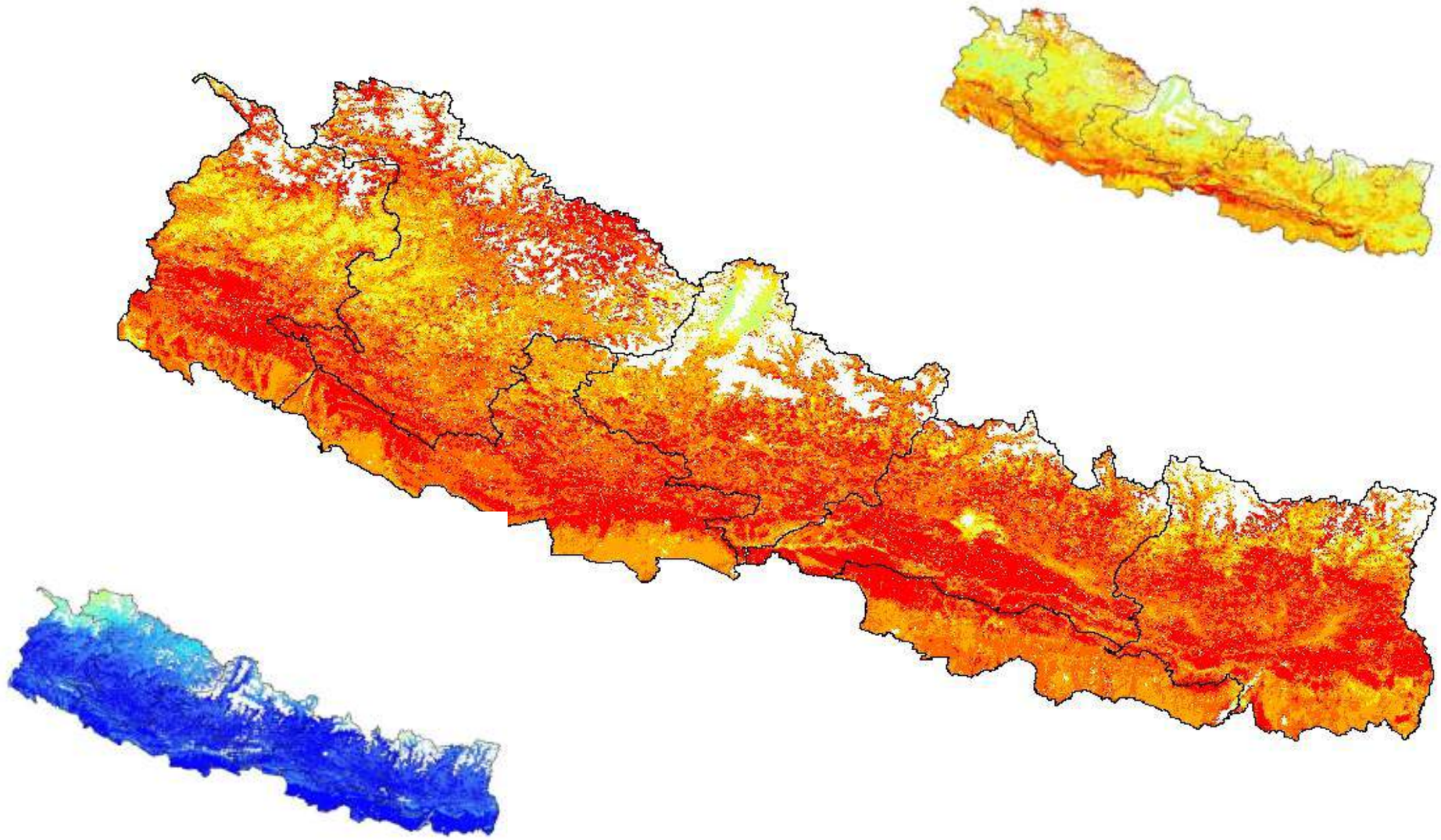
THE DROUGHT ATLAS OF NEPAL

Dr. Hemu Kharel Kafle



The Drought Atlas of Nepal

Dr. Hemu Kharel Kafle

Center for Water and Atmospheric Research

Kathmandu Institute of Applied Sciences

RESEARCH • INNOVATE • DISCOVER • OUTREACH

The Drought Atlas of Nepal

(Historical monthly drought of Nepal from 2000-2020)

Dr. Hemu Kharel Kafle

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Acknowledgement

The Center for Water and Atmospheric Research (CENWAR) at Kathmandu Institute of Applied Sciences has produced the first edition of the Nepal Drought Atlas. This Atlas uses a Drought Severity Index (DSI) to highlight the intensity of drought. Descriptive graphs and visuals are used to highlight the drivers and effects of drought in Nepal.

We would like to thank our collaborators Prof. Dr. Dibas Shrestha from Central Department of Hydrology and Meteorology, Tribhuvan University, Kathmandu, Nepal; Devesh Koirala from Nepal Academy of Science and Technology, Khumaltar, Lalitpur, Nepal and Er. Dipak Gyawali from Nepal Water Conservation Foundation, Kathmandu, Nepal for their valuable inputs.

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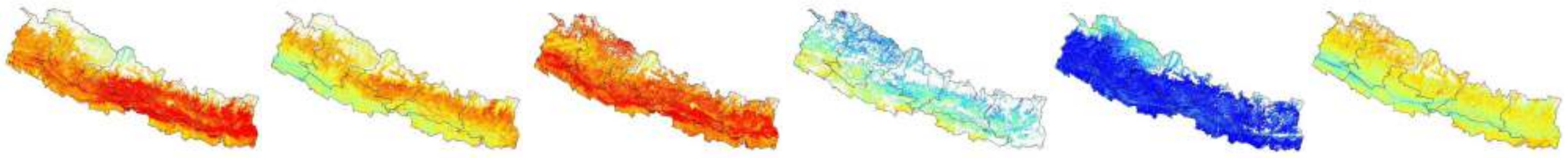
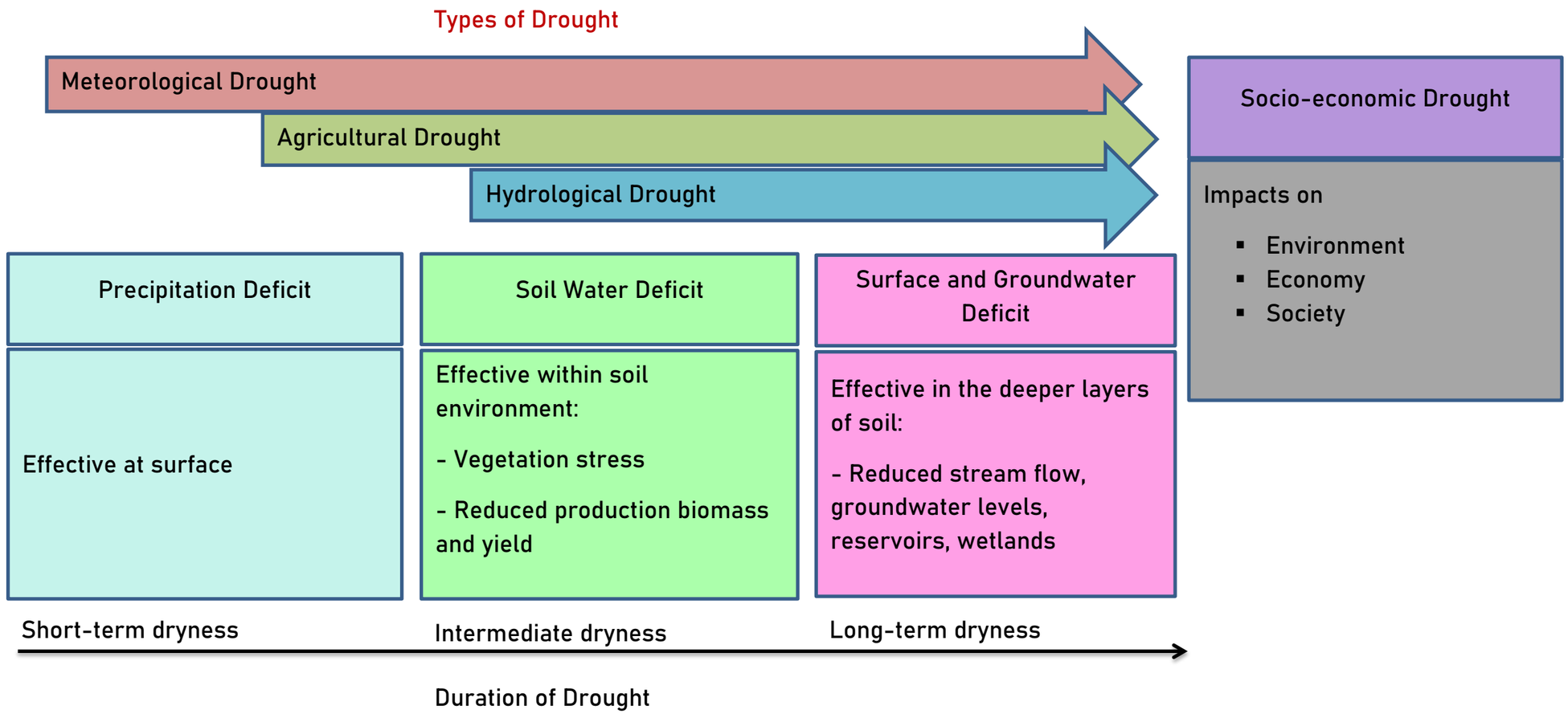


What is Drought?

Drought is a period of time when there is a lack of water on land. Drought mainly results from abnormally low rainfall leading to water scarcity (Wilhite, 2000b). It is defined as “severe water shortage”.

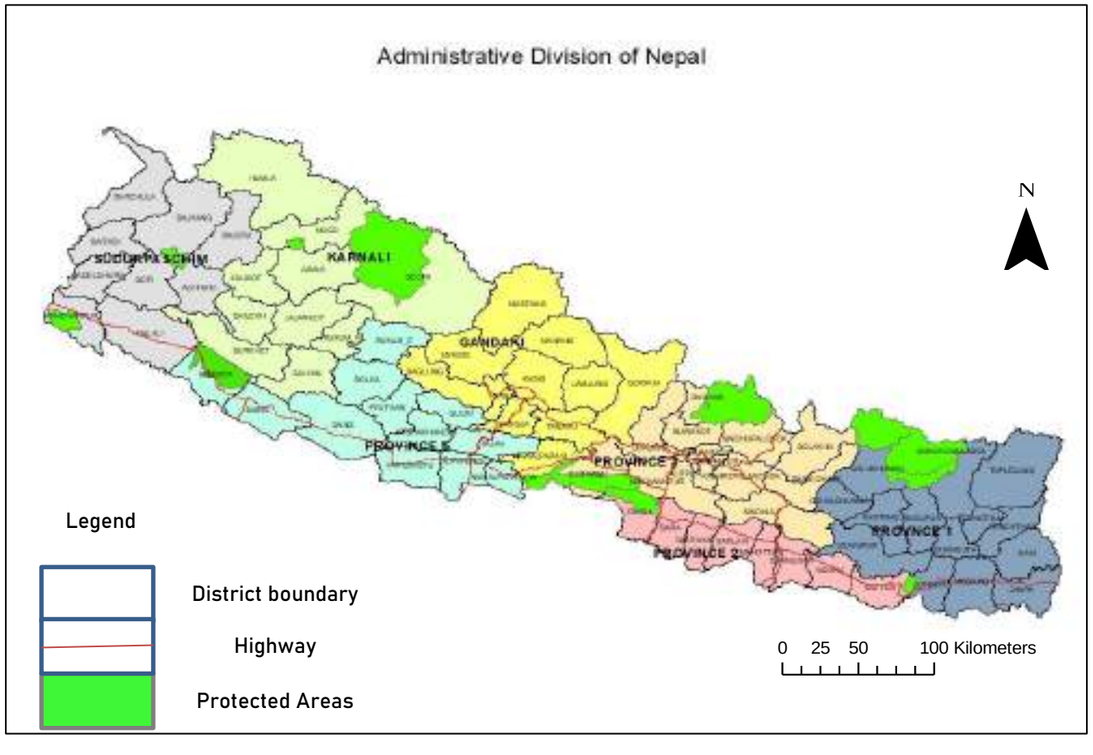
Drought is a complicated phenomenon, yet one of the least understood of all natural hazards impacting more people than any other disaster (Obasi, 1994). Since the demand for water is increasing along with the population in many parts of the world, water supply interruptions caused by drought can be expected to produce greater impacts (Hewitt, 1997).

Drought is a global phenomenon; however, their effects are more vulnerable in developing countries because of the lesser potential to mitigate the impacts of such extreme events (Wilhite, 2000).

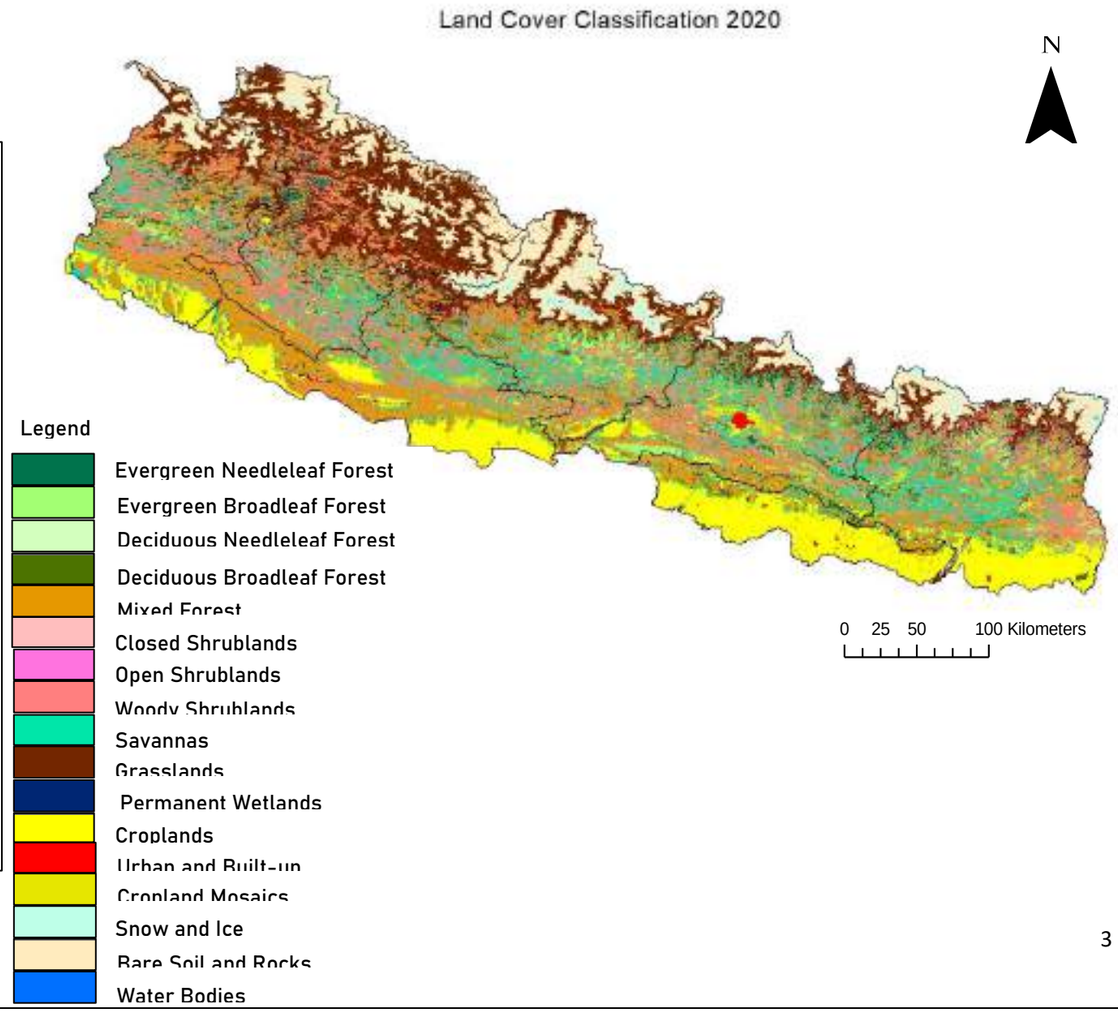


Nepal Overview

Nepal (26°22′ to 30°27′N in latitude and 80°04′ to 88°12′E in longitude) lies in the South Asian region with an area of 147,181 km^2. The elevation ranges from approx. 60m above mean sea level in the southern plain (Terai) to the northeast 8848m in the Mount Everest About the geographical division, 86% of the total area is comprised of hilly and mountainous regions and the remaining 14% as terai (flatlands) (Shakya et al., 2007). Nepal has a diverse range of climatic conditions (from subtropical to alpine/arctic, in a period ofless than 200 kilometers) due to rapid changes in altitude and a spect along the latitude. Monsoon (June to September), post-monsoon (October to November), winter (December to February), and pre-monsoon (March to May) are the four seasons based on the occurrence of monsoon rains in the temporal distribution of precipitation (NHMRCC, 2015).



The forest covers 6.5 million hectares, i.e. 44.47% of Nepal's total land area. Other land and cropland account for 28.68% and 21.88% of the total area, respectively. Settlement (1.15%), Wetland (1.22%), and Grassland (2.60%) cover the remaining territory (MoFE Nepal, 2019). The land cover type data were derived from MCD12Q1 data (collection v005, 500m) of Terra and Aqua combined MODIS for the years 2000-2020 obtained from Earth Data (Earth data Search (https://earthdata.nasa.gov). According to the International Geosphere-Biosphere Programme (IGBP), the landcover was classified into 17 categories (International Geosphere Biosphere Programme, 2017).



Remotely Sensed Data

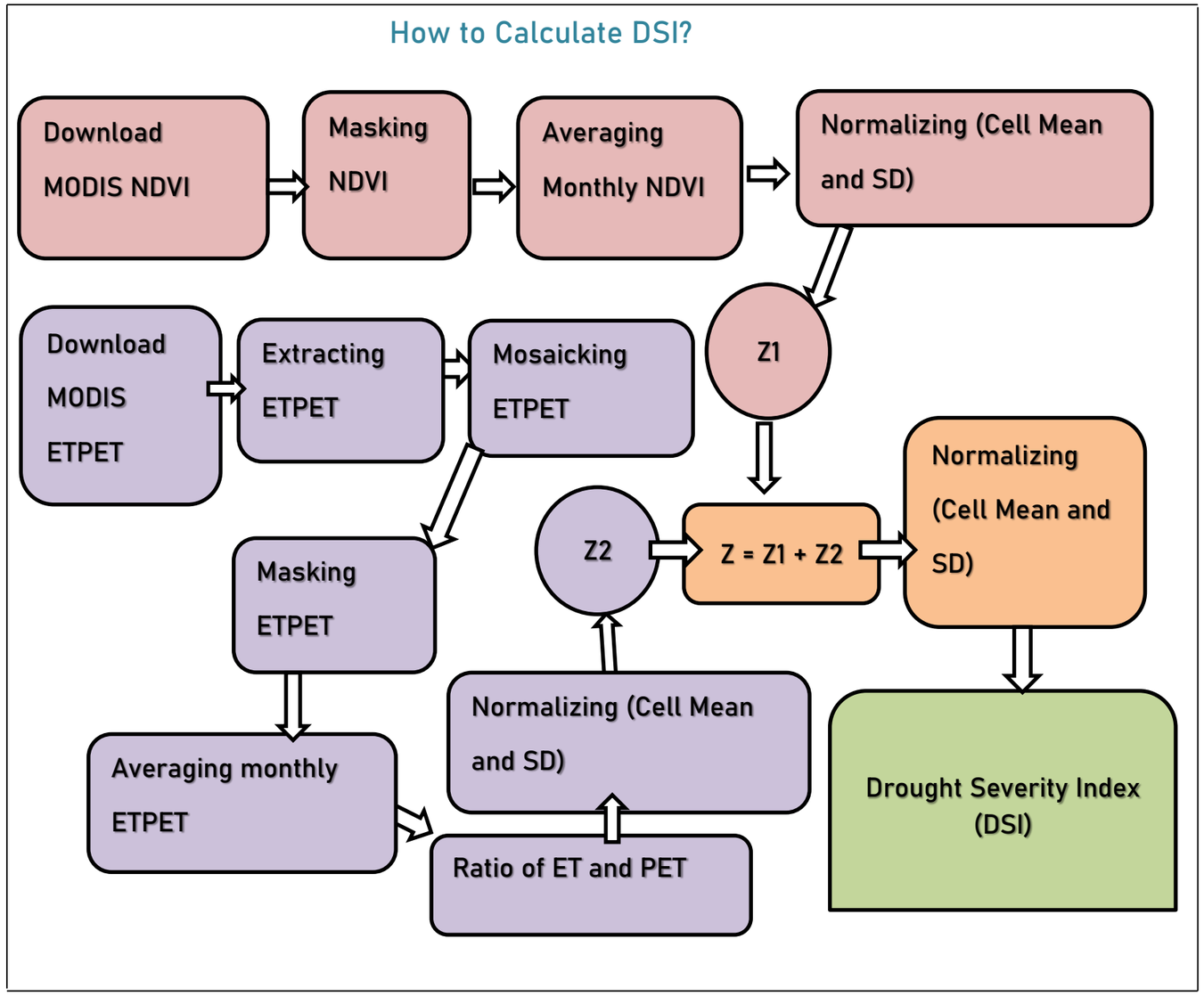
The Moderate-Resolution Imaging Spectrometer (MODIS) is an advanced narrowband-width sensor from which NASA and the USGS allow free composited reflectance data available every eight days via the Earth Resources Observation Systems (EROS) data center (Justice and Townshend, 2002a). MODIS products of Land cover, NDVI and ET/PET have been used for this study.

MODIS NDVI Data

This data includes MOD13A1 (MODIS/Terra Vegetation Indices 16-Day L3 Global 500m SIN Grid) NDVI products at 500m spatial resolution for twenty one years (2000-2020). Global MOD13A1 data are provided every 16 days at 500-meter spatial resolution as a gridded level-3 product in the Sinusoidal projection i.,e obtained from NASA Land Processes Distributed Active Archive Center (LP DAAC, https://lpdaac.usgs.gov/).

MODIS ET, PET

This data set includes 8-day MOD16A2 Gap-Filled ET/PET (MODIS/Terra Net Evapotranspiration Gap-Filled 8-Day L4 Global 500m SIN Grid V006). The MOD16A2GF Version 6 product is a year-end gap-filled 8-day composite dataset produced at 500 meter (m) pixel resolution. The ET/PET datasets are obtained from Earth Data (https://earthdata.nasa.gov/).



Drought Severity Index (DSI)

DSI was chosen to investigate the spatiotemporal variability of droughts across the country using observed satellite products from 2000 to 2020. This newly proposed remote sensing index by Mu et al., 2013 has performed well in many parts of the world. According to Mu et al. (2013), the DSI Index, which combines the NDVI and ET/PET, is calculated as shown in equations (1) to (4). The incorporation of both transpiration and vegetation indicator data in DSI has been regarded as an improvement over other drought index. To study drought in Nepal, monthly DSI values were calculated over a twenty one year period (2000–2020). Following are the equation systems that were used:

$$Z_{Ratio} = \frac{ET/PET - \overline{ET/PET}}{\sigma_{ET/PET}} \quad (1)$$

$$Z_{NDVI} = \frac{NDVI - \overline{NDVI}}{\sigma_{NDVI}} \quad (2)$$

$$Z = Z_{Ratio} + Z_{NDVI} \quad (3)$$

$$DSI = \frac{Z - \bar{Z}}{\sigma_Z} \quad (4)$$

Where Z_{Ratio} and Z_{NDVI} is the standardized value of ET/PET ratio and NDVI respectively. $\overline{ET/PET}$ and $\overline{NDVI}$ is mean. σ_{Ratio} and σ_{NDVI} is the standard deviation of ET/PET ratio and NDVI respectively. $\bar{Z}$ and σ_Z represents the mean and standard deviation of the sum of Z_{Ratio} and Z_{NDVI} respectively. Drought Severity Index is represented by the DSI calculated in equation (4). Positive DSI value indicates wet condition, while negative values indicate dry conditions, Mu et al. (2013) classified DSI, as shown in table.

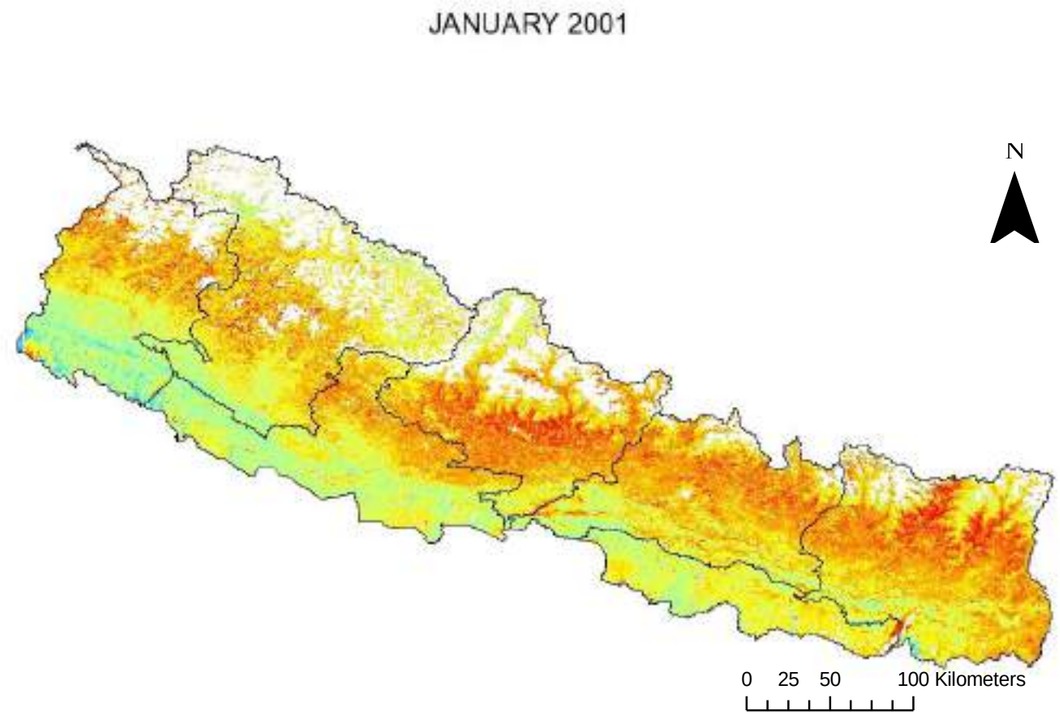
The generate DSI is then imported to ArcGis to export monthly DSI maps i.,e displayed in this atlas. In mean monthly DSI maps of Nepal, extreme dry condition is denoted by Red colour whereas dark blue colour denotes extreme wet condition.

Category	DSI Values	Colour
Extreme Drought	-1.5 or less	
Severe Drought	-1.2 to -1.49	
Moderate Drought	-0.9 to -1.19	
Mild Drought	-0.6 to -0.89	
Incipient Drought	-0.3 to -0.59	
Near Normal	0.29 to -0.29	
Incipient Wet Spell	0.3 to 0.59	
Slightly Wet	0.6 to 0.89	
Moderately Wet	0.9 to 1.19	
Very Wet	1.2 to 1.49	
Extremely Wet	1.5 or greater	

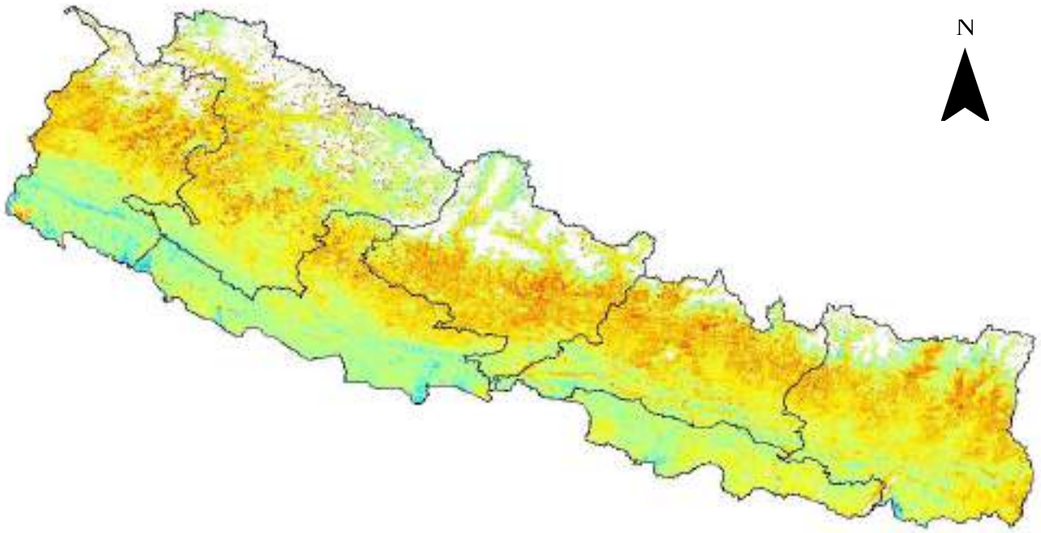
January DSI Maps

In January, drought normally ranges from mild drought to near normal condition. Incipient drought usually defined the characteristics of this winter month.

Mean January DSI Values		
Year	Values	Drought Condition
2001	-0.78	Mild Drought
2002	-0.54	Incipient Drought
2003	-0.60	Mild Drought
2004	-0.39	Incipient Drought
2005	-0.33	Incipient Drought
2006	-0.66	Mild Drought
2007	-0.67	Mild Drought
2008	-0.48	Incipient Drought
2009	-0.64	Mild Drought
2010	-0.54	Incipient Drought
2011	-0.48	Incipient Drought
2012	-0.40	Incipient Drought
2013	-0.63	Mild Drought
2014	-0.32	Incipient Drought
2015	-0.24	Near Normal
2016	-0.50	Incipient Drought
2017	-0.31	Incipient Drought
2018	-0.40	Incipient Drought
2019	-0.24	Near Normal
2020	-0.29	Near Normal



JANUARY 2002



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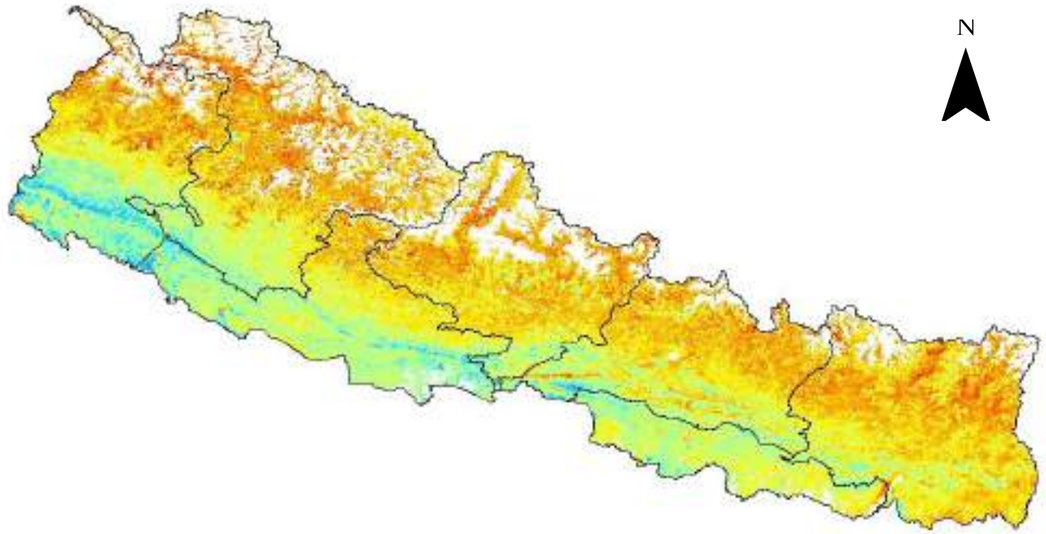

Legend

- Extreme Drought (-1.5 or less)
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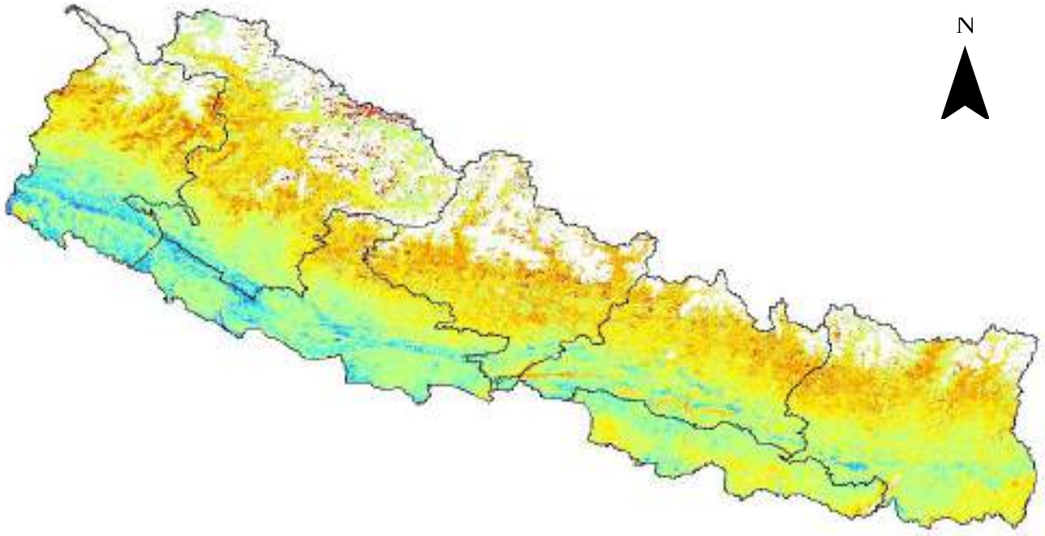
- Extremely Wet (1.5 or greater)

JANUARY 2004



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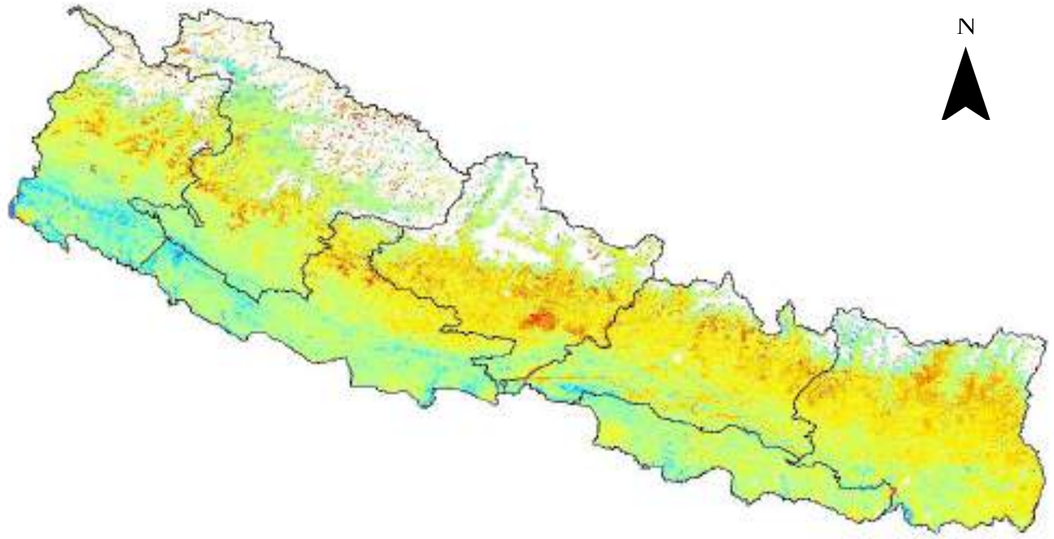

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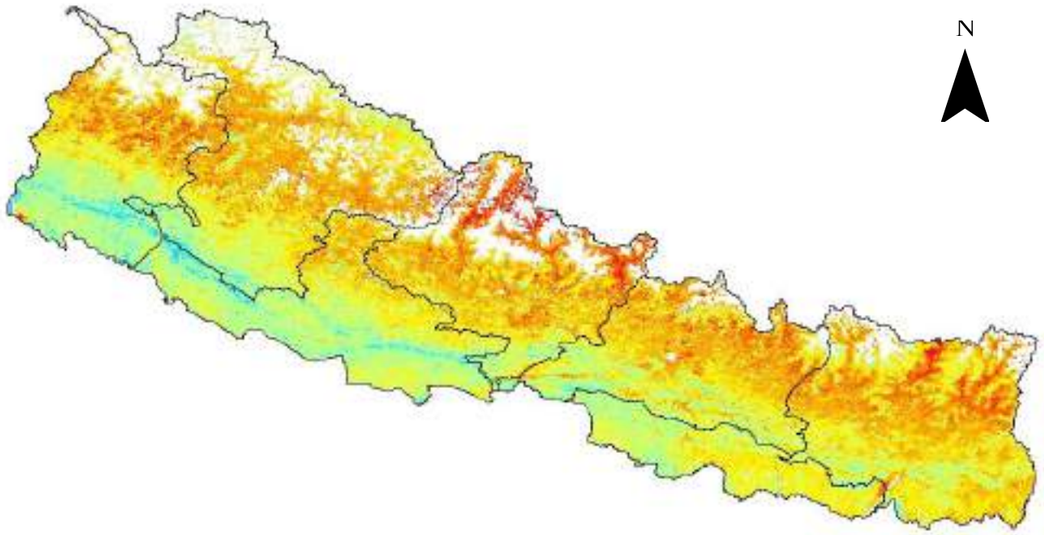

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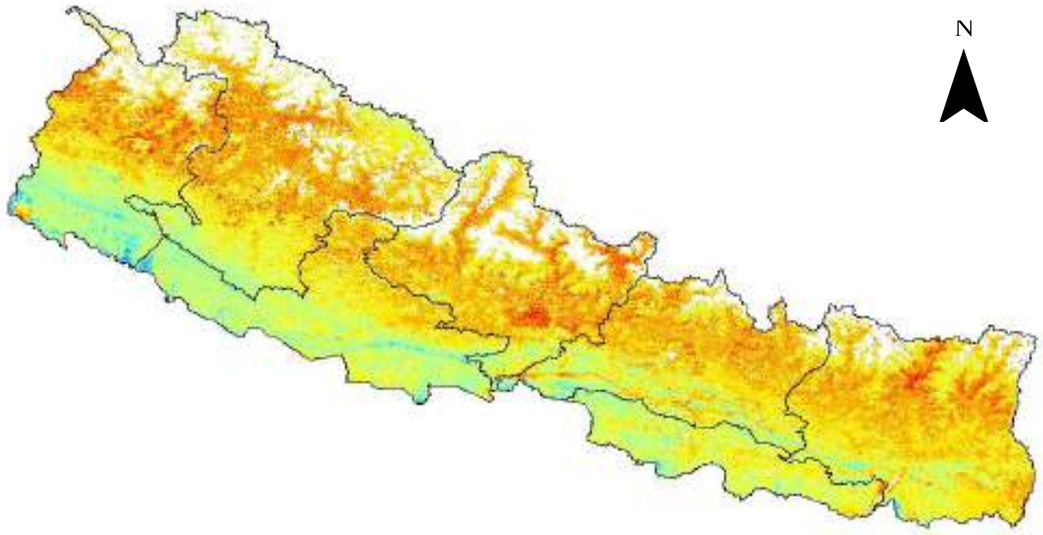

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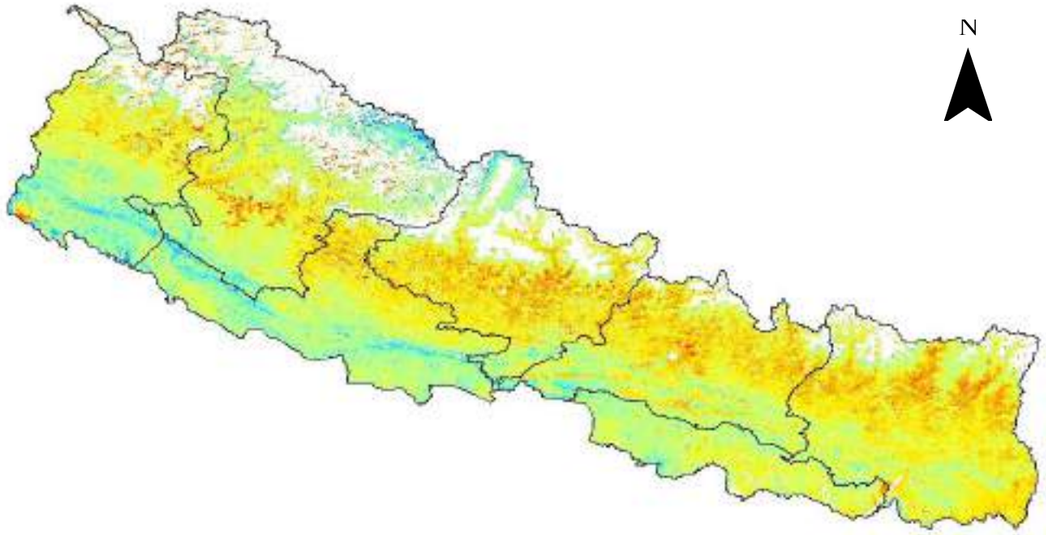
JANUARY 2008



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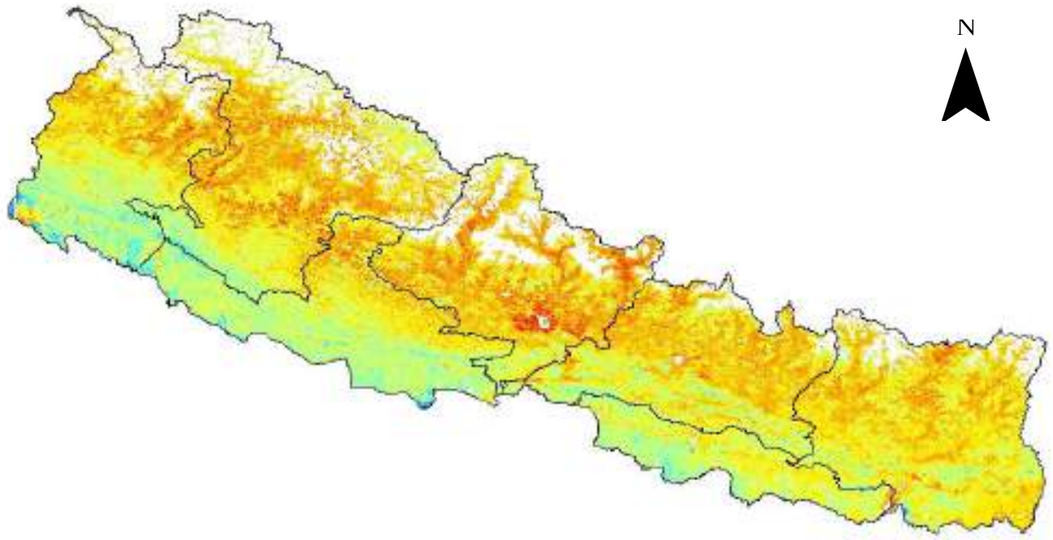

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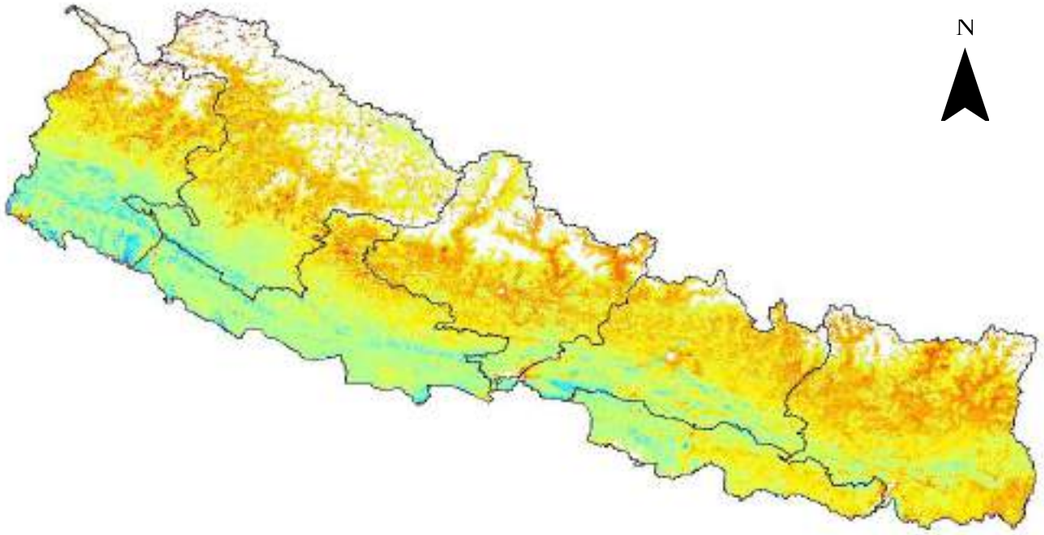

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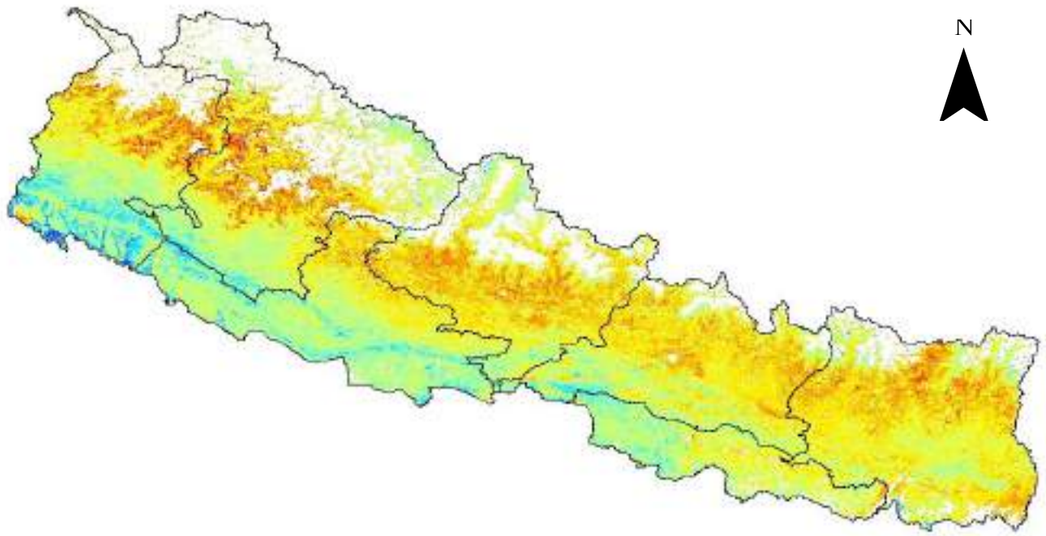

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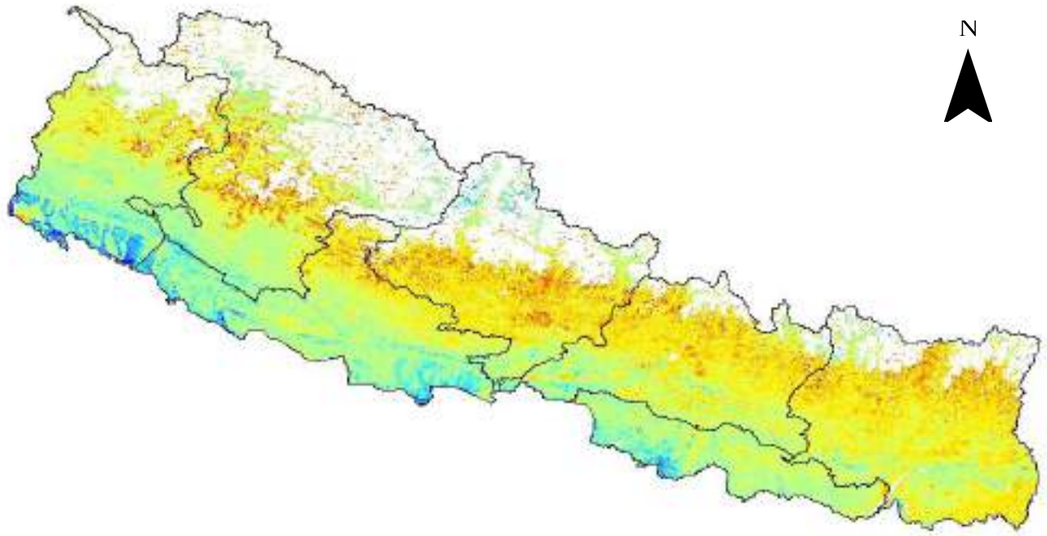

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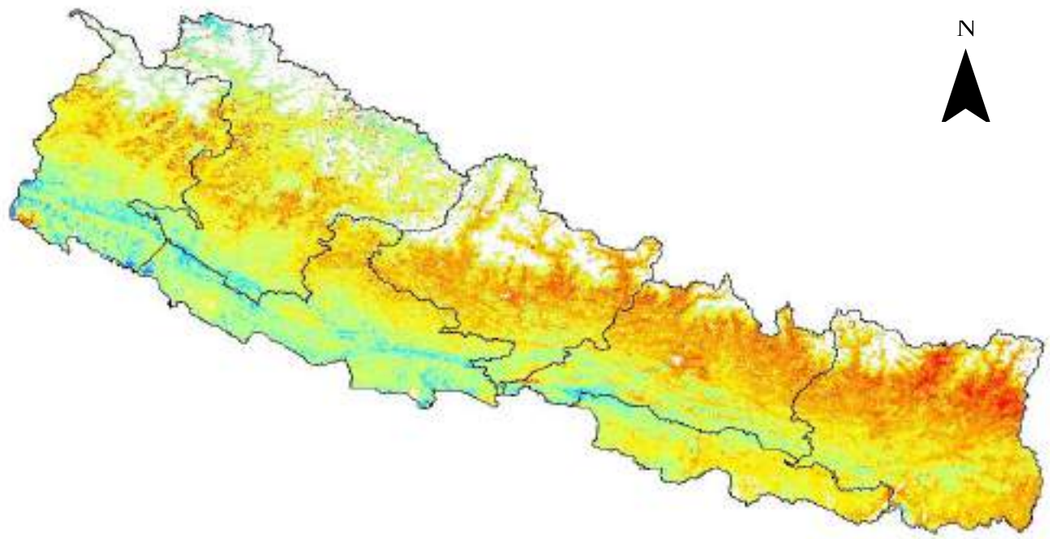

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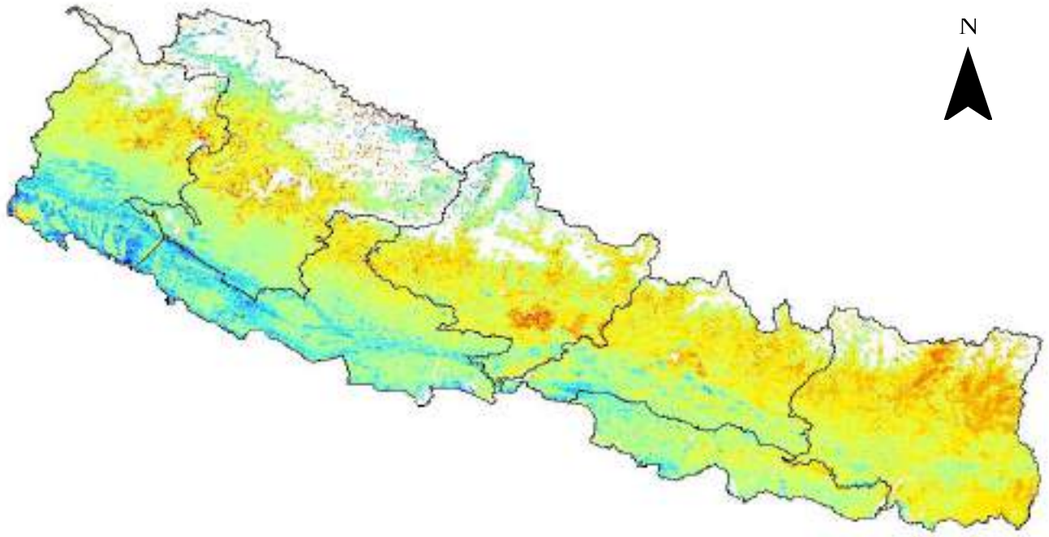

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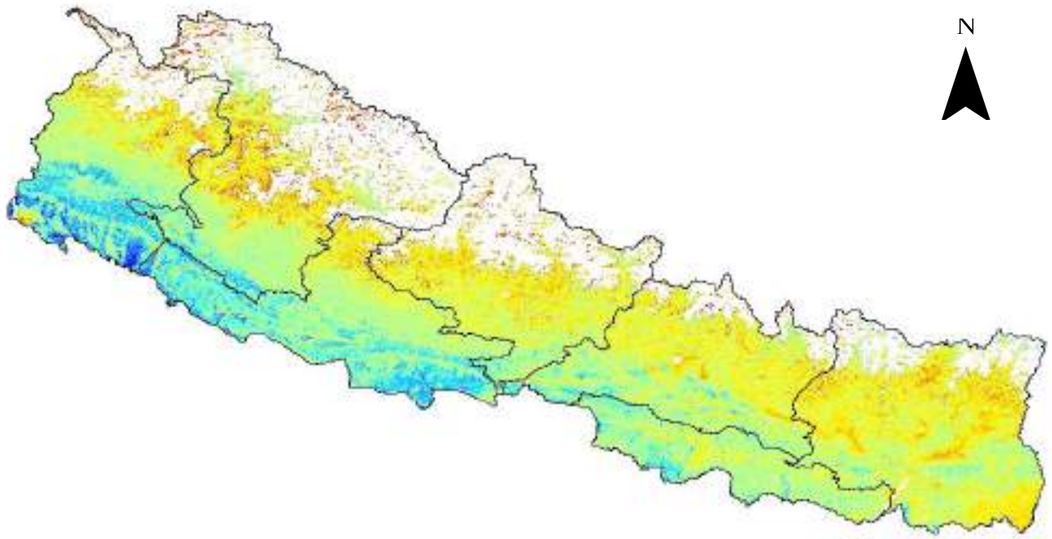

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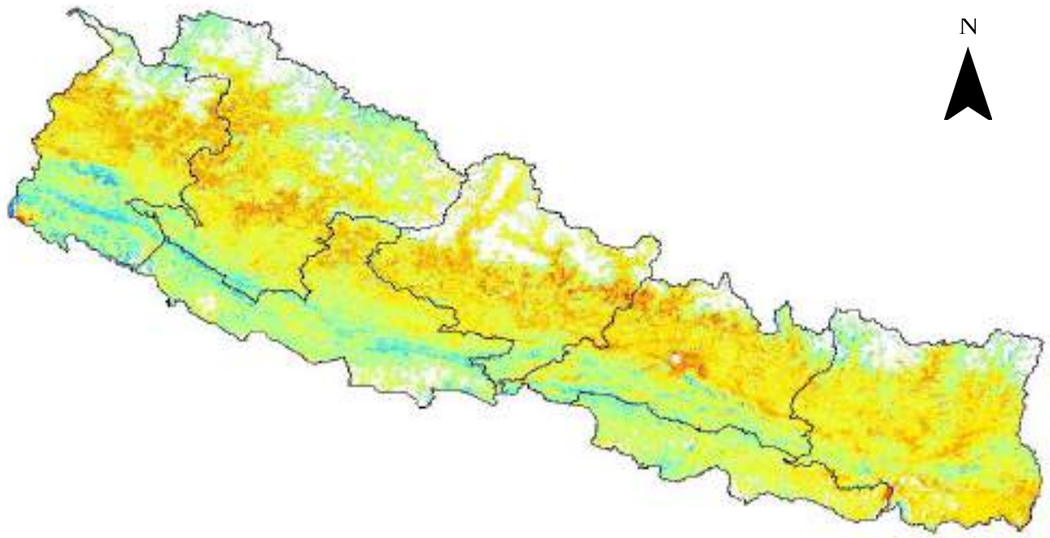
JANUARY 2016



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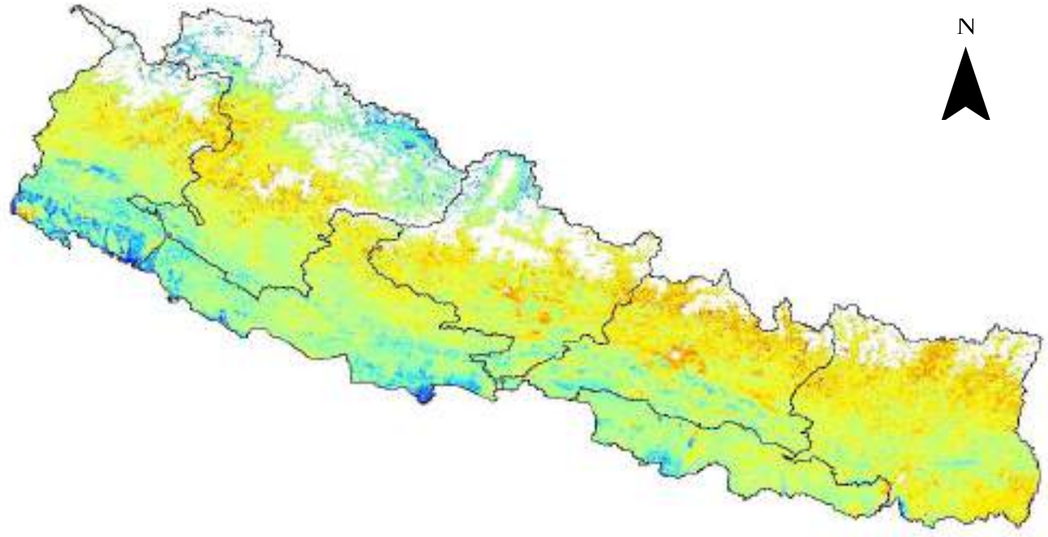

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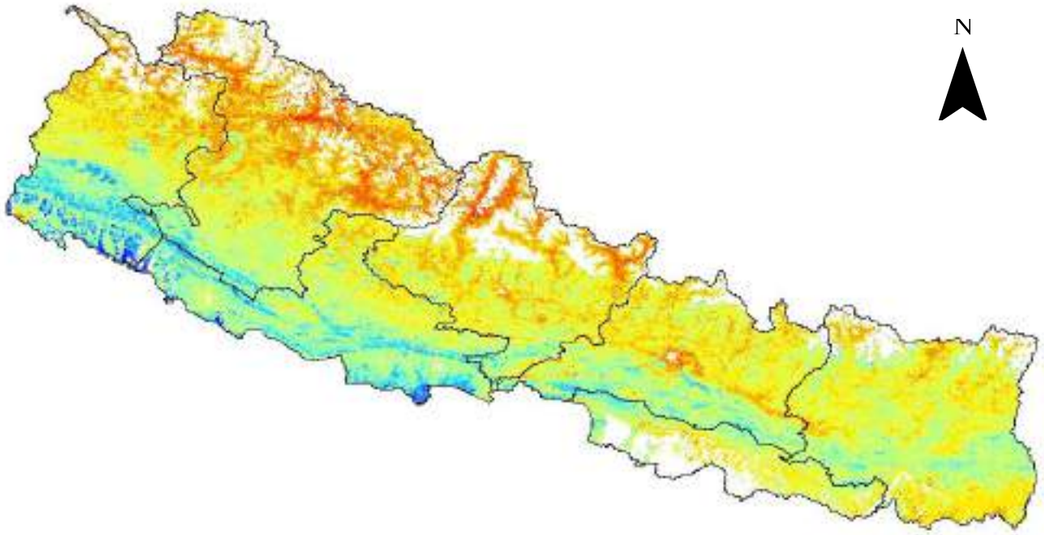
JANUARY 2018



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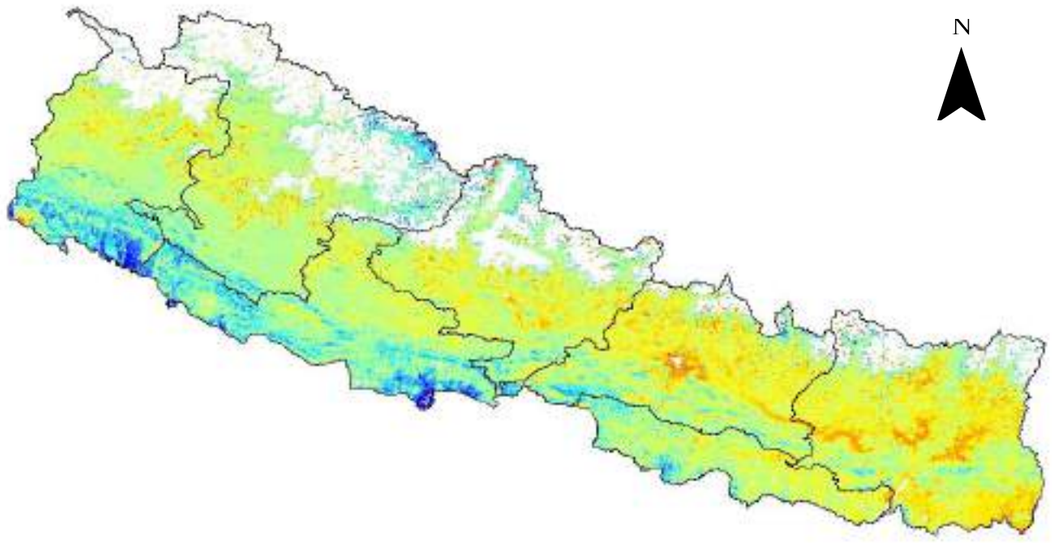

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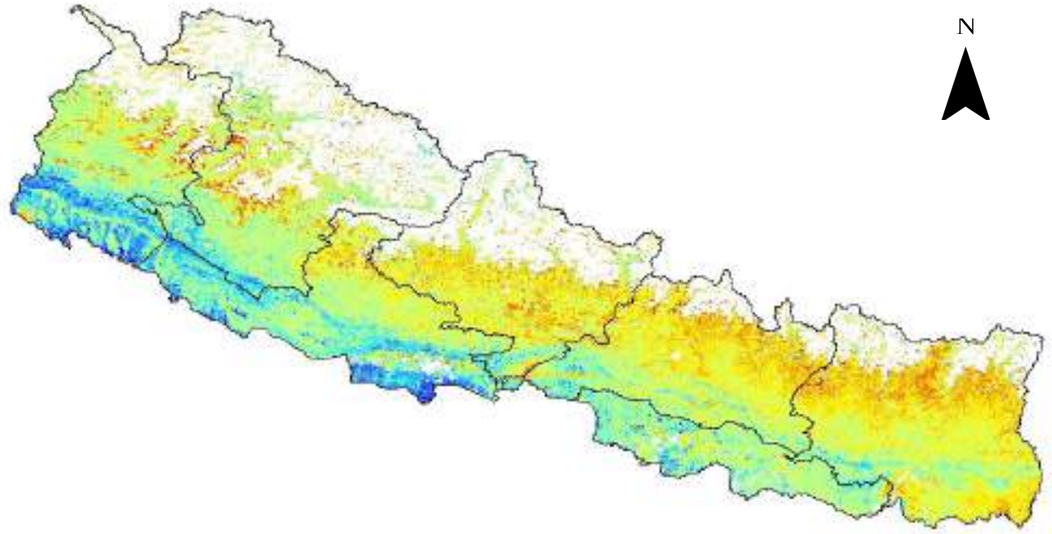
JANUARY 2020



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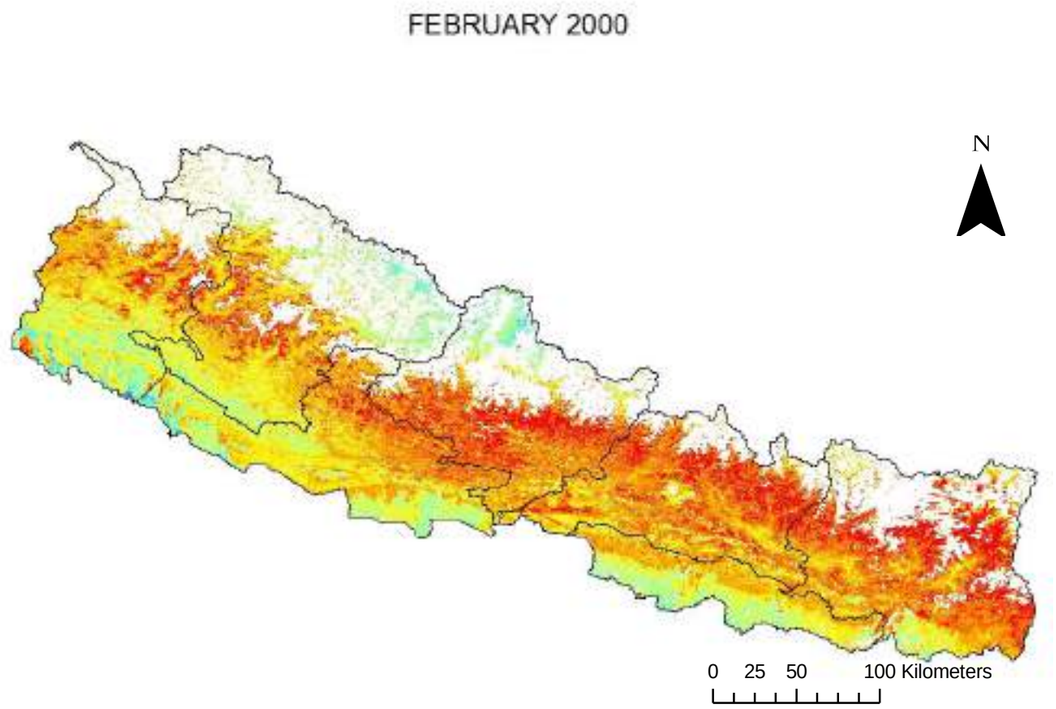
February DSI Maps

Drought condition normally ranges from moderate drought to near normal condition in February. Most of the year experienced mild and incipient drought in this winter month.

Mean February DSI Values		
Year	Values	Drought Condition
2000	-0.78	Mild Drought
2001	-0.97	Moderate Drought
2002	-0.57	Incipient Drought
2003	-0.56	Incipient Drought
2004	-0.67	Mild Drought
2005	-0.57	Incipient Drought
2006	-0.88	Mild Drought
2007	-0.36	Incipient Drought
2008	-0.66	Mild Drought
2009	-0.92	Moderate Drought
2010	-0.66	Mild Drought
2011	-0.58	Incipient Drought
2012	-0.63	Mild Drought
2013	-0.55	Incipient Drought
2014	-0.33	Incipient Drought
2015	-0.32	Incipient Drought
2016	-0.67	Mild Drought
2017	-0.62	Mild Drought
2018	-0.50	Incipient Drought
2019	-0.20	Near Normal
2020	-0.49	Incipient Drought



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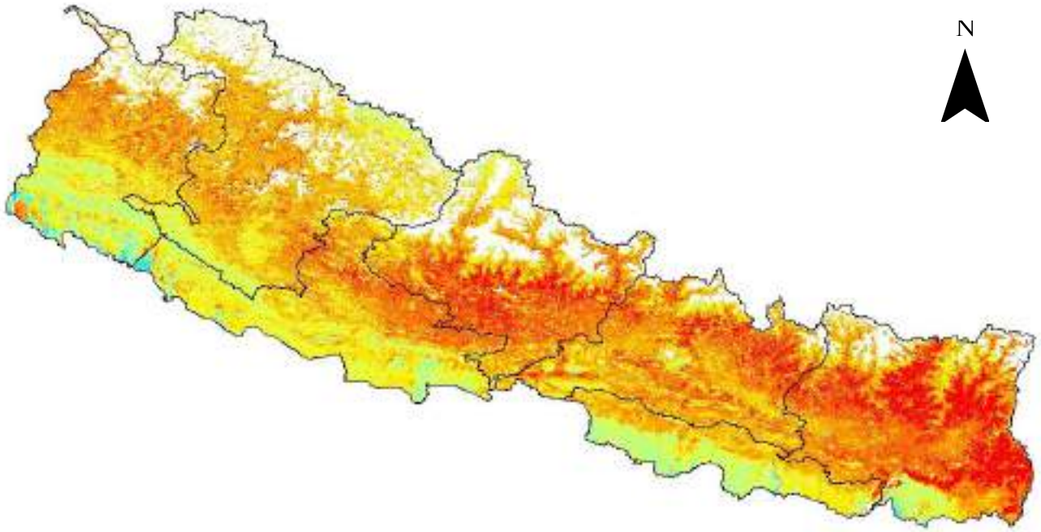

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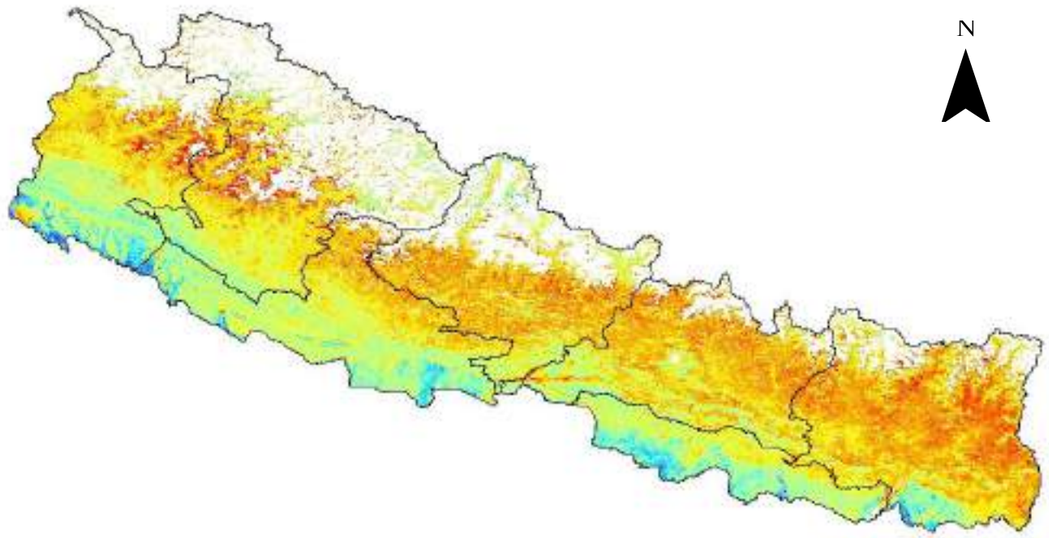

Legend

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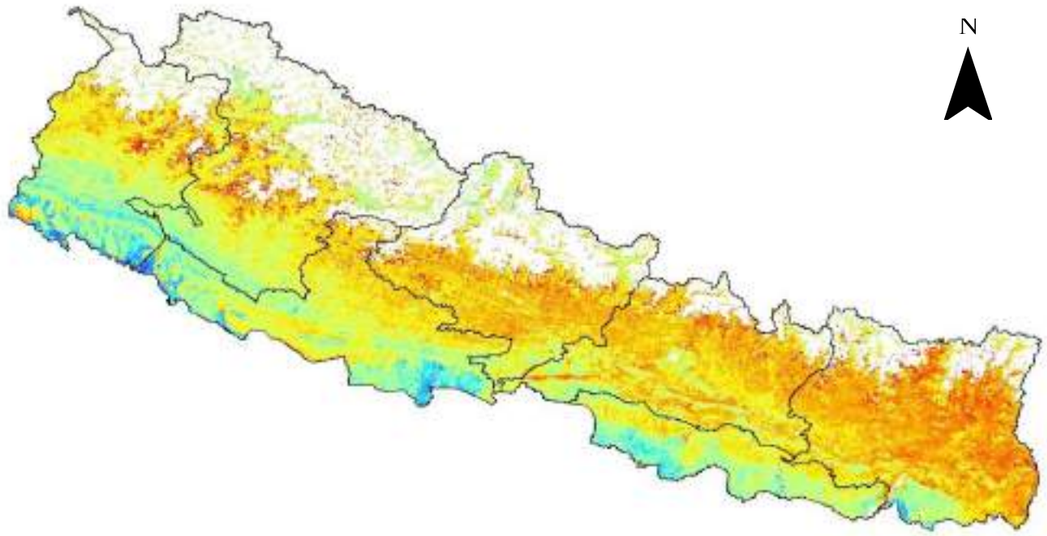

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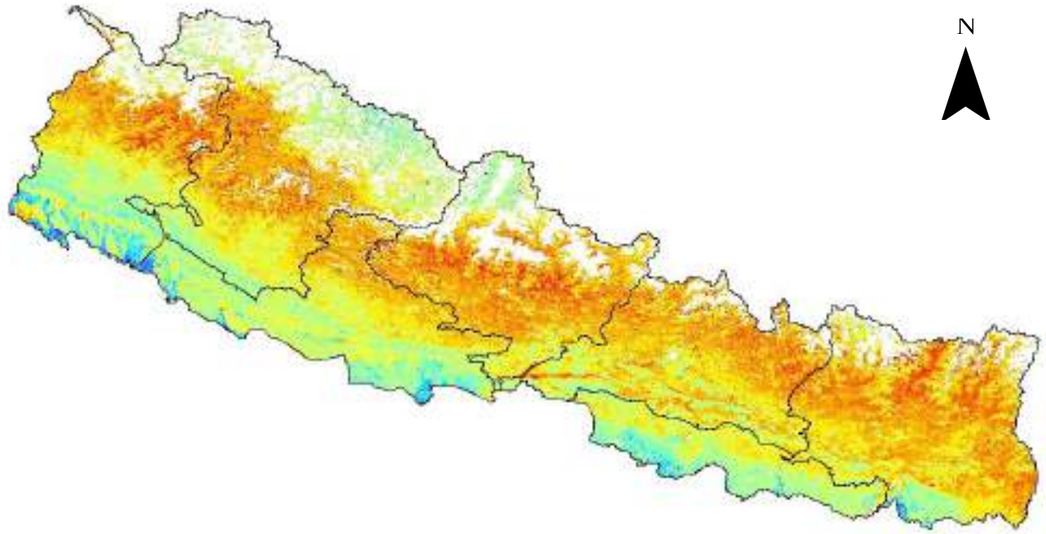

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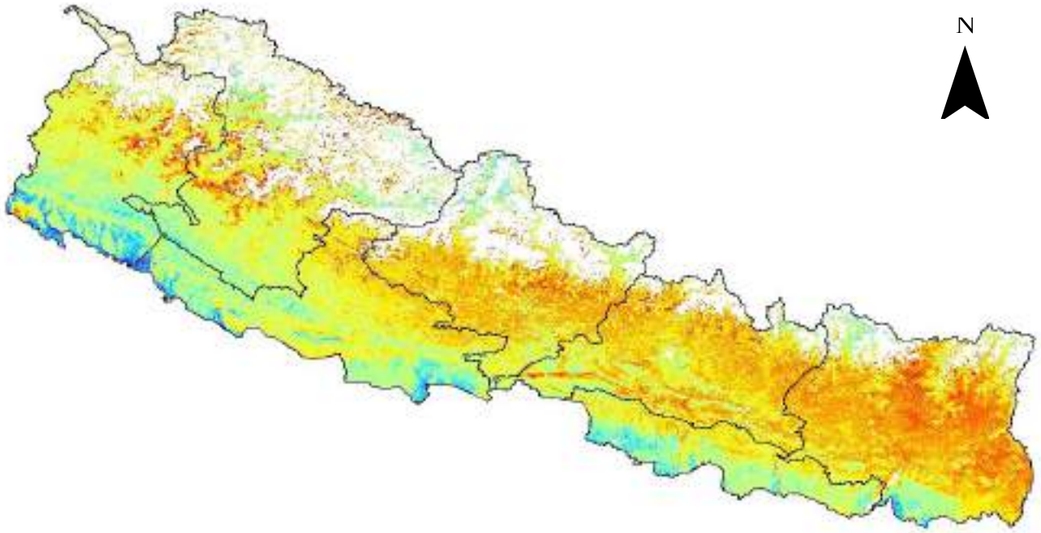

N

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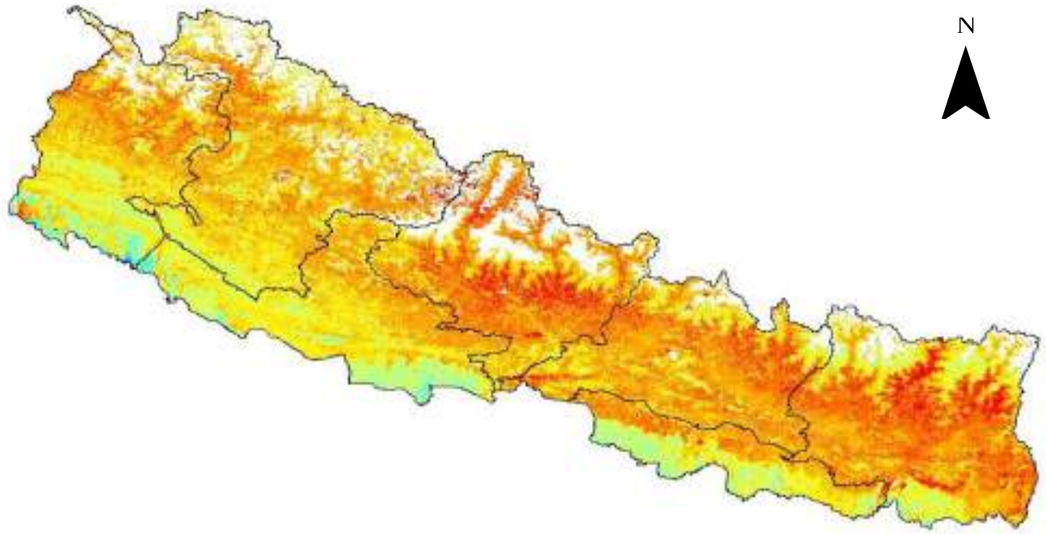
FEBRUARY 2006



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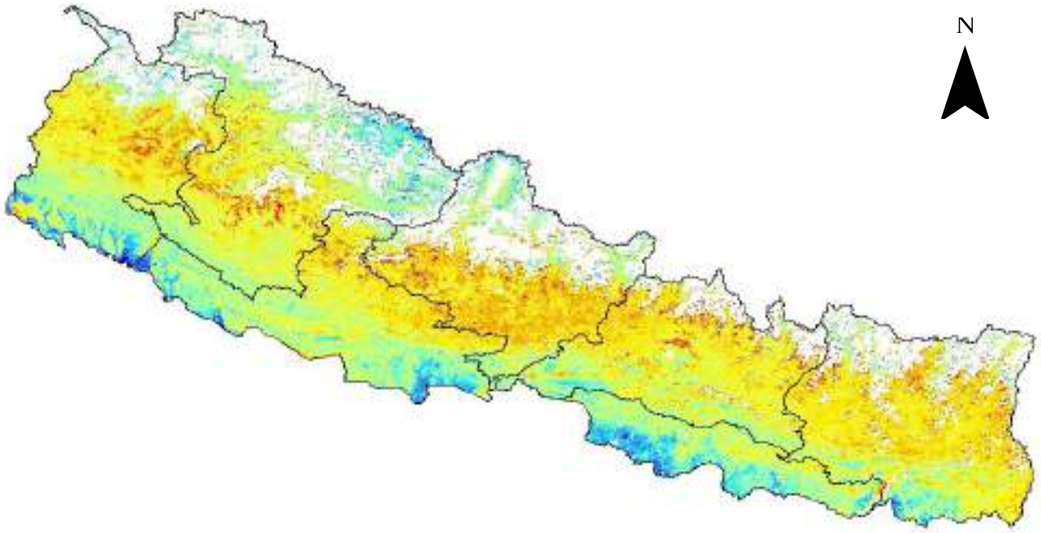

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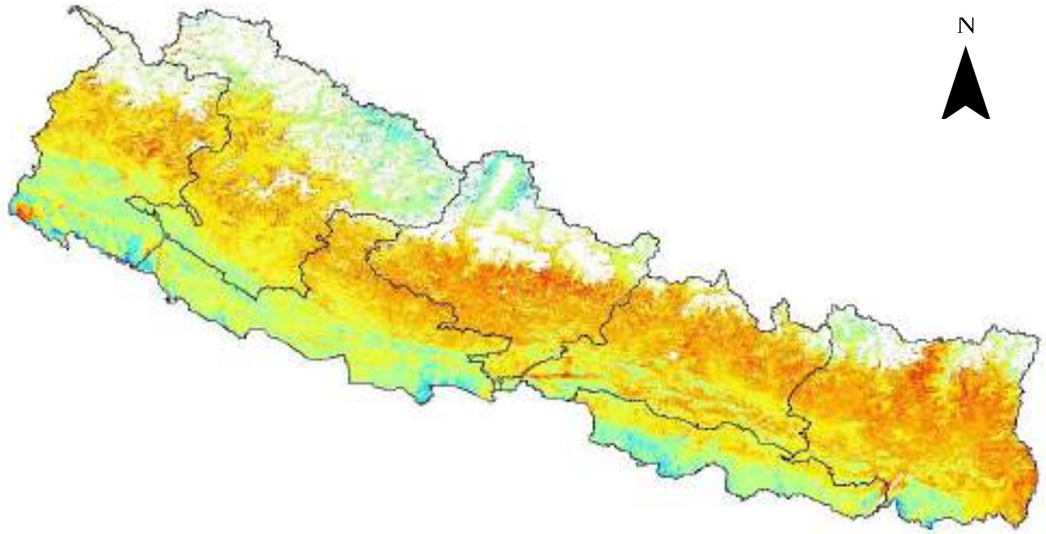

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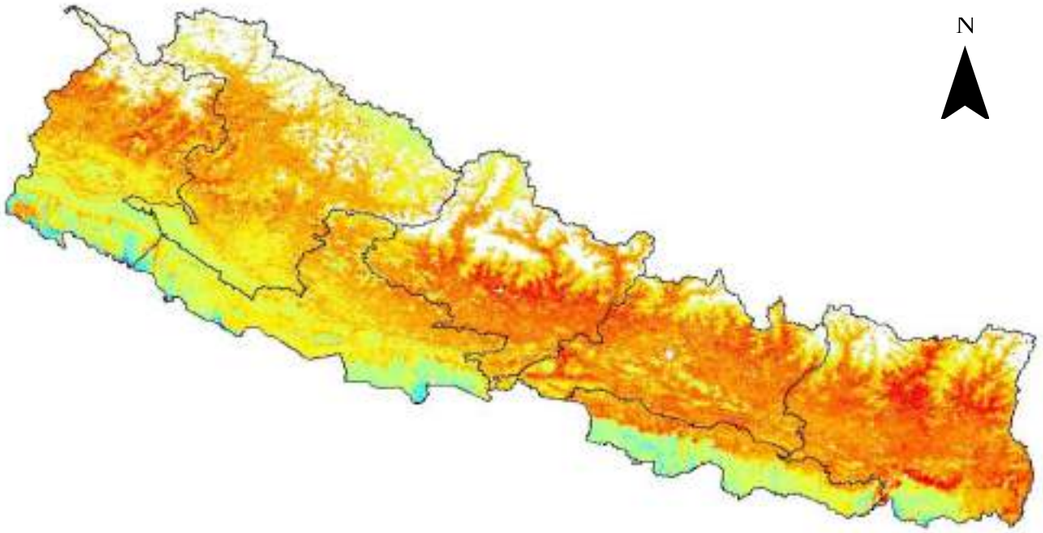

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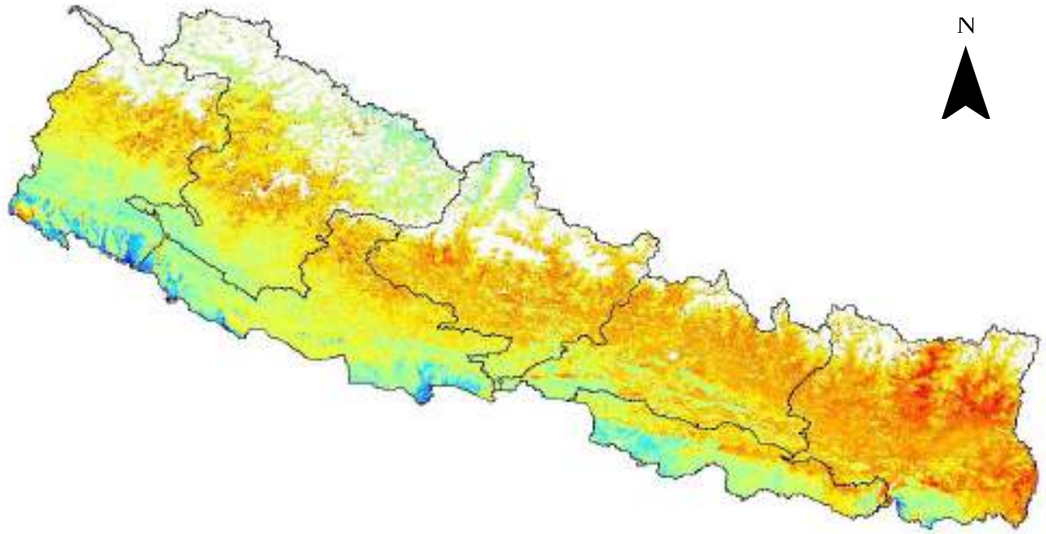

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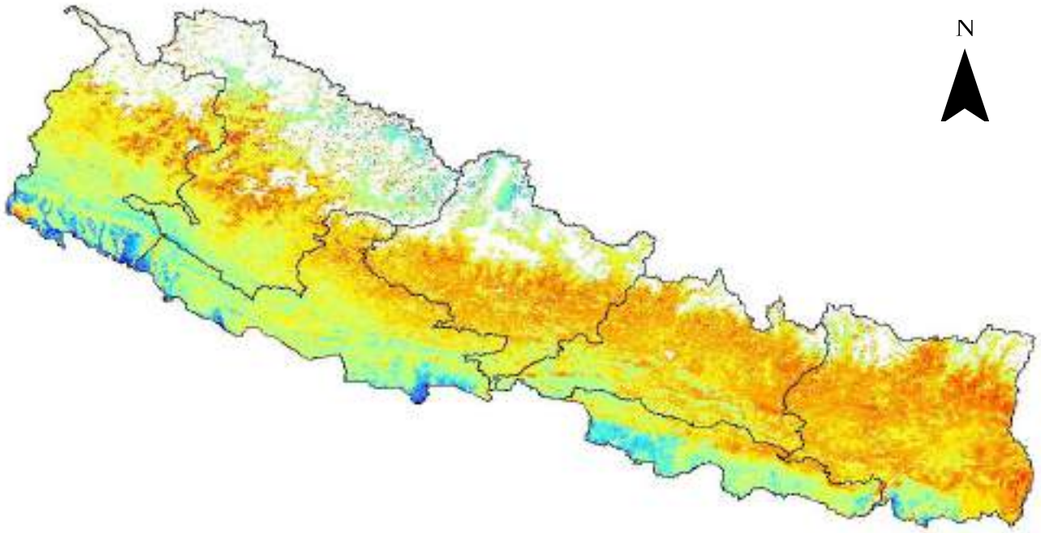
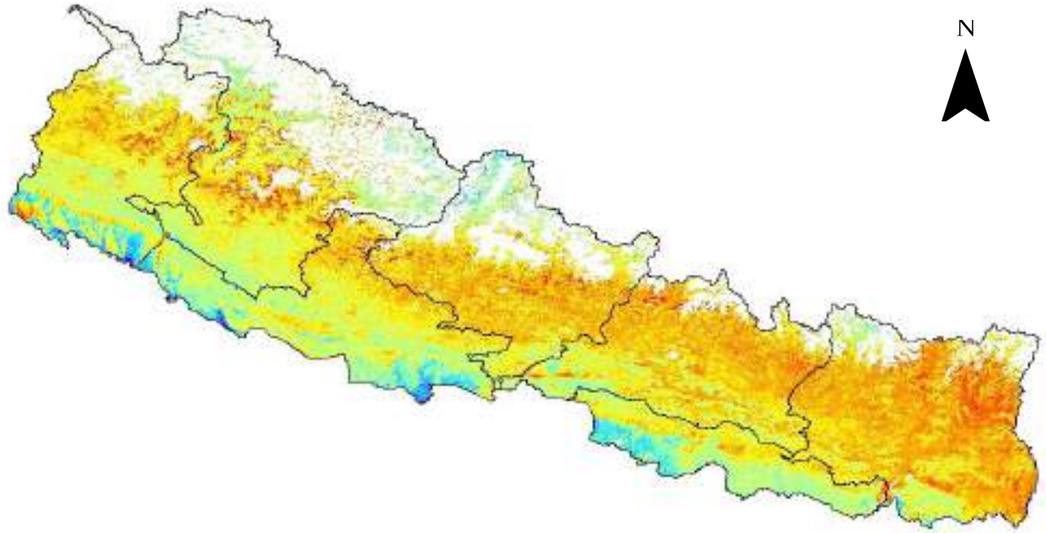


FEBRUARY 2012



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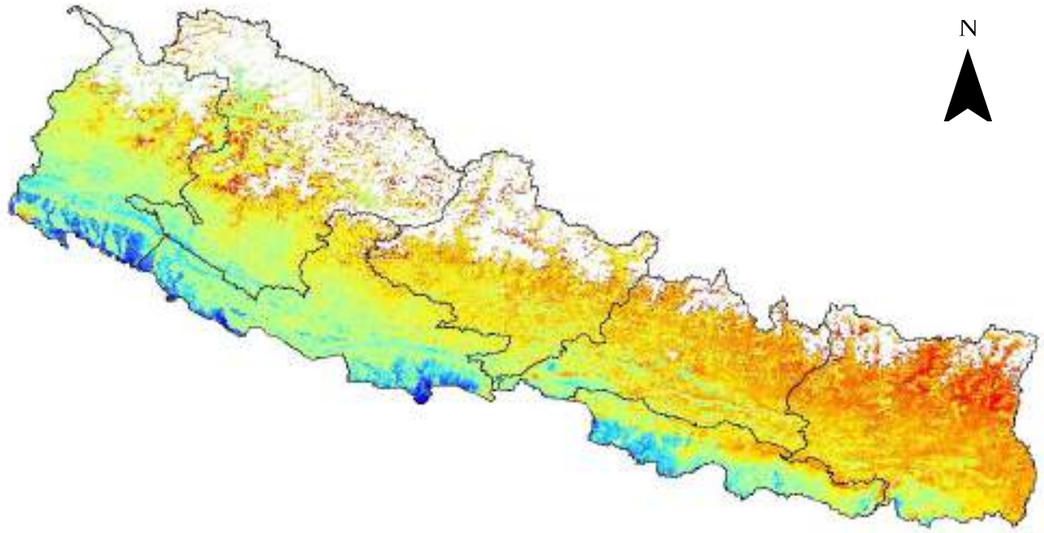

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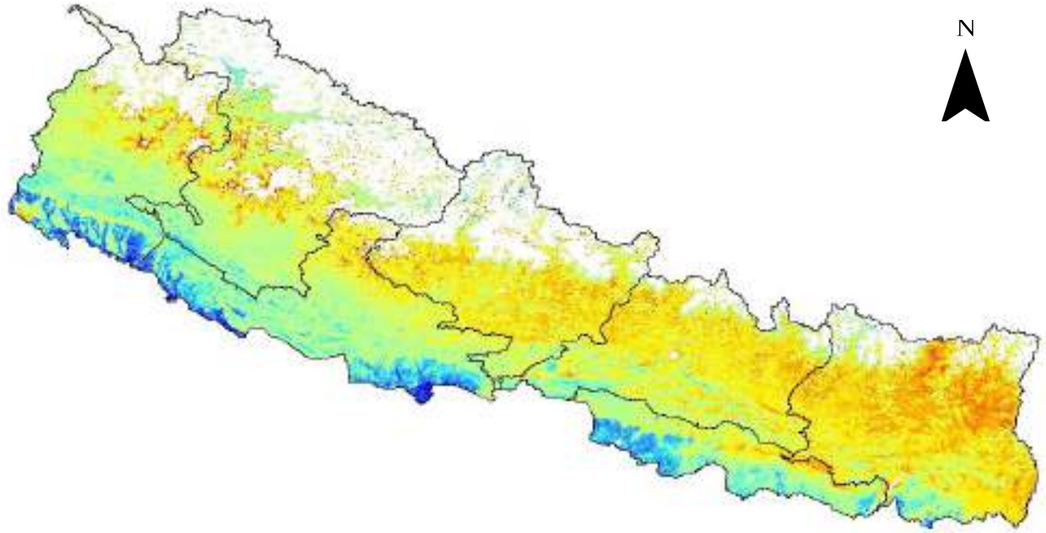

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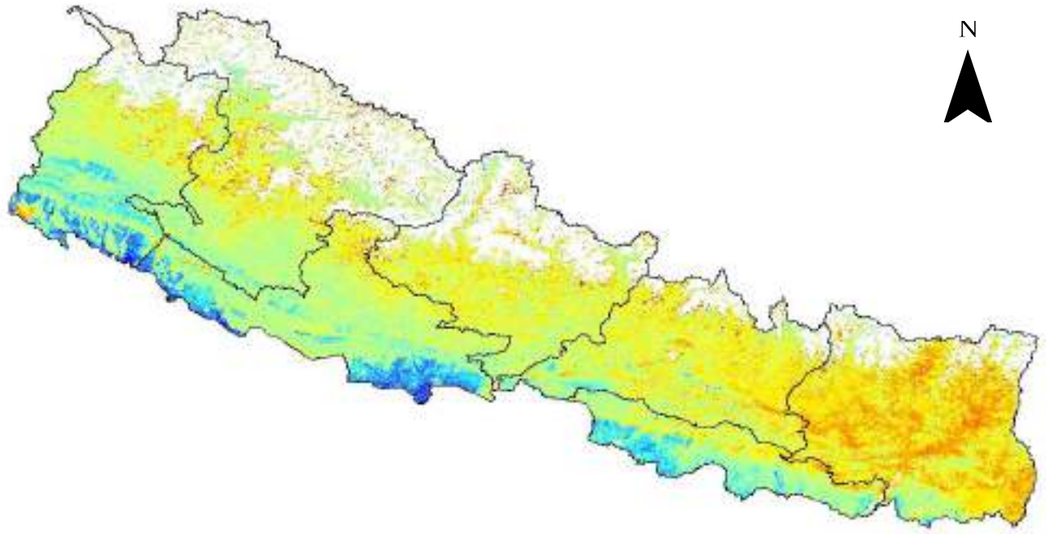
FEBRUARY 2015



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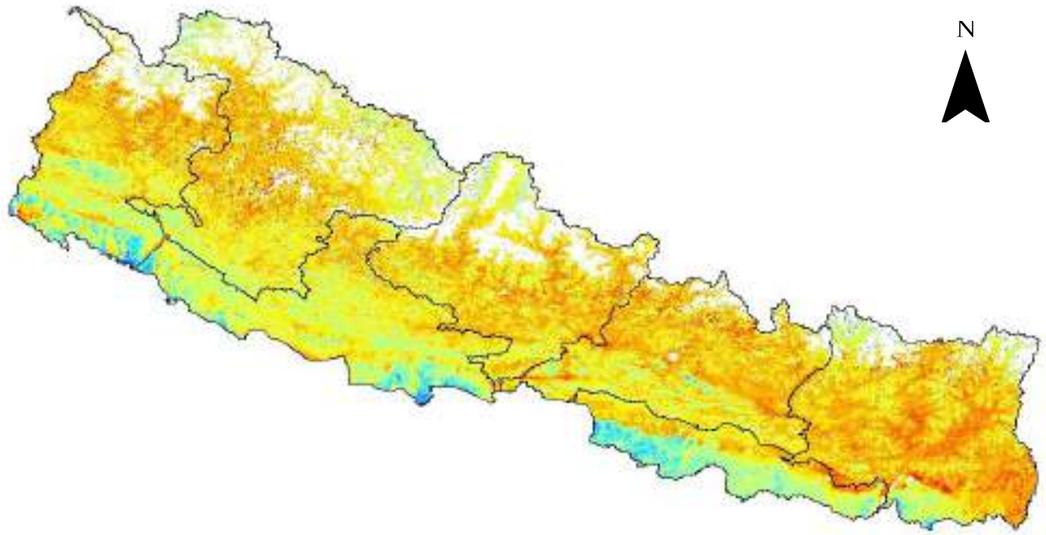

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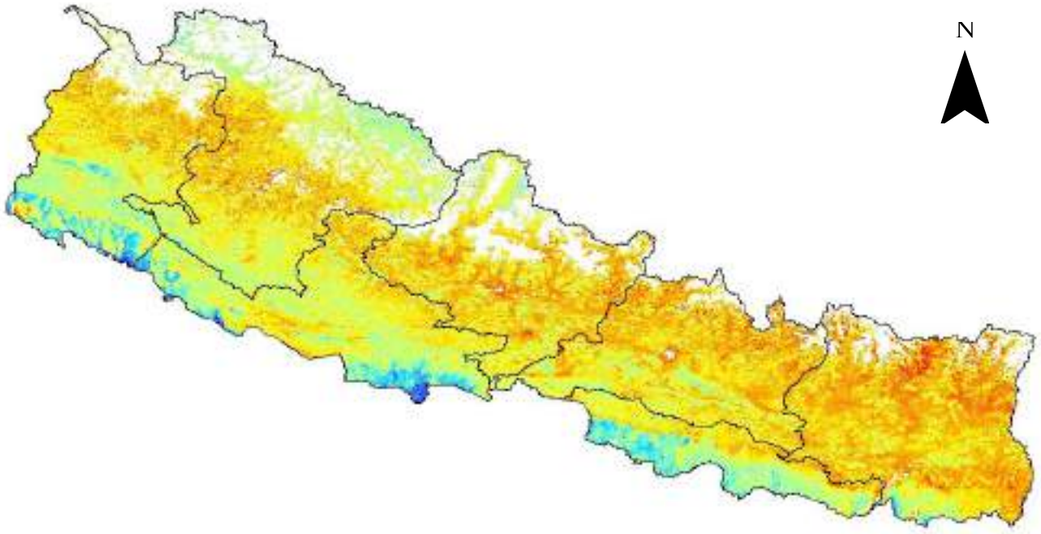

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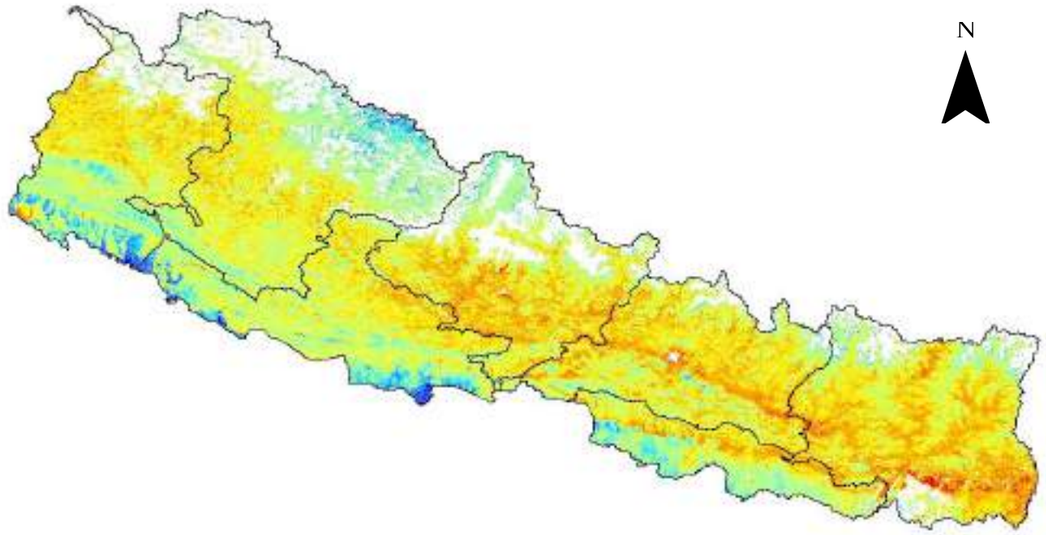

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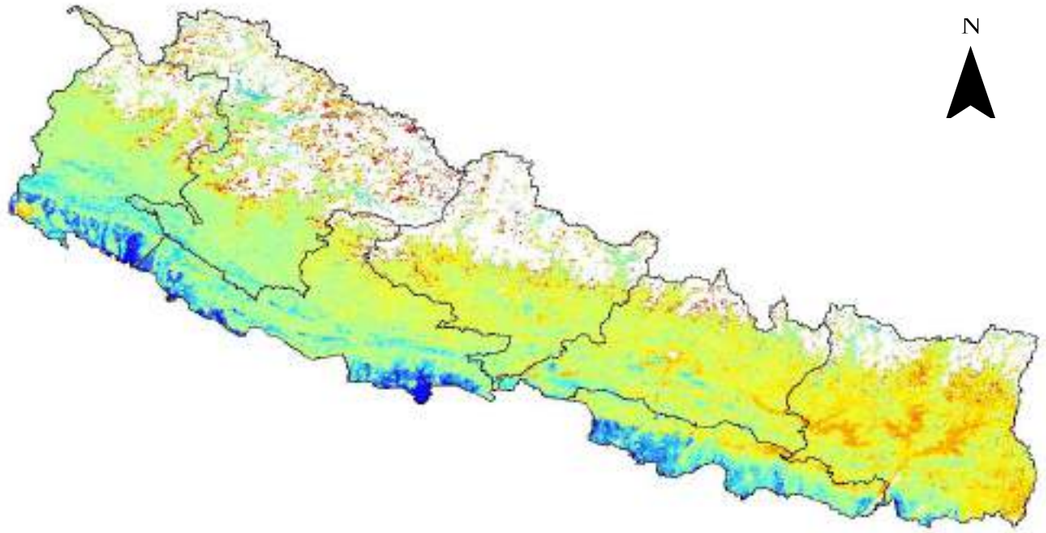
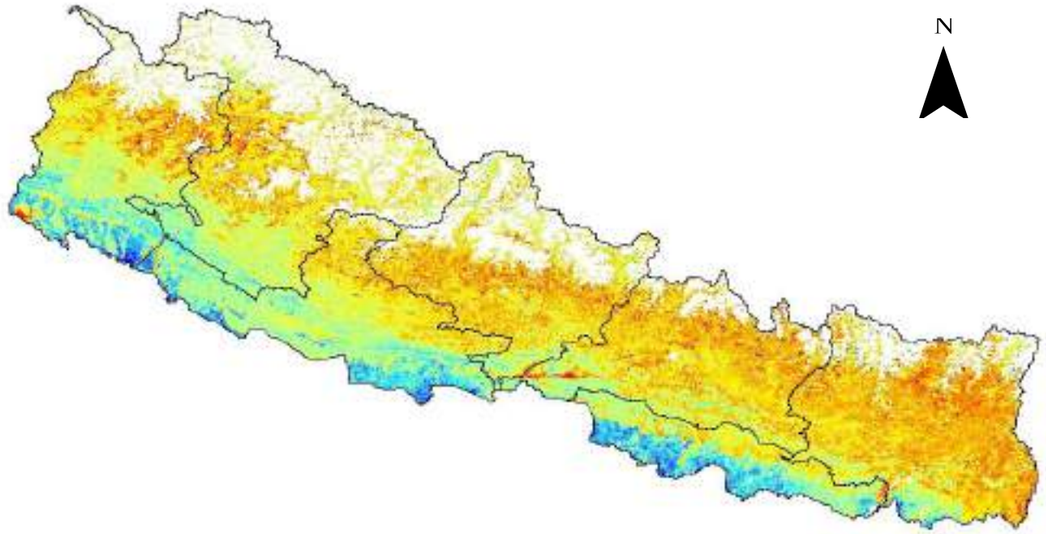
FEBRUARY 2019



FEBRUARY 2020



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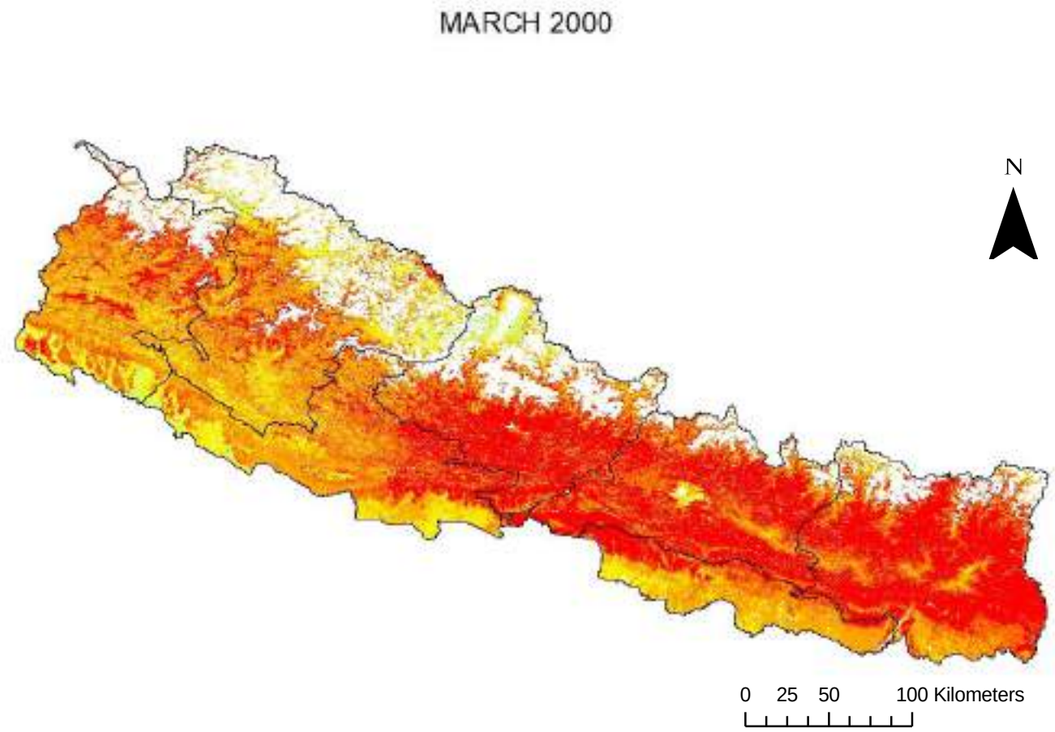
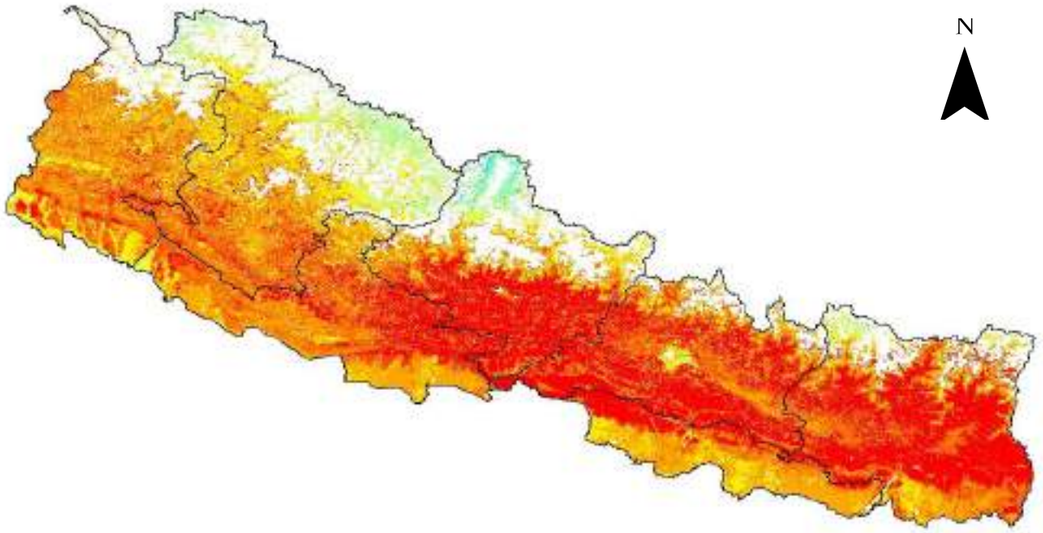
March DSI Maps

In March, drought conditions are marked from severe drought to near normal condition. Moderate to mild drought was seen in this pre-monsoon month. Severe drought condition exhibited in 2001 and 2009.

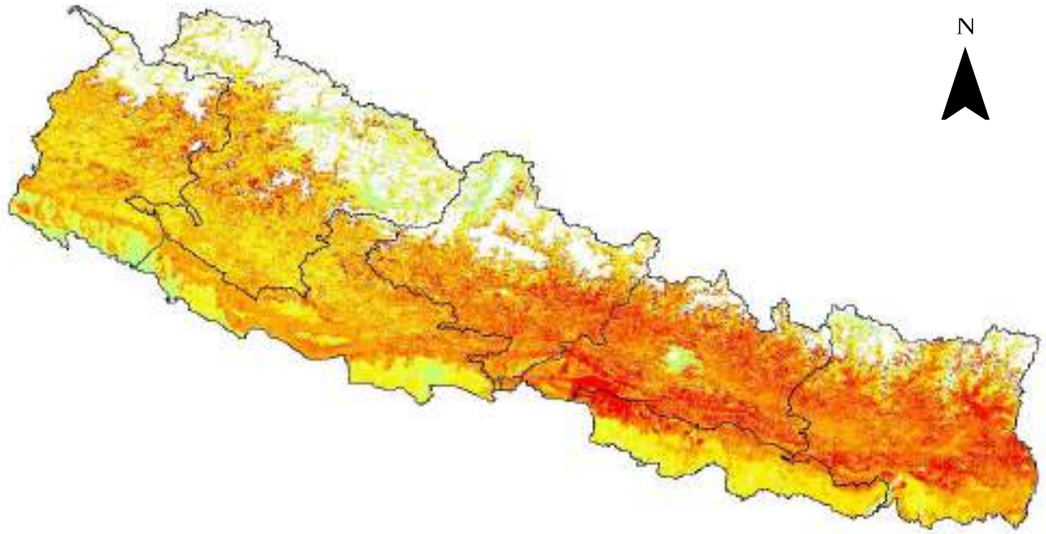
Mean March DSI Values		
Year	Values	Drought Condition
2000	-0.05	Near Normal
2001	-1.29	Severe Drought
2002	-1.06	Moderate Drought
2003	-0.84	Mild Drought
2004	-1.11	Moderate Drought
2005	-0.83	Mild Drought
2006	-0.99	Moderate Drought
2007	-0.84	Mild Drought
2008	-1.00	Moderate Drought
2009	-1.20	Severe Drought
2010	-1.07	Moderate Drought
2011	-0.94	Moderate Drought
2012	-1.09	Moderate Drought
2013	-0.84	Mild Drought
2014	-0.75	Mild Drought
2015	-0.60	Mild Drought
2016	-0.96	Moderate Drought
2017	-0.77	Mild Drought
2018	-0.85	Mild Drought
2019	-0.56	Incipient Drought
2020	-0.78	Mild Drought



MARCH 2001



MARCH 2002



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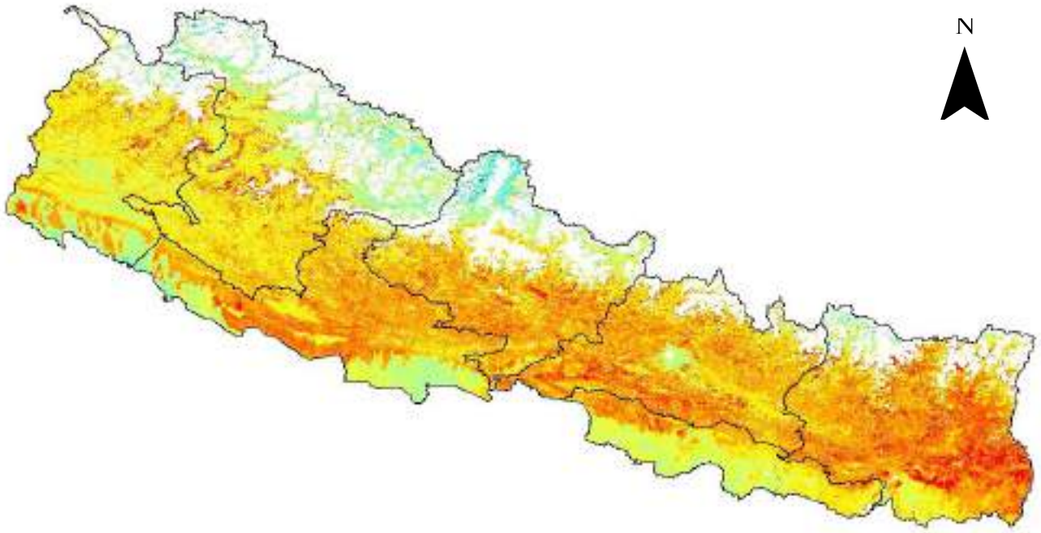
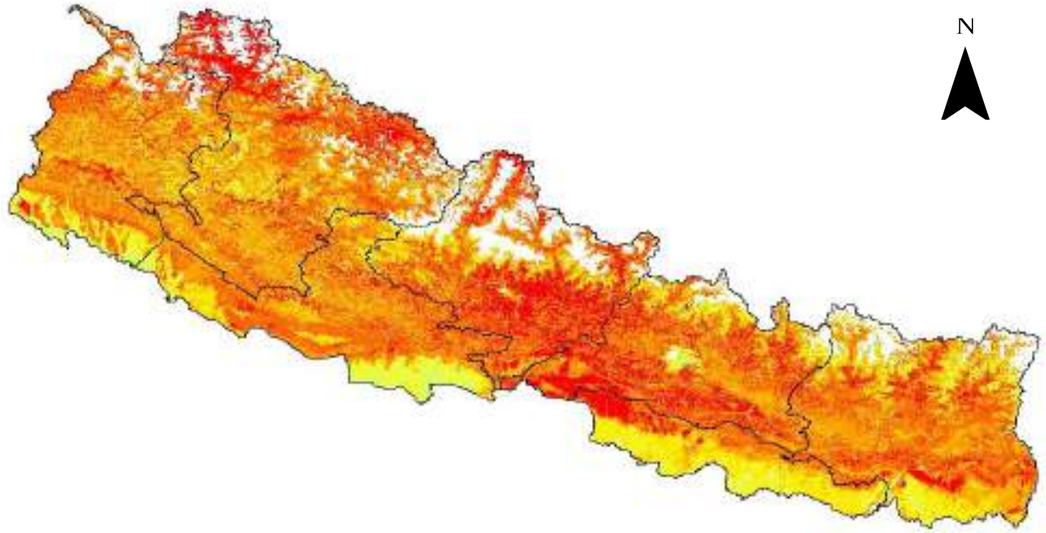


MARCH 2004



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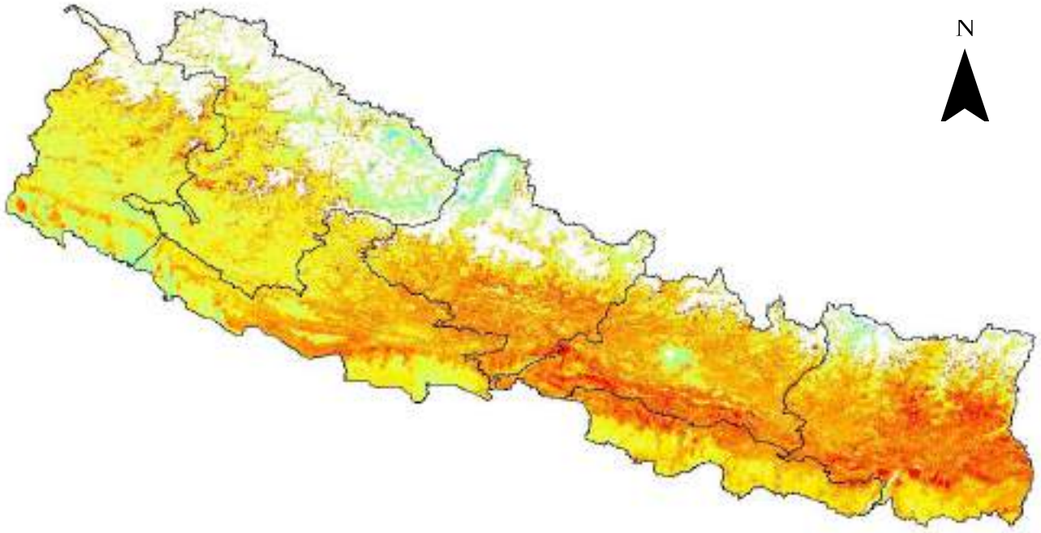
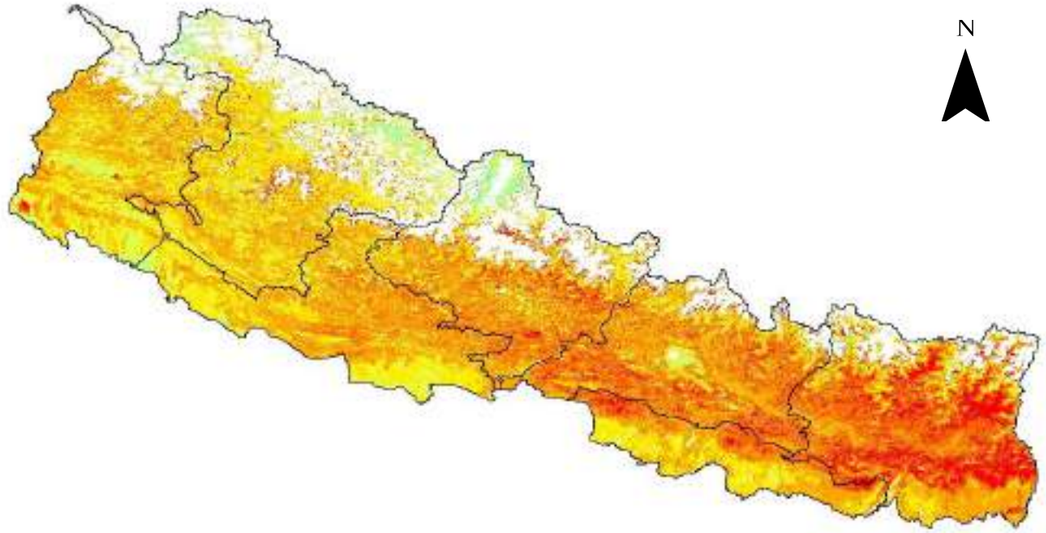


MARCH 2006



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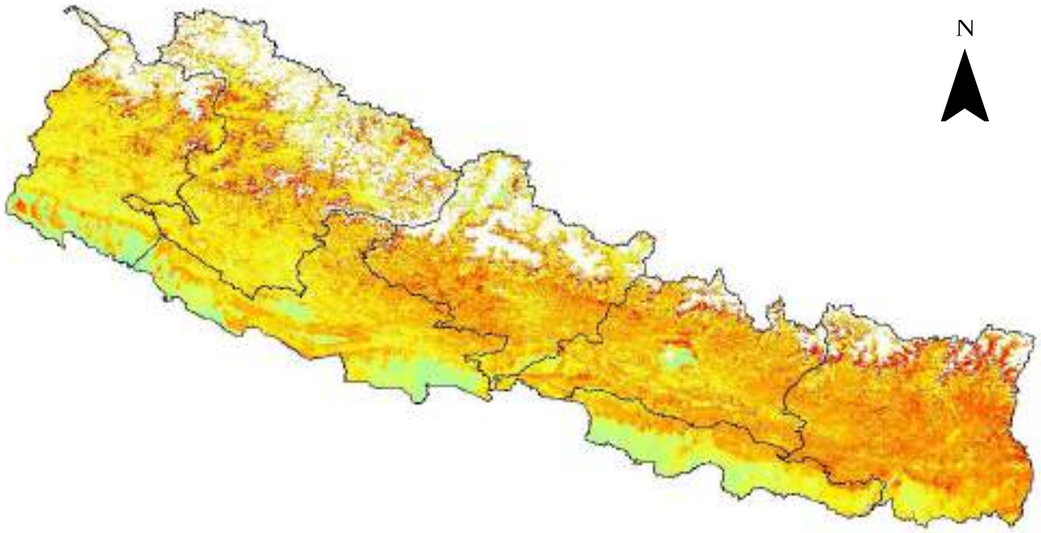

N

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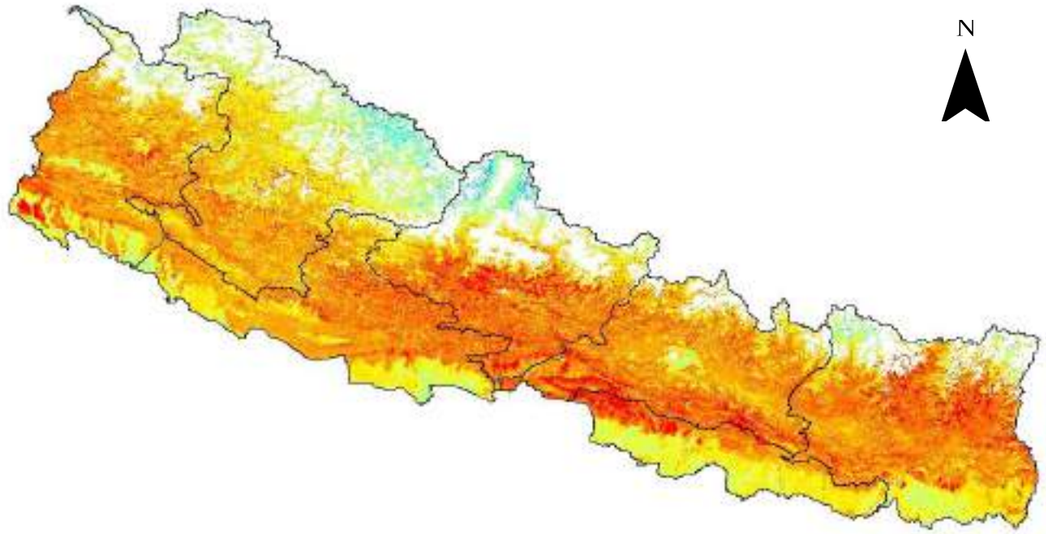
MARCH 2008



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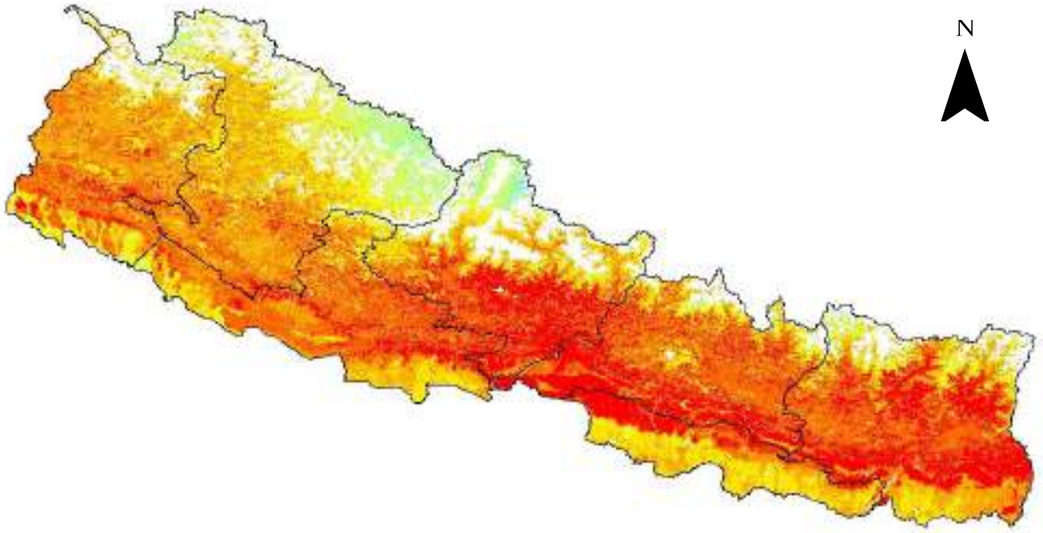
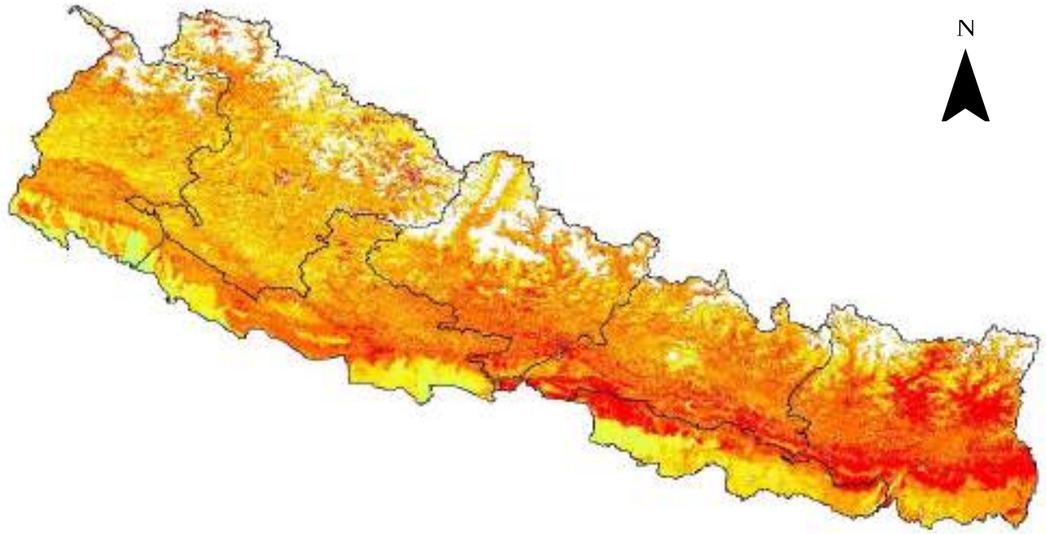


MARCH 2010



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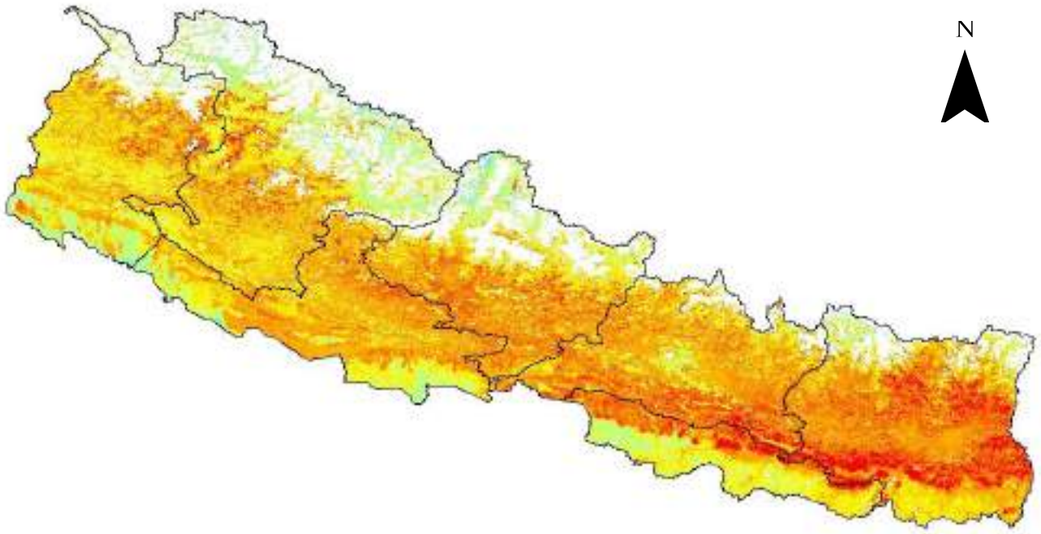
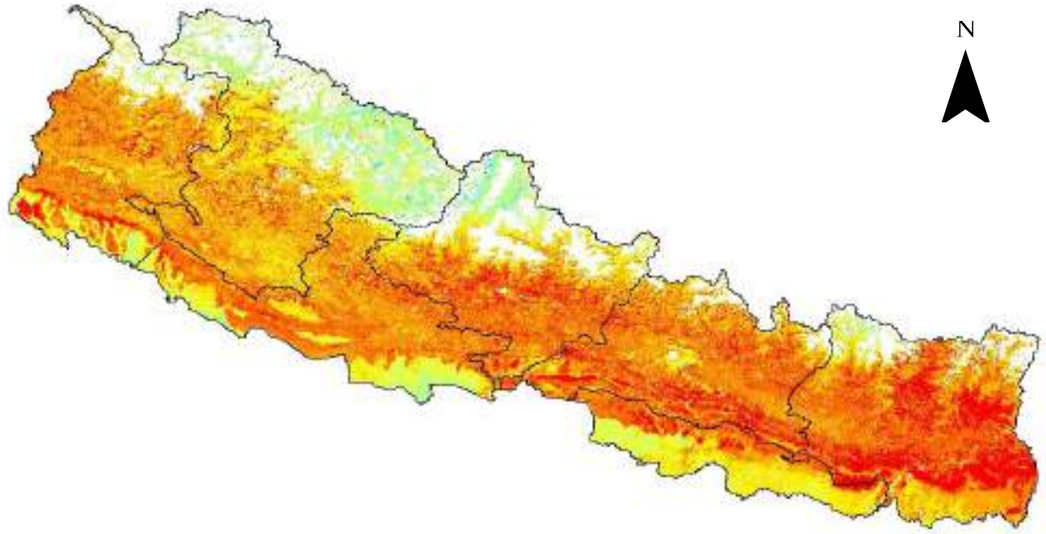


MARCH 2012



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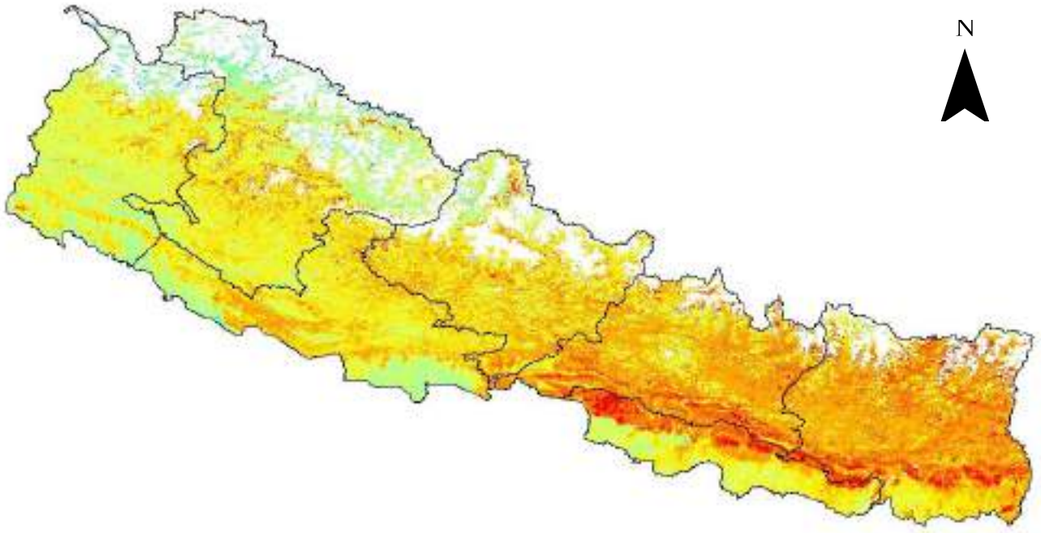

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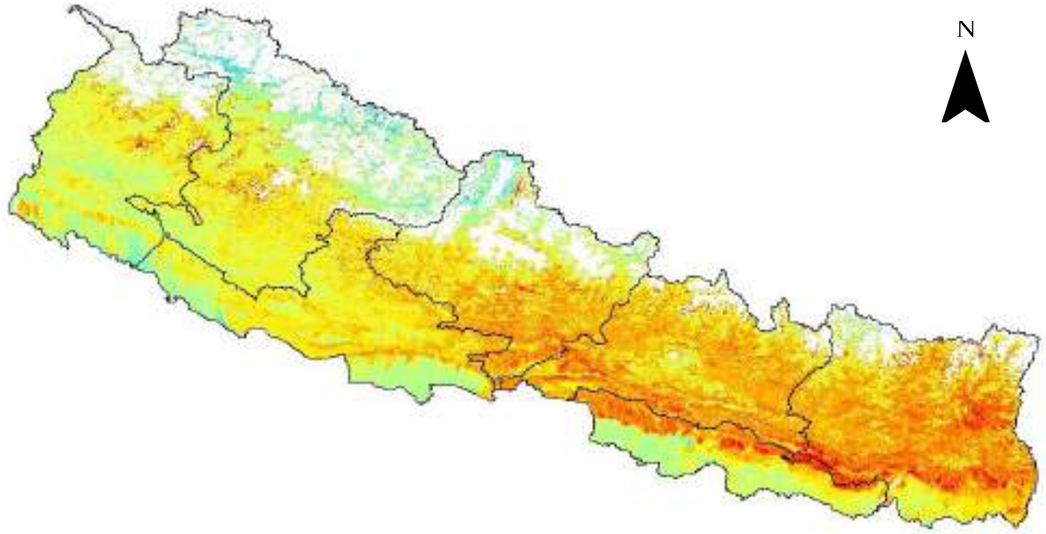

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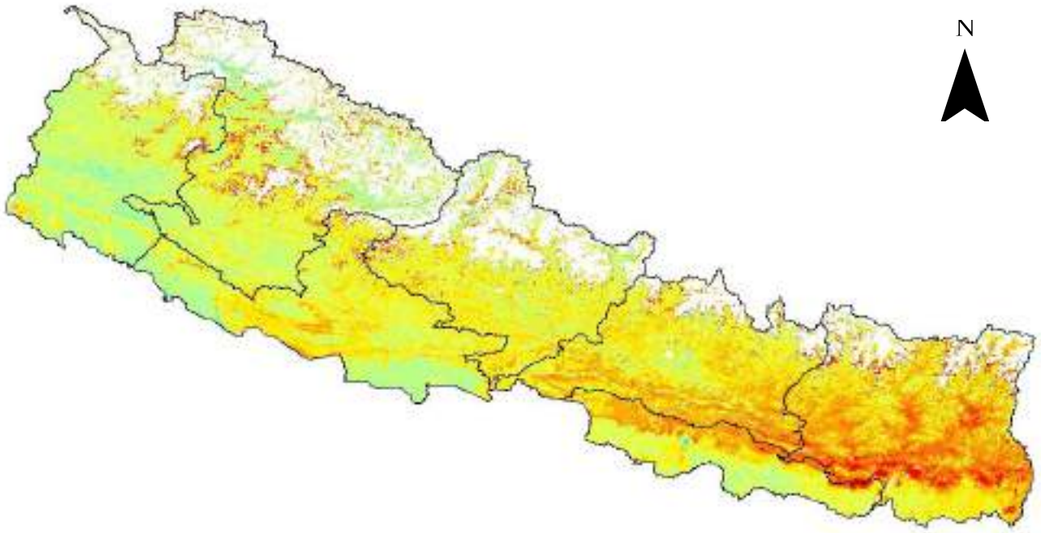

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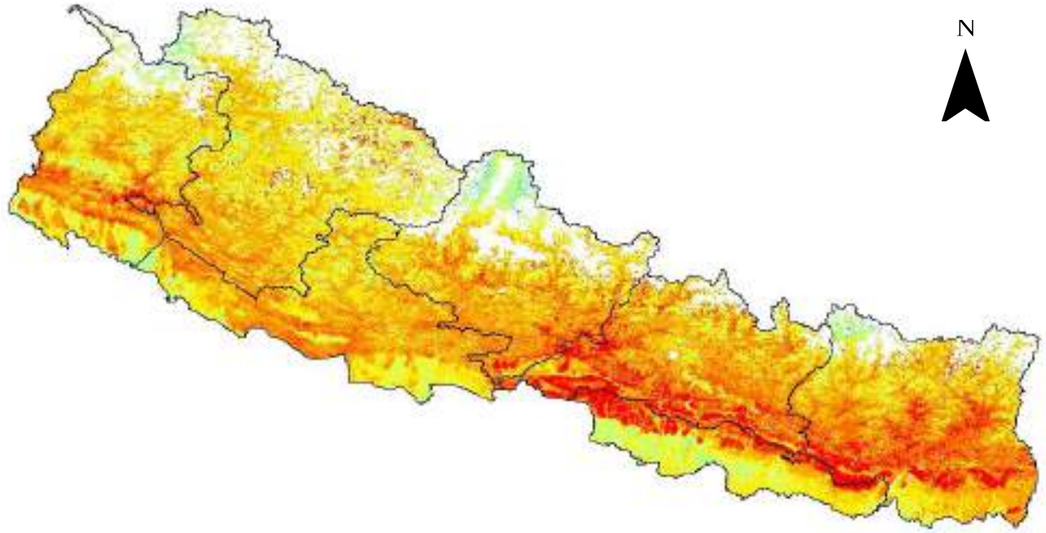

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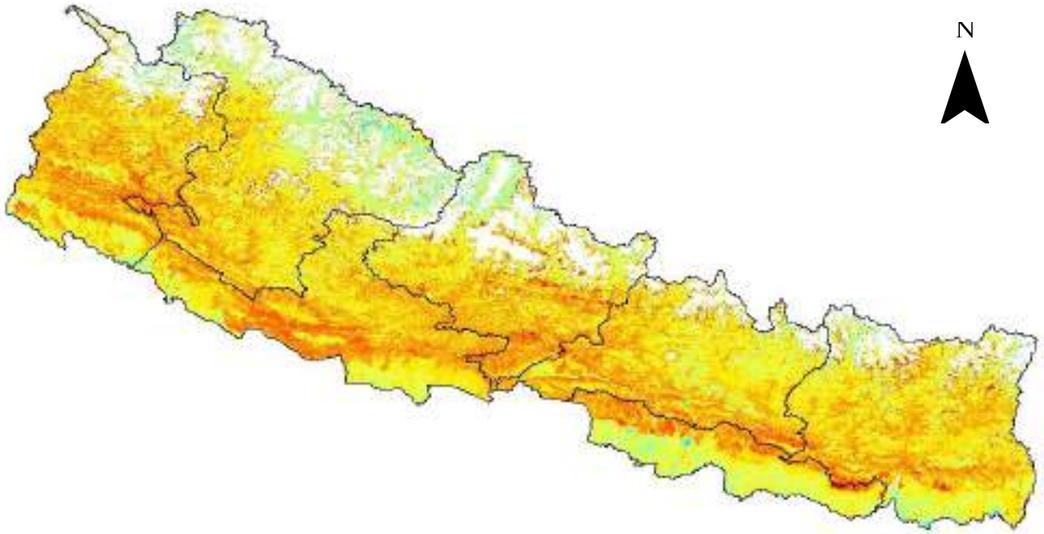

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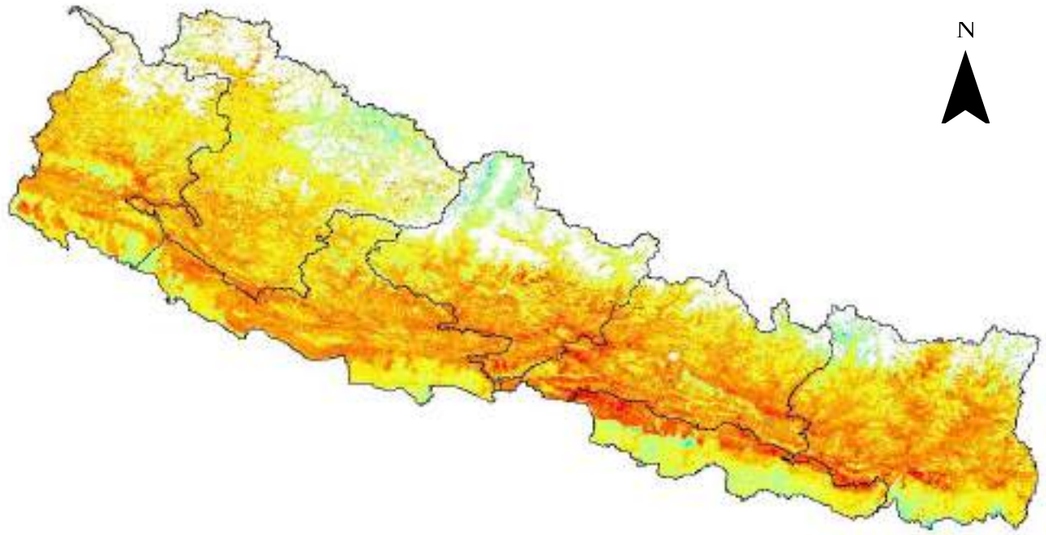

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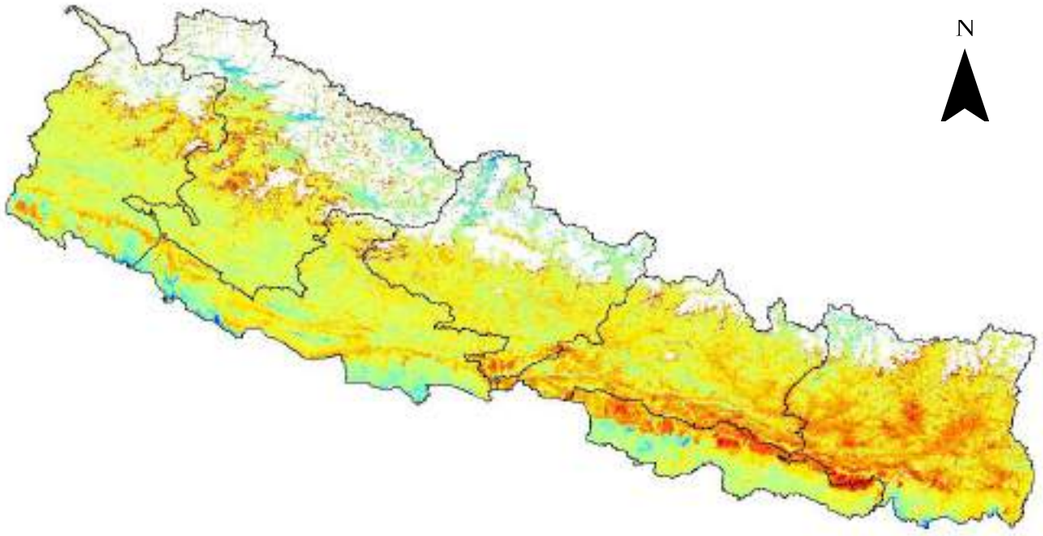

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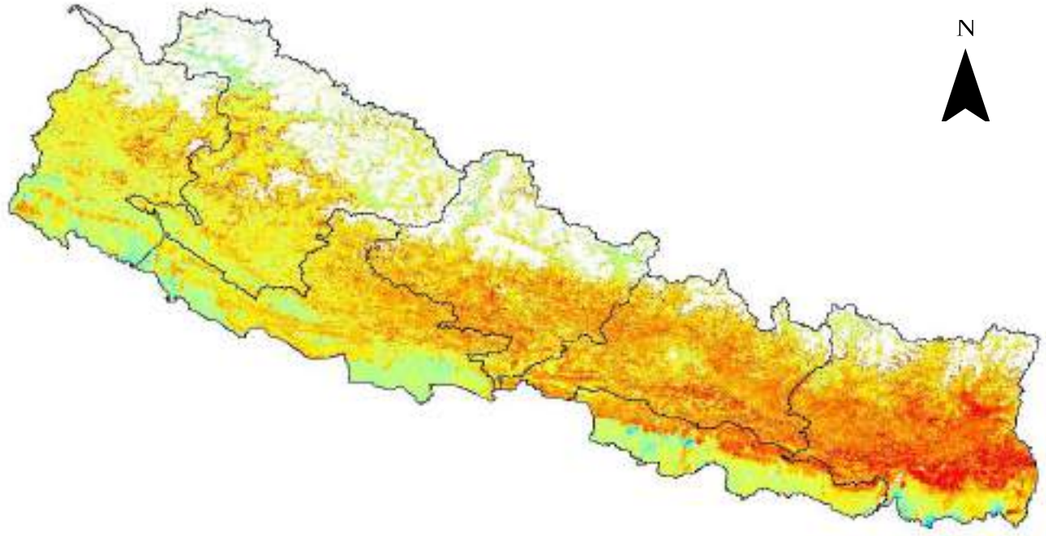

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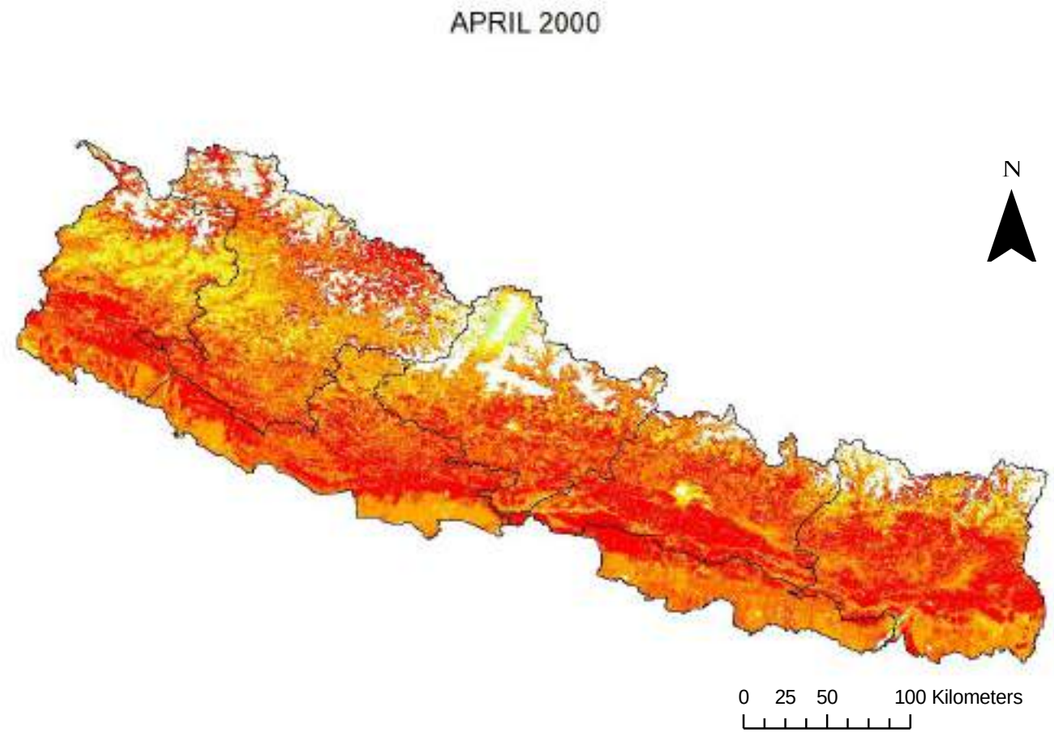
April DSI Map

In April, drought conditions usually vary from severe drought to incipient drought condition. This pre-monsoon month experienced moderate drought in most of the years. Severe drought condition was identified in 2000, 2001, 2009 and 2010

Mean April DSI Values		
Year	Values	Drought Condition
2000	-1.39	Severe Drought
2001	-1.32	Severe Drought
2002	-1.10	Moderate Drought
2003	-1.06	Moderate Drought
2004	-1.00	Moderate Drought
2005	-1.10	Moderate Drought
2006	-1.08	Moderate Drought
2007	-0.84	Mild Drought
2008	-1.04	Moderate Drought
2009	-1.26	Severe Drought
2010	-1.25	Severe Drought
2011	-0.95	Moderate Drought
2012	-0.98	Moderate Drought
2013	-0.88	Mild Drought
2014	-0.97	Moderate Drought
2015	-0.55	Incipient Drought
2016	-1.08	Moderate Drought
2017	-0.84	Mild Drought
2018	-0.58	Incipient Drought
2019	-0.43	Incipient Drought
2020	-0.75	Mild Drought



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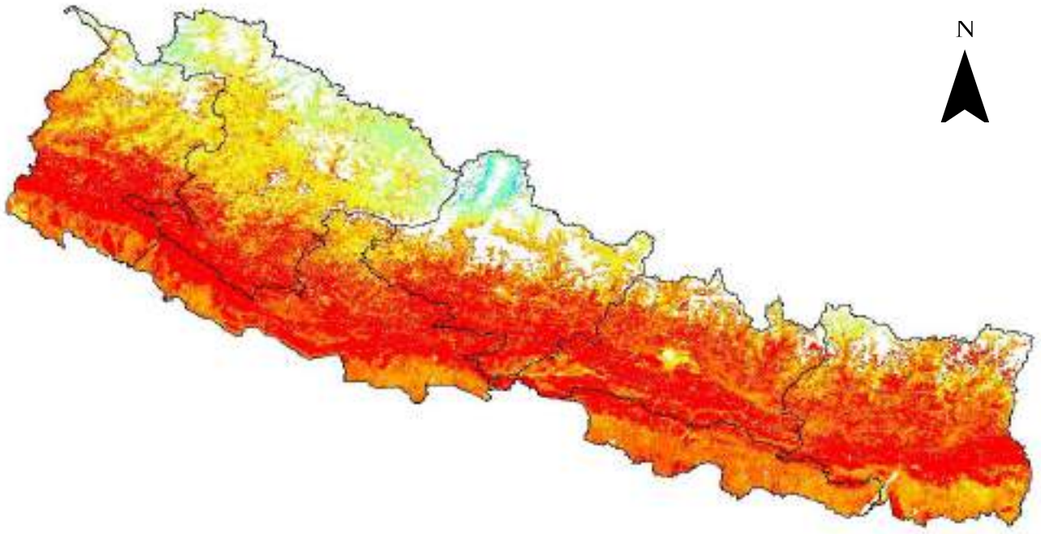
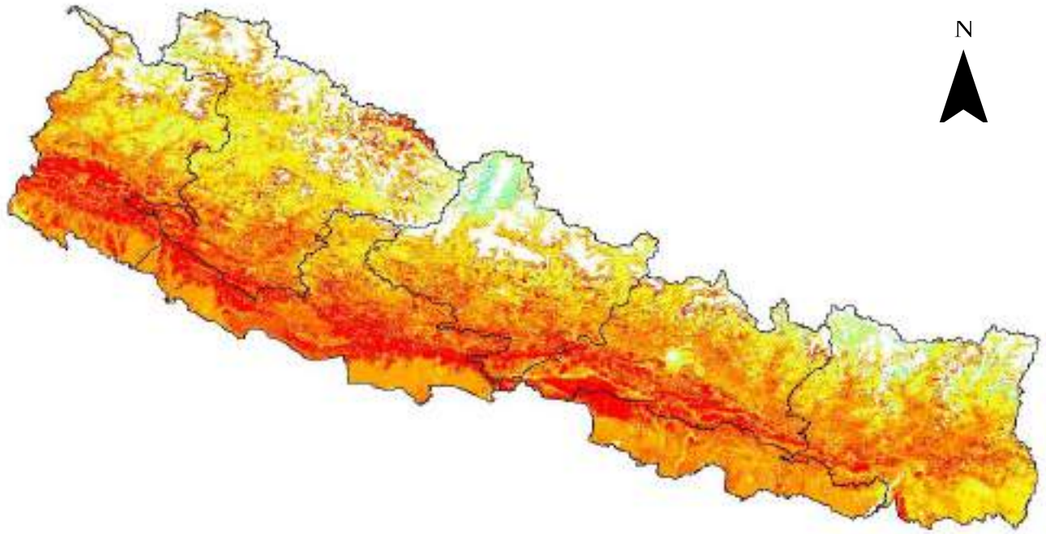


APRIL 2002



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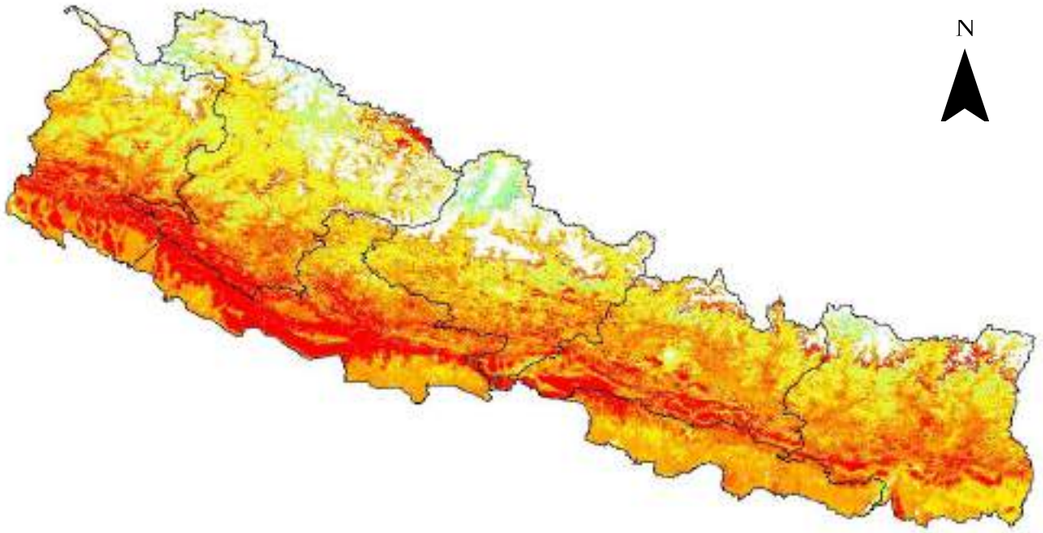

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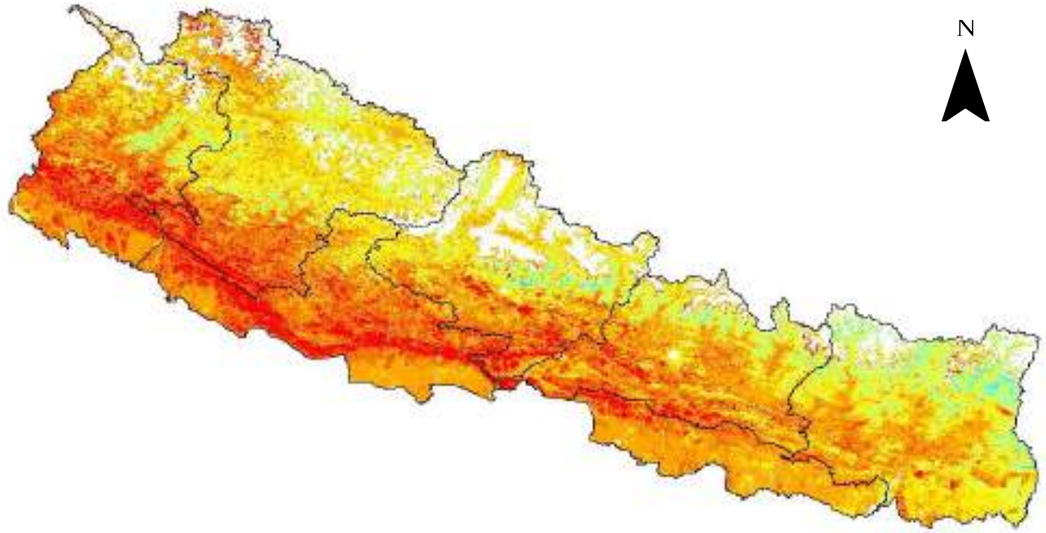

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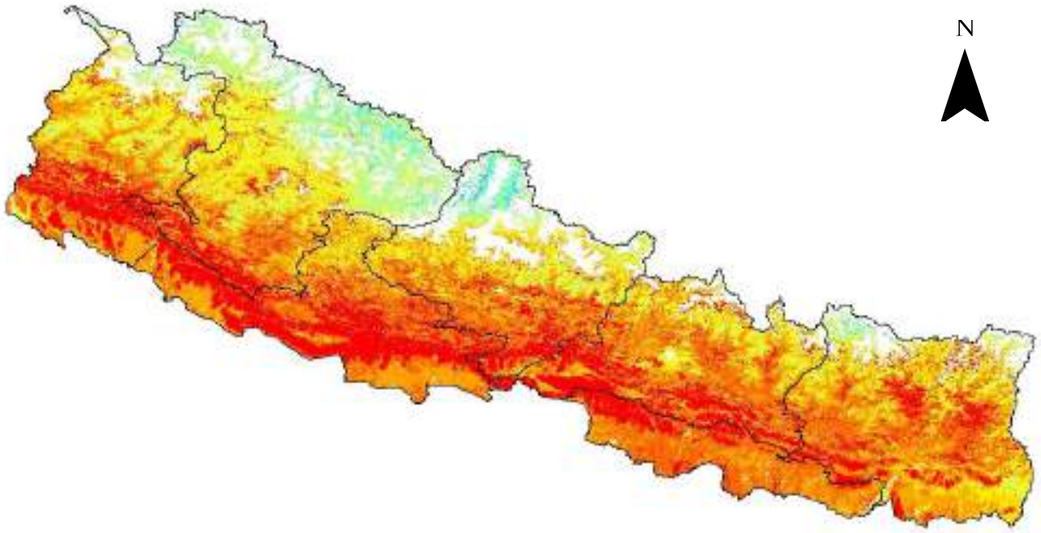

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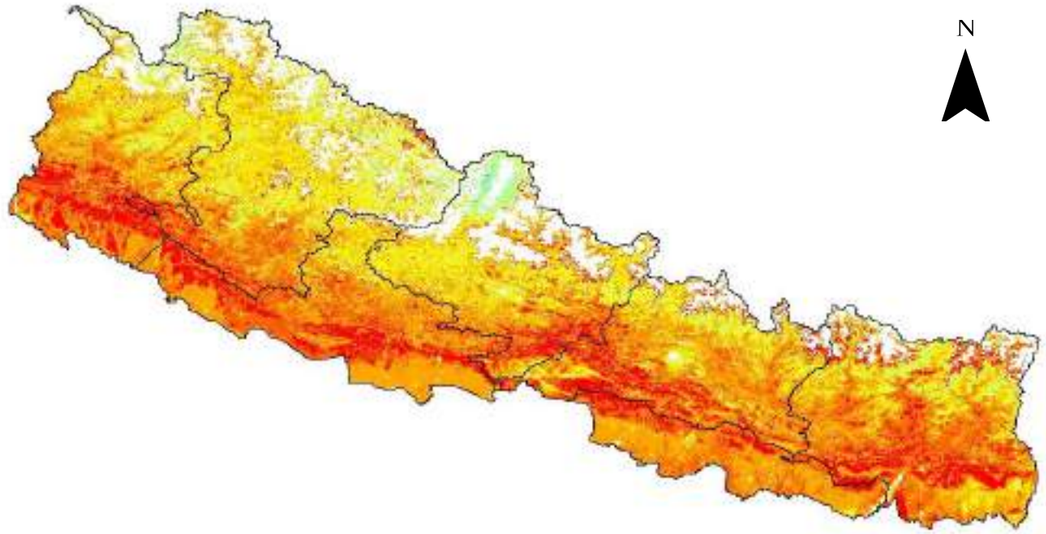

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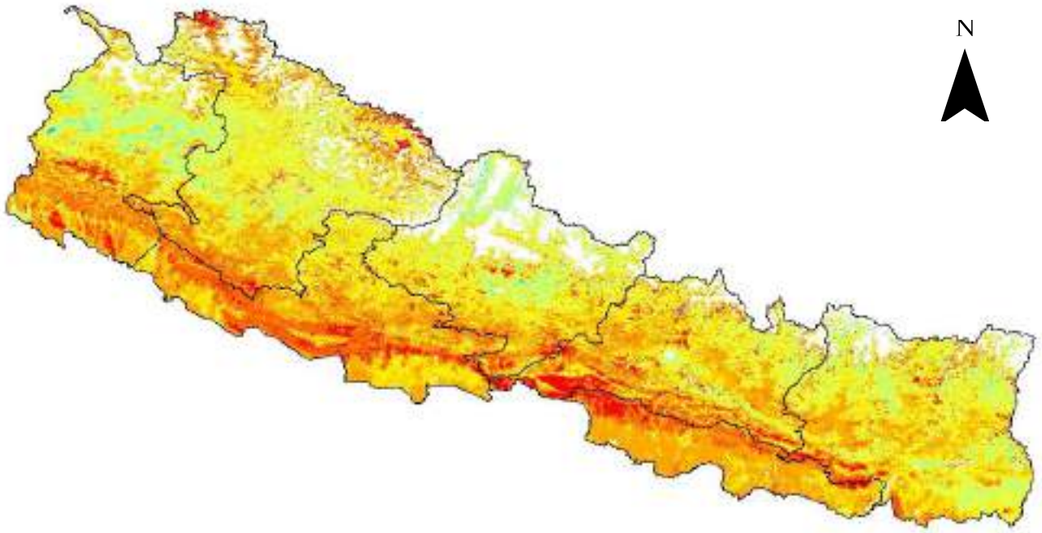

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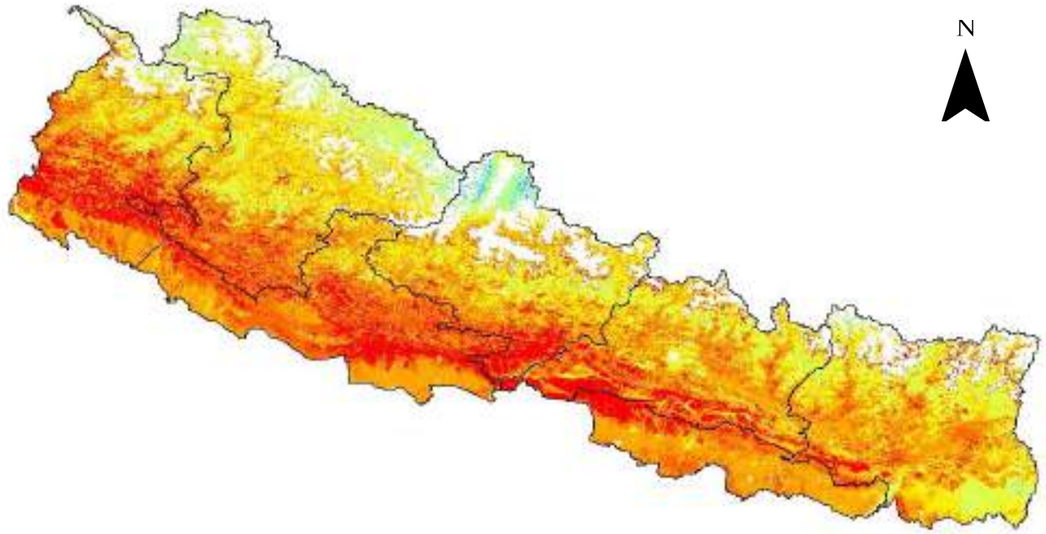

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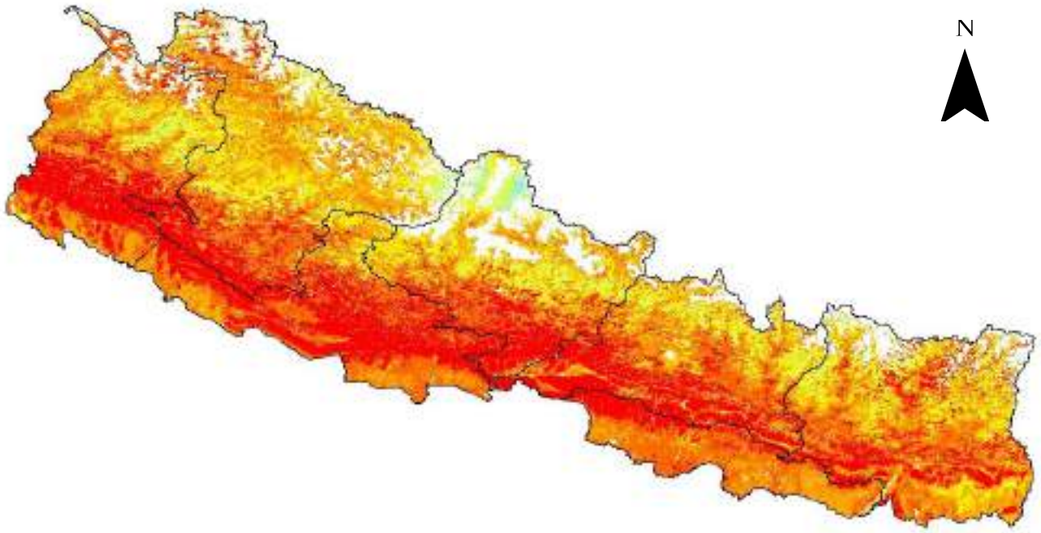

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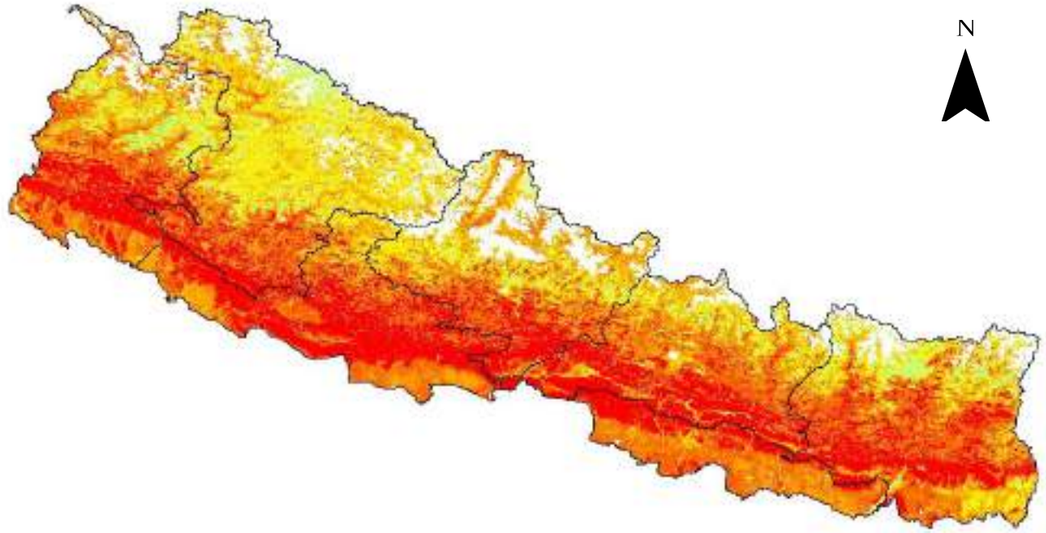

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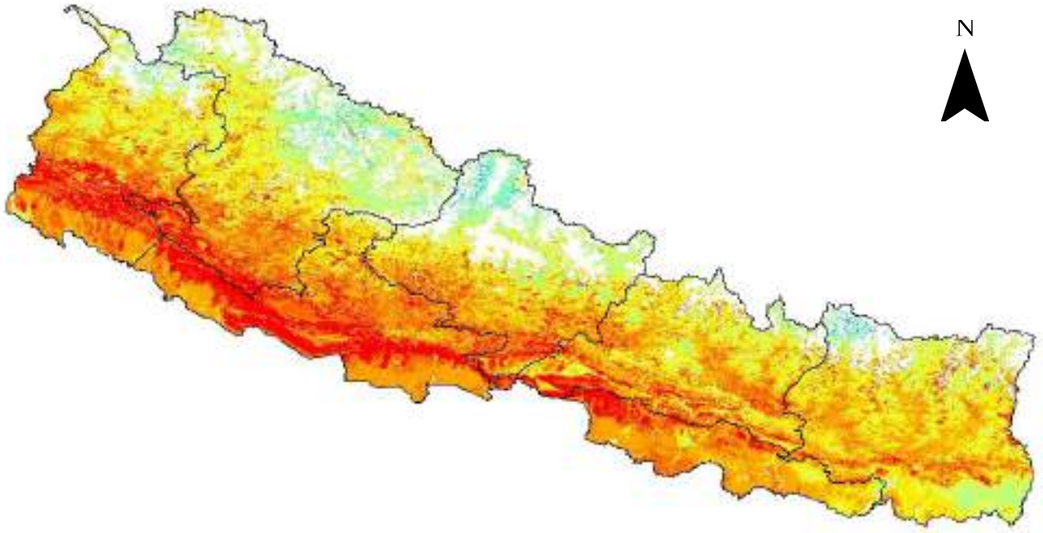

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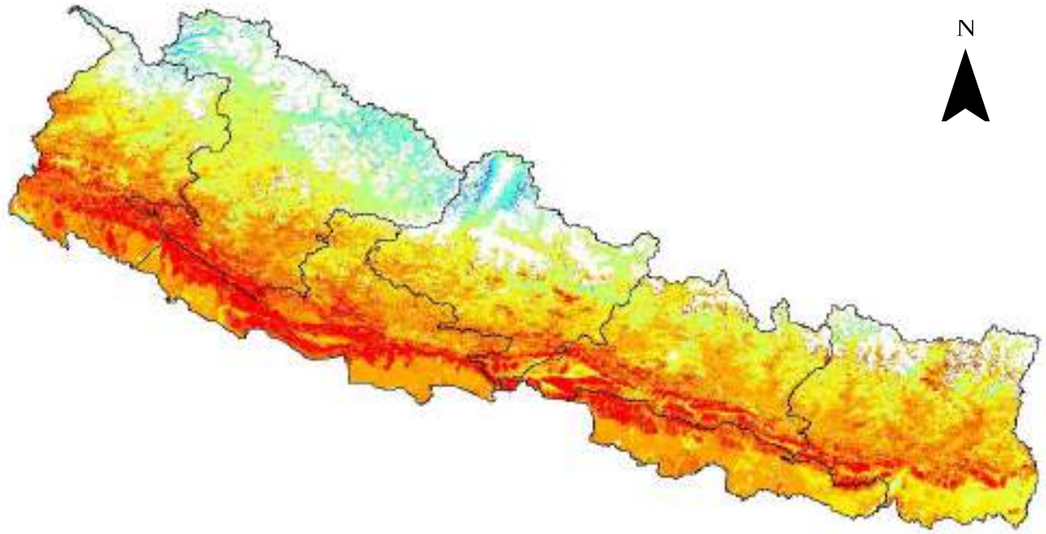

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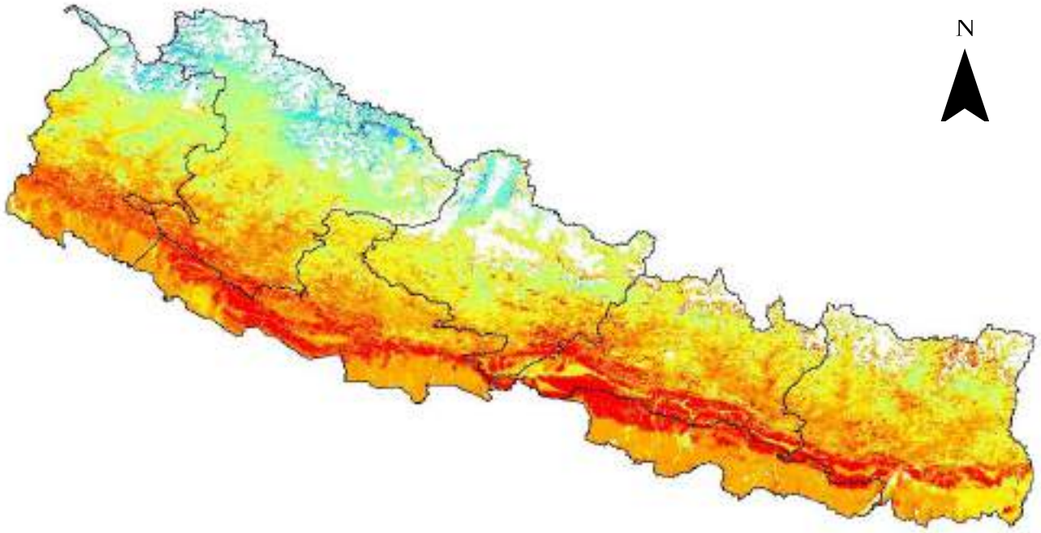

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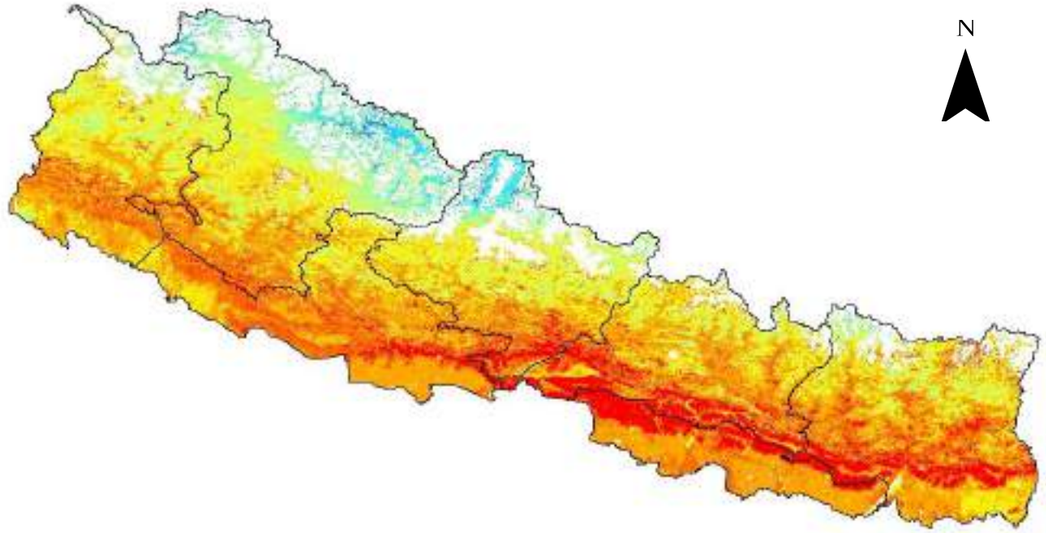

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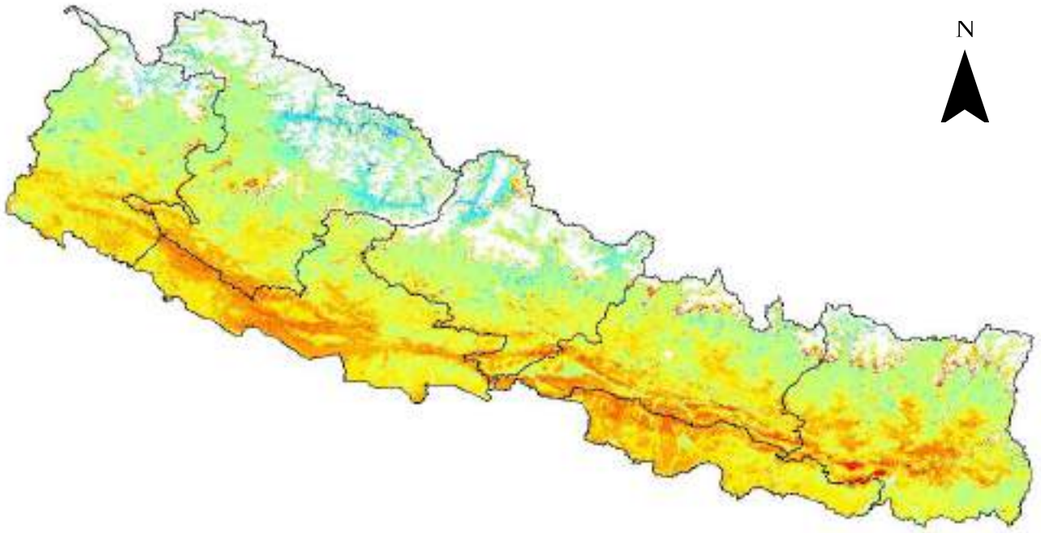

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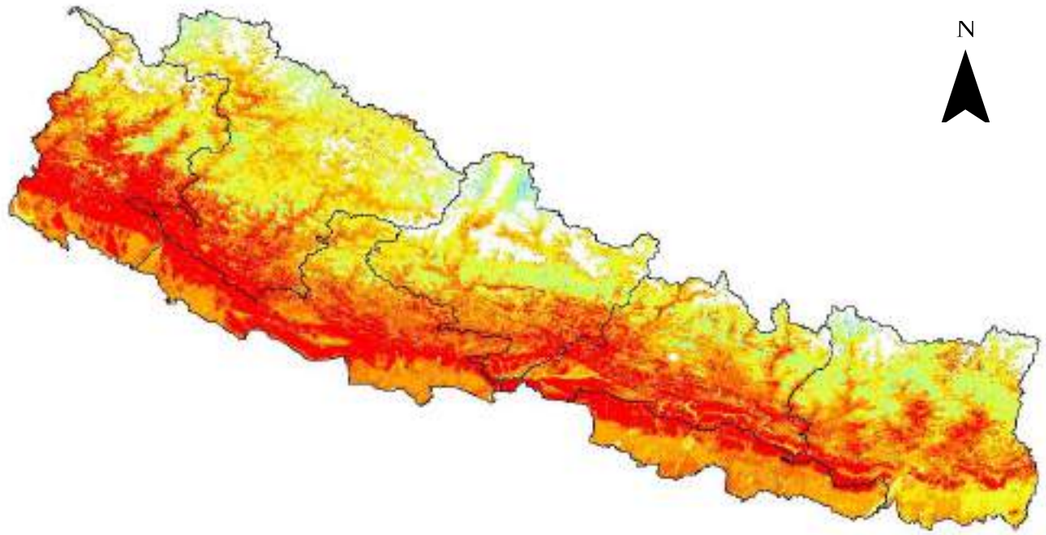

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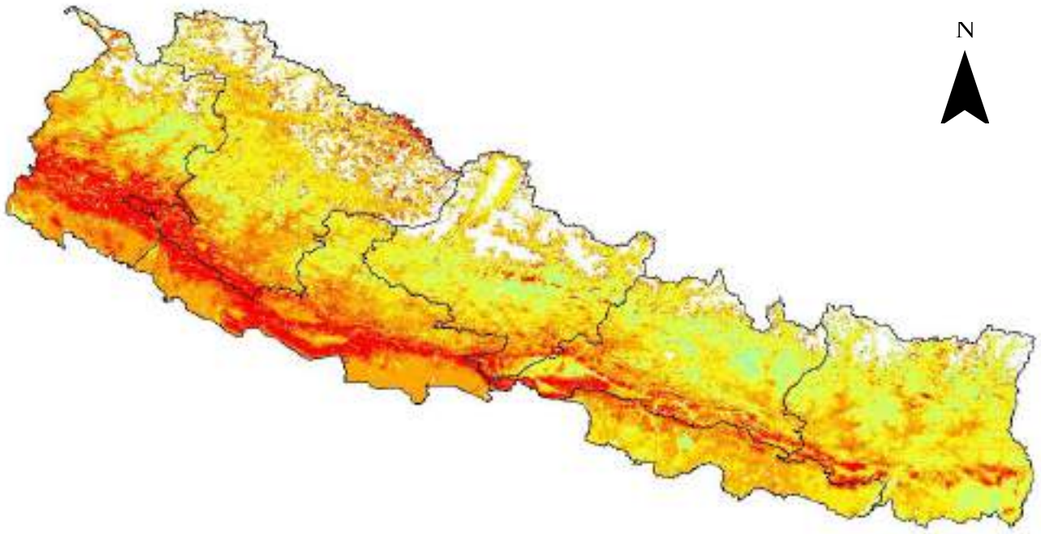

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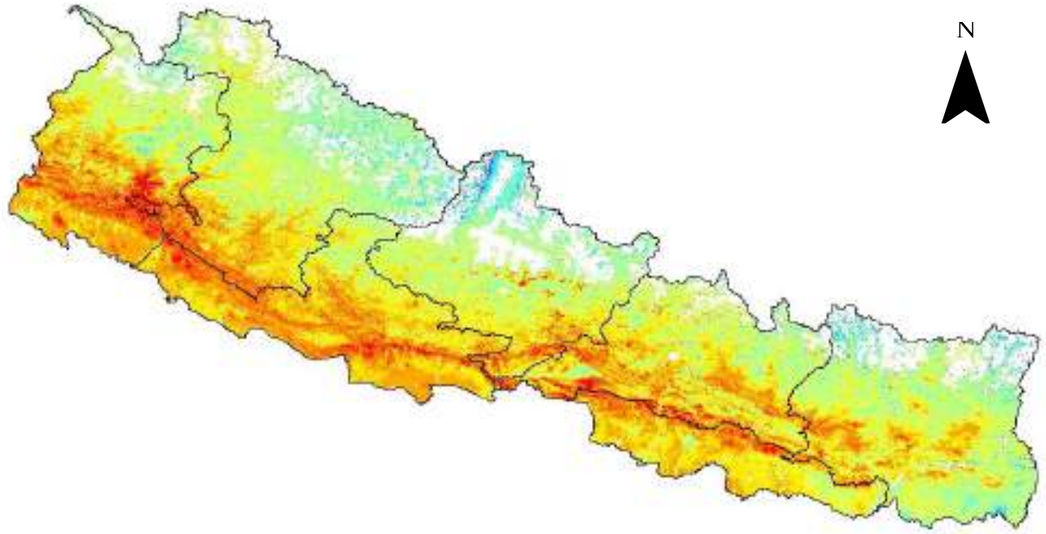

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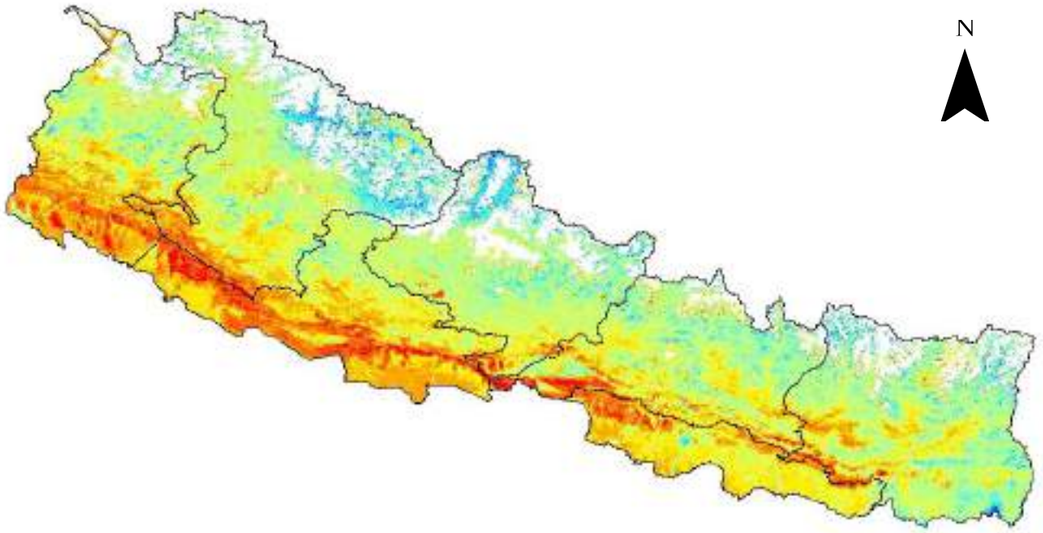

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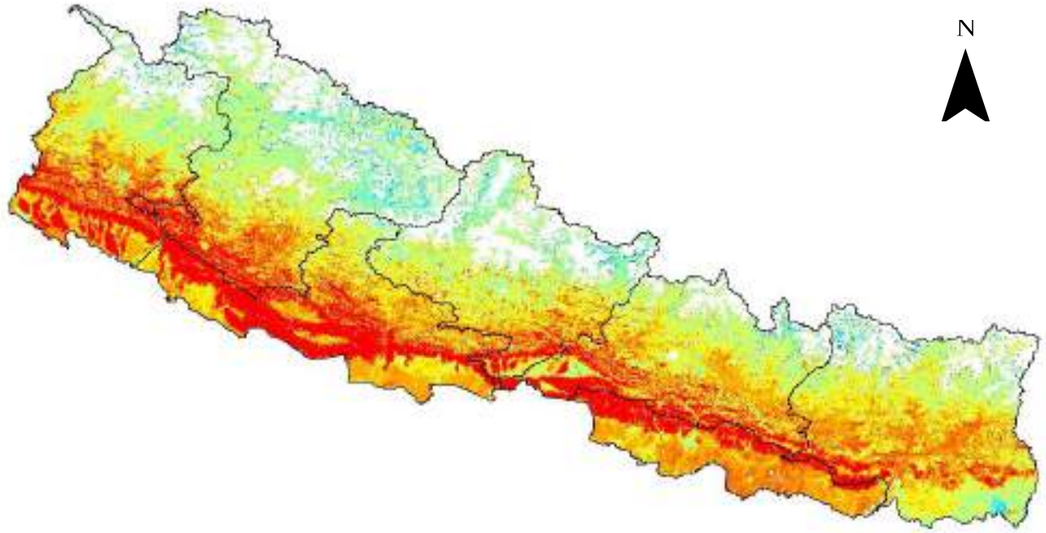

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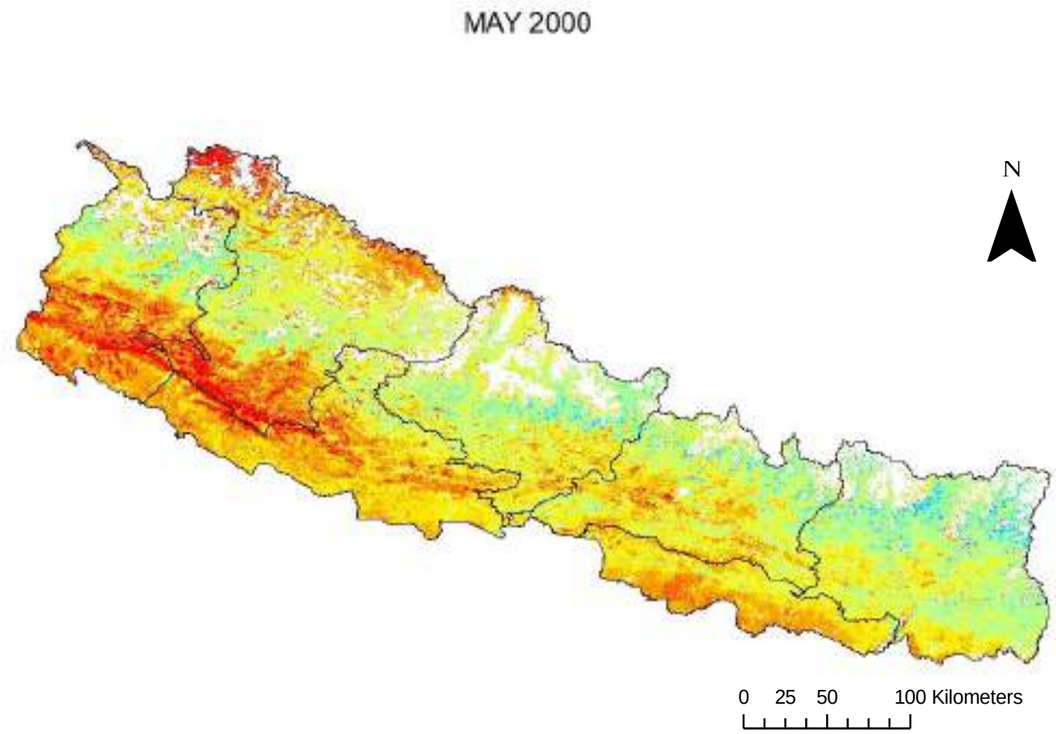
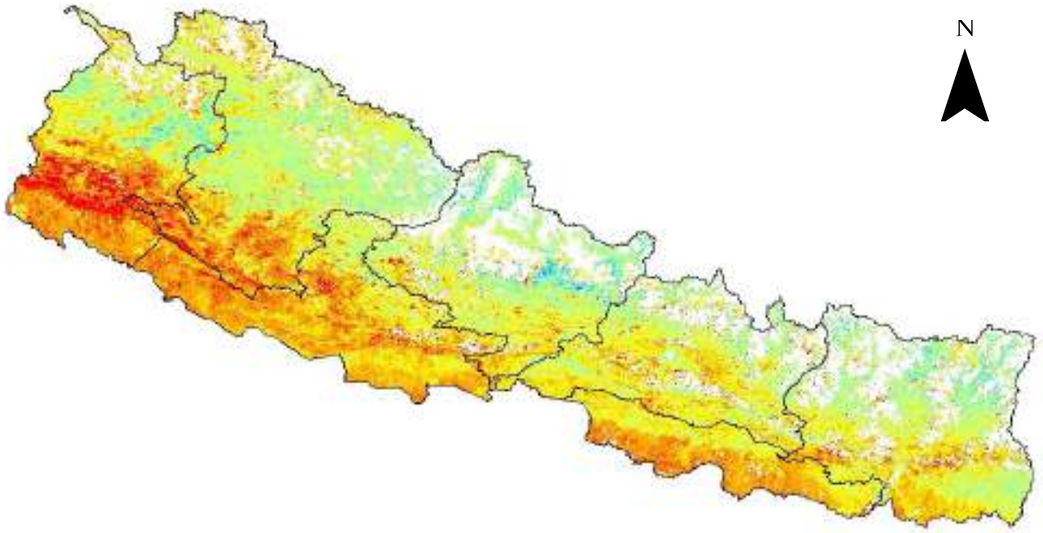
May DSI Maps

In May, drought can range from severe drought to near normal condition. Mild drought is more dominated in this pre-monsoon month. In 2000, severe drought condition was prevailed.

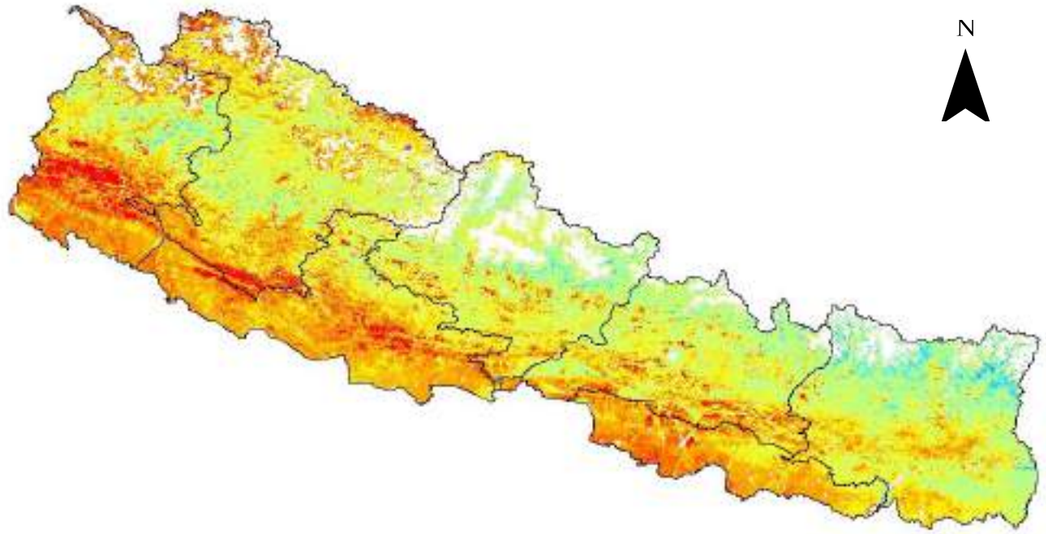
Mean May DSI Values		
Year	Values	Drought Condition
2000	-1.33	Severe Drought
2001	-0.60	Mild Drought
2002	-0.62	Mild Drought
2003	-0.84	Mild Drought
2004	-0.76	Mild Drought
2005	-0.82	Mild Drought
2006	-0.40	Incipient Drought
2007	-0.33	Incipient Drought
2008	-0.63	Mild Drought
2009	-0.60	Mild Drought
2010	-0.67	Mild Drought
2011	-0.34	Incipient Drought
2012	-0.84	Mild Drought
2013	-0.63	Mild Drought
2014	-0.66	Mild Drought
2015	-0.47	Incipient Drought
2016	-0.54	Incipient Drought
2017	-0.20	Near Normal
2018	-0.01	Near Normal
2019	-0.30	Incipient Drought
2020	-0.57	Incipient Drought



MAY 2001



MAY 2002



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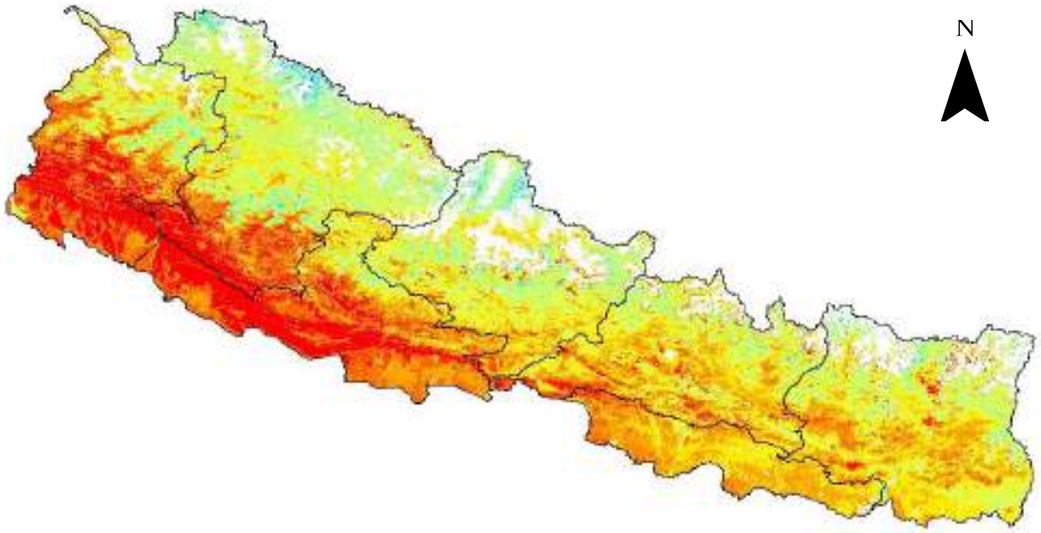
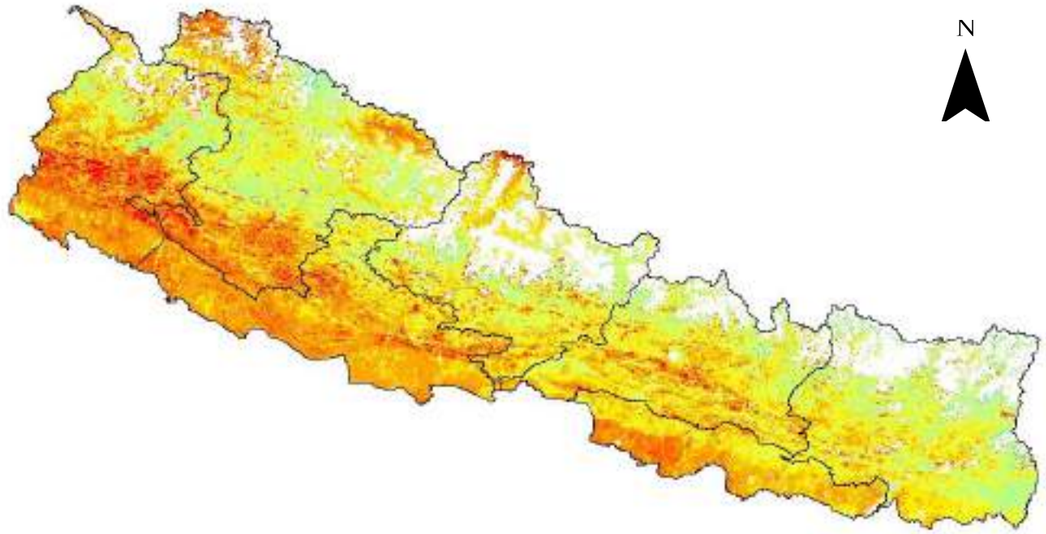


MAY 2004



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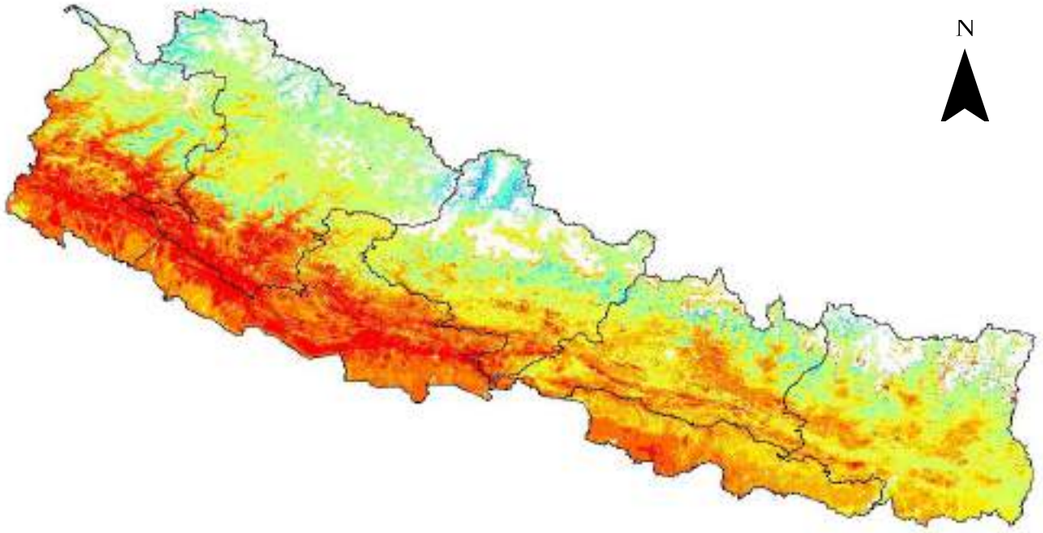
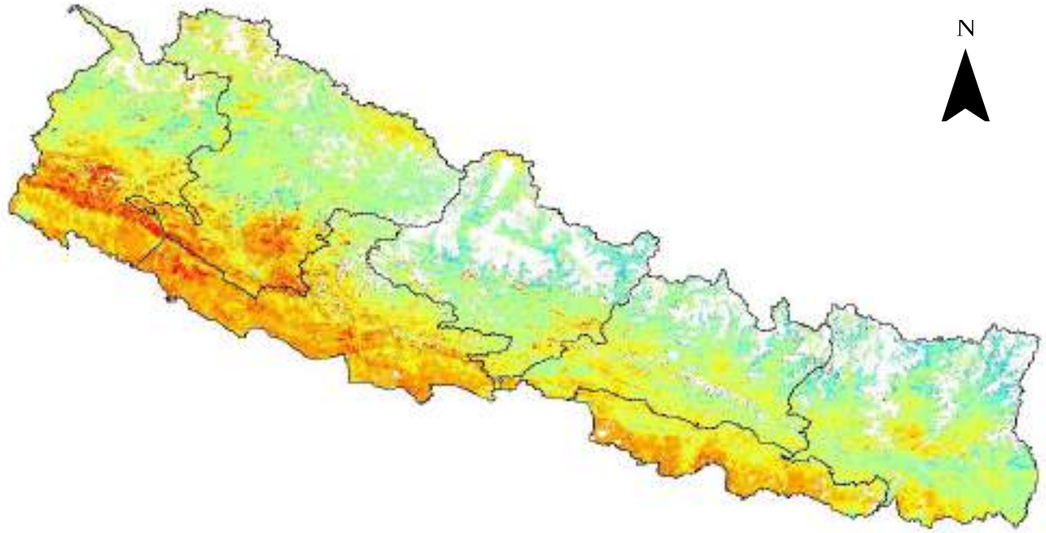


MAY 2006



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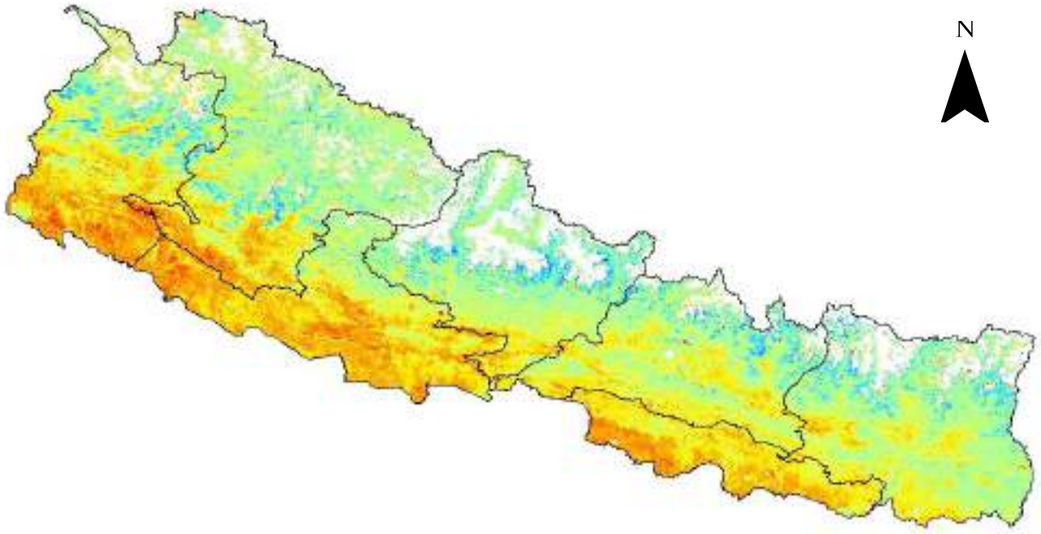
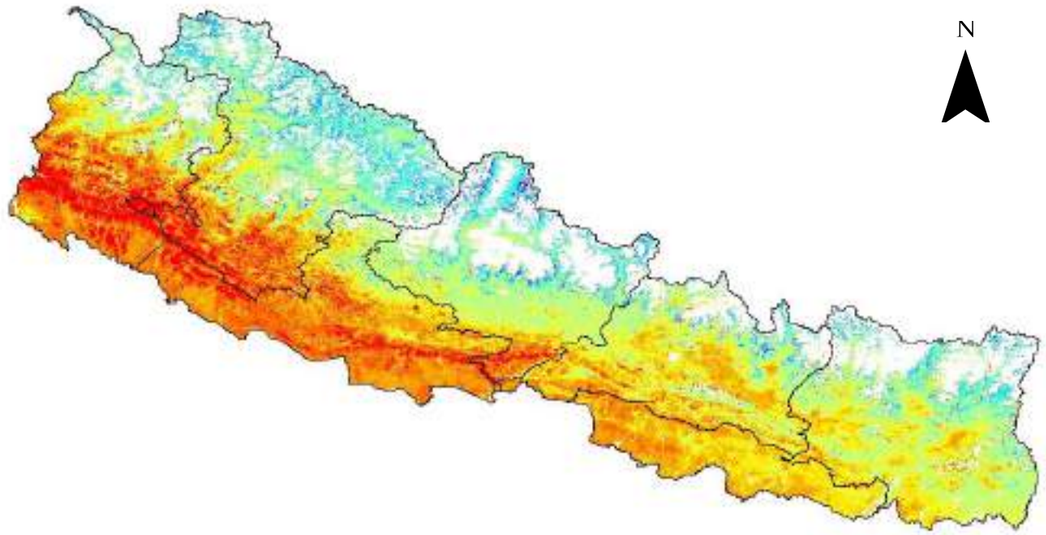


N

0 25 50 100 Kilometers

MAY 2008



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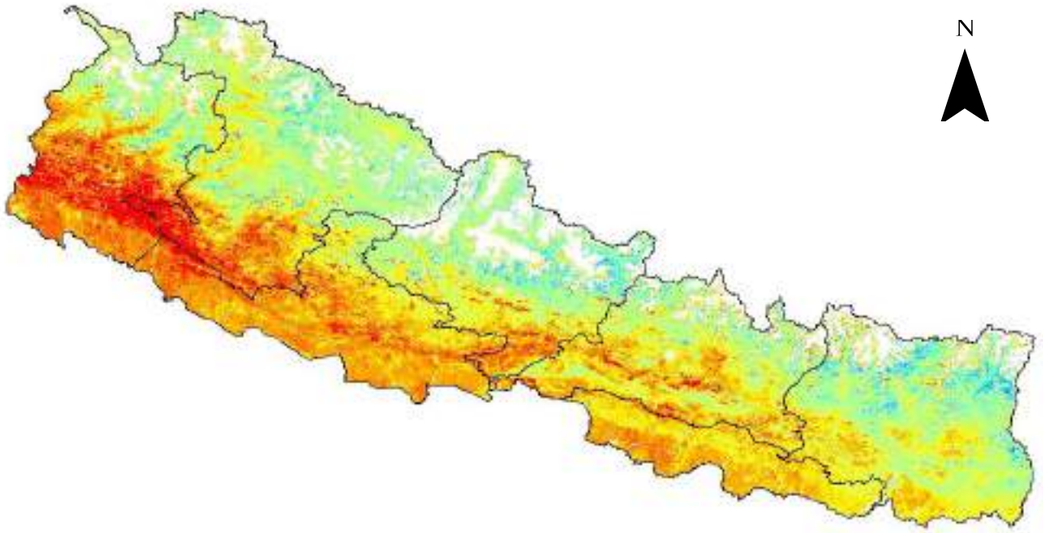

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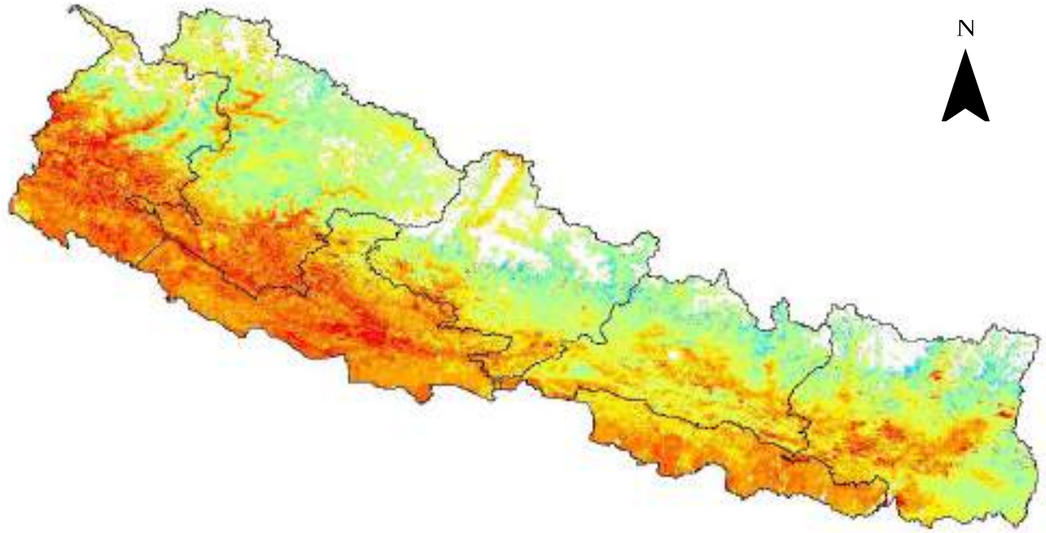

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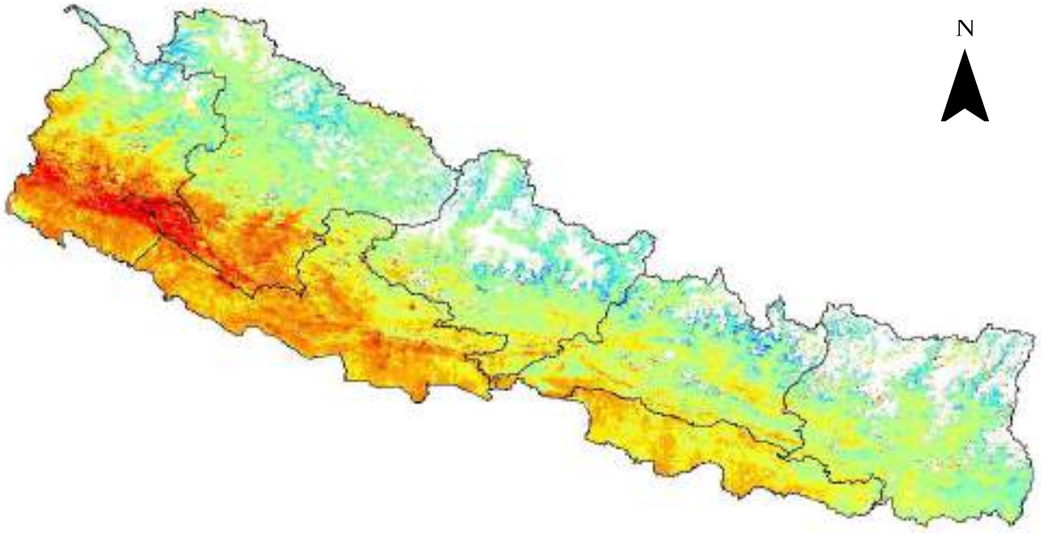

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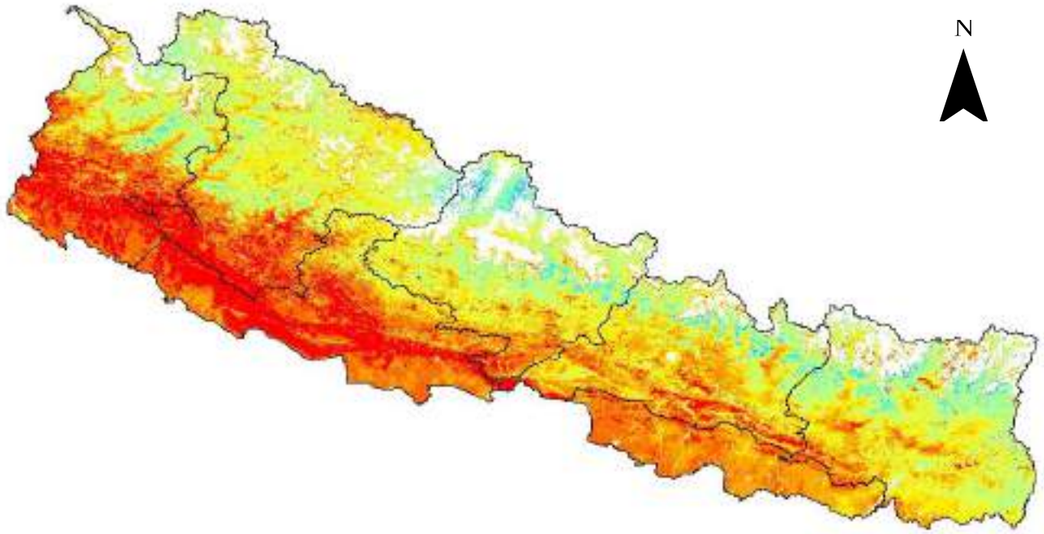
0 25 50 100 Kilometers

MAY 2012



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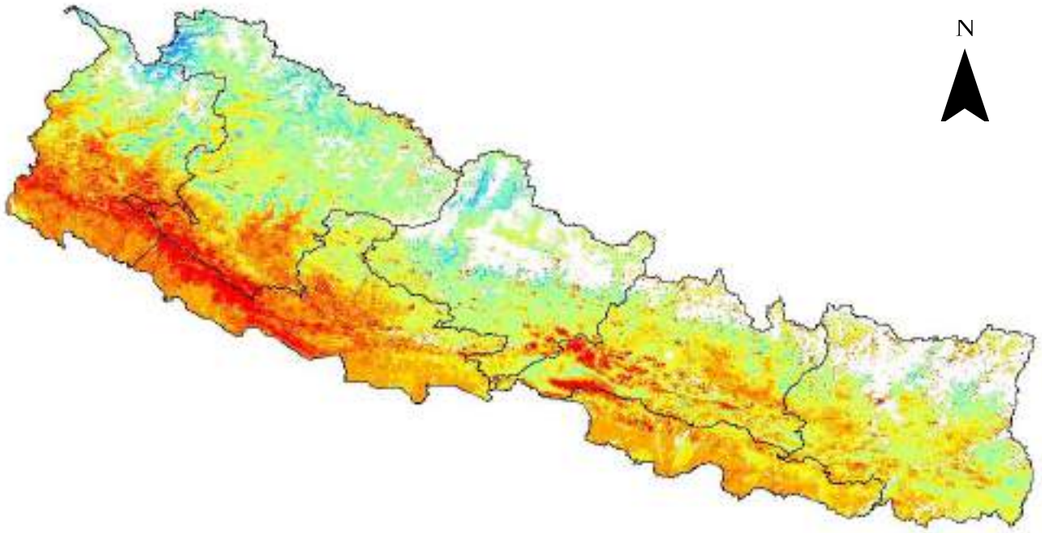

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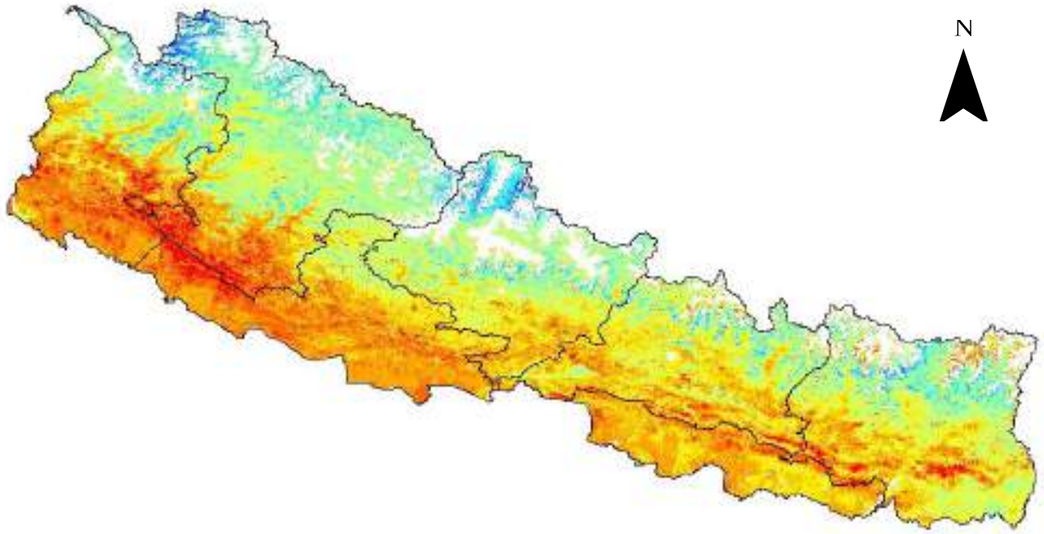
MAY 2014



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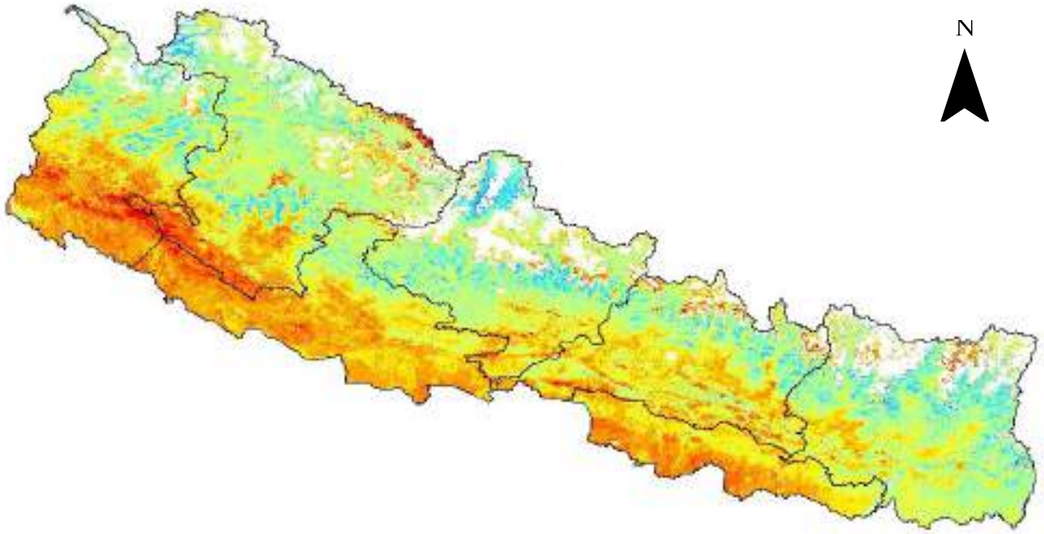

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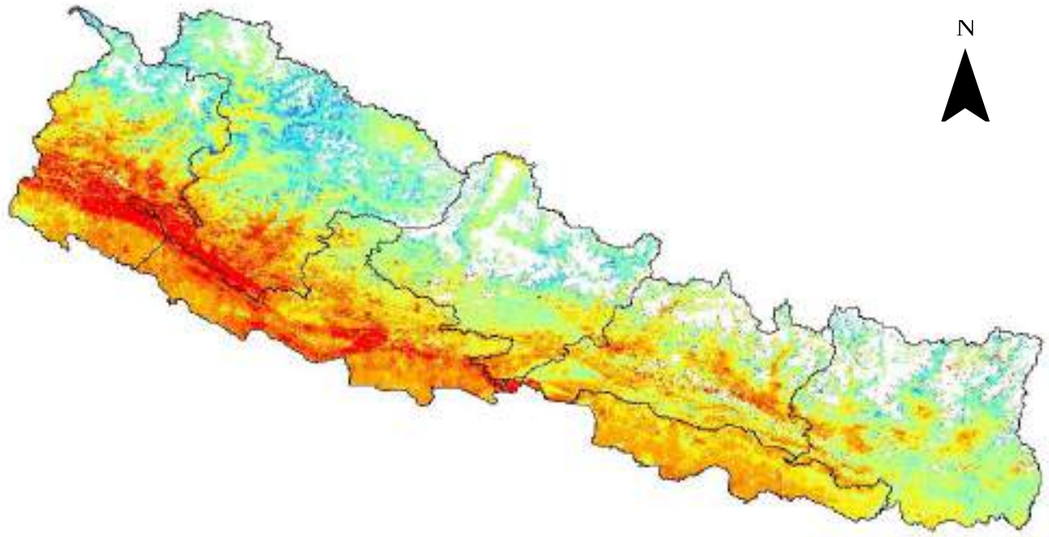

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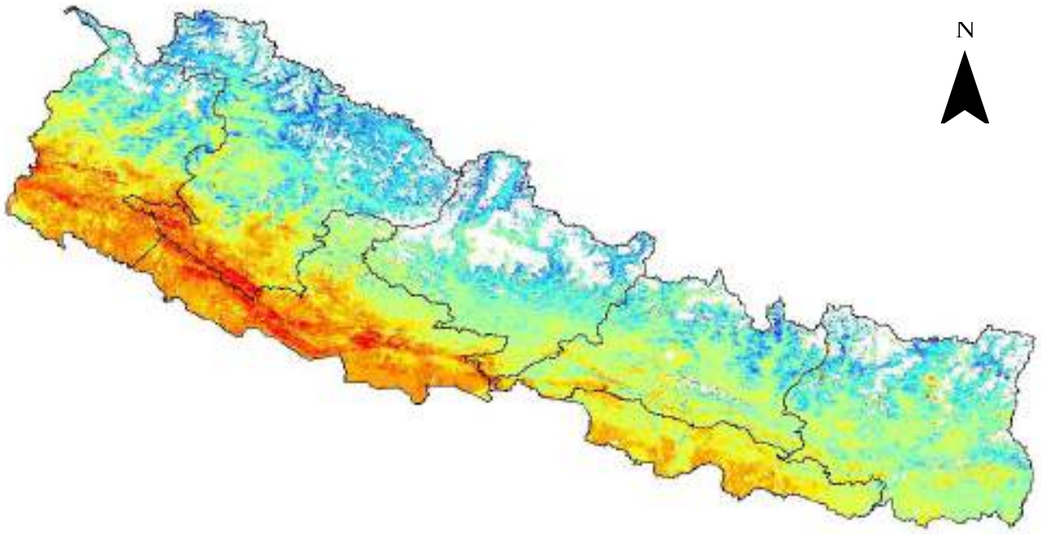

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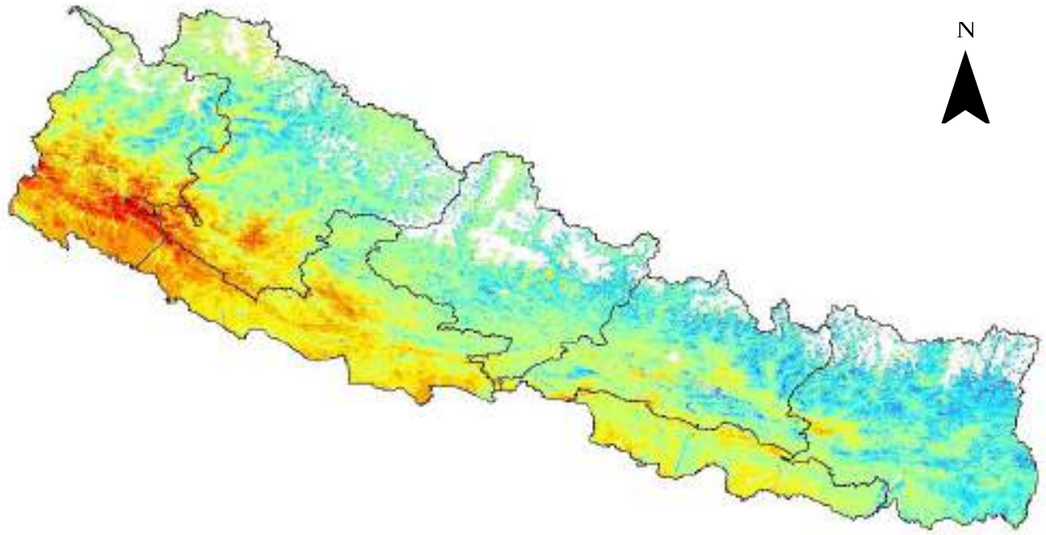

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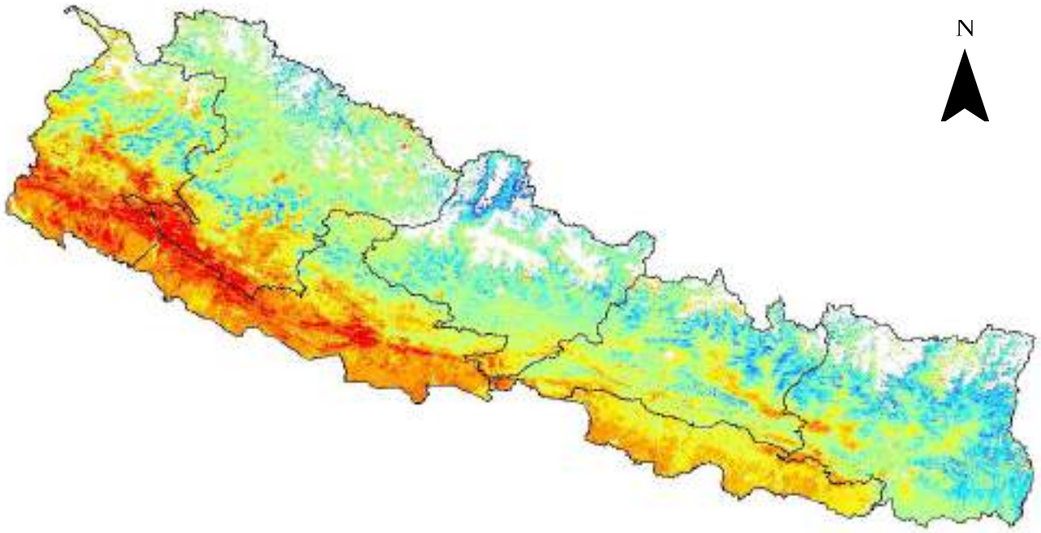
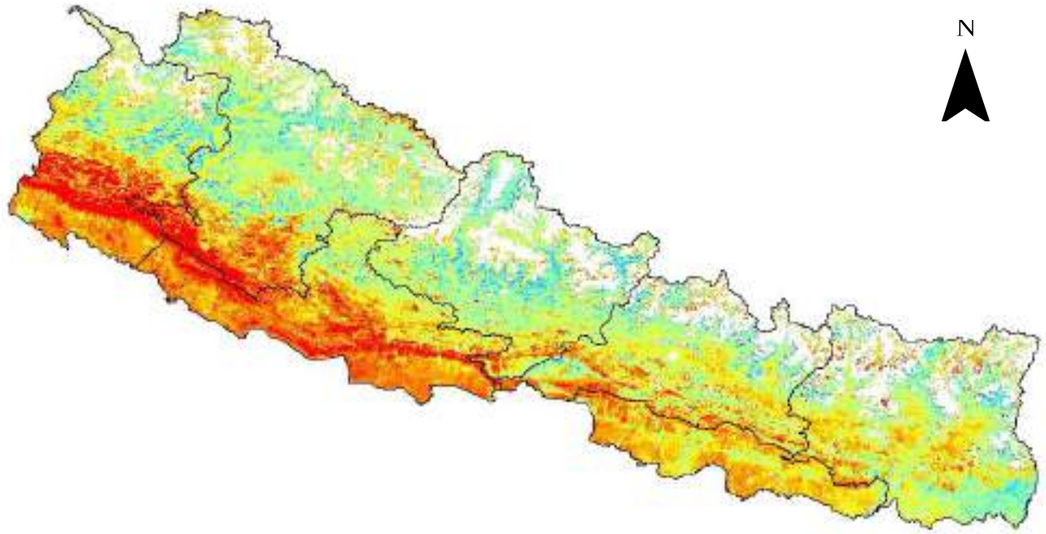


MAY 2020



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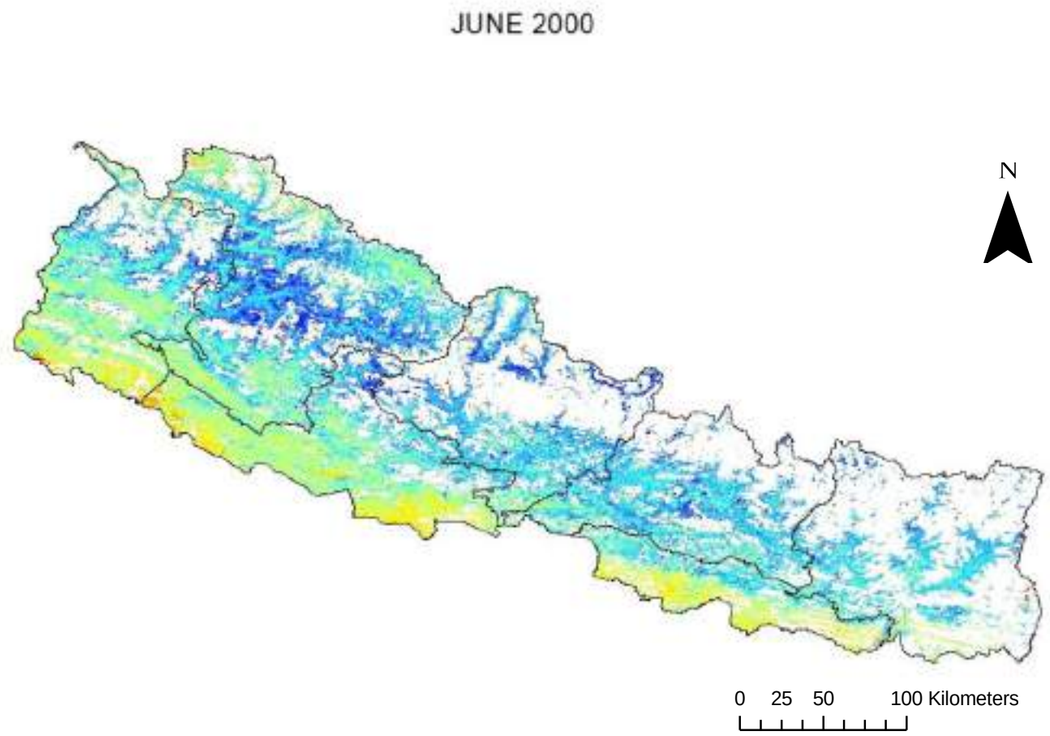
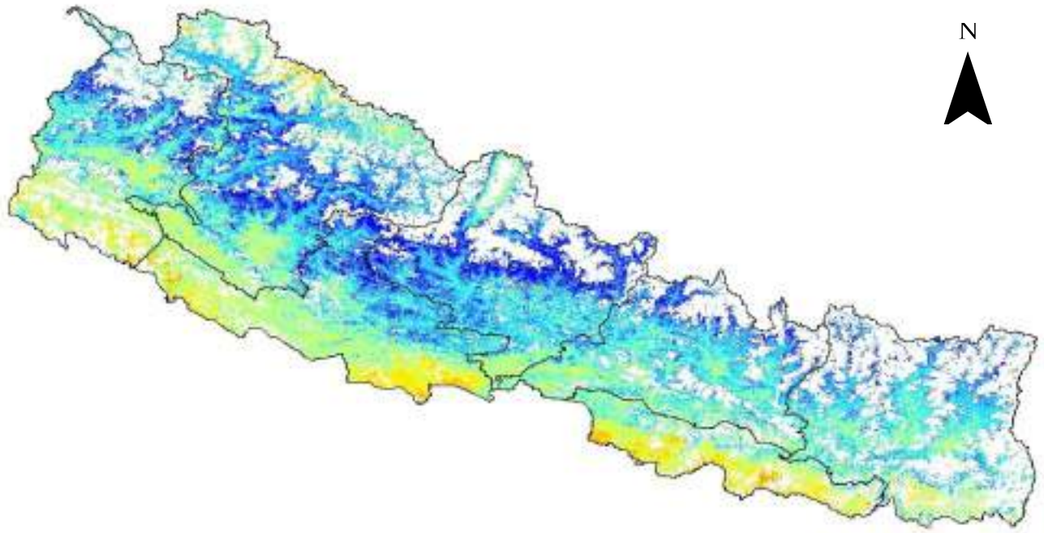
June DSI Maps

In June (monsoon month), drought is marked by incipient drought to slightly wet condition. June undergoes near normal conditions in most of the years.

Mean June DSI Values		
Year	Values	Drought Condition
2000	-0.57	Incipient Drought
2001	0.55	Incipient Wet Spell
2002	0.07	Near Normal
2003	-0.52	Incipient Drought
2004	0.09	Near Normal
2005	-0.55	Incipient Drought
2006	0.33	Incipient Wet Spell
2007	0.41	Incipient Wet Spell
2008	0.64	Slightly Wet
2009	-0.20	Near Normal
2010	-0.17	Near Normal
2011	0.36	Incipient Wet Spell
2012	-0.47	Incipient Drought
2013	0.58	Incipient Wet Spell
2014	-0.24	Near Normal
2015	-0.03	Near Normal
2016	0.29	Near Normal
2017	0.22	Near Normal
2018	0.46	Incipient Wet Spell
2019	0.15	Near Normal
2020	0.47	Incipient Wet Spell



JUNE 2001



N

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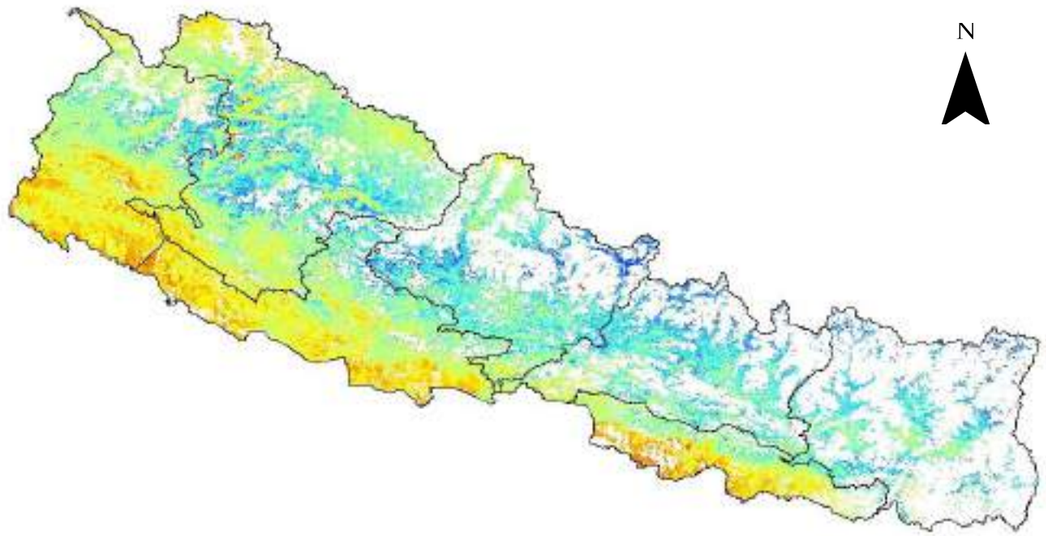
JUNE 2002



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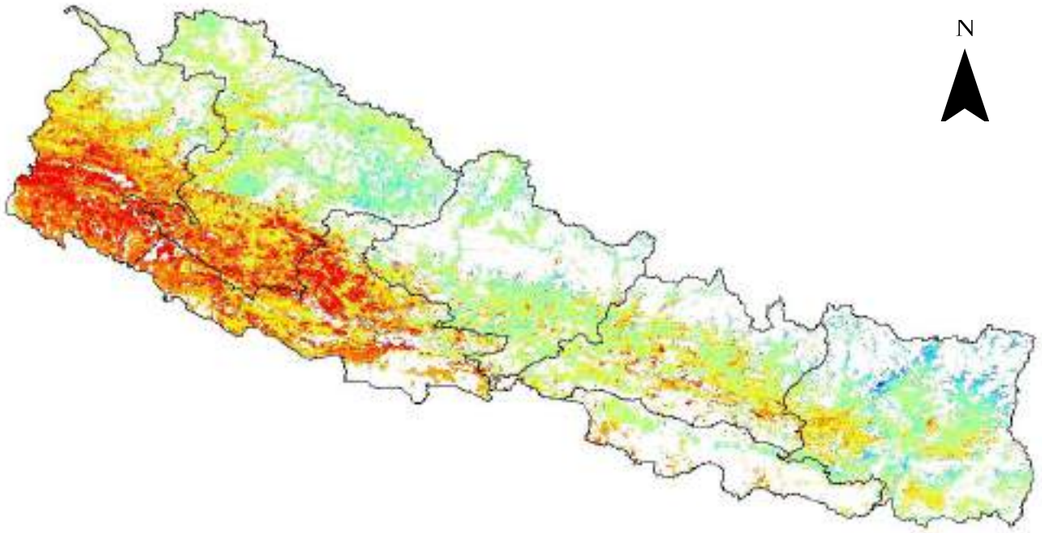

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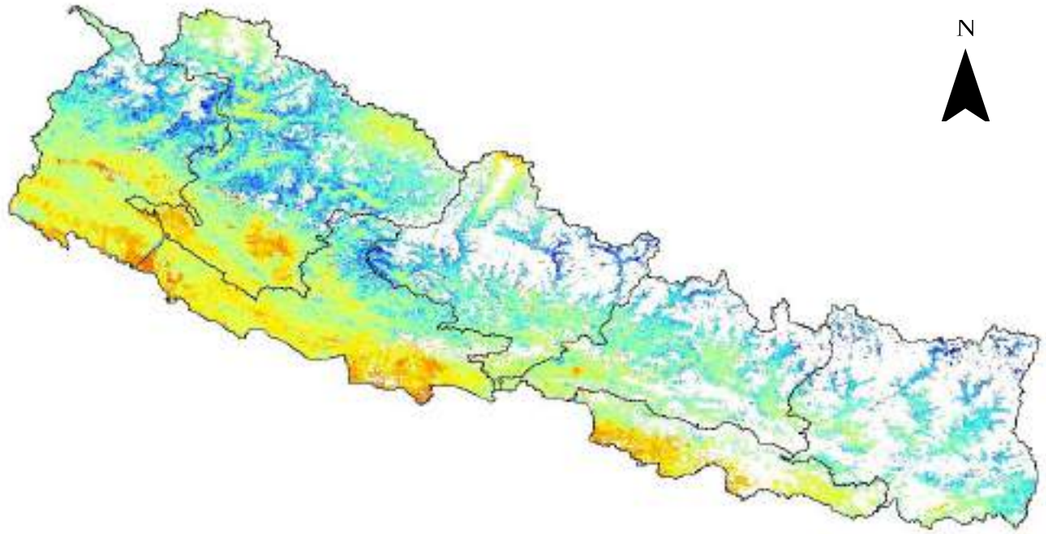

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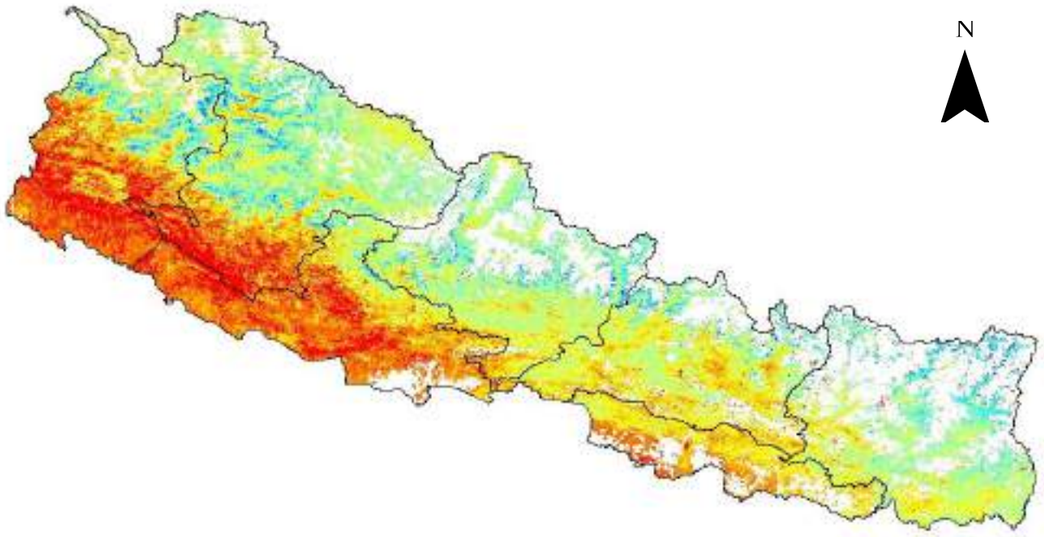

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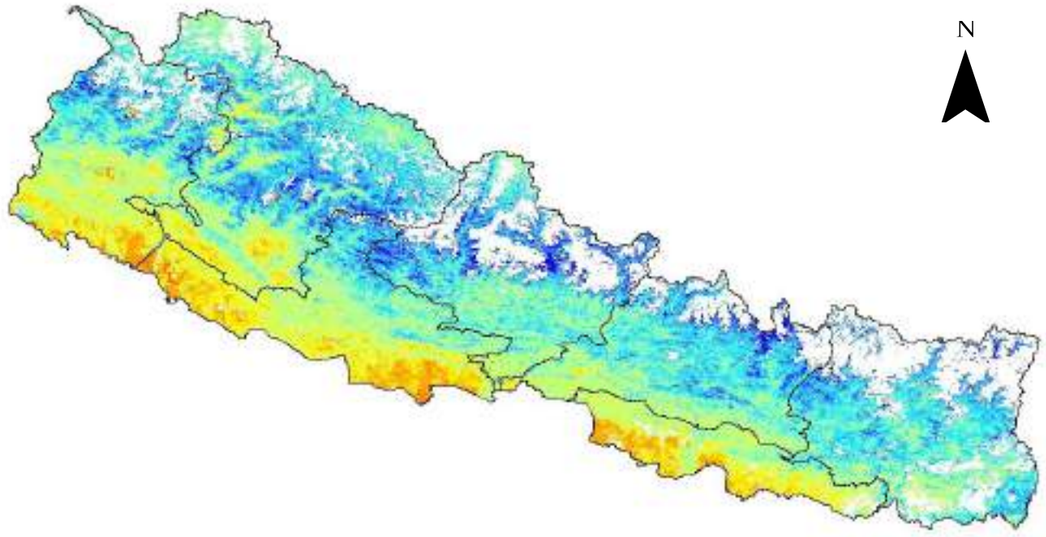

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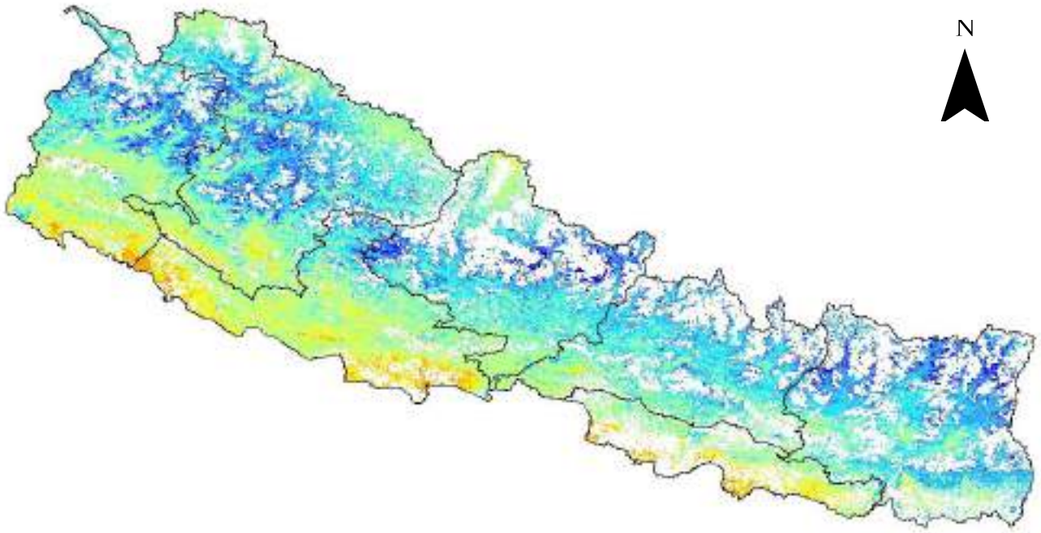

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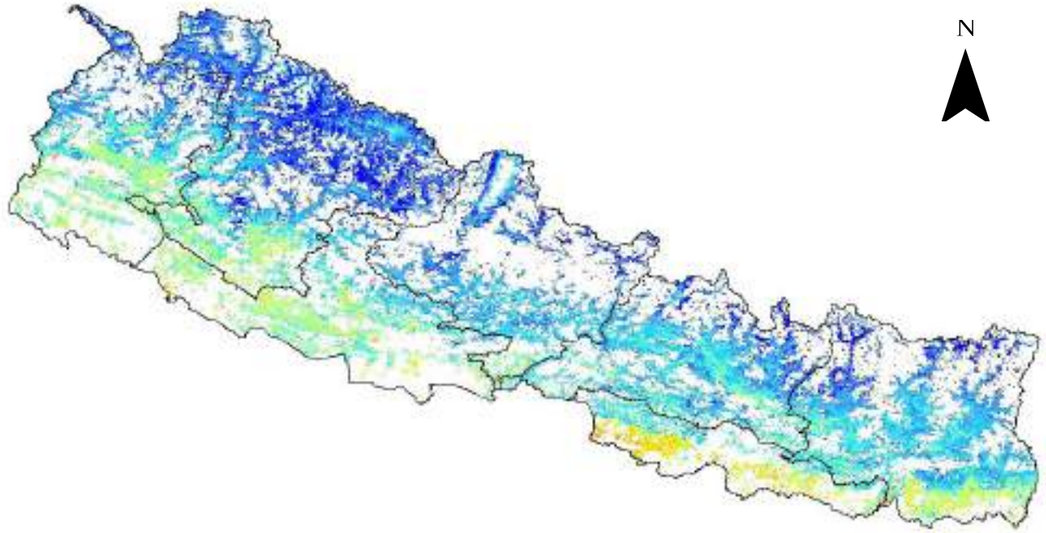

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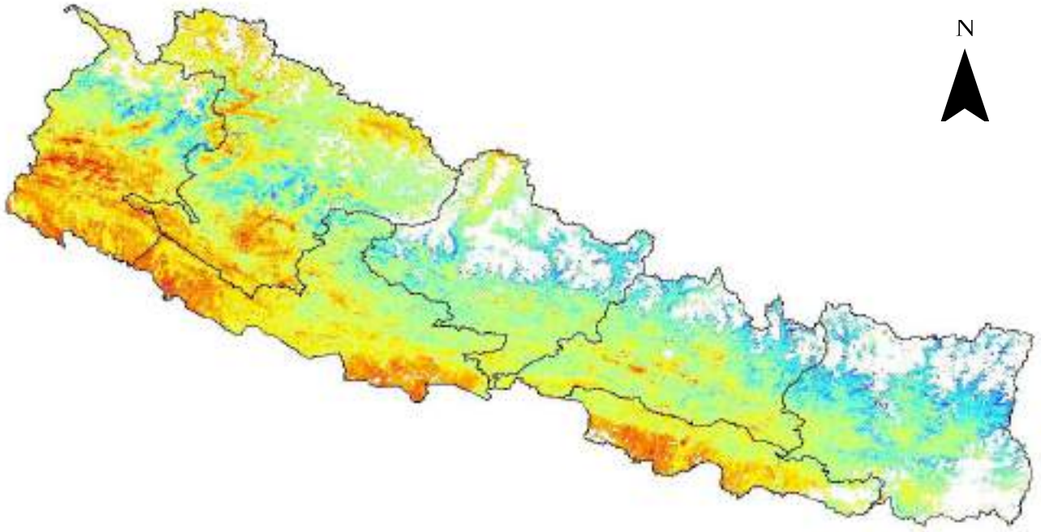

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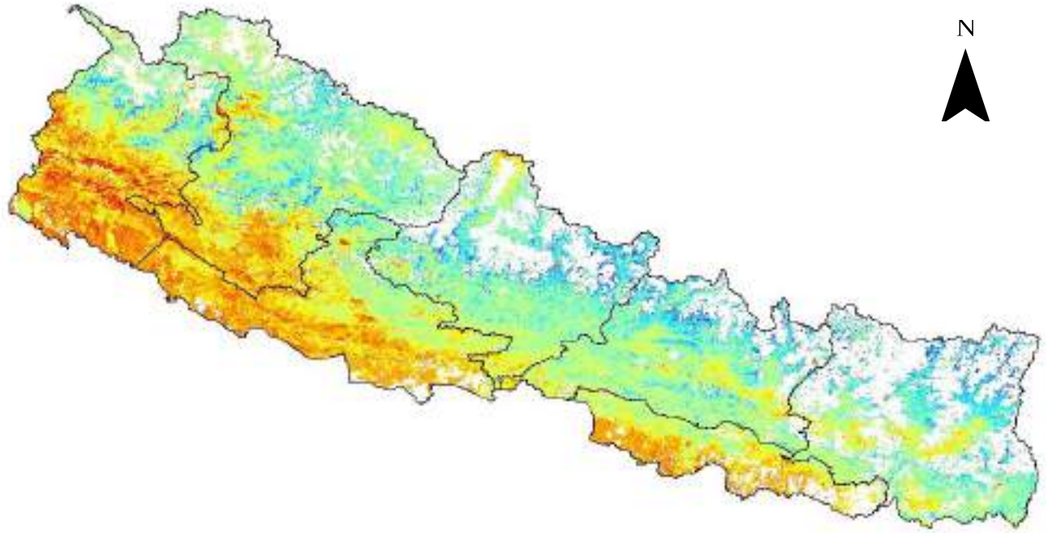

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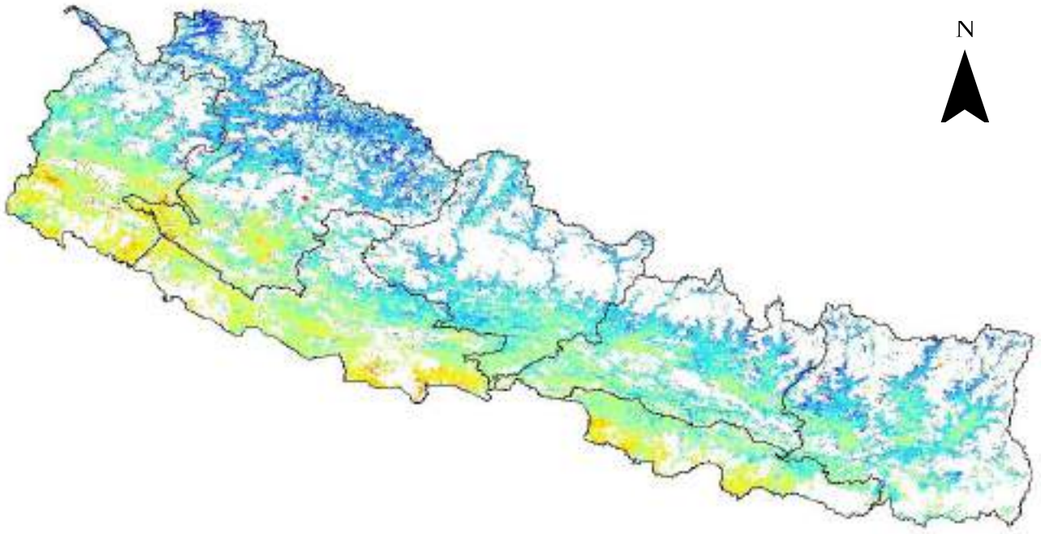

N

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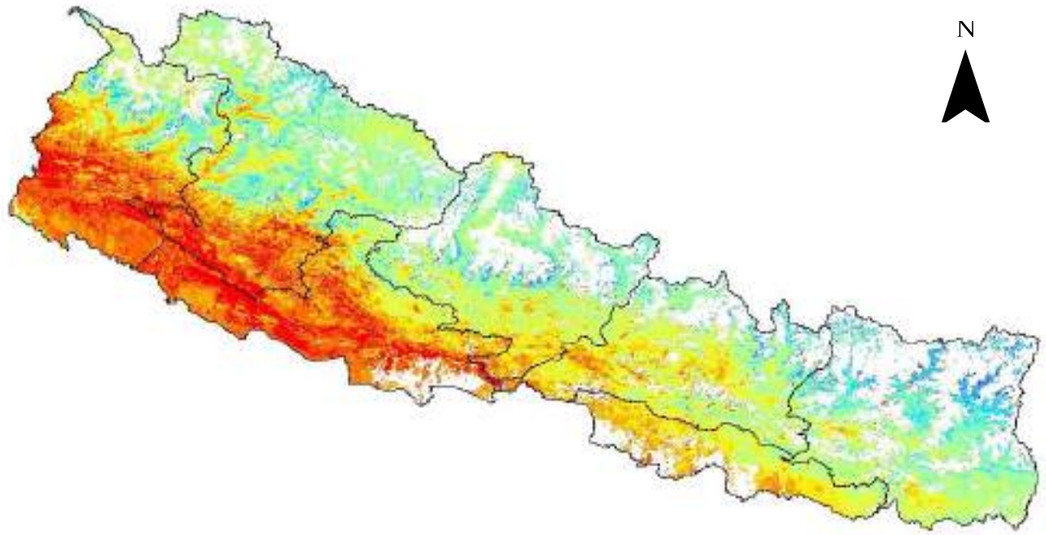

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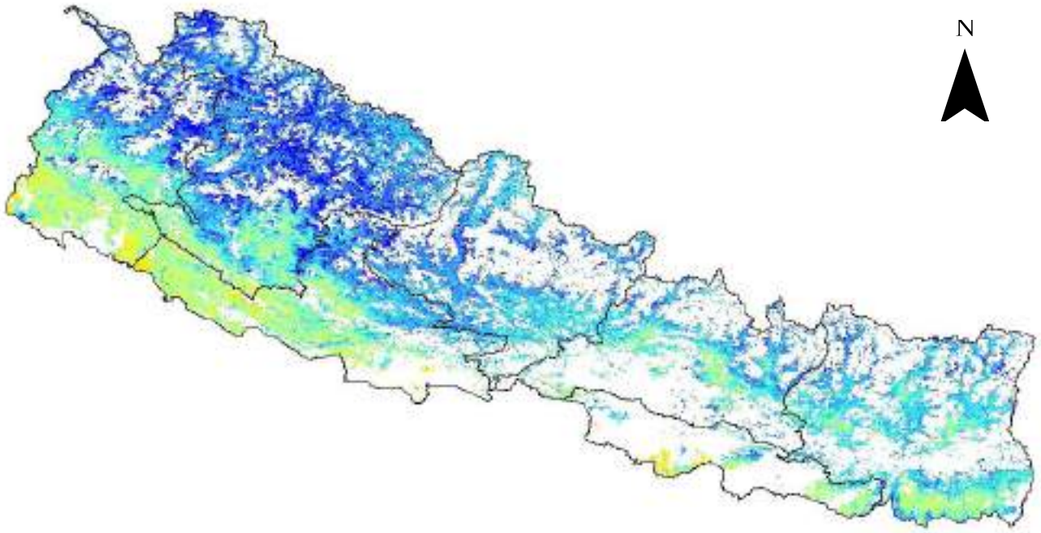
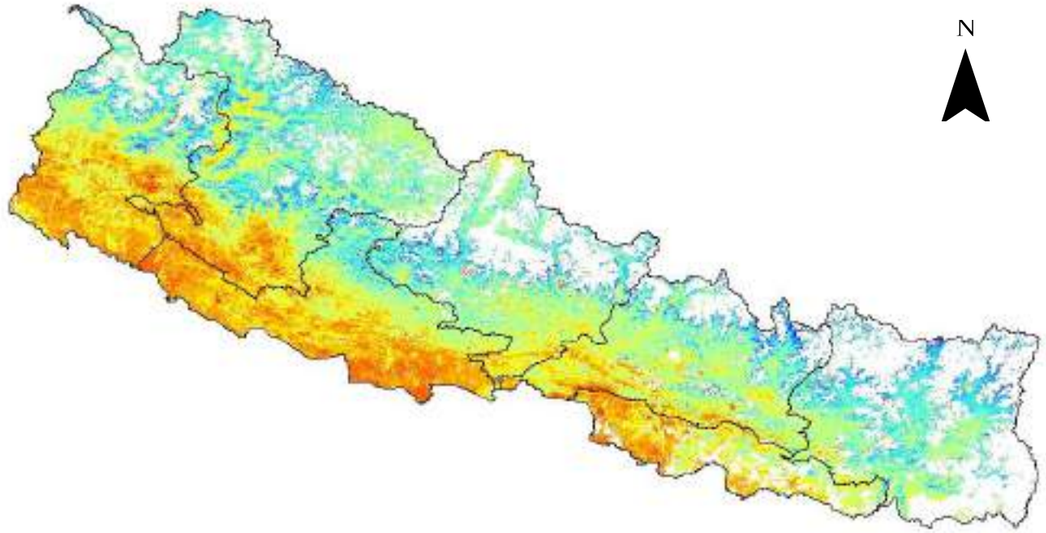
JUNE 2013



JUNE 2014



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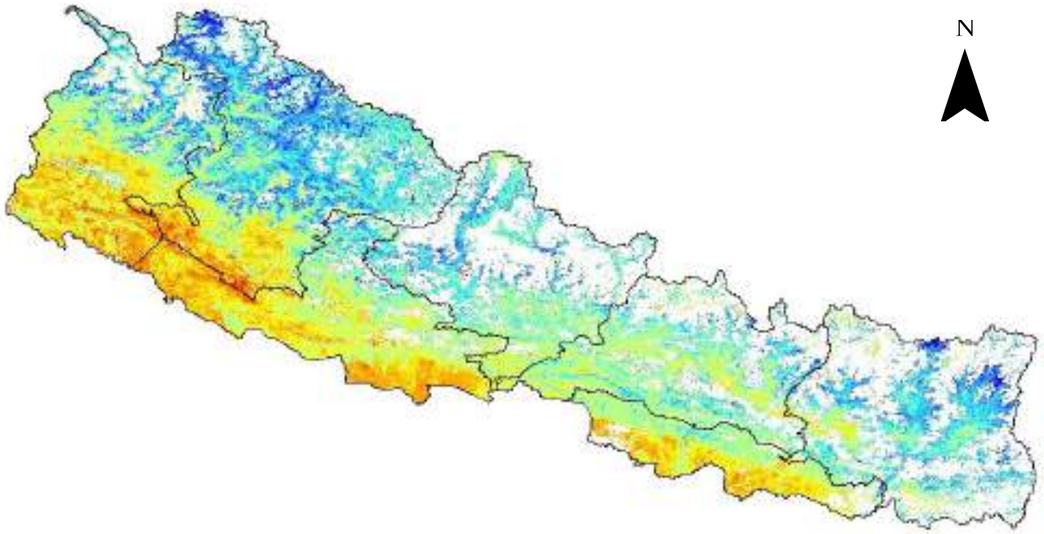
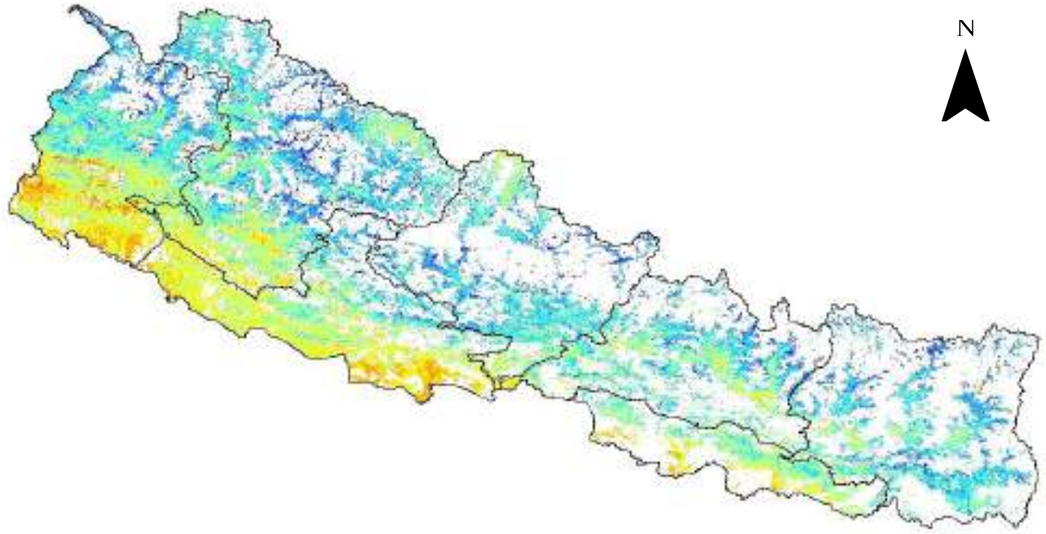


JUNE 2016



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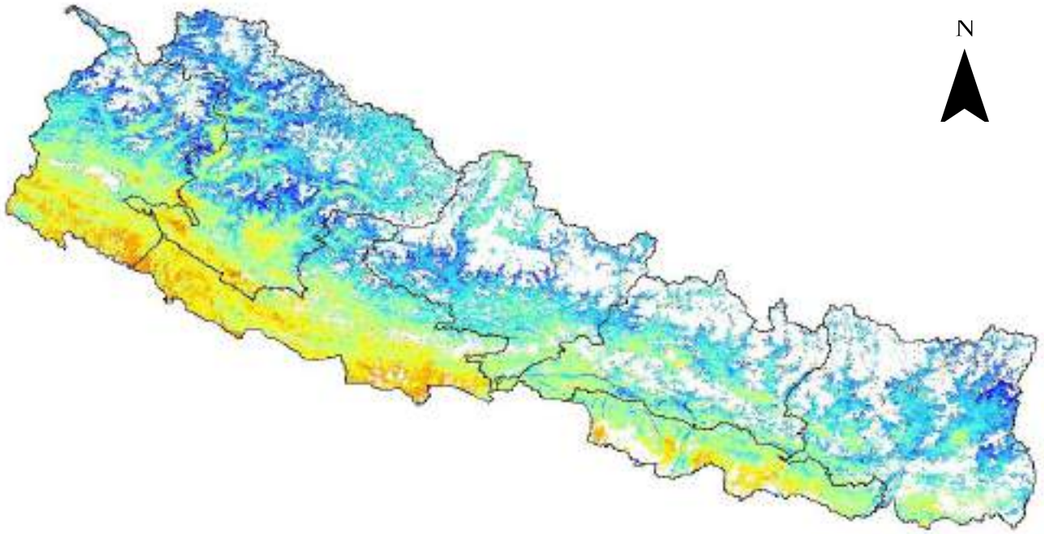
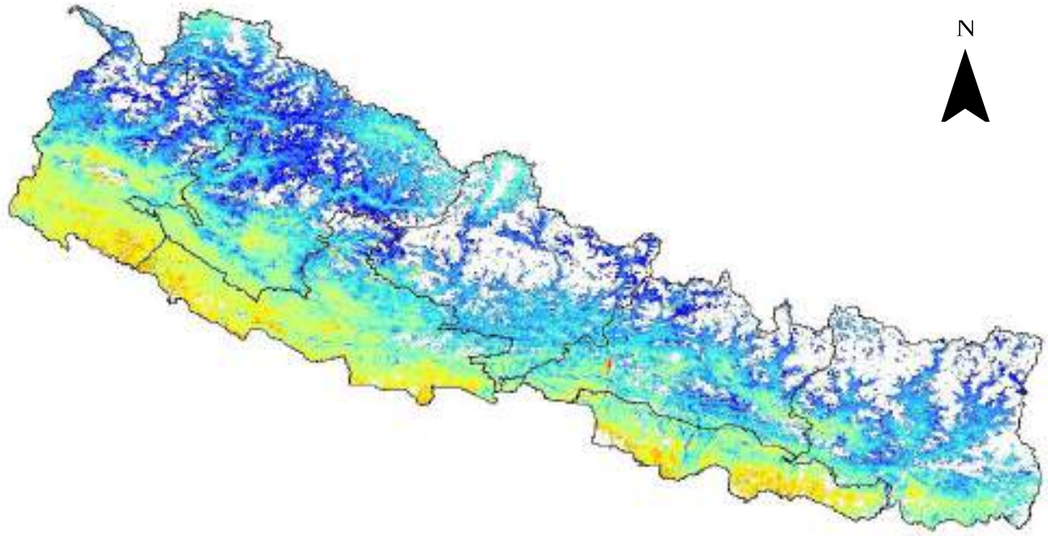


JUNE 2018



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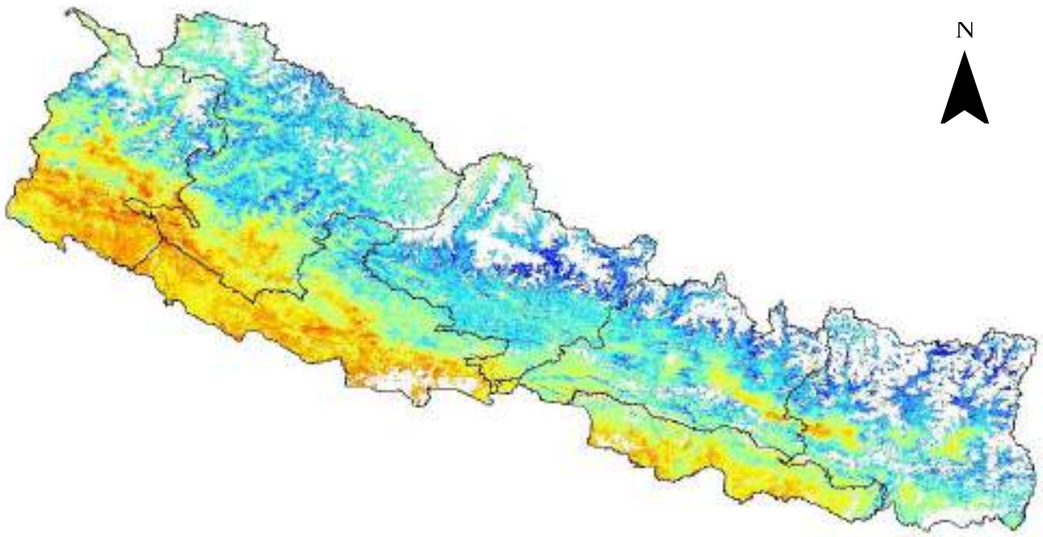
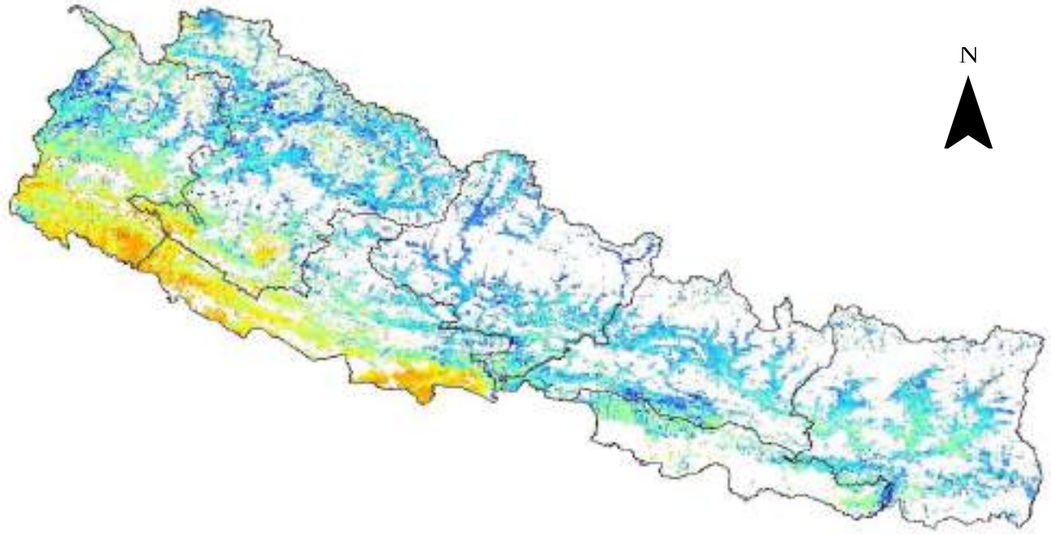


JUNE 2020



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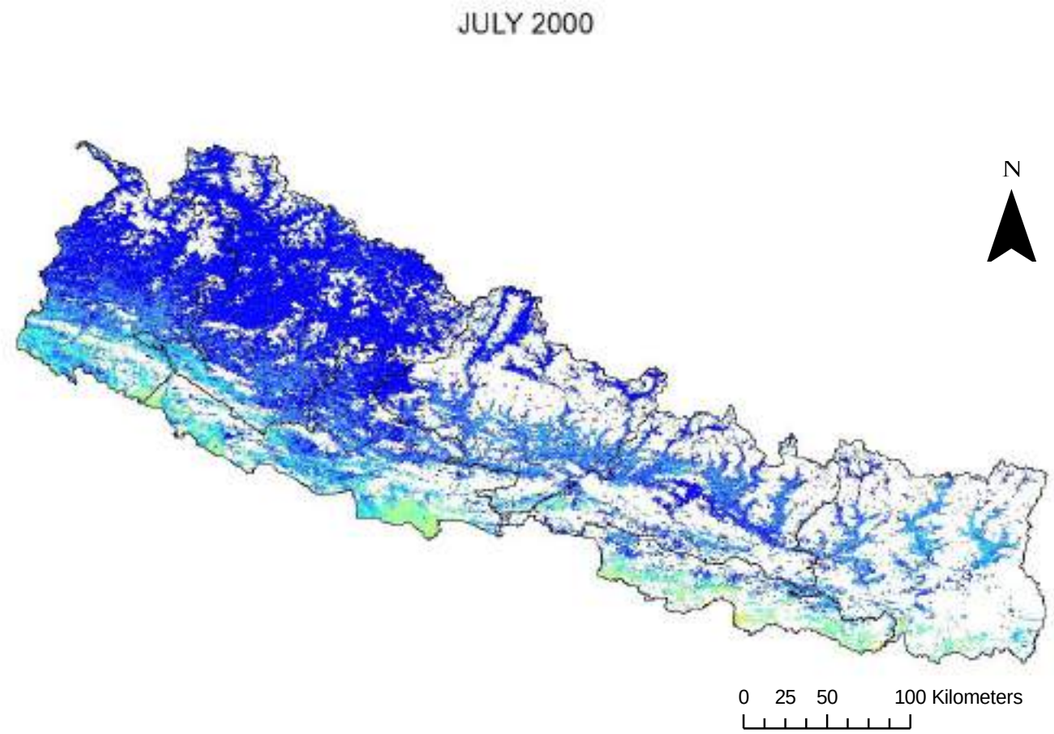
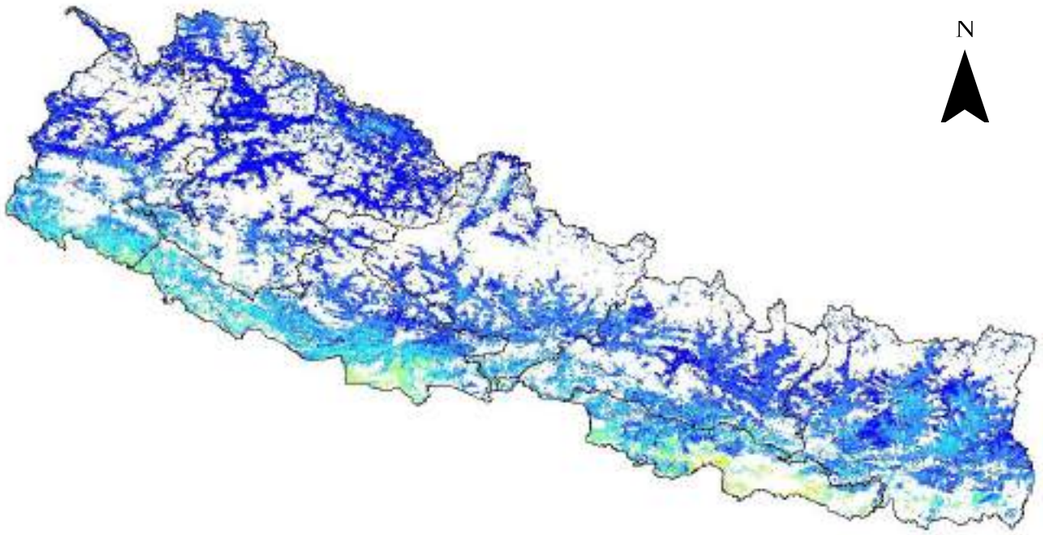
July DSI Maps

In July, drought condition vary from incipient wet spell to extremely wet condition. July is the monsoon month and was seen in wet condition in most of the years.

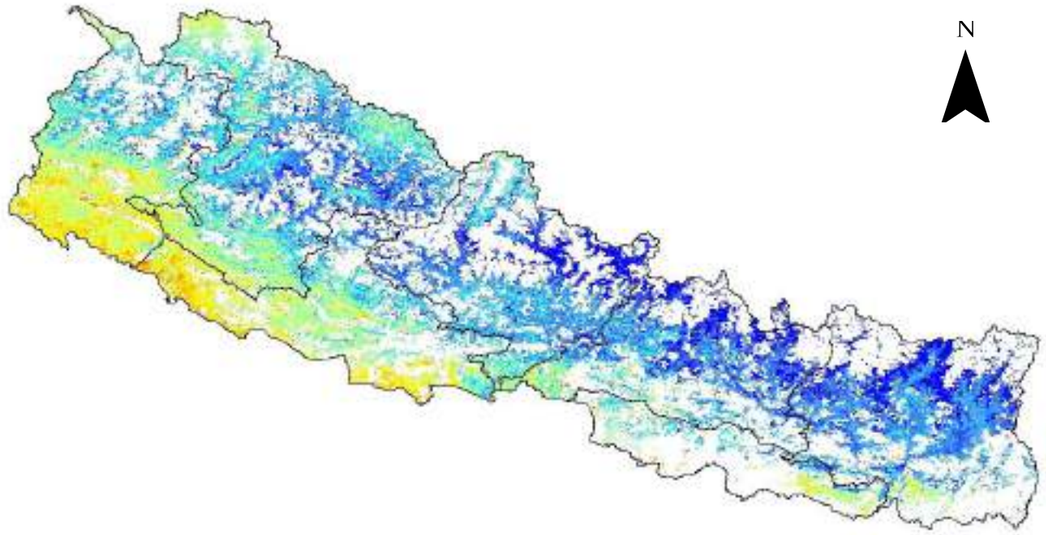
Mean July DSI Values		
Year	Values	Drought Condition
2000	0.47	Incipient Wet Spell
2001	1.19	Moderately Wet
2002	0.90	Moderately Wet
2003	1.47	Very Wet
2004	1.12	Moderately Wet
2005	1.35	Very Wet
2006	1.44	Very Wet
2007	1.25	Very Wet
2008	1.58	Extremely Wet
2009	1.09	Moderately Wet
2010	1.39	Very Wet
2011	1.50	Extremely Wet
2012	1.51	Extremely Wet
2013	1.51	Extremely Wet
2014	1.35	Very Wet
2015	0.82	Slightly wet
2016	1.62	Extremely Wet
2017	1.54	Extremely Wet
2018	1.59	Extremely Wet
2019	1.25	Very Wet
2020	1.54	Extremely Wet



JULY 2001



JULY 2002



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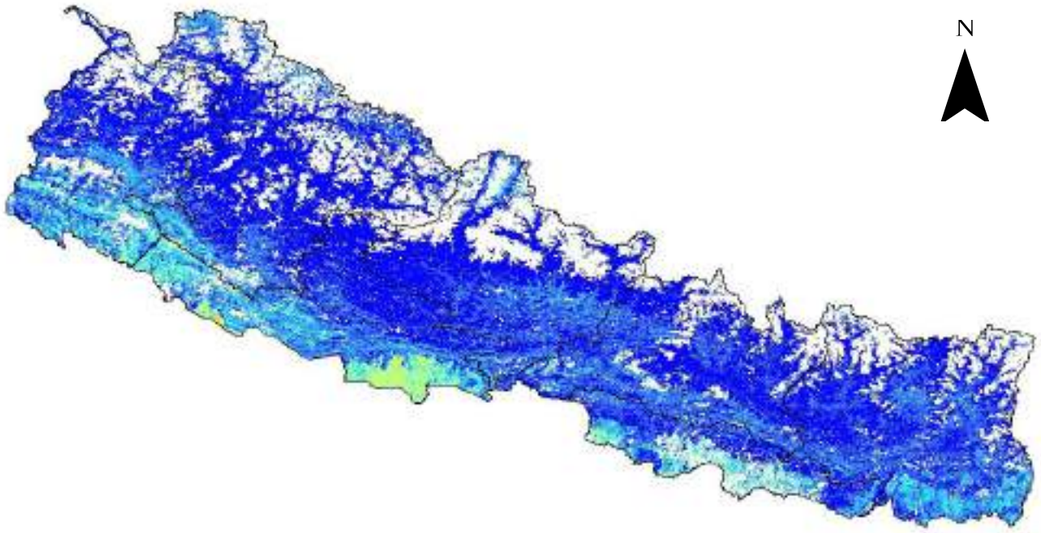
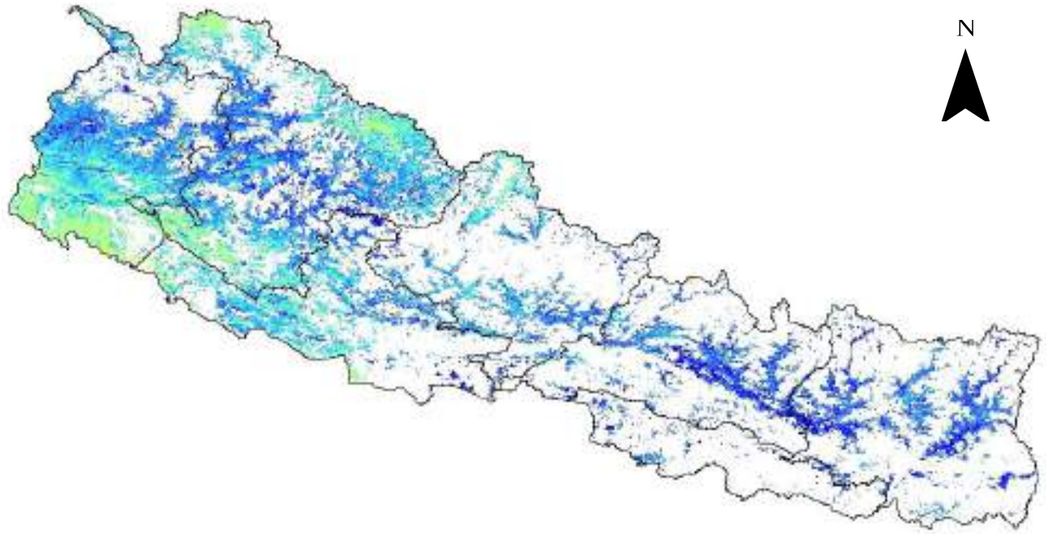
JULY 2003



N

0 25 50 100 Kilometers

JULY 2004



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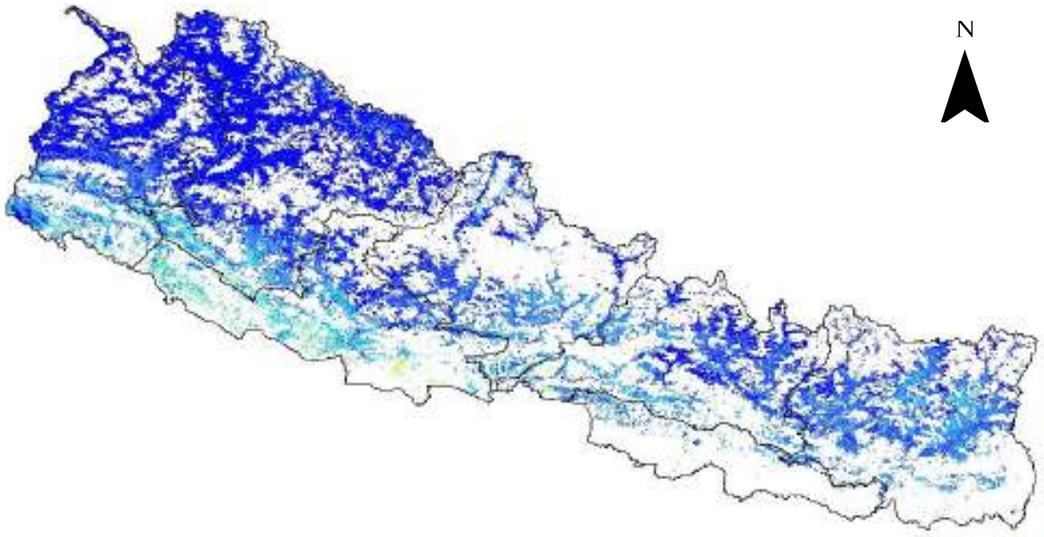
JULY 2005



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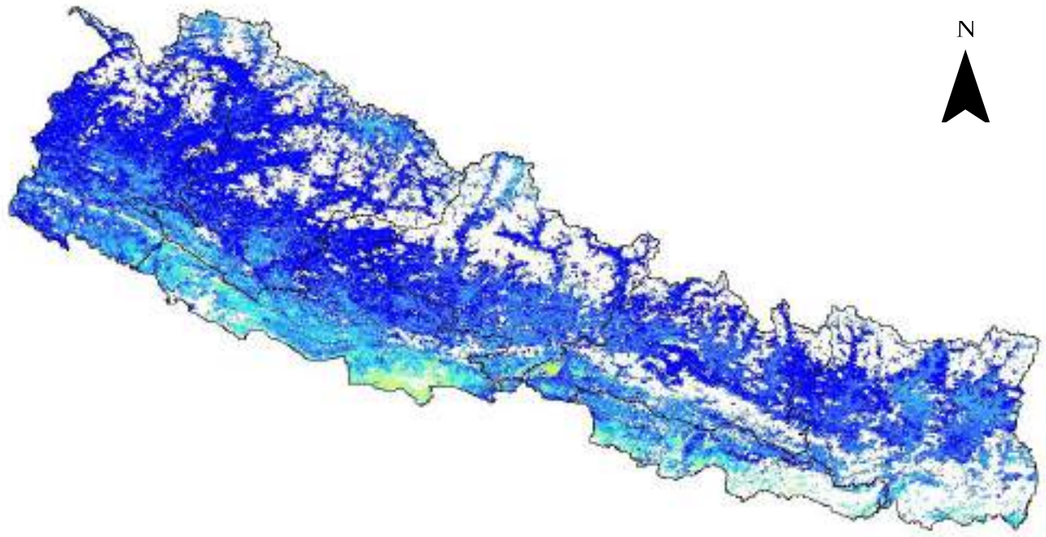

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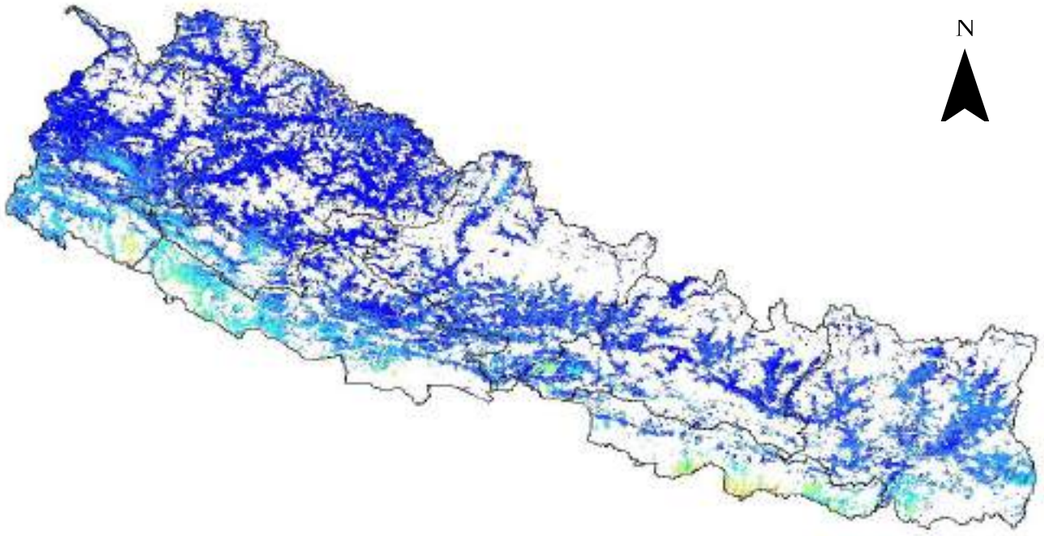

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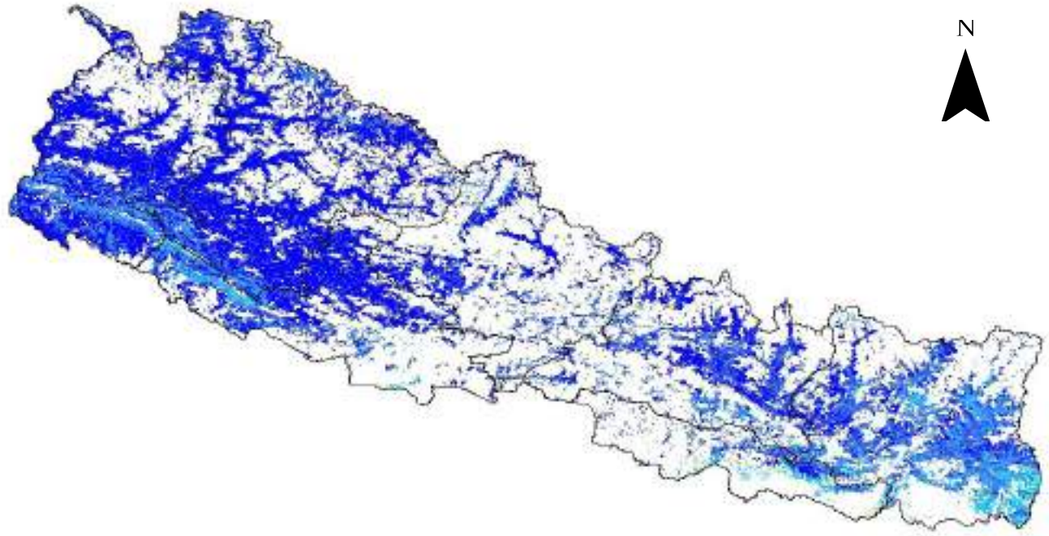

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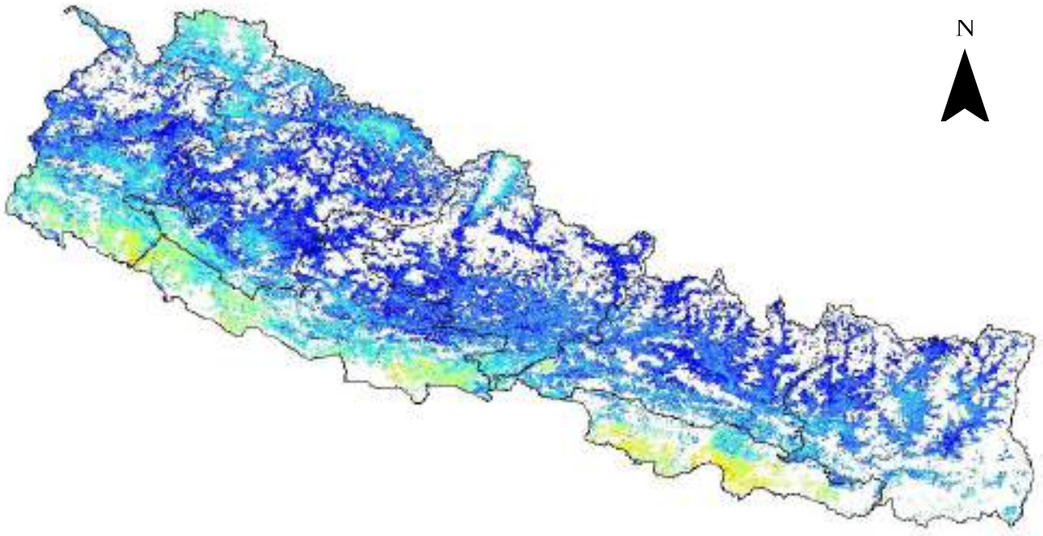
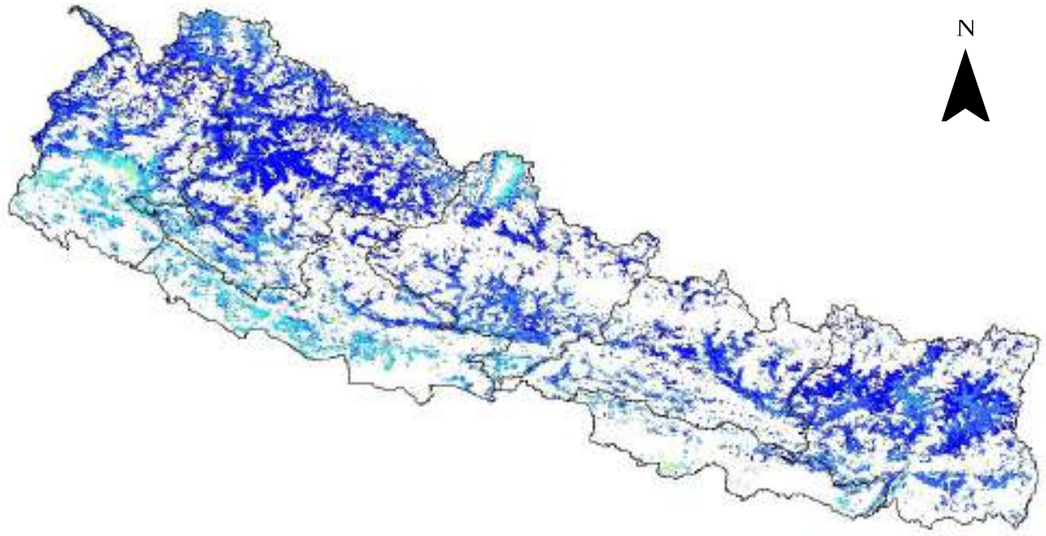


JULY 2010



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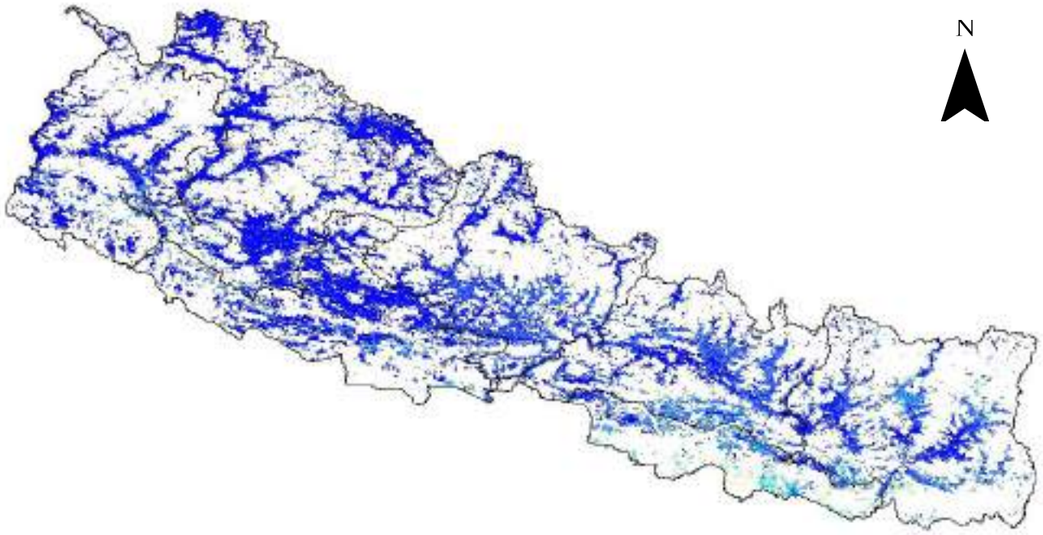
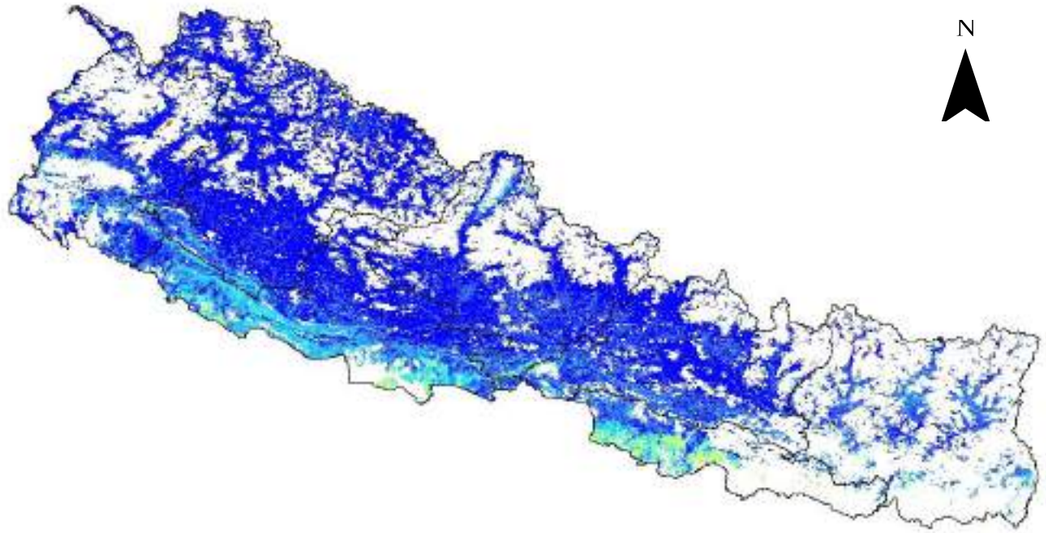


JULY 2012



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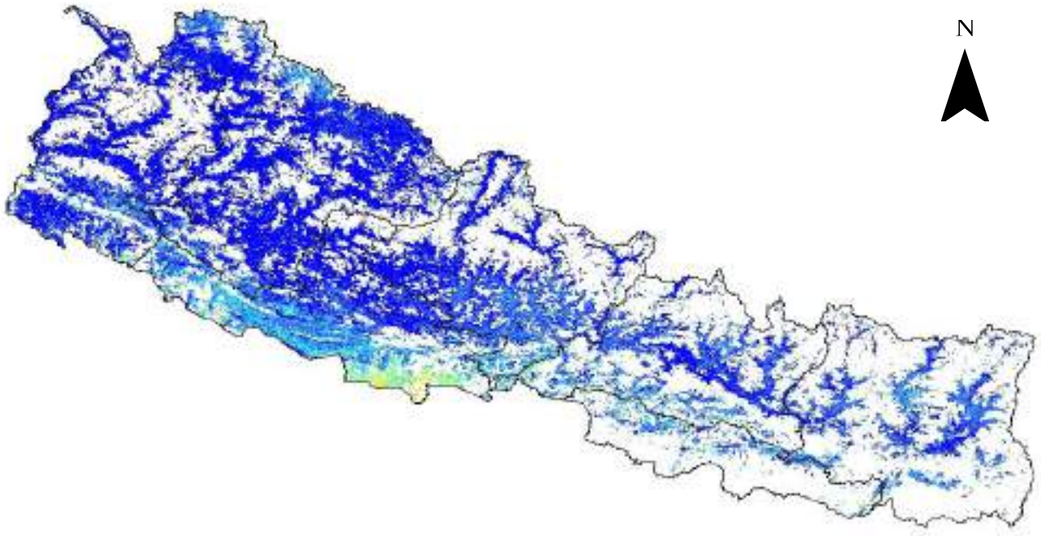

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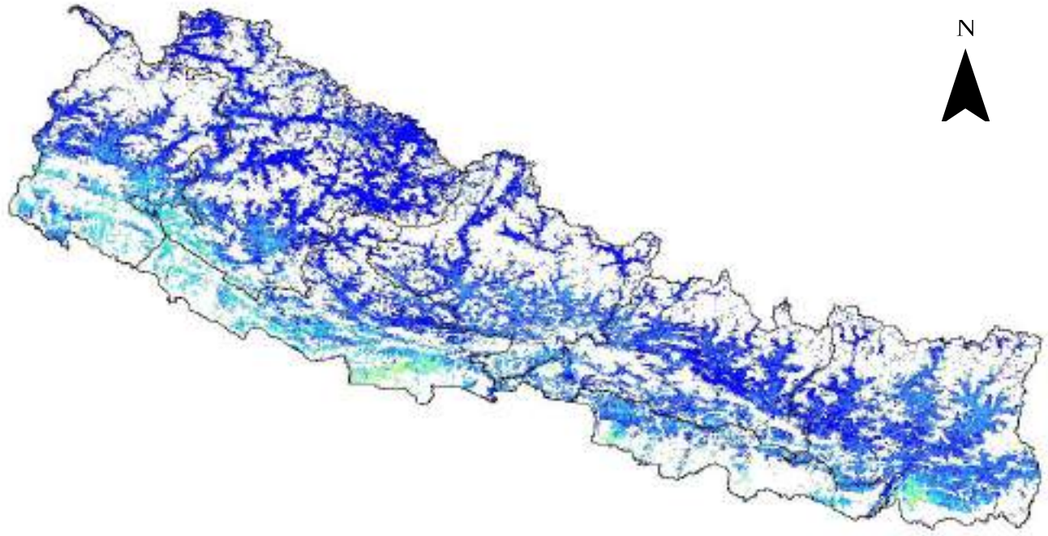

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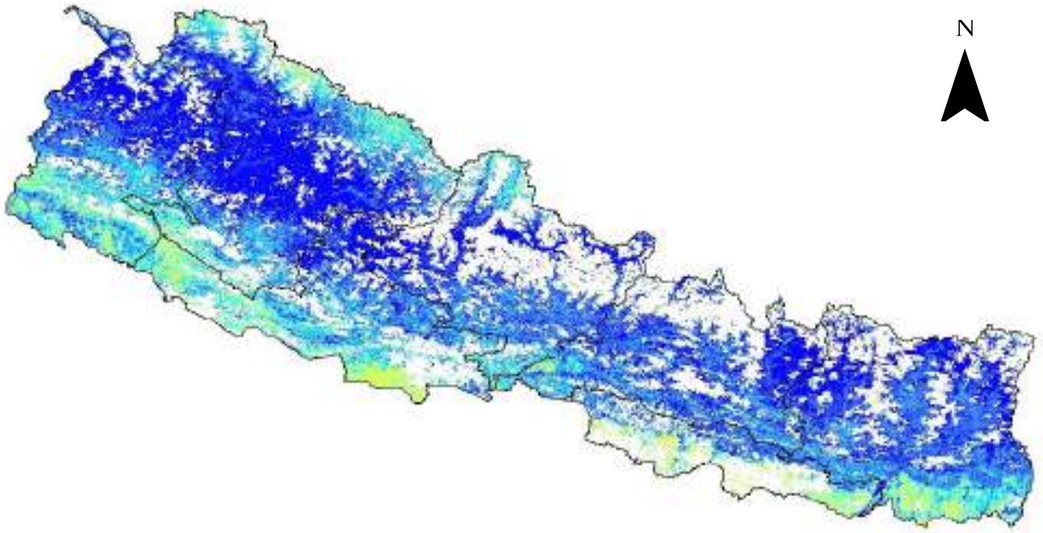

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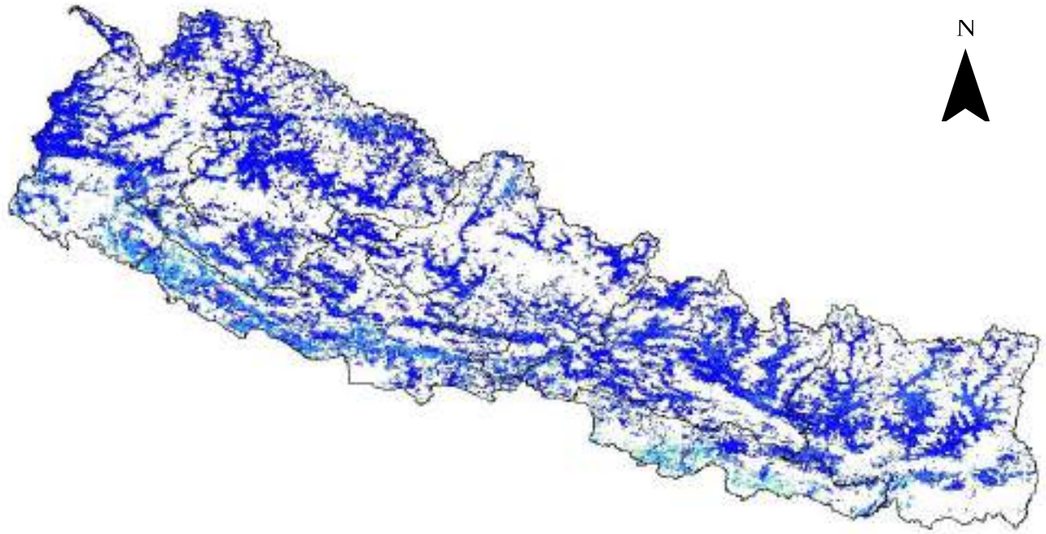

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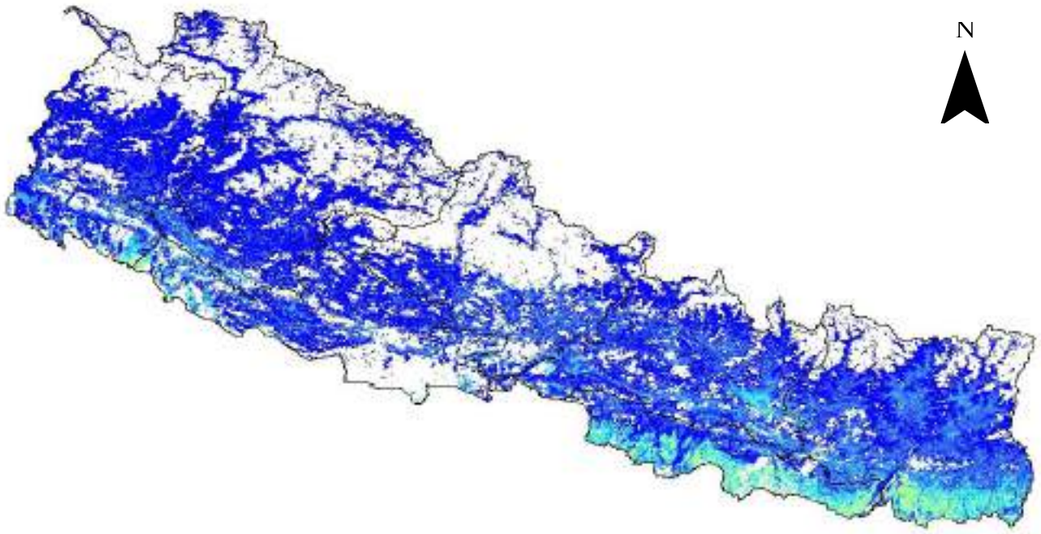
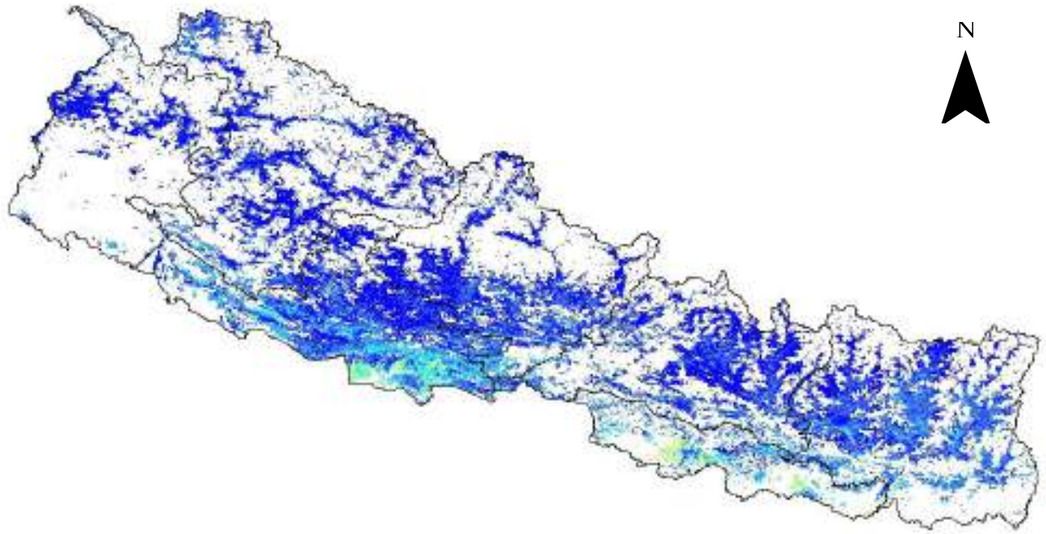


JULY 2018



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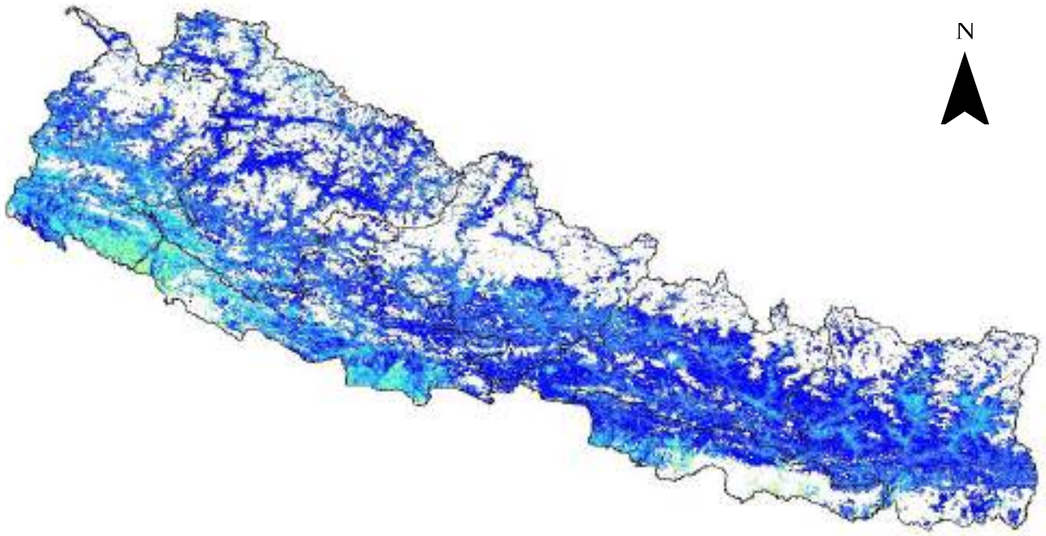
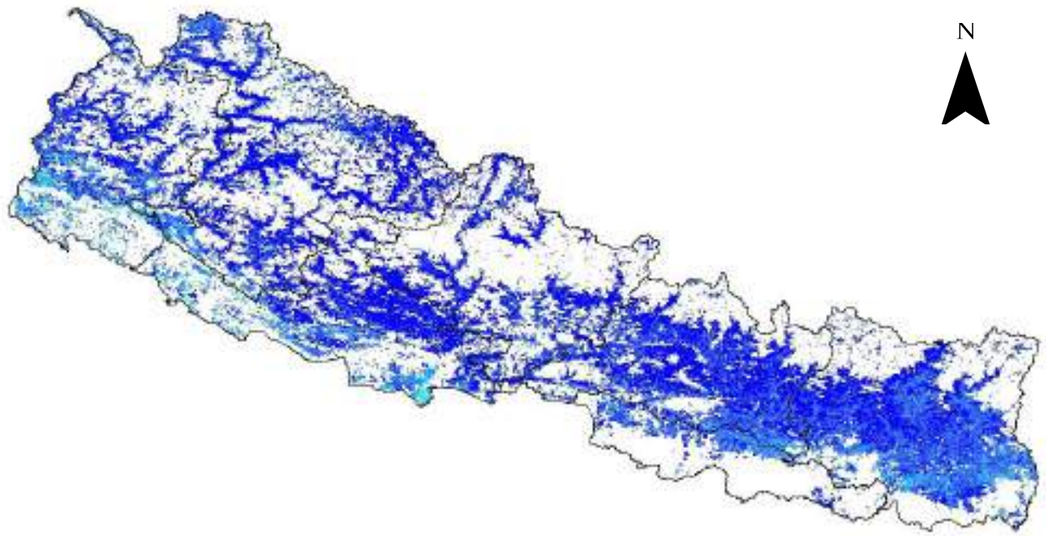


JULY 2020



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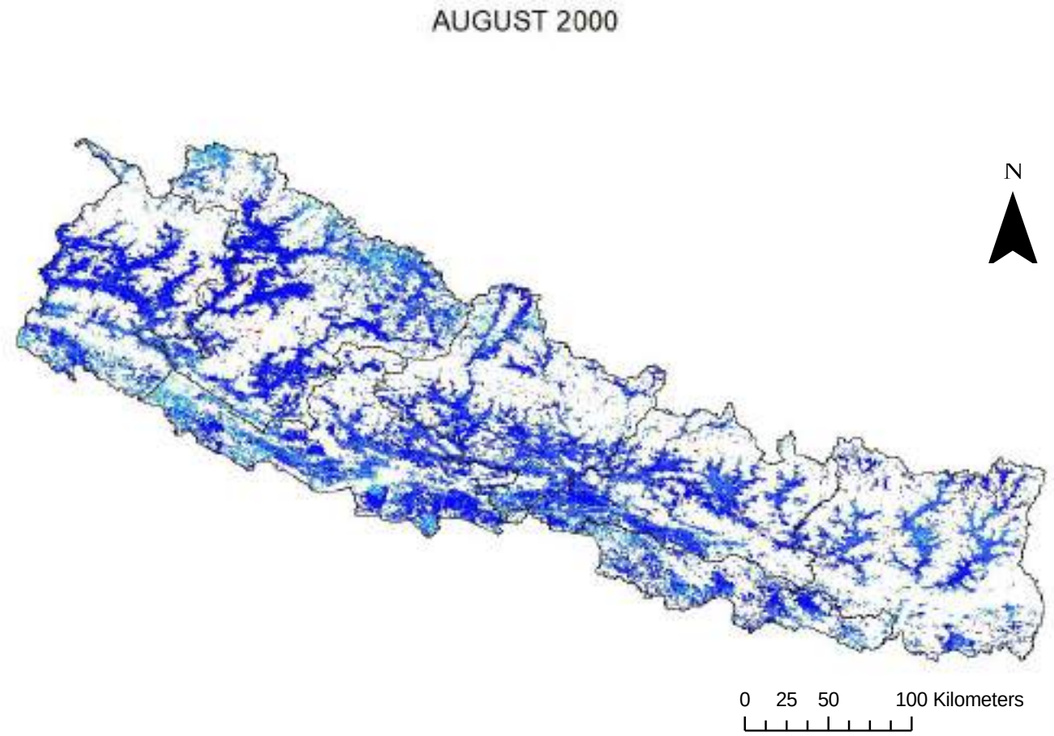
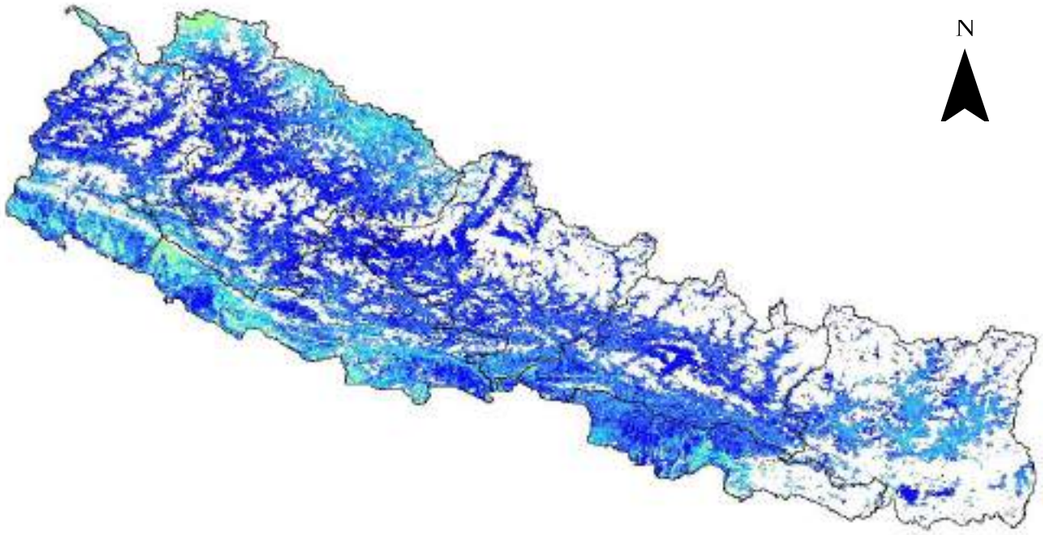
August DSI Maps

August is the monsoon month. This month is generally seen in wet condition ranging from very wet to extremely wet condition.

Mean August DSI Values		
Year	Values	Drought Condition
2000	1.35	Very Wet
2001	1.35	Very Wet
2002	1.33	Very Wet
2003	1.56	Extremely Wet
2004	1.53	Extremely Wet
2005	1.46	Very Wet
2006	1.45	Very Wet
2007	1.58	Extremely Wet
2008	1.73	Extremely Wet
2009	1.51	Extremely Wet
2010	1.79	Extremely Wet
2011	1.73	Extremely Wet
2012	1.47	Very Wet
2013	1.53	Extremely Wet
2014	1.37	Very Wet
2015	1.34	Very Wet
2016	1.81	Extremely Wet
2017	2.02	Extremely Wet
2018	1.86	Extremely Wet
2019	1.86	Extremely Wet
2020	1.61	Extremely Wet



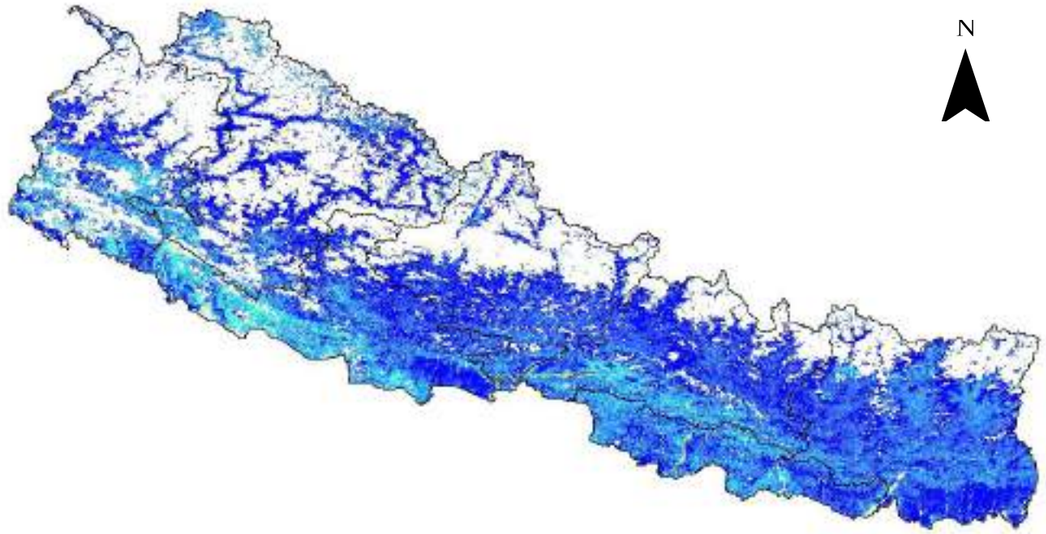
AUGUST 2001



N

0 25 50 100 Kilometers

AUGUST 2002



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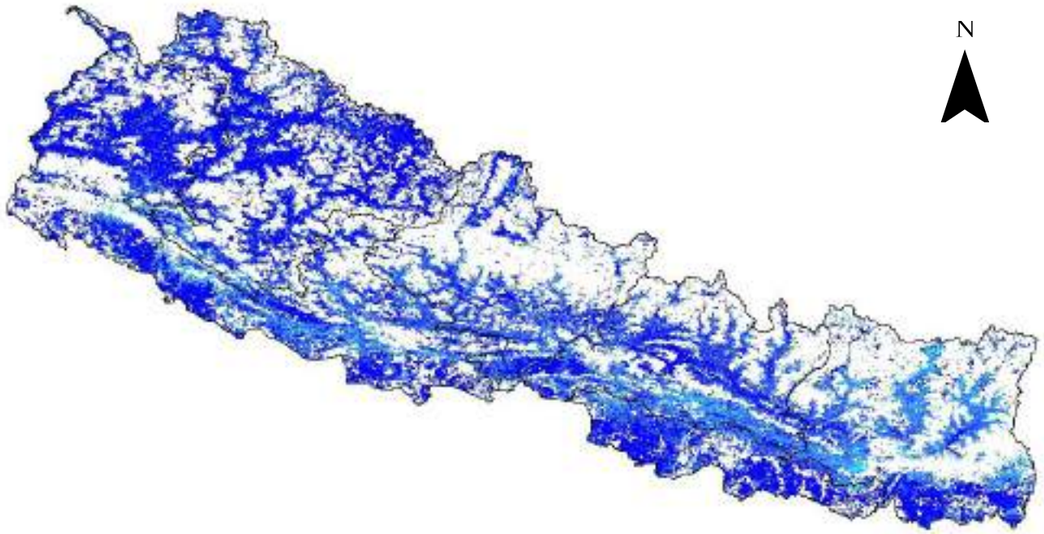

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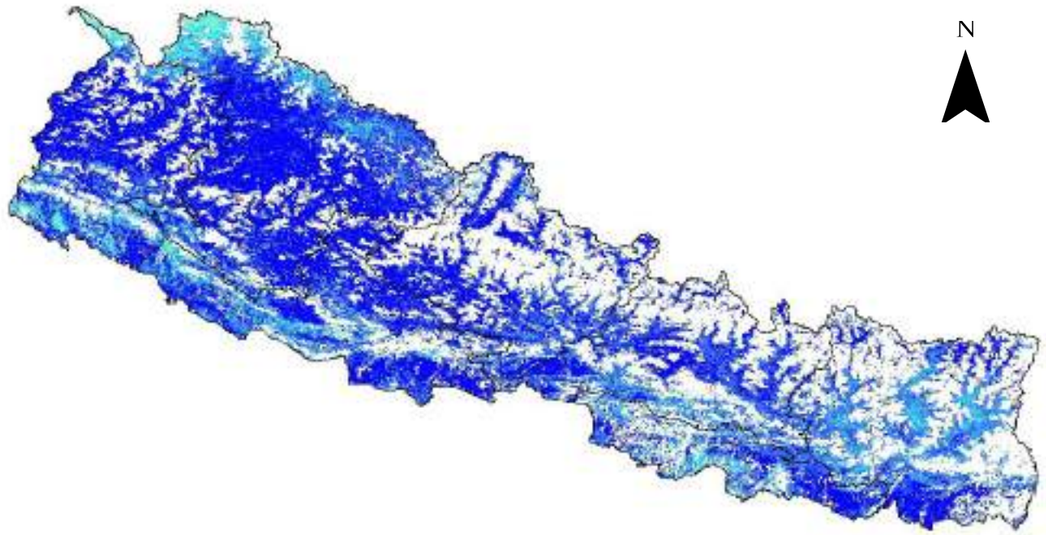
0 25 50 100 Kilometers

AUGUST 2004



N

0 25 50 100 Kilometers

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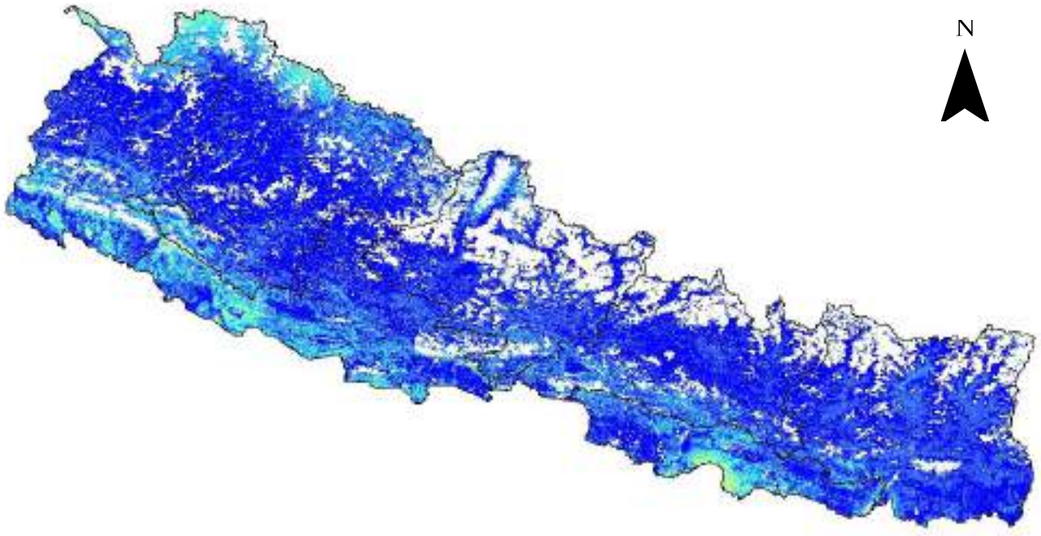
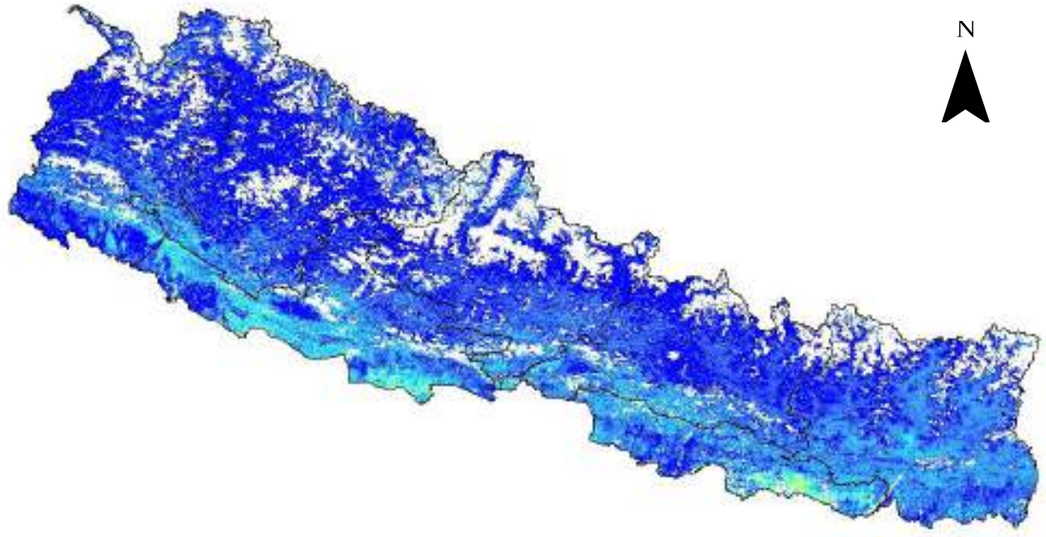
AUGUST 2005



AUGUST 2006



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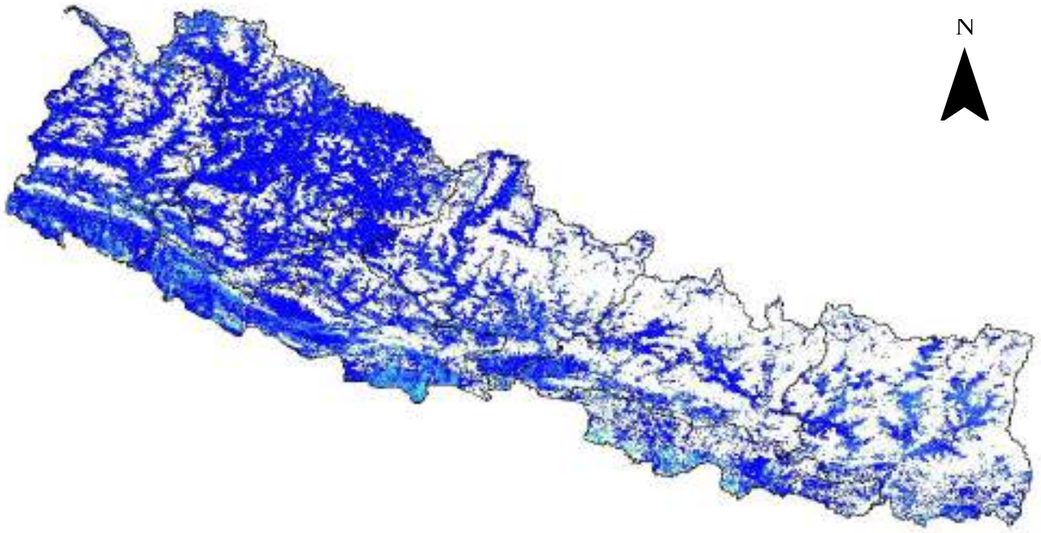

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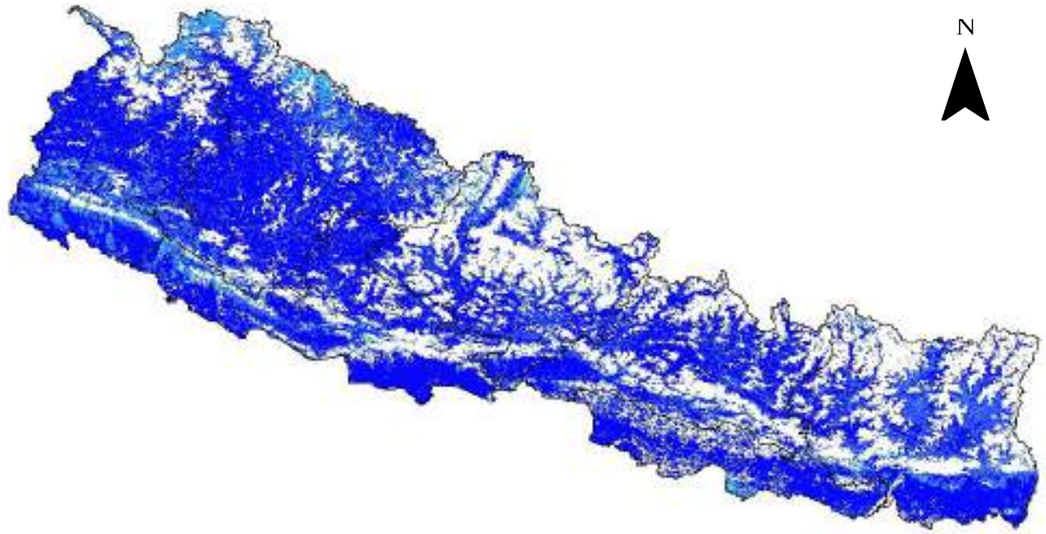
AUGUST 2008



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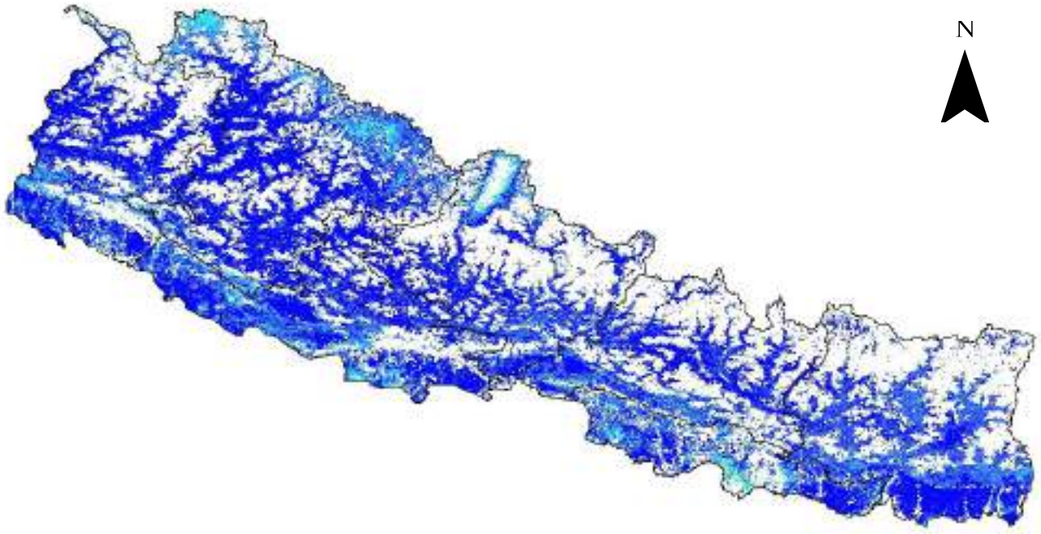

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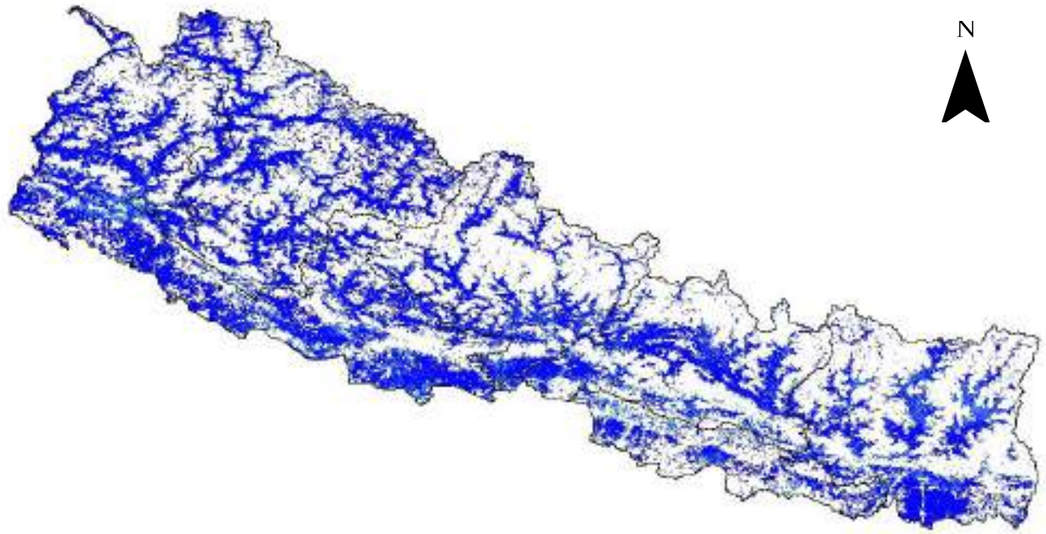
AUGUST 2010



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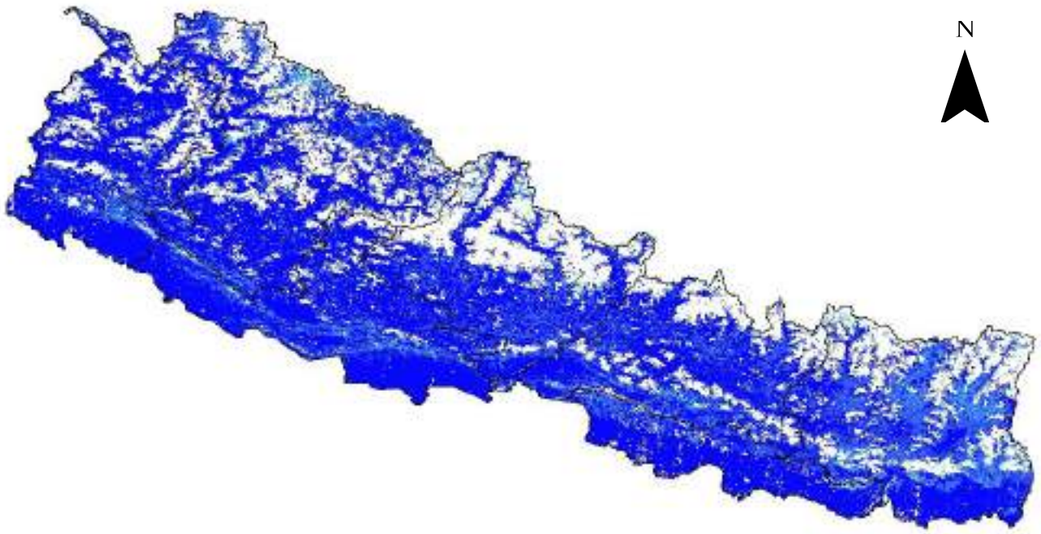

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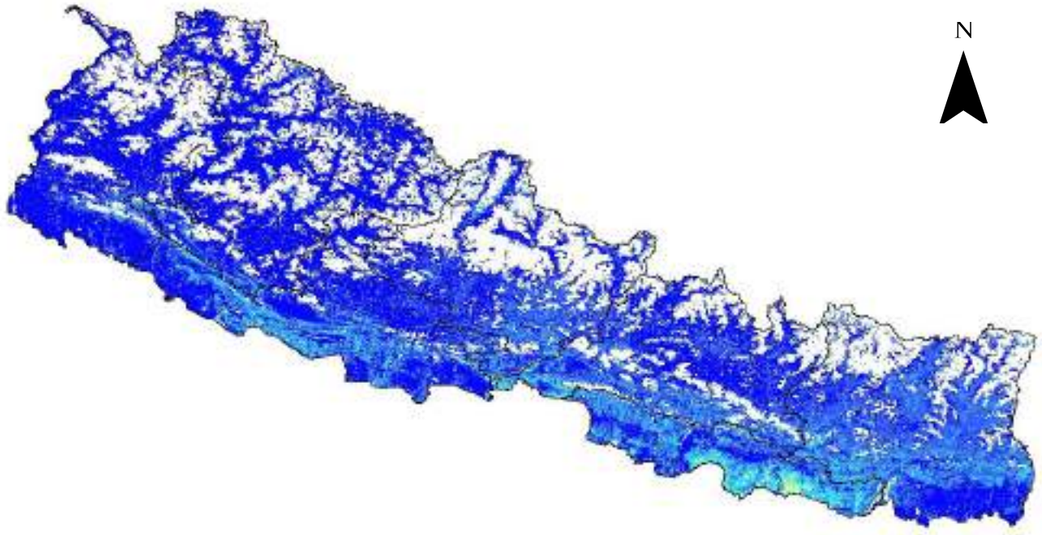
AUGUST 2012



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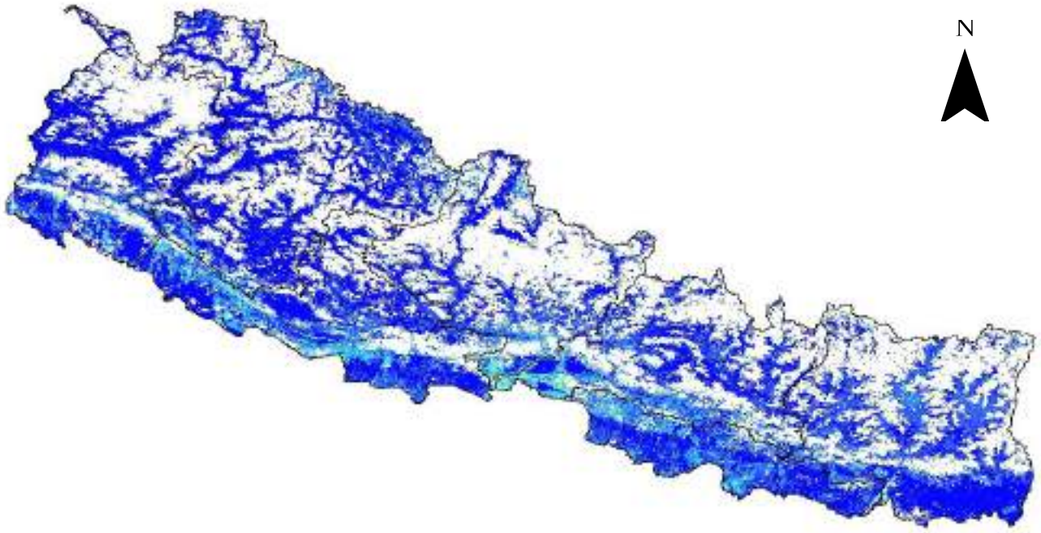

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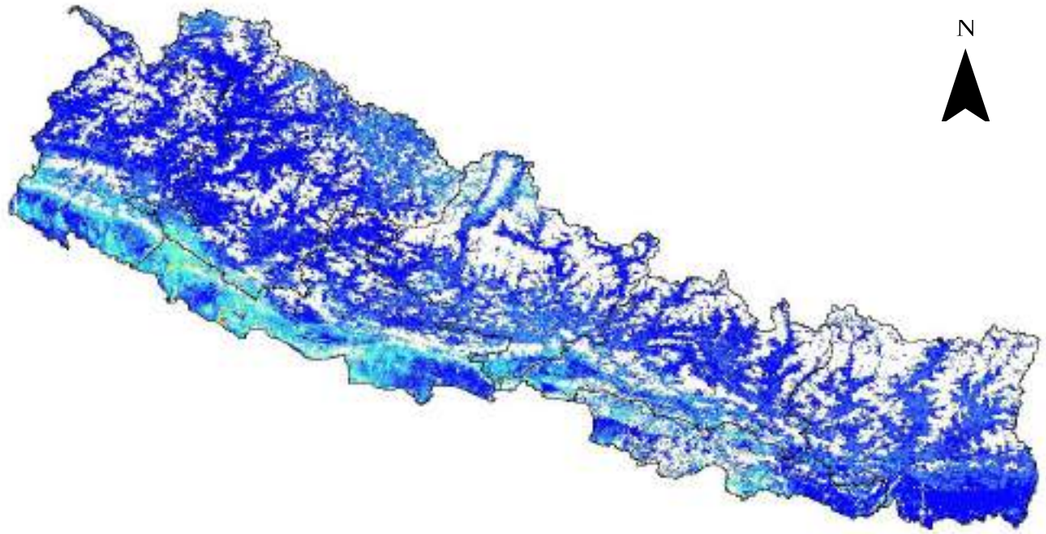
AUGUST 2014



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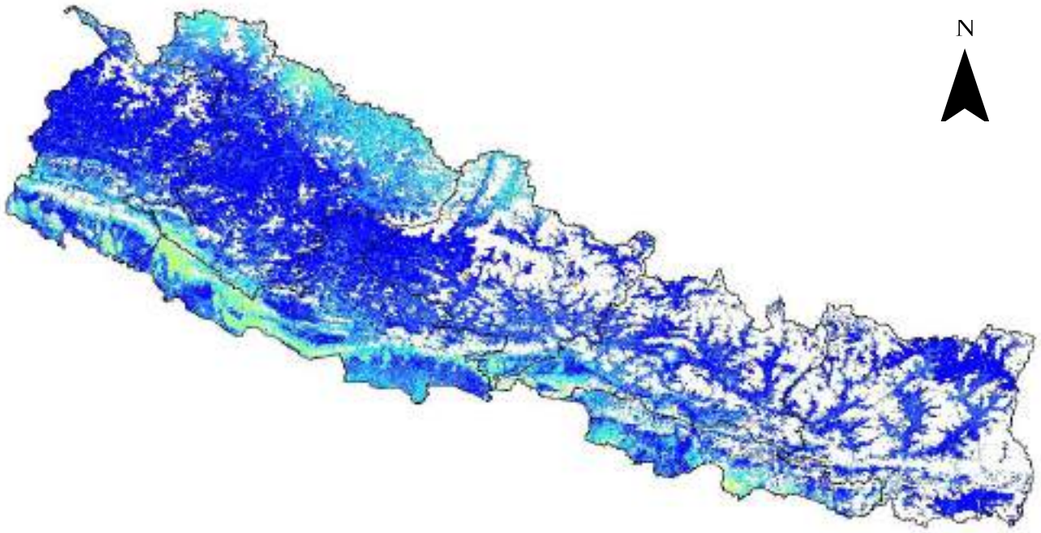

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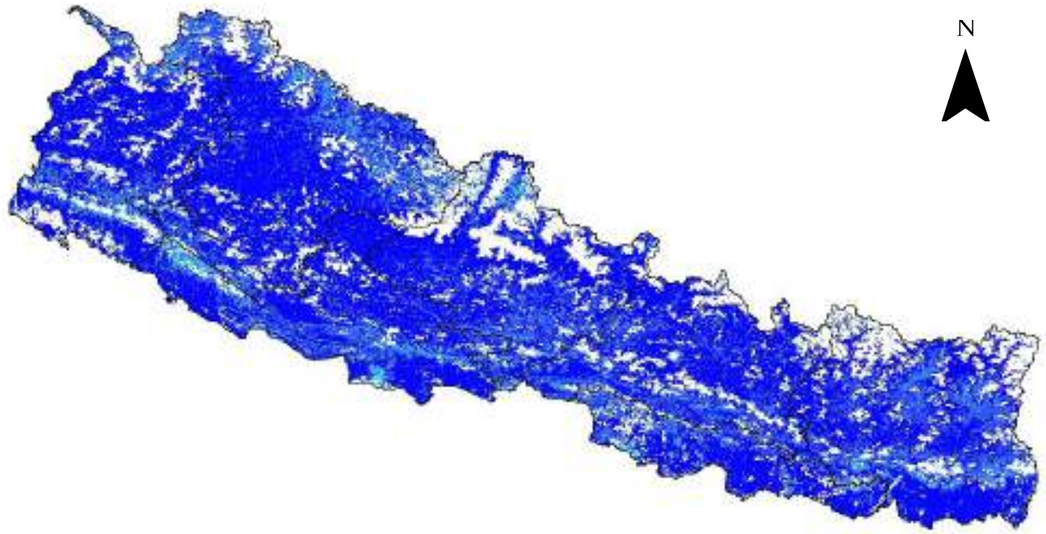
AUGUST 2016



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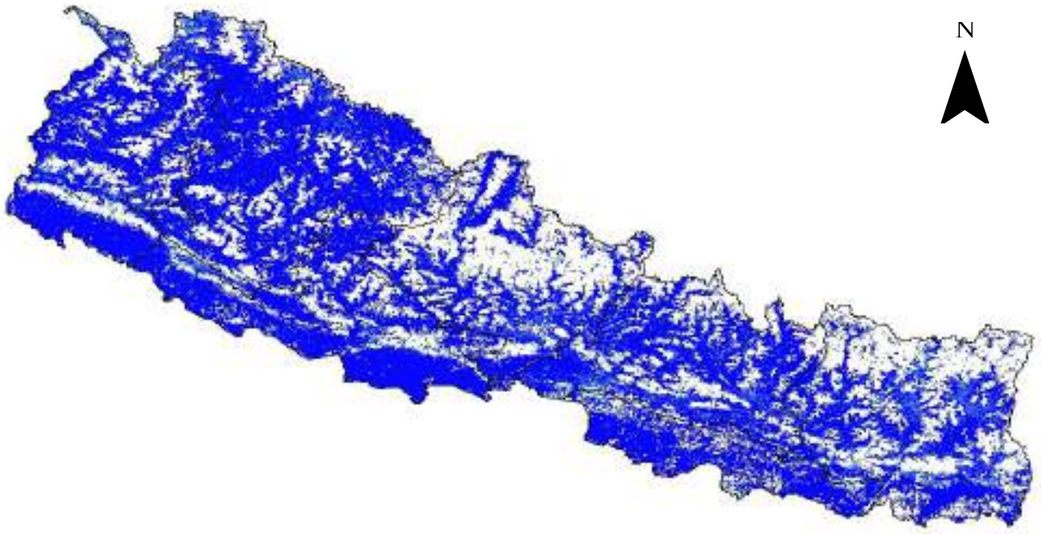
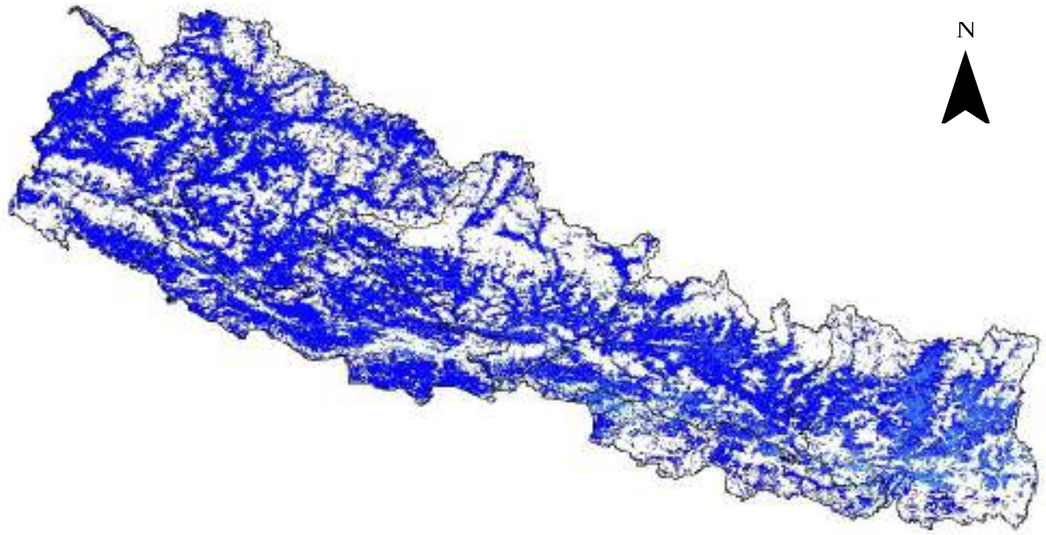


AUGUST 2018



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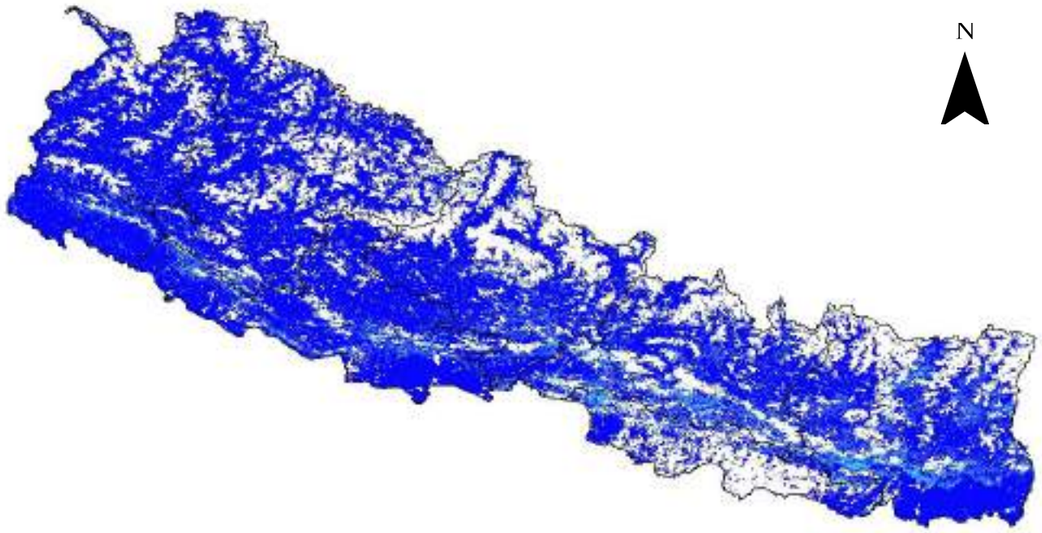

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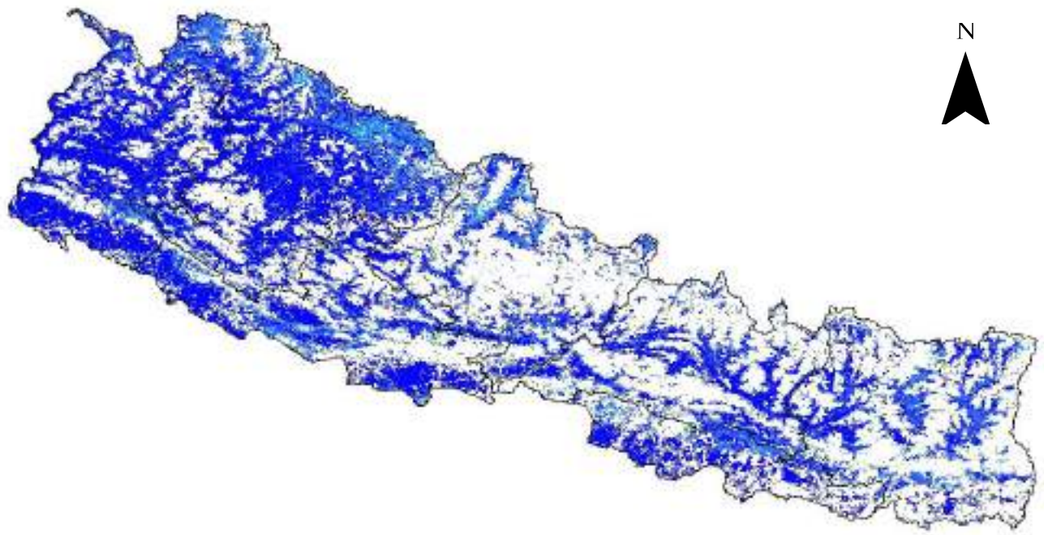
AUGUST 2020



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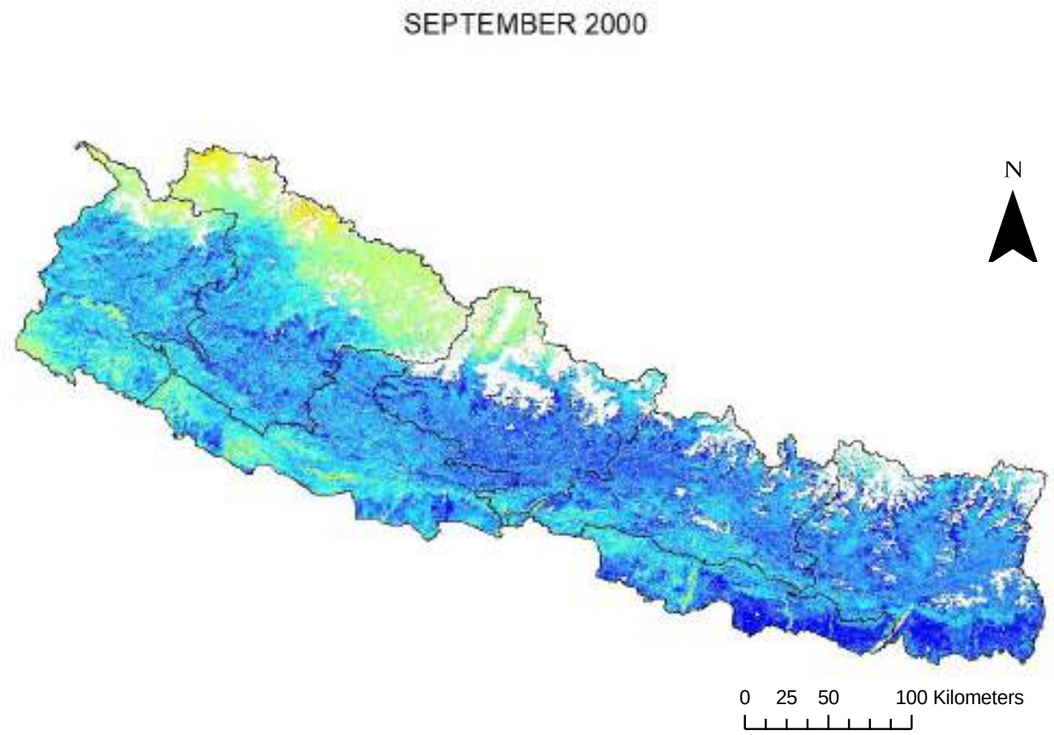
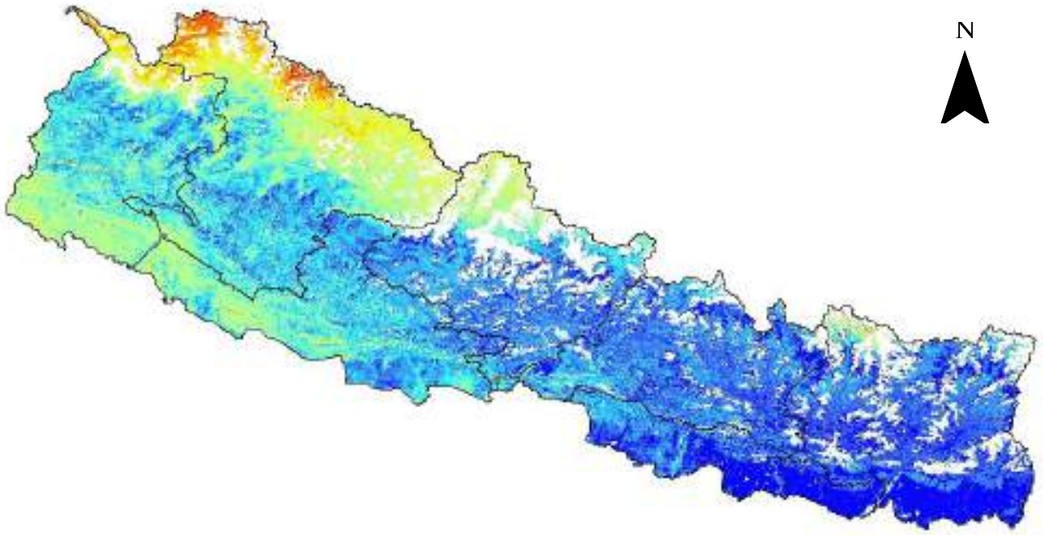
September DSI Maps

In September, drought conditions is characterized by moderately wet to extremely wet condition. This monsoon month is also dominated by wet condition.

Mean September DSI Values		
Year	Values	Drought Condition
2000	1.44	Very Wet
2001	1.01	Moderately Wet
2002	0.96	Moderately Wet
2003	1.57	Extremely Wet
2004	1.23	Very Wet
2005	1.32	Very Wet
2006	1.19	Moderately Wet
2007	1.36	Very Wet
2008	1.33	Very Wet
2009	1.57	Extremely Wet
2010	1.47	Very Wet
2011	1.52	Extremely Wet
2012	1.30	Very Wet
2013	1.24	Very Wet
2014	1.27	Very Wet
2015	0.98	Moderately Wet
2016	1.58	Extremely Wet
2017	1.63	Extremely Wet
2018	1.50	Extremely Wet
2019	1.78	Extremely Wet
2020	1.45	Very Wet



SEPTEMBER 2001



N

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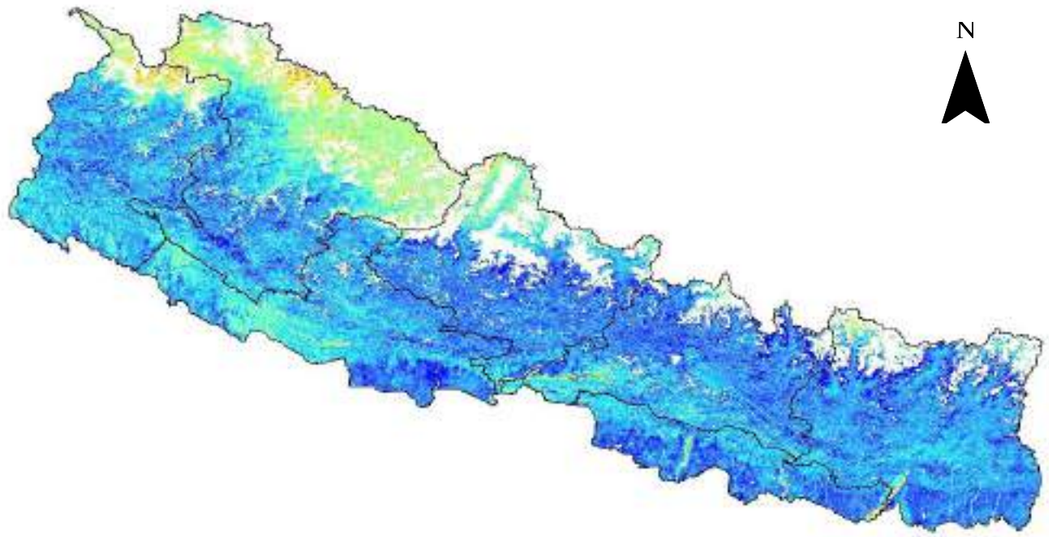
SEPTEMBER 2002



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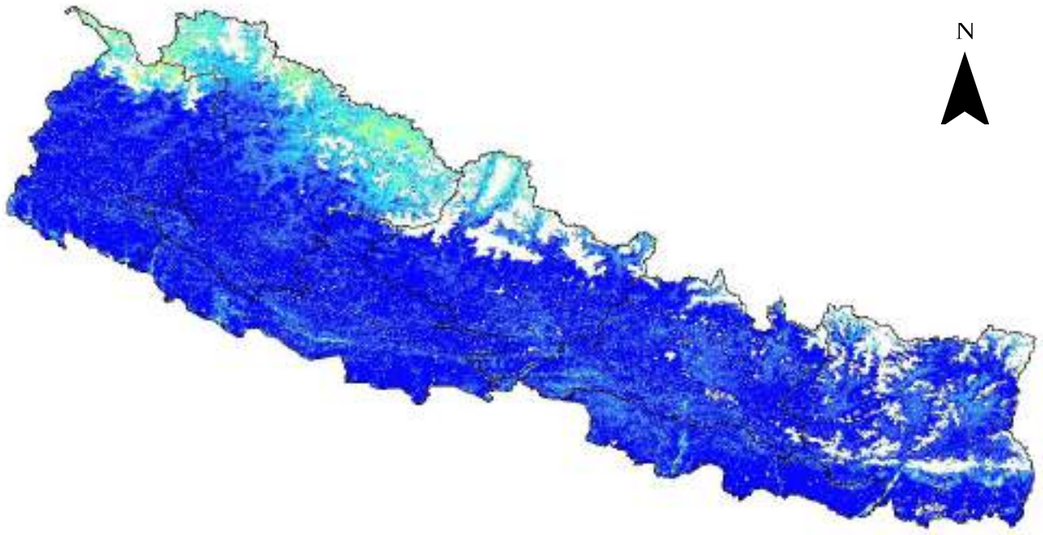

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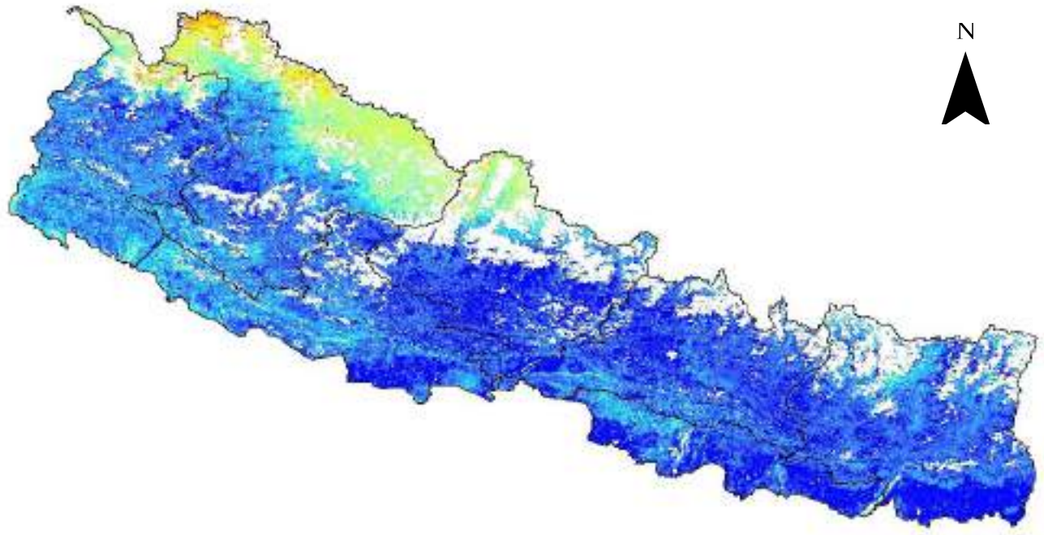

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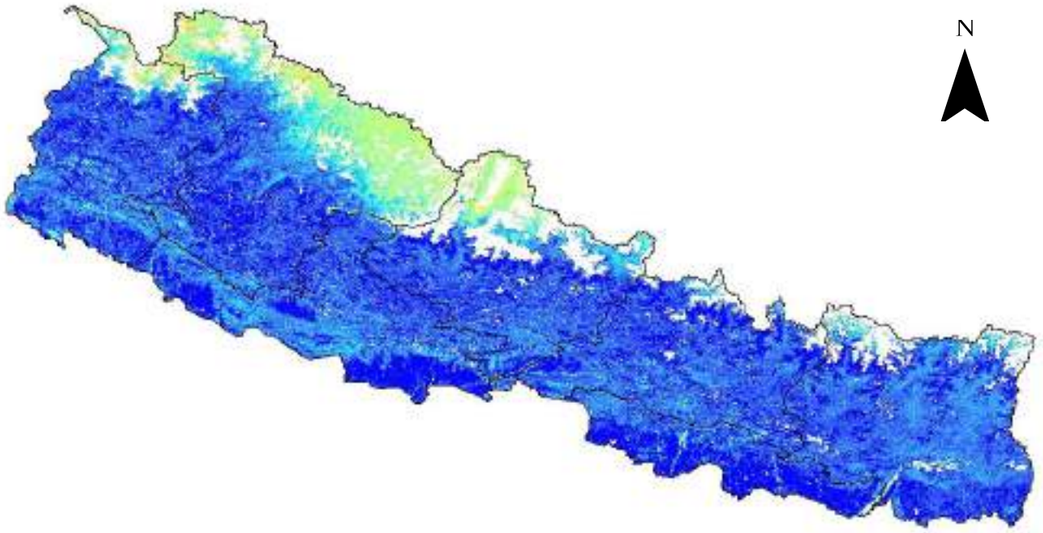

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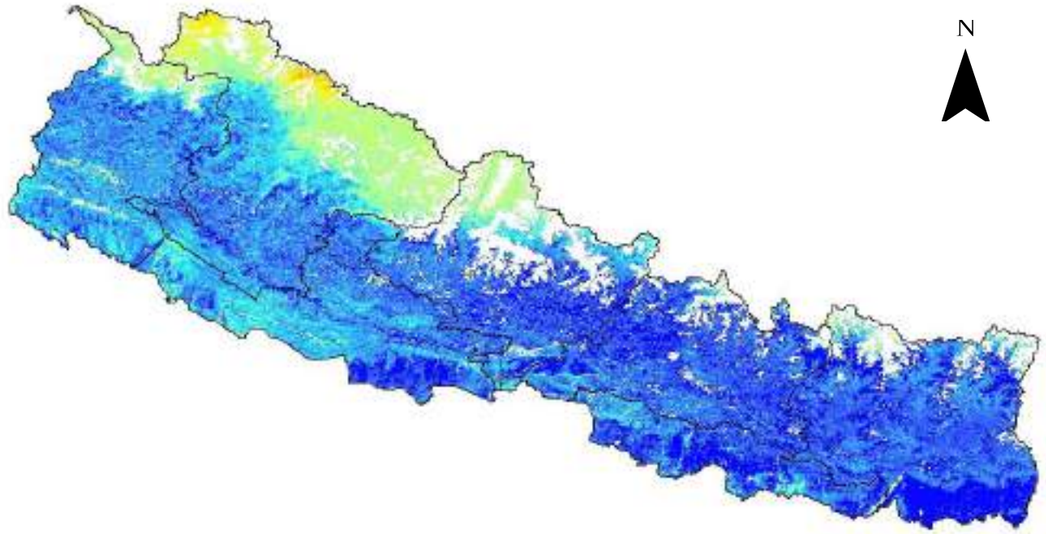

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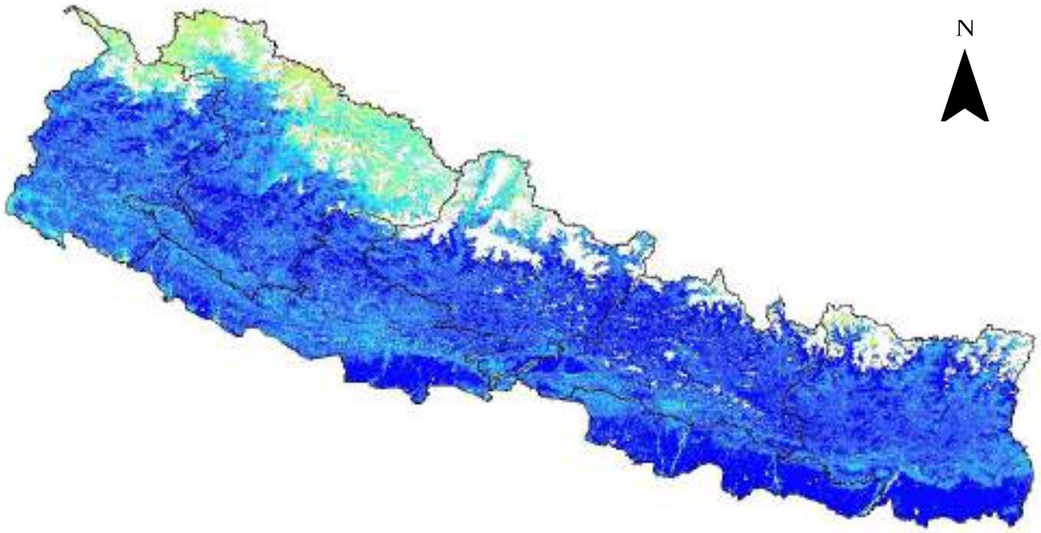

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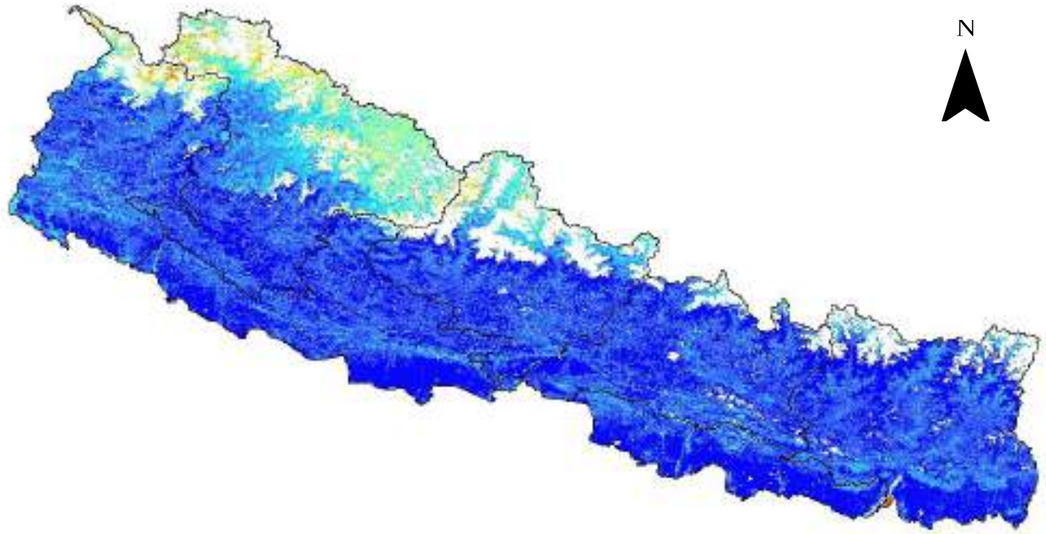

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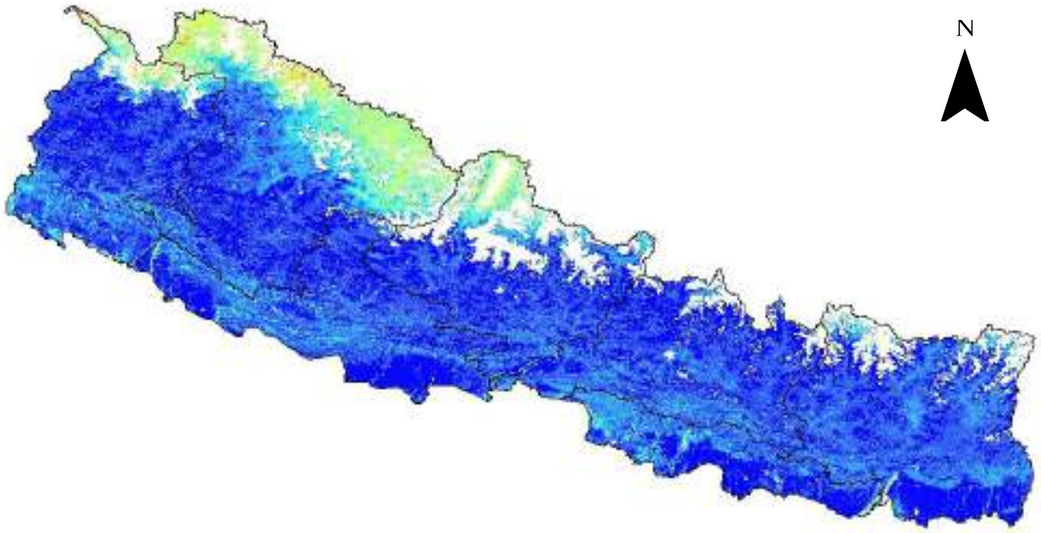

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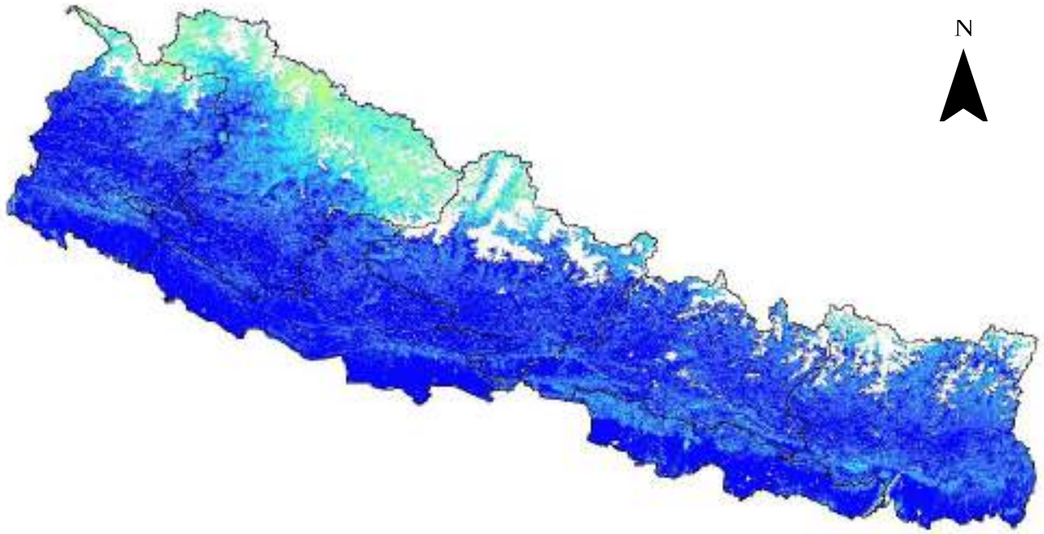

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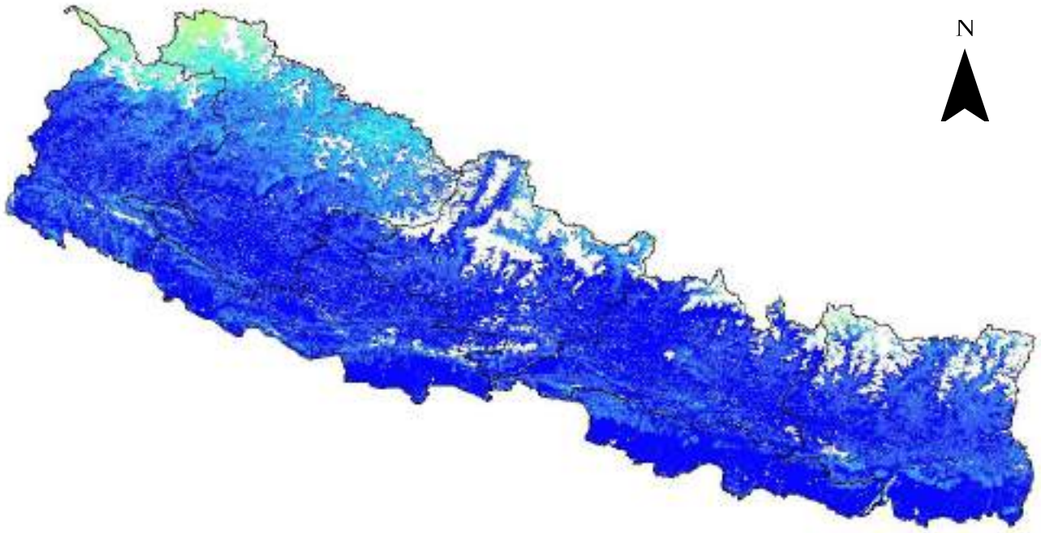

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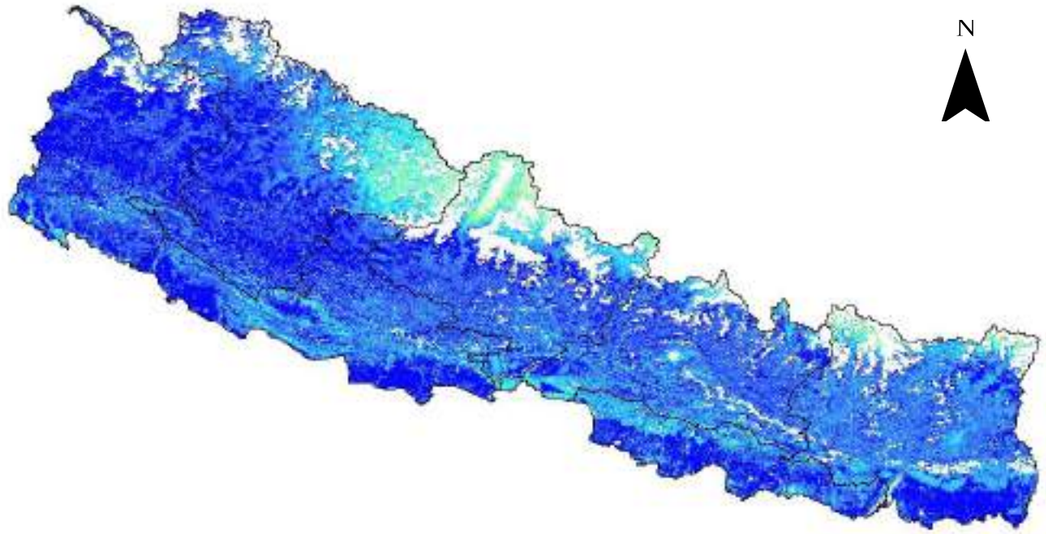

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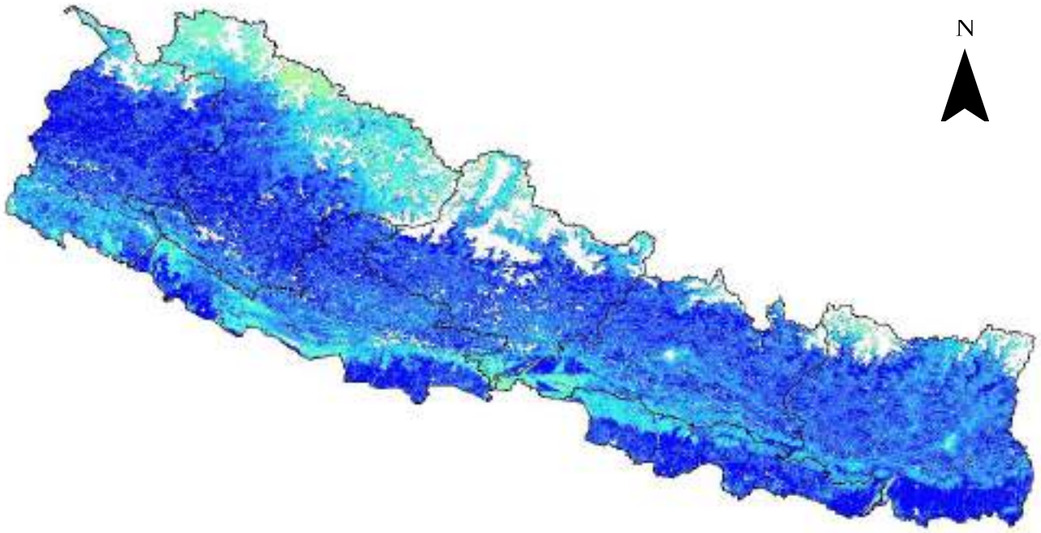

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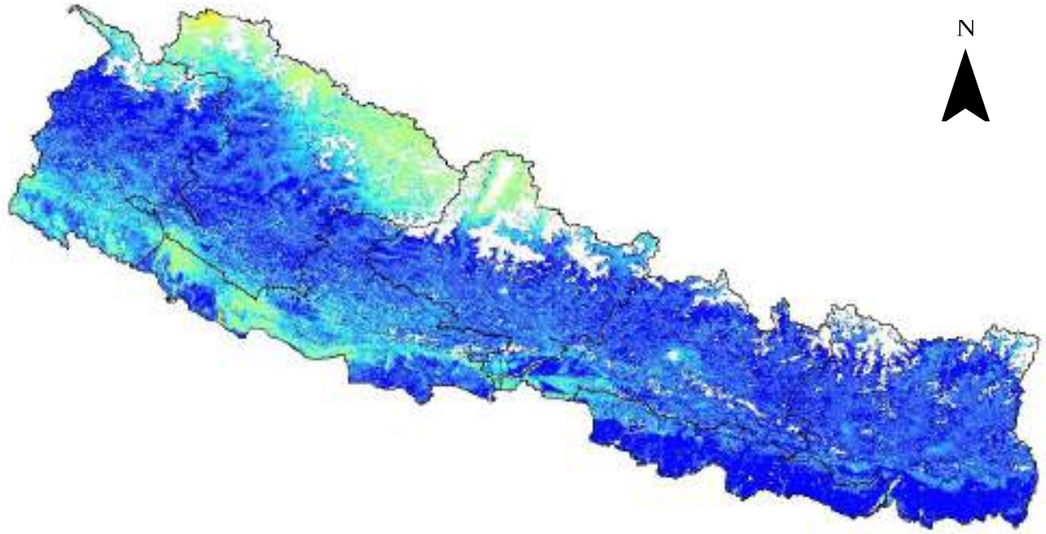

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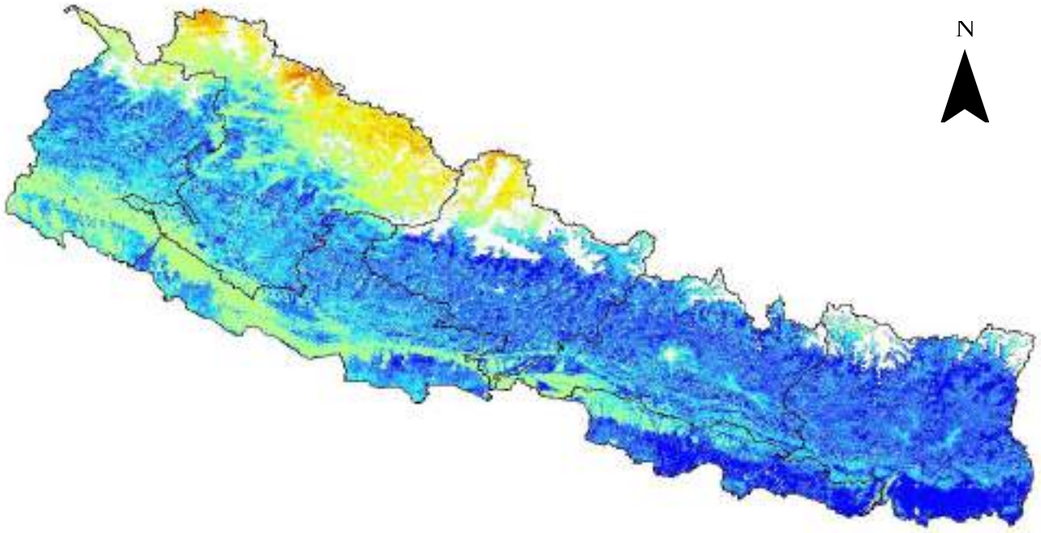
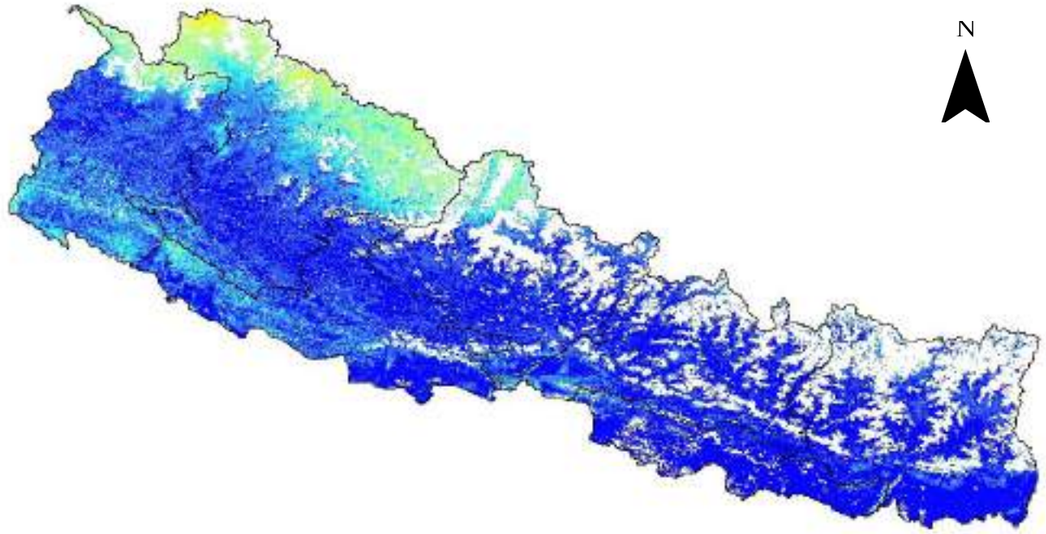
SEPTEMBER 2015



SEPTEMBER 2016



Legend

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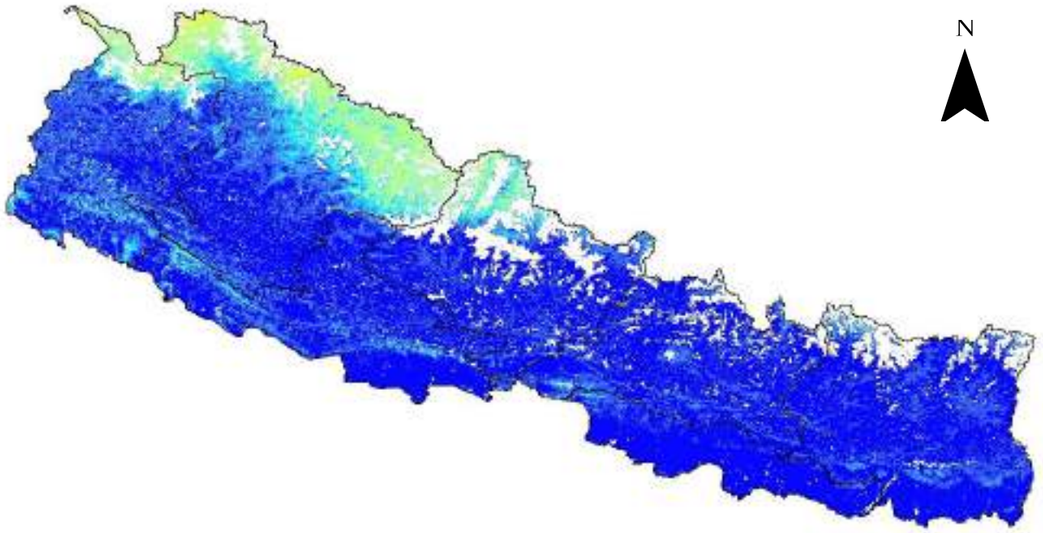
SEPTEMBER 2017



N

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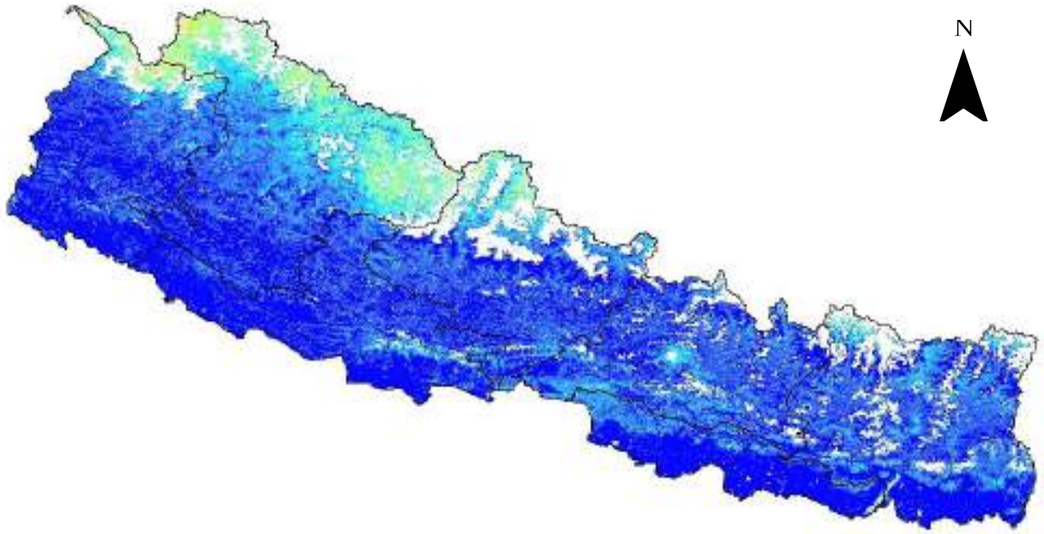
SEPTEMBER 2018



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0 25 50 100 Kilometers

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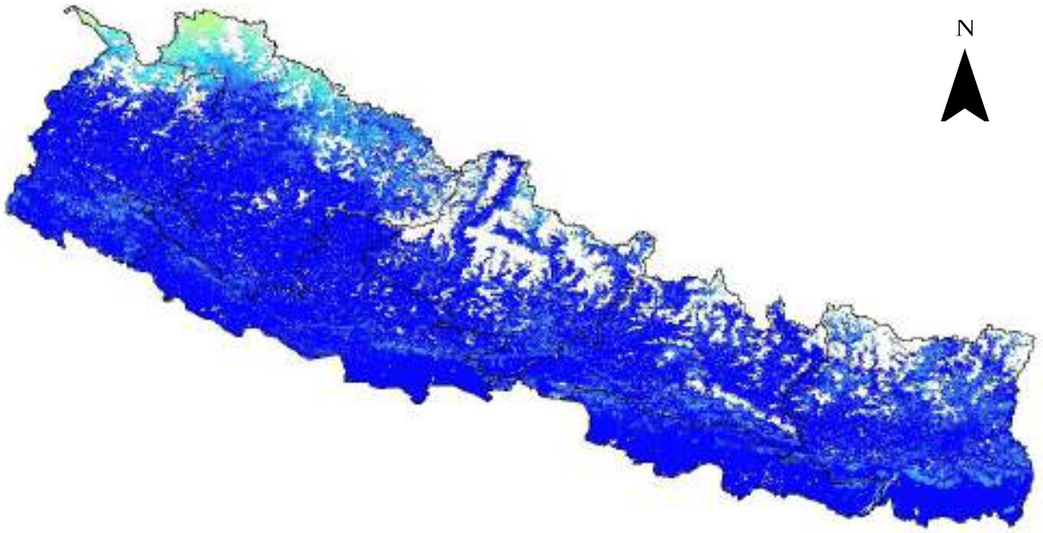
SEPTEMBER 2019



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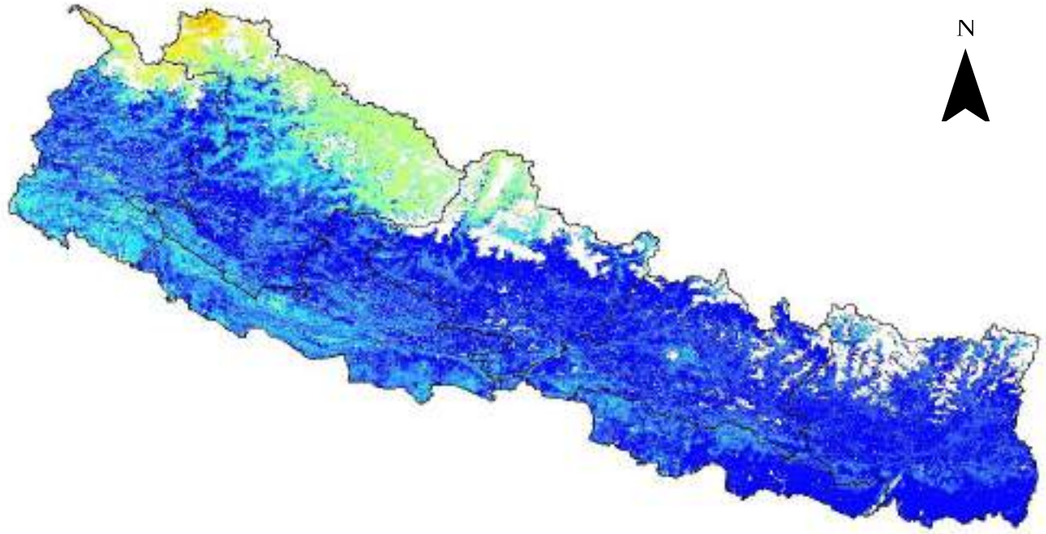
SEPTEMBER 2020



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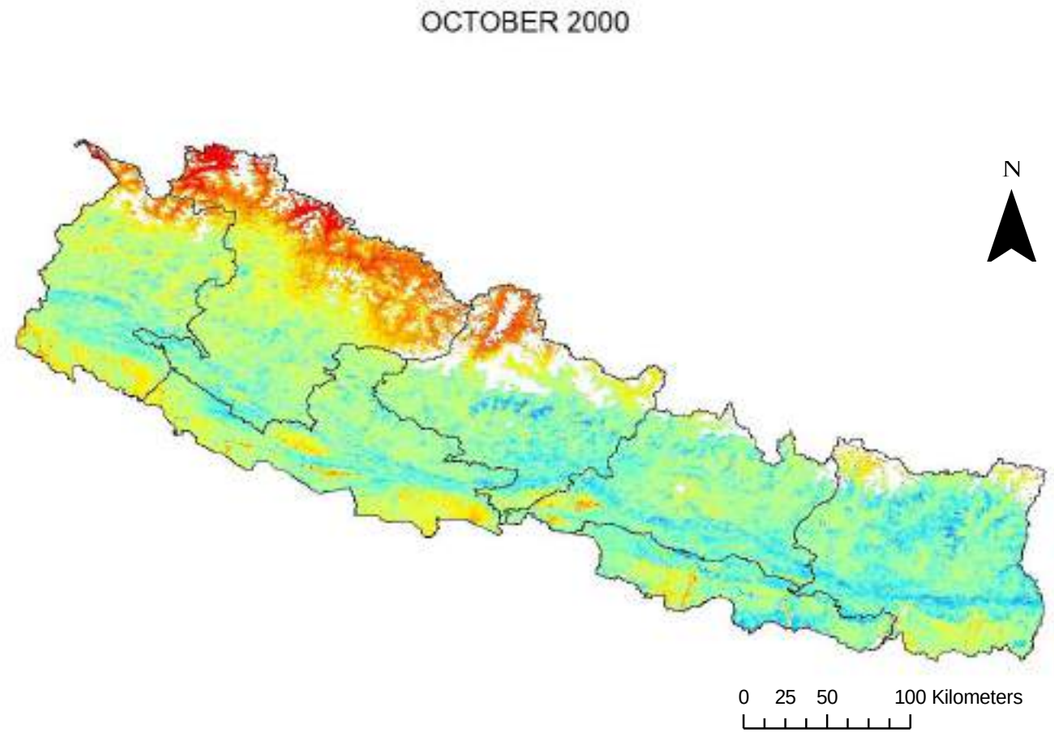
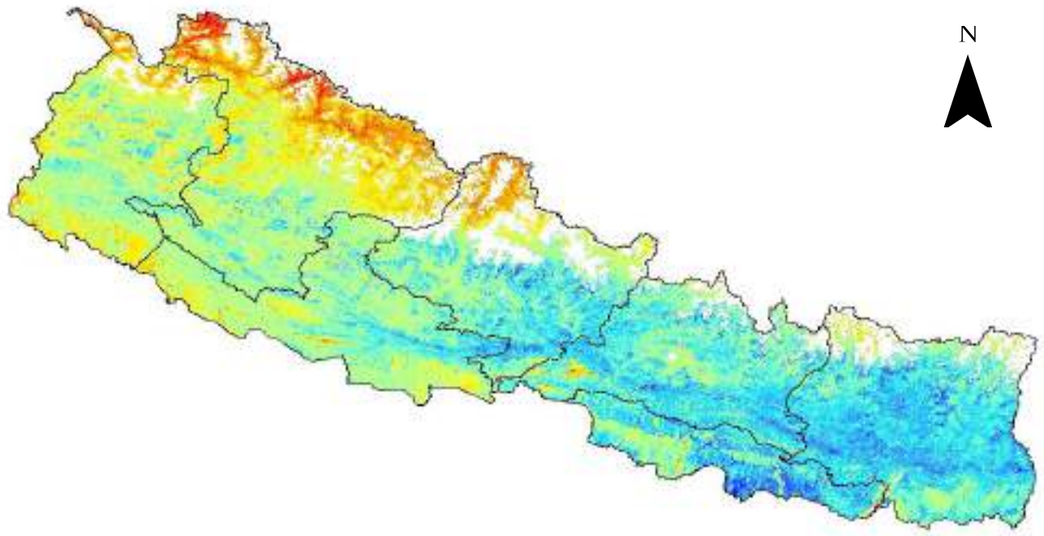
October DSI Maps

In October (post monsoon), drought conditions can ranges from moderate drought to incipient drought condition. Incipient wet spell condition is majorly identified in October.

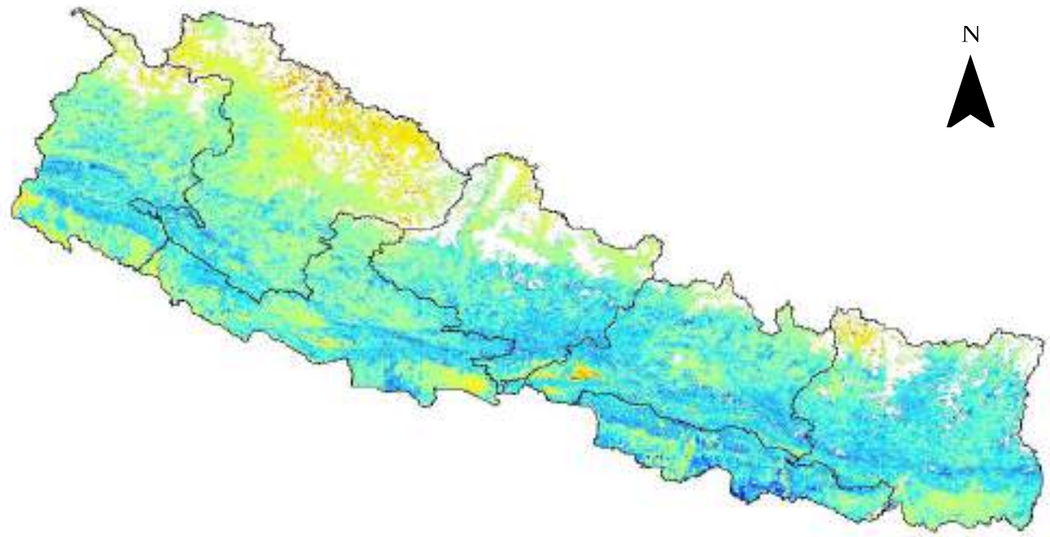
Mean October DSI Values		
Year	Values	Drought Condition
2000	0.99	Moderately Wet
2001	0.22	Near Normal
2002	0.39	Incipient Wet Spell
2003	0.49	Incipient Wet Spell
2004	0.40	Incipient Wet Spell
2005	0.75	Slightly Wet
2006	0.52	Incipient Wet Spell
2007	0.67	Slightly Wet
2008	0.48	Incipient Wet Spell
2009	0.42	Incipient Wet Spell
2010	0.80	Slightly Wet
2011	0.75	Slightly Wet
2012	0.34	Incipient Wet Spell
2013	0.95	Moderately Wet
2014	0.70	Slightly Wet
2015	0.51	Incipient Wet Spell
2016	0.52	Incipient Wet Spell
2017	0.23	Near Normal
2018	0.58	Incipient Wet Spell
2019	1.19	Moderately Wet
2020	0.29	Near Normal



OCTOBER 2001



OCTOBER 2002



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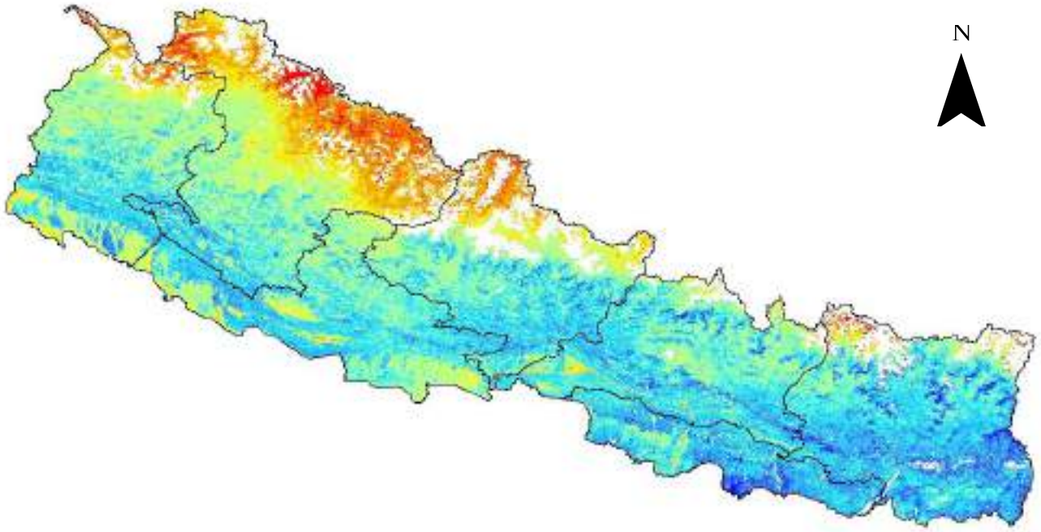

N

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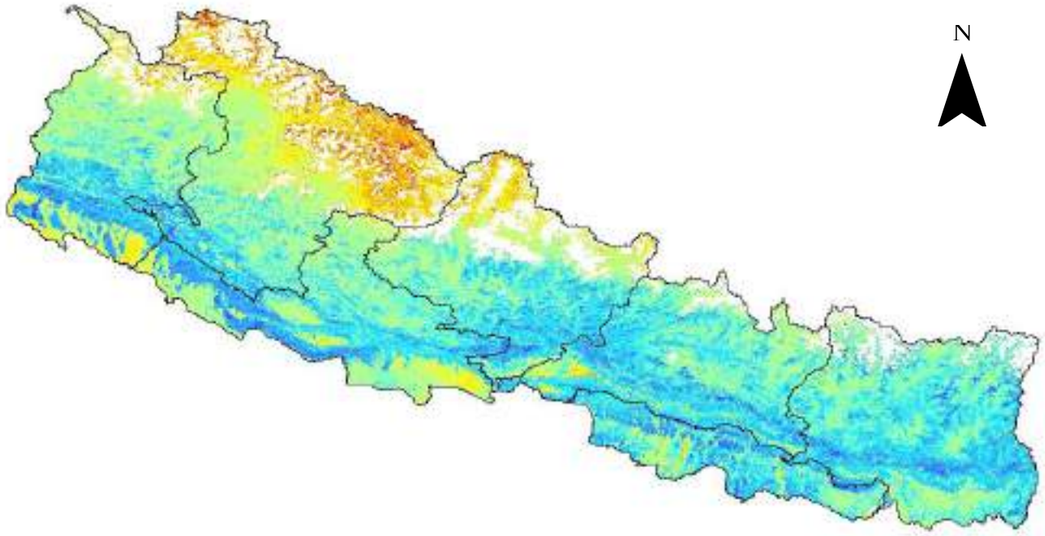
OCTOBER 2004



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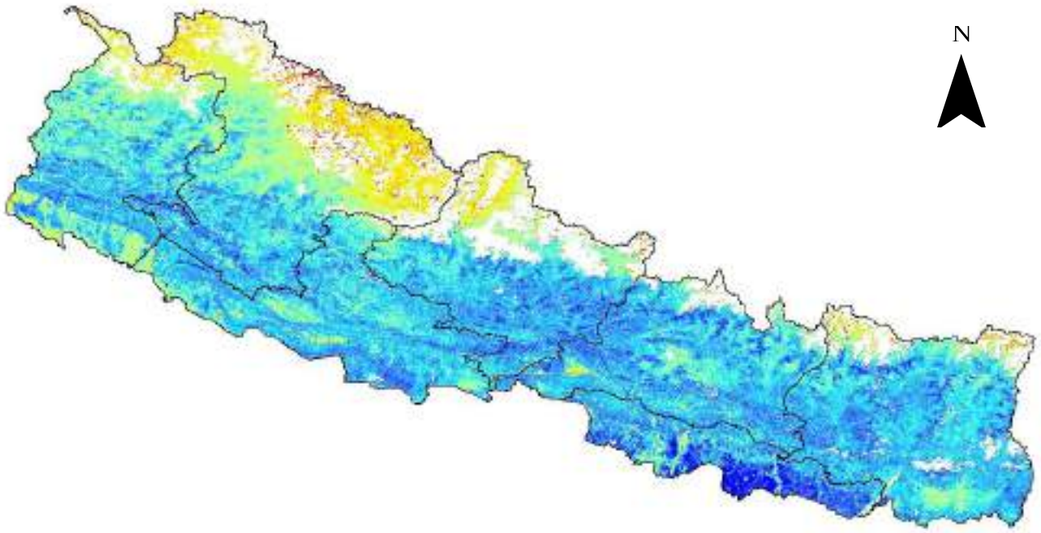
OCTOBER 2005



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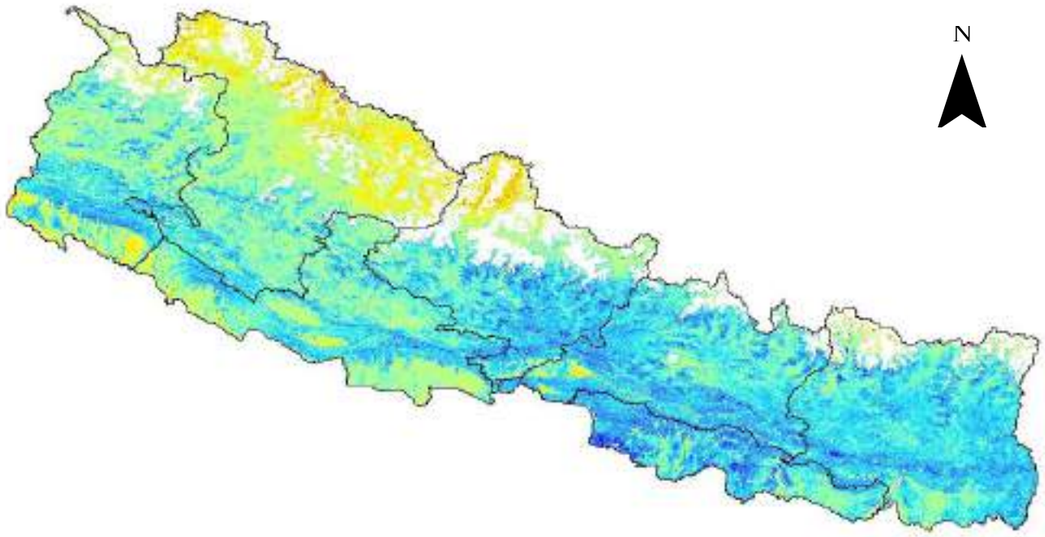
OCTOBER 2006



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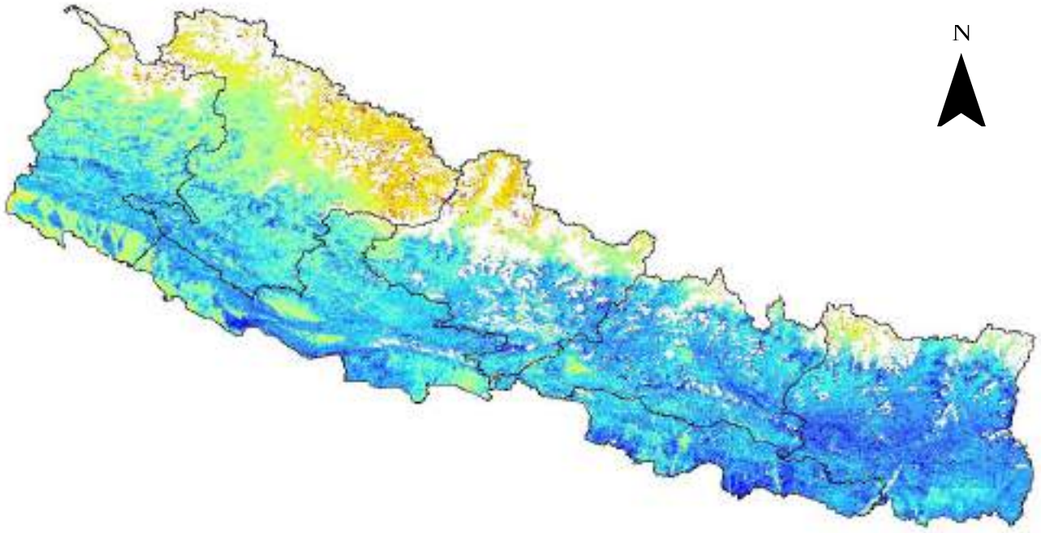
OCTOBER 2007



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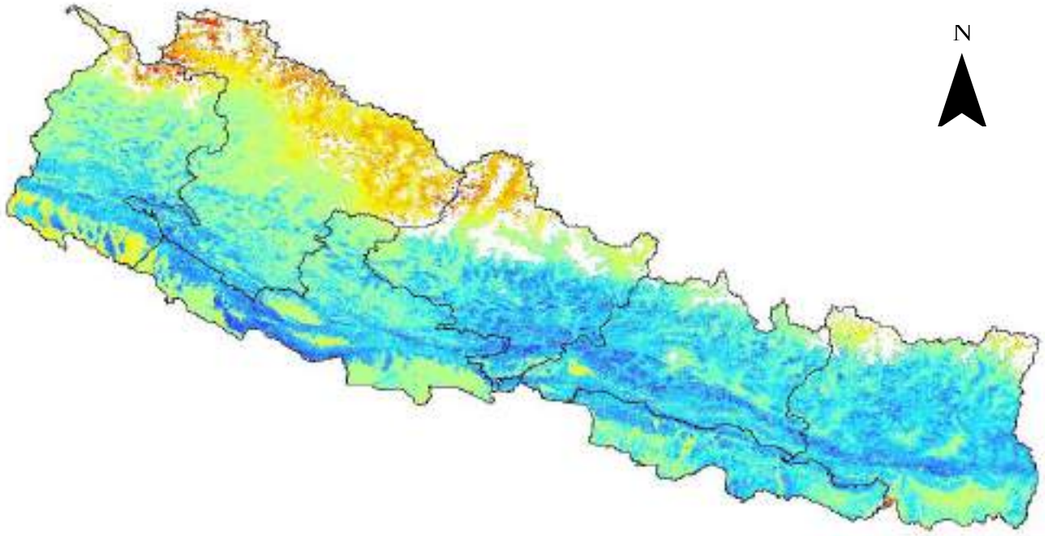
OCTOBER 2008



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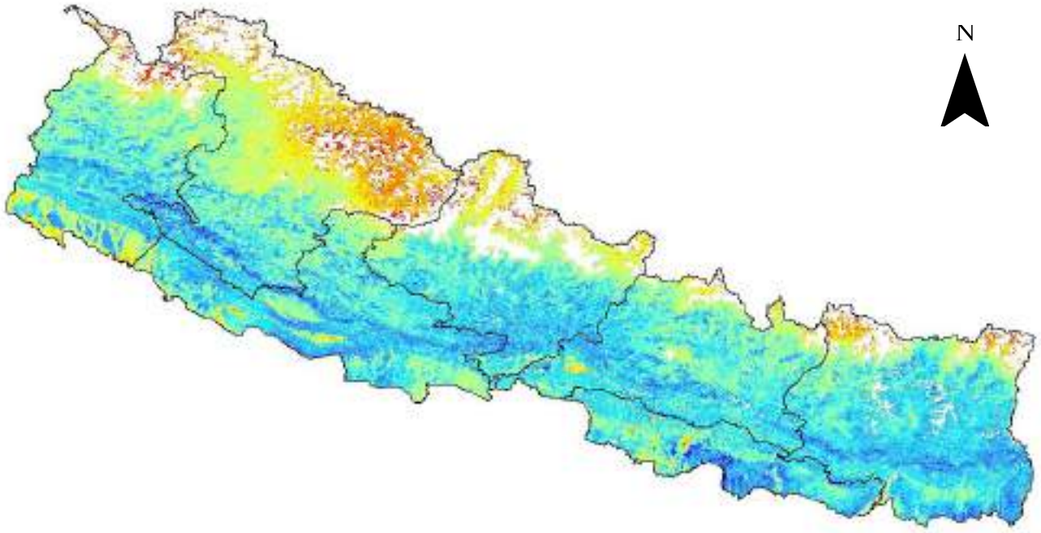
OCTOBER 2009



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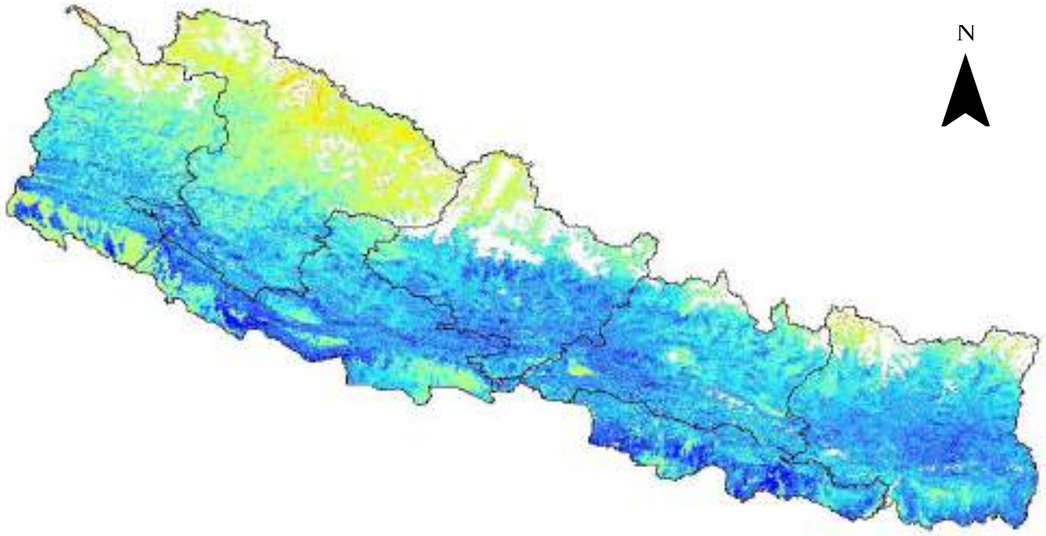
OCTOBER 2010



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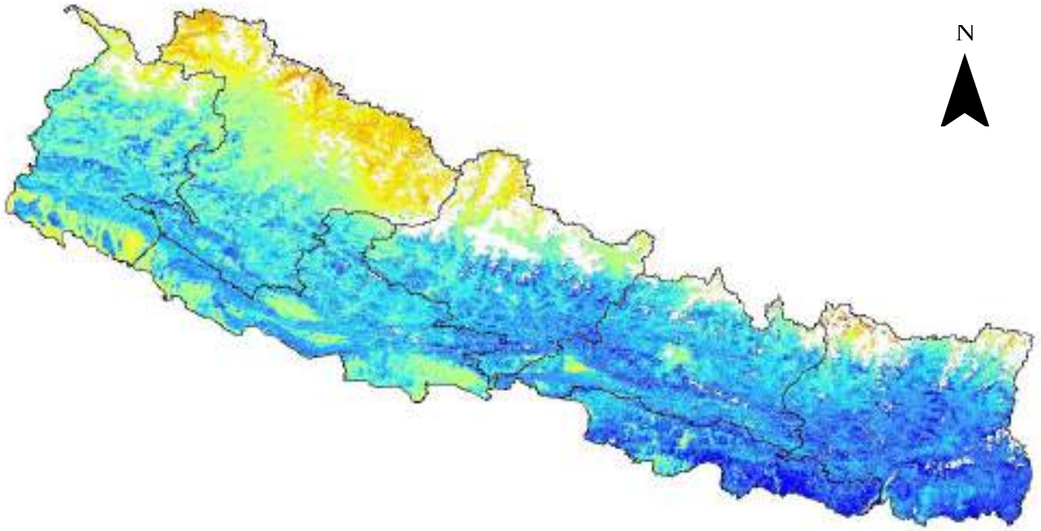

N

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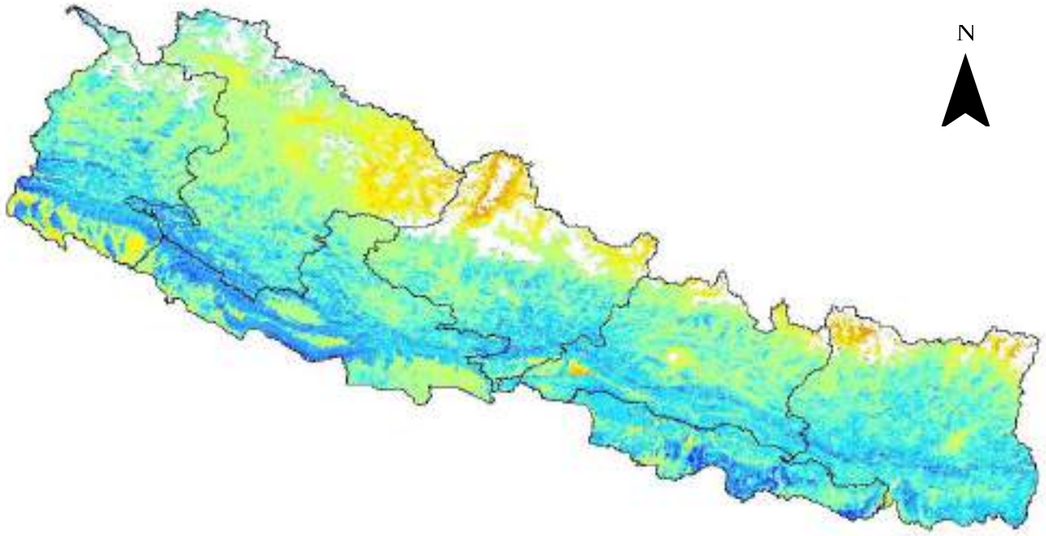
OCTOBER 2012



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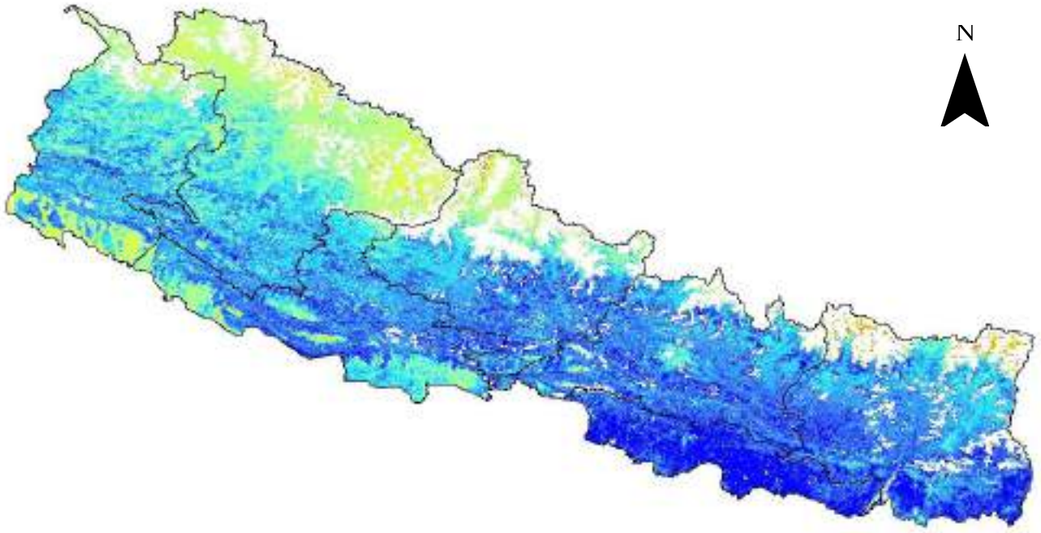

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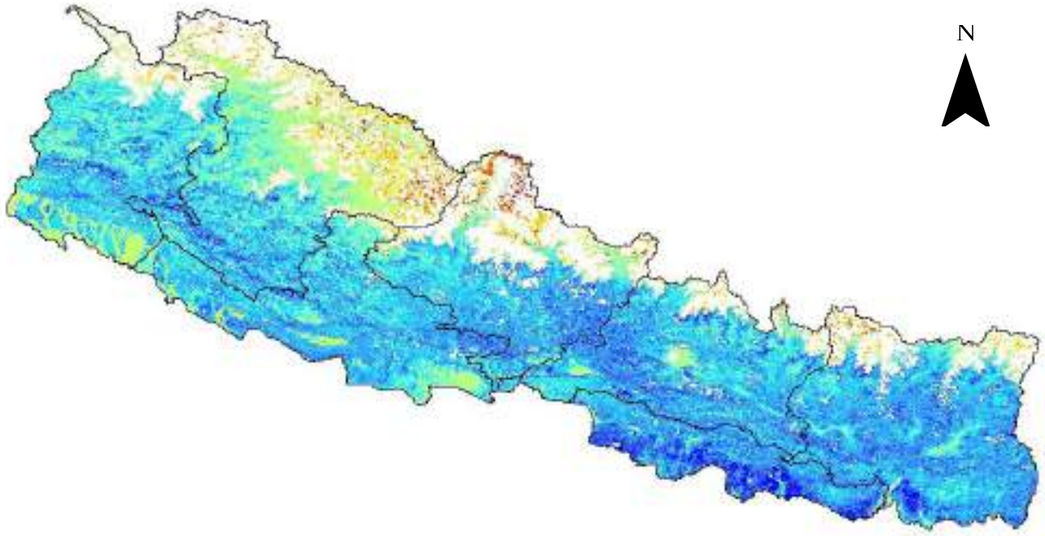
OCTOBER 2014



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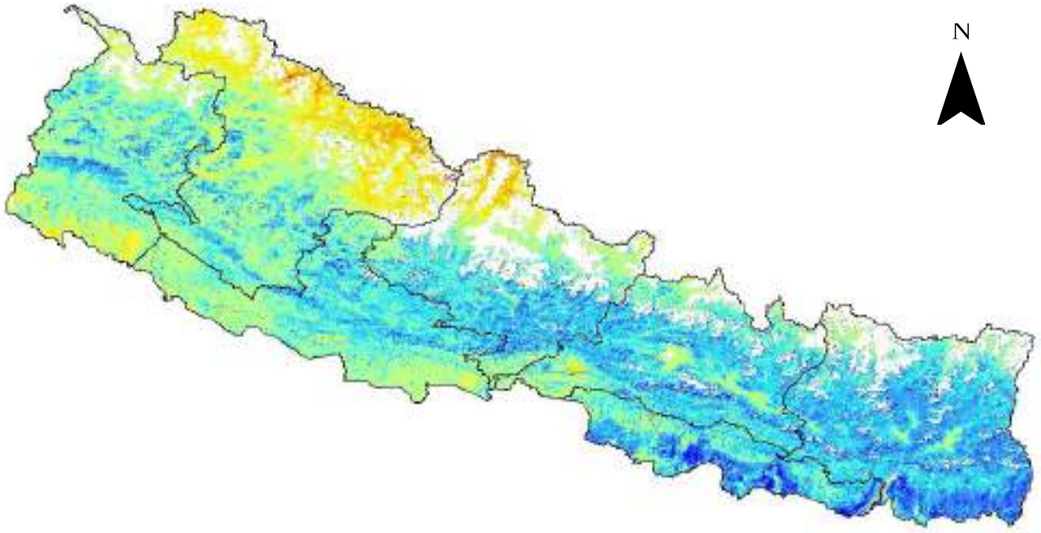

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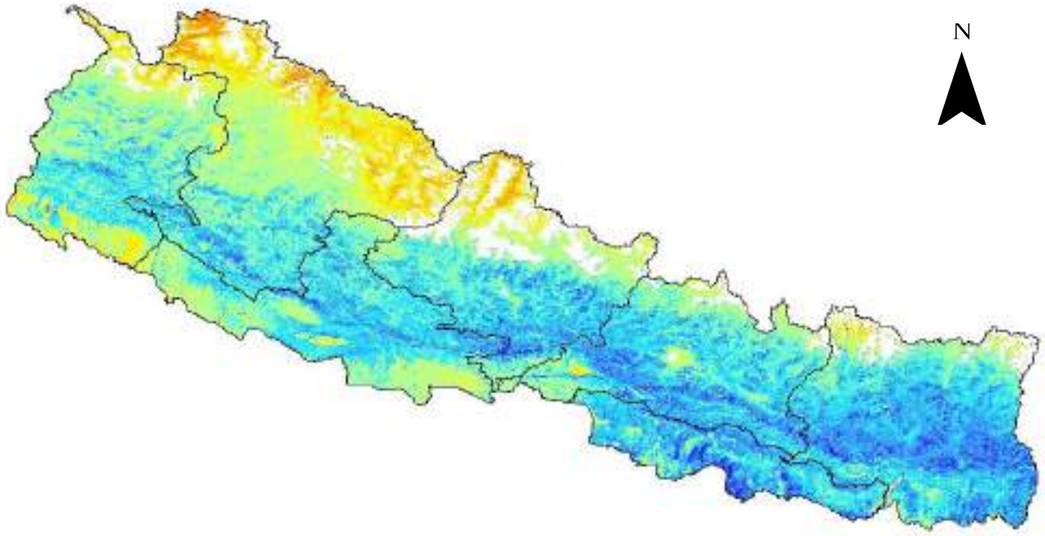
OCTOBER 2016



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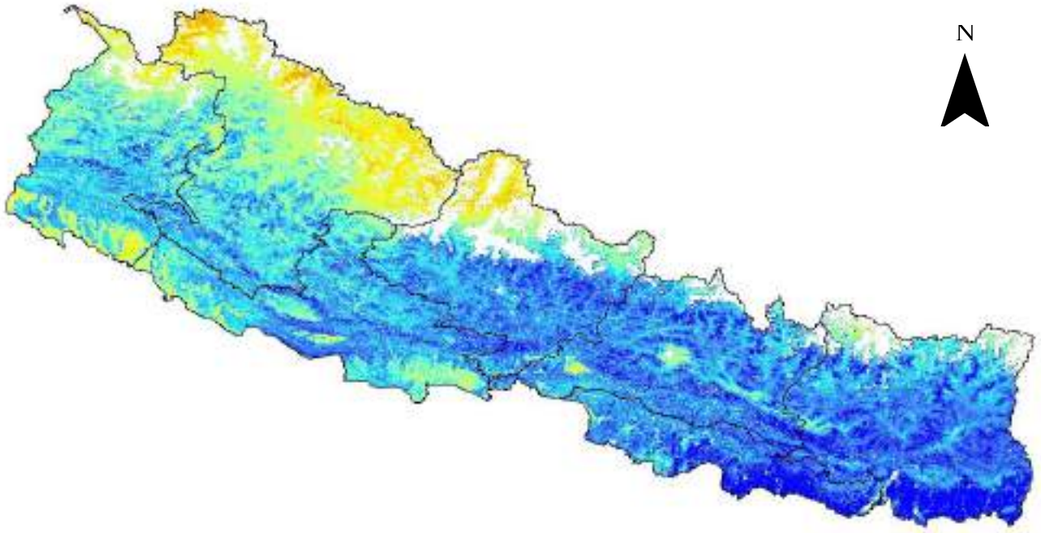

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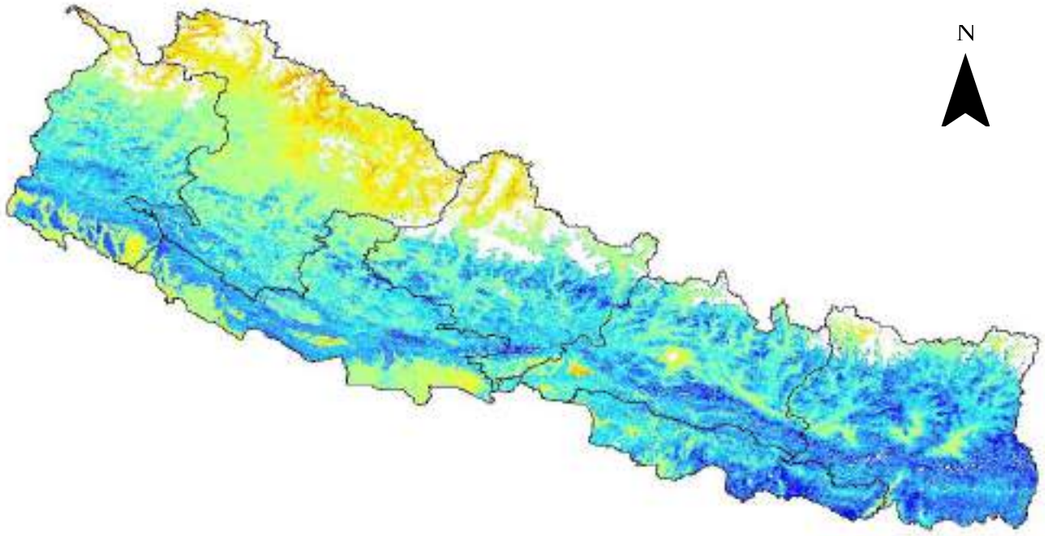
OCTOBER 2018



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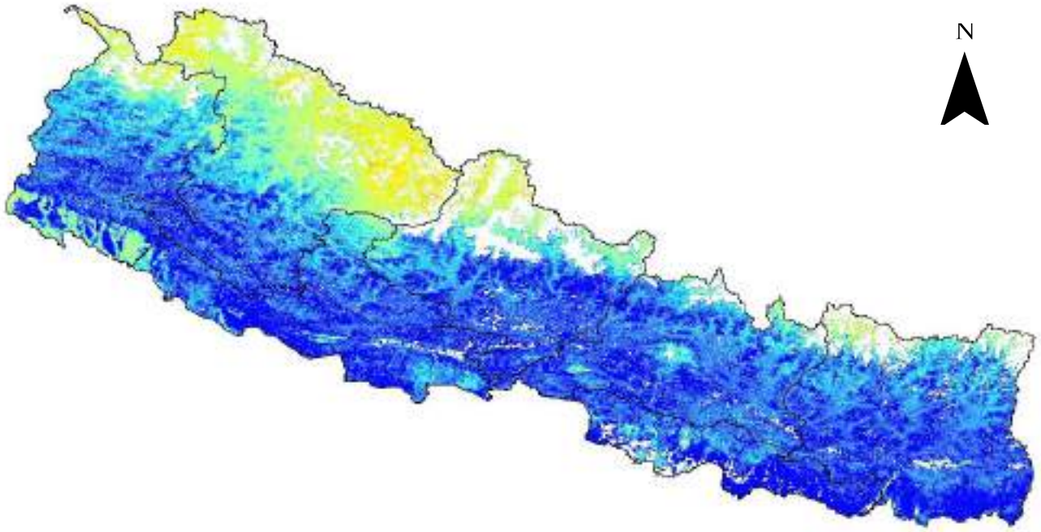

N

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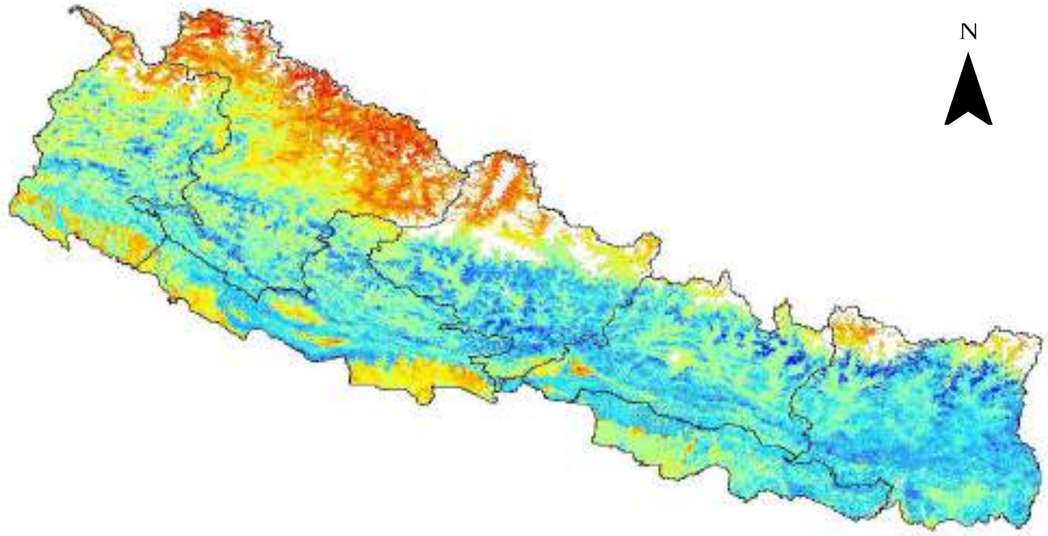
OCTOBER 2020



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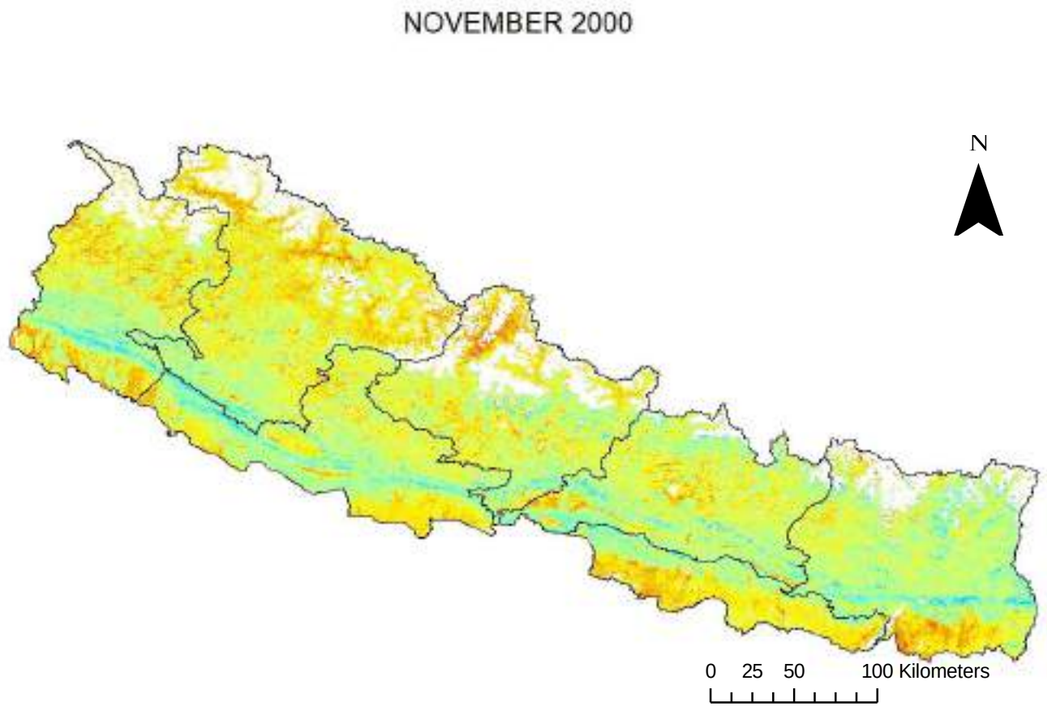
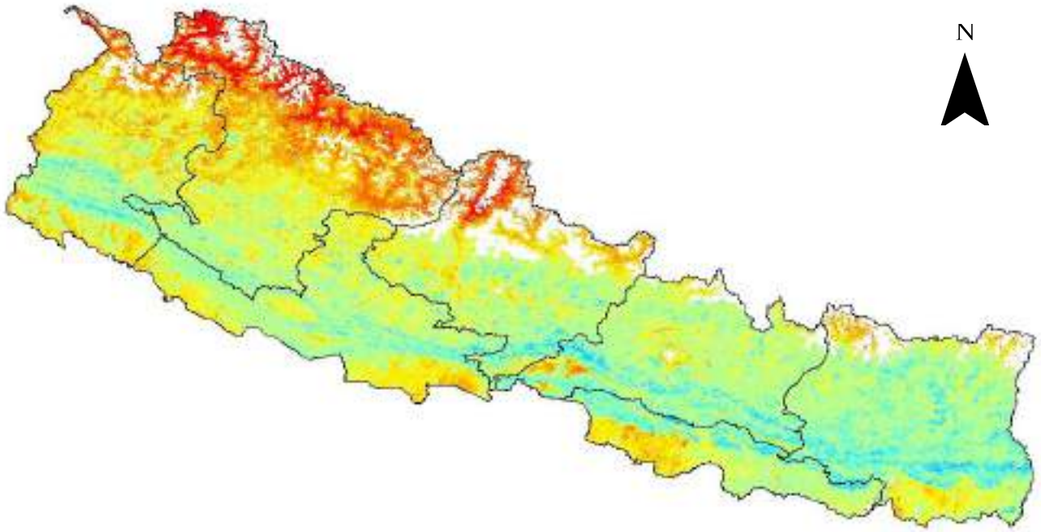
November DSI Maps

In November, drought normally ranges from incipient drought to near normal condition. As November is post monsoon month, drought condition is mostly in near normal state.

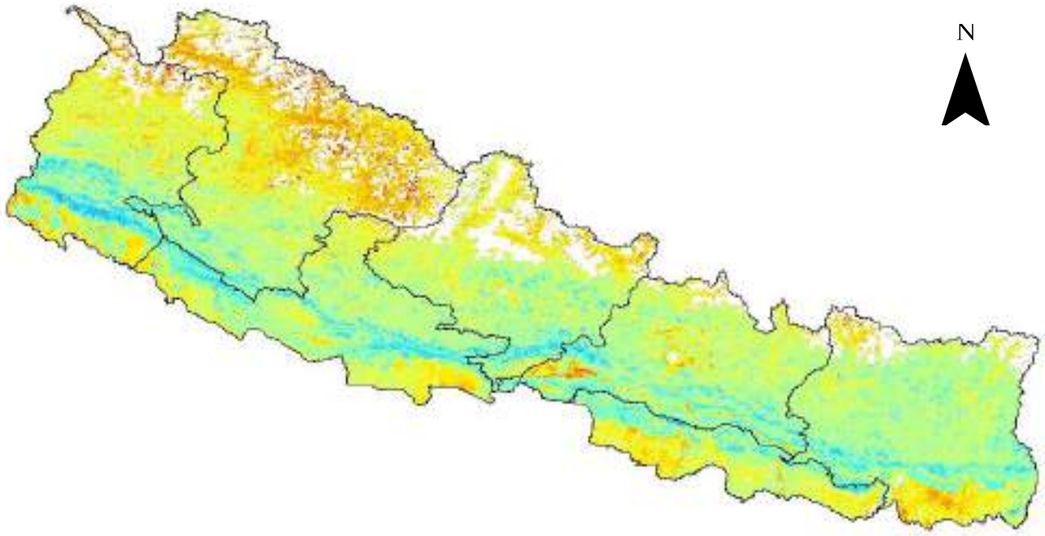
Mean November DSI Values		
Year	Values	Drought Condition
2000	-0.37	Incipient Drought
2001	-0.24	Near Normal
2002	-0.20	Near Normal
2003	-0.08	Near Normal
2004	-0.02	Near Normal
2005	-0.03	Near Normal
2006	-0.05	Near Normal
2007	0.12	Near Normal
2008	-0.16	Near Normal
2009	-0.04	Near Normal
2010	0.19	Near Normal
2011	0.22	Near Normal
2012	-0.17	Near Normal
2013	0.12	Near Normal
2014	-0.01	Near Normal
2015	-0.02	Near Normal
2016	0.01	Near Normal
2017	0.29	Near Normal
2018	0.06	Near Normal
2019	0.40	Incipient Wet Spell
2020	-0.28	Near Normal



NOVEMBER 2001



NOVEMBER 2002



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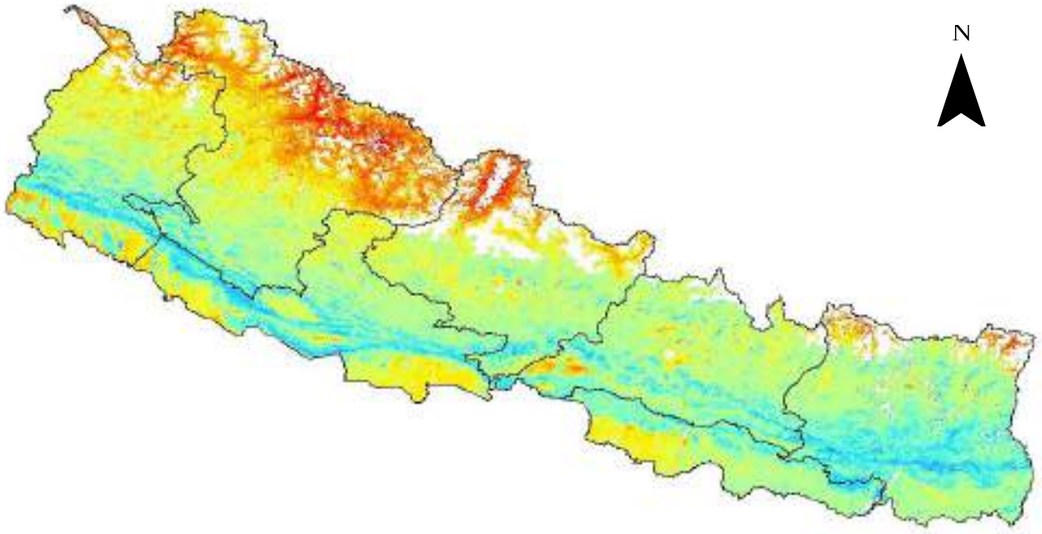

N

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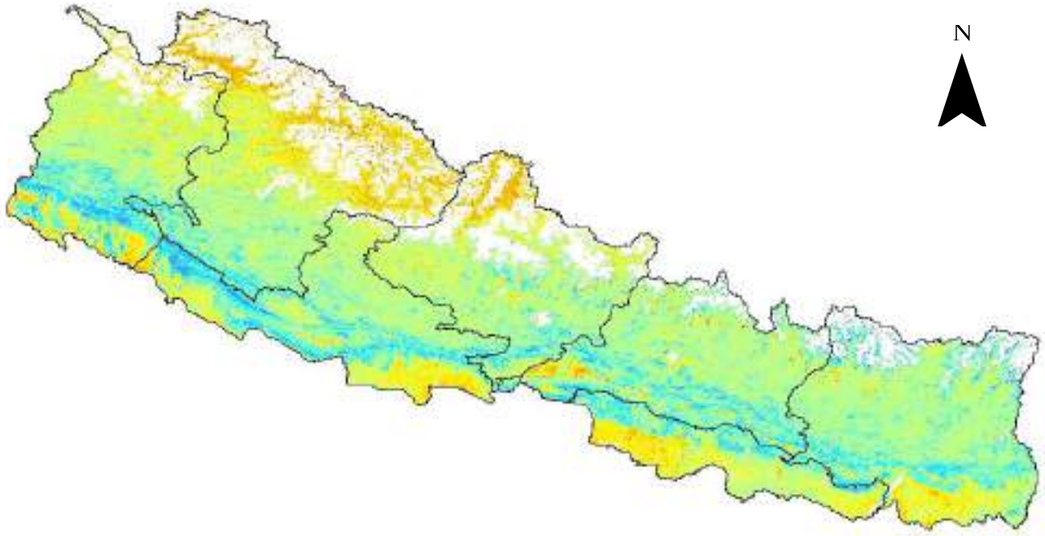
NOVEMBER 2004



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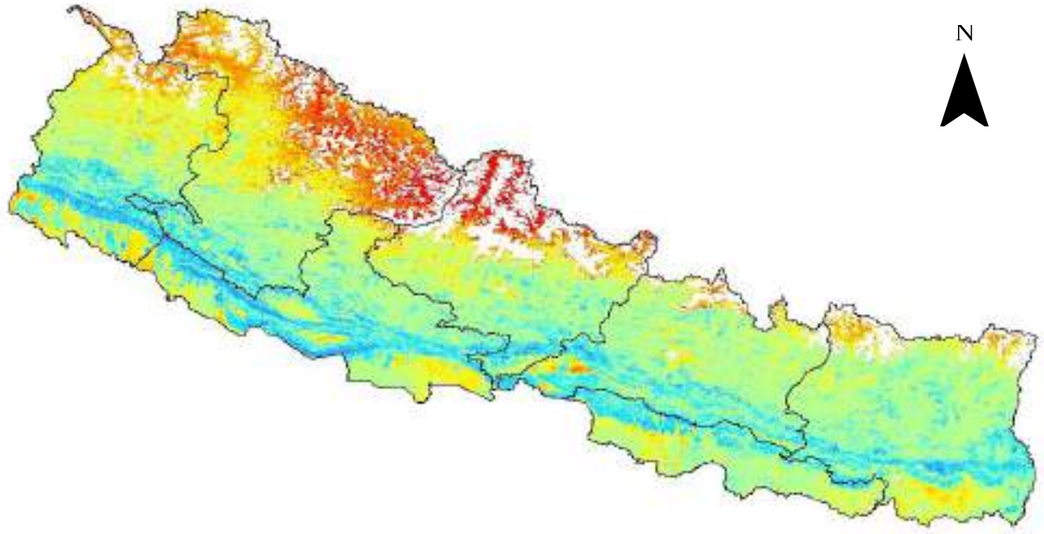
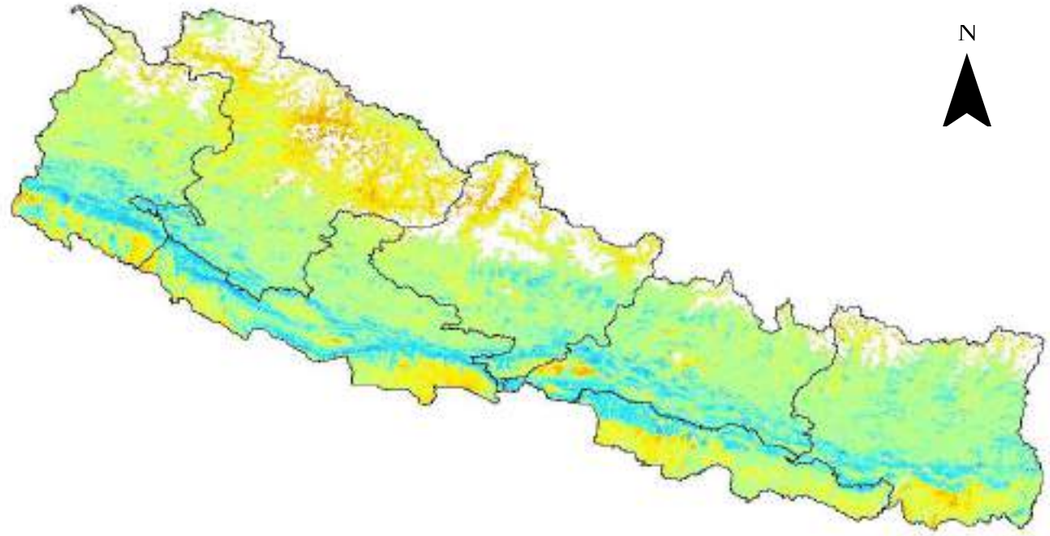
- Very Wet (1.2 to 1.49)
- Extremely Wet (1.5 or greater)

NOVEMBER 2005



NOVEMBER 2006



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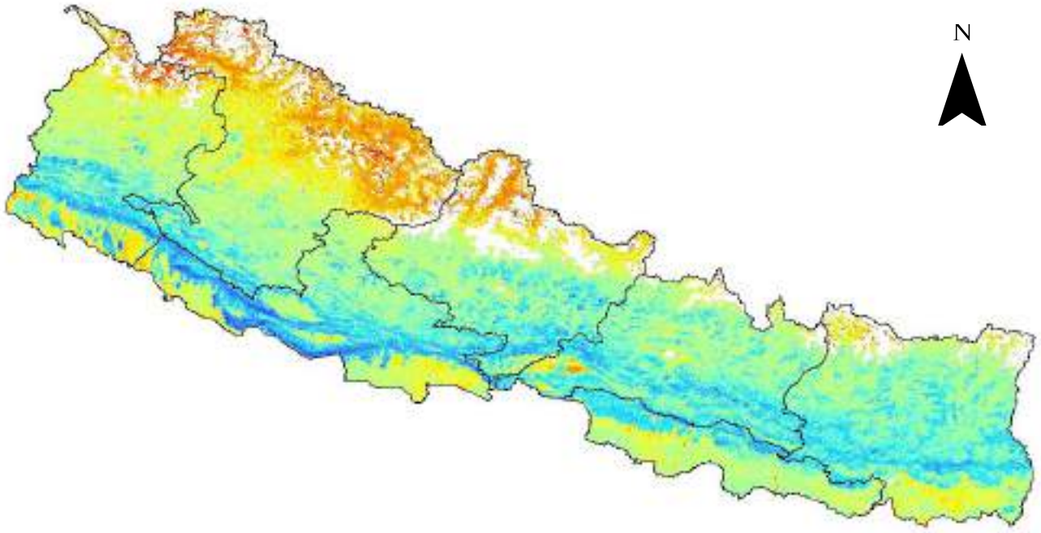
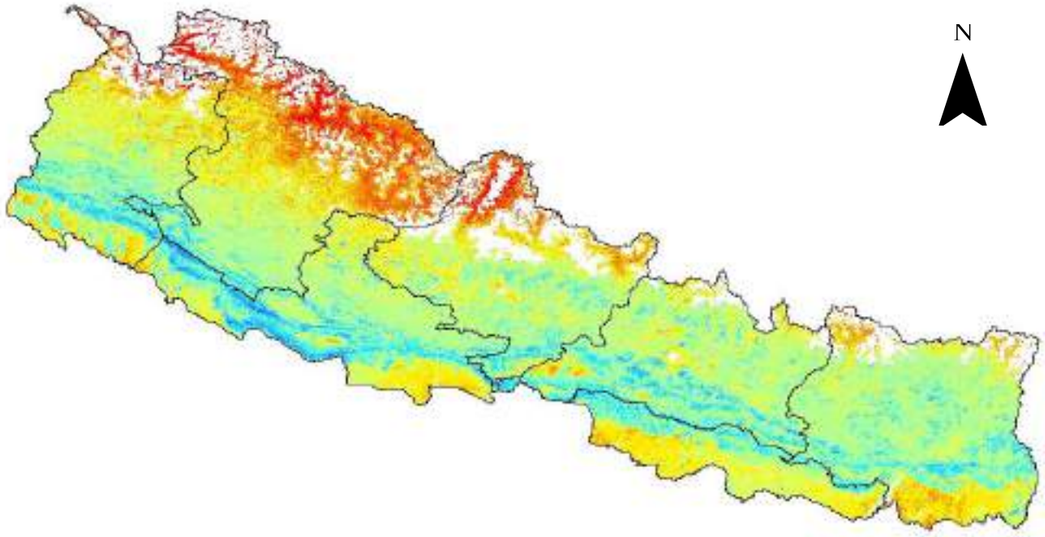


N

0 25 50 100 Kilometers

NOVEMBER 2008



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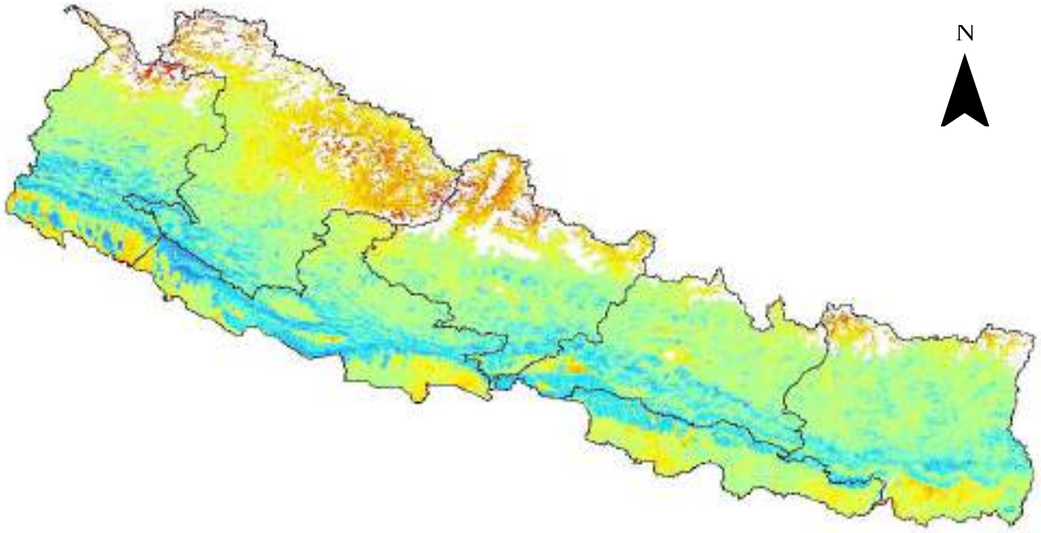

N

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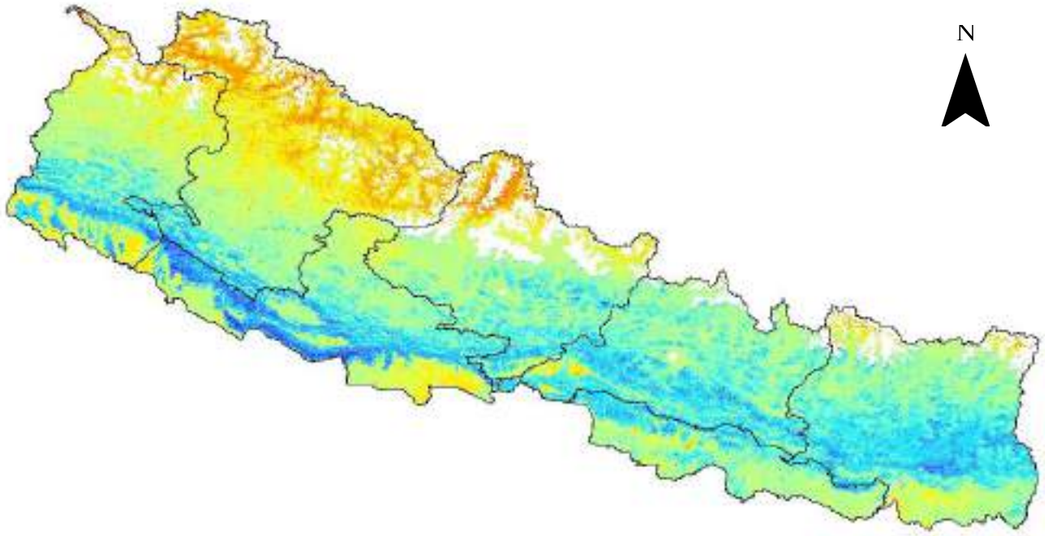
NOVEMBER 2010



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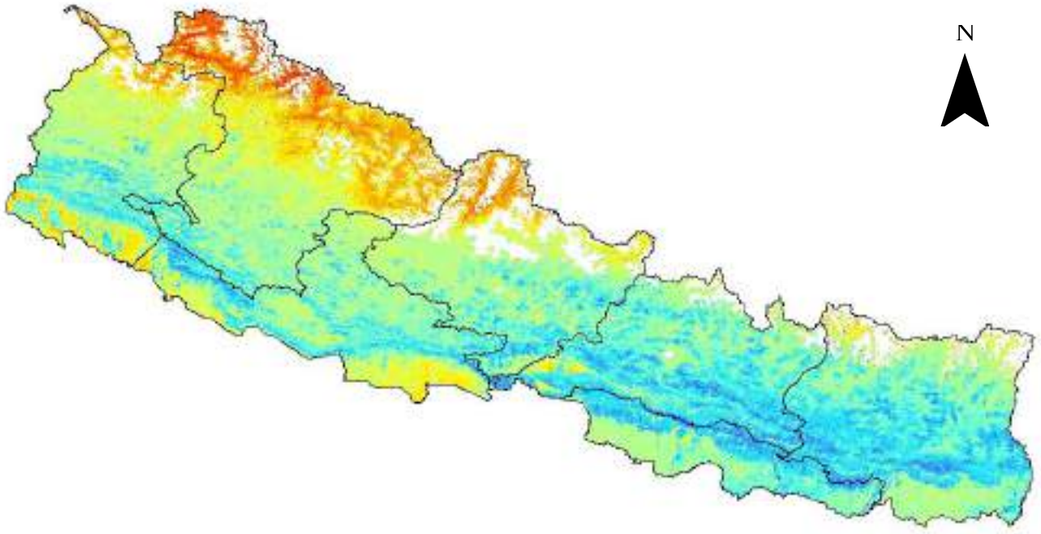
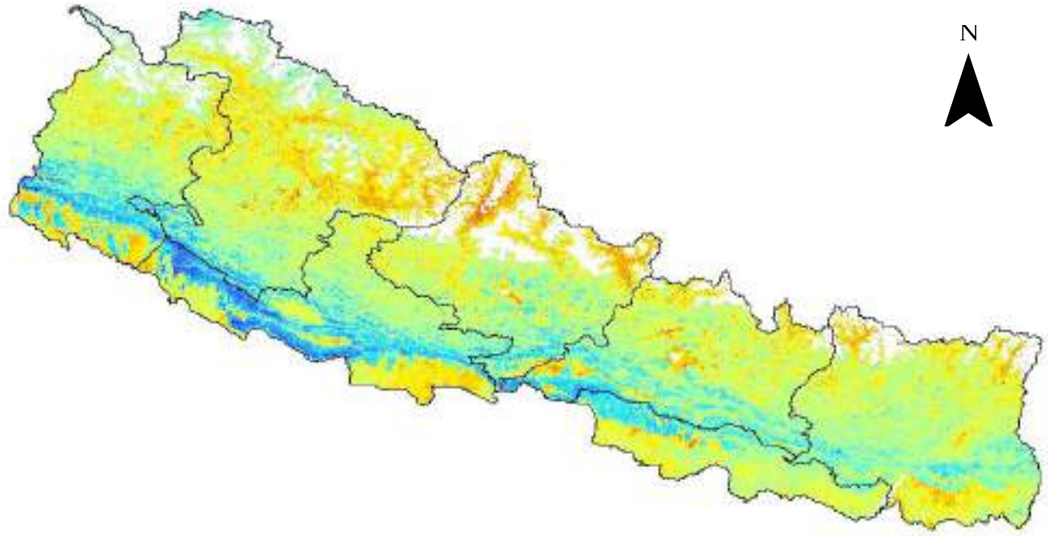


NOVEMBER 2012



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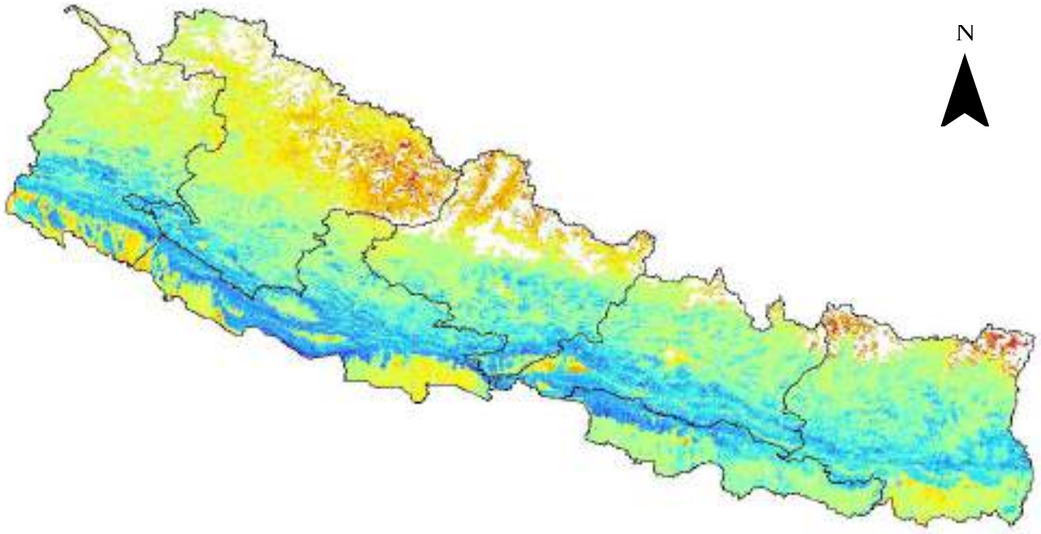
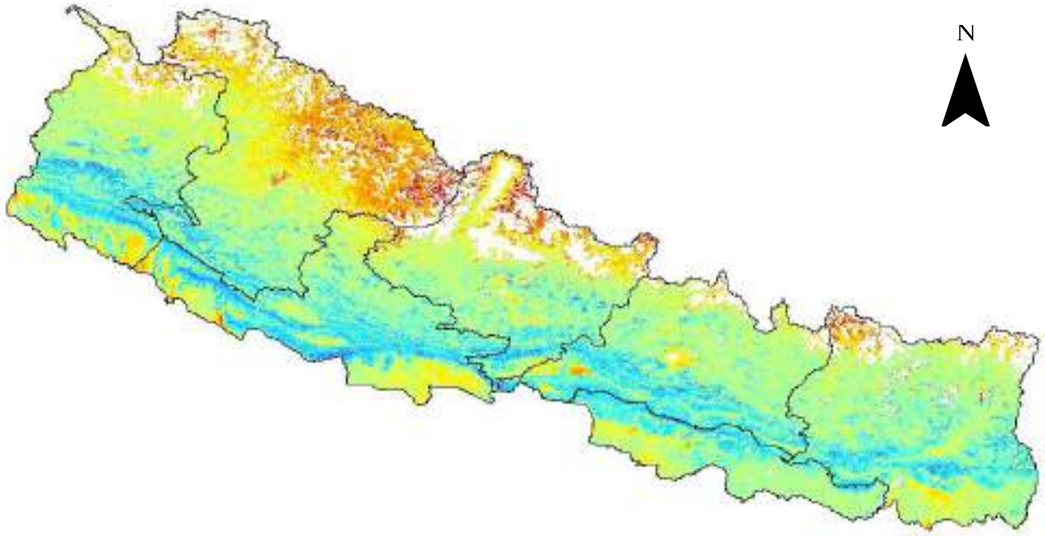


NOVEMBER 2014



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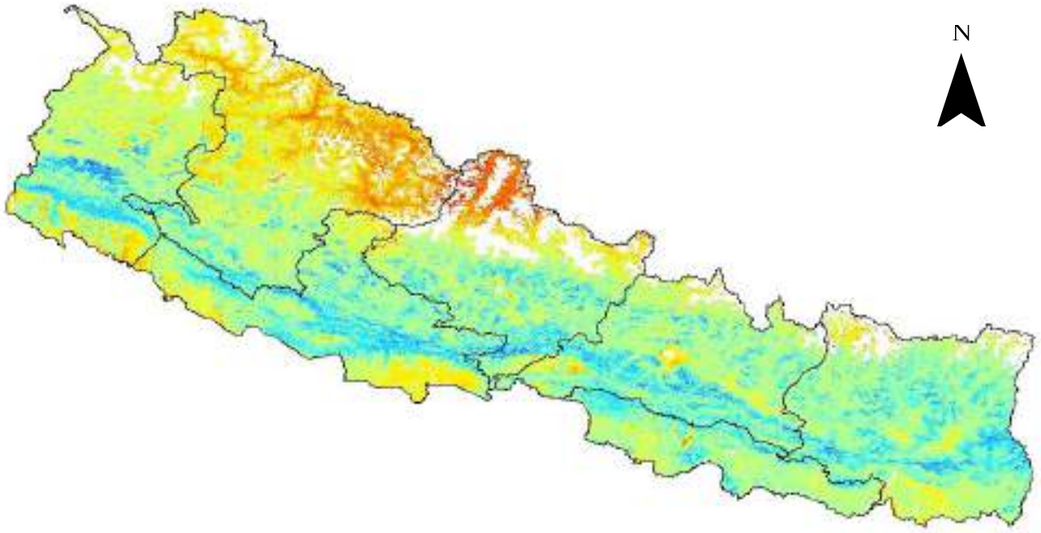
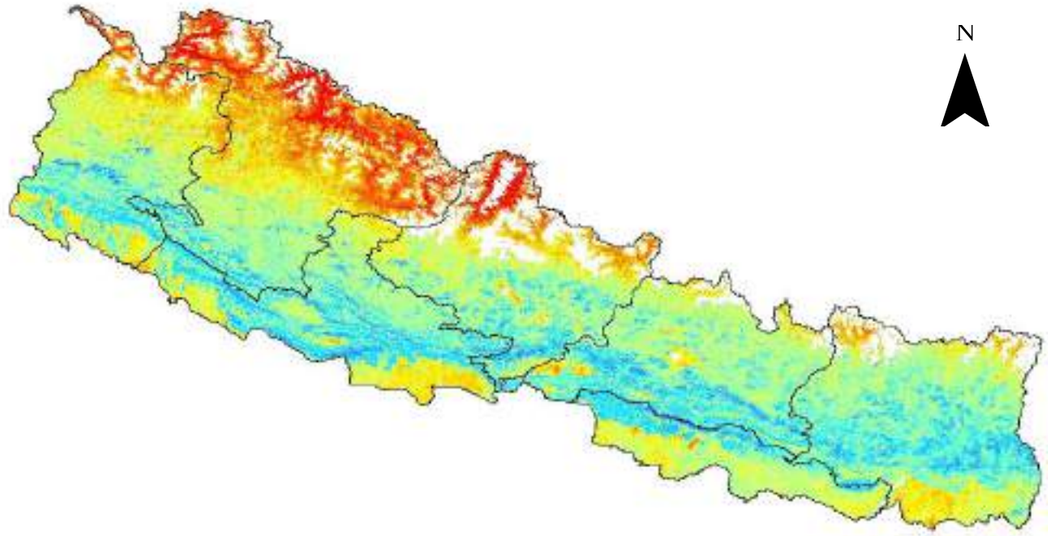


NOVEMBER 2016



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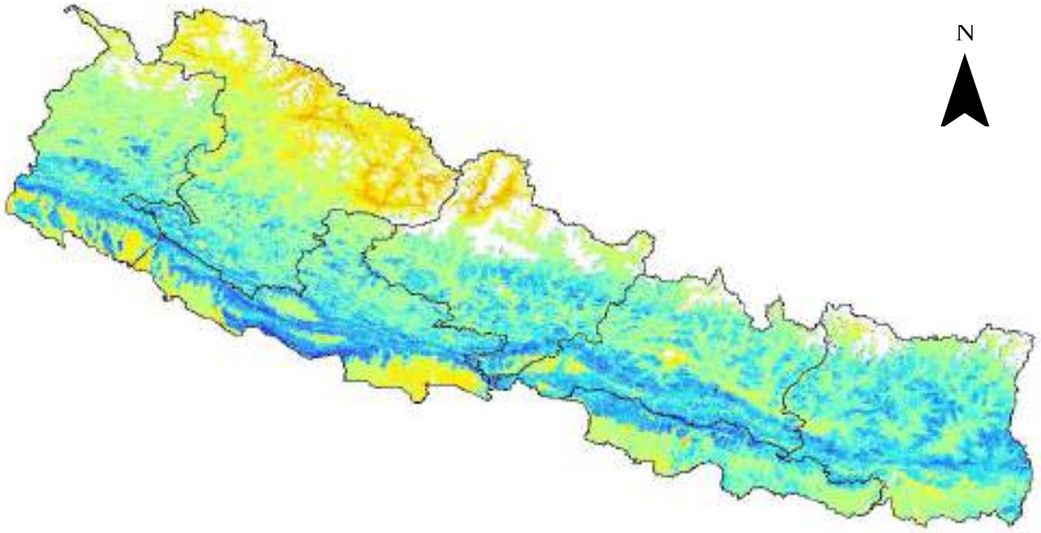
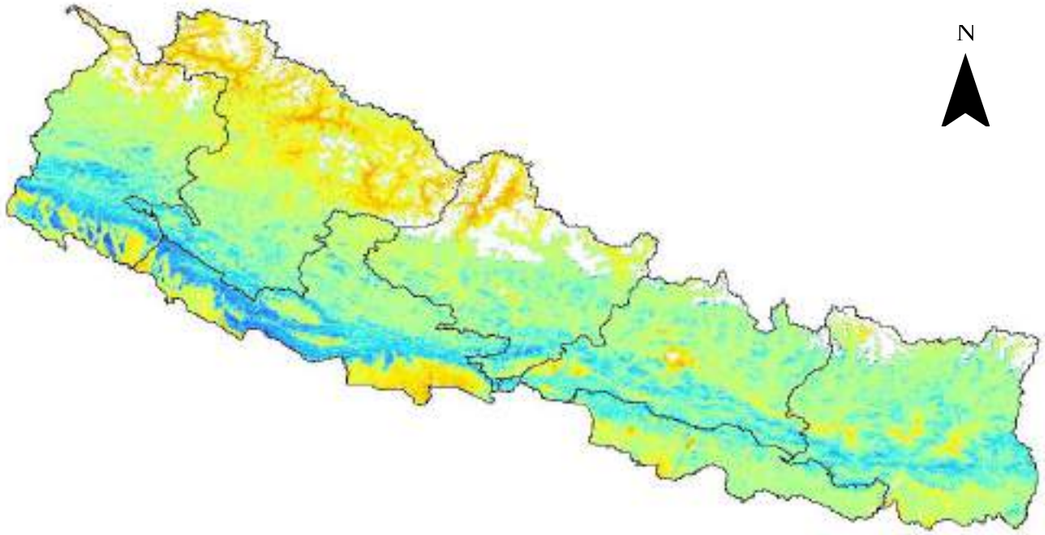


NOVEMBER 2018



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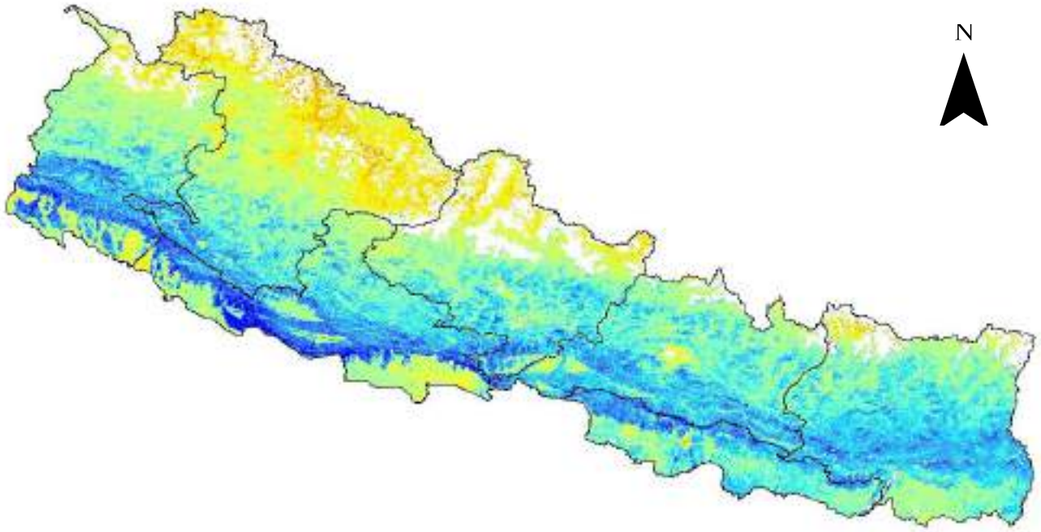
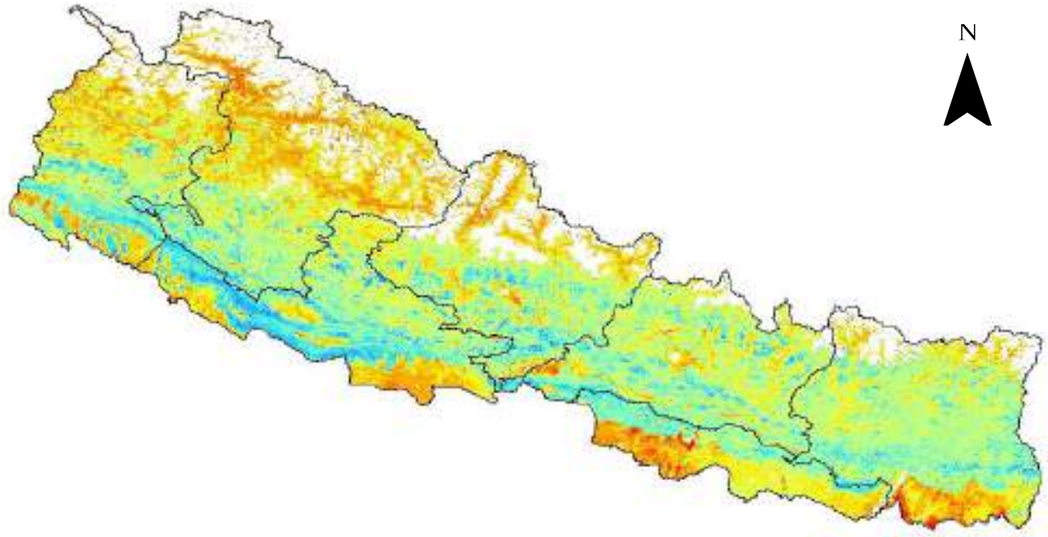


N

0 25 50 100 Kilometers

NOVEMBER 2020



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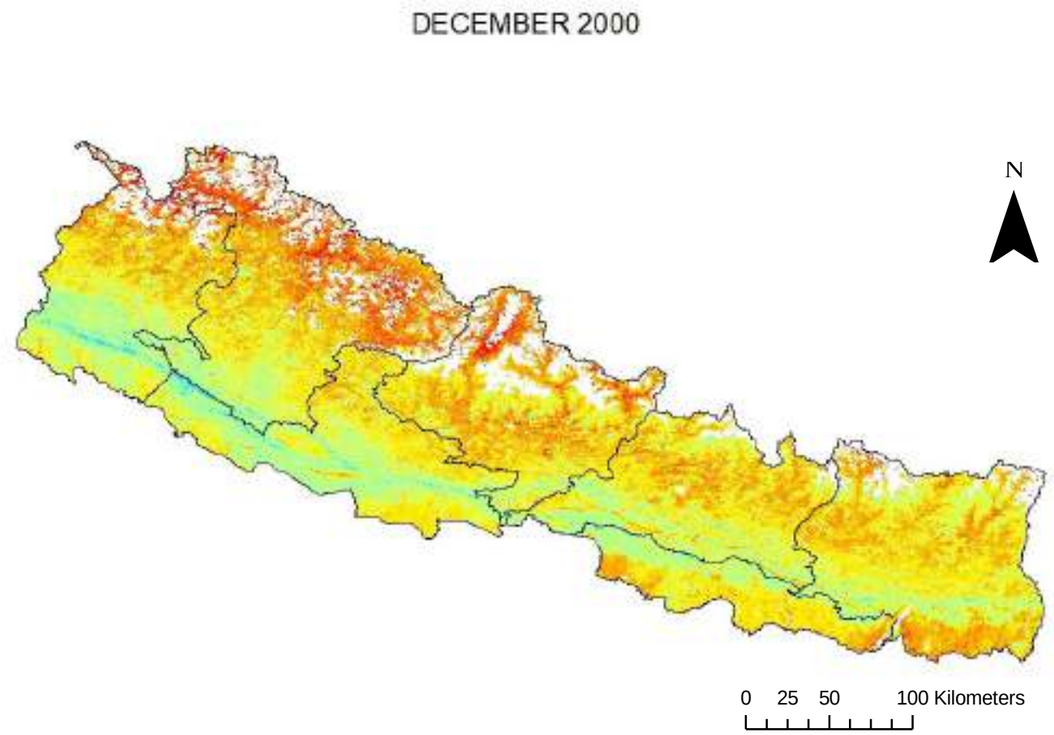
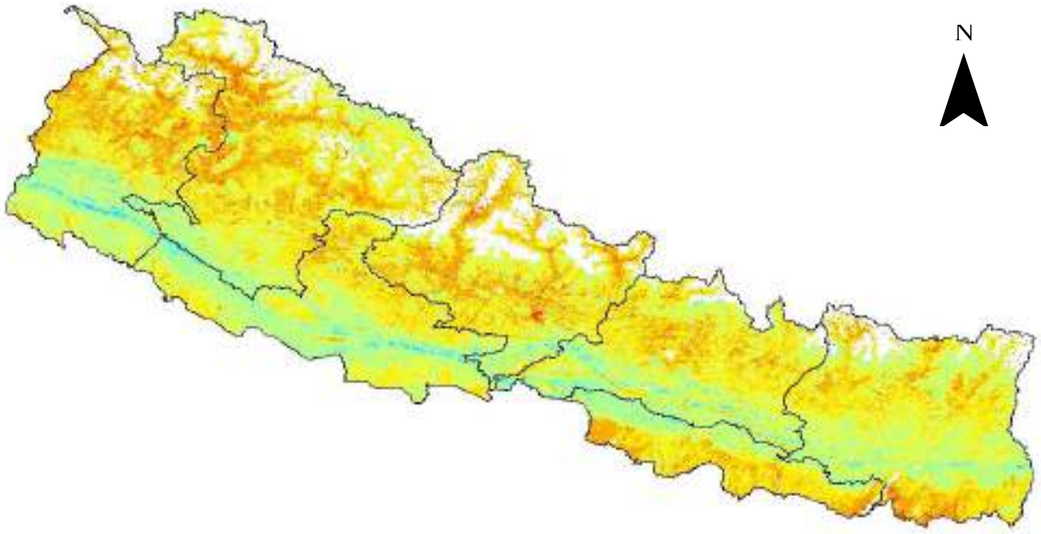
December DSI Maps

In December, drought condition typically vary from mild drought to near normal condition. This winter month is mostly dominated by incipient drought

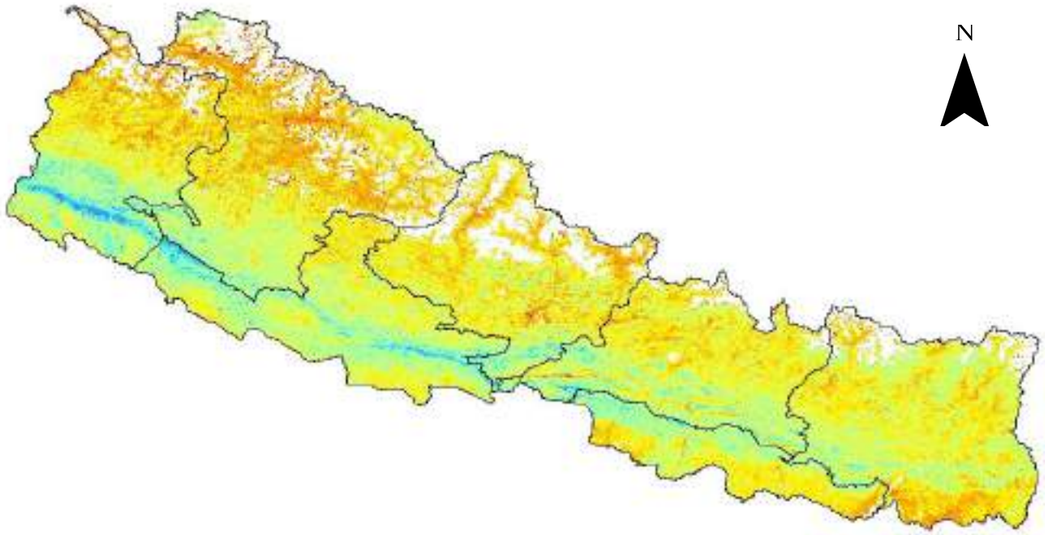
Mean December DSI Values		
Year	Values	Drought Condition
2000	-0.66	Mild Drought
2001	-0.57	Incipient Drought
2002	-0.47	Incipient Drought
2003	-0.42	Incipient Drought
2004	-0.31	Incipient Drought
2005	-0.45	Incipient Drought
2006	-0.33	Incipient Drought
2007	-0.34	Incipient Drought
2008	-0.34	Incipient Drought
2009	-0.33	Incipient Drought
2010	-0.33	Incipient Drought
2011	-0.37	Incipient Drought
2012	-0.48	Incipient Drought
2013	-0.14	Near Normal
2014	-0.24	Near Normal
2015	-0.37	Incipient Drought
2016	-0.32	Incipient Drought
2017	-0.15	Near Normal
2018	-0.33	Incipient Drought
2019	-0.01	Near Normal
2020	-0.59	Incipient Drought



DECEMBER 2001



DECEMBER 2002



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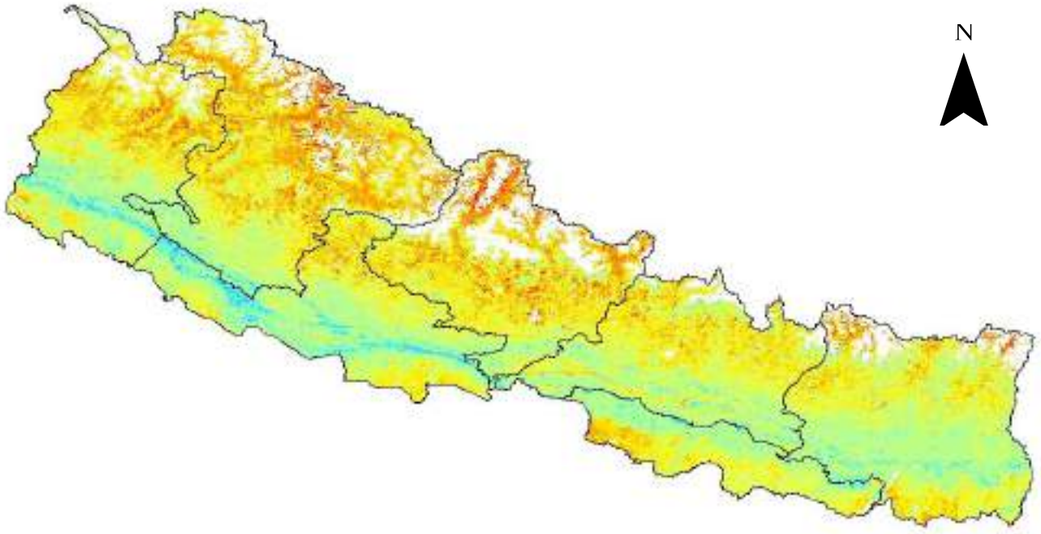
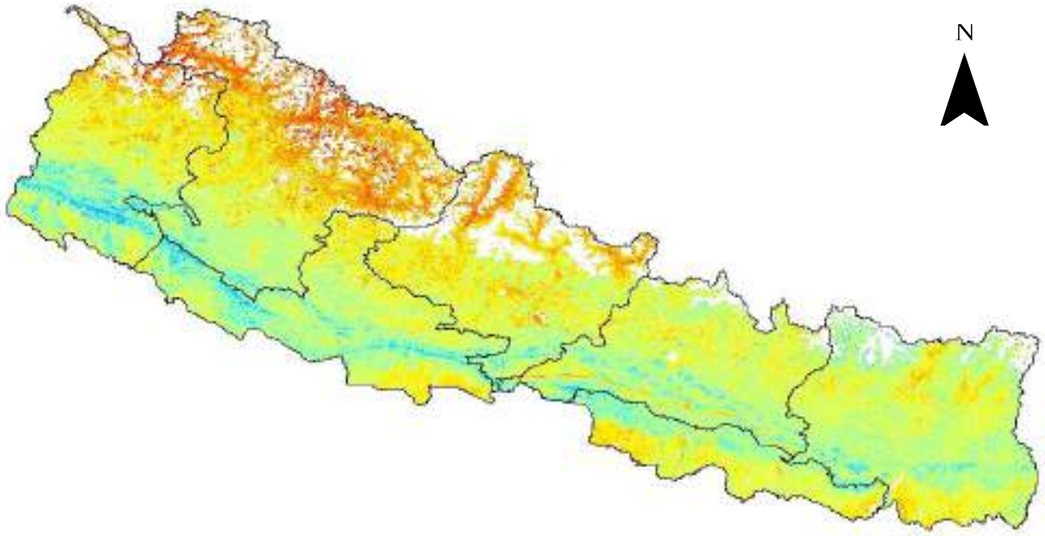


N

0 25 50 100 Kilometers

DECEMBER 2004



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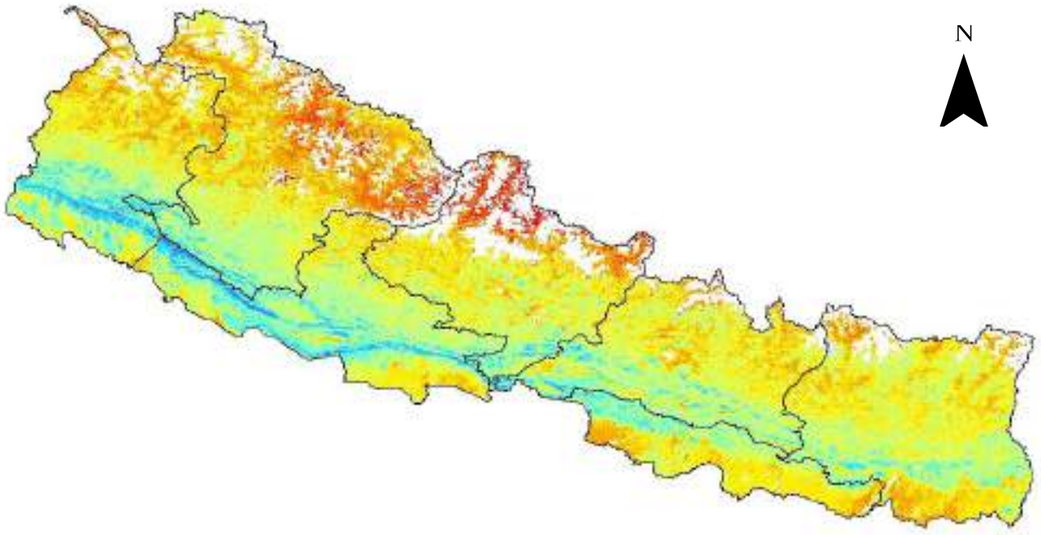

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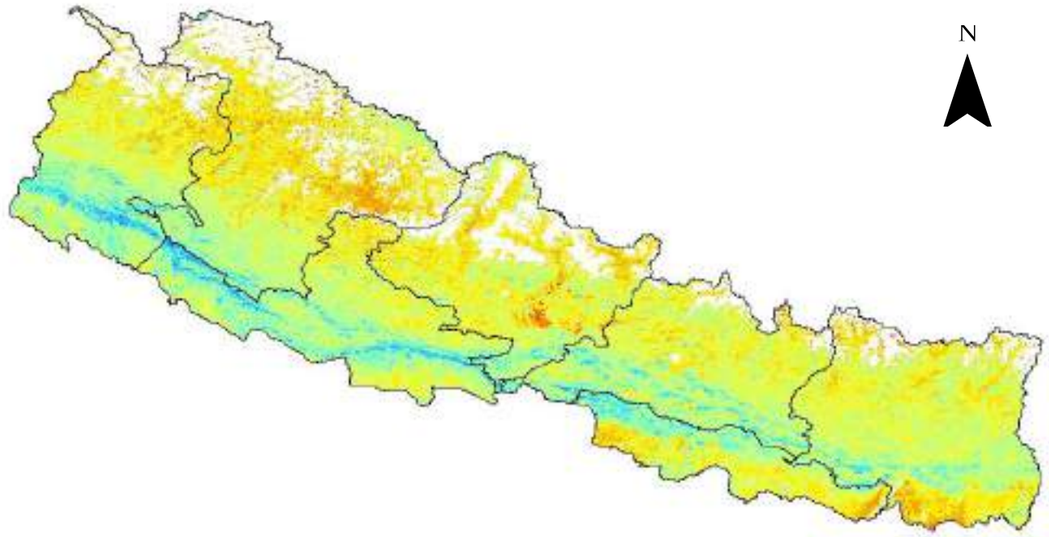

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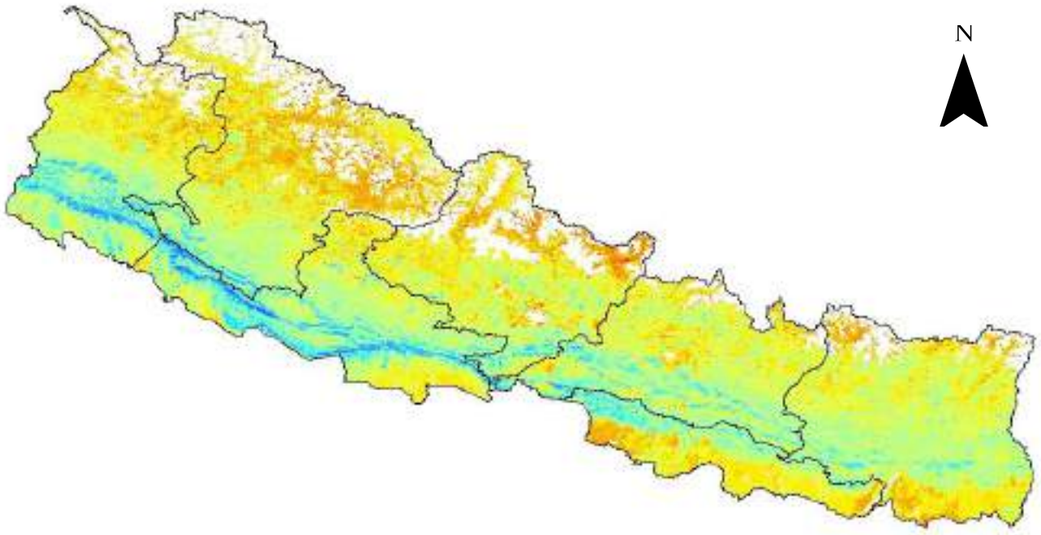

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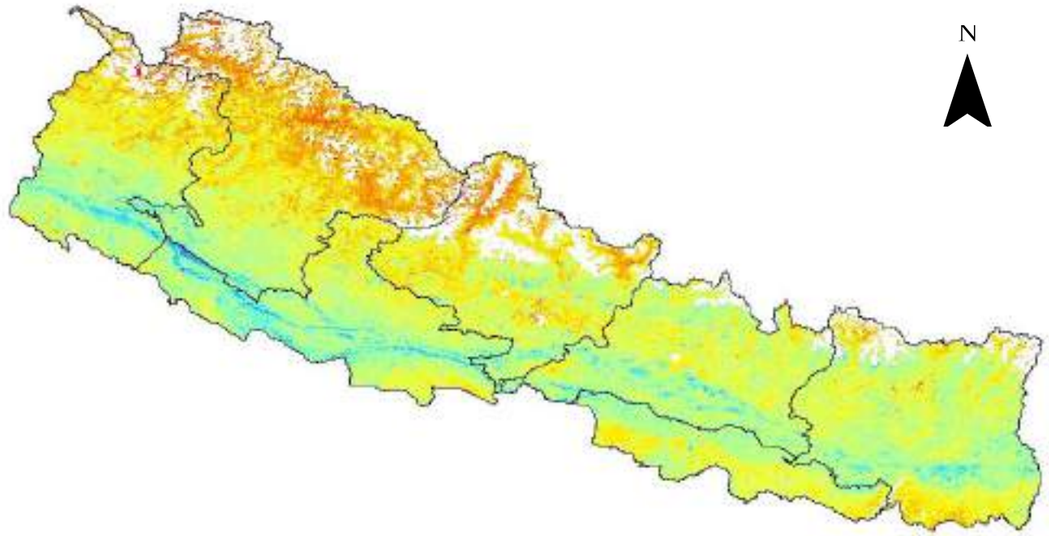

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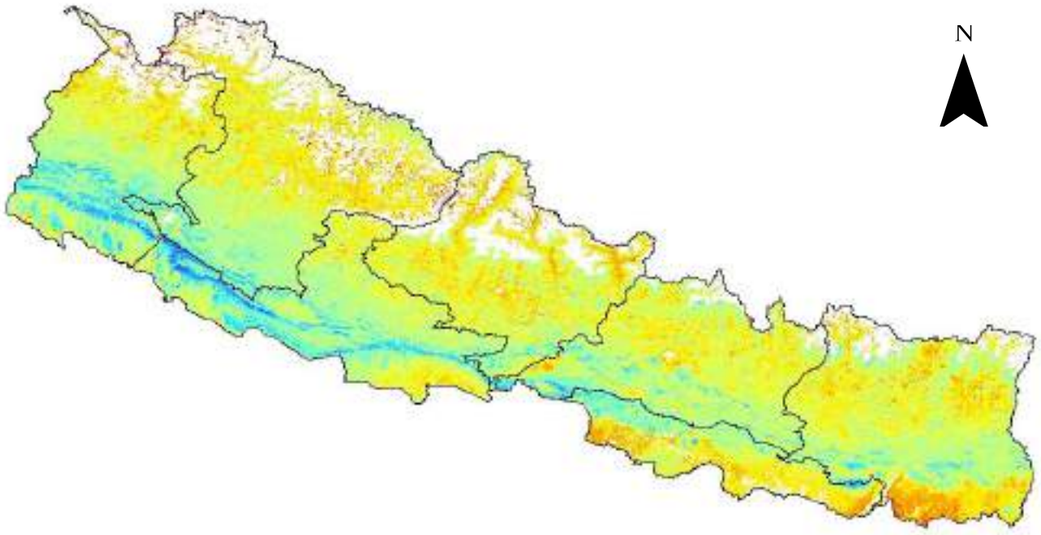

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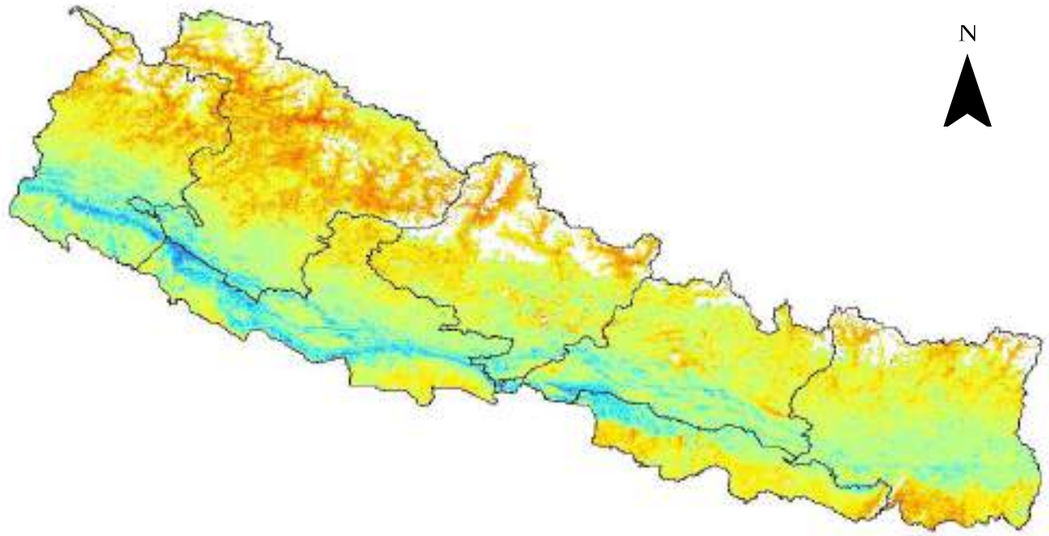

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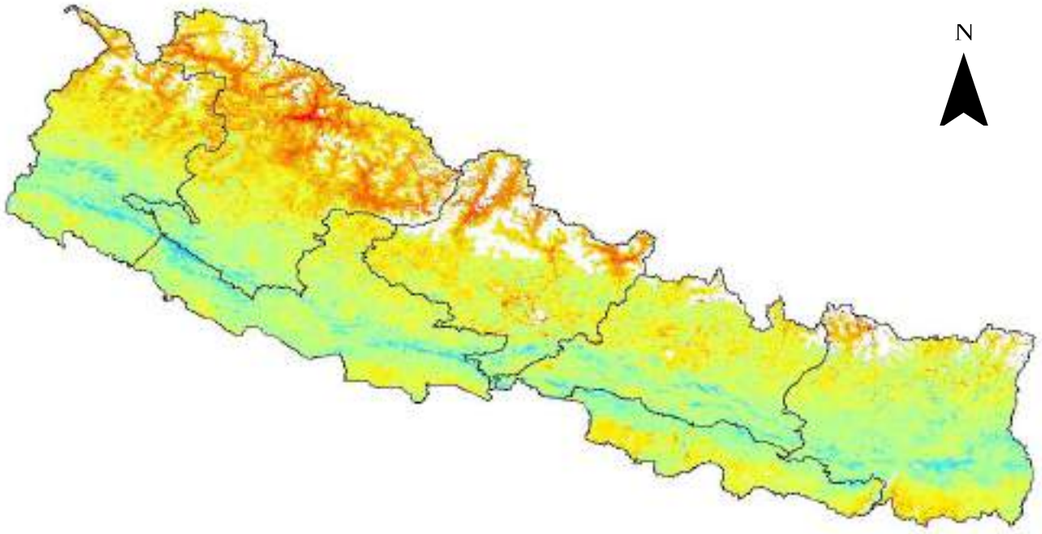

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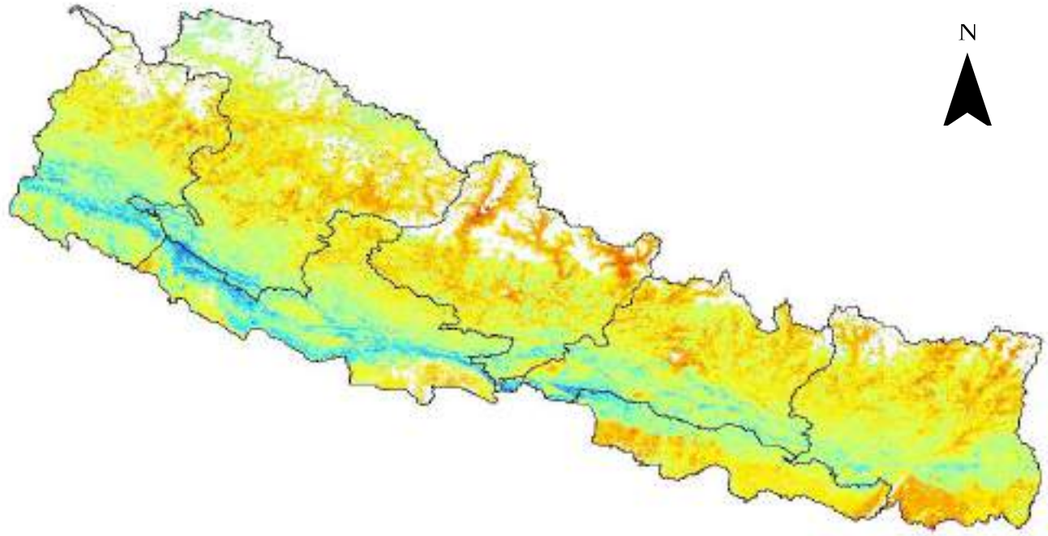

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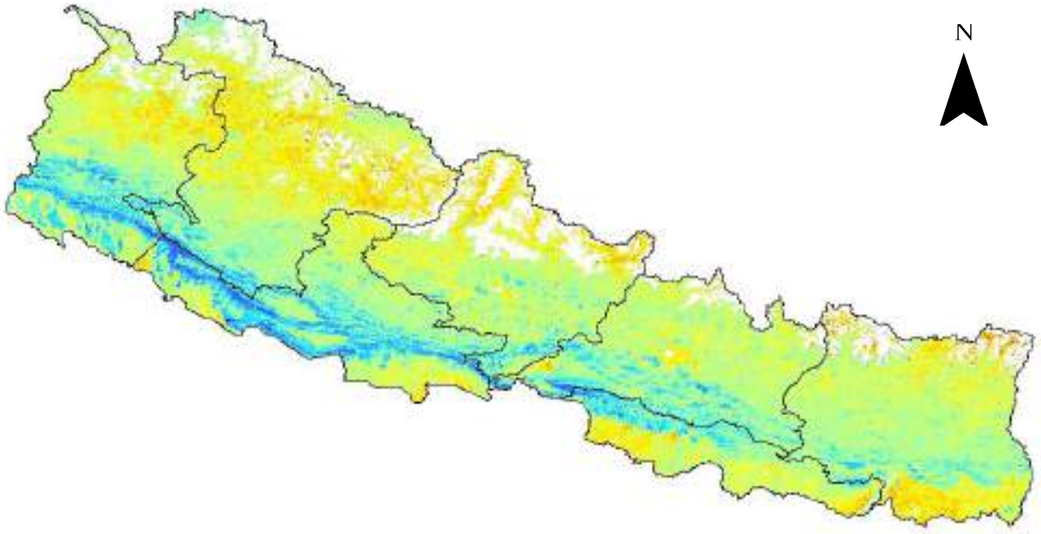
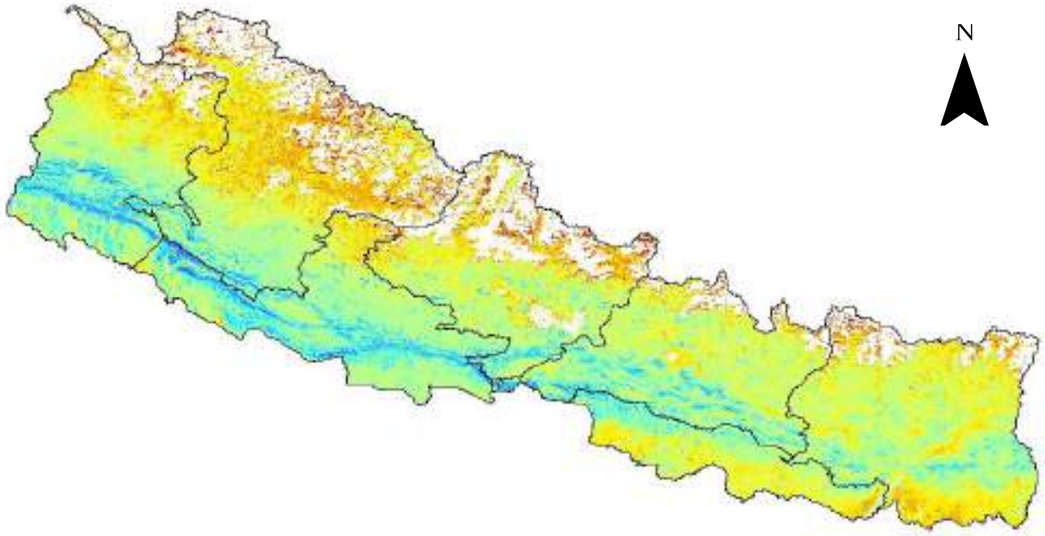


N

0 25 50 100 Kilometers

DECEMBER 2014



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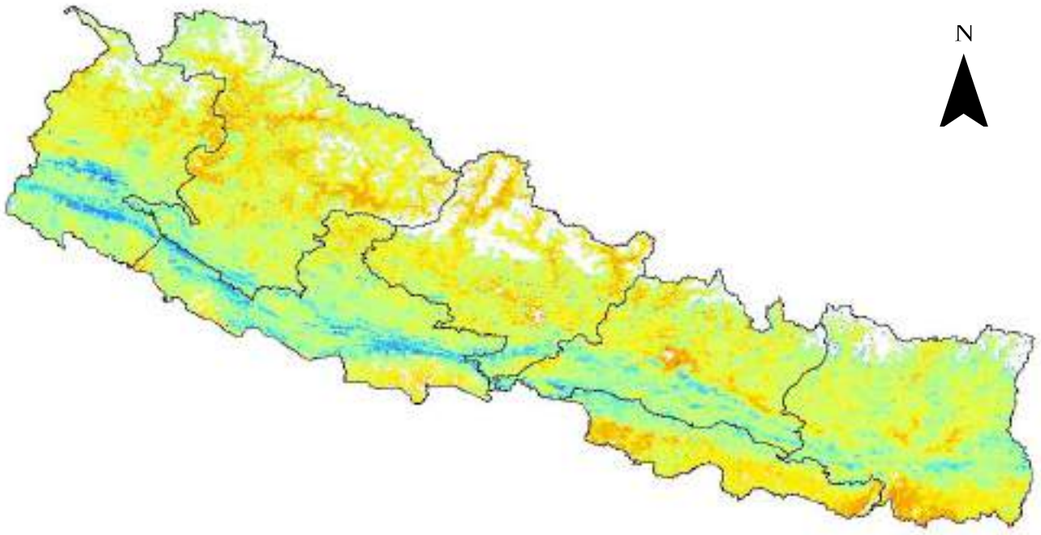

N

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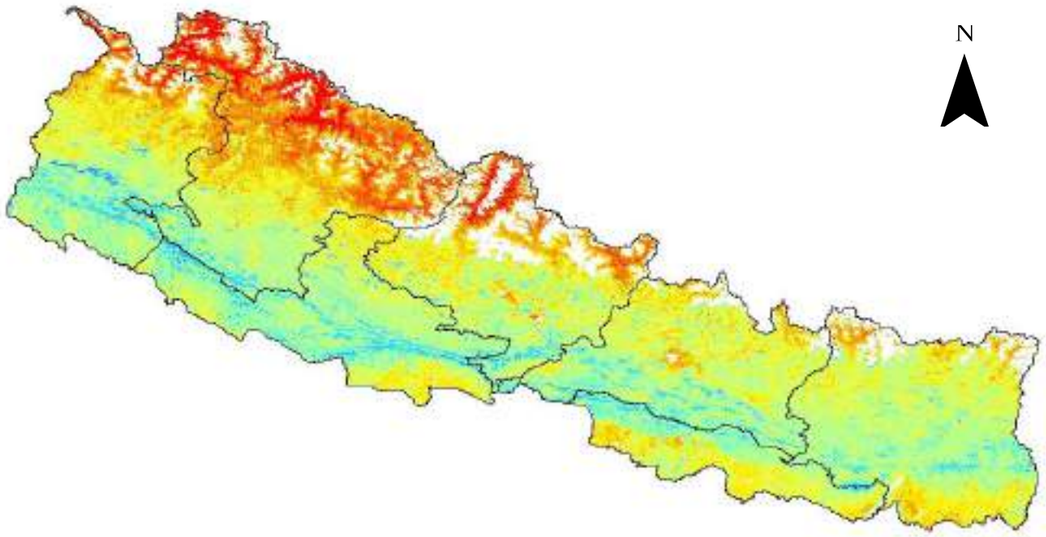

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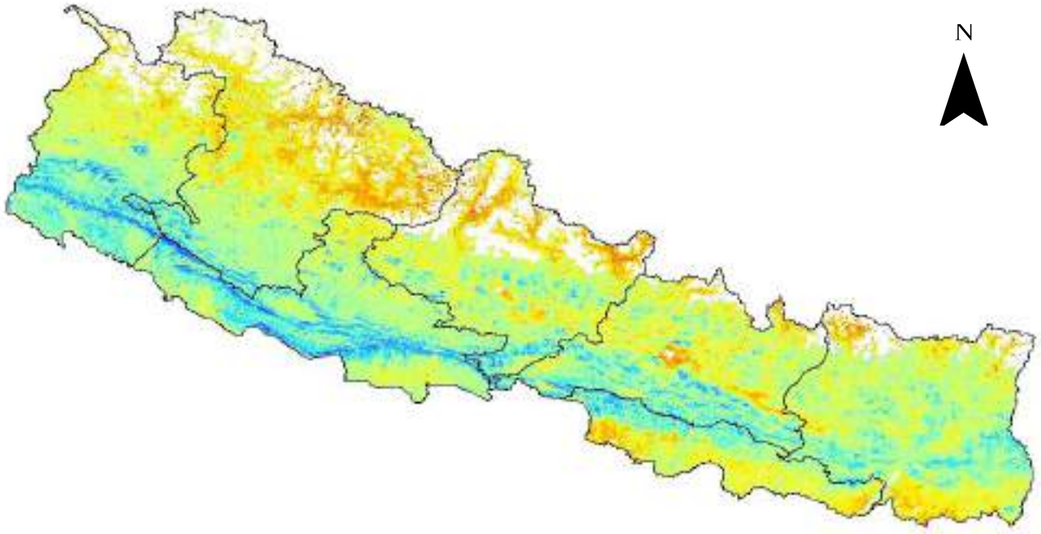
- Slightly Wet (0.6 to 0.89)
- Moderately Wet (0.9 to 1.19)
- Very Wet (1.2 to 1.49)
- Extremely Wet (1.5 or greater)

DECEMBER 2017



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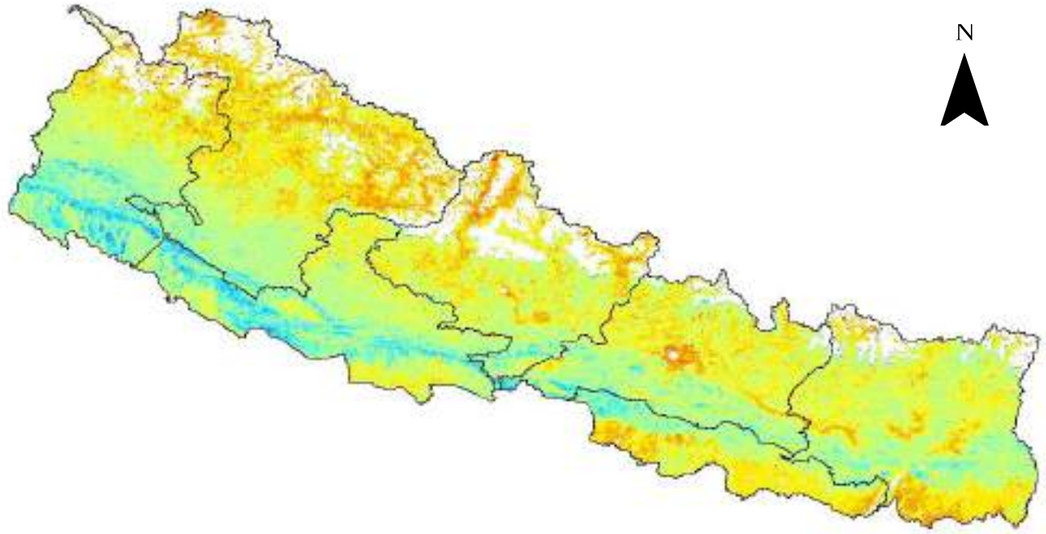

Legend

- Extreme Drought (-1.5 or less)
- Severe Drought (-1.2 to -1.49)
- Moderate Drought (-0.9 to -1.19)
- Mild Drought (-0.6 to -0.89)
- Incipient Drought (-0.3 to -0.59)
- Near Normal (0.29 to -0.29)
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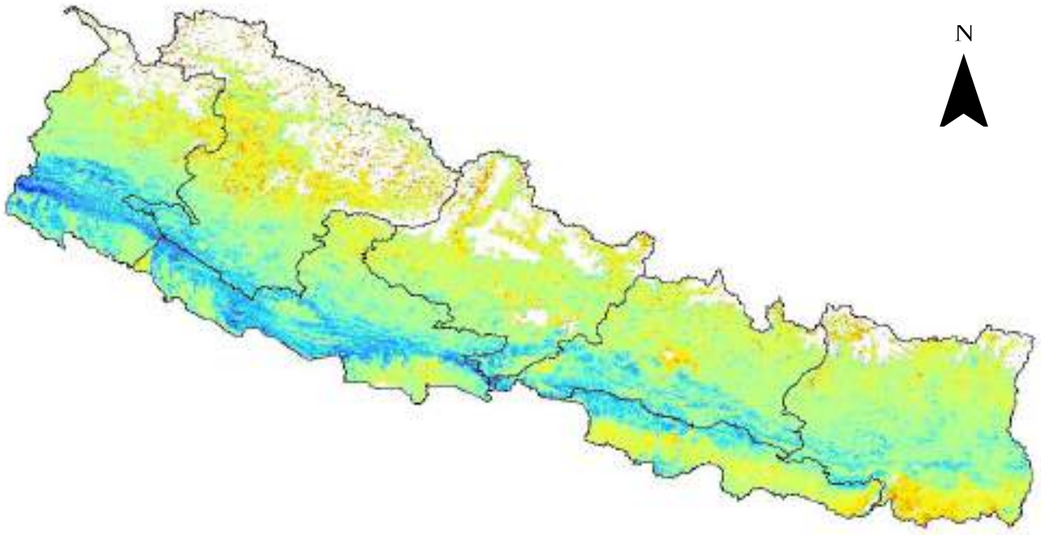
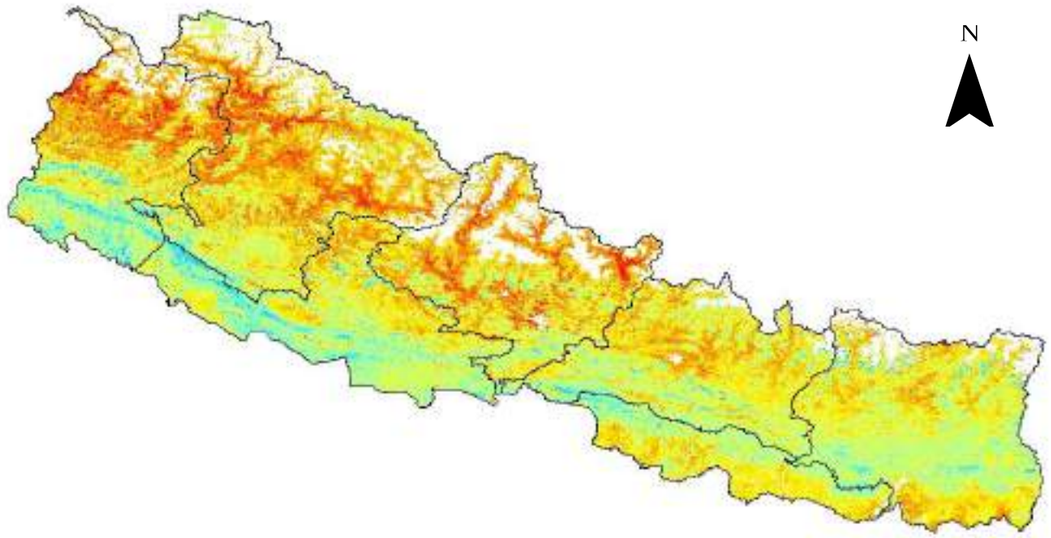
DECEMBER 2019



N

0 25 50 100 Kilometers

DECEMBER 2020



N

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Legend

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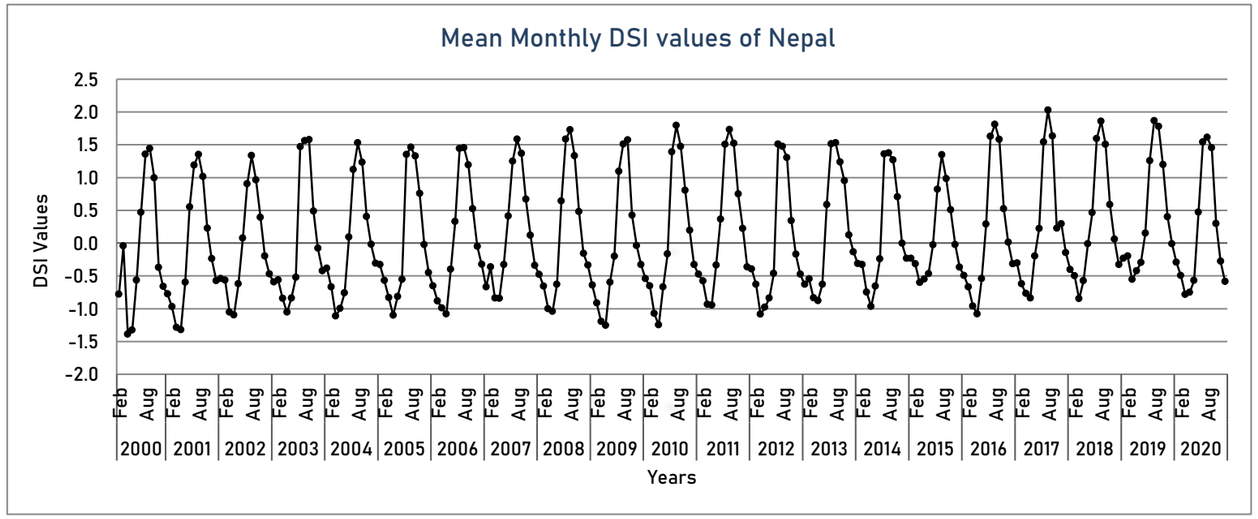
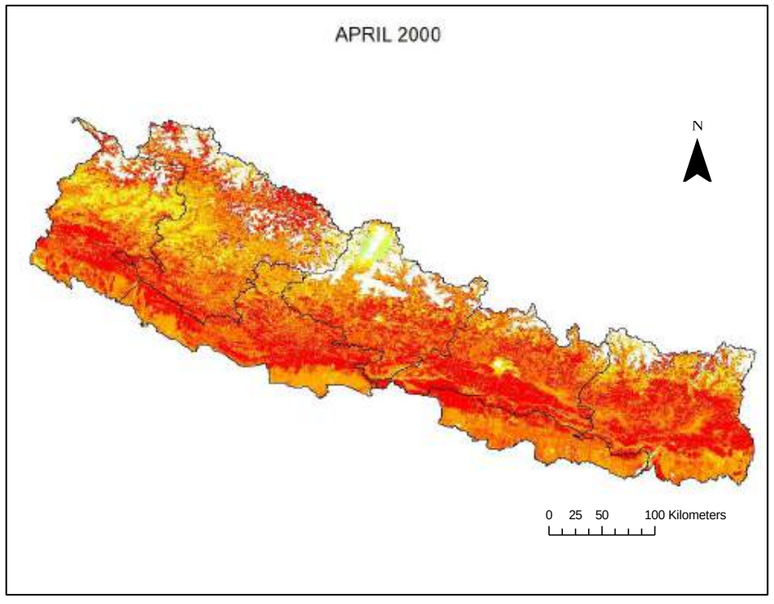
Drought Severity Index of Nepal

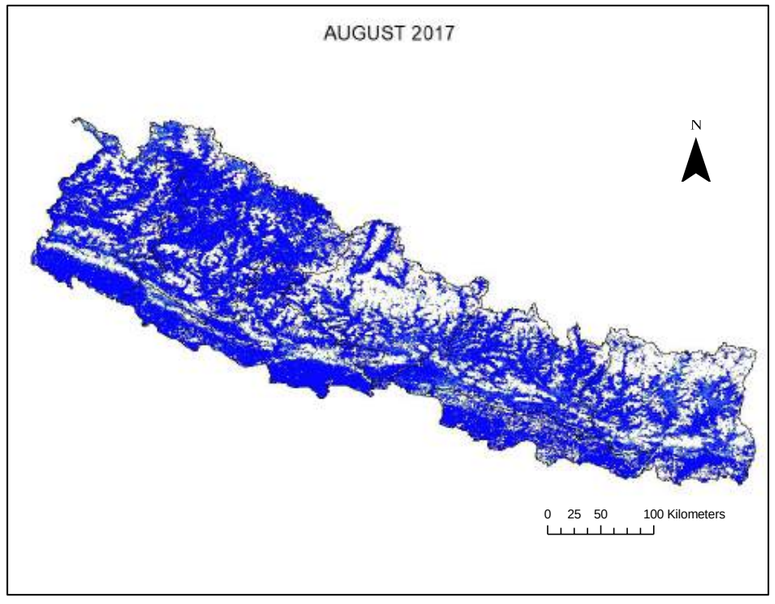


Droughts are one of the greatest threats to agricultural crop production in Nepal, a country whose economy relies heavily on its agriculture. This study presents spatial and temporal drought characteristics using satellite-based MODIS data.

The spatial maps revealed that the extremely dry conditions in these years started to develop in pre-monsoon (MAM) season over the country. In the context of Nepal, Pre-Monsoon (March-April-May) is considered as the dry period which is followed by Post-Monsoon (October-November). But the normal onset of monsoon in the later months provided enough water for vegetation growth that the shortage was no more visible for the monsoon (JJAS) season. However, the spatial maps of 2003, 2005, 2012 for June month had drought events in western Nepal. Thus, the pattern for such drought occurrences depends upon the rainfall systems in Nepal. Whereas, particular years in 2003 and 2004, certain areas of central and western regions showed to have experience the severe drought conditions.

Lowest DSI value was identified in April 2000 and August 2017 being the wettest month with value 2.02. Mean monthly DSI values normally range from moderate to incipient drought. The DSI values usually fluctuate betweem 1.5 to -1.





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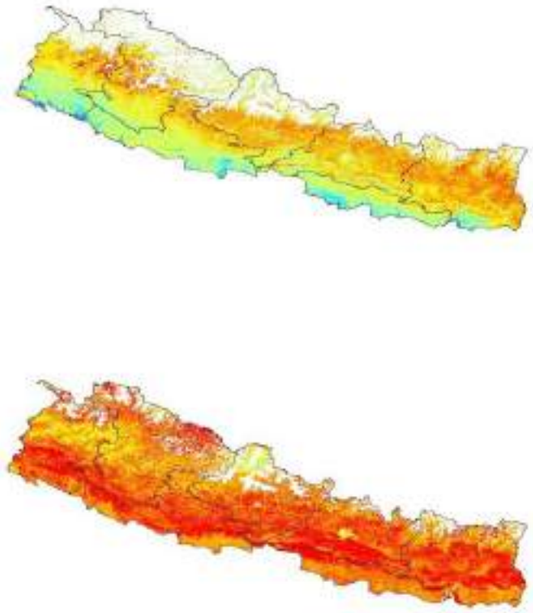
As a result of changing climatic conditions, alter in precipitation events such as drought have emerged as a source of vulnerability in several South Asian nations, including Nepal, India, Pakistan, and Bangladesh. Recent declines in agricultural productivity have weakened rural economies, encouraging widespread famine and urban migration.

Drought monitoring and assessment techniques are used to forecast drought and identify drought-prone areas, allowing drought mitigation measures to be put in place to lessen the impact of drought on food production and water supplies. To estimate the severity of the drought in Nepal, we applied the Drought Severity Index (DSI), which combines the Normalized Difference Vegetation Index (NDVI) and the ratio of Evapotranspiration to Potential Evapotranspiration (ET/PET).

This Atlas provides an overview of Nepal's drought frequency during the last two decades. It portrays the spatiotemporal occurrences of drought in Nepal's several provinces. I hope this atlas will assist in the creation of policies and plans for timely drought mitigation and forecasting in the agricultural sector.

Dr. Hemu Kharel Kafle



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