

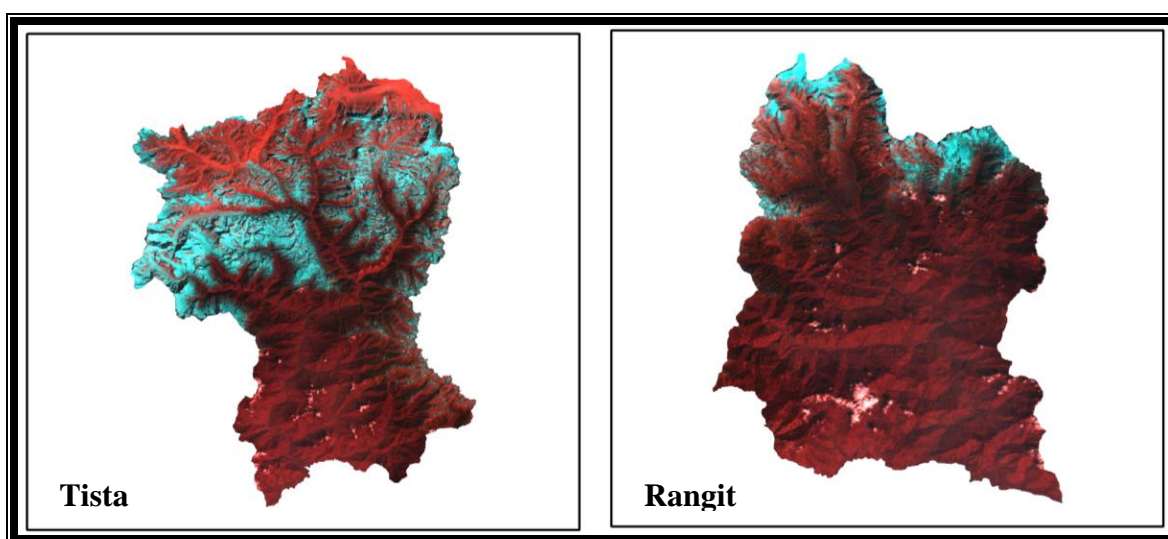
SNOW COVER ATLAS OF SIKKIM

Sub-basins: Tista and Rangit

(Integrated Studies of Himalayan Cryosphere

A Project of Indian Space Research Organisation)

Year 2014 - 2015



CEPT
UNIVERSITY



Center for Applied Geomatics
CEPT University- Ahmadabad 380009

&

Space Applications Centre (ISRO)
Ahmedabad-380015

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Report Number	SAC/EP SA/GHCAG/CSD/SR/ 133 /2018
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Abstract	This atlas gives subbasin-wise distribution of snow cover in the Tista basin from October 2014 to June 2015. The subbasins included in this report are Tista and Rangit. The areal extent of snow cover was estimated in fully automatic mode using Normalized Difference Snow Index (NDSI) based algorithm. For this purpose AWiFS sensor of Resourcesat satellite was used. This atlas gives snow cover products, statistics and seasonal snow depletion curve. It is expected that this data will be useful for hydrological and climatological applications.
Key words	Snow cover, NDSI, AWiFS, depletion curve, Sikkim, Tista and Rangit.
Security Classification	Unrestricted
Distribution	Among concerned

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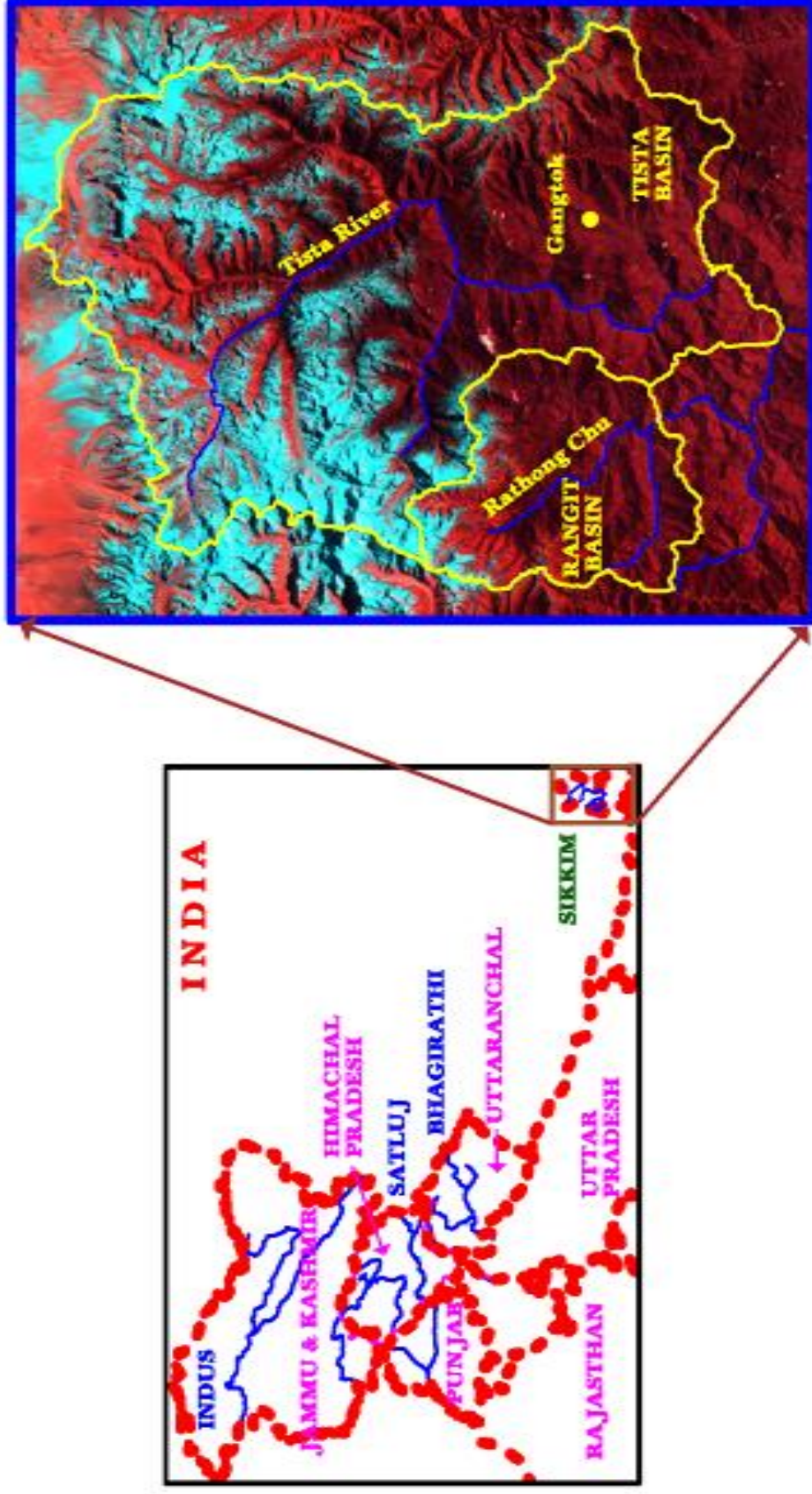


Figure 1: Location map of Tista and Rangit sub-basins (Part of Tista basin)

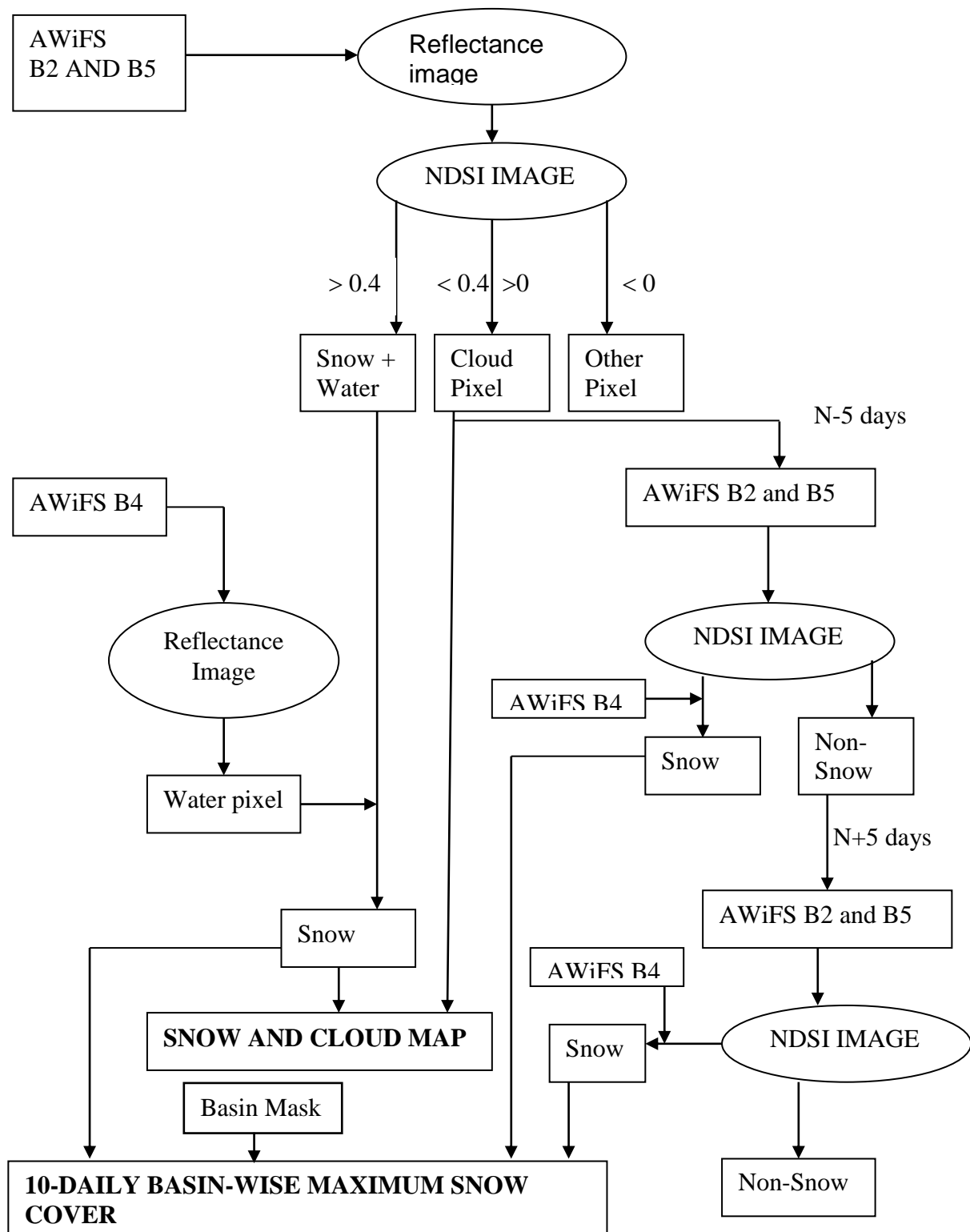


Figure 2: Algorithm for snow cover mapping using AWiFS data

1. Introduction

Snow covers almost 40 per cent of the Earth's land surface during Northern Hemisphere winter. This makes albedo and areal extent of snow as important component of the Earth's radiation balance (Foster and Chang, 1993). In addition, large areas in the Himalayas are also covered by snow during winter. Area of snow can change significantly during winter and spring. This can affect stream flow for rivers originating in the higher Himalayas. All the rivers originating from higher Himalayas receive almost 30-50 % of annual flow from snow and glacier melt run off (Agarwal et al., 1983). In addition, snow pack ablation is highly sensitive to climatic variation. Increase in atmospheric temperature can influence snowmelt and stream runoff pattern (Kulkarni et al., 2002). Therefore, mapping of the areal extent and reflectance of snow are important parameter for various climatological and hydrological applications. In addition, extent of snow cover can also be used as input for numerous other applications.

Mapping and monitoring of seasonal snow cover using field methods are normally very difficult in a mountainous terrain, like the Himalayas. Therefore, remote sensing techniques have been extensively used for snow cover monitoring. Snow cover monitoring using satellite images were started by using the TIROS-1 satellite from April 1960 (Singer and Popham 1963). Since then, the potential for operational satellite-based mapping has been enhanced by the development of higher temporal frequency and satellite sensors with higher spatial resolution. In addition, satellites with better radiometric resolutions, such as NOAA have been used successfully for snow mapping (Hall et al., 1995). This is possibly due to the distinct spectral reflectance characteristics of snow in visible and near infrared regions. India has launched series of Indian Remote Sensing satellite (IRS) to study the different earth resources. Previously launched satellites have flown with many sensors having different spatial, temporal and spectral resolutions. Recently launched RESOURCESAT-1 satellite has three different sensors namely LISS III, LISS IV & AWiFS with different spatial, temporal and spectral resolutions as desired for different applications. AWiFS (Advanced Wide Field Sensor) is an advanced version of earlier Indian satellite sensor WiFS (Wide Field Sensor) with improved spectral and spatial resolutions maintaining the same repetivity. There are a series of other polar orbiting satellites, like Landsat, NOAA and MODIS etc., which have provided information on different

aspects of snow. Geo-stationary satellites also proved their utility in mapping/monitoring the snow-covered regions. Information generated from satellite observations has been extensively used for snowmelt runoff modeling (Kulkarni et al., 1997).

2. Study Area:

This Atlas gives distribution of snow cover in Sikkim state and two sub basins of the Tista basin. These are Tista and Rangit sub basins. Locations of these basins are shown in Figure 1.

3. Data used:

AWiFS data from October 2014 to June 2015 were used in this study.

4. Normalised Difference Snow Index (NDSI):

In general, the reflectance of snow is high at the red end of the visible spectrum. It tends to decline in the near-infrared region until 1090 nm, where slight gain in reflectance occurs and gives a minor peak at approximately 1090 to 1100 nm. One of the important difficulties in snow cover monitoring is the presence of cloud cover. Cloud has strong reflectivity in visible, NIR and SWIR regions while snow absorbs in SWIR, and this difference can be utilized for snow/cloud discrimination. Normalized Difference Snow Index (NDSI) utilize the normalized ratio of green and SWIR and is used as an automated approach for snow mapping addressing the shadow and cloud problems in snow bound areas.

Normalized Difference Snow Index was calculated using the ratio of green wavelength (band 2) and SWIR (band 5) of AWiFS sensor:

$$\text{NormalizedDifferenceSnowIndex(NDSI)} = (band2 - band5) / (band2 + band5) \quad ..(1)$$

To estimate NDSI, DN numbers were converted into reflectance. This involves conversion of digital numbers into the radiance values, known as sensor calibration, and then estimation of reflectance

from these radiance values. Various parameters needed for estimating spectral reflectance are maximum and minimum radiances and mean solar exo-atmospheric spectral irradiances in the satellite sensor bands, satellite data acquisition time, solar declination, solar zenith and solar azimuth angles, mean Earth-Sun distance etc. (Markham and Barker, 1987; Srinivasulu and Kulkarni, 2004).

5. Snow cover monitoring algorithm

An algorithm is developed to provide changes in the areal extent of snow (Kulkarni et. al., 2006). Snow extent is estimated at an interval of 5-days and 10-days, depending upon availabilities of AWiFS data. In 5-daily product, snow extent is generated scene-wise. In this product, snow and cloud extents are given. Estimate of cloud is important because, at times, snow is covered by cloud and this may be classified as non-snow area, leading to erroneous conclusions. In 10-daily product, three scenes are analyzed, if available. For example, 10 March product data of 5, 10 and 15 March was used. If any pixel is identified as snow on any one date then this pixel will be classified as snow on final product. This provides snow cover at an interval of 10 days, an important requirement in hydrological applications. Therefore, this product is generated basin-wise. Since this product is using three scenes, probability becomes high that at least in one scene, pixel may be cloud-free and this helps in overcoming problem associated with snow under cloud cover. Since three consecutive cloud free scenes are not available, two corresponding data scenes have been merged to analyze maximum snow cover. This gives a composite snow cover extent for the mean date. For instance, 12 October scene is the product of 7 and 17 October. Differentiation between water and snow is difficult using NDSI image. In addition, separation of snow and water pixels is also difficult based on reflectance due to mountain shadow. Therefore, in the present algorithm, water bodies are marked in pre-winter season and are masked in the final products during winter. Flow diagram of the algorithm is given in Figure 2.

6. Results and discussions

In this atlas, state and basin-wise snow cover statistics, maps, and seasonal depletion curves have been provided from September 2014 to June 2015. Snow ablation pattern was estimated for Tista and Rangit basins in the Sikkim Himalaya. The highest snow areal extent of 43% observed in Tista and 13% in Rangit basins, respectively in the month of March & April. Snow cover was less in Rangit

sub-basin as it in lower altitude & latitude. Accumulation starts from November & ablation starts from mid of April in Tista sub-basin. Accumulation starts from January & ablation starts from mid of April in Rangit sub-basin.

Acknowledgements

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TEESTA SUB-BASIN

AREAL EXTENT OF SNOW (5 DAILY)**BASIN NAME: TEESTA****BASIN AREA: 5468 sq km**

S No	Date	Snow cover (sq km)	Snow cover (%)	S No	Date	Snow cover (sq km)	Snow cover (%)
October 2014							
1	02-Oct-2014	474 (C)	9				
November 2015							
2	04-Nov-2014	947	17				
January 2015							
3	01-Jan-2015	1658 (C)	30				
February 2015							
4	03-Feb-2015	2189	40				
March 2015							
5	04-Mar-2015	2360	43				
April 2015							
6	03-Apr-2015	1880 (C)	34	7	06-Apr-2015	2073	38
May 2015							
8	01-May-2015	1513 (C)	28	9	05-May-2015	1885	34
June 2015							
10	03-June-2015	567 (C)	10	11	08-June-2015	450 (C)	8
12	13-June-2015	364 (C)	7	13	17-June-2015	406 (C)	7

AREAL EXTENT OF SNOW (10 DAILY)

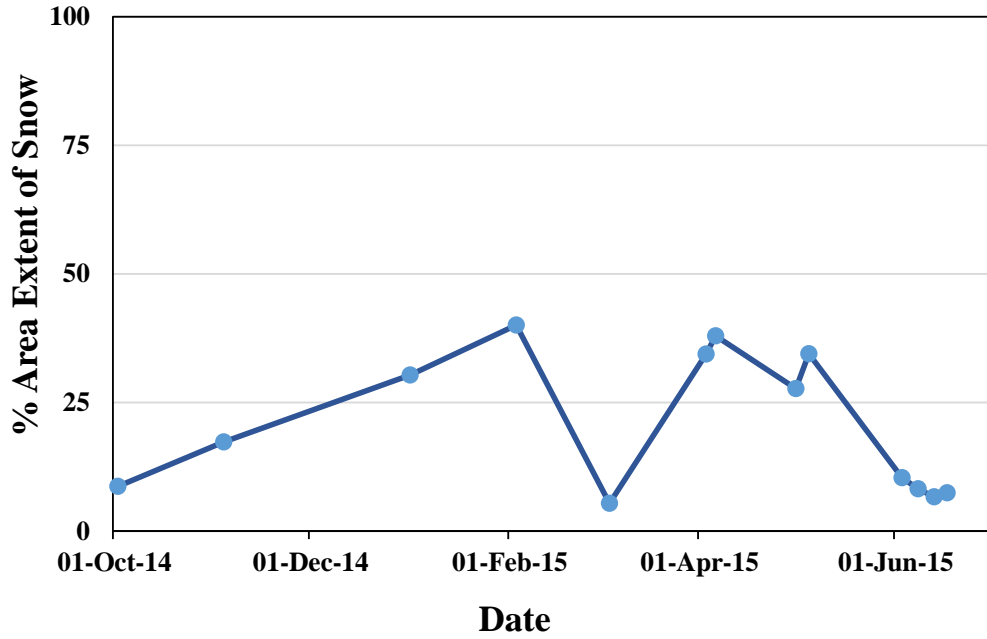
BASIN NAME: TEESTA

BASIN AREA: 5468 sq km

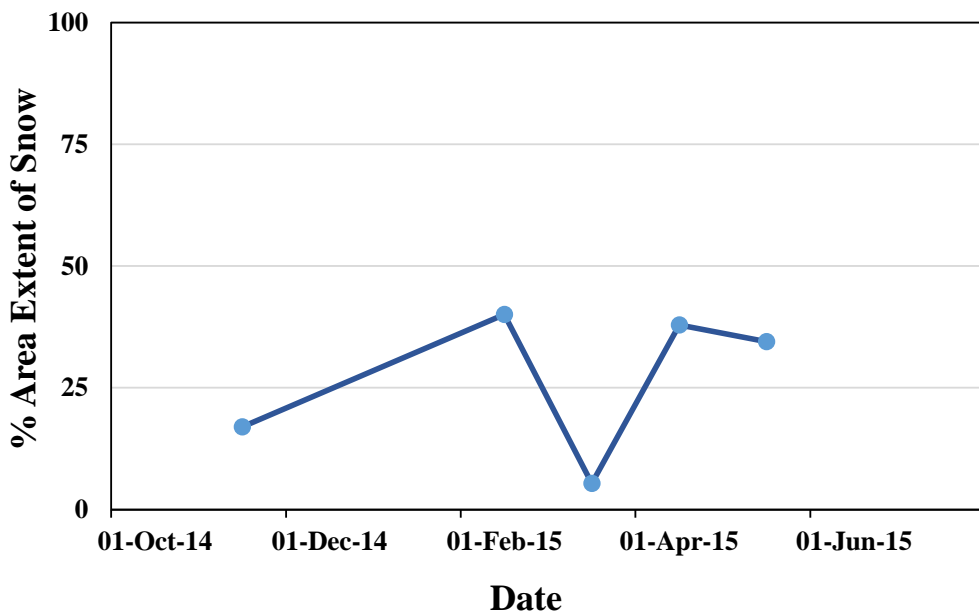
S. No	Date	Snow cover (sq km)	Snow cover (%)	S No	Date	Snow cover (sq km)	Snow cover (%)
April 2015							
1	05-Apr-2015	2424	44				
May 2015							
2	05-May-2015	2071	38				
June 2015							
3	05-June-2015	567	10	4	15-June-15	362	7

SNOW COVER DEPLETION CURVE

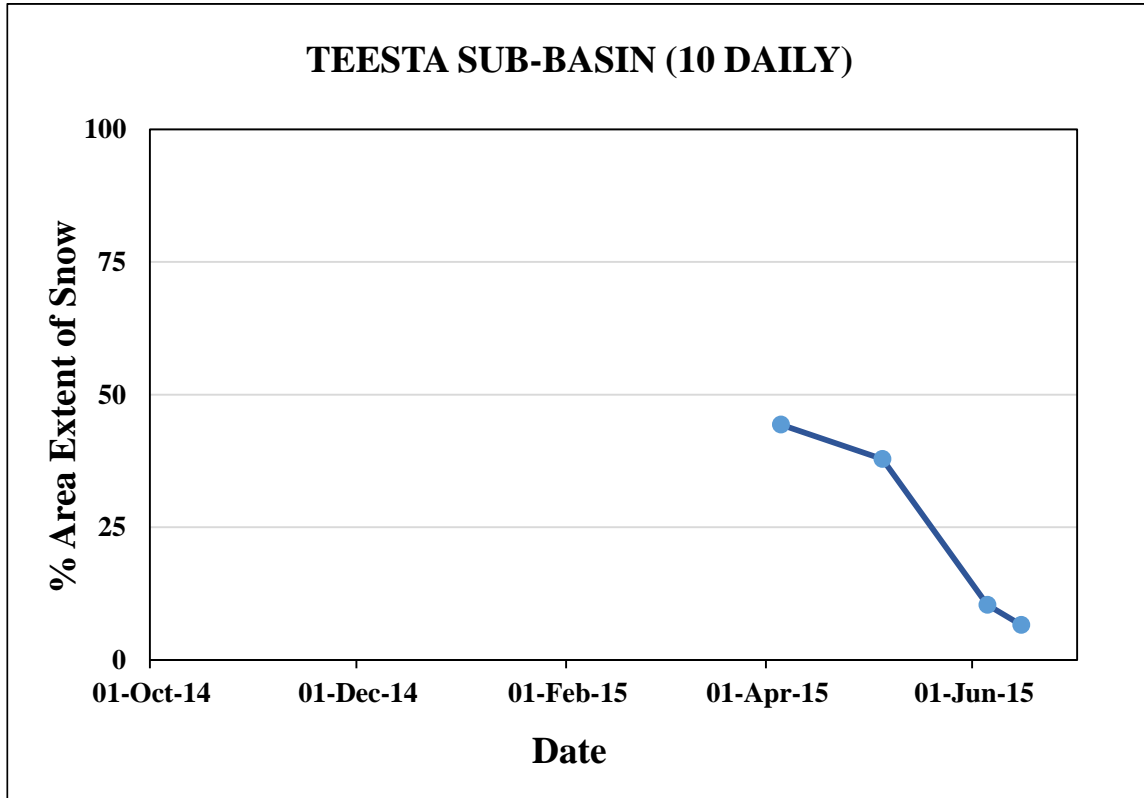
TEESTA SUB-BASIN (5 DAILY) : WITH CLOUDY DATA



TEESTA SUB-BASIN (5 DAILY) : WITHOUT CLOUDY DATA

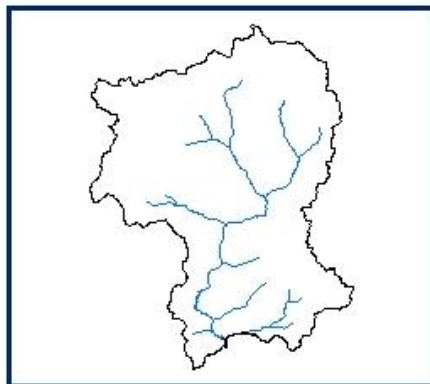


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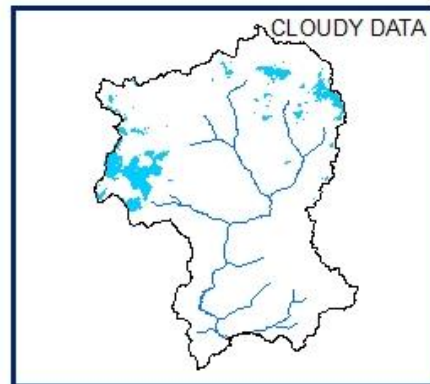


SNOW COVER MAP

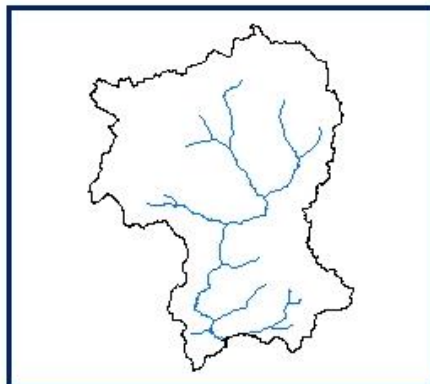
SNOW COVER MAP : TEESTA SUB-BASIN



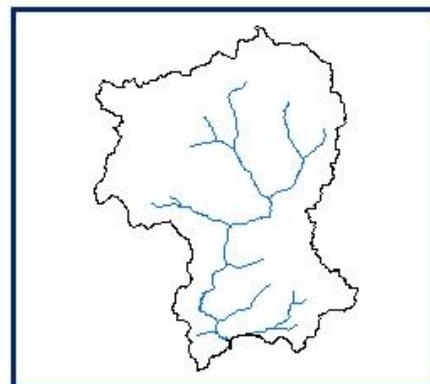
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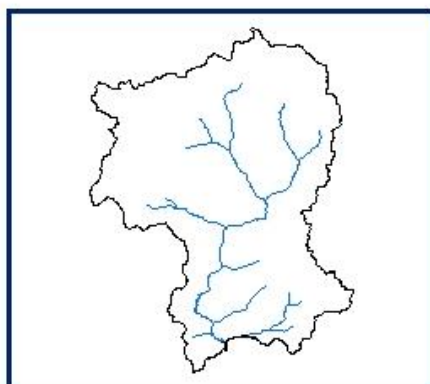
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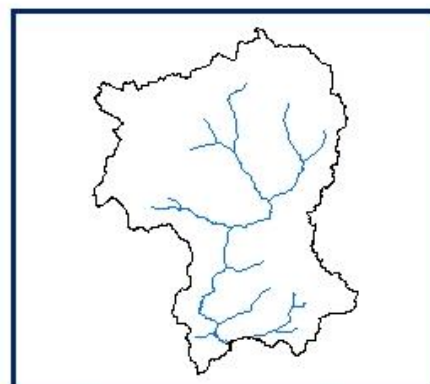
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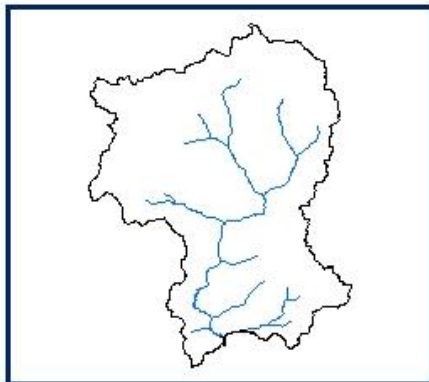


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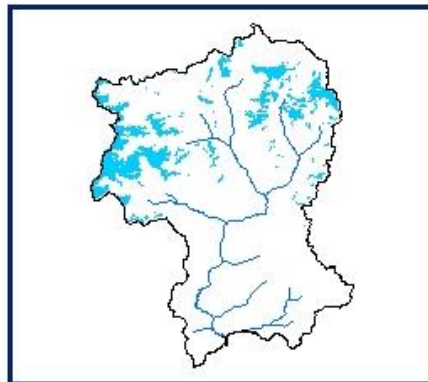
 SNOW

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Kilometers

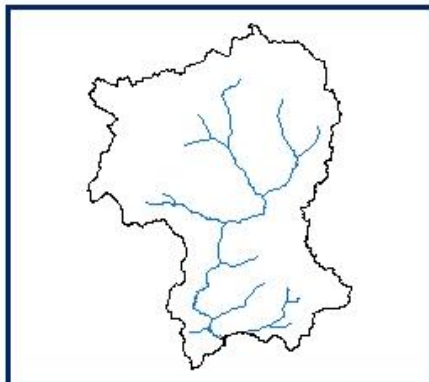
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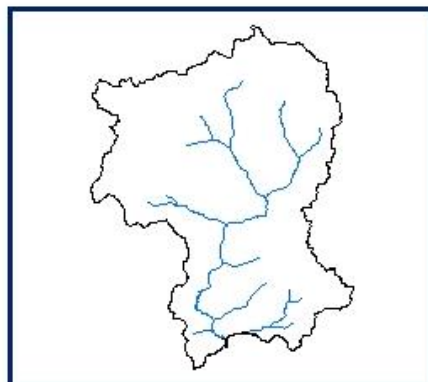
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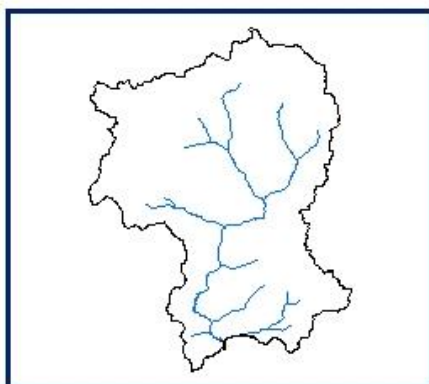
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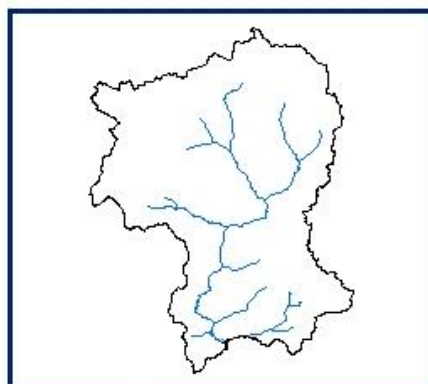
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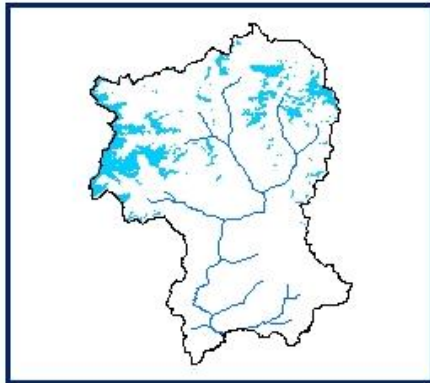


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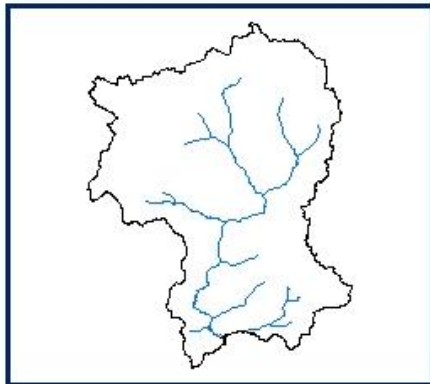
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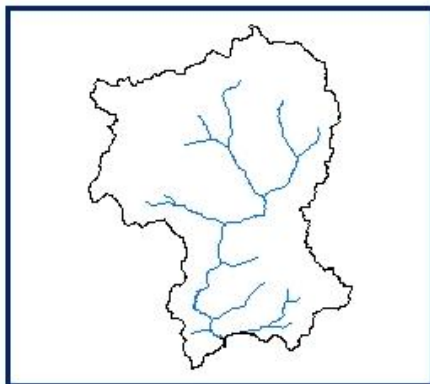
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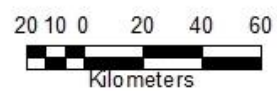


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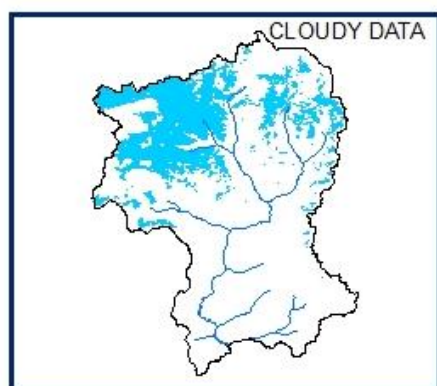


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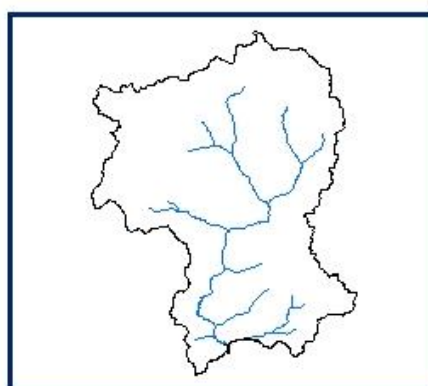
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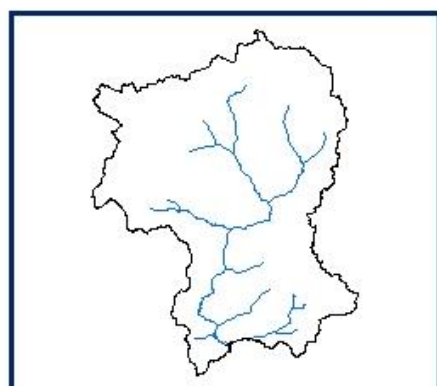
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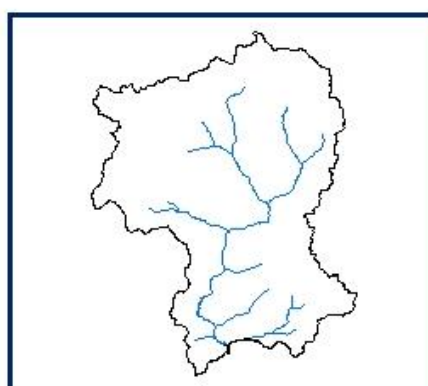
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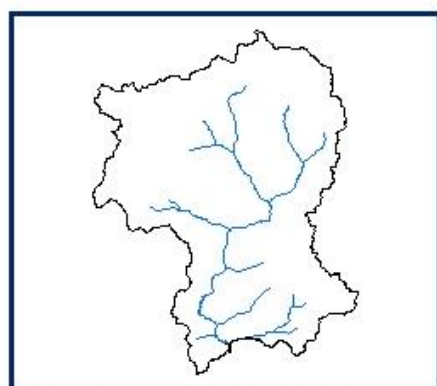
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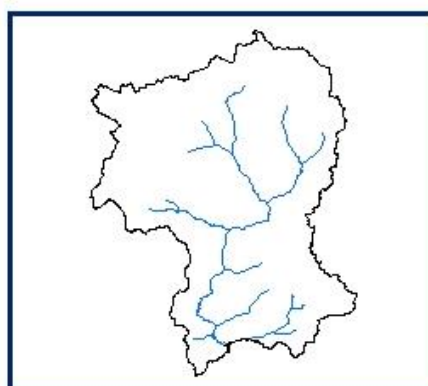
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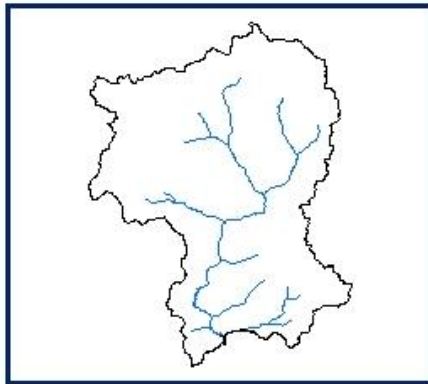


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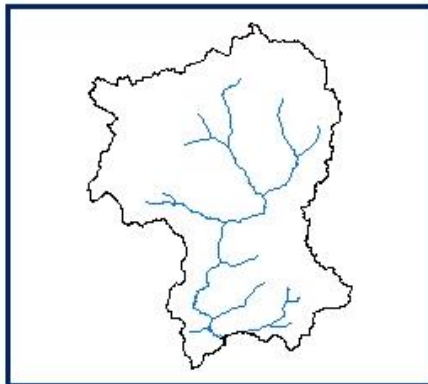
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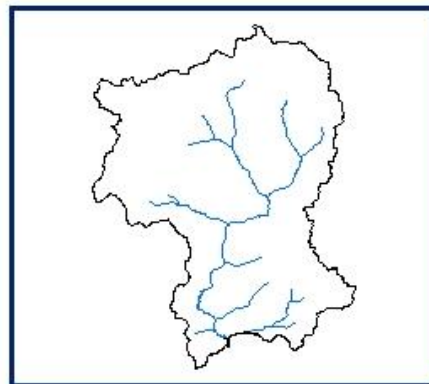
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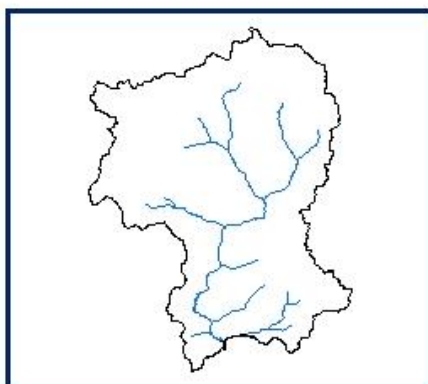
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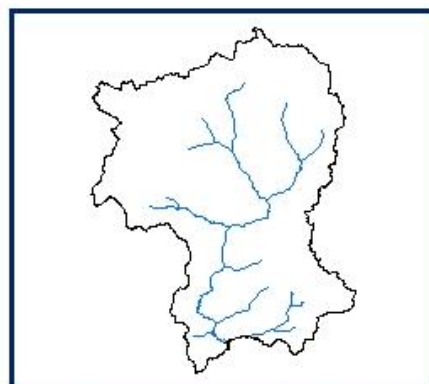
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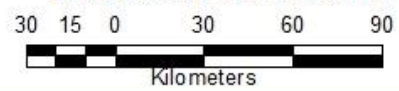


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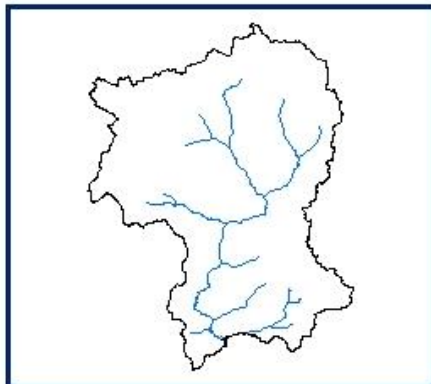
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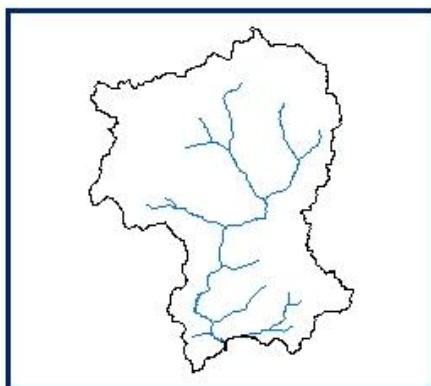
10 DAILY SNOW COVER MAP : TEESTA SUB-BASIN



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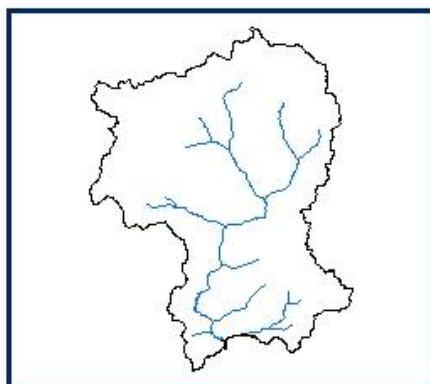


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Kilometers

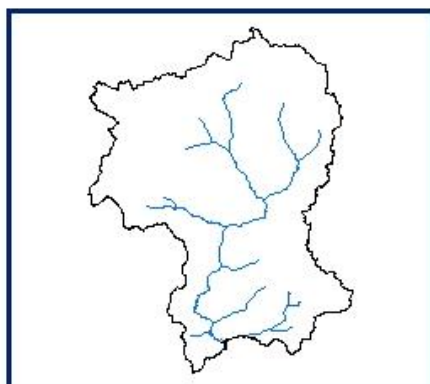
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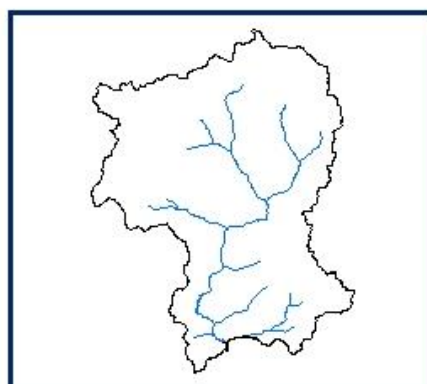
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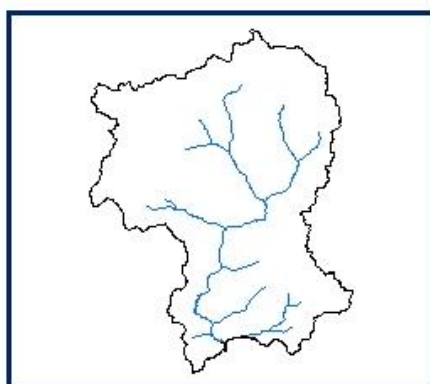
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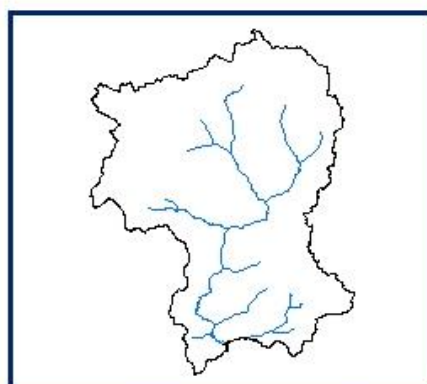
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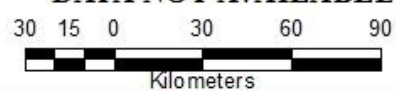


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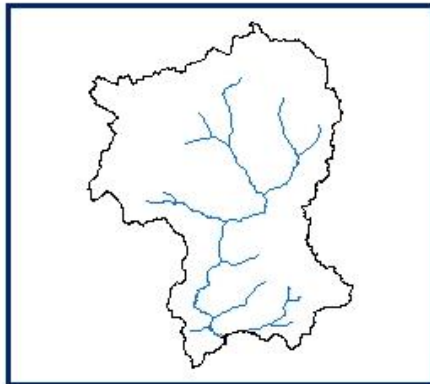
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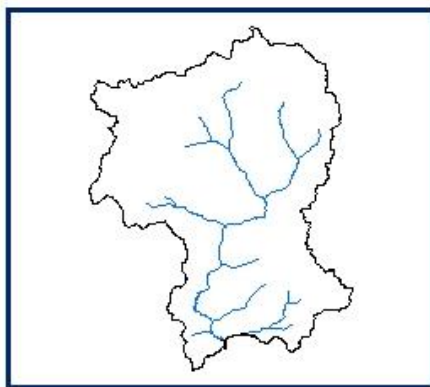
10 DAILY SNOW COVER MAP : TEESTA SUB-BASIN



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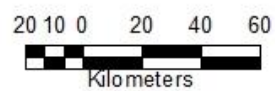


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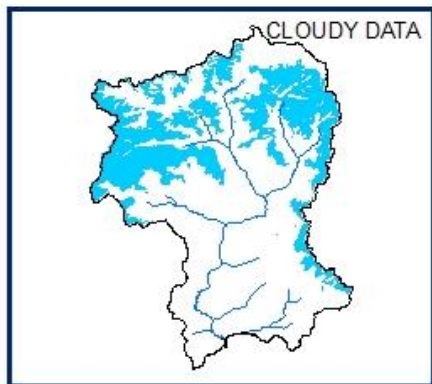


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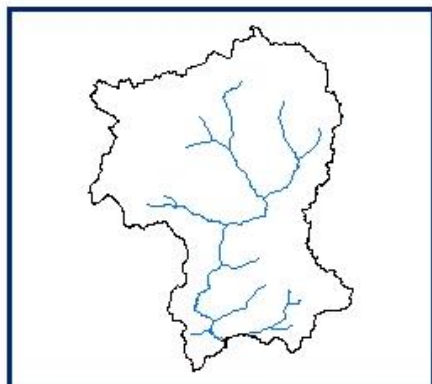
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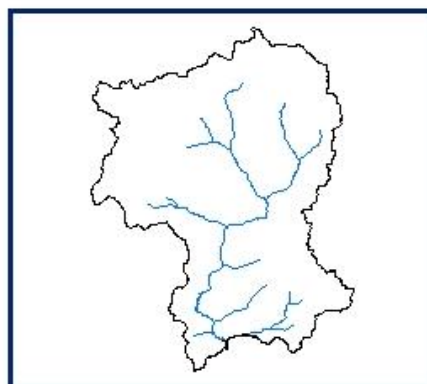
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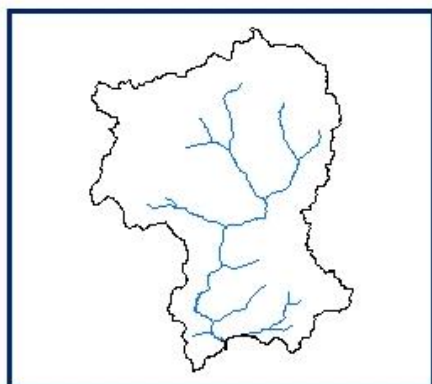
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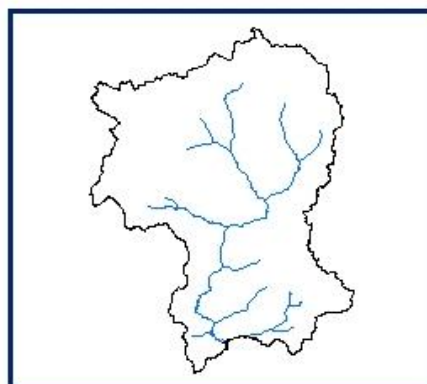
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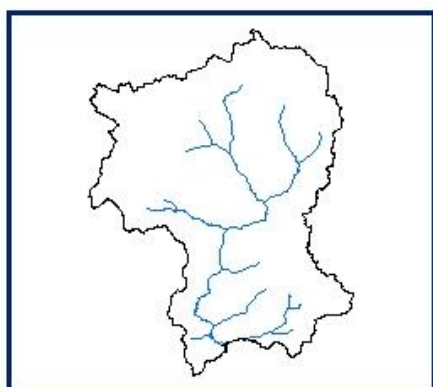
 SNOW

30 15 0 30 60 90
Kilometers

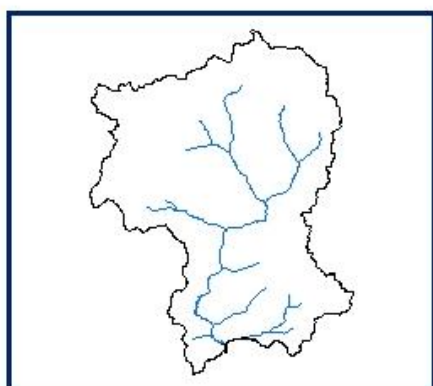
10 DAILY SNOW COVER MAP : TEESTA SUB-BASIN



DATA USED
03 APRIL 2015
06 APRIL 2015

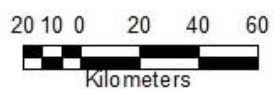


DATA NOT AVAILABLE

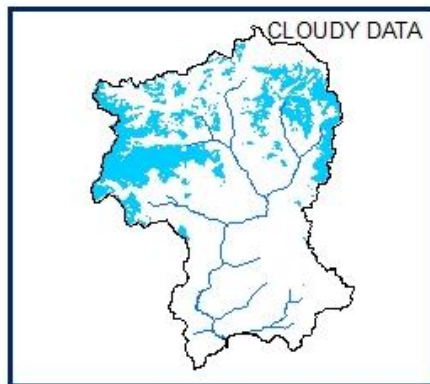


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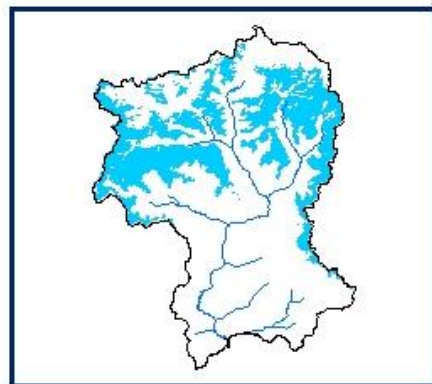
 SNOW



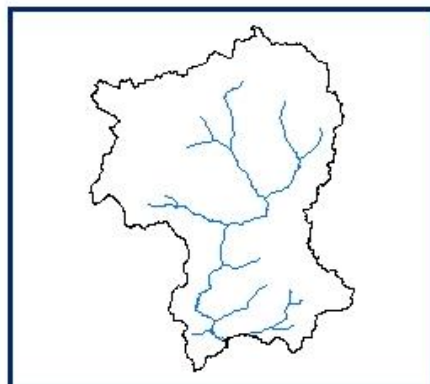
SNOW COVER MAP : TEESTA SUB-BASIN



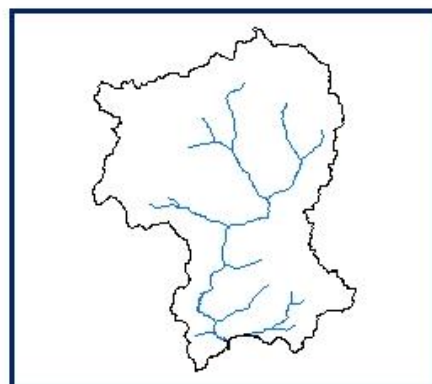
01 MAY 2015



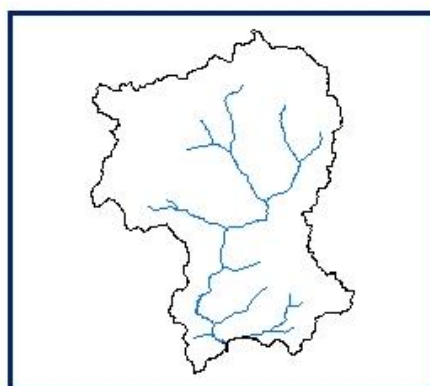
05 MAY 2015



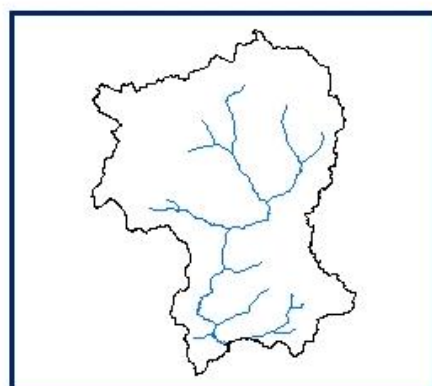
DATA NOT AVAILABLE



DATA NOT AVAILABLE



DATA NOT AVAILABLE



DATA NOT AVAILABLE

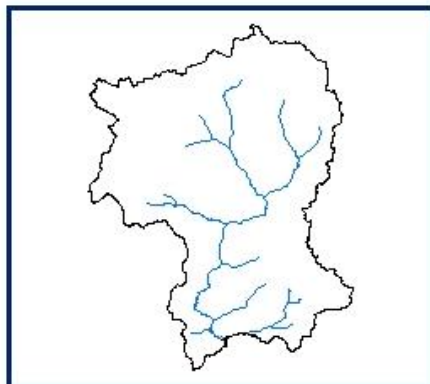
 SNOW

30 15 0 30 60 90
Kilometers

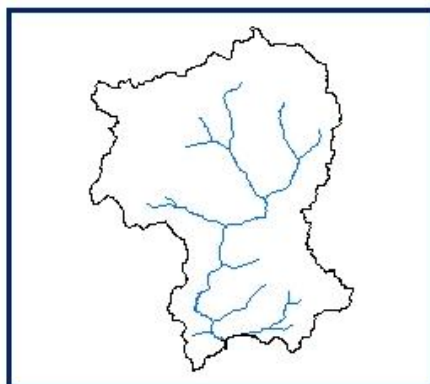
10 DAILY SNOW COVER MAP : TEESTA SUB-BASIN



DATA USED
01 MAY 2015
05 MAY 2015

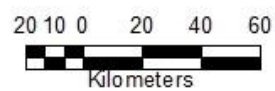


DATA NOT AVAILABLE

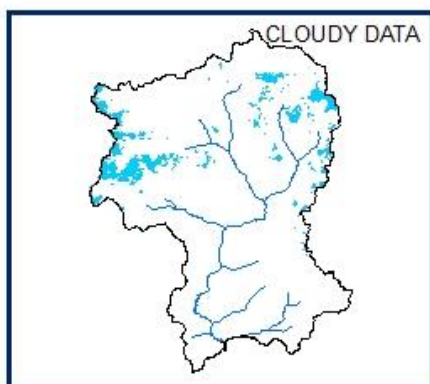


DATA NOT AVAILABLE

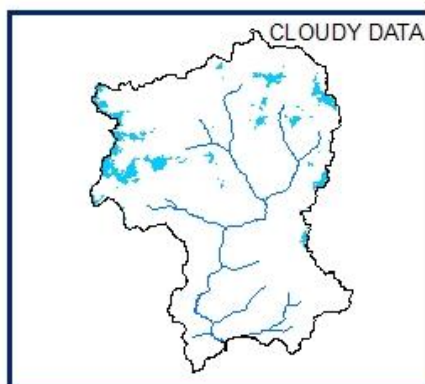
 SNOW



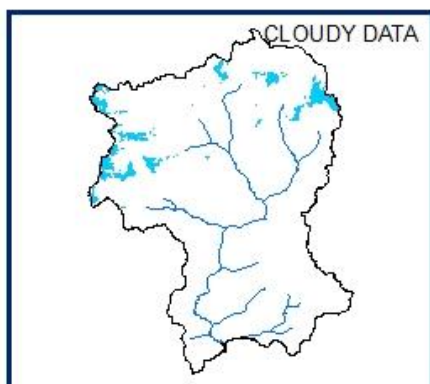
SNOW COVER MAP : TEESTA SUB-BASIN



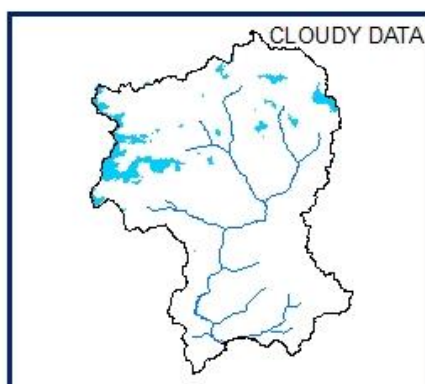
03 JUNE 2015



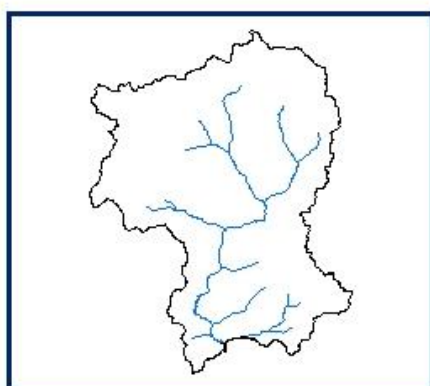
08 JUNE 2015



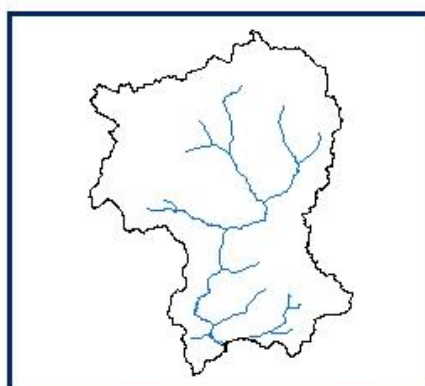
13 JUNE 2015



17 JUNE 2015



DATA NOT AVAILABLE

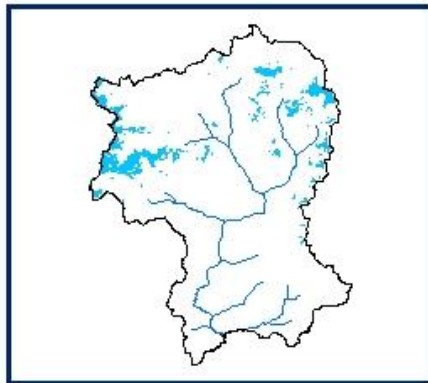


DATA NOT AVAILABLE

 SNOW

30 15 0 30 60 90
Kilometers

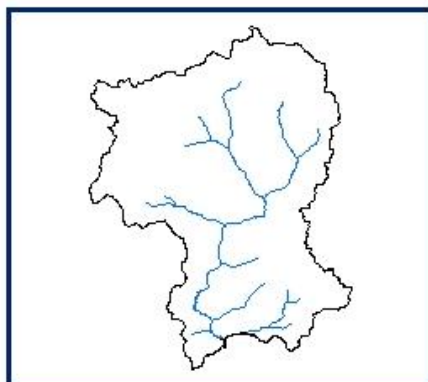
10 DAILY SNOW COVER MAP : TEESTA SUB-BASIN



DATA USED
03 JUNE 2015
08 JUNE 2015



DATA USED
13 JUNE 2015
17 JUNE 2015



DATA NOT AVAILABLE

 SNOW



RANGIT SUB-BASIN

AREAL EXTENT OF SNOW (5 DAILY)

BASIN NAME: RANGIT

BASIN AREA: 1632 sq km

S No	Date	Snow cover (sq km)	Snow cover (%)	S No	Date	Snow cover (sq km)	Snow cover (%)
October 2014							
1	01-Oct-2014	19 (C)	1	2	02-Oct-14	37 (C)	2
November 2014							
3	04-Nov-2014	71	4				
January 2015							
4	01-Jan-2015	59	4				
February 2015							
5	03-Feb-2015	90	6				
March 2015							
6	04-Mar-2015	295 (C)	18				
April 2015							
7	02-Apr-2015	86 (C)	5	8	03-Apr-2015	169 (C)	10
9	06-Apr-2015	194 (C)	12				
May 2015							
10	05-May-2015	94 (C)	6				
June 2015							
11	03-June-2015	34 (C)	2	12	08-June-2015	36 (C)	2
13	13-June-2015	55(C)	3	14	17-June-2015	21 (C)	1

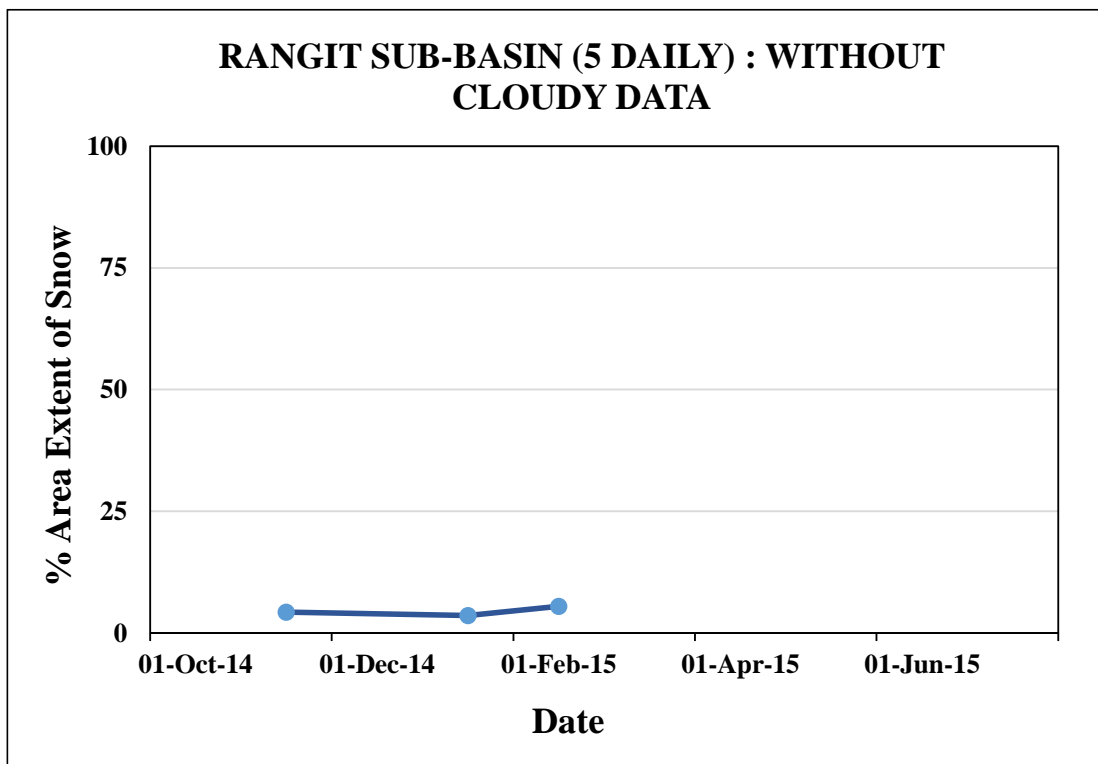
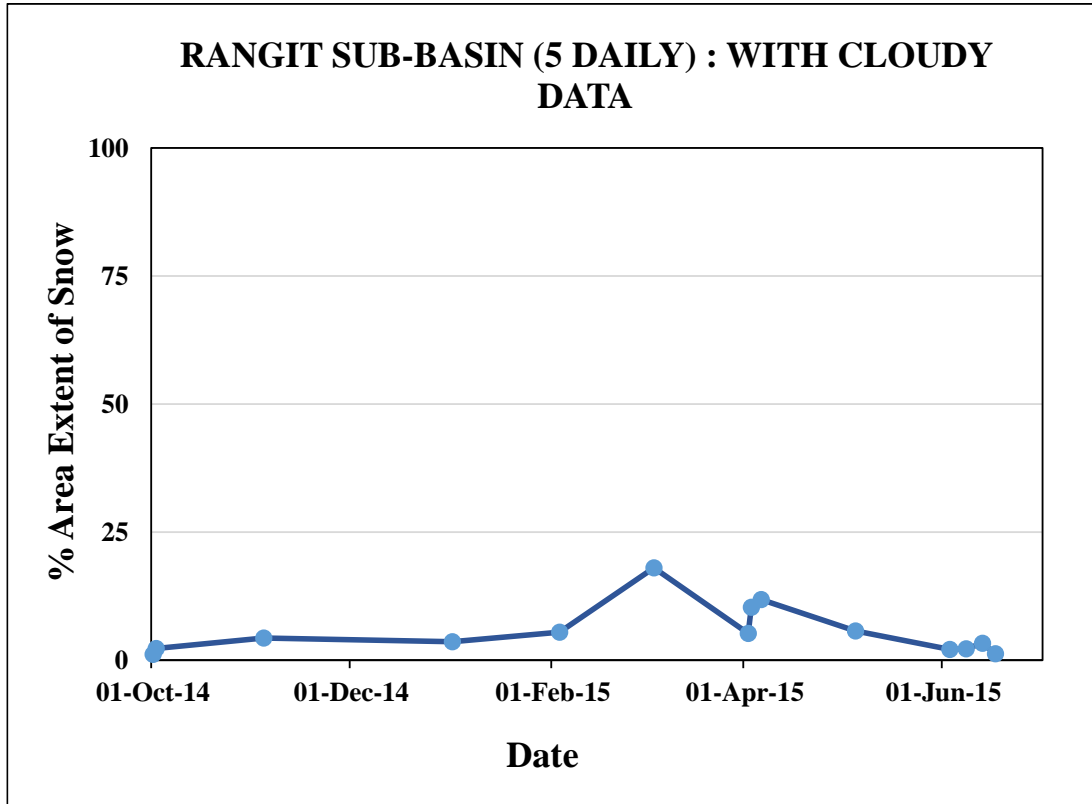
AREAL EXTENT OF SNOW (10 DAILY)

BASIN NAME: RANGIT

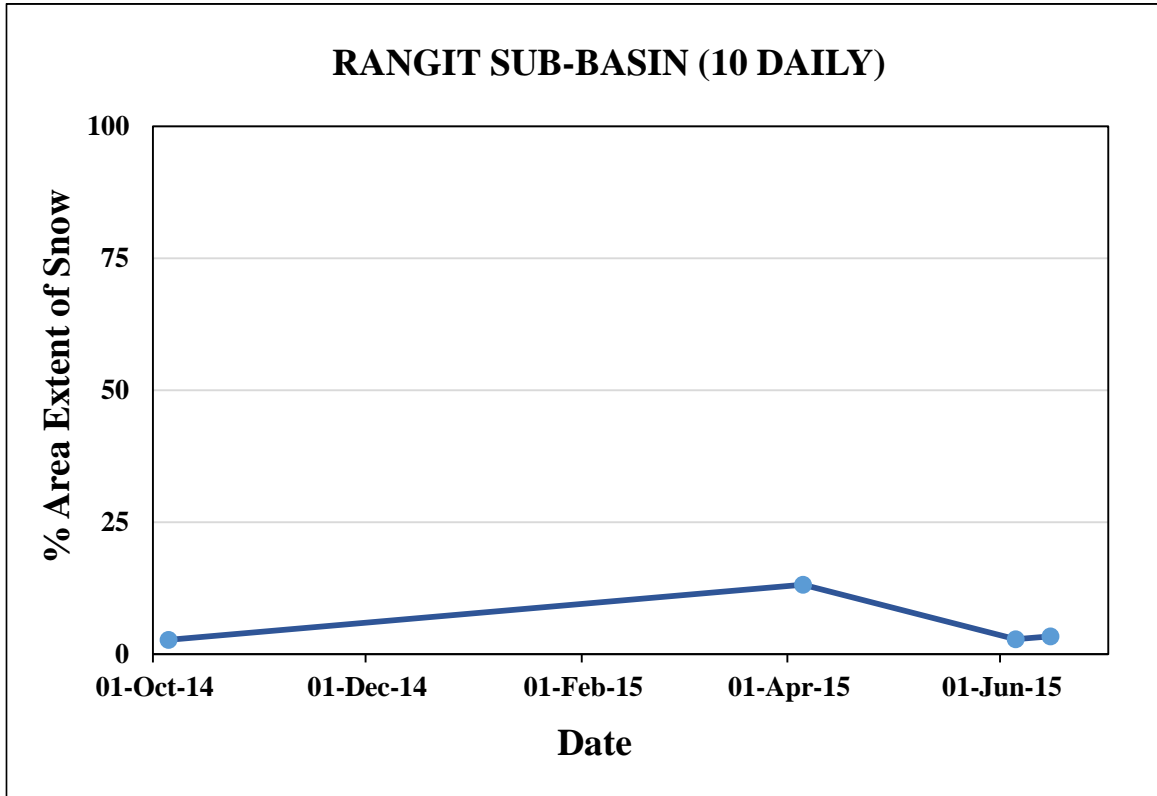
BASIN AREA: 1632 sq km

S. No	Date	Snow cover (sq km)	Snow cover (%)	S No	Date	Snow cover (sq km)	Snow cover (%)
October 2014							
1	05-Oct-2014	44	3				
April 2015							
2	05-Apr-2015	215	13				
May 2015							
3	05-June-2015	46	3	4	15-June-2015	55	3

SNOW COVER DEPLETION CURVE

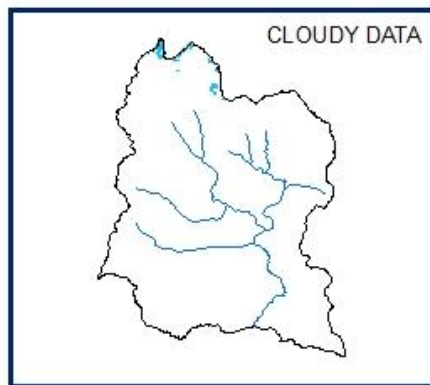


SNOW COVER DEPLETION CURVE

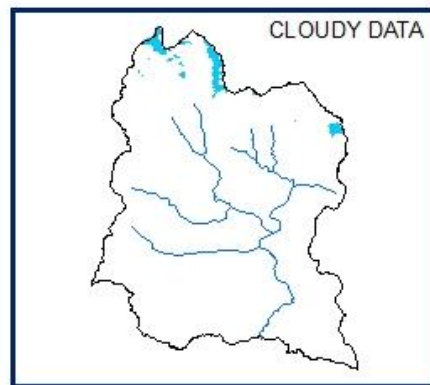


SNOW COVER MAP

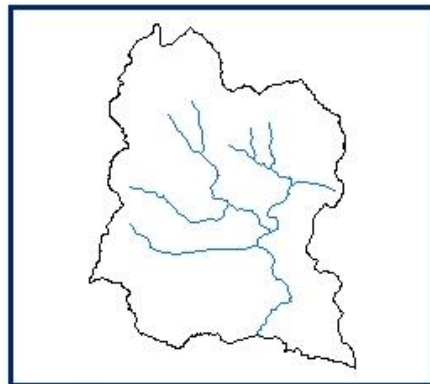
SNOW COVER MAP : RANGIT SUB-BASIN



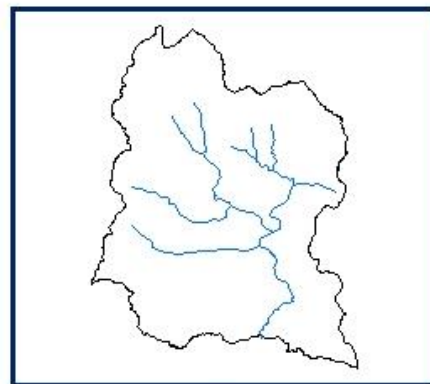
01 OCTOBER 2014



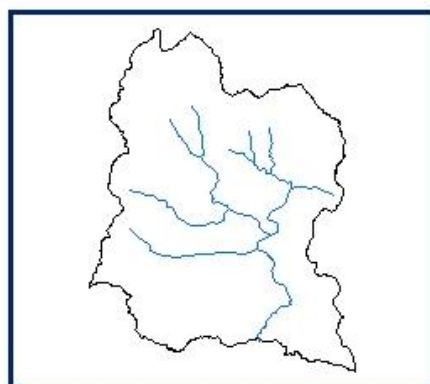
02 OCTOBER 2014



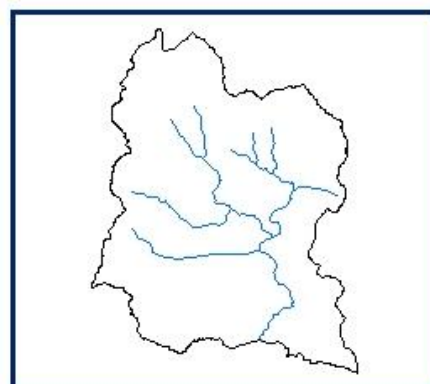
DATA NOT AVAILABLE



DATA NOT AVAILABLE




DATA NOT AVAILABLE



DATA NOT AVAILABLE

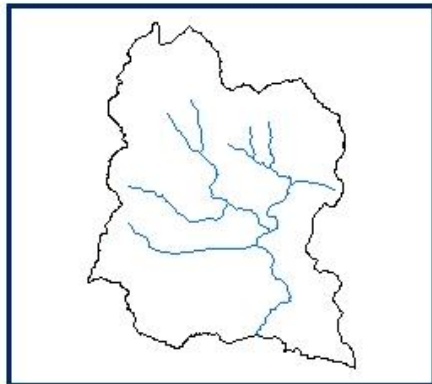
 SNOW

10 5 0 10 20 30

Kilometers

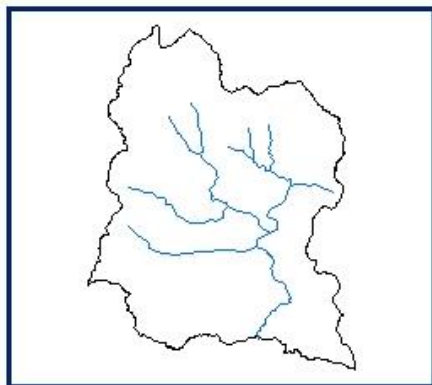
10 DAILY SNOW COVER MAP : RANGIT SUB-BASIN



DATA USED
01 OCTOBER 2014
02 OCTOBER 2014

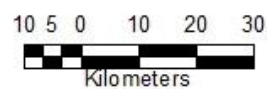


DATA NOT AVAILABLE

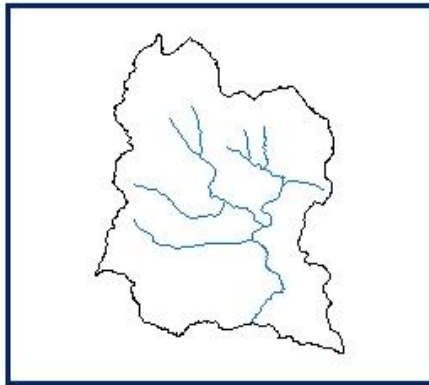


DATA NOT AVAILABLE

 SNOW



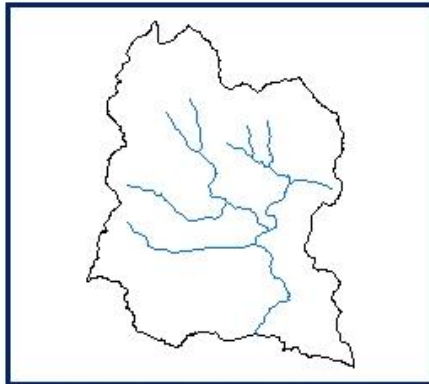
SNOW COVER MAP : RANGIT SUB-BASIN



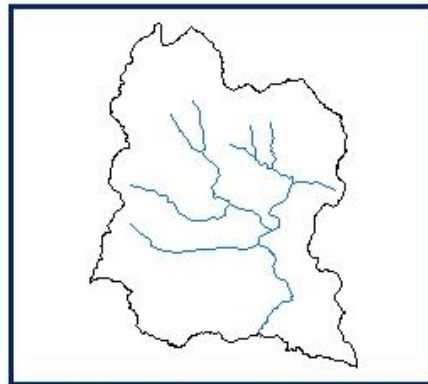
DATA NOT AVAILABLE



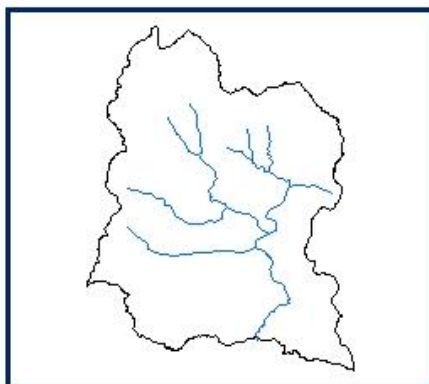
04 NOVEMBER 2014



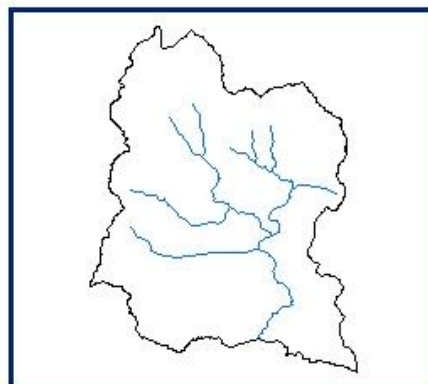
DATA NOT AVAILABLE



DATA NOT AVAILABLE




DATA NOT AVAILABLE



DATA NOT AVAILABLE

 SNOW

10 5 0 10 20 30

 Kilometers

10 DAILY SNOW COVER MAP : RANGIT SUB-BASIN



DATA USED
04 NOVEMBER 2014

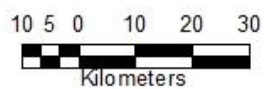


DATA NOT AVAILABLE



DATA NOT AVAILABLE

 SNOW



SNOW COVER MAP : RANGIT SUB-BASIN



01 JANUARY 2015



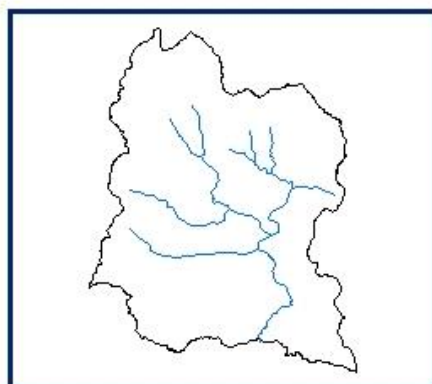
DATA NOT AVAILABLE



DATA NOT AVAILABLE



DATA NOT AVAILABLE




DATA NOT AVAILABLE



DATA NOT AVAILABLE

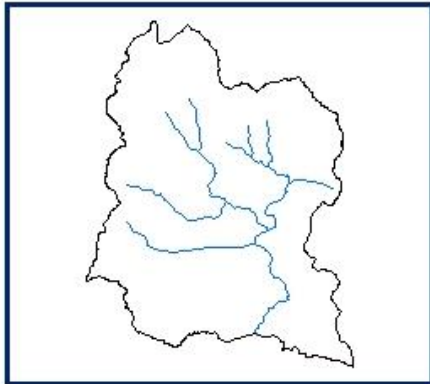
 SNOW

10 5 0 10 20 30

 Kilometers

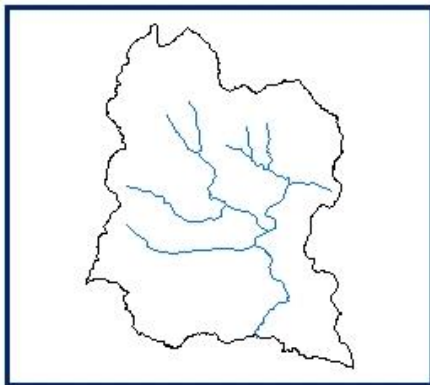
10 DAILY SNOW COVER MAP : RANGIT SUB-BASIN



DATA USED
01 JANUARY 2015

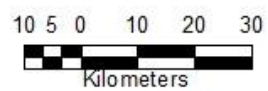


DATA NOT AVAILABLE

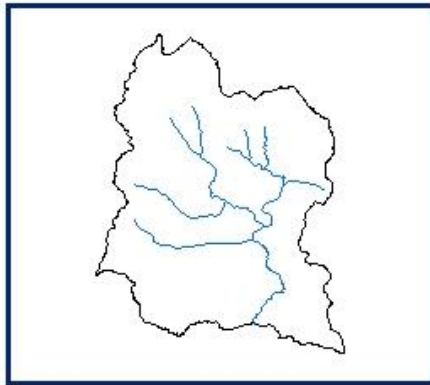


DATA NOT AVAILABLE

 SNOW



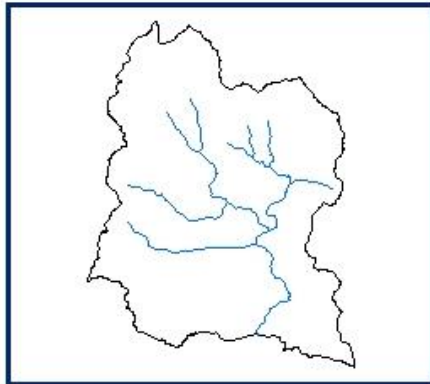
SNOW COVER MAP : RANGIT SUB-BASIN



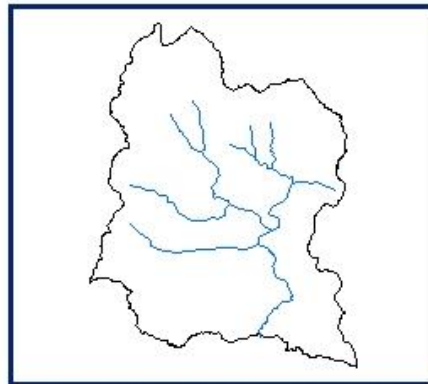
DATA NOT AVAILABLE



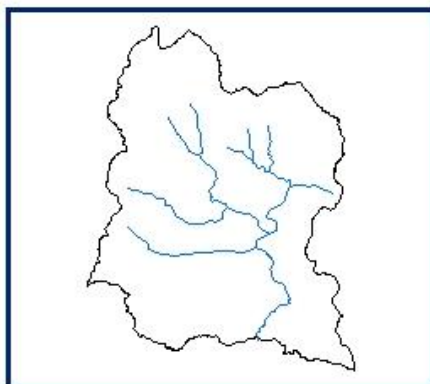
03 FEBRUARY 2015



DATA NOT AVAILABLE



DATA NOT AVAILABLE




DATA NOT AVAILABLE



DATA NOT AVAILABLE

 SNOW

10 5 0 10 20 30

 Kilometers

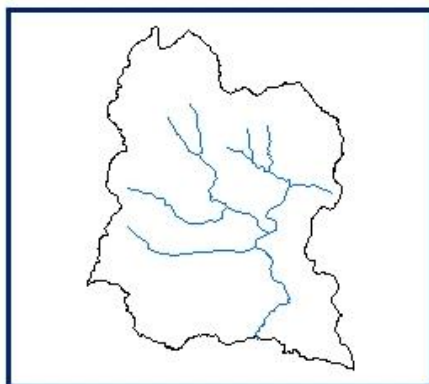
10 DAILY SNOW COVER MAP : RANGIT SUB-BASIN



DATA USED
03 FEBRUARY 2015

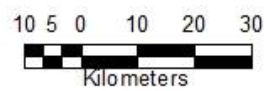


DATA NOT AVAILABLE



DATA NOT AVAILABLE

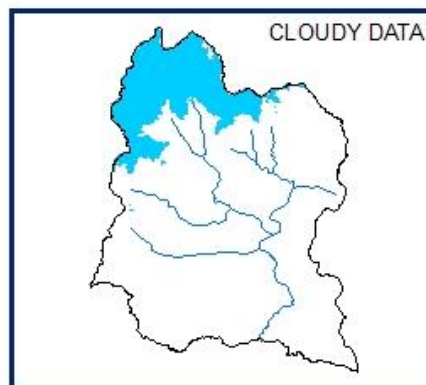
 SNOW



SNOW COVER MAP : RANGIT SUB-BASIN



DATA NOT AVAILABLE



04 MARCH 2015



DATA NOT AVAILABLE



DATA NOT AVAILABLE



DATA NOT AVAILABLE



DATA NOT AVAILABLE

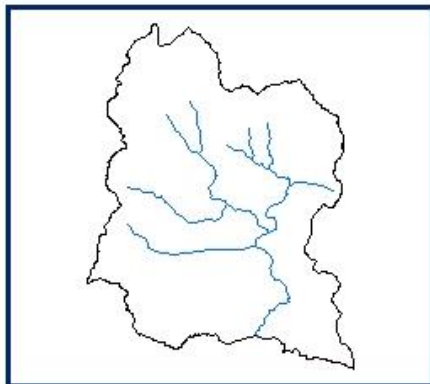
 SNOW

10 5 0 10 20 30
Kilometers

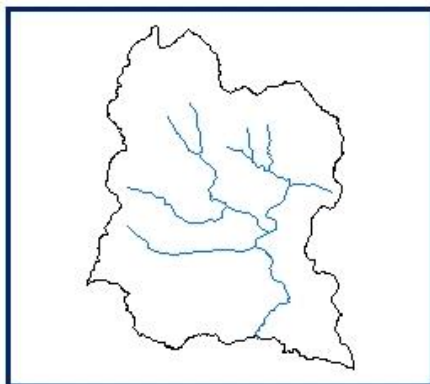
10 DAILY SNOW COVER MAP : RANGIT SUB-BASIN



DATA USED
04 MARCH 2015




DATA NOT AVAILABLE

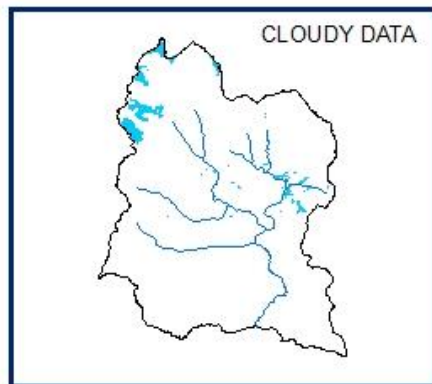


DATA NOT AVAILABLE

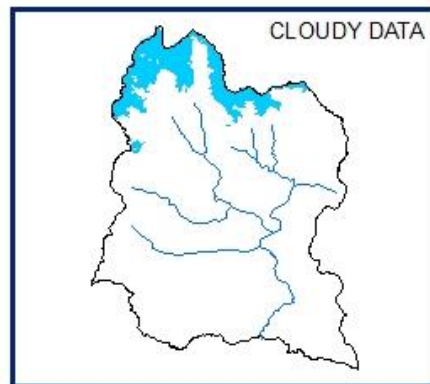
 SNOW

10 5 0 10 20 30

Kilometers

SNOW COVER MAP : RANGIT SUB-BASIN



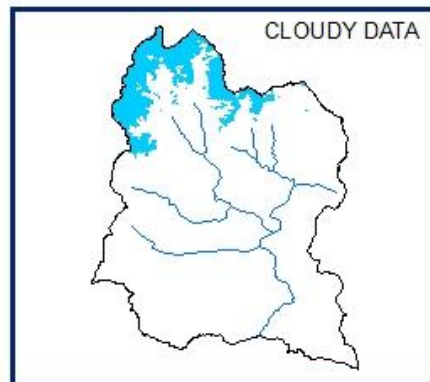
02 APRIL 2015



03 APRIL 2015



DATA NOT AVAILABLE



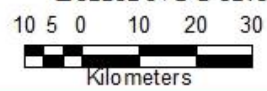
06 APRIL 2015



DATA NOT AVAILABLE



DATA NOT AVAILABLE



10 DAILY SNOW COVER MAP : RANGIT SUB-BASIN



DATA USED
02 APRIL 2015
03 APRIL 2015
06 APRIL 2015

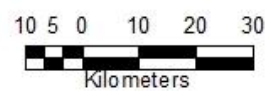


DATA NOT AVAILABLE

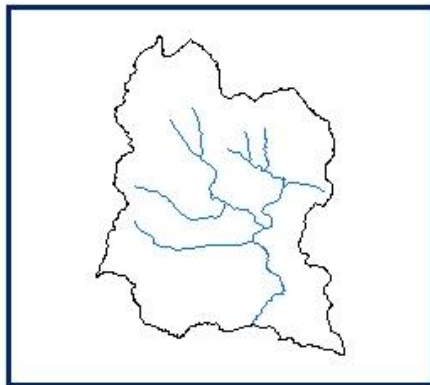


DATA NOT AVAILABLE

 SNOW



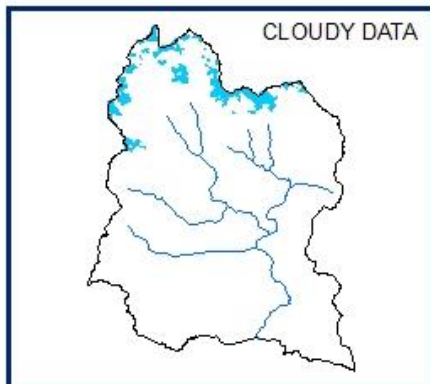
SNOW COVER MAP : RANGIT SUB-BASIN



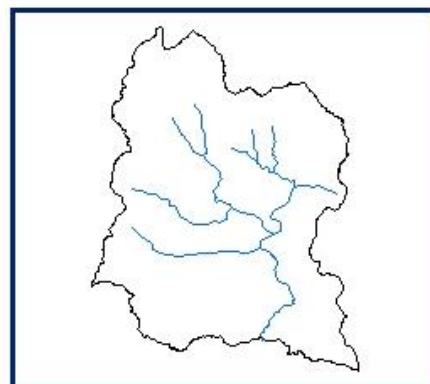
DATA NOT AVAILABLE



DATA NOT AVAILABLE



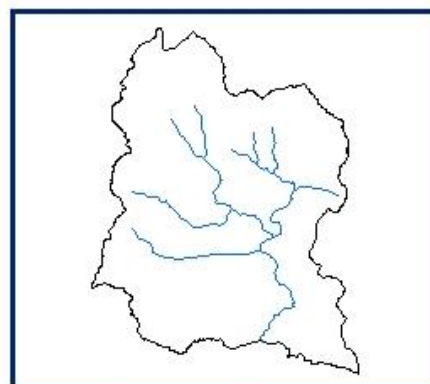
05 MAY 2015



DATA NOT AVAILABLE




DATA NOT AVAILABLE

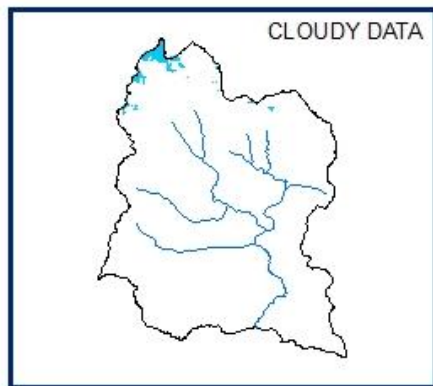


DATA NOT AVAILABLE

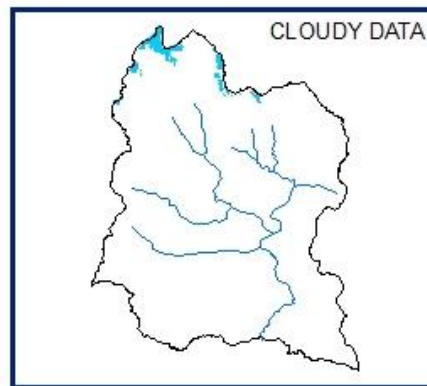
 **SNOW**

10 5 0 10 20 30

 Kilometers

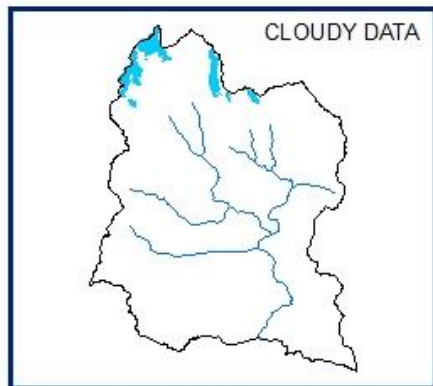
SNOW COVER MAP : RANGIT SUB-BASIN



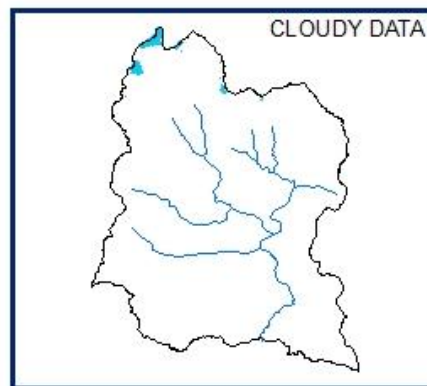
03 JUNE 2015



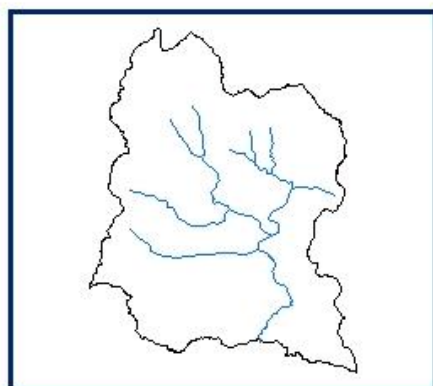
08 JUNE 2015



13 JUNE 2015



17 JUNE 2015




DATA NOT AVAILABLE



DATA NOT AVAILABLE

 SNOW

10 5 0 10 20 30

Kilometers

10 DAILY SNOW COVER MAP : RANGIT SUB-BASIN



DATA USED
03 JUNE 2015
08 JUNE 2015



DATA USED
13 JUNE 2015
17 JUNE 2015



DATA NOT AVAILABLE

 SNOW

