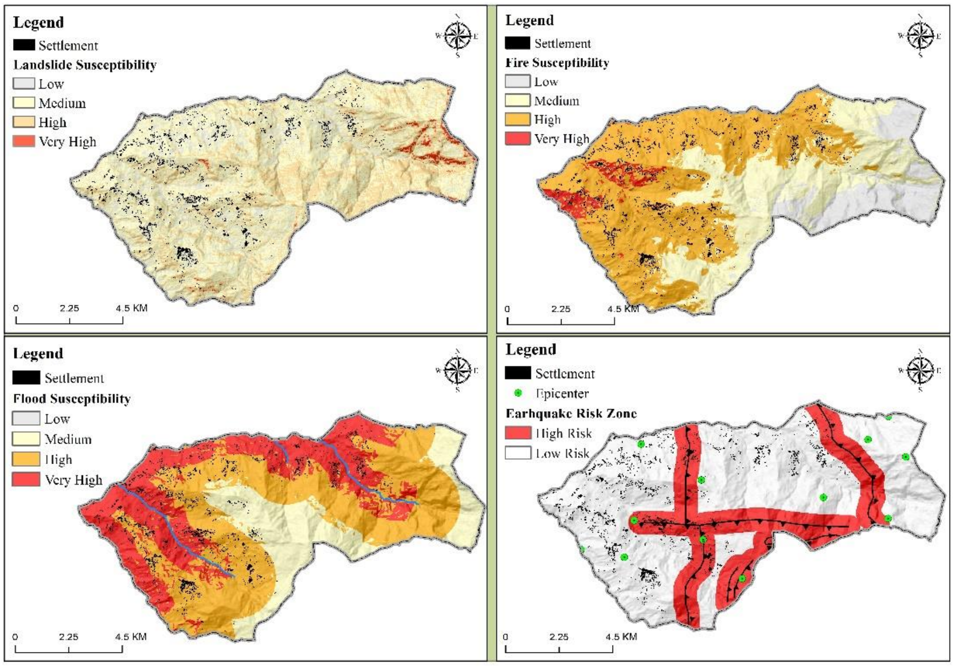


Figure 52: Multi-Hazard susceptibility map for Sunkoshi Rural Municipality

5.4 Multi-Hazard: Case of 2021 Melamchi Cascading Disaster

Figure 53: Bhremathang disaster first observer Dorze Ghale captured the image during June 18

On July 15 2021, a huge landslide dam outburst flood was observed in Melamchighyang, which washed away Nakhote Bridge (Chokpu brdidge) along with the discharge measuring equipment that provided crucial information till the last minutes. The disaster flooded the head works of the mega Melamchi water supply project and washed away the camp taking lives of the workers. The havoc downstream was unmeasurable as it demolished concrete bridges in Timbu and Halde, and destroyed huge agriculture areas, settlements, roads, fisheries and almost everything along the river in Helambu Rural Municipality. Reaching Melamchi Municipality, it continued the destruction by demolishing 2 more concrete bridges, inundated the Melamchi Pul bazaar and rendered hundreds of hectares of land to be unusable. The loss and damage were huge, but the disaster was not gone and still building higher in the mountain. The lack of understanding of the disaster increased the damage that was observed in the Melamchi river valley. Remoteness, Fragility, Lack of Accessibility clearly magnified the disaster. There are some crucial ongoing environmental processes that should be understood to explain the disaster. The discussion on the upstream of Melamchi River will elaborate the mountain processes while keeping Bhremathang (Figure 54), the mountain valley at 3500 masl as the focus of discussion.

Figure 54: Top view of Melamchighyang Landslide (Photo by Dorze Ghale)

5.4.1 Landslide Damming in Melamchighyang

The landslide dam formed in Melamchi-ghyang during June 15 was caused due to slope failure along the crack that was generated during 2015 earthquake (as corroborated by Purna Gautam, School Headmaster, Melamchi-ghyang). This slope failure blocked the river channel for 45 minutes exactly when the landslide mixed flood approached the channel. This intensified the event creating a scenario for cascading disasters.

5.4.2 Regular Sedimentation in Bhremathang

Bhremathang is a large floodplain (imitation) of Melamchi River at an altitude of 3500 masl and is observed as a pasture in mountain valley where Melamchi River spreads the deposits before flushing down through the narrow river valley. Winter precipitation as well as debris inflow at Bhremathang is observed from two sides of the streams channel towards north which brings down the eroded sand, silt and gravel originating at the mountain above 4000m. Every year with summer as well as winter precipitation, multiple events of deposition and flushing (Feb 9, Feb 16, March 6, April 2 during 2021) was observed in the valley (Figure 3), which suggests that sedimentation was ongoing.

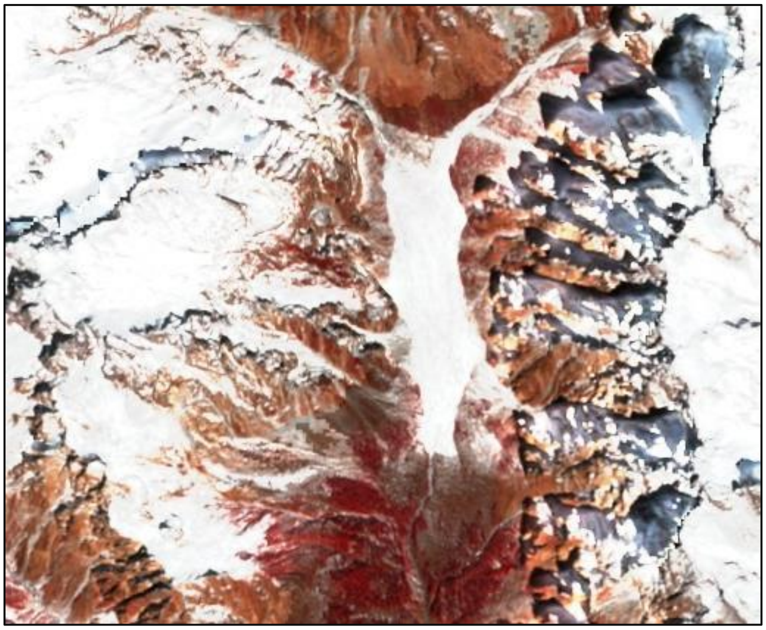


Figure 55: Deposition and flushing events during February, March and April of 2021 was observed (Image Feb 11, 2021)

5.4.3 High Sediment Yield from Melamchi and Pemdang

Melamchi river (Top right) and Pemdang River (Top Left) above Bhremathang possesses high sediment yield as observed in the satellite imageries. This suggests of the ongoing erosion in the upper valleys. In this particular case, Moraines observed in the Melamchi upstream are highly likely to cause frequent sedimentation while there still are chances of lake breaching and slope failures in Pemdang catchment.

5.4.4 Post - Earthquake Environment

2015 April 25 earthquake of 7.8 magnitudes was highly devastating while concentrating the damage in Sindhupalchowk with highest casualties and above 90% of houses being destroyed. The effects of earthquake clearly scarred the topography as multiple debris flow initiated on that day as observed in satellite imageries. Particularly, in Bhremathang, multiple debris deposition was observed in post-earthquake imageries compared below (2014-11-05 to 2015-06-01).

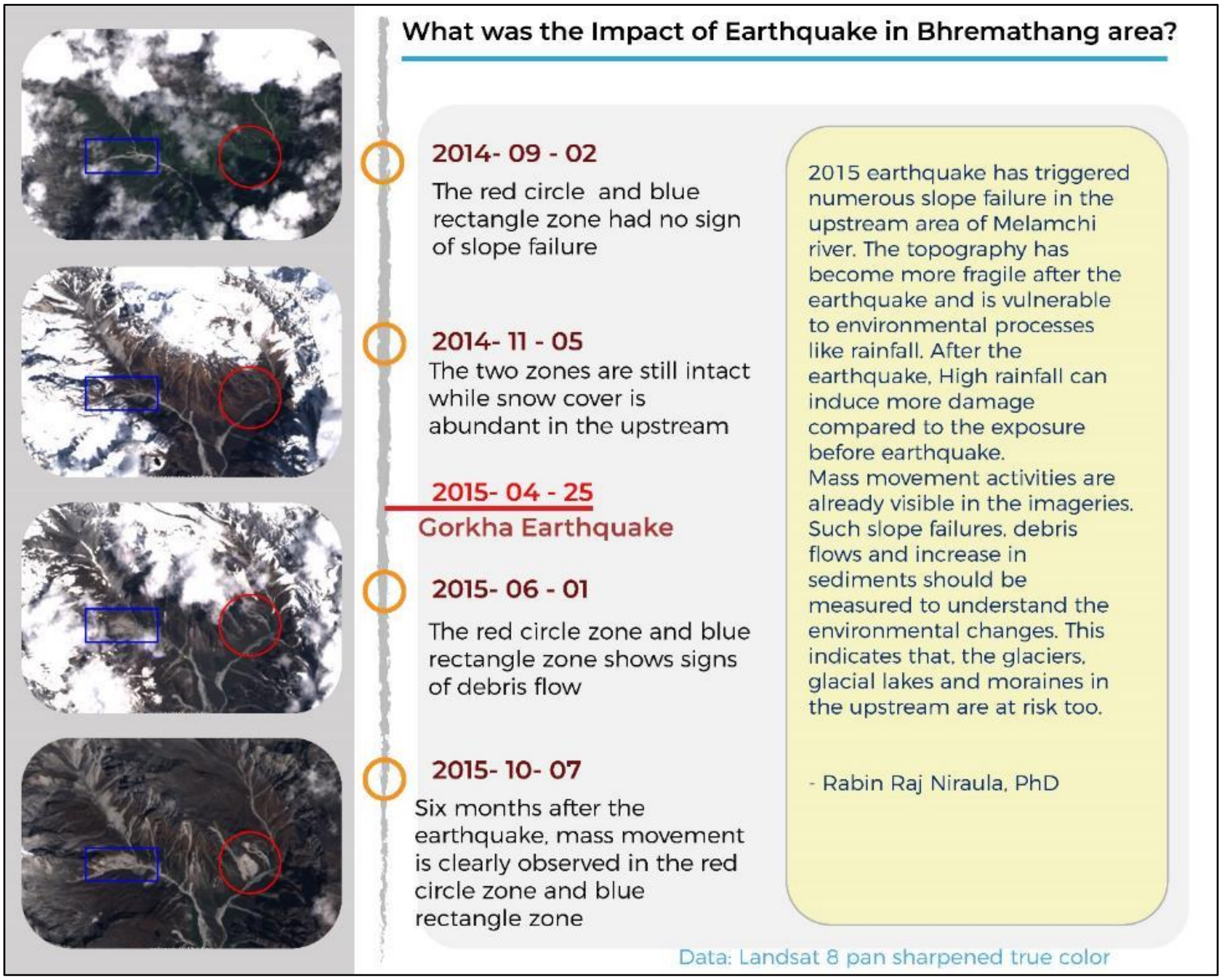


Figure 56: Info graphics on Impact of Earthquake in Bhremathang area

5.4.5 Heavy rainfall

Rainfall recorded in Shermathang was 110 mm on June 12 followed by consecutive days of high rainfall (Figure 5) which suggests that there are high chances of rainfall induced erosion which can intensify the debris movement along the high gradient river channel.

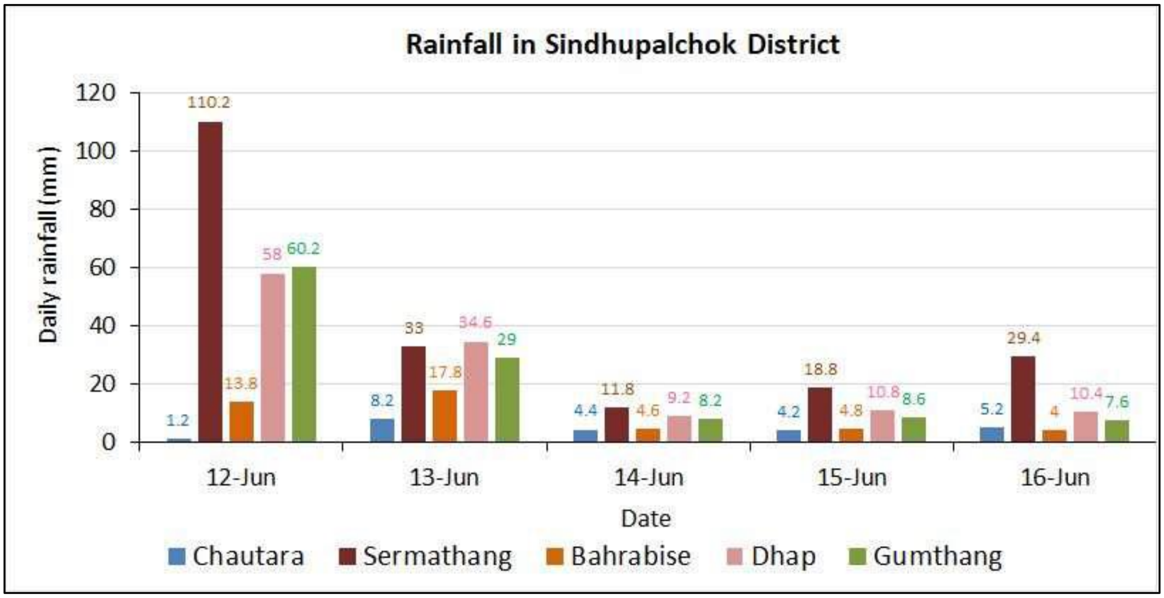


Figure 57: Daily rainfall in measuring station around Melamchi watershed (Source: DHM, 2021)

5.4.6 Deposition caused erosion

Deposition of large volume of sediments above 15 ft is clearly observed in the image acquired from social media. The white dotted line separates the deposited volume of debris from the land surface that existed in the Bhremathang.

Figure 58: Sediment deposition layer visible in Photo taken during visit of Dongba Ninma Gyalzen, Chief of Helambu Rural Municipality on August 1

Figure 59: Sediment deposition layer in reference to existing vegetation as visible in Photo on August 1 – online sources

5.4.7 High Gradient River Flood

Due to high gradient of Melamchi river channel, the erosion seems to have magnified downstream with toe cutting visible towards both sides of the river.

Figure 60: Photo facing north showing side cutting in Melamchi river downstream from Bhremathang (Source: by Dorze ghale)

Figure 61: Photo facing south showing side cutting in Melamchi river downstream from Bhremathang (Source: by Dorze ghale)

5.4.8 Downstream morphology

Melamchi River has steep gradient from Bhremathang to Chokpu Bridge and further down to Ambathan (Headworks of Melamchi Water Supply Project) which has intensified the scouring process. From Ambathan onwards, down to Halde, Kiwool, Chanuate, Gyalthum, Talamarang and Melamchi the river gradient gradually decreases and deposition process increases. While the disaster has deposited large volume of sediments in the river channel, the channel meandering has increased resulting in extensive damage to agriculture fields, roads and infrastructures.

5.4.9 Understanding the Mountain Environment:

Helambu and Melamchi municipalities in Sindhupalchowk were devastated by flood on June 15, 2021 which reoccurred on August 1, 2021. The disaster that built in Bhremathang is a consequence of multiple events rather than a single cause. Also, illustrated in the figure, there is numbers of glacial lakes, Glaciers, Moraines and active landslides in the upstream region of Bhremathang. Most possibly, rainfall induced flushing of sediments from Glaciers (B), Moraines (C), and active landslides (D) are observed in satellite imageries (Sentinel 2 archive). Multiple events of deposition and flushing was observed in Bhremathang during 2021 alone on Feb 9, Feb 16, March 6 and April 2 (Sentinel 2 Time series). The sediment yield accumulated in the Bhremathang seems high in volume (above 15ft depth) which can initiate the erosion process and further intensify the erosion causing cracks and abrasion in the fragile surface of the Bhremathang. Further erosion can cause side cutting, toe cutting increasing the volume of debris.

Further downstream, the formation of landslide dam in Melamchi River near Chokpu Bridge (below Melamchighyang) was the triggering factor for the massive mudflow that destroyed the infrastructures, land and lives consequently depositing fluvial mass in the Melamchi *Pul bazaar*.

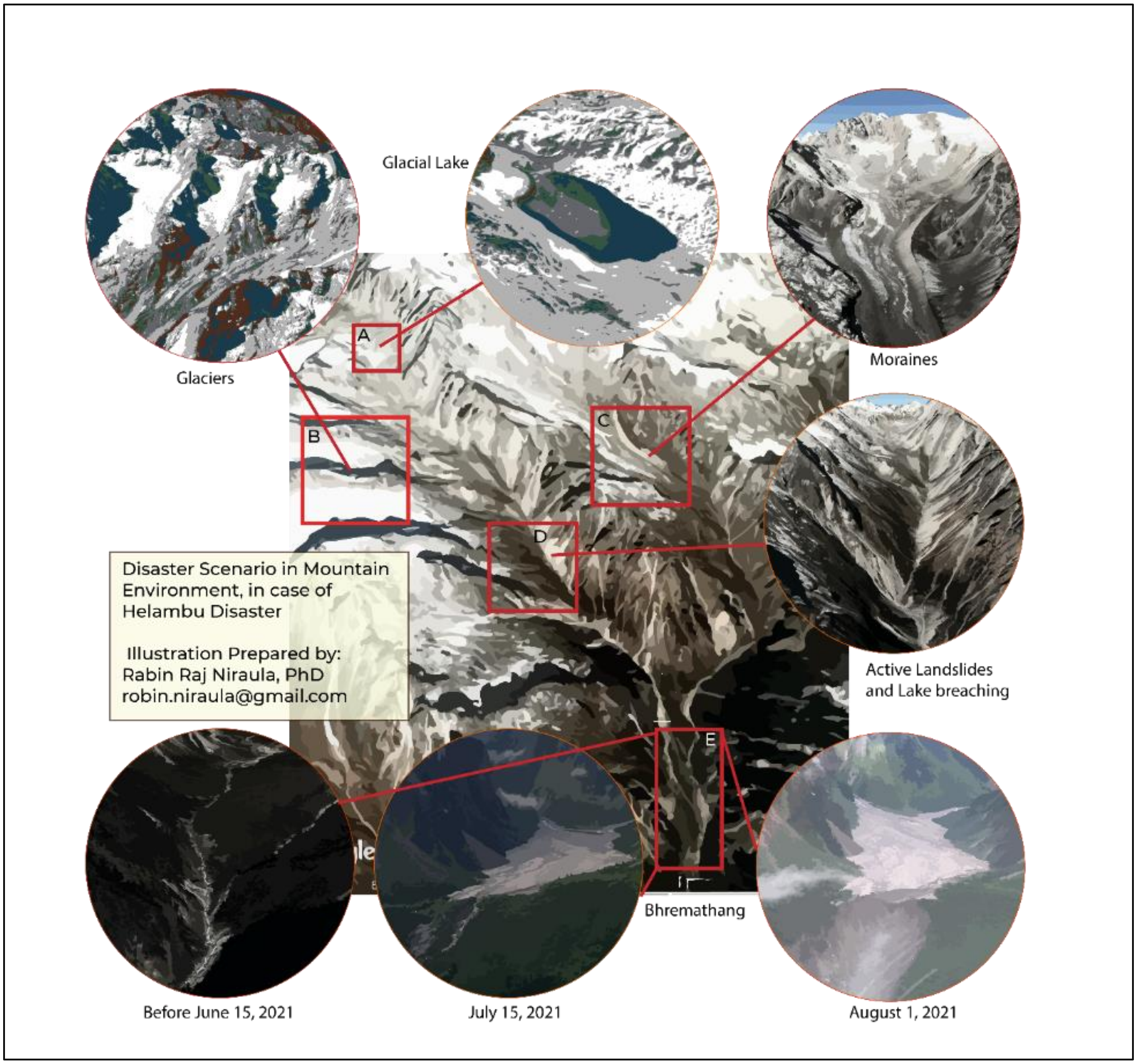


Figure 62: Illustration of Multi-Hazard Scenario in Helambu

6 CONCLUSION AND POLICY RECOMMENDATIONS

Nepal is rated among the most disaster-prone countries where Sindhupalchowk district is among the most disaster affected district as major multiple hazards have occurred within the last 8 years. Major hazards including Jure landslide damming Sunkoshi river in 2014, Gorkha earthquake killing 3500 alone in this district in 2015, Bhotekoshi GLOF damaging the hydropower in 2016 and Melamchi Flood destroying 25 lives and Drinking water supply project in 2021 all demonstrating the disastrous effect of high magnitude have occurred in a series. Loss of lives and infrastructure has incurred huge cost and the lack of understanding of the underlying factors has challenged the government.

This study aims to understand the spatial distribution of multiple hazards and their risk by application of GIS and statistical methods – Analytical Heuristic Process and Frequency Ratio method for assessment of susceptibility in Sindhupalchowk district. The blending of the different methods in GIS enhances the decision-making process with better illustration and mapping capabilities to facilitate the development of hazard maps. Such mapping helps to identify the highly susceptible areas for single hazard as well as multi-hazards that can play a significant role to address disaster risk reduction and also provide a guide for policymakers.

The five major challenge identified during the study that hinders the scientific method to understand such disasters and its underlying factors are the lack of geological data including faults, high variation in the topography within a short spatial extent increase need of high-resolution DEM data, computation limitation for the provided data resolution, gap in meteorological data record provided by Department of Hydrology and Meteorology and inadequate stations for river discharge measurement.

The results show that Panchpokhari, Helambu, Bhotekoshi and Jugal have high susceptibility of Landslide, flood and Fire hazard with high exposure to earthquake damage. Whereas Chautara Sangachowk, Bahrabise, Indrawati, Melamchi, Balefi and Sunkoshi has high susceptibility of Flood and Fire Hazard with high exposure to earthquake damage. Multi-Hazard assessment method can be improved with rigorous data, but it provides huge opportunity to reduce exposure to hazards.

6.1 Conclusion and Recommendations

1) Located in the central Himalayas, Nepal is a multi-hazard prone country in the world due to its geology, topography and climatic conditions. Earthquakes, landslides, floods, fire, and thunderbolts are the major disaster events that caused damage in the past. These phenomena not only cause loss of lives and properties, but also pose severe threats to physical infrastructure, and disrupt economic

development. Nepal exhibits the huge losses due to large exposure at risk and the high level of hazards More than 80% of the population is exposed to the multi hazard risk in Nepal.

2) Nepal is exposed to most disaster types including earthquakes, floods, landslides, droughts, storms, avalanches, hailstorms, fires, lightning, road accidents, epidemics, and ecological hazards. A wide range of physiological, geological, ecological, meteorological, and demographic factors contribute to the vulnerability of the country to disasters. Nepalese people are constantly under the threat of a multitude of disasters. The earthquake of 1934, 1980, 1988, 2015 and the flood of July 1993, 2008, 2013, 2014 and 2017 are the most devastating disasters which not only caused heavy losses to human lives and physical properties but also adversely affected the development process of the country.

3) Bagmati Province in Nepal has faced multiple disasters that indicate the high vulnerability of the province. Sindhupalchowk is especially vulnerable to multi hazard related disasters. Although the epicenter of the 2015 Earthquake was at Gorkha, the biggest damage was recorded in Sindhupalchowk, Dolakha and Rasuwa. Multiple disasters in Sindhupalchowk including the Jure landslide in 2014, the earthquake of April 2015, Bhotekoshi flood 2016, Lidi Landslide in 2020 and Melamchi Flood in 2021 have indicated a highly fragile landscape and high multi hazard risk of the district.

4) Over the years, the Government of Nepal (GoN) has made efforts to shift its focus from a reactive to a proactive approach to Disaster Risk Reduction and Management by strengthening legal frameworks, policy, strategy, planning, institutional capacities, and multi-stakeholder partnerships for DRRM. The Disaster Risk Reduction and Management (DRRM) Act, 2017; National DRR Policy, 2018; and National DRR Strategic Action Plan, 2018-2030 are the major legal and policy frameworks that are guiding proactive approach for multi hazard assessment and mapping.

5) The DRR National Strategic Action Plan, 2018 – 2030 has incorporated several activities related to risk assessment and hazard mapping. Hazard wise risk assessment is the first priority action out of the eighteen priority actions of the DRR national strategic action plan. The strategic action plan has provisioned to consider the hazard, risk and vulnerability as a base for land use planning, to avoid settlement and infrastructure development in the high-risk areas, control moderate risk areas and promote settlement and infrastructure development only in low risk areas.

6) In the last decade Sindhupalchowk district was badly affected by a series of hazards. In the last 11 years during the period of 2011 to 2021, a total 267 disaster incidents of different 8 disasters happened in the Sindhupalchowk district. Earthquake, landslide, flood, fire, thunderbolt, windstorm, heavy rainfall and animal incident are recorded as frequently repeated disasters in the district. In

terms of incident numbers, Fire, landslide and thunderbolt are the top three frequently repeated disasters in the Sindhupalchowk district. In terms of human casualty, the earthquake, landslide, and thunderbolt rank in top three devastative disasters. Similarly, the landslide, flood and earthquake are the top three disasters for missing people and earthquake, landslide and flood are major three disasters causing building damage in the district.

7) The record of past disaster events and loss and damage data shows that the district is prone to the multi hazards; seismic hazards (earthquake and landslide), hydro meteorological and climatic hazards (flood, landslide and thunderbolt) and human induced hazards (fire). Earthquake, landslide, flood, fire and thunderbolt are major top five disasters in the Sindhupalchowk district. The Jure landslide 2014, Gorkha earthquake 2015, Bhotekoshi Flood 2016, Tatopani Bhotekoshi flood and landslide; and Lidi Landslide 2020; and Melamchi flood 2021 are the major disaster events of the last decade in Sindhupalchowk. Sindhupalchowk is one of the hardest-hit districts by natural disasters. Among numerous reasons contributing to landslides include the prevalence of thrusts beneath the earth surface, topography, vegetation type and density, land use practice, pattern and frequency of rainfall and earthquake are major causes of landslides.

8) The Main Central Thrust (MCT) is extended to the southwestern part to the east-west of the district and the Main Boundary Thrust (MBT) is extended from the southern part of the district in the Mahabharat range area. There is a long fault line that has created anticline and syncline in around the Balefi river area and Barabise area, Taramarag area, and upper part of the Barabise area falls in Main Central Thrust. The dynamics of plate movements together with diverse geological conditions and a high degree of topography change in the district have contributed to the evolution of geological hazards, most prominently earthquakes, landslides, floods, soil erosion, and debris flow. Apart from this, the high rate of glaciers melting due to global warming has posed a serious threat to Glacial Lake outbursts as well. However, the amount of risk of all these hazards is not the same throughout the district. The active faults are the major trigger to develop the landslides because of its movement during the seismic event and plate tectonic movement.

9) Sindhupalchowk district is prone to multi hazard. A multi-hazard approach is relatively new. They can take many forms. Sometimes, one hazard causes another: In 2015, the Mw 7.8 Gorkha earthquake caused thousands of landslides and claimed thousands of lives and damage of property. Climate change and urbanization further trigger the multi hazard risk in mountain environment. The hazard assessment should begin with the identification of what natural hazards can be expected and how they might change in the short and medium term. This could include earthquakes, floods,

landslides, thunderstorms, wildfire, drought, and epidemics. Consideration should be given to both extensive (frequent, low impact) and intensive (occasional, high impact) events.

10) Sindhupalchowk is a mountain district having much of its area under rugged topography with high mountains and deep river valleys. As shown in slope map below, only 14 % of its area lies under 17 degrees of slope while 27% under 17-26 degrees, 29% in 26-35 degrees, 21% in 35-46 degrees and 8% above 46 degrees shows that the district has more than 85% of its land in a high slope terrain. This already increases the risk for all kinds of mass movements existing under gravity. A small trigger can create mass movement in such terrain with high slopes. Slope, aspect, soil, elevation, rainfall, drainage pattern and density differ the hazardous context, vulnerability level and exposure of a particular area. Similarly, road, settlement, land use are built environments, such anthropogenic activities trigger the disaster risk altering the natural system in improper way.

11) Many faults are mapped as individual segments across district. These fault segments are crossed along the East-West direction with different lengths. Fault has several different dip directions from vertical to unspecified, and fault type from exposed to conceal. Basically, all these faults are associated with the Main Central Thrust (MCT) and recent epicenter area that may have created a new fault line during the seismic event. The map indicates the district is surrounded by fault lines. Amongst them, the central and northern part of the district is more vulnerable to the seismic activity that may create more damage.

12) Based on the recent earthquakes (Nepal earthquake 2015) and the epicenter of the aftershocks indicate the zone is very sensitive to potential of the seismic hazards. The frequent seismological event and higher density of the epicenter locations shows that the district lies under seismic prone area. Empirical evidence and past studies on Landslide Hazard in Sindhupalchowk shows the concentration of the landslides and high potential areas that are prone to landslides are the northern area of Jugal, Panchpokhari and Helambu rural municipalities. However, in Jugal Rural Municipality the high potential area has extended to the western middle part of the municipality.

13) Various factors have been combined to the vulnerability map of the Sindhupalchowk district, which is classified into four susceptibility ranges as low, medium, high and very high. Of the total area of Sindhupalchowk district, 56.01% of the districts are highly sensitive, 31.02% are moderately sensitive to landslide risk, 11.50% are very highly sensitive and 1.45% are low sensitive to flood risk. Similarly, 50.69% of districts are moderately sensitive, 34.49% highly sensitive, 6.49% very highly sensitive and 8.34% sensitive to low landslide susceptibility range. Regarding fire, 46.77%, 32.70%, 15.59% and 4.92% of districts area have high, medium, low and very high fire risk.

14) Multi hazard susceptibility in each rural/ municipalities is in range of Low, Medium, High and Very High and the majority of rural/municipalities have large percentage of medium and high susceptibility. Moreover, as per landslide, Jugal, Helambu, Panch pokhari and Bhotekoshi have large percentage of its area under very high and high susceptibility to landslide.

15) As per flood susceptibility, all rural/ municipalities have majority of area under medium susceptibility whereas Balefi, Bahrabise, Chautara, Indrawati, Melamchi, Tripurasundari and Sunkoshi have large areas under very high and high susceptibility. Whereas Chautara Sangachok Gadhi shows largest percentage i.e., 22% under highest susceptibility to fire hazard.

16) Sindhupalchowk has been affected by major multi hazards in past decade. It in one of the severely affected districts by Earthquake, Landslide and Flood. Jure Landslide, 2015 earthquake and Melamchi Flood all have clearly revealed that Sindhupalchowk has one of the weakest topography and geology. In this situation, it is likely that future disasters and its impact will be of same scale in the district. The most alarming recent disaster of Melamchi flood has revealed that mountain terrain in the district is much fragile which could be possibly due to the impact of earthquake. Heavy rainfall event during June 15, 2021, was observed as one of the rare meteorological conditions which triggered cascading disasters of landslides and floods. In this scenario, it is likely that future extreme events might trigger similar consequences.

17) Landslide is a major and frequent geo-hazard of the Sindhupalchowk district. Landslide hazard is a function of susceptibility (spatial propensity to landslide activity) and temporal frequencies of landslide triggers. So, in any types of landslide assessment there is a need to consider topology and other factors that influence the propensity to landslide activity as well as triggering factor. The nature of slope and slope materials, hydrological condition, vegetation presence, geology, drainage pattern and density are the major parameters that need to be assessed in detail in assessment in small spatial unit.

18) There is long fault line in northern and central part of the district and the fault line extended towards east west directions. The fault line exhibits the high susceptibility to earthquake. So, detail assessment and seismic micro zonation is important for infrastructure development.

19) The river banks of major rivers; Bhotekoshi, Sunkoshi, Balefi, Indrawati and Melamchi are highly hazardous area of flood (GLOF and LDOF) and population also concentrated in the high risk areas. The detain flood risk mapping zonation and risk mapping is the first step for flood risk reduction. An effective early warning system may reduce the risk of the area.

20) Preparation of multi hazard base Risk Sensitive Land Use Plan (RSLUP) and its proper implementation should be priority action of all local levels towards disaster risk reduction and sustainable development through risk informed development practice.

21) Constitution and existing law have provided role and responsibility to local government for disaster risk reduction and management. The local government can do the assessment and mapping; prepare law, policy and plan and disaster preparedness and response activities in their area. The local level should proactively work for improvement of disaster risk reduction and management capacity. In this regard, considering multi hazard situation of the district some indicative activities have been recommended in next chapter.

7 INDICATIVE DRRM PLANS

The multi hazard assessment and vulnerability mapping of the Sindhupalchowk district shows the major hazard of the district and susceptible area to the particular hazard in the district. However further assessment is requiring preparing a municipality base multi hazard and risk map and prepare risk sensitive land use planning. Therefore, based on the current multi hazard assessment and vulnerability mapping of the district the following activities have been recommended as indicative plan. The indicative plan not only included the hazard assessment activities, but also covered the all aspect of disaster risk reduction and management including capacity building, policy and plan formulation; and its implementation. The respective local level is primarily responsible to disaster risk reduction and management interventions at their area and the province and federal government should support to the local level for their capacity enhancement and implementation.

SN	Activities	Outcomes	Area	Timeframe	Responsibility
1	Hazard assessment mapping and delineation of the major landslide prone areas in municipality level	Landslide hazard map will be available at municipality level	All local levels	2 years	Local level, Province gov.
2	Landslide risk assessment and mapping for vulnerable infrastructure shelters, schools, hospitals, health posts, water supply structures	Information of landslide risk level (high, medium and low) will be available at municipality level	All local levels	2 years	Local level, Province gov.
3	Flood hazard assessment mapping and delineation of flood prone areas of major flood prone rivers (Indrawati, Melamchi, Balefi, Sunkoshi and Bhotekoshi)	Flood hazard maps of major flood prone rivers will be available at municipality level	Bhotekoshi, Barhabise, Balefi, Sunkoshi, Indrawati and Melamchi municipality	3 Years	Local level, Province gov.
4	Flood assessment and mapping for flood vulnerable infrastructures, shelters, schools, hospitals and supply	The information on flood risk level (high, medium and low) will be	Bhotekoshi, Barhabise, Balefi, Sunkoshi,	3 Years	Local level, Province gov.

	structures	available at municipality level	Indrawati and Melamchi municipality		
5	Assessment mapping and delineation of hazardous areas of seismic hazard at municipality level	Seismic hazard map will be available at local level	All local levels	2 years	Local level, Province gov.
6	Earthquake risk assessment and mapping of the earthquake vulnerable infrastructures, shelters, schools, hospital, health posts and water supply structures	Information of earthquake risk level will be available at all municipal level.	All local levels	3 years	Local level, Province gov.
7	Fire and wildfire risk assessment and mapping for infrastructure, settlement, schools, hospitals, health posts and other structures	Information of fire and wild fire risk level will be available at local level.	All local levels	2 years	Local level, Province gov.
8	Hazard Assessment, mapping and delineation of avalanche and Glacial Lake Outburst Flood (GLOF) affected area	Hazard map of the potential avalanche and GLOF will be available	Bhotekoshi, Barhabise, Balefi, Sunkoshi, Indrawati and Melamchi municipality	3 years	Local level, Province gov.
9	Prepare Risk Sensitive Land Use Plan (RSLUP) of all municipalities based on the multi hazard risk assessment and mapping	Prepare Risk Sensitive Land Use Plan (RSLUP) of all local level will be available at local level	All local levels	3 years	Local level, Province gov.
10	Prepare land use policy to implement the risk sensitive land use plan	Land use policy will be available at local level	All local levels	3 years	Local level, Province gov.
11	Relocate settlement of high risk area of landslide flood and earthquake risk to the low risk	High risk settlement will be shifted in safe locations	High risk areas based on the detail	Continue	Local level

	areas		hazard map		
12	Establish real time flood, GLOF and landslide monitoring system in high risk areas	Real time information of the flood, GLOF and landslide will be available	High risk areas based on the detail landslide and flood hazard map	2 years	Local level, Province gov. Federal gov.
13	Prepare DRR policy and strategic action plan of each local level focusing to particular local hazard	DRR policy and priority action of the all local level will be available for planning	All local levels	1 years	Local level
14	Develop and implement ecosystem based and low cost landslide risk reduction and control measures	Major landslide risk will be reduced	High landslide risk areas based on the landslide hazard map	Continue	Local level
15	Implement flood control and flood risk reduction risk reduction measures	Major flood risk will be reduced	High landslide risk areas based on the flood hazard map	Continue	Local level
16	Develop program and implement afforestation, bio-dykes, forest conservation watershed protection for flood and landslide risk reduction	Risk reduction activities will be implemented at needy areas	Based on the hazard mapping	Regular	Local level
17	Assign DRR focal person in all municipalities	Focal person for DRR activities will be available at local level	All local levels	1 Years	Local level
18	Establish Local Emergency Operation Centre (LEOC) at local level	LEOC will be functional for disaster information management and	All local levels	1 Years	Local level

		emergency response at local level			
19	Prepared/update Disaster Preparedness and Response Plan/Monsoon Preparedness and Response Plan of all municipalities	Disaster preparedness and response plan will be available at all local level	All local levels	Regular	Local level
20	Form/reform emergency clusters at local level for resource mobilization, effective response and sufficient preparedness	Emergency clusters will be active for DRR at local level	All local levels	1 years	Local level
21	Develop guidelines for mainstreaming disaster risk reduction into sectorial development plans	DRR activities will be integrated in local level regular plans	All local levels	Regular	Local level
22	Develop and enforce Disaster Impact Assessment (DIA) in local infrastructure development projects	Potential risk will be assessed and reduction measures will be incorporate in local projects	All local levels	Regular	Local level
23	Develop and implement social mobilization programs at community level for representation and effective participation of the people at risk in the formulation of DRRM policy and program	Participatory planning practice will be placed at local level	All local levels	Regular	Local level
24	Develop and implement special programs on disaster risk reduction on the basis of priority to the highly vulnerable area for the highly vulnerable groups	Targeted activities to at risk people and area will be implemented at community	All at risk community and groups	Regular	Local level
25	Develop guidelines for risk transfer mechanisms and its promotion; life insurance,	Risk transfer mechanism will be placed and reduced	All local levels	2 years	Local level

	property insurance, crop insurance and livestock insurance	the government cost as compensation to disaster losses			
26	Identify place for helipad and construct helipad in remote and inaccessible wards of the district for emergency use	Helipad will be operational at remote areas for rescue and relief operations during disaster	All local levels	2 years	Local level, Province gov.
27	Identify and manage open spaces at urban and dense settled areas for emergency use	Open spaces will be available at local level for emergency purpose	All municipalities	Regular	Local level
28	Establish/update flood and GLOF early warning system in high risk major river basin (Bhotekoshi, Balefi, Indrawati and Melamchi)	EWS will be available at high flood risk river basin	Bhotekoshi, Balefi, Indrawati and Melamchi River basin	3 years	Local level, Province and federal government
29	Establish mechanism for coordination and communication of upstream downstream community and municipalities for flood EWS	EWS coordination and communication mechanism will be placed in major watersheds	Community and local level of Bhotekoshi, Balefi, Indrawati and Melamchi River basin	3 Years	Local level, District and Province gov.
30	Conduct awareness raising and training program on the steps to be followed after receiving the early warning of different hazards	Community will be aware on EWS	At all high flood and landslide risk communities	3 Years	Local level
31	Form search and rescue team at community and develop as a first community responder in all local level	Community first responder will be formed and developed at community	All wards	Regular	Local level
32	Establish a Disaster Risk Reduction web portal at	An integrated disaster data	All local levels	1 years	Local level,

	province and local level linking to the district, province and central DRR portal	management system will be functional at all local level			Province and federal government

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9 ANNEXES

9.1 Population in Sindhupalchowk

Local Level	Male	Female	Total
Balephi Rural Municipality	3332	1097	4429
Barhabise Municipality	4616	1609	6225
Bhotekoshi Rural Municipality	3233	950	4183
Chautara Sanghachowkgadhi Municipality	7519	3387	10906
Helambu Rural Municipality	3341	862	4203
Indrawati Rural Municipality	4844	1367	6211
Jugal Rural Municipality	3331	610	3941
Lisankhupakhar Rural Municipality	2620	1060	3680
Melamchi Municipality	8260	1837	10097
Panchpokhari Thangpal Rural Municipality	4103	904	5007
Sunkoshi Rural Municipality	2927	1432	4359
Tripurasundari Rural Municipality	2480	914	3394

9.2 Education status in Sindhupalchowk

Local Level	Male	Female	Total
Balephi Rural Municipality	74.65	58.27	66.04
Barhabise Municipality	70.97	55.05	62.76
Bhotekoshi Rural Municipality	68.93	49.68	59.45
Chautara Sanghachowkgadhi Municipality	72.05	55.92	63.23
Helambu Rural Municipality	59.11	46.94	52.82
Indrawati Rural Municipality	67.83	50.33	58.47
Jugal Rural Municipality	57.04	42.91	49.91
Lisankhupakhar Rural Municipality	75.74	58.05	66.29
Melamchi Municipality	69.05	51.07	59.66
Panchpokhari Thangpal Rural Municipality	52.86	38.89	46.03
Sunkoshi Rural Municipality	71.34	55.52	62.69
Tripurasundari Rural Municipality	66.28	53.89	59.7

9.3 Photographs

Presentation and disciussion on inception report at District Administration Office, Sindhupalchowk

Government officials with study team members during the presentation of inception report in District Admistration Office of Sindhupalchowk in presence of Chief District Officer Mr. Bedhnidhi khanal

The 2015 earthquake shook the entire hillside leading to the house being completely destroyed at Baseri of Bahrabise Municipality Ward number 5 but there were no casualties.

This landslide which occurred on 28 Bhadra 2077 in ward no 7 of Barhabise municipality in a place called Nakhkuche (नाखकुच्चे) which caused 32 casualties and destroyed about 40 houses as explained by the local personnel Tilak Bahadur Sewa.

Close up view of Nakhkuche (नाखकुच्चे) landslide at ward no 7 of Barhabise Municipality

Close up view of Nakhkuche (नाखकुच्चे) landslide at ward no 7 of Barhabise Municipality with relocated settlements

Interaction with local from Barhabise Municipality Ward No 7 of place called Nakhkuche of Barhabise Municipality

Monsoon feed river near Nakhkuche (नाखकुच्चे) landslide at ward no 7 of Barhabise Municipality which causes severe flooding during monsoon season at downstream.

The landslide just above the main market area of Barhabise Municipality

A landslide which occurred in Bhir gaun of golche in Jugal Rural Municipality. Due to this landslide, people living across Sehera river have difficulty accessing the school located beyond the landslide as the landslide damaged the path as there's no suitable bridge to cross the river

Interaction with Ward Chairman Mr Shyam Bahadur Tmanag of Barabhise Municipality Ward 5

This is monsoon fed river named Yalmu khahare khola (याल्मु खहरे खोला) of ward 5 of Barhabise Municipality. This river usually swells up during moonson season creating havoc to the people of this ward. In year 2077 Asar 24 this river flooded causing casualty of 21 people and damaged 14 houses.

The flood of aanbu kholsa (आँबु खोल्सा) 2 years back at Balephi Rural Municipality casued the damage to two houses destroying the agricultural land as well.

Landslide at Sheherea phat (शेहेरा फाँट) of Chautara Sangachowkgadi Municipality.

High tension line at risk of slide due to road construction on the way to Jalbire (जलबिरे) from Balephi (बलेफी) bazar of Balephi Rural Municipality

Damaged Road Section along Barhabise-Bhotekoshi Municipality Road Section

Interaction with municipal officials of Barhabise Municipality

Rock fall at Balefi Rural Municipality Ward no 1

Lidi Landslide at Jugal Rural Municipality

House at flood risk zone

Settlement at high hills around Ssinhupalchowk

Settlement at high risk zones of landslide around Sinhupalchowk

Interaction with locals of Jugal Rural Municipality

Interaction with locals of Jugal Rural Municipality

Interaction with locals of Lisankhu Pakhar Rural Municipality

Dip angle measurement of rocks at Chautara Sangachowkgadi Municipality

House and land inundated in aftermath of Melamchi Flood

Bridge Washed away by Melamchi Flood

Chanaute Bazar and bridge in Helambu during 2016

Chanaute Bridge in Helambu which was washed away in second flood August 1, 2021

Extension of Damage of Melamchi Flood , June 18, 2021

Wide view of damage of melamchi flood

Zoom in View of Melamchi Flood

9.4 Ward wise data for Multi Hazard Vulnerability of Sindhupalchowk District

Jugal	**Landslide**																						
Ward 1			Ward 2			Ward3			Ward 4			Ward 5			Ward 6			Ward 7			Langtang NP		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	327.33	14.285714	Low	150.21	2.17601	Low	667.17	5.848382	Low	250.65	15.516185	Low	200.97	10.92252	Low	255.24	9.474493	Low	39.51	7.008301	Low	887.67	2.758596
Medium	1447.2	63.160376	Medium	2363.13	34.233377	Medium	6062.13	53.14036	Medium	1162.98	71.992869	Medium	1120.59	60.902954	Medium	1655.55	61.453914	Medium	288.09	51.101533	Medium	9037.53	28.085765
High	503.37	21.968655	High	3691.98	53.483703	High	4250.52	37.259868	High	197.73	12.240236	High	483.12	26.257093	High	748.08	27.768683	High	231.84	41.123883	High	16565.6	51.480546
Very High	13.41	0.585255	Very High	697.68	10.10691	Very High	427.95	3.75139	Very High	4.05	0.25071	Very High	35.28	1.917433	Very High	35.1	1.30291	Very High	4.32	0.766284	Very High	5687.55	17.675094

Jugal	**Flood**																						
Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6			Ward 7			Langtang		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Medium	704.7	30.758957	Medium	1197.18	17.341086	Medium	4079.79	35.794037	Medium	614.52	38.030522	Medium	188.46	10.242113	Medium	606.6	22.514698	Medium	38.52	6.839246	Medium	9464.58	29.40262
High	1210.77	52.848052	High	4060.35	58.813944	High	6626.61	58.138562	High	747.36	46.251532	High	1074.96	58.420152	High	1793.61	66.57202	High	473.49	84.068392	High	22484.7	69.850865
Very High	375.57	16.392992	Very High	1646.19	23.844971	Very High	691.56	6.067402	Very High	253.98	15.717946	Very High	576.63	31.337735	Very High	294.03	10.913282	Very High	51.21	9.092362	Very High	240.3	0.746515

Jugal	**Fire**																						
Ward `1			Ward 2			WARD 3			Ward4			Ward 5			Ward 6			Ward 7			Langtang		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Medium	303.3	13.238529	Low	50.67	0.733952	Low	2715.84	23.827422	Low	82.44	5.101927	Medium	492.21	26.749817	Low	62.46	2.318279	Medium	5.4	0.958773	Low	11109.1	34.61656
High	1929.33	84.211974	Medium	2544.39	36.855348	Medium	5919.12	51.931398	Medium	870.84	53.893283	High	1346.49	73.176816	Medium	1973.16	73.236237	High	481.05	85.410674	Medium	13579.9	42.315922
Very High	58.41	2.549497	High	4082.31	59.132033	High	2758.5	24.201699	High	662.58	41.00479	Very High	1.35	0.073368	High	657.81	24.41542	Very High	76.77	13.630553	High	7399.8	23.058263
			Very High	226.35	3.278667	Very High	4.5	0.039481							Very High	0.81	0.030064				Very High	2.97	0.009255

Balefi	**Landslide**																						
ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6			Ward 7			Ward 8		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	148.23	20.940877	Low	157.86	19.993161	Low	233.01	18.777198	Low	139.23	15.806682	Low	153.72	15.473818	Low	55.44	10.690732	Low	48.06	6.43296	Low	29.16	10.536585
Medium	478.08	67.539733	Medium	532.62	67.45697	Medium	839.79	67.67479	Medium	639.63	72.616736	Medium	691.2	69.577822	Medium	337.95	65.168344	Medium	403.02	53.945308	Medium	174.33	62.99187
High	81	11.443102	High	99	12.53847	High	167.67	13.511749	High	101.97	11.576581	High	148.5	14.94836	High	124.74	24.054148	High	270.63	36.224551	High	72.27	26.113821
Very High	0.54	0.076287	Very High	0.09	0.011399	Very High	0.45	0.036263							Very High	0.45	0.086775	Very High	25.38	3.397181	Very High	0.99	0.357724

Balefi	**Flood**																						
Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6			Ward 7			Ward 8		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
High	303.93	42.920691	Medium	70.65	8.936703	Medium	557.55	44.930374	Medium	155.34	17.619437	High	271.17	27.333757	Medium	55.17	10.640514	Medium	300.96	40.240674	High	50.4	18.122977
Very High	404.19	57.079309	High	311.85	39.446721	High	668.16	53.843922	High	490.95	55.685994	Very High	720.9	72.666243	High	265.59	51.223746	High	312.48	41.780987	Very High	227.7	81.877023
			Very High	408.06	51.616576	Very High	15.21	1.225704	Very High	235.35	26.694569				Very High	197.73	38.13574	Very High	134.46	17.978339			

Balefi	**Fire**																						
Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6			Ward 7			Ward 8		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Medium	93.24	13.16726	Medium	6.66	0.842441	Medium	140.49	11.321439	Medium	84.96	9.636586	Medium	5.4	0.544316	High	455.04	87.762541	High	649.62	86.859206	High	239.94	86.278317
High	555.66	78.469751	High	780.03	98.668033	High	1084.5	87.394836	High	789.3	89.526337	High	977.67	98.54849	Very High	63.45	12.237459	Very High	98.28	13.140794	Very High	38.16	13.721683
Very High	59.22	8.362989	Very High	3.87	0.489526	Very High	15.93	1.283725	Very High	7.38	0.837076	Very High	9	0.907194									

Barabhise — Landslide

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	78.75	6.644392	Low	115.65	4.437614	Low	110.79	16.378393	Low	86.31	23.271051	Low	46.17	7.189909
Medium	669.96	56.526691	Medium	1305.63	50.098422	Medium	463.77	68.560404	Medium	252.9	68.187333	Medium	244.71	38.107919
High	413.55	34.892551	High	1104.3	42.373174	High	100.71	14.888238	High	31.5	8.493084	High	309.87	48.255081
Very High	22.95	1.936366	Very High	80.55	3.09079	Very High	1.17	0.172964	Very High	0.18	0.048532	Very High	41.4	6.447092

Ward 6			Ward 7			Ward 8			Ward 9		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	126	9.831461	Low	368.73	10.147117	Low	381.51	19.823232	Low	128.07	11.297237
Medium	700.02	54.620787	Medium	2245.59	61.796612	Medium	1302.03	67.653386	Medium	643.32	56.748174
High	444.06	34.648876	High	975.96	26.857539	High	240.21	12.481294	High	344.43	30.382661
Very High	11.52	0.898876	Very High	43.56	1.198732	Very High	0.81	0.042088	Very High	17.82	1.571928

Barabhise — Flood

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5		
Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage
Medium	530.82	44.933719	Medium	640.53	24.59141	High	477.54	70.596062	High	194.85	52.446705	Medium	1.62	0.252845
High	519.66	43.989029	High	1143.99	43.92039	Very High	198.9	29.403938	Very High	176.67	47.553295	High	286.83	44.767524
Very High	130.86	11.077251	Very High	820.17	31.4882							Very High	352.26	54.979632

Ward 6			Ward 7			Ward 8			Ward 9		
Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage
Medium	261.81	20.442727	Medium	1090.44	30.004953	Medium	1015.29	52.742064	Medium	262.71	23.192436
High	703.08	54.898103	High	2346.93	64.579	High	651.06	33.821123	High	482.76	42.618783
Very High	315.81	24.659171	Very High	196.83	5.416048	Very High	258.66	13.436813	Very High	387.27	34.188781

Barabhise — Fire

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	194.67	16.48	Low	0.45	0.017277	Medium	32.94	4.869611	High	345.69	93.047481	Medium	20.7	3.230791
Medium	734.31	62.16381	Medium	540.27	20.7422	High	638.37	94.372006	Very High	25.83	6.952519	High	597.33	93.229386
High	252.18	21.348571	High	1579.23	60.630248	Very High	5.13	0.758382				Very High	22.68	3.539823
Very High	0.09	0.007619	Very High	484.74	18.610276									

Ward 6			Ward 7			Ward 8			Ward 9		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Medium	369.54	28.854533	Low	75.78	2.085191	Medium	440.73	22.894946	Medium	9.36	0.826315
High	865.8	67.603654	Medium	1215.9	33.457157	High	1388.79	72.14456	High	672.39	59.359606
Very High	45.36	3.541813	High	2267.28	62.38732	Very High	95.49	4.960494	Very High	450.99	39.814079
			Very High	75.24	2.070332						

Bhotekoshi — Landslide

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	211.77	4.199011	Low	154.35	2.139551	Low	114.57	5.530695	Low	425.61	5.020809	Low	332.01	6.780751
Medium	2352.87	46.653104	Medium	2439.45	33.814888	Medium	994.86	48.025373	Medium	4584.69	54.084384	Medium	3143.97	64.210352
High	2316.51	45.932152	High	3981.96	55.196677	High	775.44	37.433202	High	3216.24	37.941139	High	1342.98	27.42813
Very High	162.18	3.215732	Very High	638.37	8.848884	Very High	186.66	9.010731	Very High	250.38	2.953667	Very High	77.4	1.580766

Bhotekoshi — Flood

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5		
Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage
Medium	907.11	17.987935	Medium	759.69	10.54769	Medium	113.22	5.467901	Low	26.55	0.31352	Medium	2377.44	48.559716
High	3644.1	72.262279	High	4983.66	69.194147	High	1739.79	84.022254	Medium	3944.52	46.579448	High	2291.49	46.804169
Very High	491.67	9.749786	Very High	1459.08	20.258163	Very High	217.62	10.509845	High	3624.48	42.800208	Very High	226.98	4.636115
									Very High	872.82	10.306824			

Bhotekoshi — Fire

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	18.45	0.365862	Low	1030.95	14.314098	Low	1.08	0.052158	Low	4349.07	51.356637	Low	1134.81	23.178735
Medium	2558.07	50.726371	Medium	3727.89	51.759428	Medium	790.56	38.179684	Medium	3004.56	35.479791	Medium	2211.03	45.160757
High	2399.58	47.583524	High	2295.27	31.868393	High	1186.02	57.27822	High	1114.11	13.156133	High	1539.99	31.454622
Very High	66.78	1.324243	Very High	148.23	2.058081	Very High	92.97	4.489938	Very High	0.63	0.007439	Very High	10.08	0.205886

Chautara Landslide

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6			Ward 7		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	285.57	12.472975	Low	155.25	13.377278	Low	98.1	9.324209	Low	218.16	27.523561	Low	236.07	24.523186	Low	224.64	18.148768	Low	190.98	17.289986
Medium	1366.92	59.703605	Medium	703.35	60.604886	Medium	616.5	58.597092	Medium	539.28	68.036789	Medium	658.08	68.362004	Medium	874.17	70.624591	Medium	738.54	66.862218
High	624.69	27.284878	High	291.69	25.133773	High	325.53	30.940975	High	35.19	4.43965	High	67.05	6.965221	High	138.6	11.197557	High	173.61	15.717429
Very High	12.33	0.538543	Very High	10.26	0.884064	Very High	11.97	1.137725				Very High	1.44	0.149589	Very High	0.36	0.029085	Very High	1.44	0.130367

Ward 8			Ward 9			Ward 10			Ward 11			Ward 12			Ward 13			Ward 14		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	276.93	22.269668	Low	229.14	16.548586	Low	114.21	16.450609	Low	306.36	23.453218	Low	185.76	18627641.3	Low	210.06	18.819545	Low	208.71	18.795591
Medium	892.8	71.795614	Medium	962.37	69.502762	Medium	519.75	74.863884	Medium	925.65	70.862615	Medium	727.74	72976311.7	Medium	807.21	72.318981	Medium	803.07	72.321284
High	73.8	5.934718	High	192.69	13.916152	High	60.3	8.685507	High	74.16	5.677277	High	89.28	8952819.84	High	98.82	8.853411	High	98.64	8.883125
			Very High	0.45	0.032499				Very High	0.09	0.00689				Very High	0.09	0.008063			

Chautara Flood

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6			Ward 7		
Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage
Medium	664.65	29.027947	Medium	184.86	15.927419	Medium	156.42	14.867408	High	304.83	38.52804	Medium	334.26	34.674634	Medium	332.64	26.881955	Medium	15.48	1.40145
High	1392.84	60.830942	High	490.86	42.292184	High	655.83	62.335329	Very High	486.36	61.47196	High	610.2	63.299412	High	612.99	49.538148	High	482.76	43.705695
Very High	232.2	10.141111	Very High	484.92	41.780397	Very High	239.85	22.797263				Very High	19.53	2.025955	Very High	291.78	23.579897	Very High	606.33	54.892854

Ward 8			Ward 9			Ward 10			Ward 11			Ward 12			Ward 13			Ward 14		
Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage
Medium	506.7	40.788234	Medium	265.68	19.177548	Medium	383.94	55.216153	Medium	1030.14	78.807491	Medium	545.85	54.453223	Medium	103.77	9.300637	Medium	207.09	18.621025
High	566.19	45.577048	High	540.9	39.043721	High	223.83	32.190008	High	275.94	21.109887	High	403.47	40.249596	High	525.6	47.108171	High	640.08	57.554423
Very High	169.38	13.634717	Very High	578.79	41.778731	Very High	87.57	12.593839	Very High	1.08	0.082622	Very High	53.1	5.297181	Very High	486.36	43.591191	Very High	264.96	23.824553

Chautara Fire

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6			Ward 7		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Medium	38.79	1.694116	Medium	1.89	0.162841	Medium	11.43	1.086399	High	590.22	74.599022	High	670.59	69.564	High	818.55	66.150265	High	748.71	67.782938
High	1839.15	80.323101	High	834.57	71.906017	High	996.84	94.747648	Very High	200.97	25.400978	Very High	293.4	30.436	Very High	418.86	33.849735	Very High	355.86	32.217062
Very High	411.75	17.982784	Very High	324.18	27.931141	Very High	43.83	4.165954												

Ward 8			Ward 9			Ward 10			Ward 11			Ward 12			Ward 13			Ward 14		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
High	1032.39	83.109805	High	910.35	65.711687	High	586.26	84.31271	High	1083.51	82.896096	Medium	0.18	0.017957	High	914.94	82.003711	High	1069.11	96.131747
Very High	209.88	16.89583	Very High	475.02	34.288313	Very High	109.08	15.68729	Very High	223.56	17.103904	High	656.28	65.469564	Very High	200.79	17.996289	Very High	43.02	3.868253
												Very High	345.96	34.51248						

Helambu Landslide

Ward 1			Ward 2			Ward 3			Ward 4		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	335.07	4.957654	Low	231.93	8.898788	Low	197.37	20.14144	Low	159.57	16.252635
Medium	3517.92	52.050708	Medium	1777.95	68.217135	Medium	657.18	67.064658	Medium	624.96	63.653864
High	2736.63	40.490838	High	590.4	22.652716	High	123.48	12.601029	High	196.56	20.020167
Very High	169.02	2.500799	Very High	6.03	0.231362	Very High	1.89	0.192873	Very High	0.72	0.073334

Ward 5			Ward 6			Ward 7			Langtang		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	156.6	8.518138	Low	47.7	2.160267	Low	191.43	12.876082	Low	44.91	0.382033
Medium	1093.86	59.499682	Medium	970.2	43.939023	Medium	828.18	55.705551	Medium	2134.71	18.159198
High	578.97	31.492632	High	1098	49.72691	High	461.7	31.055149	High	6592.32	56.078458
Very High	9	0.489548	Very High	92.16	4.1738	Very High	5.4	0.363218	Very High	2983.59	25.38031

Helambu Flood

Ward 1			Ward 2			Ward 3			Ward 4		
Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage
Medium	2014.47	29.76819	Medium	1598.85	61.292437	Medium	403.92	41.253792	High	416.52	42.388716
High	4285.89	63.333378	High	977.58	37.475849	High	430.38	43.956246	Very High	566.1	57.611284
Very High	466.83	6.898432	Very High	32.13	1.231714	Very High	144.81	14.789962			

Ward 5			Ward 6			Ward 7			Langtang		
Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage
Medium	257.94	13.996191	Medium	377.01	17.036073	Medium	189.72	12.727931	Medium	4402.71	37.3787
High	1454.31	78.912927	High	1719.72	77.709545	High	1245.78	83.576863	High	7375.95	62.6213
Very High	130.68	7.090882	Very High	116.28	5.254382	Very High	55.08	3.695206			

Helambu Fire

Ward 1			Ward 2			Ward 3			Ward 4		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	1292.13	19.094041	Low	18.36	0.703837	Medium	8.64	0.882434	High	634.86	64.608903
Medium	4316.49	63.785559	Medium	1027.17	39.376898	High	888.66	90.762019	Very High	347.76	35.391097
High	1149.93	16.992725	High	1489.14	57.086669	Very High	81.81	8.355547			
Very High	8.64	0.127675	Very High	73.89	2.832597						

Ward 5			Ward 6			Ward 7			Langtang		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Medium	114.66	6.221614	Low	15.03	0.679165	Medium	167.22	11.218452	Low	7971.84	67.682433
High	1499.58	81.369341	Medium	867.24	39.188255	High	1092.6	73.300326	Medium	3806.28	32.316039
Very High	228.69	12.409044	High	899.91	40.664525	Very High	230.76	15.481222	High	0.18	0.001528
			Very High	430.83	19.468055						

Indrawati Landslide

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	153.72	8.37871	Low	118.62	17.024025	Low	119.34	16.861648	Low	259.47	15.563593	Low	223.38	19.572589	Low	127.08	14.680807
Medium	1006.92	54.883493	Medium	500.58	71.841901	Medium	484.83	68.502035	Medium	1198.71	71.901317	Medium	819.9	71.83976	Medium	603.36	69.702641
High	643.86	35.094432	High	77.58	11.134074	High	103.5	14.623601	High	208.89	12.529691	High	98.01	8.587651	High	134.37	15.522978
Very High	30.15	1.643365				Very High	0.09	0.012716	Very High	0.09	0.005398				Very High	0.81	0.093575

Ward 7			Ward 8			Ward 9			Ward 10			Ward 11			Ward 12		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	70.29	14.845086	Low	74.43	13.052399	Low	107.1	18.438178	Low	145.71	16.754631	Low	104.4	30.184751	Low	213.3	29.588015
Medium	348.84	73.674206	Medium	404.46	70.92803	Medium	420.39	72.373722	Medium	603	69.336645	Medium	233.19	67.421285	Medium	461.16	63.970037
High	54.36	11.480707	High	91.35	16.019571	High	53.37	9.1881	High	119.61	13.753493	High	8.28	2.393963	High	46.44	6.441948
									Very High	1.35	0.155231						

Indrawati Flood

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6		
Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage
Medium	459.27	25.033113	High	469.98	67.371952	High	173.16	24.478372	Medium	593.91	35.676056	Medium	466.02	40.810214	Medium	225.54	26.049896
High	1118.61	60.971302	Very High	227.61	32.628048	Very High	534.24	75.521628	High	1052.28	63.21025	High	482.67	42.268285	High	605.61	69.948025
Very High	256.77	13.995585							Very High	18.54	1.113694	Very High	193.23	16.921501	Very High	34.65	4.002079

Ward 7			Ward 8			Ward 9			Ward 10			Ward 11			Ward 12		
Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage
Medium	219.15	46.398628	Medium	228.78	40.113618	Medium	58.77	10.102104	Medium	191.88	22.058976	Medium	346.5	100	Medium	569.61	78.866044
High	248.13	52.534299	High	332.1	58.229446	High	259.74	44.647277	High	409.59	47.087429				High	152.64	21.133956
Very High	5.04	1.067073	Very High	9.45	1.656935	Very High	263.25	45.250619	Very High	268.38	30.853595						

Indrawati Fire

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Medium	22.86	1.246014	High	578.7	82.957038	High	276.75	39.122137	Medium	5.4	0.324377	Low	13.68	1.197982	Medium	1.71	0.197505
High	1461.6	79.666421	Very High	118.89	17.042962	Very High	430.65	60.877863	High	1449.9	87.095205	Medium	1114.47	97.596154	High	828.81	95.727651
Very High	350.19	19.087564							Very High	209.43	12.580418	High	13.77	1.205864	Very High	35.28	4.074844

Ward 7			Ward 8			Ward 9			Ward 10			Ward 11			Ward 12		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Medium	7.74	1.63872	Medium	0.18	0.031561	High	334.17	57.441213	High	703.89	80.920848	High	345.33	99.662338	Medium	0.18	0.024922
High	446.67	94.56936	High	546.75	95.865552	Very High	247.59	42.558787	Very High	165.96	19.079152	Very High	1.17	0.337662	High	705.15	97.632399
Very High	17.91	3.791921	Very High	23.4	4.102888										Very High	16.92	2.342679

Lisangkhupakhar Landslide

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6			Ward 7		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	130.68	11.471006	Low	316.71	14.757811	Low	170.37	14.728079	Low	385.65	16.648535	Low	124.38	12.043573	Low	99	18.929616	Low	292.86	20.074028
Medium	746.55	65.53168	Medium	1544.67	71.977354	Medium	834.84	72.169921	Medium	1656.09	71.493512	Medium	734.76	71.145969	Medium	351.63	67.234555	Medium	1025.1	70.265268
High	257.85	22.633907	High	284.67	13.264835	High	151.38	13.086439	High	274.14	11.834641	High	173.43	16.793028	High	72.36	13.835829	High	140.94	9.660703
Very High	4.14	0.363407				Very High	0.18	0.015561	Very High	0.54	0.023312	Very High	0.18	0.017429						

Lisangkhupakhar Flood

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6			Ward 7		
Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage
Low	805.41	71.221647	Low	1683.81	78.293438	Low	138.06	11.926606	Low	188.55	8.1508	Medium	417.6	40.64827	High	210.42	40.144231	Medium	193.95	13.288524
Medium	325.44	28.778353	Medium	466.83	21.706562	Medium	1019.52	88.073394	Medium	2050.38	88.635568	High	546.84	53.228208	Very High	313.74	59.855769	High	1133.37	77.65308
									High	74.34	3.213633	Very High	62.91	6.123522				Very High	132.21	9.058396

Lisangkhupakhar Fire

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6			Ward 7		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Medium	16.83	1.488261	Medium	7303.09	38.742007	Medium	16.47	1.422796	Low	1.08	0.046687	Low	0.09	0.00876	Medium	42.12	8.035714	Low	0.09	0.006166
High	896.67	79.291683	High	10447.4	55.422002	High	1108.35	95.747162	Medium	831.69	35.953002	Medium	802.08	78.072711	High	477.18	91.037088	Medium	630.27	43.183079
Very High	217.35	19.220056	Very High	1100.12	5.835991	Very High	32.76	2.830042	High	1356.57	58.64296	High	225.18	21.918528	Very High	4.86	0.927198	High	802.71	54.997842
									Very High	123.93	5.357351							Very High	26.46	1.812912

Melamchi	Landslide																			
Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6			Ward 7		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	164.16	17.963364	Low	90.72	20.647276	Low	263.97	18.560942	Low	260.82	13.817766	Low	98.28	10.227592	Low	232.11	18.275227	Low	283.86	21.979094
Medium	644.13	70.484538	Medium	307.08	69.88939	Medium	962.73	67.693963	Medium	1209.87	64.096696	Medium	607.77	63.248103	Medium	885.6	69.727891	Medium	911.07	70.543554
High	105.48	11.542249	High	41.49	9.442851	High	194.58	13.681812	High	413.55	21.909121	High	252.63	26.290156	High	152.28	11.989796	High	96.57	7.477352
Very High	0.09	0.009848	Very High	0.09	0.020483	Very High	0.9	0.063283	Very High	3.33	0.176417	Very High	2.25	0.234148	Very High	0.09	0.007086			

Ward 8			Ward 9			Ward 10			Ward 11			Ward 12			Ward 13			SNP		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	88.47	11.88059	Low	328.86	17.4224	Low	187.11	19.292873	Low	221.85	17.410651	Low	156.51	10.568216	Low	174.69	15.164063	Low	56.52	23.724972
Medium	550.71	73.954556	Medium	1329.57	70.438182	Medium	705.24	72.717149	Medium	910.98	71.493149	Medium	1057.14	71.382558	Medium	848.7	73.671875	Medium	165.24	69.361541
High	105.21	14.128596	High	228.87	12.125113	High	77.4	7.980698	High	141.39	11.0962	High	266.4	17.988453	High	128.61	11.164063	High	16.47	6.913487
Very High	0.27	0.036258	Very High	0.27	0.014304	Very High	0.09	0.00928				Very High	0.9	0.060772						

Melamchi	Flood																			
Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6			Ward 7		
Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage
Medium	269.1	29.548374	Medium	186.12	42.255823	Medium	739.53	51.685747	Medium	502.65	26.504366	Medium	315.27	32.808841	Medium	333.36	26.267641	Medium	243	18.820577
High	630.81	69.265738	High	254.07	57.682877	High	685.8	47.930557	High	1362.15	71.825171	High	611.55	63.641472	High	724.23	57.066875	High	851.13	65.920814
Very High	10.8	1.185888	Very High	0.27	0.0613	Very High	5.49	0.383696	Very High	31.68	1.670463	Very High	34.11	3.549686	Very High	211.5	16.665485	Very High	197.01	15.258609

Ward 8			Ward 9			Ward 10			Ward 11			Ward 12			Ward 13			SNP		
Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage
Medium	349.74	47.028924	Medium	970.29	51.333206	Medium	18.9	1.949499	Medium	318.24	24.978808	Medium	127.62	8.610116	Medium	338.4	29.358944	Medium	236.16	100
High	370.26	49.788213	High	845.46	44.729073	High	589.41	60.796509	High	664.74	52.175756	High	894.78	60.367964	High	713.79	61.927071			
Very High	23.67	3.182863	Very High	74.43	3.93772	Very High	361.17	37.253992	Very High	291.06	22.845437	Very High	459.81	31.02192	Very High	100.44	8.713985			

Melamchi	Fire																			
Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6			Ward 7		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Medium	18.99	2.085186	Medium	45.18	10.257458	Low	1.53	0.106932	Medium	34.74	1.831815	High	736.92	76.688208	Medium	19.71	1.553081	Medium	2.16	0.167294
High	841.95	92.449847	High	378.45	85.921537	Medium	388.53	27.154359	High	1822.23	96.084852	Very High	224.01	23.311792	High	1199.43	94.511028	High	1109.88	85.961244
Very High	49.77	5.464967	Very High	16.83	3.821005	High	1040.76	72.738709	Very High	39.51	2.083333				Very High	49.95	3.935891	Very High	179.1	13.871462

Ward 8			Ward 9			Ward 10			Ward 11			Ward 12			Ward 13			SNP		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Medium	0.72	0.096817	Medium	316.26	16.73174	Medium	0.54	0.0557	Medium	0.54	0.042385	Medium	0.18	0.012144	High	1088.46	94.432732	Low	0.36	0.152439
High	533.07	71.680988	High	1546.38	81.811256	High	815.76	84.144077	High	1057.14	82.975417	High	1053.09	71.048637	Very High	64.17	5.567268	Medium	212.76	90.091463
Very High	209.88	28.222195	Very High	27.54	1.457004	Very High	153.18	15.800223	Very High	216.36	16.982198	Very High	428.94	28.939219				High	23.04	9.756098

Panchpokhari	Landslide													
Ward 1			Ward 2			Ward 3			Ward 4			Ward 5		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	136.35	9.113878	Low	250.74	5.443745	Low	155.79	5.445109	Low	133.83	6.142851	Low	193.95	8.007878
Medium	988.92	66.101185	Medium	2559.42	55.566845	Medium	1689.57	59.053161	Medium	1024.56	47.027719	Medium	1611.99	66.556427
High	363.87	24.321723	High	1742.94	37.840478	High	929.7	32.494495	High	888.3	40.77333	High	606.78	25.052952
Very High	6.93	0.463214	Very High	52.92	1.148931	Very High	86.04	3.007235	Very High	131.94	6.056099	Very High	9.27	0.382743

Ward 6			Ward 7			Ward 8			Langtang		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	283.32	20.583235	Low	291.33	13.814442	Low	177.84	10.665515	Low	265.32	1.068108
Medium	985.77	71.61632	Medium	1276.47	60.528337	Medium	1127.16	67.59864	Medium	7266.51	29.253049
High	107.28	7.793906	High	522.09	24.756743	High	357.93	21.465969	High	13503.3	54.360838
Very High	0.09	0.006539	Very High	18.99	0.900478	Very High	4.5	0.269876	Very High	3805.02	15.318005

Panchpokhari	Flood													
Ward 1			Ward 2			Ward 3			Ward 4			Ward 5		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Medium	685.71	45.781757	Medium	1362.24	29.591976	Medium	465.93	16.282946	Medium	365.4	16.78102	Medium	954.27	39.410497
High	669.15	44.676121	High	2663.46	57.858414	High	2000.79	69.921998	High	1794.33	82.404728	High	1460.88	60.333036
Very High	142.92	9.542122	Very High	577.71	12.54961	Very High	394.74	13.795056	Very High	17.73	0.814251	Very High	6.21	0.256467

Ward 6			Ward 7			Ward 8			Langtang		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
High	754.38	54.787895	Medium	554.13	26.246909	Medium	1107.27	66.484734	Medium	6962.76	28.020384
Very High	622.53	45.212105	High	1451.88	68.769716	High	537.93	32.299379	High	17393.2	69.995907
			Very High	105.21	4.983375	Very High	20.25	1.215888	Very High	492.93	1.983709

Panchpokhari	Fire													
Ward 1			Ward 2			Ward 3			Ward 4			Ward 5		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Medium	49.05	3.274847	Low	9	0.195507	Low	138.69	4.846826	Low	5.4	0.247995	Low	485.73	20.060214
High	1434.6	95.781757	Medium	2176.47	47.279517	Medium	2048.49	71.588979	Medium	1427.94	65.578243	Medium	1621.62	66.971454
Very High	14.13	0.943396	High	2417.94	52.524976	High	674.28	23.564195	High	744.12	34.173762	High	314.01	12.968332

Ward 6			Ward 7			Ward 8			Langtang		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Medium	134.28	9.752271	Low	31.23	1.479239	Medium	579.6	34.801405	Low	6722.01	27.052606
High	1186.11	86.142885	Medium	823.95	39.027198	High	1080	64.847339	Medium	13721.3	55.221161
Very High	56.52	4.104843	High	1169.37	55.388354	Very High	5.85	0.351256	High	4404.6	17.726232
			Very High	86.67	4.105209						

Sunkoshi Landslide

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6			Ward 7		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	194.31	19.180881	Low	86.22	12.399689	Low	182.52	16.385231	Low	110.61	14.073056	Low	253.17	18.982387	Low	245.16	18.251256	Low	203.67	21.203036
Medium	738.45	72.894456	Medium	495.09	71.201139	Medium	809.91	72.707441	Medium	553.05	70.365281	Medium	960.93	72.049396	Medium	938.34	69.855946	Medium	657	68.396889
High	80.28	7.924662	High	114.03	16.399172	High	121.5	10.907328	High	122.31	15.561663	High	119.61	8.968216	High	159.21	11.852596	High	99.9	10.400075
															Very High	0.54	0.040201			

Sunkoshi Flood

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6			Ward 7		
Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage
Medium	801	79.400482	Medium	461.16	66.433294	Medium	63.99	5.739425	Medium	0.63	0.080137	Medium	305.1	22.877581	Medium	27.99	2.08473	Medium	70.29	7.323019
High	198.54	19.680614	High	221.04	31.842344	High	539.73	48.409751	High	223.56	28.437321	High	790.83	59.299501	High	660.24	49.175493	High	385.11	40.121894
Very High	9.27	0.918904	Very High	11.97	1.724361	Very High	511.2	45.850823	Very High	561.96	71.482541	Very High	237.69	17.822918	Very High	654.39	48.739777	Very High	504.45	52.555087

Sunkoshi Fire

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6			Ward 7		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Medium	0.18	0.017843	Medium	2.97	0.427849	Medium	2.43	0.217953	Medium	2.79	0.354894	Medium	72.81	5.459576	Medium	17.28	1.287036	Medium	6.03	0.628223
High	971.01	96.253011	High	673.65	97.043952	High	1058.4	94.930578	High	758.79	96.519748	High	1211.13	90.815225	High	915.3	68.172677	High	925.65	96.436943
Very High	37.62	3.729146	Very High	17.55	2.528199	Very High	54.09	4.851469	Very High	24.57	3.125358	Very High	49.68	3.725199	Very High	410.04	30.540287	Very High	28.17	2.934834

Tripurasundari Landslide

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	116.82	6.918977	Low	183.15	7.157428	Low	245.16	15.193262	Low	149.4	11.96224	Low	196.11	10.865121	Low	79.38	17.413623
Medium	912.24	54.029851	Medium	1488.24	58.15982	Medium	1044.27	64.716381	Medium	832.23	66.63544	Medium	1156.5	64.073797	Medium	335.16	73.524186
High	559.8	33.15565	High	877.59	34.295864	High	319.41	19.794746	High	264.6	21.186135	High	447.12	24.771877	High	41.31	9.062192
Very High	99.54	5.895522	Very High	9.9	0.386888	Very High	4.77	0.29561	Very High	2.7	0.216185	Very High	5.22	0.289205			

Tripurasundari Flood

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6		
Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage	Class	Area	Precentage
Medium	301.14	17.863435	Medium	636.84	24.94184	Medium	393.93	24.430676	Medium	439.83	35.264829	Medium	149.67	8.302132	High	99.54	21.887987
High	874.98	51.903262	High	1186.83	46.4822	High	699.3	43.369056	High	645.84	51.782364	High	982.26	54.485547	Very High	355.23	78.112013
Very High	509.67	30.233303	Very High	729.63	28.575961	Very High	519.21	32.200268	Very High	161.55	12.952807	Very High	670.86	37.212321			

Tripurasundari Fire

Ward 1			Ward 2			Ward 3			Ward 4			Ward 5			Ward 6		
Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage	Class	Area	Percentage
Low	352.35	20.90118	Low	812.34	31.815298	Low	1.17	0.072561	Low	6.66	0.533988	Low	9.54	0.52918	High	405.27	89.115377
Medium	829.98	49.23389	Medium	871.29	34.124075	Medium	315.81	19.585845	Medium	460.89	36.953384	Medium	477.18	26.468973	Very High	49.5	10.884623
High	502.11	29.784849	High	868.77	34.025379	High	1169.37	72.521768	High	776.88	62.288931	High	1208.07	67.011133			
Very High	1.35	0.080081	Very High	0.9	0.035249	Very High	126.09	7.819826	Very High	2.79	0.223698	Very High	108	5.990714			

9.5 Health services in Sindhupalchowk

S.N	Institution	No of PHC/ORC	No of EPI Clinic	Birthing Center	DOTS Centre	Microscopy Site	Laboratory Services	HTC Site	PMTCT Site	Other Services
1	Helambu RM	13	17	1	5	0	0	0	0	0
2	Panchpokhari Thangpal RM	16	21	3	8	0	0	0	3	0
3	Indrawati RM	22	23	4	7	0	0	0	4	
4	Melamchi Mun	31	39	5	11	2	1	1	1	
5	Jugal RM	16	21	3	6	0	0	1	0	
6	Balephi RM	11	15	2	4	1	1	1	2	0
7	Chautara Sagachokgadhi Mun	33	37	2	11	1	1	1	2	
8	Sunkoshi RM	15	15	2	6	0	0	0	2	0
9	Lisankhupakhar RM	17	15	2	6	0	0	0	2	0
10	Tripurasundari RM	16	16	1	6	0	0	0	1	0
11	Bhotekoshi RM	12	15	0	4	0	0	0	1	0
12	Barhabise RM	17	16	3	6	1	1	1	3	0
		219	**250**							