Agricultural Drought Vulnerability Assessment of Tanahun District, Nepal

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Keywords: Correlation, Drought, Index, Weighted Overlay, Vulnerability

ABSTRACT

Among different types of natural hazards, drought is the most complex and least-understood one. Low rainfall and an increase in soil temperature are the prime causes of agricultural drought. The most immediate consequence of drought is a fall in crop production such that farmers face difficulty to survive as well as a decrease in the economy of the country and a change in environmental conditions. Geographic Information System (GIS) and Remote Sensing (RS) technologies play a key role in studying agricultural drought. Such geospatial techniques have played a key role in studying different types of hazards either natural or manmade. Temporal satellite data of 10 years (2007-2016) of our study area are used to analyze and assess drought severity. The drought risk map of that area is prepared. Land Use Land Cover (LULC) map of the study area is prepared using ERDAS Imagine software. Ten rainfall stations, inside the district as well as nearby districts, are taken to derive the Standardized Precipitation Index(SPI) from which meteorological drought risk map is prepared using GIS. Three indices as Standardized Precipitation Index (SPI), Normalized Difference Vegetation Index (NDVI), and Moisture Stress Index (MSI) are considered for the study. Landsat imageries are obtained from the United States Geological Survey (USGS) and radiometric corrections are applied, then NDVI and MSI are extracted by ERDAS imagine. Different weights are given to these three indices and integrated, then the final drought risk map is prepared with five different severity classes. The total area covered by different risk levels are classified as very high, high, moderate, slight, and no risk as 1.02%, 48.8%, 34.07%, 14.24%, and 1.87% respectively. Correlation between mean rainfall and mean NDVI is performed and found to be the positive medium correlation of 0.32. The drought risk map shows that most of the area of the district is vulnerable to agricultural drought. As the rate of rainfall decreases, the crop production also decreases so that it is necessary to irrigate the agricultural area by means of constructing irrigation channels at possible locations and changing the type of plantation at the place where the unavailability of water resources would be the best alternative.

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1. Drought

Drought is the slow-onset natural hazard accumulate over a considerable period of time. The prime cause of it is the occurrence of precipitation below normal.
Among natural hazards, drought is known to cause extensive damage and affects a significant number of people (Wilhite 1993). It is a slowly developing phenomenon, only indirectly affecting our life. To reduce the damage from drought, it is crucial to characterize droughts. Drought characterization enables operations such as drought early warning (Kogan 2000) and drought risk analysis (Hayes et al. 2004), which allows improved preparation and contingency planning. It originates from a deficiency of precipitation results in a water shortage situation for a certain activity. It is a normal, recurring feature of climate with characteristics and impacts that can vary from region to region. Although drought first appears as below-average rainfall within a normal part of the climate, it can develop as an extreme climatic event and turn into a hazardous phenomenon that can have a severe impact on communities and water-dependent sectors (McKee et al., 1993). Insufficient supply of moisture resulting either from sub-normal rainfall, erratic rainfall distribution, higher water need, or a combination of all the three factors. Agricultural drought is considered to have set in when the soil moisture availability to plants has dropped to such a level that it adversely affects the crop yield and hence agricultural production. It results from interactions between weather, soil, crop, and human actions.

1.1 Objectives

The general objective of this project is to identify the agricultural drought risk zone of the project area.
The specific objectives of this project are:

- To analyze the pattern of rainfall and vegetation index.
- To prepare Land Use Land Cover map and provide information on the environmental situation of the project area.

1.2 Study Area

Based on the objective and scope of our project, we choose Tanahun district (a part of Gandaki state) of Nepal. This district lies in the middlemost of our country Nepal. This district, with Damauli as its district headquarter, covers an area of 1546 km² and has a population of 323,288(2011), is surrounded by Syangja, Kaski, Lamjung, Chitwan, Gorkha, Nawalpur, Parasi and Palpa. Some general information about Tanahun district are:

Table 1: Geographic Information of Tanahun

Latitude	27° 55' N
Longitude	84° 15' E
State	Gandaki
Headquarter	Damauli
Total Area	1546 km^2

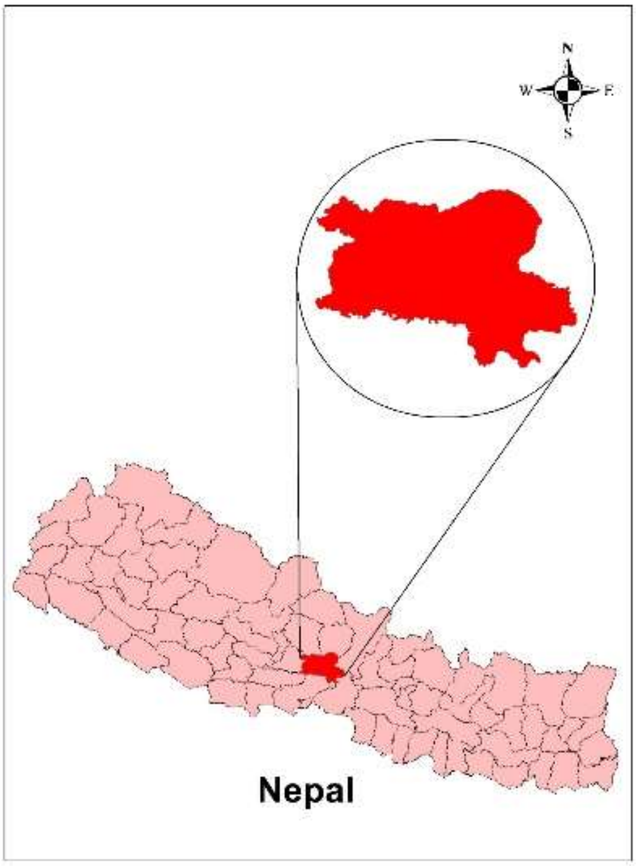

Figure 1: Study Area

1.3 Agricultural Drought Assessment Indices

Different types of drought require different indices that can be used to quantify the moisture condition of a region and thereby detect the onset and measure the severity of drought events, and to quantify the spatial extent of a drought event thereby allowing a comparison of moisture supply condition between regions (Quiring and Papakryiakou, 2003; Beyene Ergogo, 2007). It has become clear that no single indicator or index is adequate for monitoring drought on a regional scale. Instead, a combination of monitoring tools integrated together is preferable for producing regional or national maps (Martini et al., 2004).

1.4 NDVI- Rainfall Relationship

The relationship between NDVI and rainfall is known to vary spatially, notably due to the effects of variation in properties such as vegetation type and soil background (Li et al., 2002; Nicholson & Farrar, 1994), with the sensitivity of NDVI values to fluctuations in rainfall, therefore, varying regionally.
Vegetation amount and condition is a function of environmental variables such as rainfall. Consequently, a strong relationship, involving a brief time-lag in the vegetation response to rainfall would be expected between vegetation indices, such as the NDVI [(infrared reflectance (IR)-red reflectance(R))/(IR+R)] and rainfall (Li et al., 2002).

1.5 Agricultural Drought Vulnerability Map

Agricultural drought vulnerability map of the study area is produced from the output derived from satellite-based vegetation, soil moisture stress, and precipitation indices of each year by using Multi-Criteria Evaluation (MCE) techniques. In order to compute the frequency of drought occurrence, drought class image from each index is reclassified into Boolean image based on their threshold value and frequency maps are generated at each pixel level for each drought index in GIS software. The seasonal frequency maps derive from each drought indices are reclassified into a common scale based on the frequency of drought occurrence. According to Lemma Gonfa (1996), the probability of drought occurrence in the given area can be classified into high, moderate, and low drought probability zones when drought occurs more than 50 percent, 30 to 50 percent, and less than 30 percent respectively. Finally, maps from each drought indices are weighted according to the percentage of influence using ArcGIS software, and then combine together using weighted overlay analysis.

2. METHODOLOGY

The methodology of this project is:

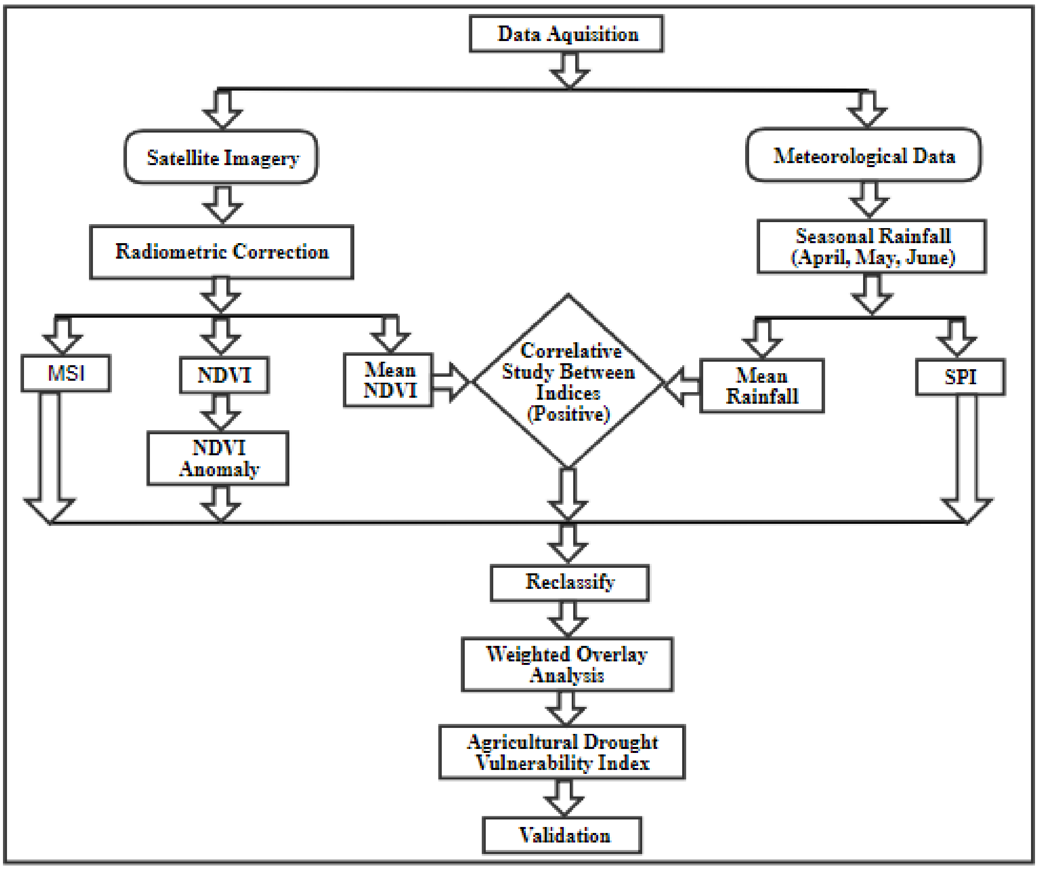

Figure 2: Schematic Representation of Methodology

2.1 Data Acquisition

The first phase of the methodology is data acquisition. The relevant data has been collected from different sources. Remote sensing data have an immense role in agricultural drought study. In this study the seasonal (April, May, June) satellite images in the time period of ten years (2007-2016) have been used. All the satellite images have been downloaded from United States Geological Survey (USGS). Seasonal rainfall data has collected from the Department of Hydrology and Meteorology (DHM) in the time period of 2007-2016.

2.2 Radiometric Correction

Radiometric correction of Landsat image normally involves the process of improving the fidelity of the brightness value. The main purpose for applying radiometric correction is to reduce the influence of error in image brightness value that may limit one's ability to interpret the image. In a whole project, the radiometric correction was applied for strip correction and haze removal.

2.3 Land Use Land Cover

The land use land cover map is the one that shows the ground coverage of desired class. In our project, we prepare the land use land cover map using unsupervised classification in GIS. We defined 7 classes. The description of class is shown in table 2.

Table 2: Land Cover Type

Land Class Type	**Description**
Forest	Area covered by big and dense trees
Grassland	Area covered by grasses
Shrubland	Area covered by small trees
Barren Area	Unused land
Agriculture Area	All type of land used for agriculture
Water Body	River, Rivulet, Lake, and Pond
Built-up Area	Settlement area, Industrial area, and other Infrastructure like bridges, road, etc.

The ground truth points were selected randomly using Google Earth. The Accuracy assessment of the land cover map includes the generation of 249 random points. After the post-classification and refinement, accuracy assessment of the land cover map was performed using an error matrix.

2.4 NDVI Anomaly

NDVI can be used as an index to assess crop condition through analysis of NDVI anomaly (Murali et al., 2008). The vegetative drought index has been calculated using NDVI values. Maximum NDVI and long term mean maximum NDVI were computed in order to derive NDVI anomaly. NDVI anomaly percentage was then derived using the following formula for each grid cell in the study area:

NDVI Anomaly = [(NDVI Max - Mean NDVI Max)/(Mean NDVI Max)]*100%

Where, NDVI max = Maximum NDVI of the year and

Mean NDVI max = Long-term mean maximum NDVI of the range of the year

NDVI anomaly at 100% shows the low deviation from mean NDVI and NDVI anomaly at -100% shows the high.

2.5 Moisture Stress Index (MSI)

Moisture Stress Index is used to determine the soil moisture condition during drought. It is a good indicator of agricultural drought. It has been calculated by using the SWIR band and NIR band of Landsat data. MSI value ranges from 0 to 4. It is computed as:

MSI= [SWIR Band / NIR Band]

2.6 Standardized Precipitation Index (SPI)

Standardized Precipitation Index (SPI) is an index that was developed to quantify precipitation deficit at different time scales, and can also help assess drought severity. It is defined as:

SPI = $[(X_{ij} - X_{im}) / \sigma]$

Where Xij= Seasonal precipitation, Xim= Long-term seasonal mean, and σ= Standard deviation.

2.7 Correlation Analysis of Mean NDVI and Mean Rainfall

Output data derived from the mean NDVI and mean rainfall were prepared for simple regression analysis. The average raster cell values of mean NDVI, mean rainfall were extracted using GIS software and the data were manually loaded in Excel for correlation analysis. The relationship between mean NDVI and mean rainfall result was computed to validate the visual relationship. In order to understand the response of NDVI for rainfall events at a different time interval, simple regression analysis was done based on the Pearson coefficient. Pearson coefficient (r) values range from -1 to +1. A value of 0 indicates no relation, a value greater than 0 indicates a positive association, and a value less than zero indicates a negative association between the variables. In our project, we compute the Pearson coefficient of correlation using Excel.

2.8 Reclassification

The raster image produced using any sort of data is obtained in the stretched form which needs to be reclassified for further computation or analysis. So it needs to be reclassified. Reclassification is the process of classification of stretched images into the desired class. Here in our project, the images prepared by using MSI, NDVI, and SPI are reclassified based upon their classes.

Table 3: Rank and Weights of Different Parameters for Drought Condition Maps

S.N.	**Criteria**	**Classes**	**Rank**	**Influence (%)**
1	SPI	Extremely Dry	5	50
		Moderately Dry	4	
		Normal	3	
		Moderately Wet	2	
		Extremely Wet	1	
2	MSI	Extremely Stressed	5	40
		Severe Stressed	4	
		Moderately Stressed	3	
		Low Stressed	2	
		No Stressed	1	
3	NDVI Anomaly	Very High	5	10
		High	4	
		Moderate	3	
		Low	2	
		No	1	

(Source: https://www.researchgate.net/publication/235970565)

2.9 Weighted Overlay Analysis

In order to obtain a common output from the different parameters, they need to be combined together with definite weightage. In our project, the individual weightage and ranking of the factors NDVI anomaly, SPI, and MSI are taken. Here each index is categorized under five classes ranked from 1 to 5 and a weightage is provided to the indices based upon their influence. In this study, the above-mentioned rank and weight are assigned to the parameters as mentioned in table 3.

3. RESULT AND DISCUSSION

3.1 Result

The unsupervised classification yields the LULC map of the Tanahun district (2016). The LULC map is shown in figure 3.

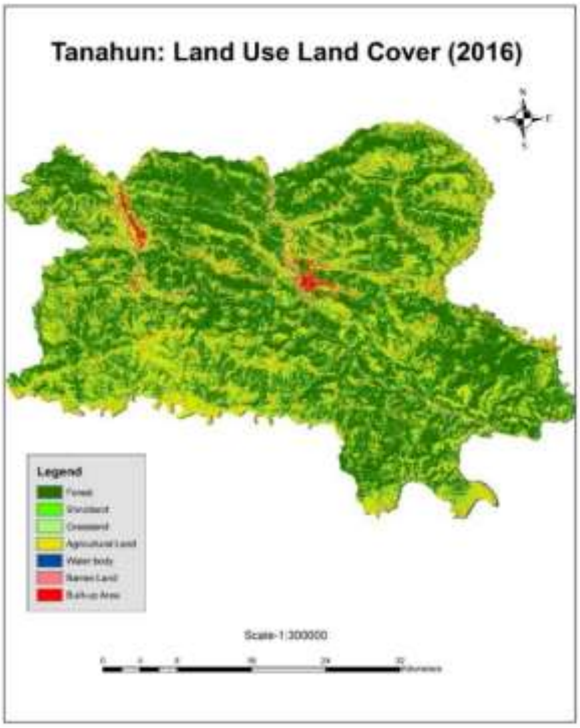

Figure 3: Land Use Land Cover of Tanahun (2016)

Area covered by different land use land cover classes are shown in table 4.

Table 4: Land Use Land Cover

Class	Area (km^2)	Coverage (%)
Forest	840.16	54.2

Agriculture area	455.41	29.5
Grassland	98.73	6.4
Shrubland	88.03	5.7
Built-up area	35.36	2.3
Waterbody	15.28	1.0
Barren area	13.21	0.9

This table shows that the large area of Tanahun district is covered with forest. Agricultural land also covers an area of 455.41 sq. km that is about 29.5% of the total area. Being a hilly region too, this seems to be a large area that is being used for agriculture. Grassland and Shrubland comprise 6.4% and 5.7% of the total coverage respectively. The built-up area seems to be relatively less along with barren land and water body. Error matrix yields an accuracy of about 88%.

The analysis of SPI revealed that drought has occurred at different levels of severity during the period of 2007-2016. The southern and middle part of the study area has been solely affected by the meteorological drought. Correlation between mean rainfall and mean NDVI value has found to be the positive correlation of value 0.32. By weighted overlay analysis, the drought risk map of Tanahun district is obtained as shown in figure 4. This map shows the area under the threat of drought with different levels of drought risk. Five different classes of risk level as very high, high, moderate, slight, and no risk did the area cover as shown in table 5.

Table 5: Drought Risk Level Area Covered

Drought Risk Level	**Area Covered**
Very High	1.02%
High	48.8%
Moderate	34.07%
Slight	14.24%
No risk	1.87%

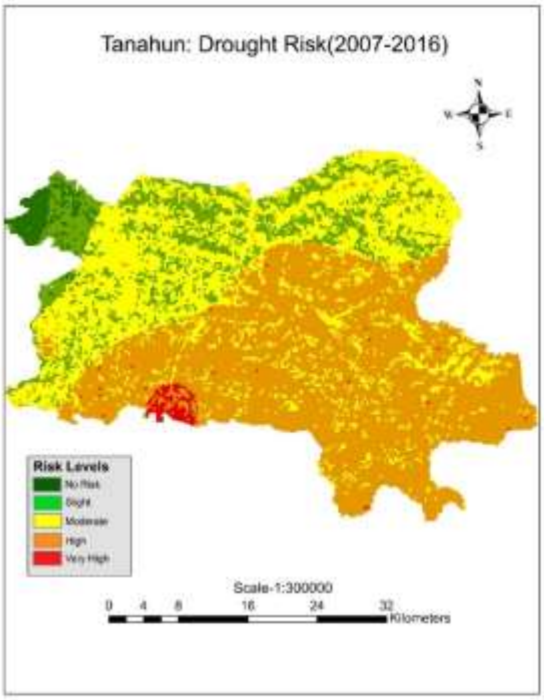

Figure 4: Drought Risk Map

3.2 Discussion

After the completion of this study, the drought-prone area of different severity classes has been identified. Drought classes are based on the weighted overlay analysis of the parameters viz. SPI, NDVI anomaly, and MSI. The risky area has low rainfall, low NDVI anomaly, and high MSI. As SPI and MSI have high weightage on weighted overlay analysis, their impact is also high on the risk area delineation. The affected area lies in plain as well as hilly regions. The impact of drought can be economic, environmental, and social level like reduction in crop production, increase in fire hazard, reduction of water level, migration of people, animals, etc.

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

Agriculture remains by far the most vulnerable and sensitive sector that is seriously affected by the impacts of climate variability and climate change which is usually manifested through rainfall variability and drought. Rainfall is one of the climatic variables that largely determine the occurrence of drought-prone areas in the Tanahun district, and is identified using RS and GIS technology and drought risk areas were to be delineated by the integration of satellite imagery and meteorological data information. The seasonal pattern of rainfall and NDVI suggest that the southern part and central part of the Tanahun district is a low rainfall area, where SPI value is low and the corresponding NDVI value is also low. MSI at that area suggest the area is either low stressed or moderately stressed.

4.2 Recommendation

Based on the findings of the study, the following recommendations are suggested:
1. Prioritization and implementation of site-specific adaptation should be made based on such identification of risk levels of specific locations.
2. Since the agricultural drought severity levels vary spatially, selection of agricultural technologies and information should be made to fit into the agricultural drought severity levels.

REFERENCES

1. Chopra, P. (2006). Drought risk assessment using remote sensing and GIS: A case study of Gujarat. Msc. Thesis, ITC, Enshede.
2. D.A.Wilhite (2000). "Drought Preparedness and Response in the Context of Sub-Saharan Africa." Journal of Contingencies and Crisis Management Vol. 8(No. 2): pp.81-92(12).
3. Das, S.et.al. 2013. Geospatial Assessment of Agricultural Drought (A Case Study of Bankura District, West Bengal).IJSAR Journal[Online] 3. Available at: https://www.researchgate.net/publication/235970565 [Accessed: 6 July 2018].
4. Farrar, T. J., S. E. Nicholson, et al. (1994). "The influence of soil type on the relationships between NDVI, rainfall and soil moisture in semiarid Botswana:II.NDVI response to soil." Remote Sensing of Environment Vol.50: pp.121-133.
5. Gonfa, L. (1996). Climate classification of Ethiopia. In: Meteorological Research Report Series No.3. Addis Ababa, pp.1-8.
6. H.P.Das (2000). Monitoring the Incidence of Large-scale Droughts in India. Drought: A Global Assessment. W. D.A., Routledge. Vol.1: pp.181-195.
7. Hayes, M.J., Wilhelmi, O.V., and Knutson, C.L. 2004. Reducing drought risk: bridging theory and practice.
8. J.Hayes, M. (1999). Drought Indices. 2005.
9. J.V.Vogt, S.Niemeyer, et al. (2000). Drought Monitoring from Space. Drought and Drought Mitigation in Europe. J. V. V. A. F.Somma, Kluwer Academic Publishers: pp.167-183.
10. K.Prathumchai, K. Honda, et al. (2001). Drought Risk Evaluation using Remote Sensing and GIS: A case study in Lop Buri Province. 22nd Asian Conference on Remote Sensing.
11. Karabulut, M. (2003). "An Examination of Relationships Between Vegetation and Rainfall Using Maximum Value Composite AVHRR-NDVI Data." Turk J Bot: pp.93101.
12. Kassa, A. (1999). Drought Risk Monitoring for the Sudan Using NDVI 1982-1993. Geographic Information Systems, University College London: pp.2-41.
13. Kee, T. B. M., N. J. Doeskenan, et al. (1995). Drought monitoring with multiple time scales. Proceedings of the Ninth Conference on Applied Climatology, Amer. Meteor. Soc., Boston.
14. Kogan, F. N. (1990). "Remote sensing of weather impacts on vegetation in nonhomogeneous areas." International Journal of Remote Sensing Vol.11: pp.1405–1421.
15. Kogan, F.N. 2000. Contribution of remote sensing to drought early warning.
16. Martini, M., Soumare, P.B., Ndione, J. and Toure, A. (2004). Crops and range land monitoring in Senegal using SPOT 4/5 vegetation data. In: Proceeding of the 2nd vegetation user conference, PP.239-245, (F. Veroustraete, E. Bartholome and W.W Verstraeten, Eds), Office for Official Publications of the European Communities.

17. McKee, T. B., N. J. Doesken, J. Kliest, 1993: The relationship of drought frequency and duration to time scales.
18. Murali, K., Ravikumar, G. and Krishnaveni, M. (2008). Remote sensing based agricultural drought assessment in Palar basin of Tamil Nadu State, India. Journal of the Indian Society of Remote Sensing, 37:9-20.
19. P.G.Gore and A.S.Ponkshe (2004). "Drought in Gujarat Districts and Sate as Key Indicators to All India Drought." Journal of Agrometeorology Vol.6 (No.1): pp.47-54.
20. Quiring, S.M. and Papakryiakou, T.N. (2003). An evaluation of agricultural drought indices for the Canadian prairies. Agricultural and forest Meteorology, 118:49-62.
21. Rouse, J.W., Haas, R.H., Deering, D.W., and Sehell, J.A. 1974. Monitoring the vernal advancement and retrogradation (Green wave effect) of natural vegetation.
22. Sigdel, M. and Ikeda, M. 2010. Spatial and temporal Analysis of Drought in Nepal using Standardized Precipitation Index and its Relationship with Climate Change. Journal of Hydrology and Meteorology .7th ed.
23. Thenkabail P.S., Gamage M.S. D.N., Smakhtin, V.U. (2004). The Use of Remote Sensing data for drought assessment and monitoring in south west Asia. Colombo, Sri Lanka, International Water Management Institute: pp. 1-23.
24. Wilhite, D.A. 1993. The enigma of drought. Drought Assessment, Management, and Planning: Theory and Case Studies.

BIOGRAPHICAL NOTES

We had completed Bachelors' Degree in Geomatics Engineering from Western Region Campus, Tribhuvan University, Nepal. This research was undertaken during our final year undergraduate program. Also we are the member of Geomatics Engineering Students' Association of Nepal (GESAN) and Youthmappers. And currently we are doing research, and just started surveyors' profession side by side.

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APPENDIX A

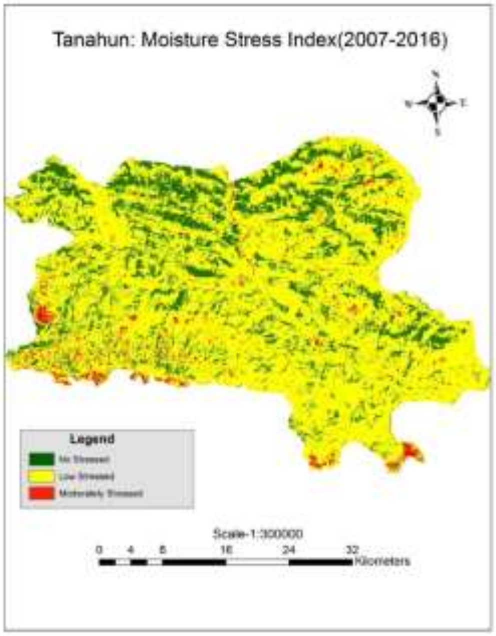


Figure 5: Reclassified MSI (2007-2016)

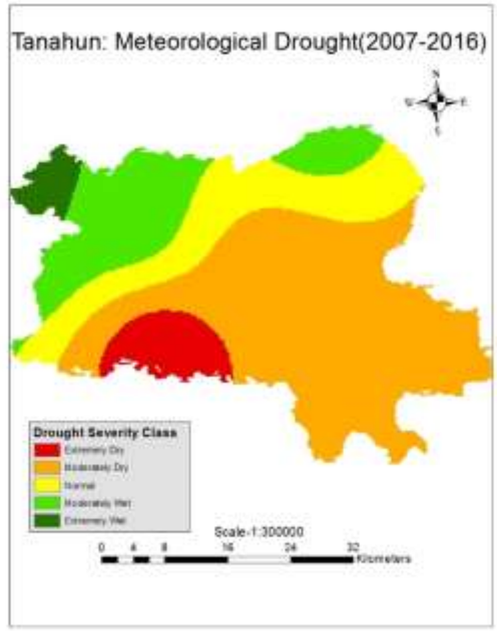


Figure 6: Meteorological Drought (2007-2016)

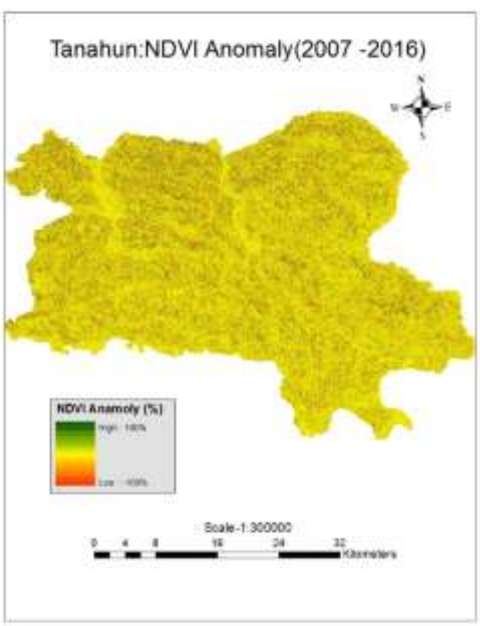


Figure 7: Reclassified NDVI Anomaly (2007-2016)

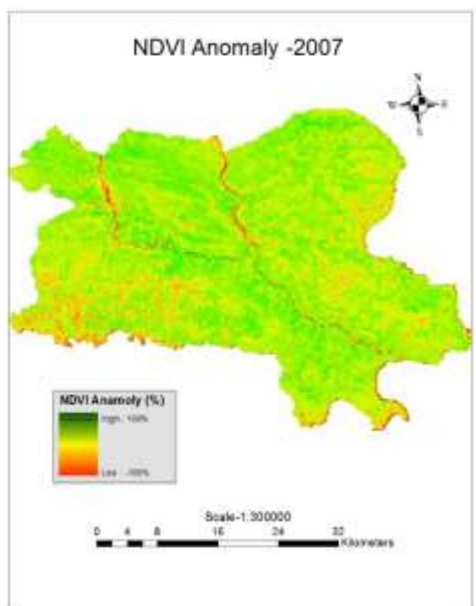


Figure 8: NDVI Anomaly 2007

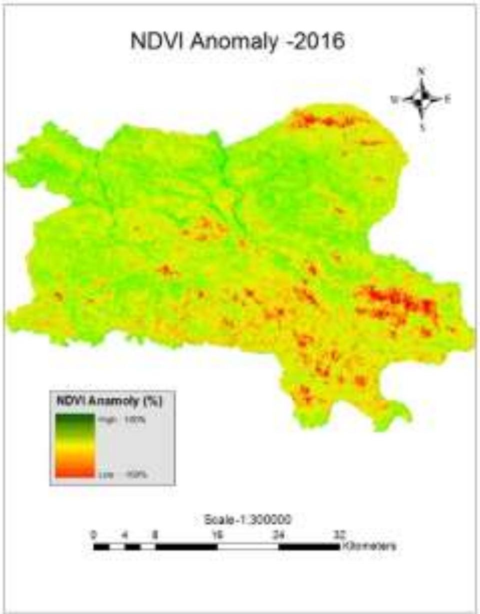
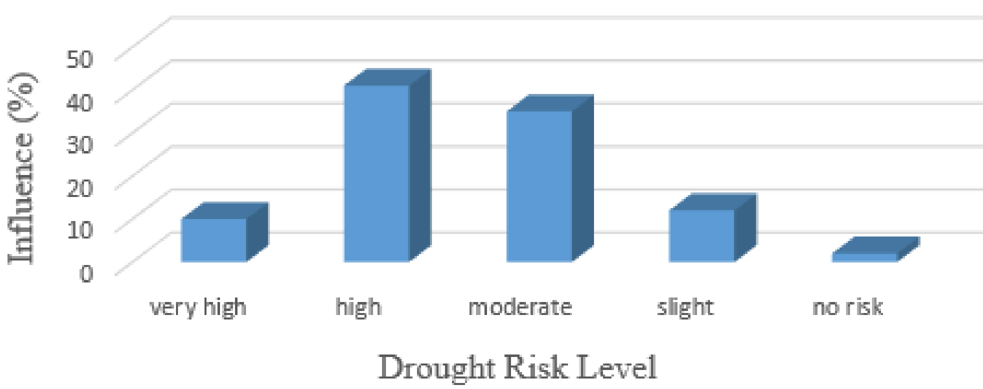


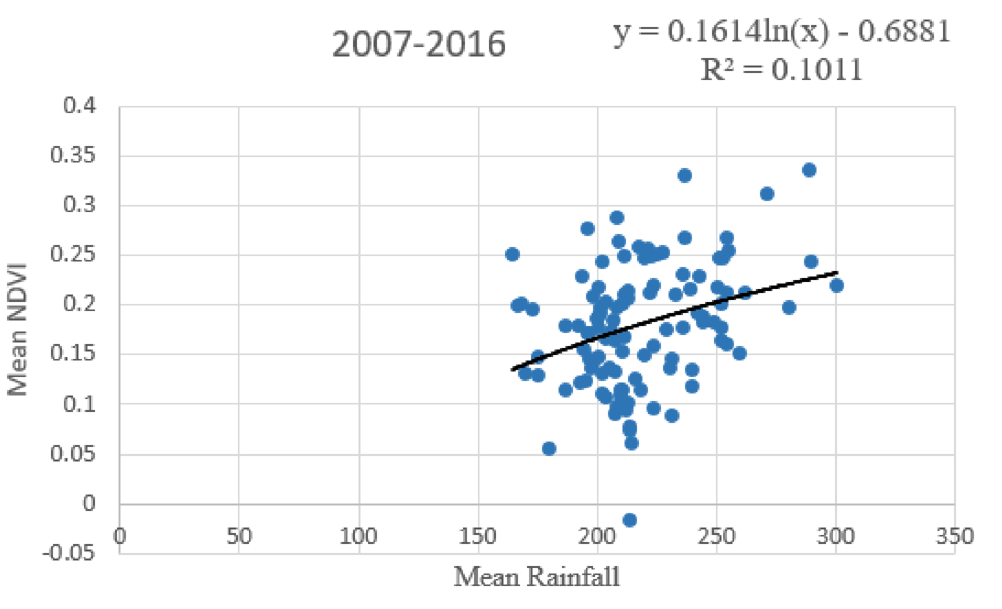
Figure 9: NDVI Anomaly (2016)

Figure 10: Meteorological Stations

APPENDIX B



Graph 1: Drought Risk Level



Graph 2: Correlation between Mean NDVI and Mean Rainfall