Geospatial Assessment of Flood and Drought on the Chure Region of Western Nepal

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Abstract

Flood troubles people of central chure region and its vicinity almost every year. Besides, the area is also becoming susceptible to the drought currently. In that perspective, it is necessary to assess the vulnerability of floods and drought in the chure region. So this research focused on the assessment of flood and drought geospatially in Butwal city which was the major city and experience flood and drought every year. This study mainly records floods, calculates drought, finds their present condition, studies their trend, and determines drought and flood vulnerable areas within Butwal. Climate data, imagery, soil data, and socioeconomic data, and other relevant information were analyzed and extracted past drought conditions through Temperature and precipitation trend analysis and SPEI model. NDVI, NDDI, NDWI were used to find drought vulnerability status, and AHP and MCDA were used to find flood vulnerability. The city faced extreme drought in 2005, 2011, 2012, and 2013. And, Flood of 1970 and 1981 are the major floods. The area was frequently affected by floods in the past but no flood has been recorded after 2017. About 43% of the area was found high to very highly vulnerable to drought and 68% of the land was found vulnerable to extremely vulnerable to flood. So geospatial vulnerability assessment can enhance the planning decision and effectiveness of activities of the preventive measures by the stakeholders.

1. Introduction

Climate change has become a major concern as it greatly affects the environment together with living beings. It causes water stress (Joshi & Dongol, 2018) and will increase flood frequency in the future (Arnell & Gosling, 2016). Reay et al. (2007) has expected elevated temperatures, plummeted rainfall, and frequent extreme climate events to be the tropic's future which would impact mankind through various interlinked disasters like droughts and floods. Both floods and droughts are water-related natural disasters that influence different environmental, biotic, and economic factors. Drought is a multi-scalar process (Gurrapu et al., 2014) affecting the larger area and climatic zones which causes more monetary loss than other hazards (World Meteorological Organization & Global Water Partnership, 2016). It is the weather-related natural disaster often induced by human activities, which affect for long term and encompass a large area, thus has a detrimental impact on human, agriculture, and their economy. It is also a complex phenomenon to predict, due to its vagueness to distinguish when it starts in spatial and temporal terms (Peduzzi et al., 2009). The water shortage time scale separates different drought types (Gurrapu et al., 2014). Drought is characterized into four types — (1) meteorological drought: caused by below-average precipitation for a long timescale; (2) agricultural drought: arises due to soil moisture deficit or lack of plant available water below essential limit; (3) hydrologic drought: caused by a deficiency in either surface water/groundwater, or streamflow or both; and (4) socio-economic drought occurs due to adverse financial return, calculated by socio-economic index (McVicar & Jupp, 1998; Senay et al., 2015). SPEI value at different time scale indicates different drought types. For example, short (1 month), medium (3, 6 months), and long timescale (12, 24, 48 months) SPEI indicate meteorological, agricultural, and hydrological drought respectively (Abdullah, 2014).

The impact of drought is both direct and indirect. The direct impact includes high fire hazards, decrease crop yield, low water level, and degradation of wildlife habitat. Similarly, indirect impacts are the result of these mentioned direct impacts. Drought is measured using drought indicators which differ accordingly with season and region (World Meteorological Organization & Global Water Partnership, 2016). All over the place, the average water stress is 13% where over 2 billion people are facing the problem of it. According to available worldwide statistics, 32 countries experience water stress between 25 to 70 percent and 22 countries above 70 percent. In Nepal, the most drought occurs from the end of March to June, which is usually common in lowland and western hills (Joshi & Dongol, 2018; Subbiah et al., 2013). Drought caused 38.9% of crop loss during 1971 and 2007 (MoHA, 2018), such hazard is rising intensely since 1990 (Joshi & Dongol, 2018). About one-third and 15.5% of households are facing food scarcity due to drought and flood respectively (CBS, 2017; Joshi & Dongol, 2018).

Flood, a chief climate-induced calamity, caused loss of approx. 20–100 billion US dollars and killed thousands of people each year in the previous decade. Such damage is ongoing and predicted to rise even more in the future. As the frequency of flood occurrence is expected to increase in the region like South and Southeast Asia and Northeast Eurasia, in contrast, it is projected to reduce in the Northern and Eastern Europe and Central Asia (Hirabayashi et al., 2013). Globally, Nepal, being the fourth most vulnerable country to climate change and related disasters and standing at the 30th position in terms of flood hazard, many populations have suffered and killed a huge number every year. Overall around 80 percent of the total population of Nepal is at risk from different natural hazards, such as floods, landslides, windstorms, hailstorms, fires, earthquakes, and Glacial Lake Outburst Floods (MoHA, 2018). While mentioning all those risks through disaster, geospatial mapping all over the disaster risk area is crucial for the preparedness of the communities and the government.

Geospatial practices like geographic information system (GIS) and remote sensing (RS) are pertinent to manage spatial problems i.e., natural hazards (Kienberger, 2012). GIS allows spatial decision-making (COVA, 1999). The combined use of GIS and RS helps to understand multiplex hazards and make them comprehensible (Meyer et al., 2009). Geospatial assessment has been employing to make complex natural hazards like floods and drought simple. While analyzing flood and drought vulnerability through RS and GIS, different factors: meteorological, edaphic, elevation, slope, and land use land cover (LULC) should be considered. The basis of rainfall and temperature trend analysis is the most supportive one to predict drought prone regions. Landsat images with good resolution provide the advantage for detailed monitoring, vulnerability assessment and the way-out for relief management. Different cities of Nepal are experiencing flood every couple of years due to its geography. Along with flooding, they are also becoming vulnerable to drought in the recent years, among them is the city Butwal, which lies in the south western part of Nepal. People residing near Butwal share an experience of need to bury hand-pump deeper than before (PCTMCDB, 2017). Although the city is highly vulnerable to flood and droughts, qualitative and quantitative vulnerability mapping has not been carried out by relating extreme events with climate change. As recent and big events like 2009 flood in the eastern Nepal, and 2017 flood shows the occurrence of frequent and catastrophic events. Thus, vulnerability assessment is important for overall Nepal, due to its exposure characteristics, recurring disasters and mediocre construction of infrastructure.

Since the year 2000, earthquakes have been a widely discussed topic in Nepal at the local policy level. However, landslides, floods, and other hazards are not given equal emphasis at a policy level or in academic researches. Such mapping can have a direct influence on policy-making in terms of preparedness and resource allocation. Apart from this, even citizens could reduce the level of vulnerability from the map and effectively initiate awareness procedures. Thus, we decided to explore on a local scale with objectives (1) to assess the temperature and precipitation trend of the city (2) to determine drought occurrence, frequency, and intensity, and (3) to prepare a drought and flood vulnerability map. This research helps in instigating researchers for a further study like assessing how flooding and drought influence forest structure and composition in the study area. A local government organization like irrigation, agriculture, forest, and soil conservation can employ research outcomes for any kind of relatable program implementation and management. The findings of the research may be useful in the future as reference material and documentation of the research may also provide relevant information to the required person.

2. Material And Methods

2.1 Study area:

The study area (Fig. 1) lies in the Rupandehi district of southwestern Nepal. It is located at 27.6874° N and 83.4323° E. The total area of the city is 101.69 km^2. Physio-graphically, the northern part of the city lies in the foothills of the Chure range and the southern part is the flat land. Tina and Danav river runs across the city. The altitude and slope of the area range between (56–1047) m above sea level and (0 – 59) degrees respectively. Four types of soil were found in the study area. Forest, agriculture, and built-up area are major land classes, whereas barren land, shrubland, and grassland also represent the study area. The climate here is subtropical monsoon and the area receives monsoon rain from mid of June to the end of September.

2.2 Data collection:

A diverse range of data was collected through different sources. Meteorological data from 1987 to 2017 was collected from the Department of Hydrology and Meteorology (DHM), Landsat images were downloaded from the earthexplorer portal of USGS, Digital Elevation Model (DEM) was downloaded from Earthdata portal, and soil data were collected from FAO SOTER database from FAO website. Precipitation data in raster format was collected from Bio variable data of WorldClim portal to prepare the flood vulnerable map, Administrative map of Nepal was downloaded from the website of the Department of Survey Nepal (Table 1). Focus group discussion (FGD) and key information informants (KII) were conducted to get an insight into the drought status and to determine the flood years in the study area respectively. And, direct field observation was done to determine whether the vulnerability maps produced accurate results or not.

Table 1
Data sources

Data	Data format and features	Sources	Uses of Data
Meteorological data	Format: CSV file Point data	Department of Hydrology and Meteorology (DHM)	To determine temperature and precipitation trends and to calculate Standardized Precipitation Evapotranspiration Index (SPEI).
Landsat – 8 OLI images (30 m * 30 m)	Format: Raster Resolution: 30m Date: 2016/01/02 (drought vulnerability map) and 2018/09/20 (flood vulnerability maps). Cloud Cover: 3.99 and 14.55 for 2016/01/02 and 2018/09/20 respectively.	USGS portal[1]	To prepare flood and drought vulnerable maps.
Elevation (30 m * 30 m)	Format: Resolution: 30m	SRTM DEM[2]	To prepare flood vulnerable map.
Soil data	Format: Vector Shape: polygon	FAO SOTER database from FAO website[3]	To prepare flood vulnerable map.
Precipitation data	Format: Raster Resolution: 1000 m	WorldClim	To prepare flood vulnerable map.
Administrative Map of Nepal	Format: Vector Shape: Polygon	Department of survey	To prepare flood vulnerable map.
Digitized River layer	Format: Vector Shape: Polygon	Google Earth Pro	To prepare flood vulnerable map.
[1] https://earthexplorer.usgs.gov/			
[2] https://earthdata.nasa.gov/			
[3] https://data.isric.org/geonetwork/srv/api/records/896e61f8-811a-40f9-a859-ee3b6b069733			
[4] https://www.worldclim.org/data/index.html			

2.3 Data analysis:

2.3.1 Temperature and precipitation trend:

The meteorological data collected from DHM had some missing values. So, before determining temperature and precipitation trends, filling those datasets was mandatory. It was done with the help of the Amelia II package in R statistical programming language as per the suggestion of (Radi et al., 2015). The package was used to generate the imputed data sets and the average of imputed data was filled in the gaps. The precipitation and temperature trend of the study were explored through this data.

2.3.2 Drought calculation:

Standardized Precipitation Index (SPI) and (SPEI) are the major indices suggested and used for drought calculation. SPI is suggested as a major tool to measure meteorological drought (Hayes et al., 2011; Mckee et al., 1993; World Meteorological Organization & Global Water Partnership, 2016). But, Gurrapu et al. (2014) found SPEI (Abdullah, 2014; Vicente-Serrano et al., 2010) to be better than SPI for calculating droughts as unlike SPI, SPEI incorporates temperature’s role in drought formation. So, SPEI was used to determine drought in this study.

2.3.3 Drought vulnerability assessment:

RS-based drought index uses multispectral bands, which gives distinct information about land surface vegetation Indices. Band 4 (Red), band 5 (Near infra-Red), and band 6 (Short-Wave Infra-Red) of Landsat 8 image were extracted to calculate normalized difference vegetation index (NDVI) and normalized difference water index (NDWI) by using equations (i) and (ii) respectively. The NDVI and NDWI values were used for drought severity assessment through normalized difference drought index (NDDI) by using equation (iii) as drought is related to vegetation state and condition (Gu et al., 2008; Singh Choudhary et al., 2012)

Where, NIR = Near Infra-Red band.

R = Red band; and

SWIR = Short-wave Infra-red band.

2.3.4 Flood Vulnerability Assessment

KII and FGD methods were used to determine the past flood occurrences and the major changes made by those floods in the study area. Various elements were responsible for the flood and the vulnerability of a particular place to flood depends on many drivers. After consultation with the expert, six variables elevation, slope, distance to a river, landcover, precipitation, and soil types were used for the flood assessment. Multiple criteria evaluation (MCE) was carried out by using an analytical hierarchical process (AHP) after reviewing the various works of literature (Malczewski & Rinner, 2015; Ouma & Tateishi, 2014) to determine the weightage and consistency of weightage of these six variables. The weightage value was used to calculate flood vulnerability mapping. For distance to river variable, multiple ring buffer was carried out at 500 m, 1000 m, 1750 m, 2750 m, and 4500 m on digitized river layer. Soil and distance to river layer were converted to raster layer to attain consistency over layer format. Band composite images were prepared to stack all the bands of Landsat images. Different raster layers i.e. soil, distance to a river, precipitation, band composite image were resampled to 29.56 m to obtain consistency over spatial resolution. All the layers were clipped by the administrative boundary layer of Butwal Municipality. On the clipped band composite image, maximum likelihood classification was performed to obtain a land-cover map. Forest, agricultural land, settlement, and water body class were prepared. Post-classification enhancement was performed by using majority filter, boundary clean, region group, set null and nibble tools of Arcmap. Accuracy assessment of classified image was carried out and a confession matrix was prepared to measure the accuracy. All the sample were reclassified according to the decision subfactor and ranking decision (Table 2) where ranking 1 indicate extremely high vulnerable, 2 highly vulnerable, 3 vulnerable, 4 moderately vulnerable and 5 least vulnerable. A flood vulnerability map was prepared using the weightage of the variable through a raster calculator.

Table 2
Weighted flood hazard ranking

Decision Factors (DF)	DF's Relative Weight	Decision sub-factors	Ranking decision
Rainfall (mm)	0.06	2275 – 2115	1
		2115–2001	2
		2001–1888	3
		1888–1714	4
		1714–1565	5
Distance to a river (m)	0.32	0-500	1
		500–1000	2
		1000–1750	3
		1750–2750	4
		2750–4500	5
Elevation (m)	0.04	56–206	1
		206–348	2
		348–513	3
		513–708	4
		708–1047	5
Slope (degrees)	0.2	0–7.19	1
		7.19–13.85	2
		13.85–22.07	3
		22.07–32.15	4
		32.15–59.19	5
Soil classes	0.34	Eutric Fluvisols	1
		Eutric Gleysols	1
		Calcaric Phaeozems	2
		Dystric Regosols	5
Land-cover	0.04	River and streams	1
		Agricultural land	2

Decision Factors (DF)	DF's Relative Weight	Decision sub-factors	Ranking decision
		Settlement	3
		Forest	4

3. Results

3.1 Temperature and precipitation trend:

The temperature and precipitation trend of Butwal from the year 1987–2017 was analyzed and found that the year 2017 received maximum total annual rainfall with 3525.5 mm and maximum average annual rainfall 293.8 mm and also 2017 receive the highest average monsoon rainfall (818.9 mm), followed by 2016, with total annual rainfall and highest average monsoon rainfall of 3368.1 mm and 766.4 mm respectively (figure 3). Total minimum annual rainfall was recorded in 2012 with 1223.9 mm and minimum average annual rainfall 101.99 mm (figure 2 a) and 2012 also received the lowest average monsoon rainfall of 284.6 mm, followed by 2005 (286.1 mm) (figure 3). Likewise, high maximum temperatures were recorded in the years 1992, 2010, and 2016 with 39.8, 39.6, and 39.6 °C respectively whereas 2016, 2011, 2017 have the highest average annual maximum temperature with 31.7, 31.69, and 31.65 °C (figure 2 b). And, the lowest minimum temperature was recorded in 2006 and 2012 with 8.8 °C each, followed by 1998 and 2017 with 9.2 °C each but the average annual minimum temperature were minimum on the year of 2011, 1987, and 2012 with 16.74, 17.83, and 18.73°C (figure 2 c). Similarly, the year 2009 received the highest average temperature of 26.39°C, followed by 2006 and 2005, with 26.35 and 26.23°C and the year 2011 received a minimum average temperature of 24.21 °C, followed by 1987 and 2013 with 24.25 and 24.34 °C (figure 2 d).

3.2 Drought occurrence, frequency, and intensity:

Butwal suffered from extreme meteorological drought in January 1998, July 2005, October 2011, and January 2012 respectively. Similarly, the city also suffered from extreme agricultural drought in July 2005 and June 2012. Likewise, in August 2012 and January to February 2013, the city suffered from extreme hydrological drought.

The city suffered from the longest severe hydrological drought from August 2012 to May 2014, followed by from October 2000 to August 2001. Similarly, a severe hydrological drought occurred for three, four, and six consecutive months in 1999, 2013, and 2010 respectively. The year 1998 received severe agricultural drought for four consecutive months and 2012 received severe agricultural drought for seven months.

Looking at the drought's intensity and duration, the drought of 2012 can be considered as the most intensive drought as Butwal suffered from severe and extreme meteorological, agricultural and hydrological drought in 2012. Besides, the year also suffered from drought in summer as well as in winter.

Table 3: Drought frequency

Various month SPEI	Drought characteristics	Frequency
SPEI 1	Moderate drought	10.8
	Severe drought	3.8
	Extreme drought	1.1
SPEI 3	Moderate drought	13.2
	Severe drought	4.3
	Extreme drought	0.5
SPEI 6	Moderate drought	12.4
	Severe drought	5.1
	Extreme drought	0.3
SPEI 12	Moderate drought	15.6
	Severe drought	4.0
	Extreme drought	0.3
SPEI 18	Moderate drought	12.4
	Severe drought	4.0
	Extreme drought	0.5
SPEI 24	Moderate drought	7.3
	Severe drought	7.0
	Extreme drought	0.0

Table 3 shows the relationship between drought intensity and frequency. The data collected from FGDs and KIIs have elucidated drought occurrence and intensity status in our study area. The survey result supported that the Tinau river, which was perennial about three decades ago has recently started drying up during summer. Local farmers have also stated that the irrigation canals which was used to irrigate the agricultural lands around Butwal have recently started drying up between the mid of March to the mid of July. They also added that the groundwater level has significantly decreased as they are experiencing the need to burying pipes deeper than before to extract the groundwater.

3.3 Drought vulnerable map:

Figure 5 shows that the central and the southern part of the city is more vulnerable to drought in comparison to the northern part. While looking at each vulnerable class, it was found that most of the city's area (41.12 km^2) was low vulnerable to drought followed by 38.47 km^2 of highly vulnerable area, 16.69 km^2 of moderately vulnerable area, 5.24 km^2 of very highly vulnerable area, and 0.08 km^2 of very low vulnerable area (Table 4).

Table 4: Drought vulnerable class with corresponding areas.

NDDI Value	Vulnerable Class	Area (km^2)	Percentage (%)
<-2	Very low vulnerable	0.08	0.08
-2–0.7	Low vulnerable	41.12	40.44
0.7–1.25	Moderately vulnerable	16.69	16.41
1.25–3	Highly vulnerable	38.47	37.83
>3	Very highly vulnerable	5.53	5.24
	Total	101.69	100

3.4 Flood years on Butwal:

From KII and FGD, it was found that floods occurred in Butwal in 1968, 1970, 1971, 1974, 1979, 1981, 1991, 1993, (1996–1998), 2005, 2007, 2008, 2009, 2011, 2013 and from (2014–2017) with significant loss of lives, properties, and infrastructures. It was also found that the Tinaus' Bifurcation was caused by the flood of 1981.

According to key informants, major floods occurred in Butwal, in 1970, 1981, 2005, and 2017. A possible reason provided by key informants during KII and FGD was the deepening of the river due to the over-extraction of river bed materials.

3.5 Flood Vulnerability Mapping:

Vulnerability for each variable responsible for flood occurrence was identified through the reclassification and mapping of these variables was done. A1 in figure 6 indicates the status of the elevation variable and A2 indicates the vulnerability of elevation for a flood. Similarly, the status of the slope, precipitation, proximity to the river, land cover, and soil types visualized through B1, C1, D1, E1, F1, and their respective vulnerability for flood were indicated by B2, C2, D2, E2, F2 (Figure 6). The Natural Break method was used to reclassify the elevation, slope, and precipitation. The elevation range was from 56m to 1047m (A1) where most of the land was under the low elevation range (A2 in Figure 6). The range for the slope was 0 to 59.18 degrees (B1) and the northern part was found less vulnerable due to the high slope compared to the central and southern part of Butwal (B2 in Figure 6). Precipitation was found higher on the eastern and central part of Butwal (C1), so was more vulnerable to flooding (C2 in Figure 6). The river passed through the northern part where it bifurcated in the center, one towards the southeastern and another on the southwestern part (D1). The land close to the river was more vulnerable than others (D2 in Figure 6). Four landcover types i.e. forest, agricultural land, settlement, and river were classified with an overall accuracy of 90.3% and kappa statistic 0.84 (confusion matrix in Appendix 1). Forest was found on the higher elevation and slope, agricultural land and settlement were near to river (E1). Thus, the river, agricultural land, and settlement were more vulnerable to flood than forest (E2 in Figure 6). Four types of soil i.e. eutric fluvisols, eutric gleysols, calcaric phaeozems, and dystric regosols were identified (F1) where and eutric fluvisols and eutric gleysols were more sensitive to flood, due to their low infiltration rate and being near to the river. Area with dystric regosols was found less vulnerable to flood because of its higher infiltration rate and geographical location (higher elevation and sloppy areas) (F2 in Figure 6).

The central and southern part of the Butwal was found more vulnerable to flood, with 26.32 km^2 followed by 27.86 km^2 and 13.956 km^2 as extremely high vulnerable, highly vulnerable, and vulnerable, in comparison to the northern part from the visual interpretation of the Flood Vulnerability Map (Figure 7).

About 68% of the land was found vulnerable to flood and more specifically 26.47% of the land was extremely high vulnerable followed by 28% and 14.03% as highly vulnerable and vulnerable respectively. About 31.94% of the land was found less vulnerable with 18.96% moderately vulnerable and 12.53% least vulnerable (Table 5).

Table 5: Flood vulnerable class with corresponding areas

Reclassified Value	Vulnerable Class	Area (km^2)	Percentage (%)
1	Extremely High Vulnerable	26.92	26.47
2	High Vulnerable	28.47	28
3	Vulnerable	14.27	14.03
4	Moderately Vulnerable	19.28	18.96
5	Least vulnerable	12.74	12.53
	Total	101.69	100

4. Discussion

The study shows that Butwal suffered from extreme episodes of drought in 1998, 2005, 2011, 2012, and 2013. Further analysis of the result shows that for the last 3 decades, both the frequency and intensity of drought have soared over time in Butwal, which resonates with the findings of (Dahal et al., 2015) in which drought risk assessment was conducted in central Nepal. (Jena & Azad, 2021) through Coupled Model Inter-comparison Phase 5 (CMIP5) simulation predicted that the drought occurrence will be increased by 16% in India. Similarly, the projected drought trends by (Spinoni et al., 2017, 2018) in their study in Europe found that drought occurrence and severity will be increased in Europe. Though drought being a complex natural hazard cannot be generalized and it is difficult to determine the onset and end of a drought period (Wilhite & Pulwarty, 2017), the proximity of Butwal with central Nepal as well as national drought scenarios in Nepal reported by (Adhakari, 2013) indicates frequent dry spells in Nepal from 2002, 2004–2006, 2008–2009, 2012, 2013 and 2015 validates our results. Additionally, (Malla, 2008) also found that Eastern Terai faced rain shortages during the monsoon of 2005/06 which decreased crop production by 12.5%. The result of this study states that although Butwal is situated in Western Terai, it has faced extreme monsoon drought in 2005.

The year 2012 received the minimum rainfall followed by 1998, similarly, rainfall records of the years 2005, 2011, and 2013 were comparatively less than other years while the mean maximum temperature for these years was higher, which elucidates that precipitation and temperature have a significant role in determining the occurrence and strength of the drought episodes as all of these years suffered an extreme episode of drought. Furthermore, the incidence of occurrence of severe drought in 2010, though both the year 2010 and 2016 recorded exactly equal maximum temperature, the higher rainfall in 2016 insinuates the more pronounced effect of precipitation over the temperature in determining the incidence and severity of drought. (Yang et al., 2020) developed an Artificial Neural Network (ANN) model for prediction of agricultural drought loss rate from 1945 to 2015 in China which revealed precipitation and temperature as important climate parameters that influence the drought characteristics. Moreover, their study also uncovered that the effect of precipitation on drought is more prominent than the temperature.

From our questionnaire survey, we found that residents of the city had to bear the burden to bury the pump set to deeper than before for water extraction that comes with extra cost and time. (PCTMCDB, 2017) presented that groundwater level in the Terai is decreasing than before in Terai increasing the need of burying deeper for water extraction which depicts that Butwal being in the Terai region of the country is no exclusion from this groundwater level shrinkage. Furthermore, declination of groundwater level has been recounted in South East Asian countries by (Zaisheng & Hao, 2006) is also parallel to our findings.

Low gradient slopes, low elevation area, and the area near rivers and streams are more vulnerable to flood. Rain or excessive water from rivers gathers in an area with a low slope gradient (Ouma & Tateishi, 2014). Our research has similar findings.

The study found that the Tinau river bifurcated into Danav river due to the flood of 1981. (Adhakari, 2013) who also mentioned that the flood around the same year is responsible for the Tinau river bifurcation.

5. Conclusion And Recommendation

Floods occurred in Butwal in 1968, 1970, 1971, 1974, 1979, 1981, 1991, 1993, (1996–1998), 2005, (2007–2009), 2011, (2013–2017), no flood has occurred after 2017 in Butwal. The floods of 1970, 1981, and 2005 were the major flood. 1981's flood was responsible for the Tinaus' bifurcation. Wards 3, 4, 6, 7, and 8, and the wards (1–3, 5) and (11–19) are highly vulnerable to the flash and river flood respectively.

Over 3753 houses and 1400 Bigha of agricultural land in Butwal are vulnerable to flood. About 68% land of Butwal's area is vulnerable to flood whereas 32% of the land was found safer from the flood. Butwal suffered from severe drought in 1987, 1988, 1992, 1996, 1998, 1999, 2000, 2001, 2005, 2009, 2011, 2012, 2013, 2014, 2016 and 2017 and from extreme drought in 2005, 2011, 2012 and 2013. About 59% area was found vulnerable to the drought and 41% area was found less vulnerable to drought. The drought of 2012 was the most intense in Butwal as it suffered from extreme meteorological, agricultural and hydrological drought.

Vulnerability mapping of disasters was found helpful to prepare a plan for the adaptation strategies. The geospatial analysis makes complex data understandable so this method can be used for hazard mapping of complex natural hazards. Documentation of various natural hazards works as reference material for relevant researches. Government and local bodies must include vulnerability and hazard maps while preparing various planning activities.

Declarations

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Figures

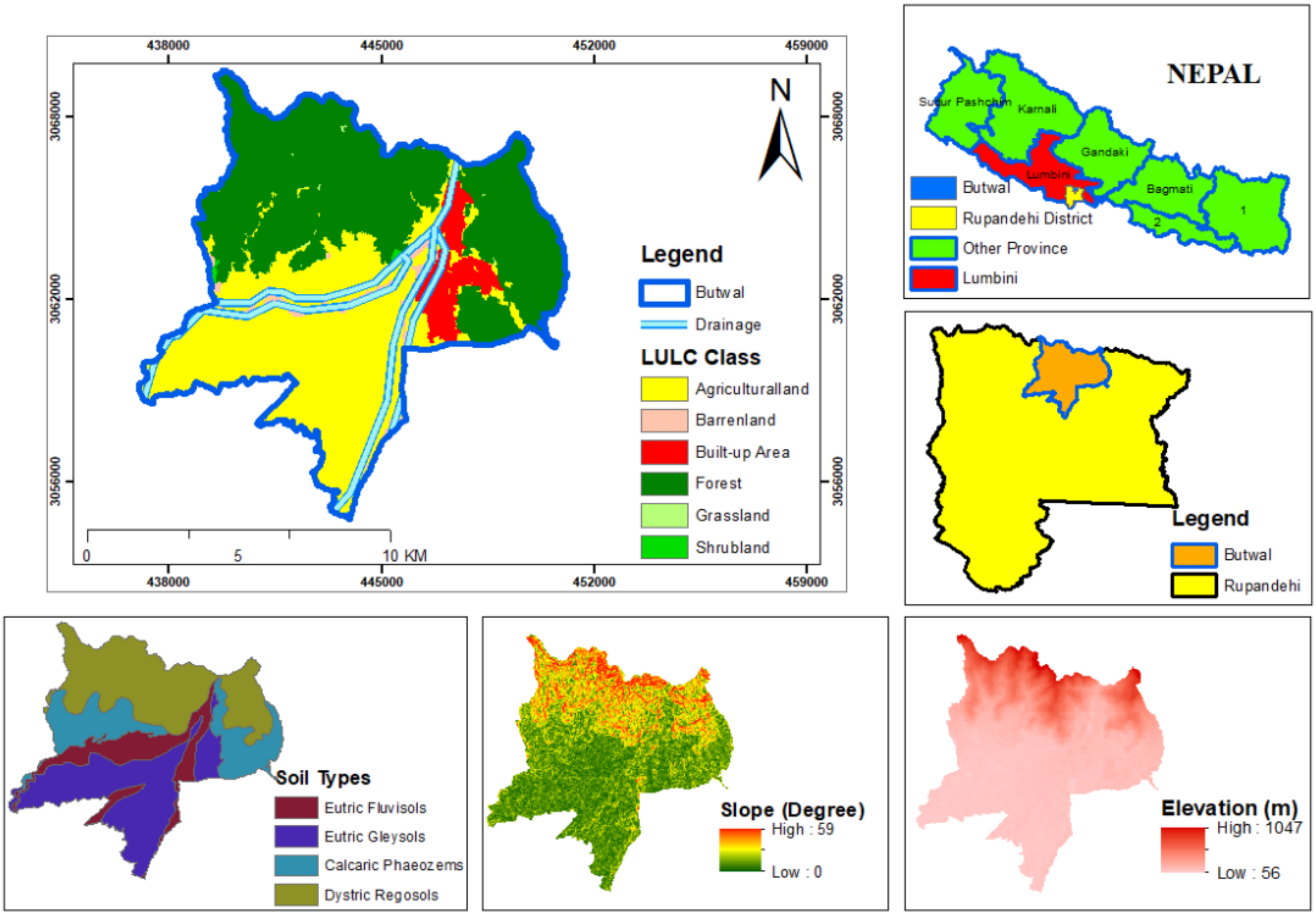

Figure 1

Map of study area showing LULC class, soil types, slope, and elevation.

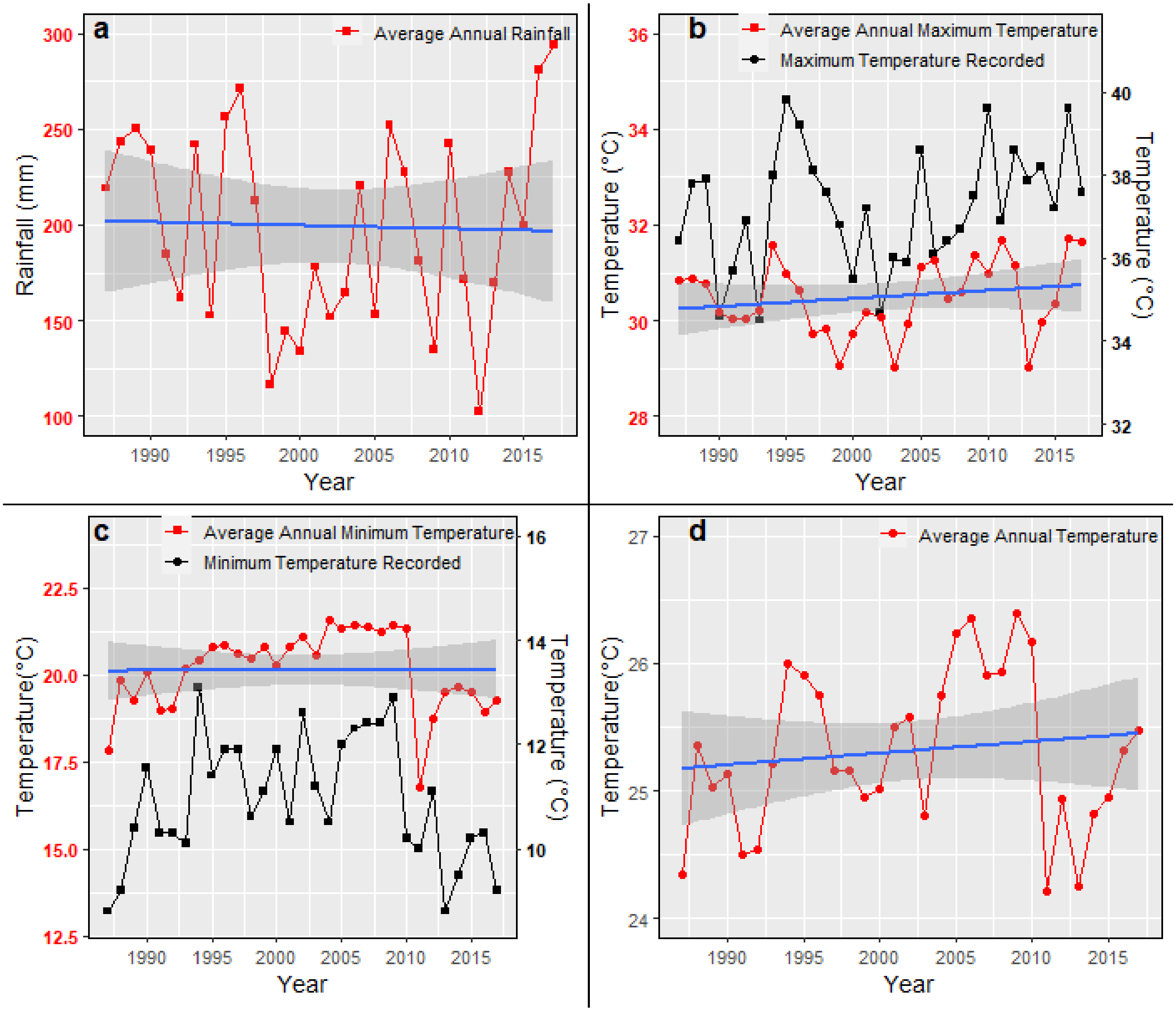

Figure 2

Total annual rainfall, maximum temperature, minimum temperature, and average temperature trend in Butwal from 1987-2017.

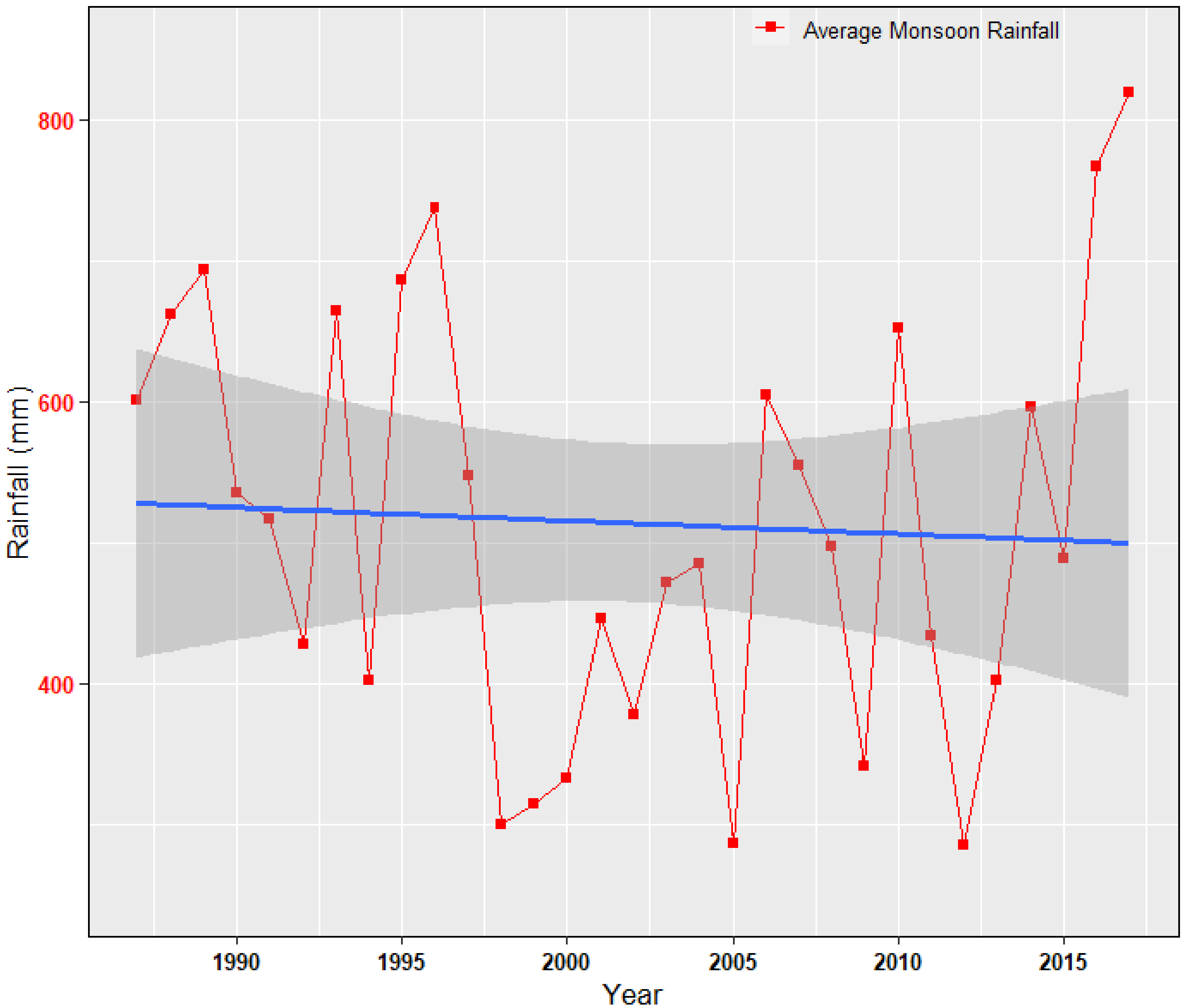

Figure 3

Average monsoon rainfall's trend in Butwal from (1987–2017).

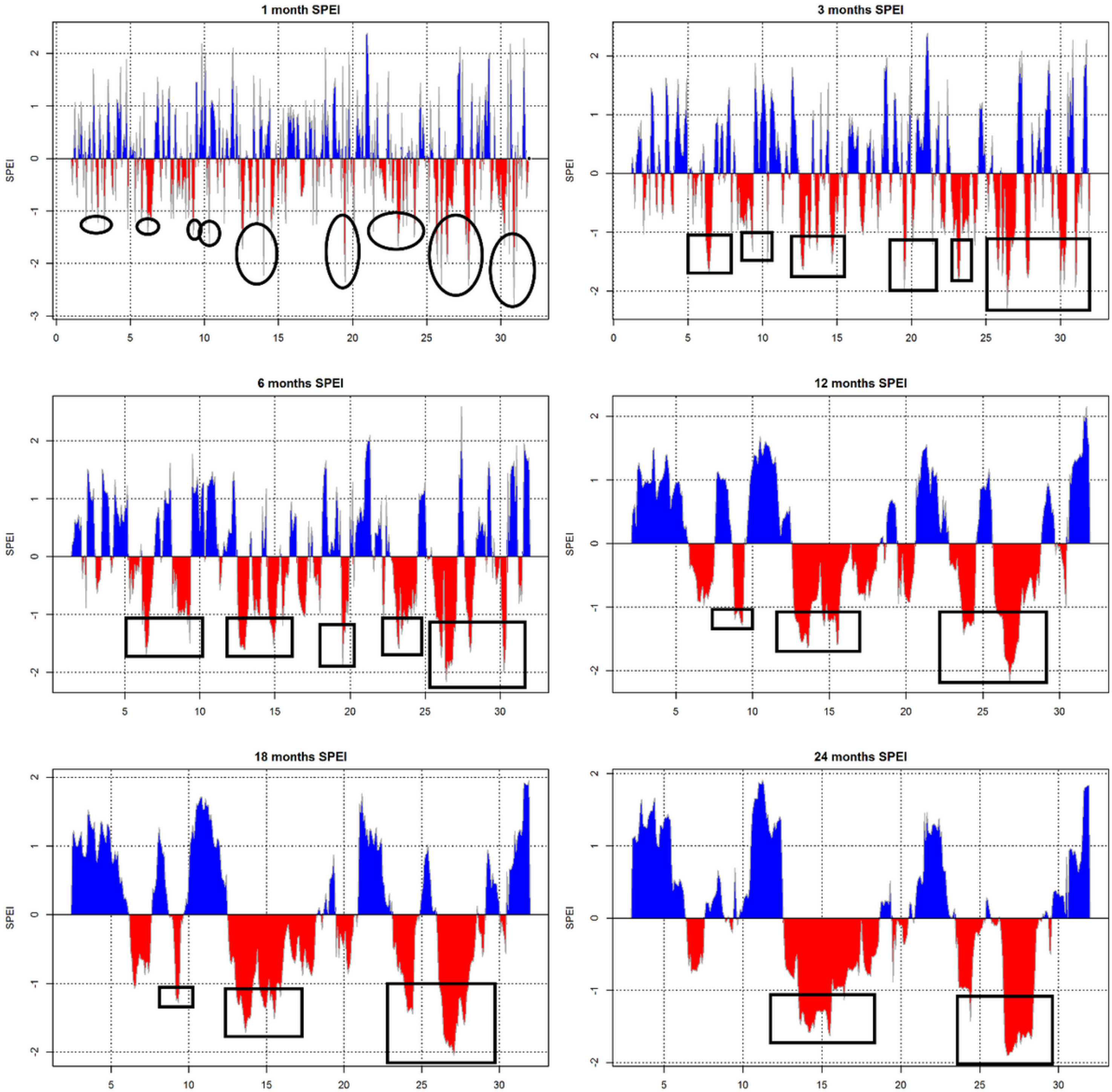

Figure 4

1, 3, 6, 12, 18, and 24 months SPEI, indicating meteorological, agricultural, and hydrological drought (negative SPEI values).

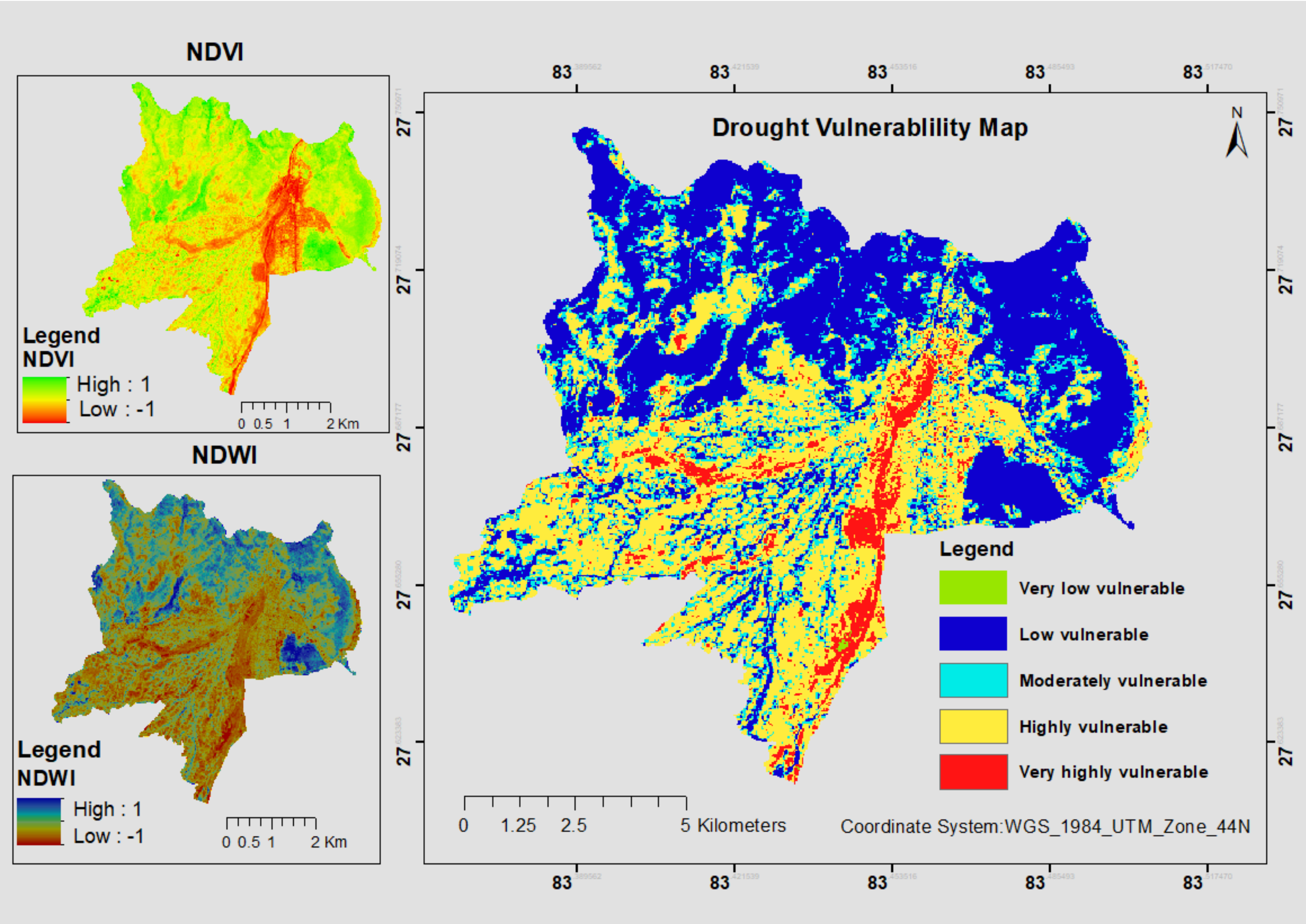

Figure 5

Drought vulnerable area in Butwal city

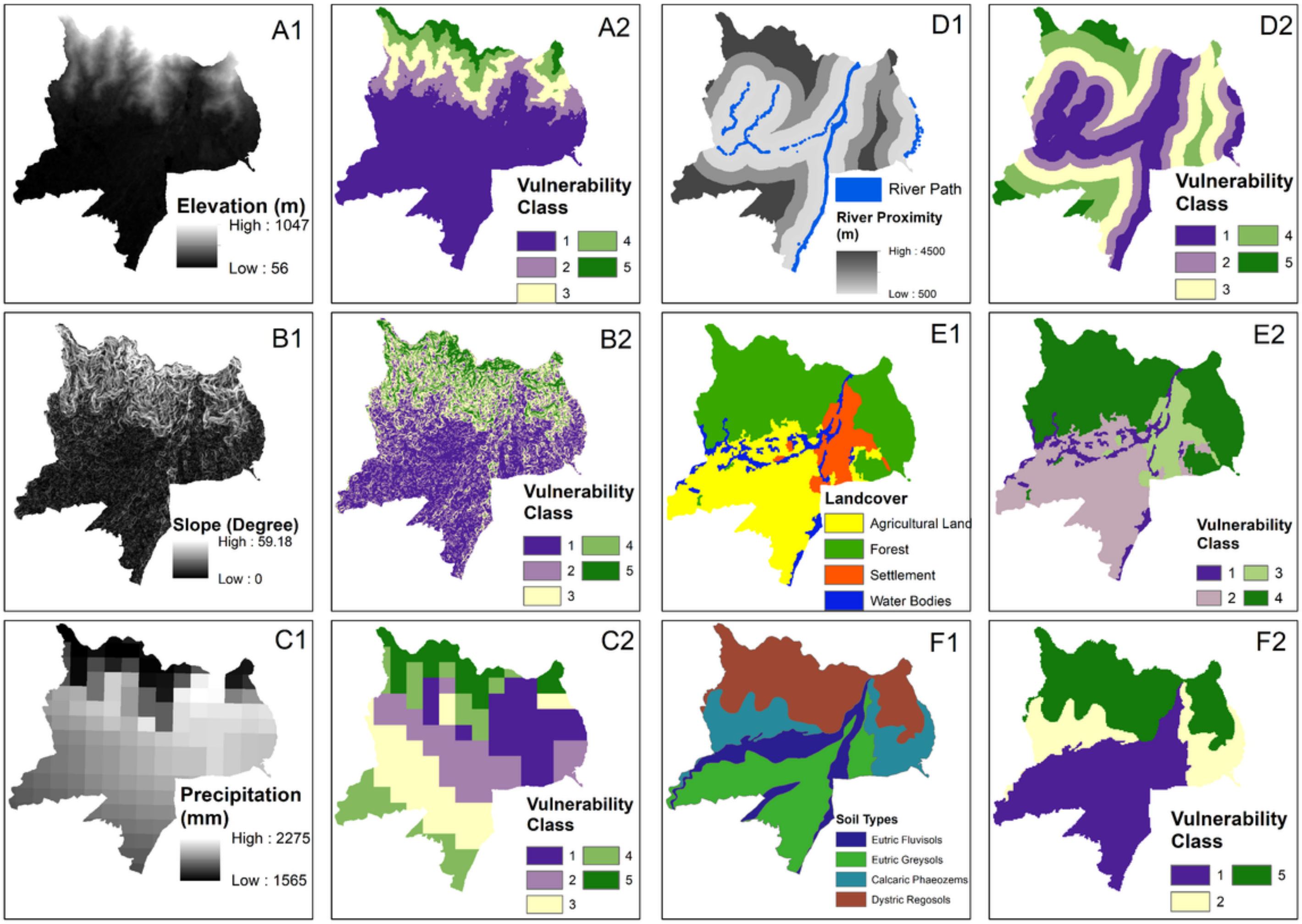

Figure 6

Status of each variable responsible for accelerating flood and their vulnerability to flooding.

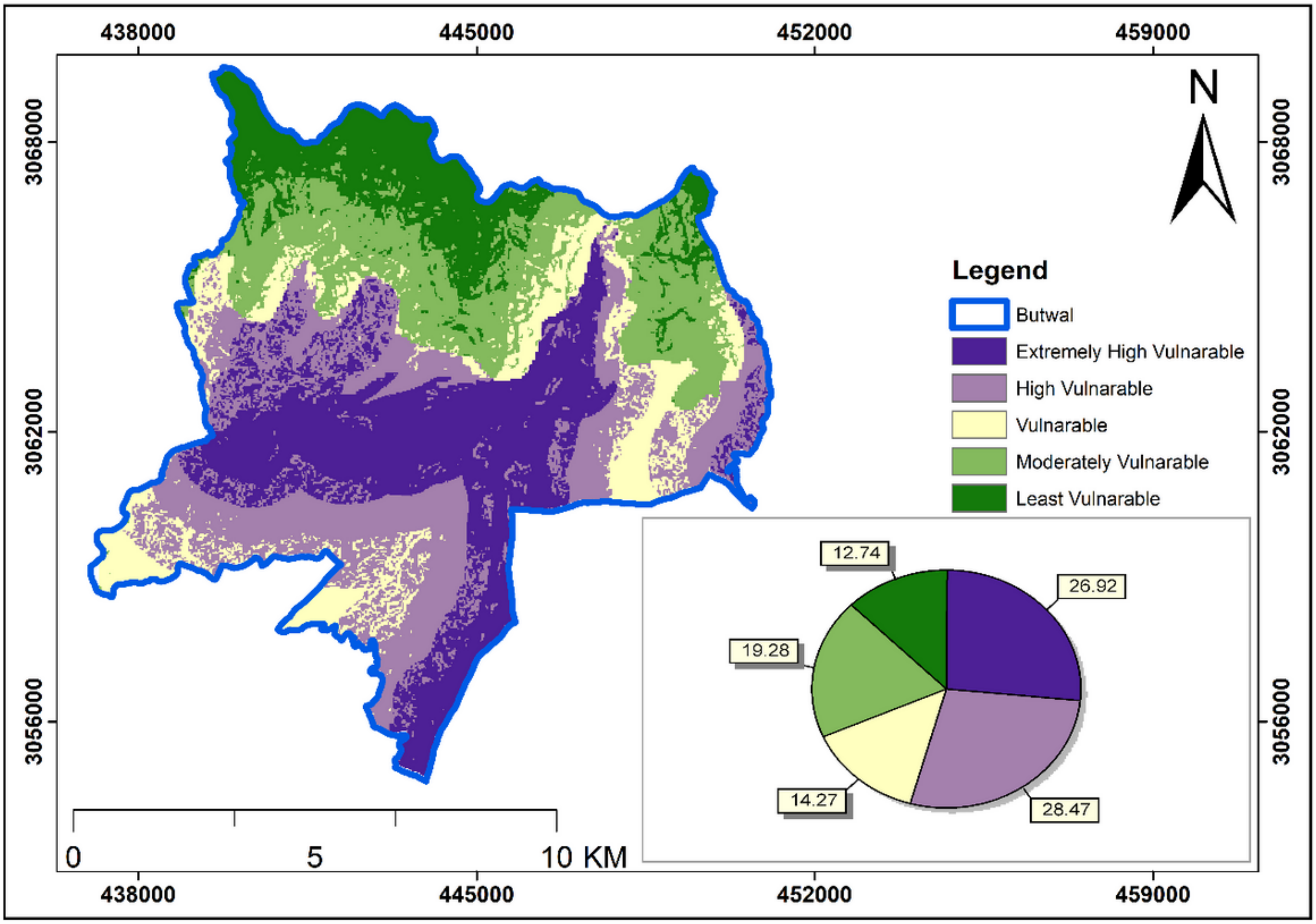

Figure 7

Flood Vulnerable map

Supplementary Files

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- Annex.docx