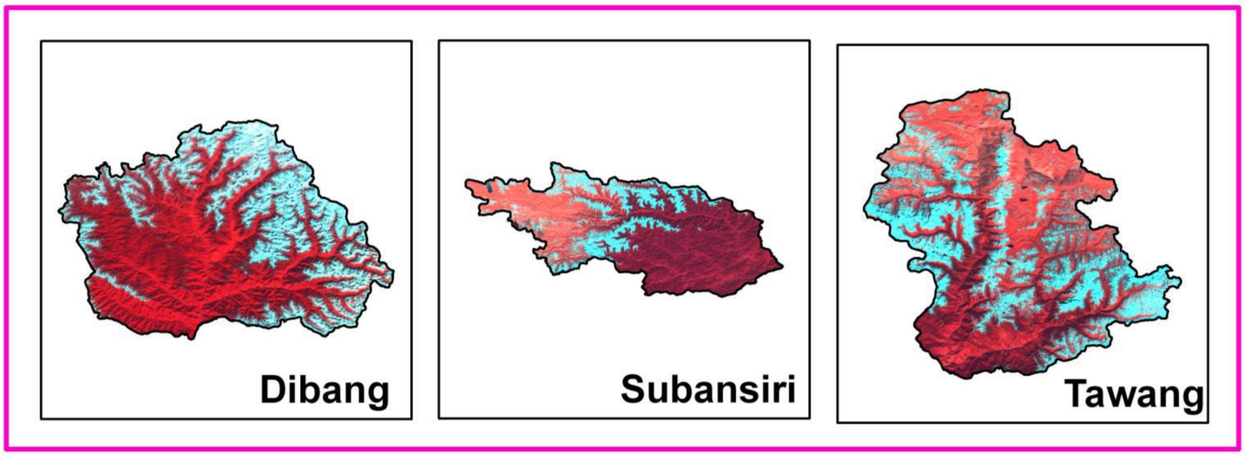
SNOW COVER ATLAS OF BHAHMAPUTRA

Sub-basins: Dibang, Subansiri and Tawang

(Integrated *Studies of Himalayan Cryosphere*

A Project of Indian Space Research Organisation)

Year 2015-2016



Center for Applied Geomatics
CEPT University- Ahmadabad 380009
&
Space Applications Centre (ISRO)
Ahmedabad-380015

July 2018

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SPACE APPLICATIONS CENTRE (ISRO), AHMEDABAD - 380015

DOCUMENT CONTROL AND DATA SHEET

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Abstract	This atlas gives sub basin-wise distribution of snow cover in the Brahmaputra basin from October 2015 to June 2016. The sub basins included in this report are Dibang, Subansiri and Tawang. 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, Dibang, Subansiri and Tawang basins.
Security Classification	Unrestricted
Distribution	Among concerned

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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 three sub-basins of the Brahmaputra basin. These are Dibang, Subansiri and Tawang sub basins. Locations of these basins are shown in Figure 1.

3. Data used:

AWiFS data from October 2015 to June 2016 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:

$$NormalizedDifferenceSnowIndex(NDSI) = (band2 - band5)/(band2 + band5) \qquad ..(1)$$

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. If three consecutive scenes are not available, then all available scenes in 10 days window was used in the analysis. 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, basin-wise snow cover statistics, maps, and seasonal depletion curves have been provided from October 2015 to June 2016. Snow ablation pattern varies from basin to basin, depending on area altitude distribution in the basins. Snow cover pattern in the Tawang sub-basin shows accumulation and ablation of snow throughout the winter season. It is also found that accumulation period started early in all the sub-basins in early-December. Accumulation starts from December and same time ablation also starts till February first week in subansiri sub-basin. In Subansiri basin there is not much variation in snow cover area. It varies between 12 % in the month of December and 28% in the month of January. Snow cover depletion curve of Dibang sub-basin also shows accumulation & ablation throughout the season. It varies between 16% in the month of June and 54% in the month of February. Snow cover reached maximum in the month of March & April and then starts ablation. Overall comparison among the three sub-basins reveal that the percentage of areal extent of snow in Subansiri sub-basin is very less compared to Tawang and Dibang sub-basins.

Acknowledgements

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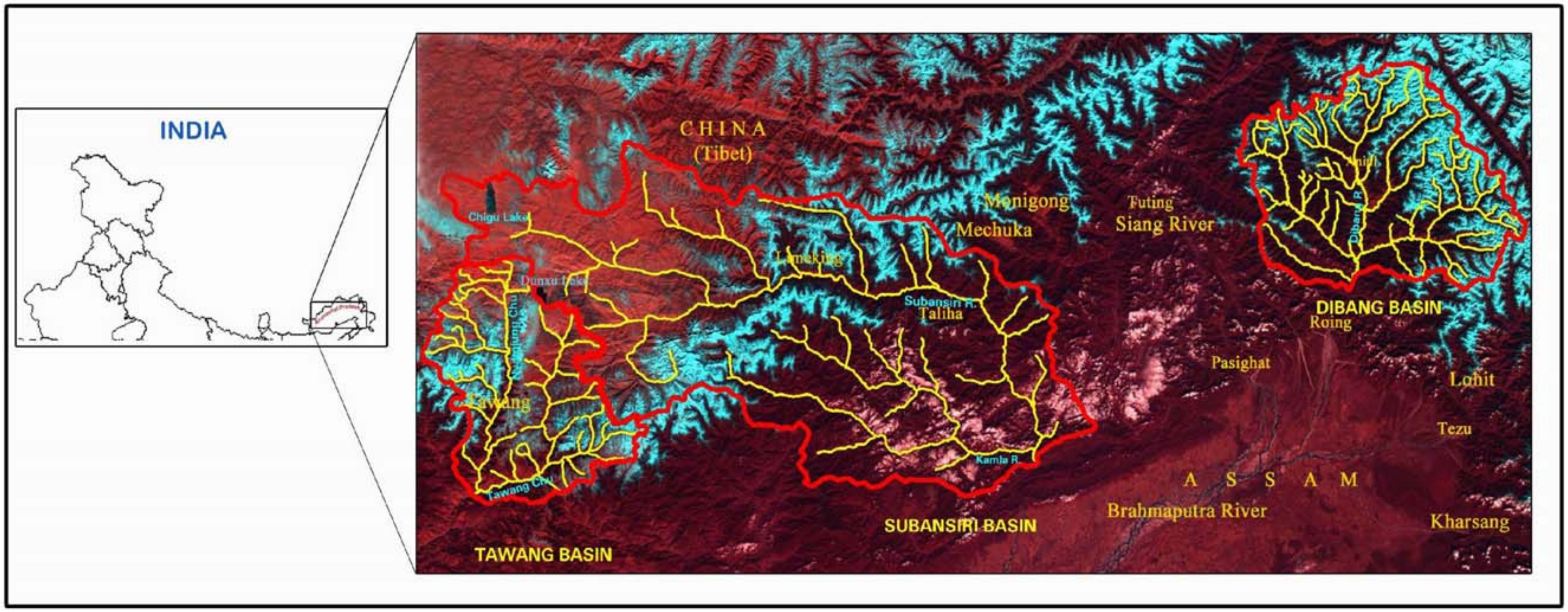


Figure 1: Location map of Dibang, Subansiri and Tawang sub-basins (Part of Brahmputra basin)

DIBANG SUB-BASIN

AREAL EXTENT OF SNOW (5 DAILY)

BASIN NAME: DIBANG **BASIN AREA: 9157 sq km**

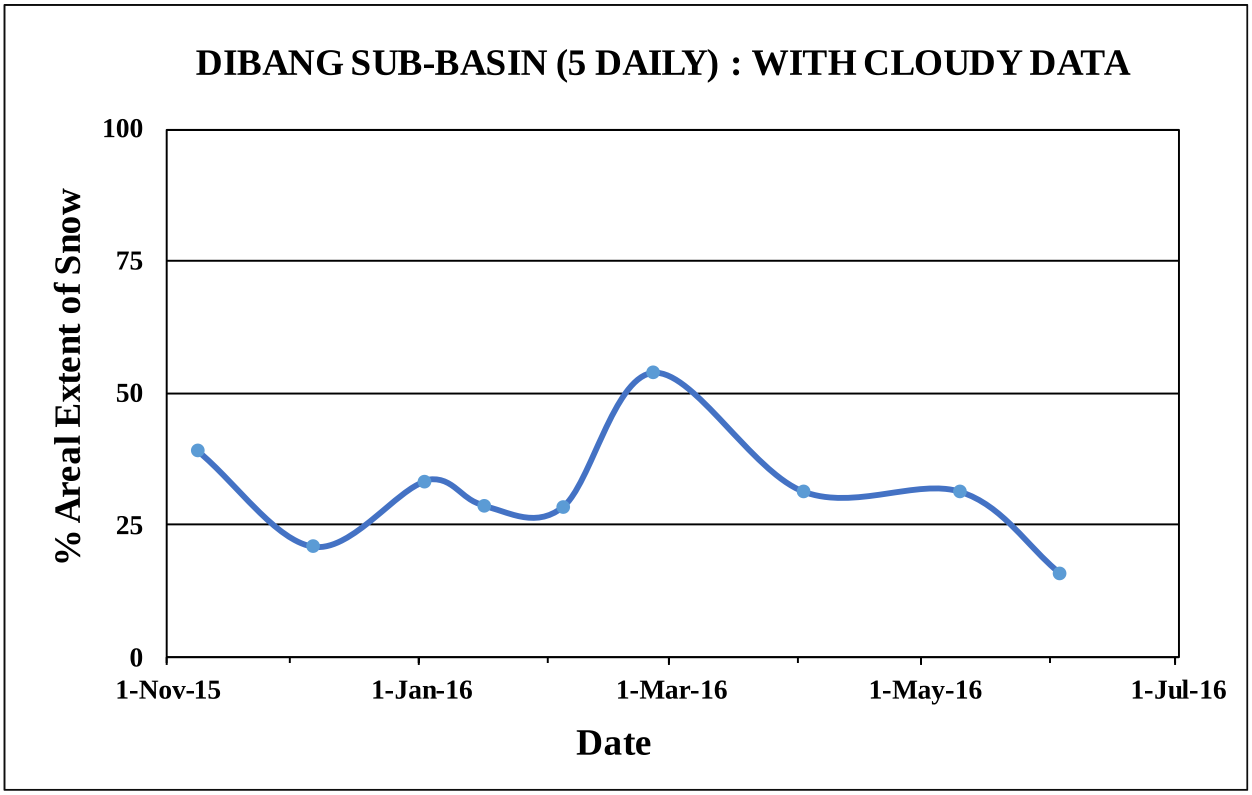
S No	Date	Snow cover (sq km)	Snow cover (%)	S No	Date	Snow cover (sq km)	Snow cover (%)
November 2015							
1	08-Nov-2015	3568	39				
December 2015							
2	06-Dec-2015	1953	21				
January 2016							
3	02-Jan-2016	3065	33	**4**	16-Jan-2016	2634 (C)	29
February 2016							
5	04-Feb-2016	2583 (C)	28	**6**	26-Feb-2016	4991	54
April 2016							
7	02-April-2016	2887	32				
May 2016							
8	10-May-2016	2883	31				
June 2016							
9	03-June-2016	1453	16				

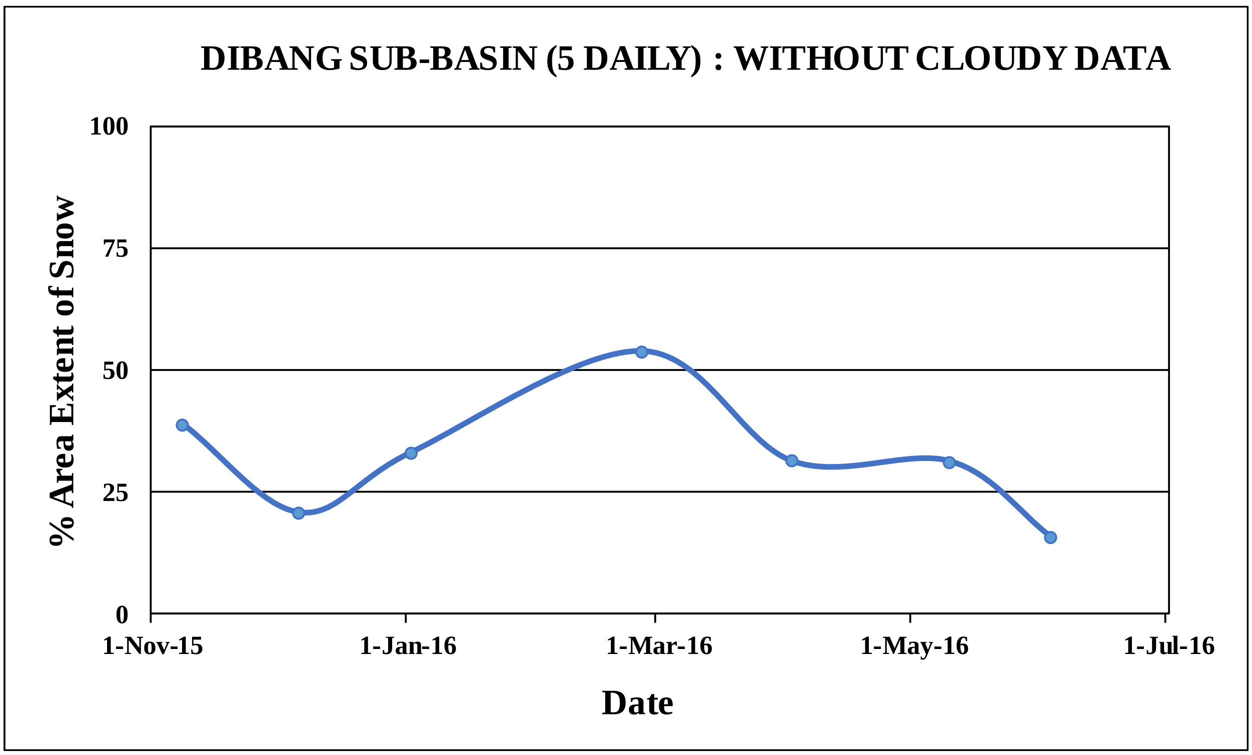
AREAL EXTENT OF SNOW (10 DAILY)

BASIN NAME: DIBANG **BASIN AREA: 9157 sq km**

S No	Date	Snow cover (sq km)	Snow cover (%)	S No	Date	Snow cover (sq km)	Snow cover (%)
			November 2015				
1	05-Nov-2015	3568	39				
			December 2015				
2	05-Dec-2015	1953	21				
			January 2016				
3	05-Jan-2016	3065	33	**4**			
			February 2016				
5	25-Feb-2016	4991	54	**6**			
			April 2016				
7	05-April-2016	2887	32				
			May 2016				
8	5-May-2016	2883	31				
			June 2016				
9	05-June-2016	1453	16				

SNOW COVER DEPLETION CURVE (5 daily)





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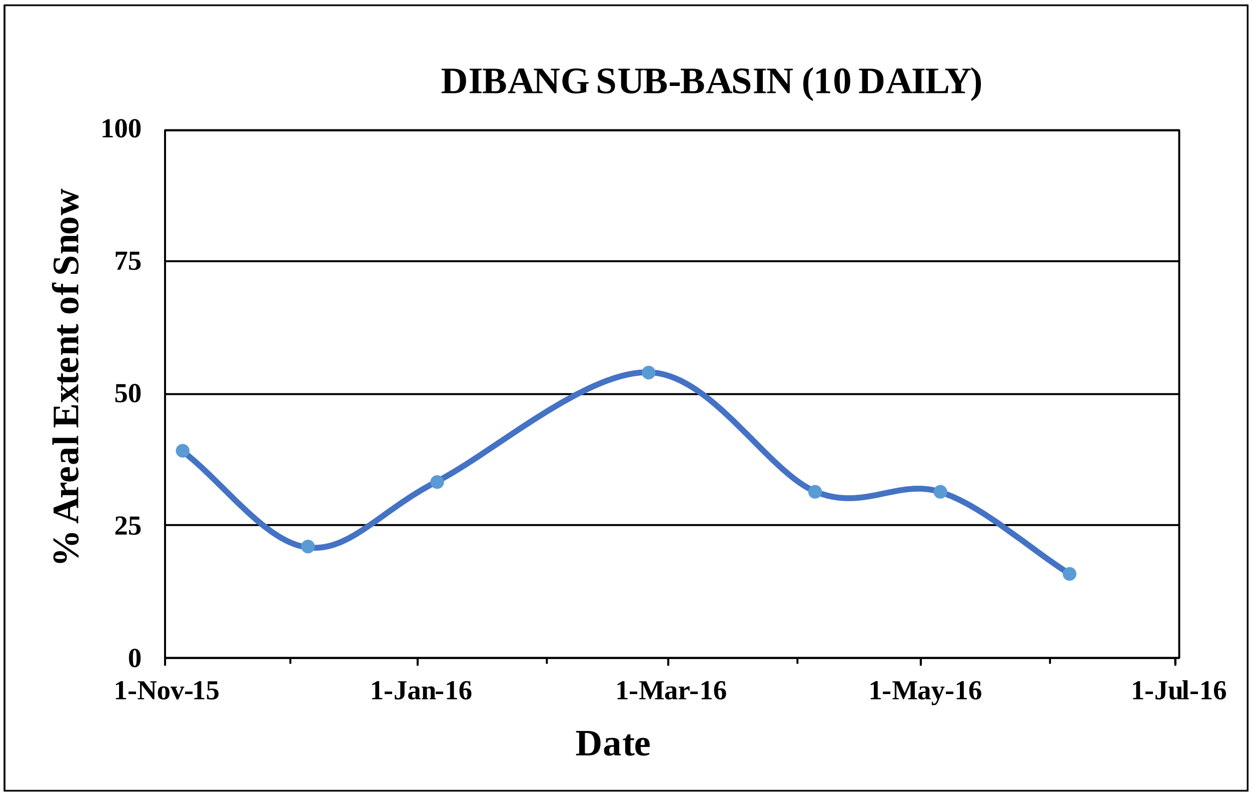
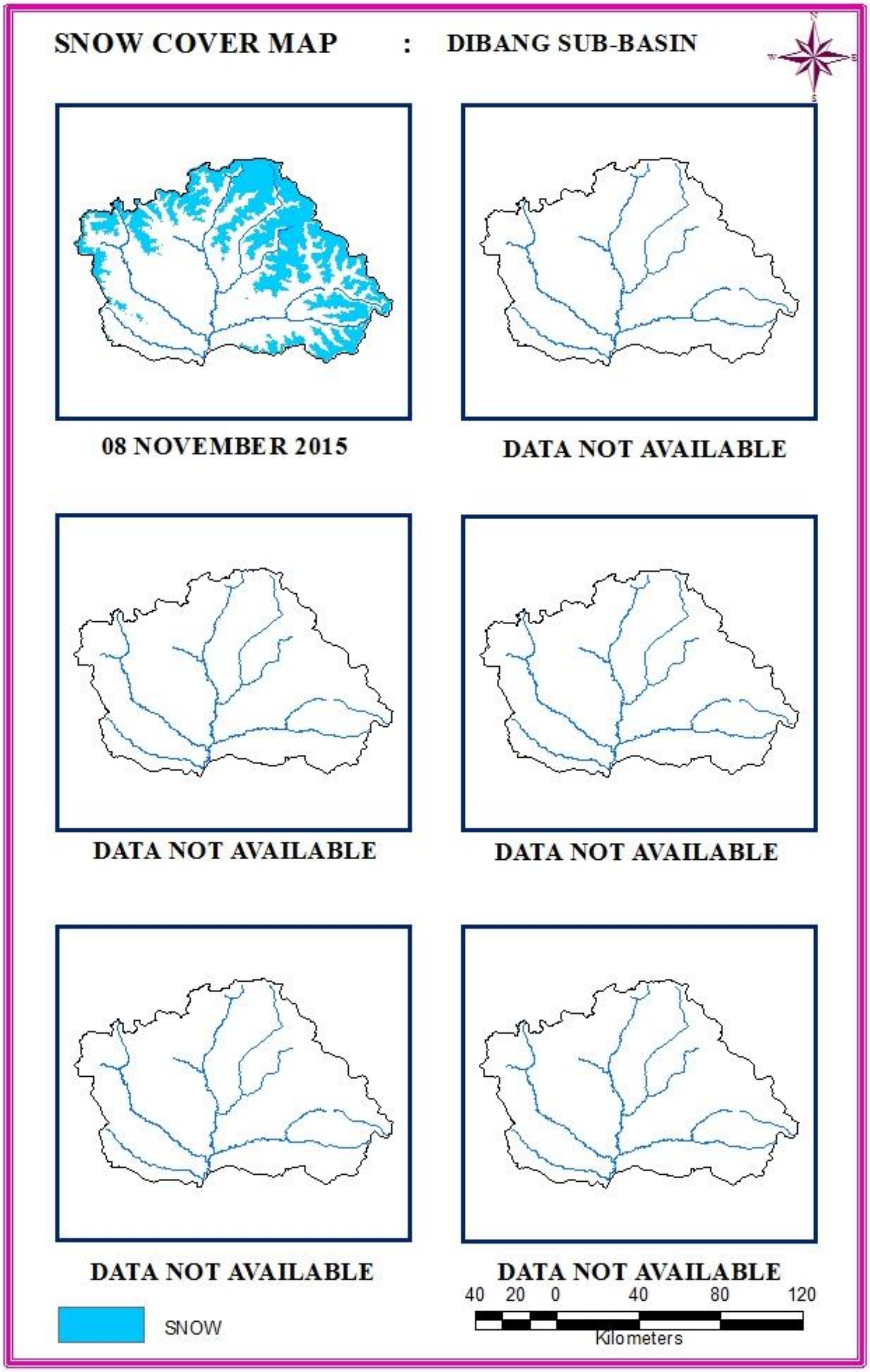


SNOW COVER MAPS


SNOW COVER MAP : DIBANG SUB-BASIN
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DATA NOT AVAILABLE
SNOW
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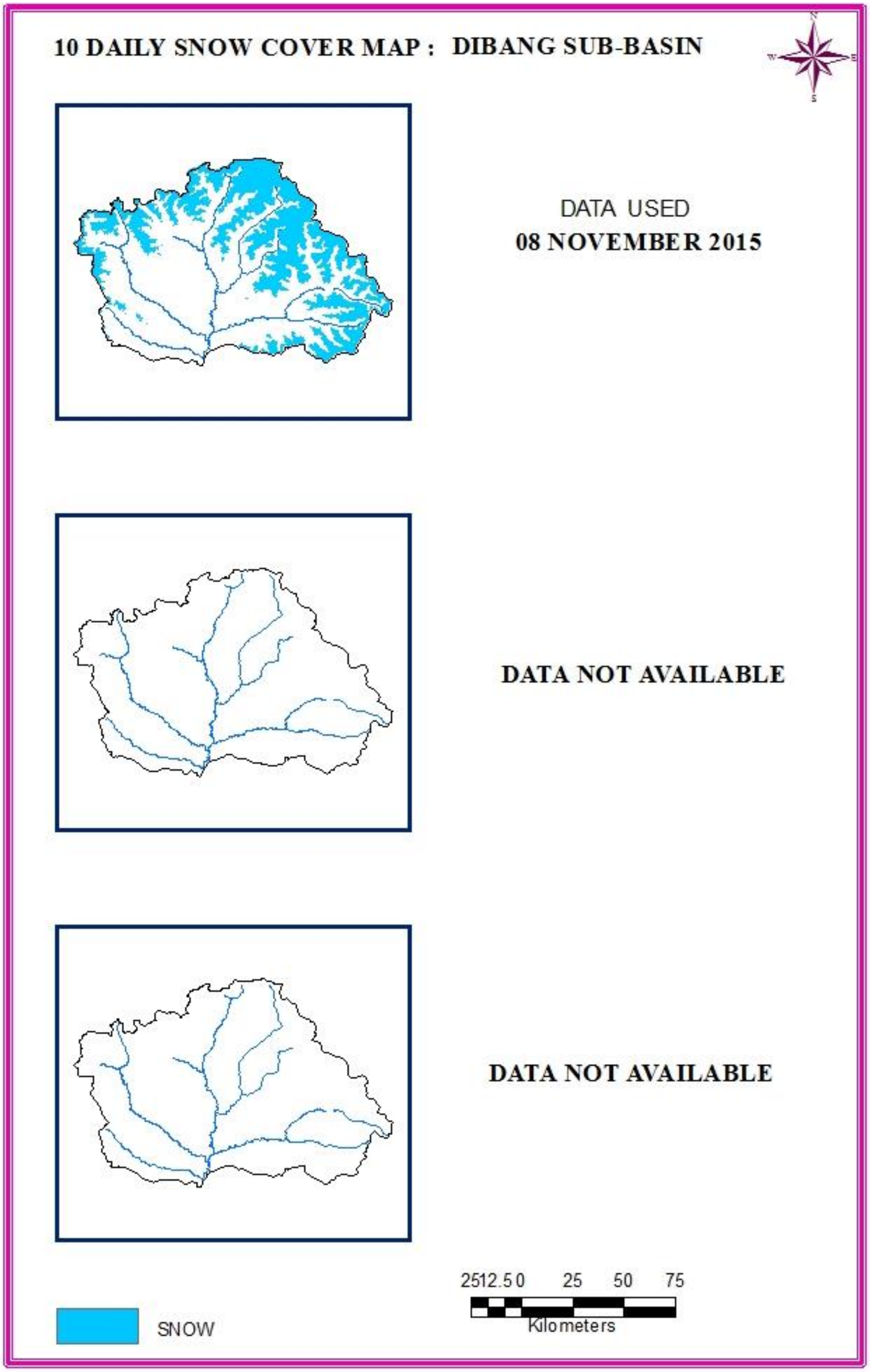
Kilometers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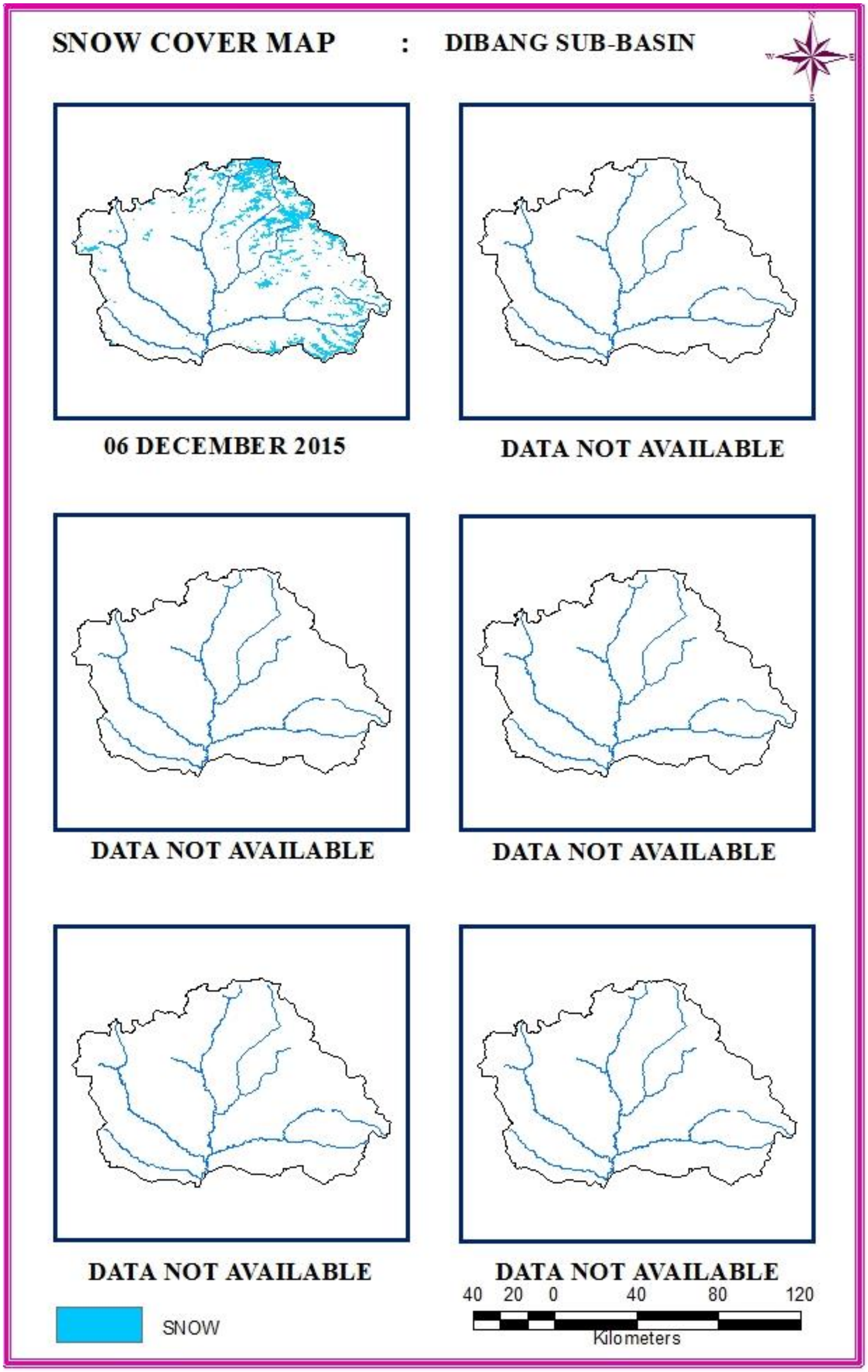
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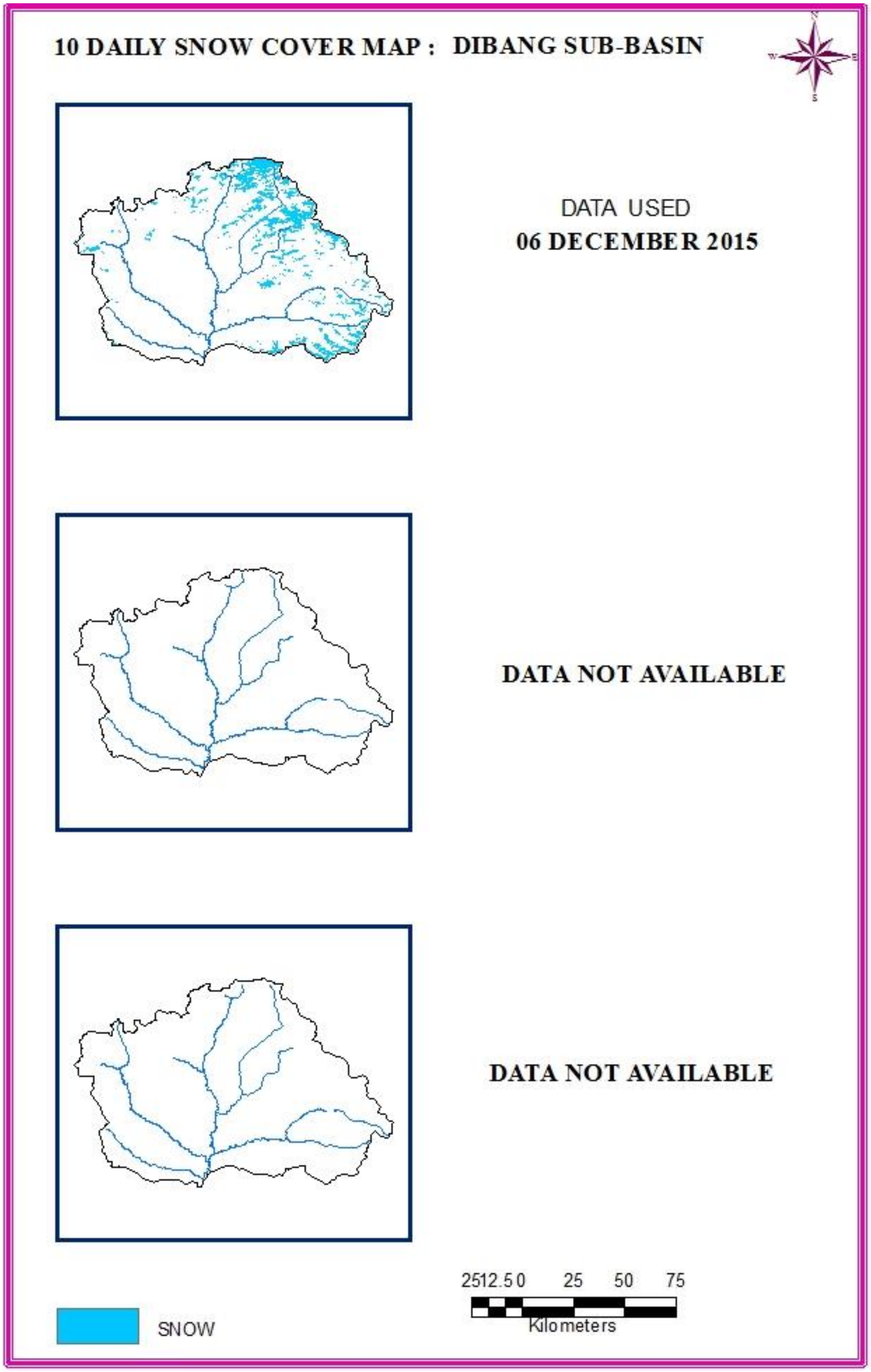
Kilometers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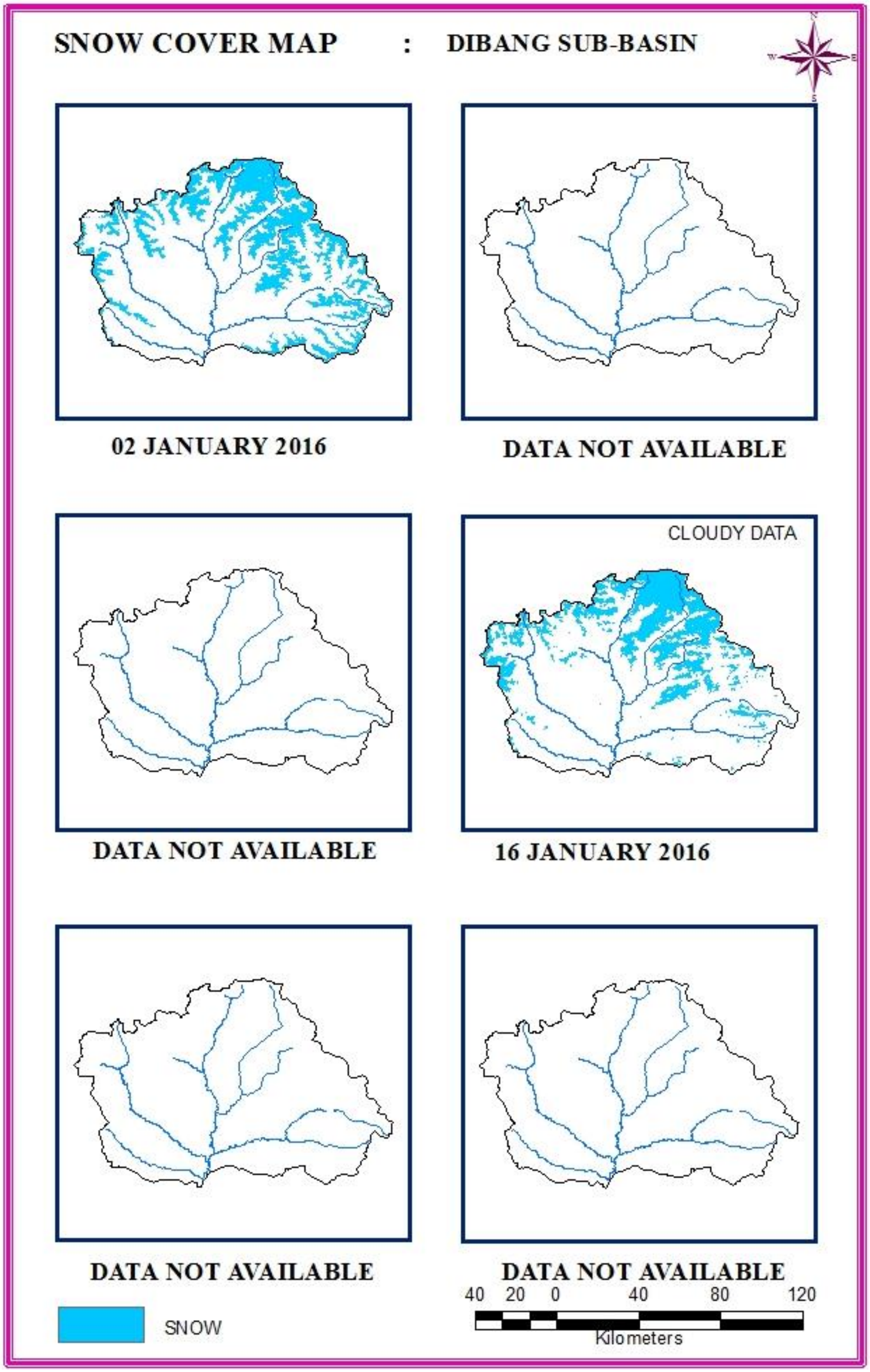
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02 JANUARY 2016
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CLOUDY DATA
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16 JANUARY 2016
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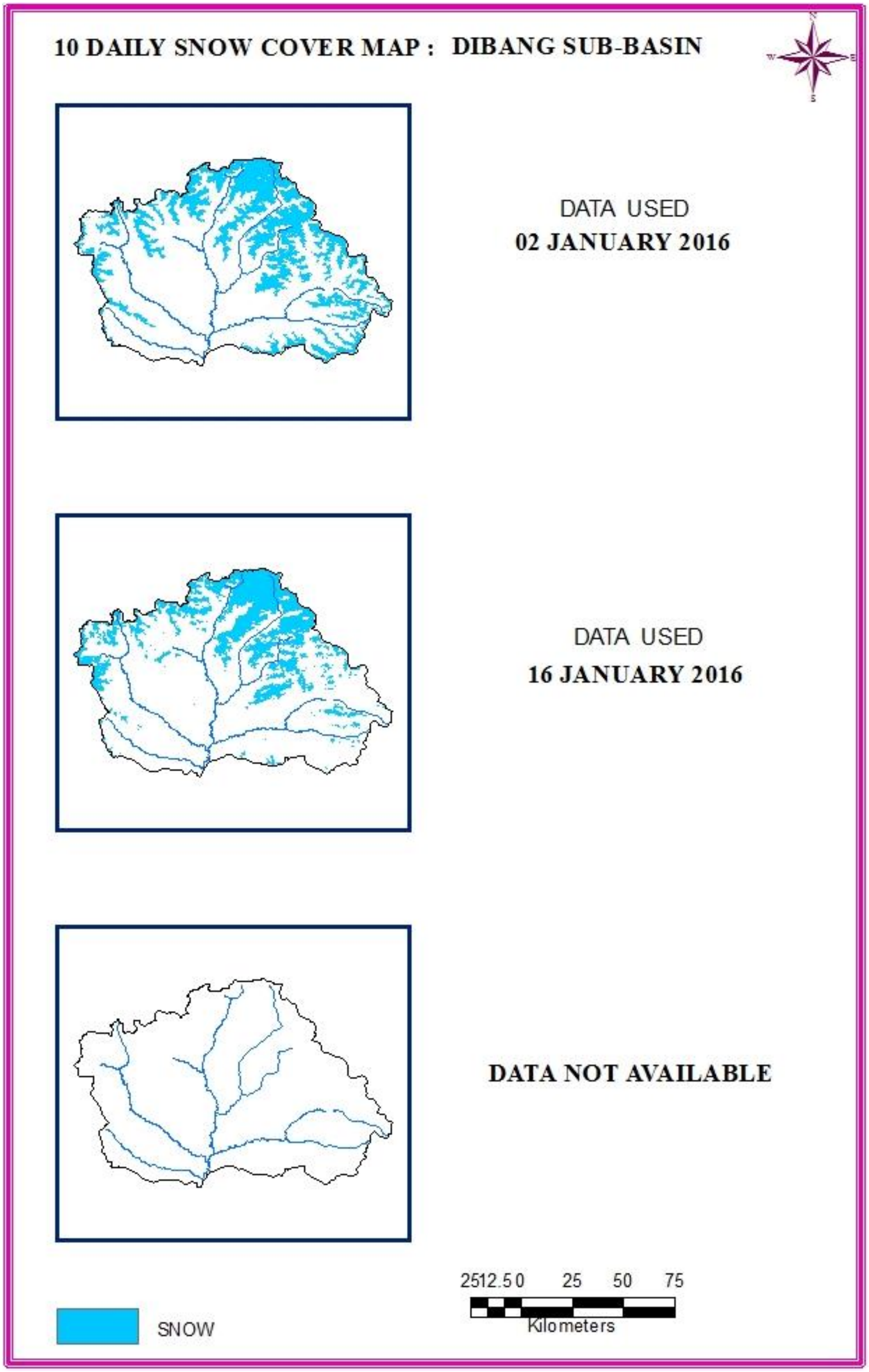
Kilometers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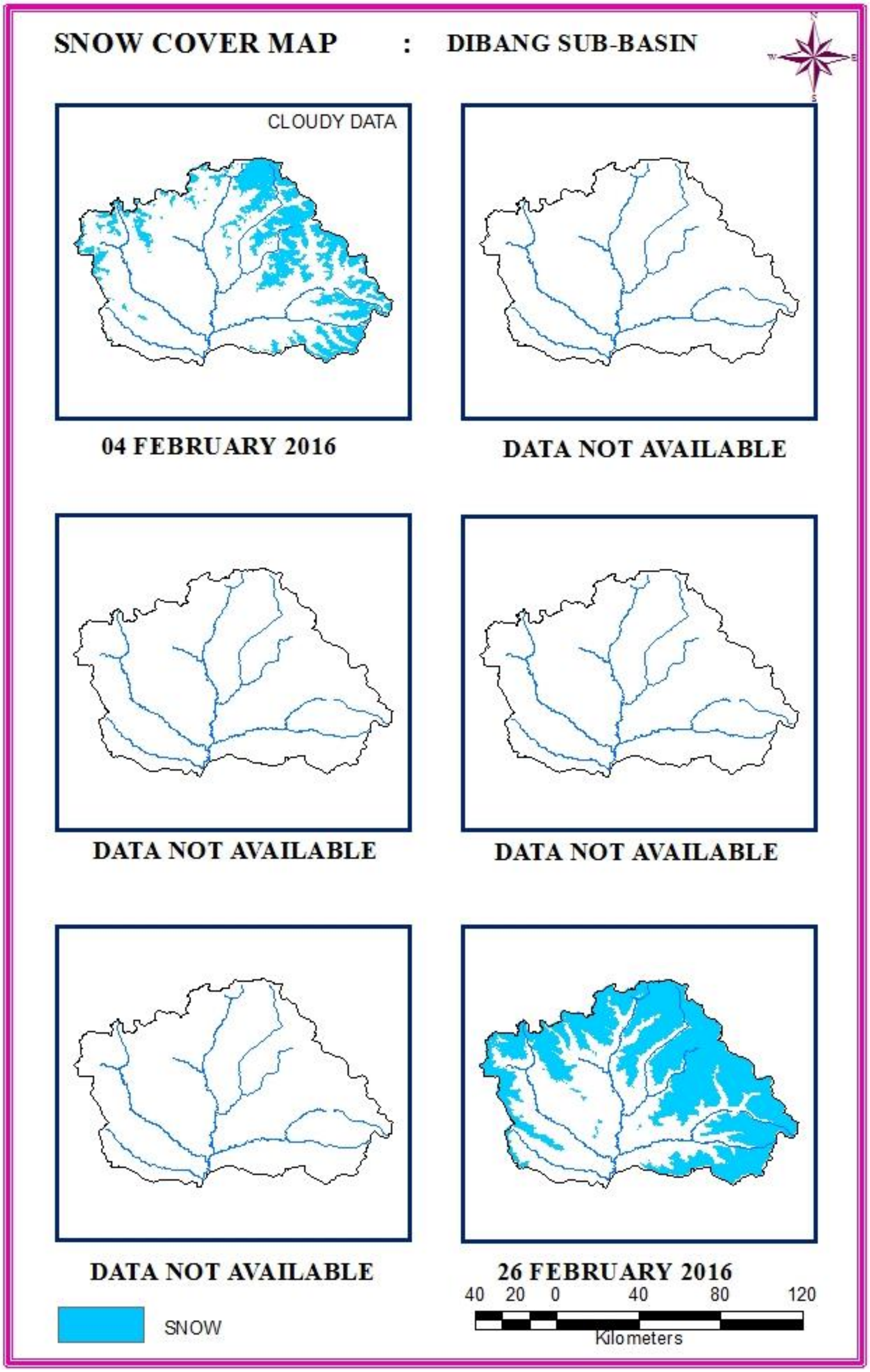
SNOW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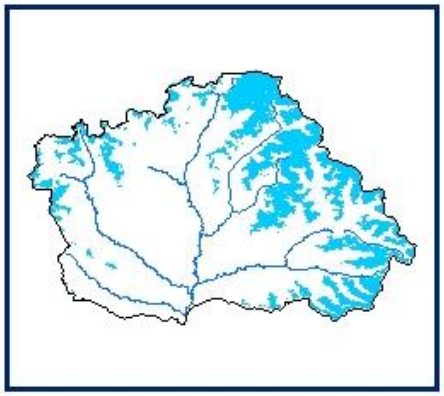
26 FEBRUARY 2016
SNOW
40 20 0 40 80 120
Kilometers

10 DAILY SNOW COVER MAP : DIBANG SUB-BASIN



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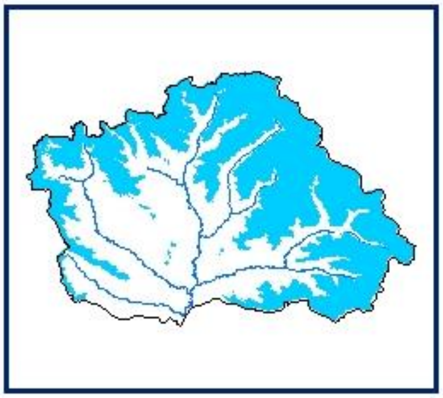

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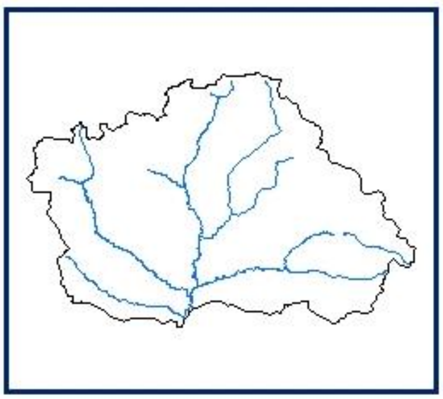

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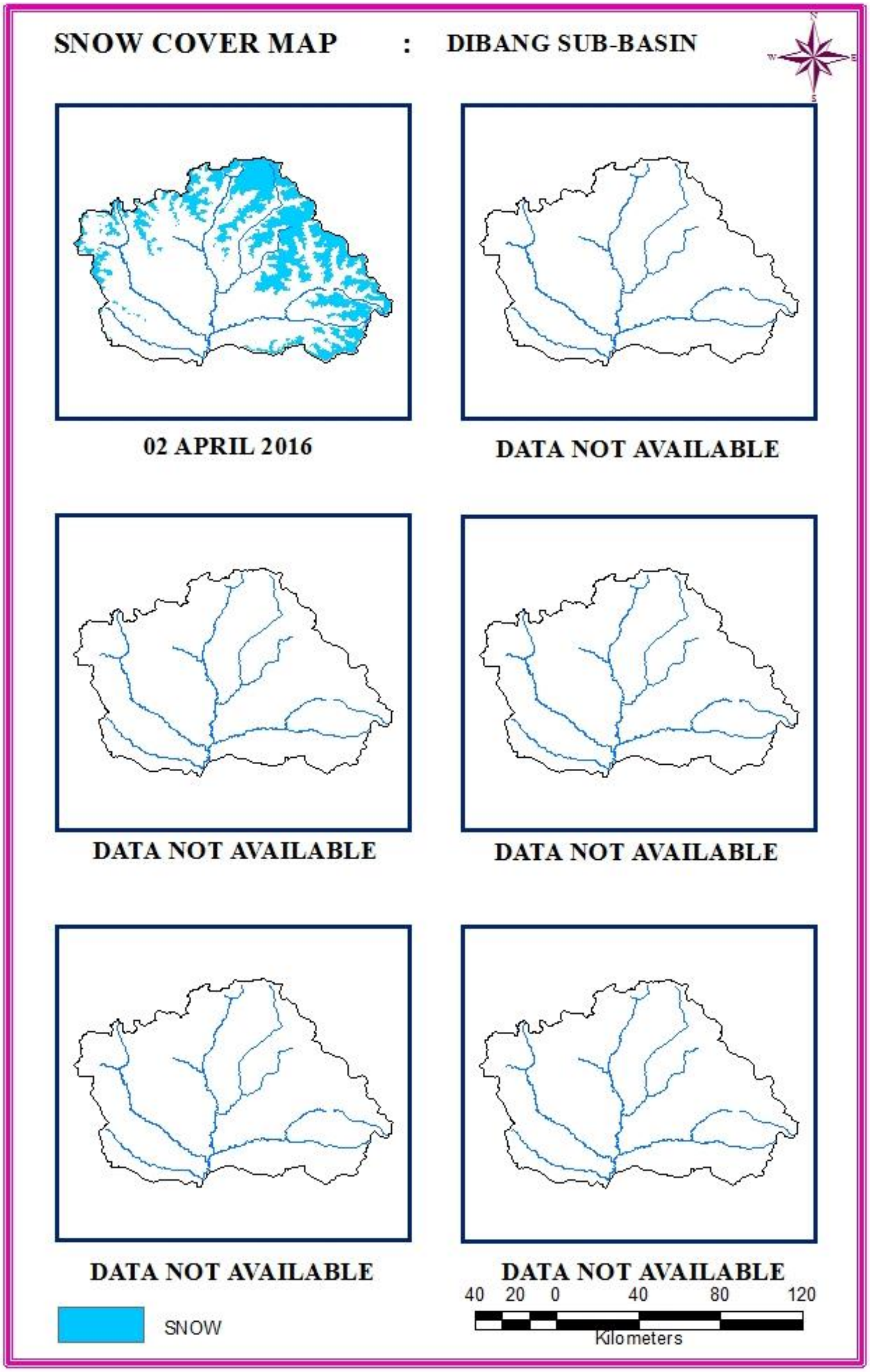
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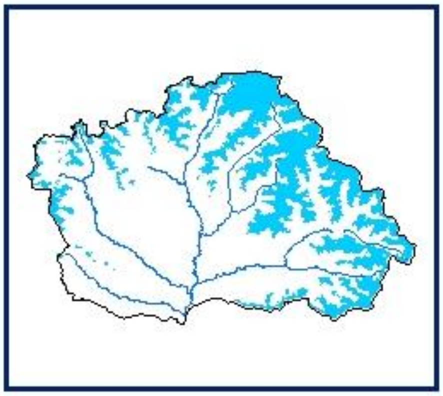
SNOW
40 20 0 40 80 120
Kilometers

10 DAILY SNOW COVER MAP : DIBANG SUB-BASIN



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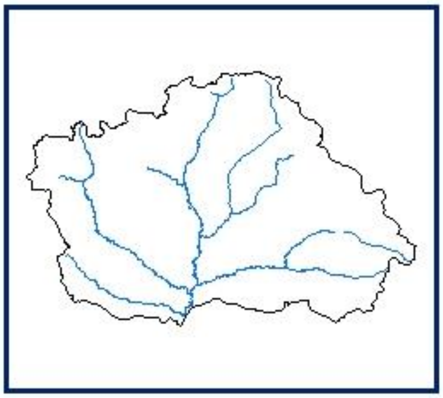

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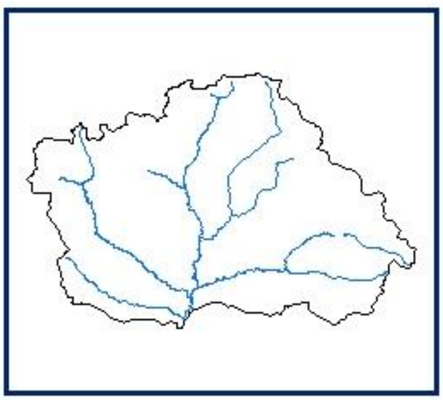

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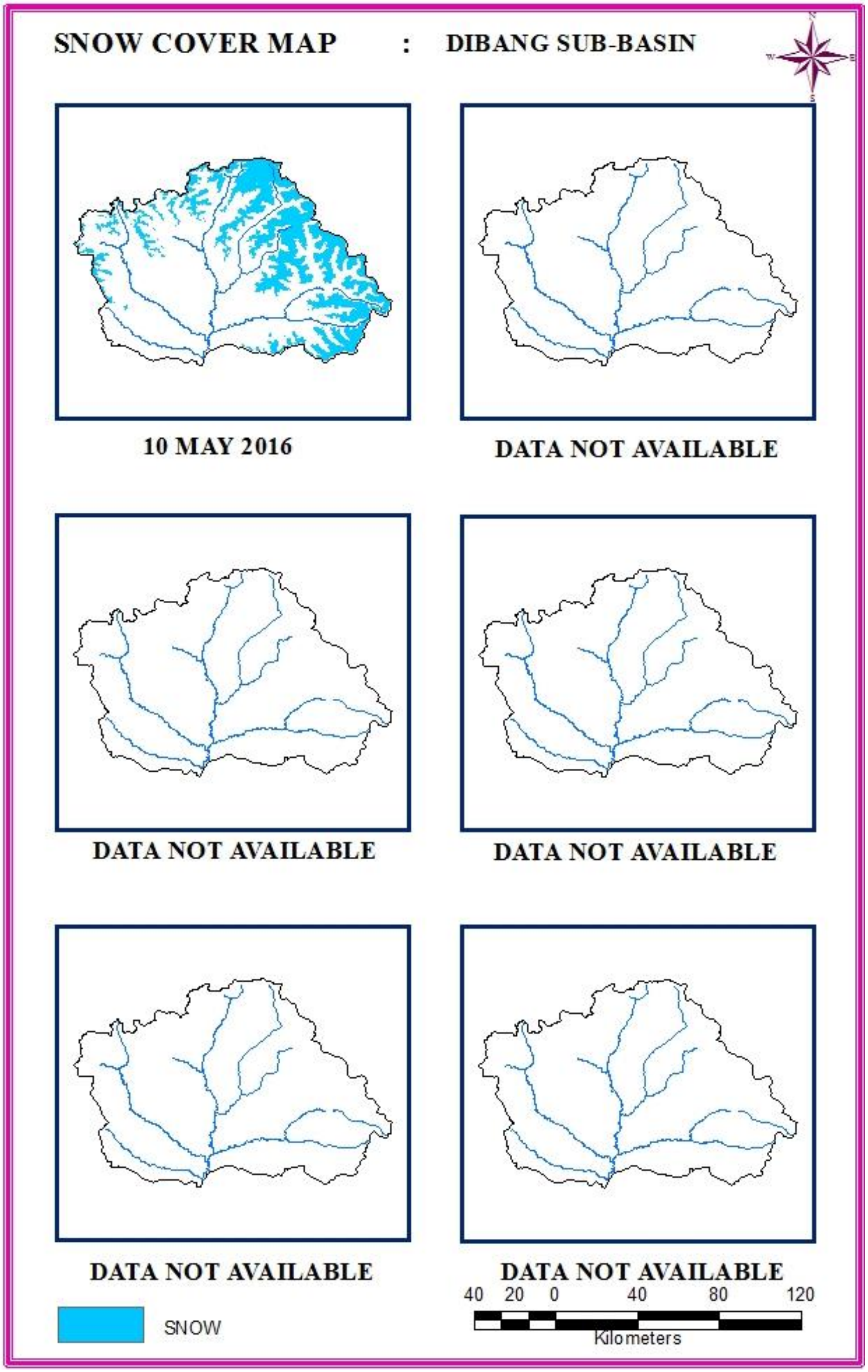
Kilometers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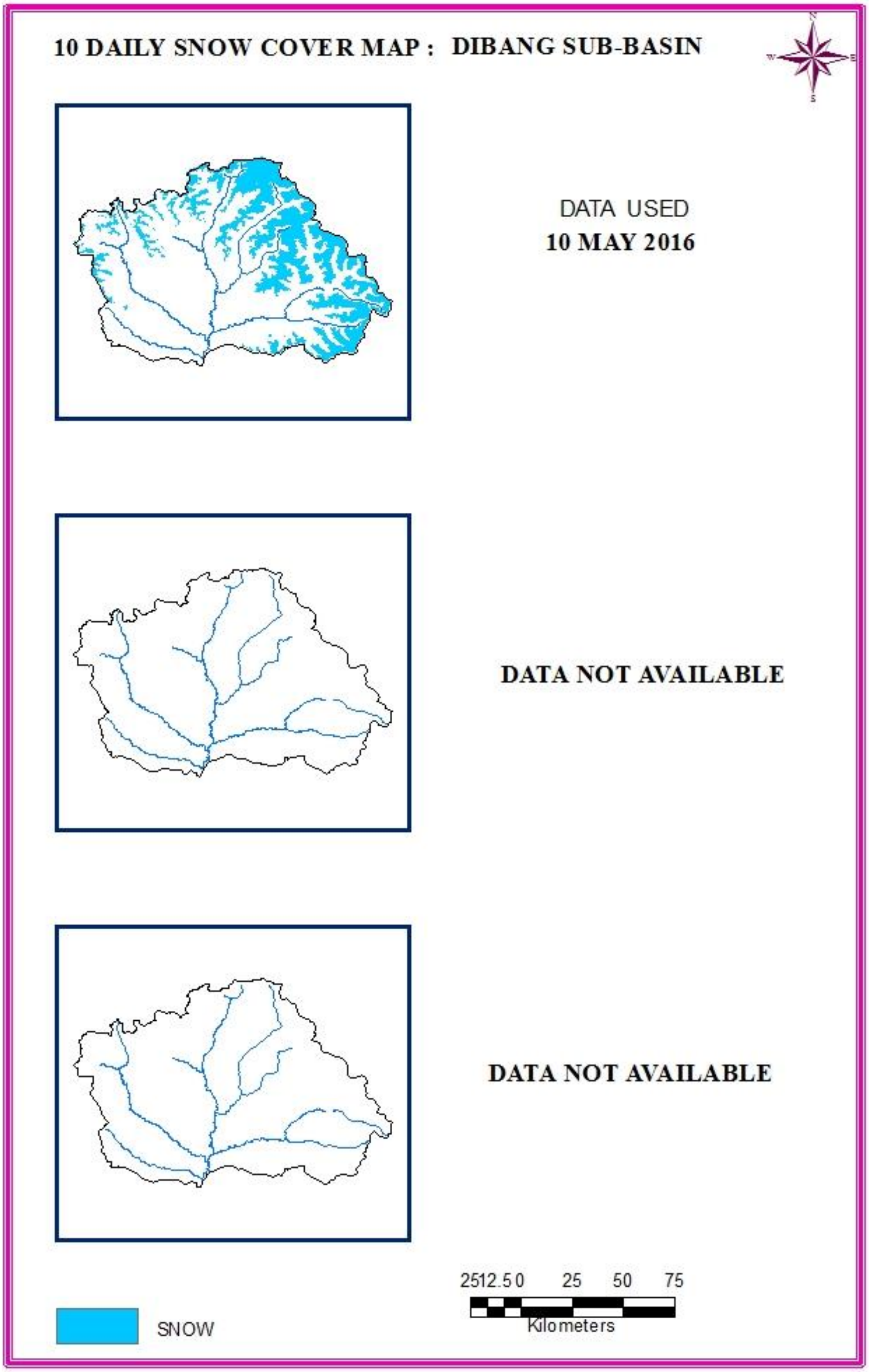
SNOW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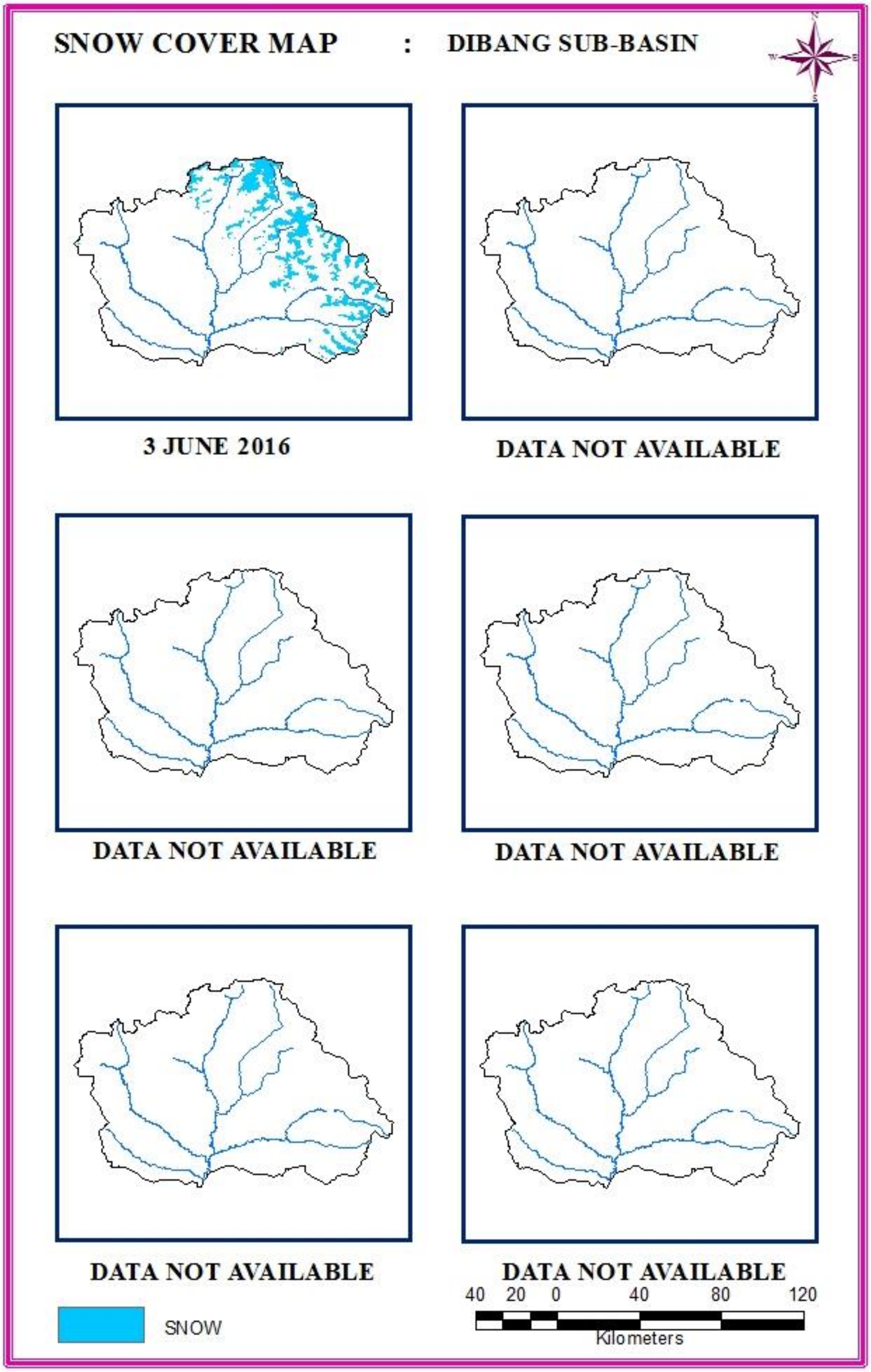
SNOW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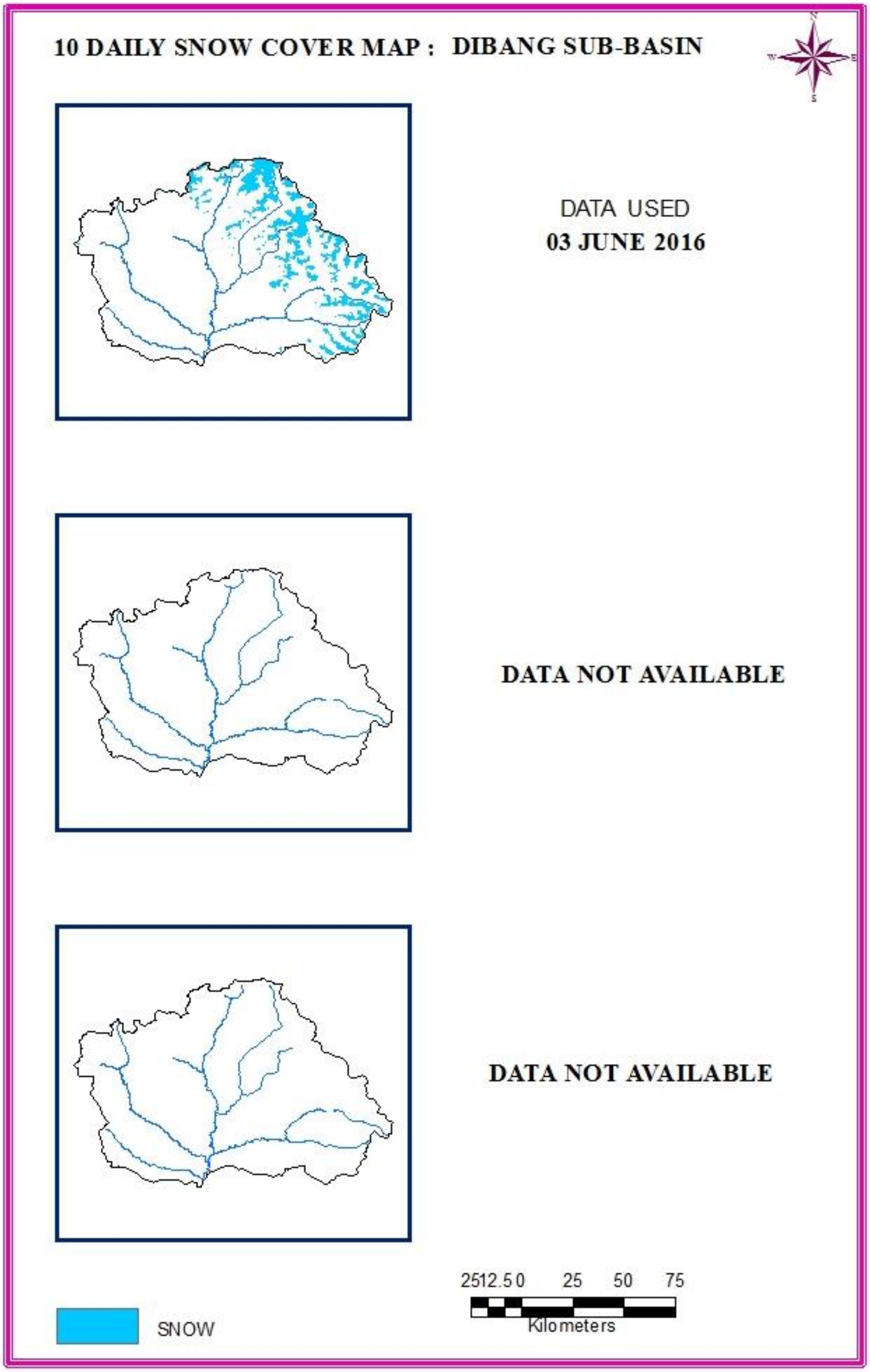
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DATA NOT AVAILABLE
25 12.5 0 25 50 75
Kilometers
SNOW

SUBANSIRI SUB-BASIN

AREAL EXTENT OF SNOW (5 DAILY)

BASIN NAME: SUBANSIRI **BASIN AREA: 25334 sq km**

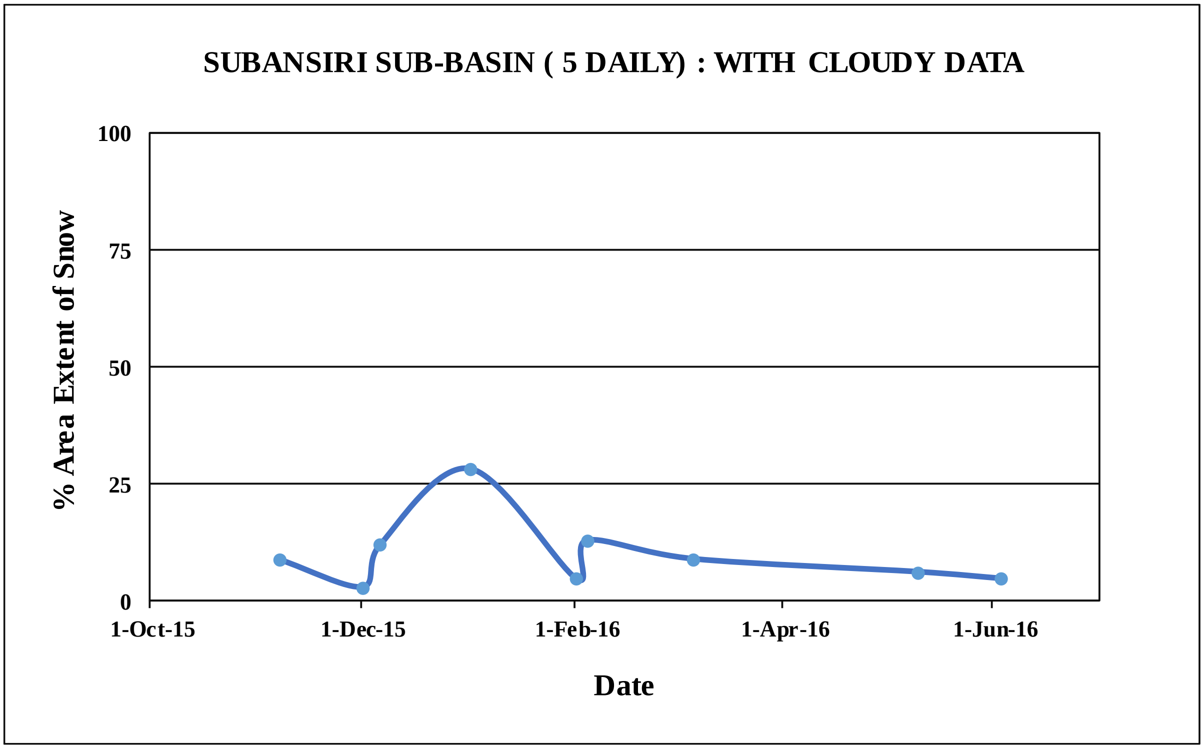
S No	Date	Snow cover (sq km)	Snow cover (%)	S No	Date	Snow cover (sq km)	Snow cover (%)
November 2015							
1	07-Nov-2015	2241 (C)	9				
December 2015							
2	01-Dec-2015	798 (C)	3	**3**	06-Dec-2015	3061	12
January 2016							
4	01-Jan-2016	7215	28				
February 2016							
5	01-Feb-2016	1179 (C)	5	**6**	04-Feb-2016	3307	13
March 2016							
7	06-Mar-2016	2154 (C)	9				
May 2016							
8	10-May-2016	1581	6				
June 2016							
9	03-June-2016	1211	5				

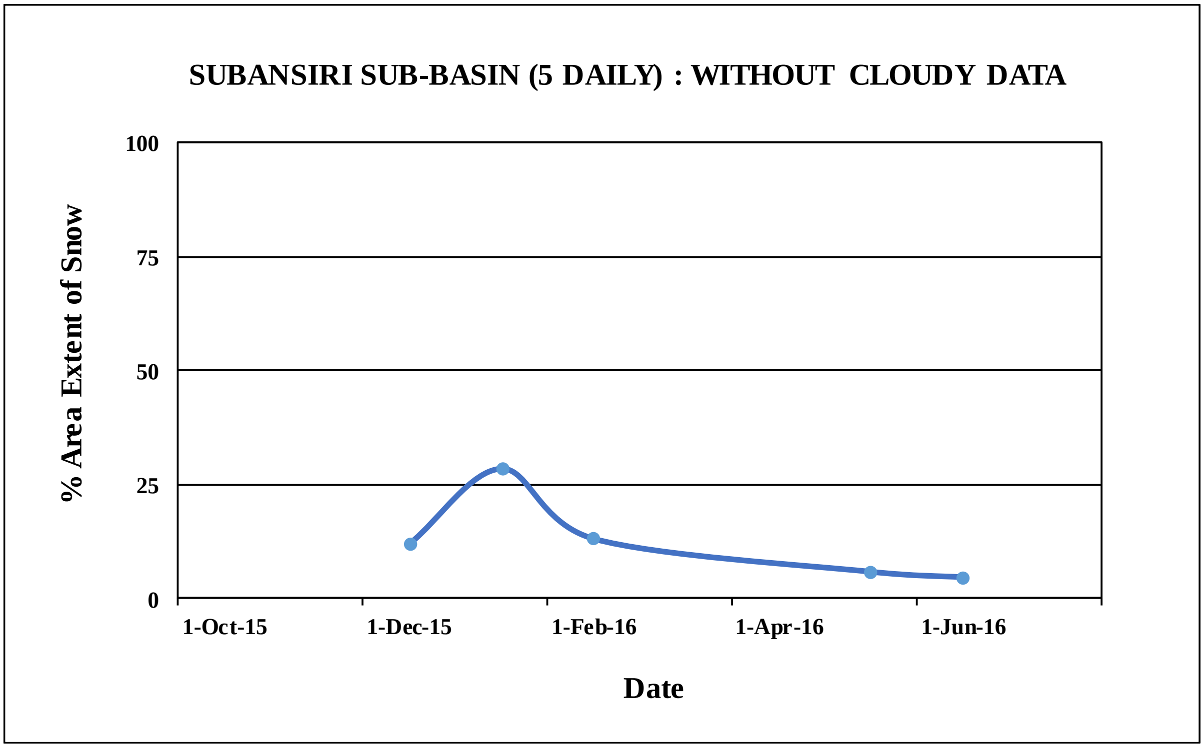
AREAL EXTENT OF SNOW (10 DAILY)

BASIN NAME: SUBANSIRI **BASIN AREA: 25334 sq km**

S No	Date	Snow cover (sq km)	Snow cover (%)	S No	Date	Snow cover (sq km)	Snow cover (%)
December 2015							
1	05-Dec-2015	2973	12				
January 2016							
2	05-jan-2016	7215	28				
February 2016							
3	05-Feb-2016	3430	14				
May 2016							
4	05-May-2016	1520	6				
June 2016							
5	5-Jun-2016	1217	5				

SNOW COVER DEPLETION CURVE





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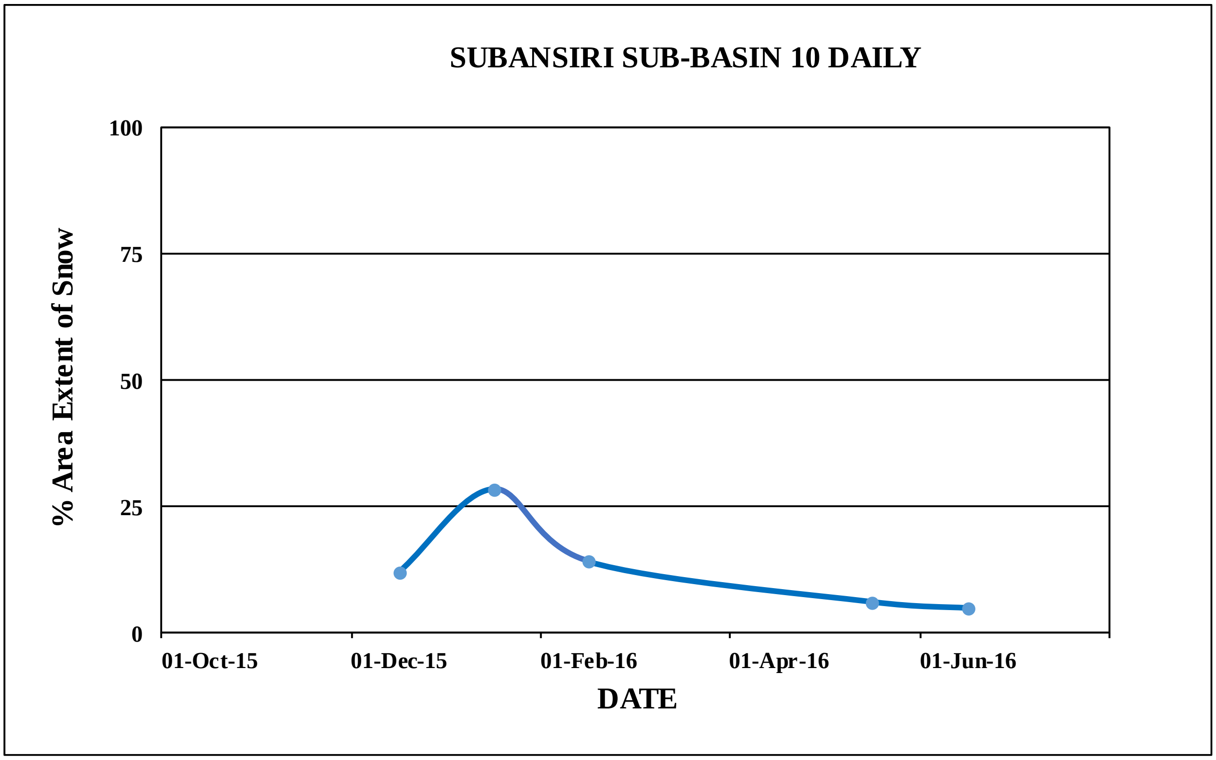
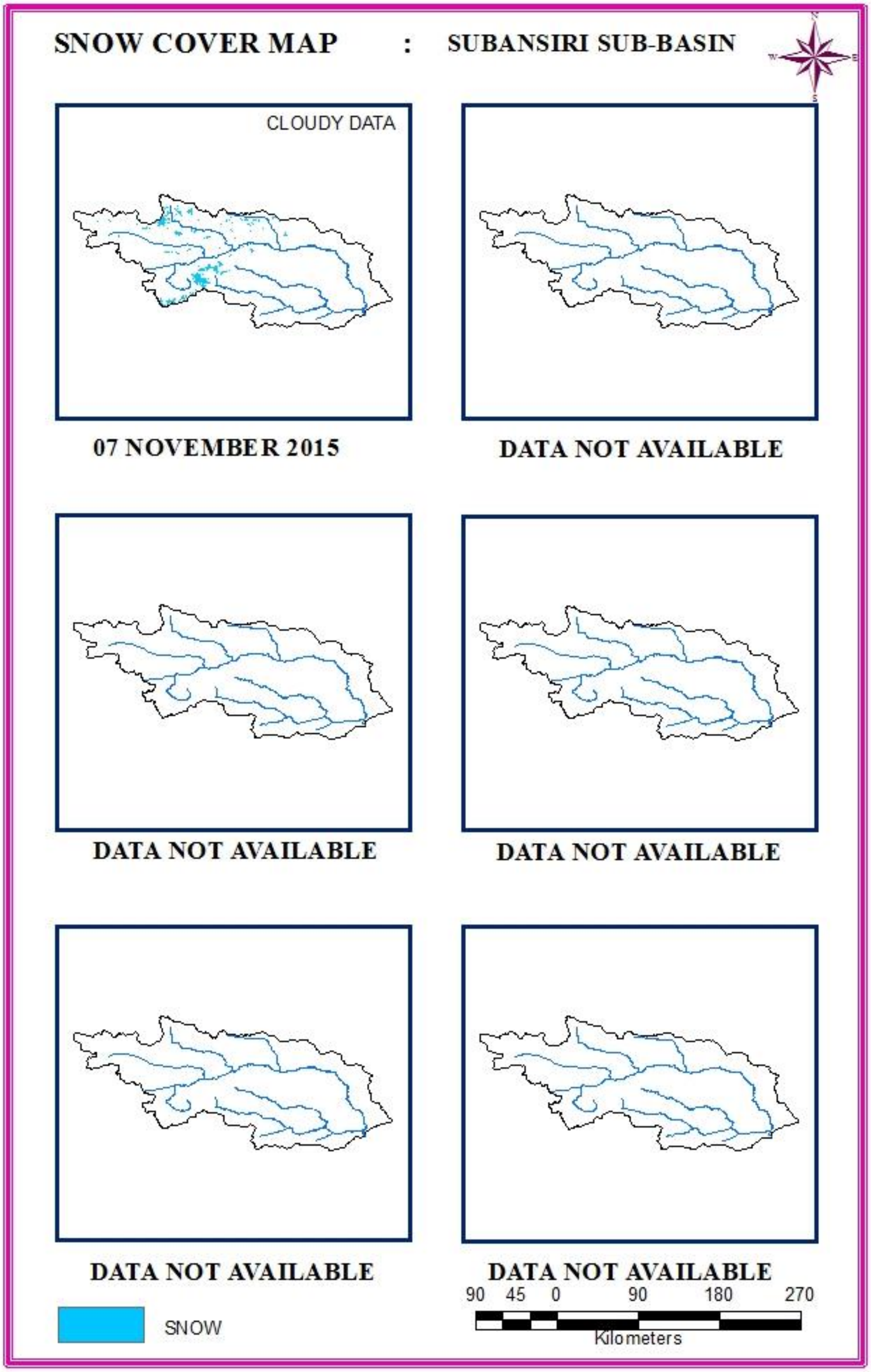


SNOW COVER MAP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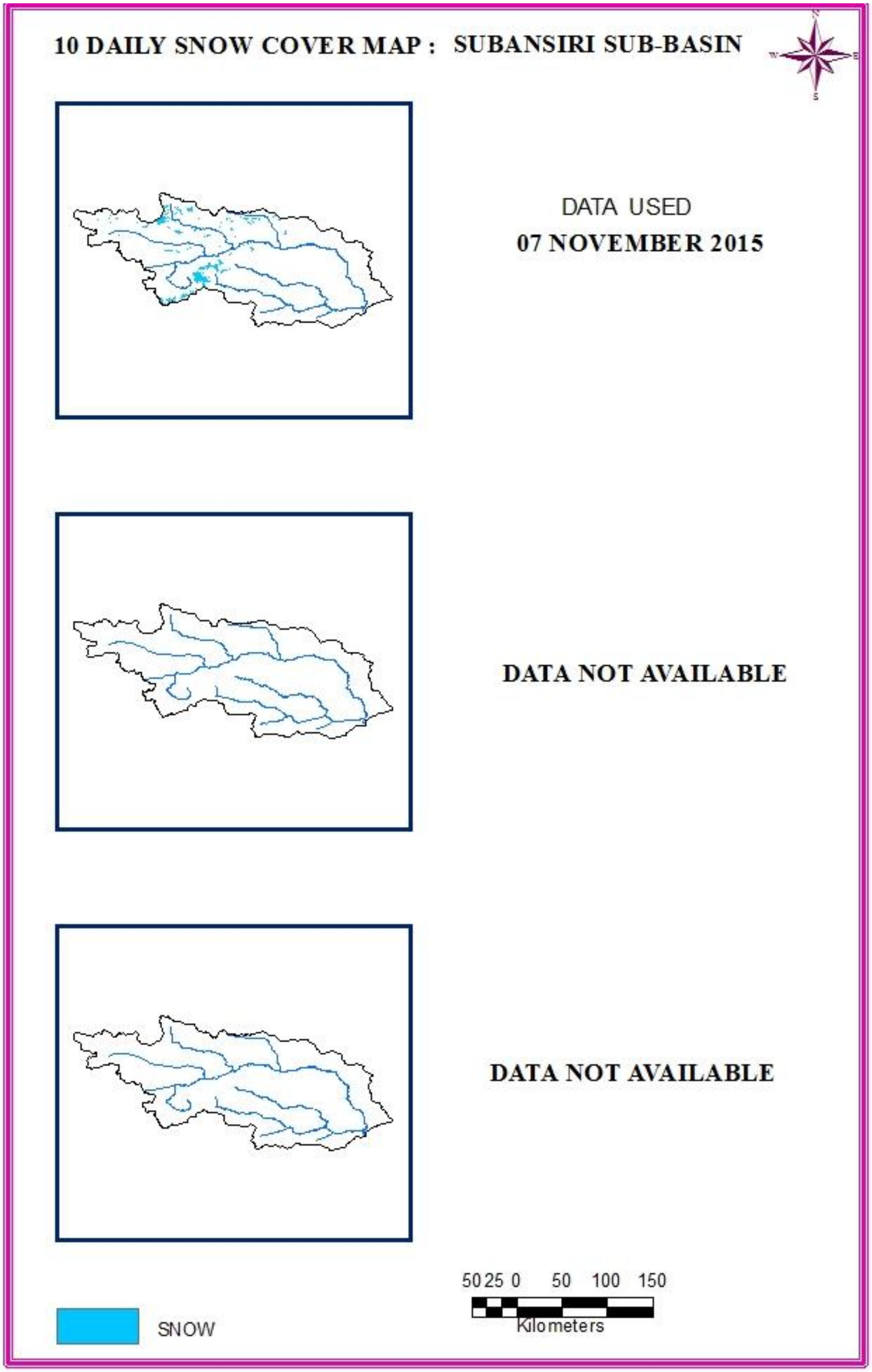
Kilometers
SNOW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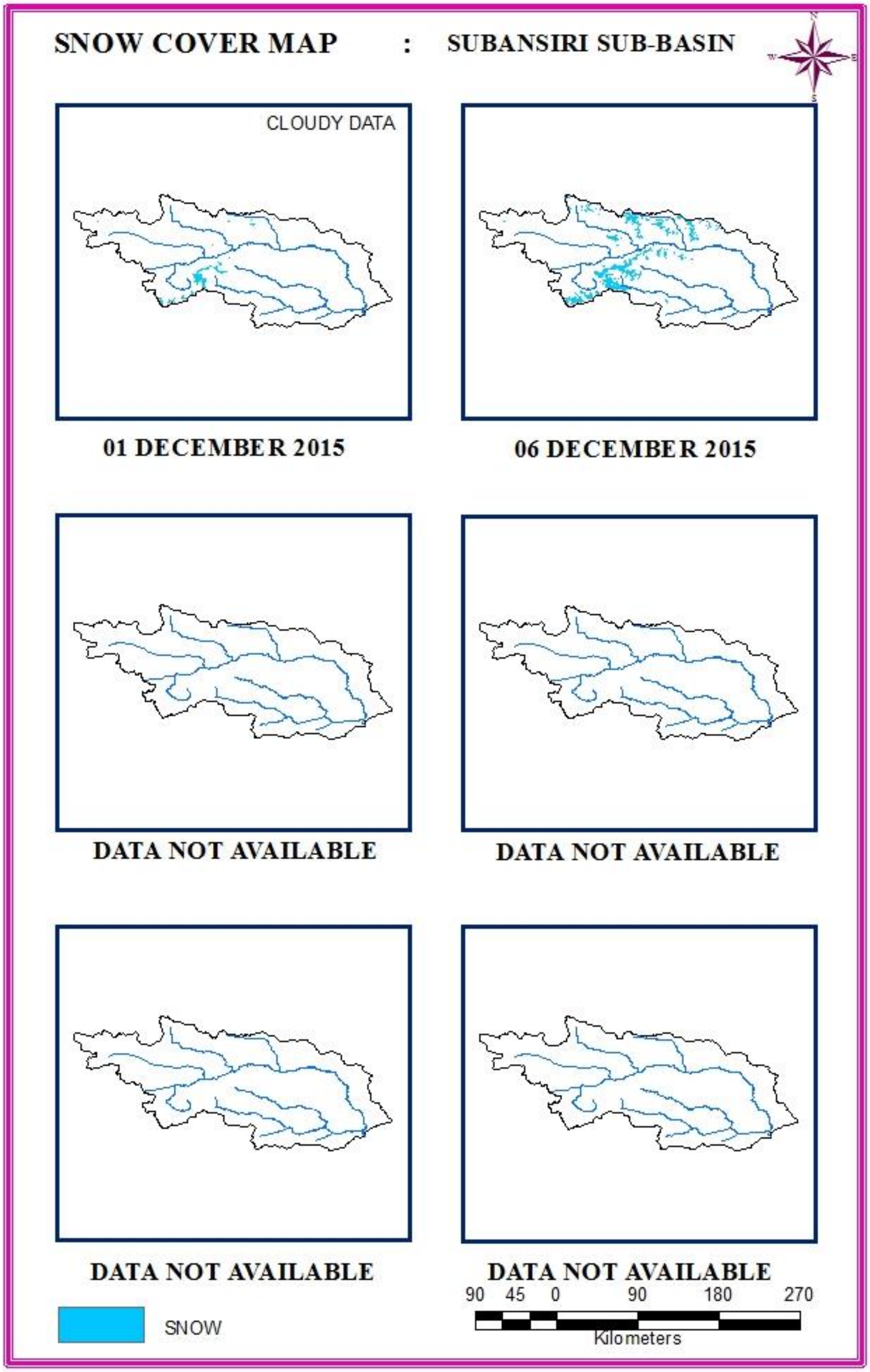
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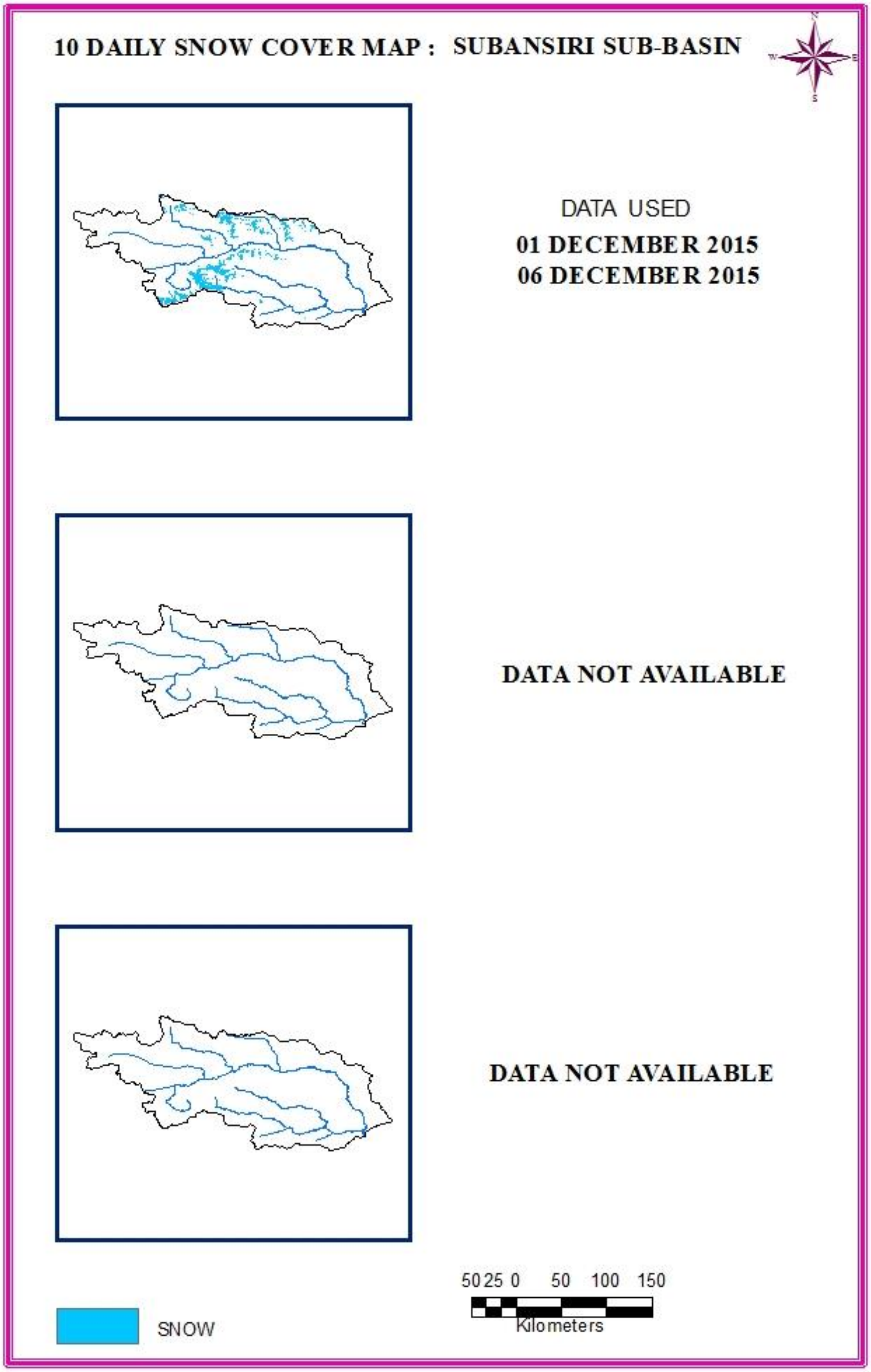
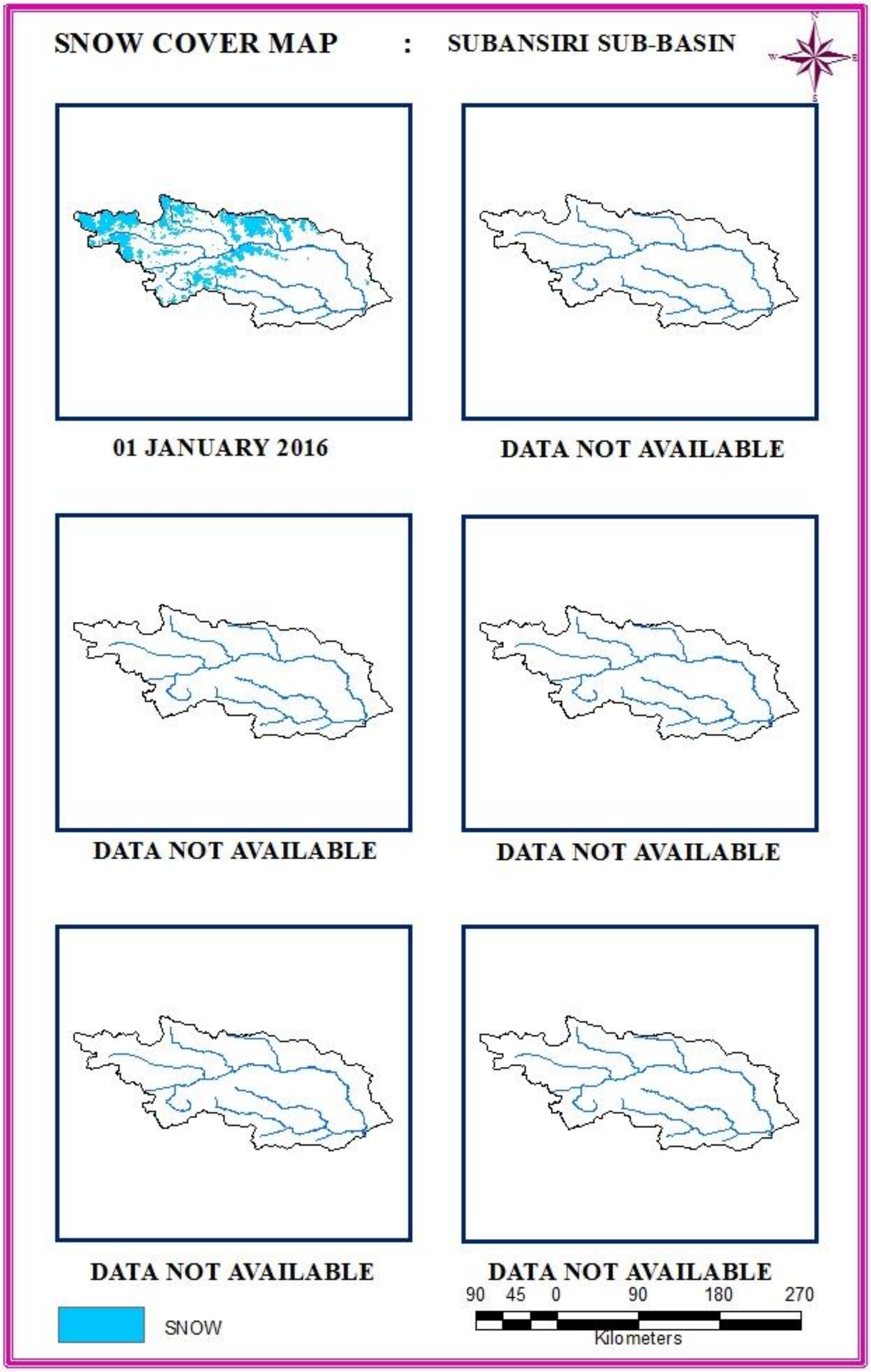
SNOW
90 45 0 90 180 270
Kilometers


10 DAILY SNOW COVER MAP : SUBANSIRI SUB-BASIN
DATA USED
01 DECEMBER 2015
06 DECEMBER 2015
DATA NOT AVAILABLE
DATA NOT AVAILABLE
50 25 0 50 100 150
Kilometers
SNOW


SNOW COVER MAP : SUBANSIRI SUB-BASIN
01 JANUARY 2016
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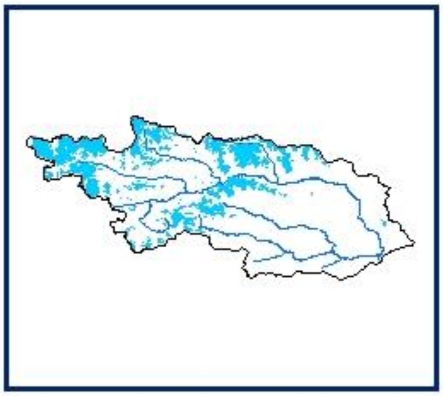
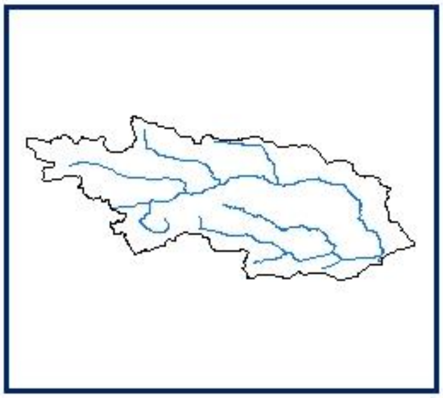
DATA NOT AVAILABLE
DATA NOT AVAILABLE
DATA NOT AVAILABLE
DATA NOT AVAILABLE
SNOW
90 45 0 90 180 270
Kilometers

10 DAILY SNOW COVER MAP : SUBANSIRI SUB-BASIN



DATA USED

01 JANUARY 2016



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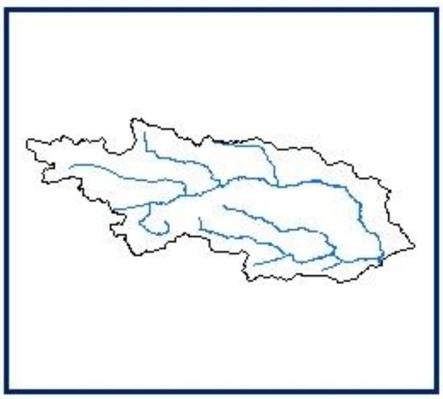

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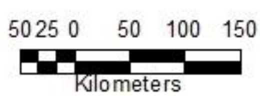
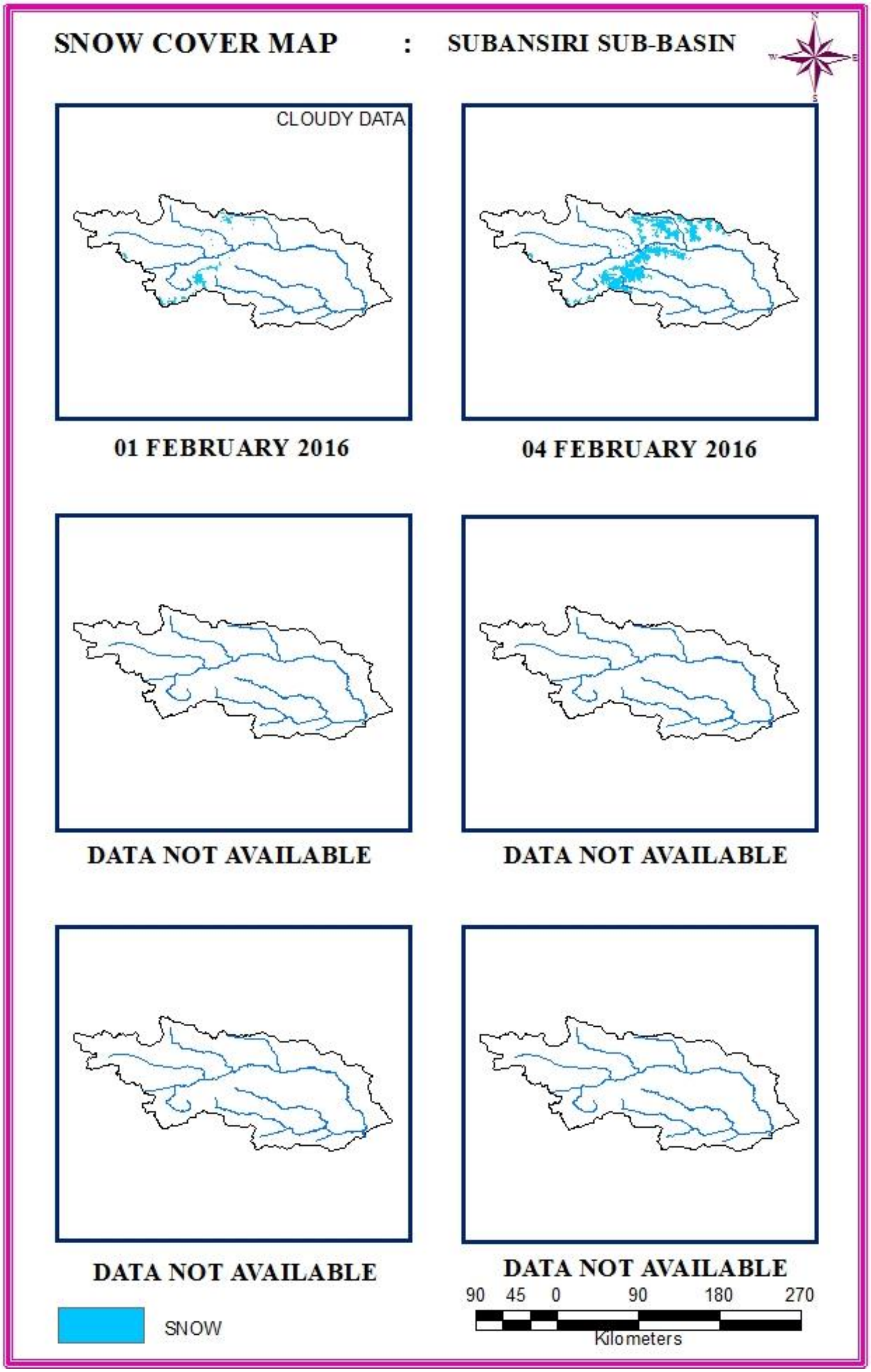
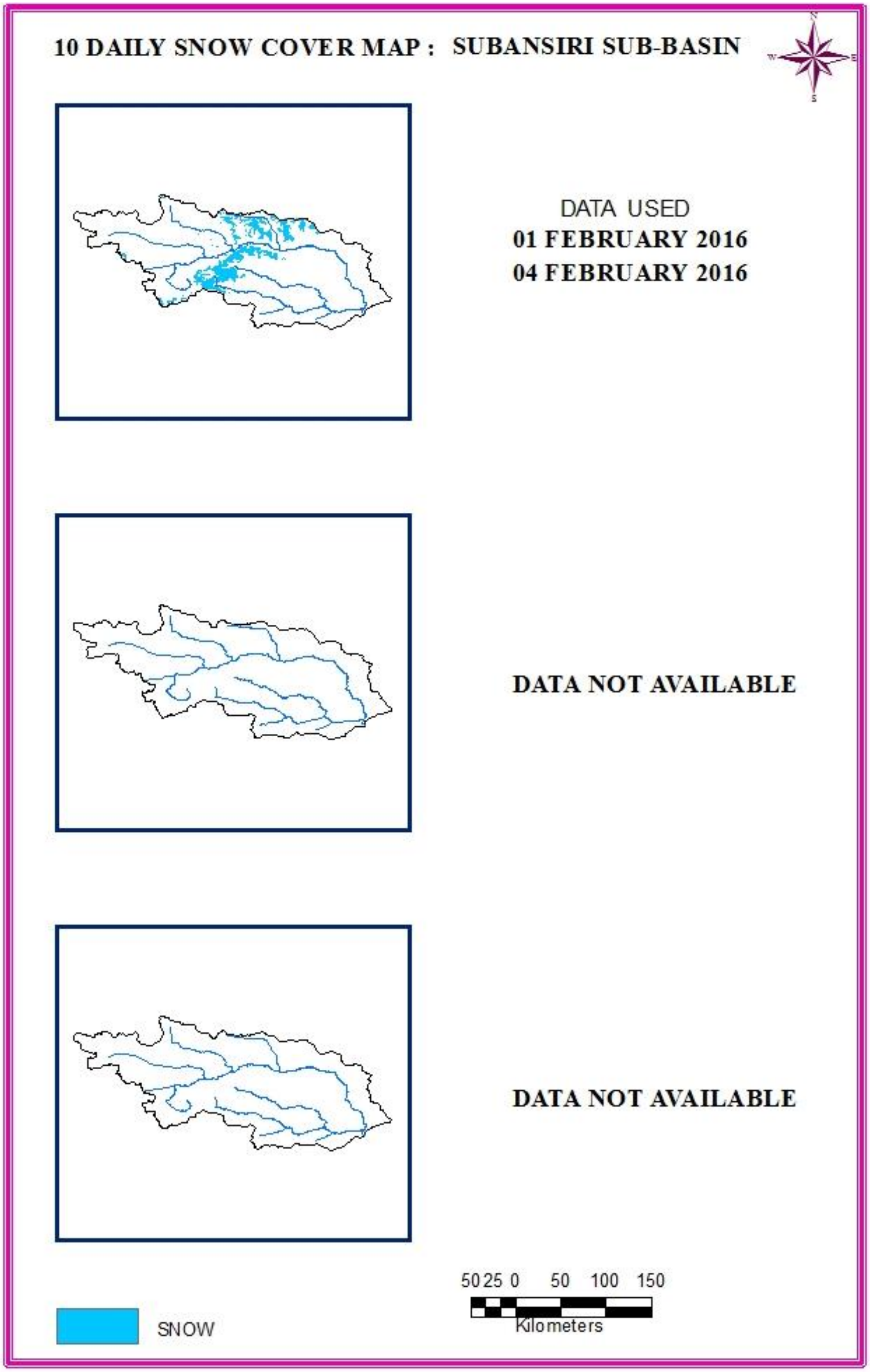
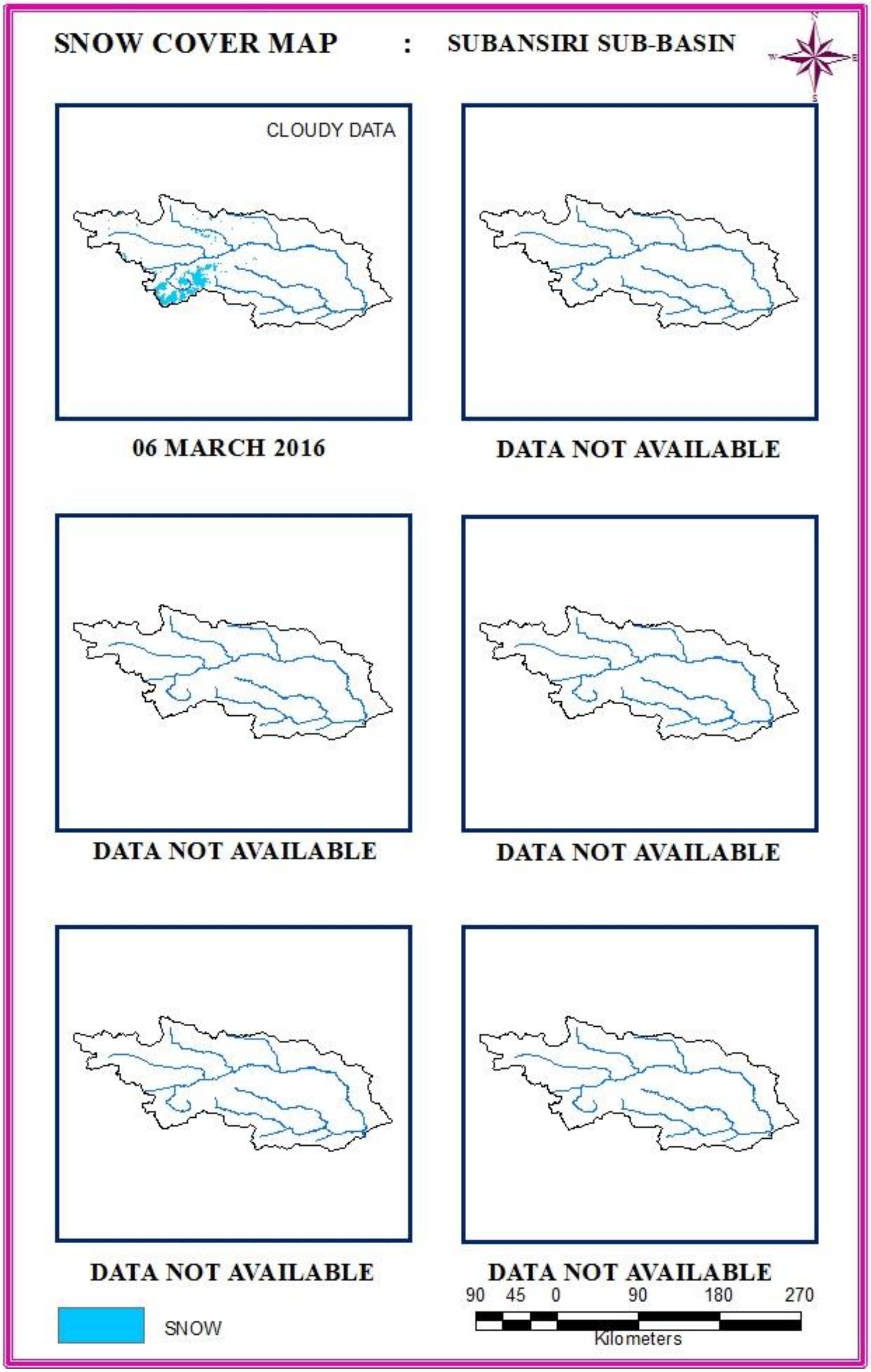
SNOW




SNOW COVER MAP : SUBANSIRI SUB-BASIN
CLOUDY DATA
01 FEBRUARY 2016
04 FEBRUARY 2016
DATA NOT AVAILABLE
DATA NOT AVAILABLE
DATA NOT AVAILABLE
DATA NOT AVAILABLE
SNOW
90 45 0 90 180 270
Kilometers


10 DAILY SNOW COVER MAP : SUBANSIRI SUB-BASIN
DATA USED
01 FEBRUARY 2016
04 FEBRUARY 2016
DATA NOT AVAILABLE
DATA NOT AVAILABLE
50 25 0 50 100 150
Kilometers
SNOW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CLOUDY DATA
06 MARCH 2016
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DATA NOT AVAILABLE
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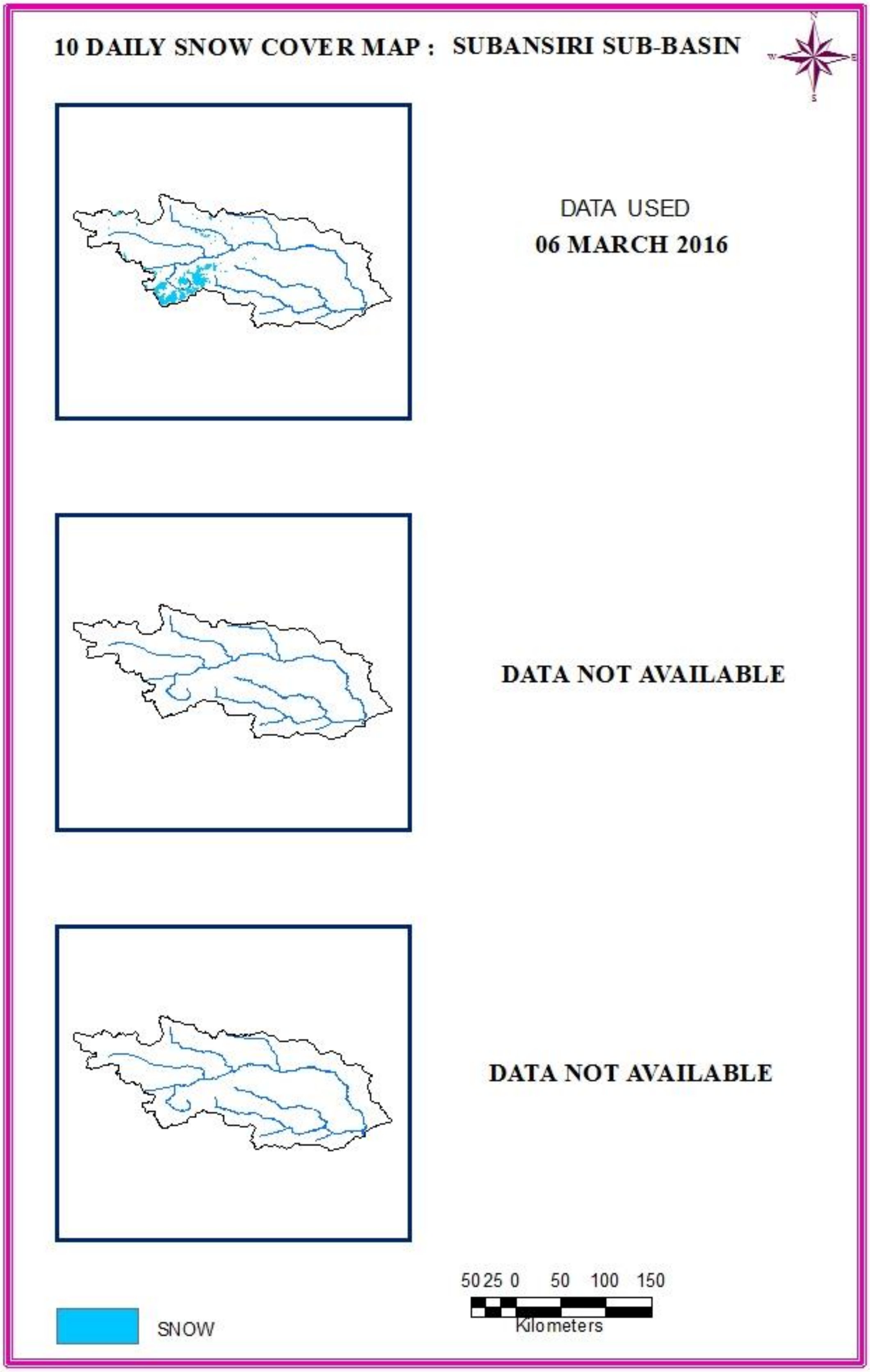
SNOW
90 45 0 90 180 270
Kilometers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DATA USED
06 MARCH 2016
DATA NOT AVAILABLE
DATA NOT AVAILABLE
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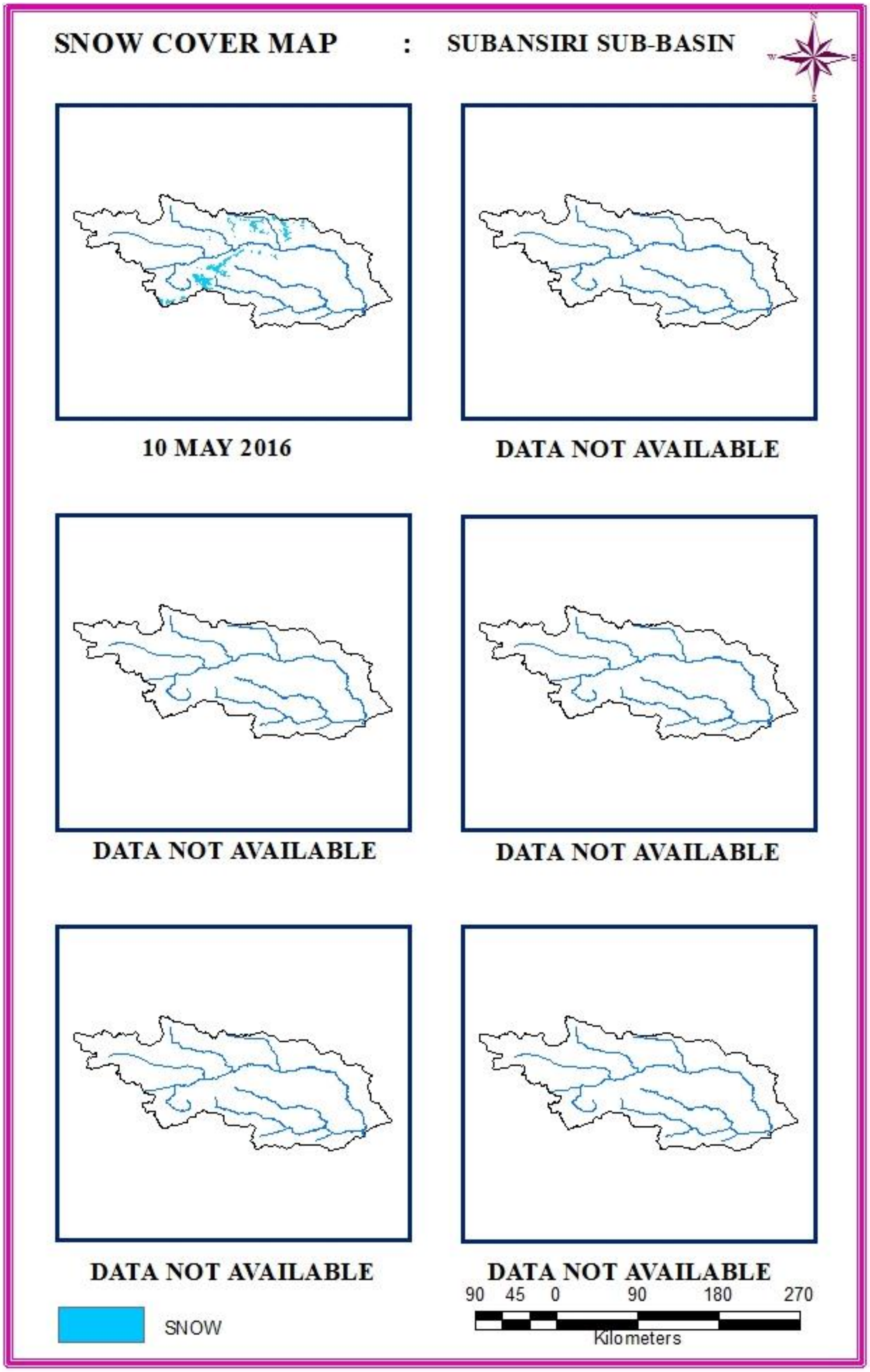
Kilometers
SNOW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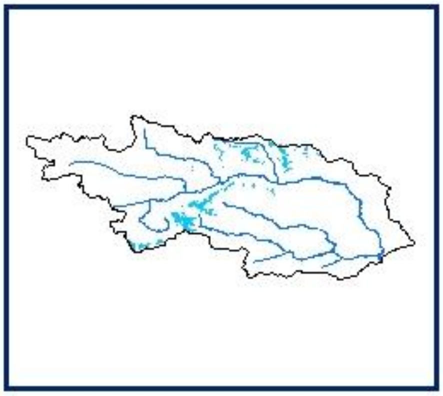
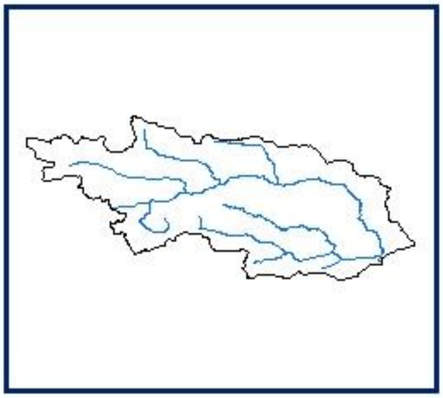
10 MAY 2016
DATA NOT AVAILABLE
DATA NOT AVAILABLE
DATA NOT AVAILABLE
DATA NOT AVAILABLE
DATA NOT AVAILABLE
SNOW
90 45 0 90 180 270
Kilometers

10 DAILY SNOW COVER MAP : SUBANSIRI SUB-BASIN



DATA USED

10 MAY 2016



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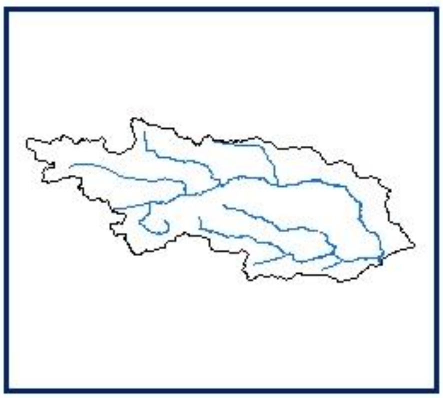

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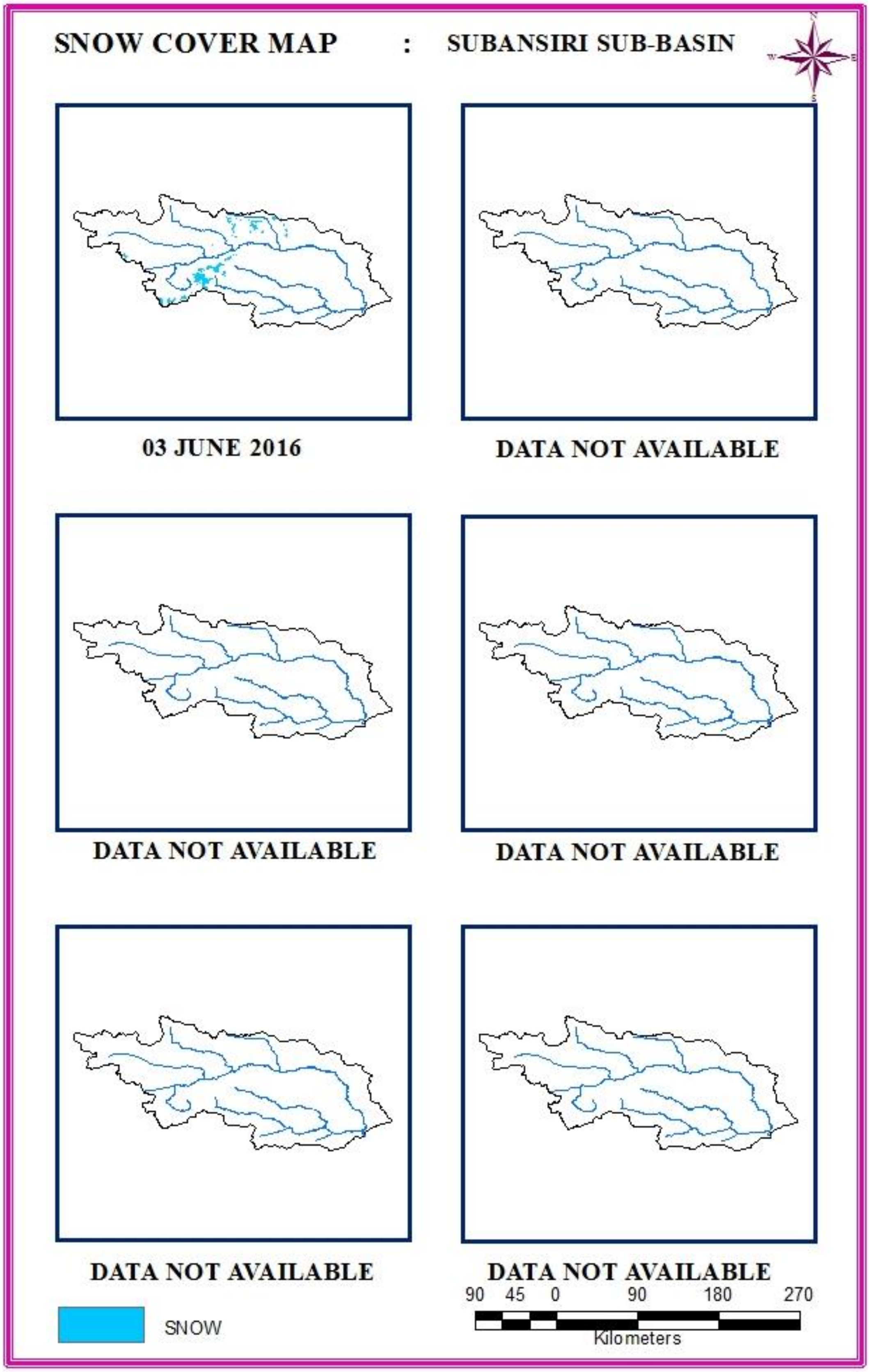
50 25 0 50 100 150

Kilometers

SNOW


SNOW COVER MAP : SUBANSIRI SUB-BASIN
03 JUNE 2016
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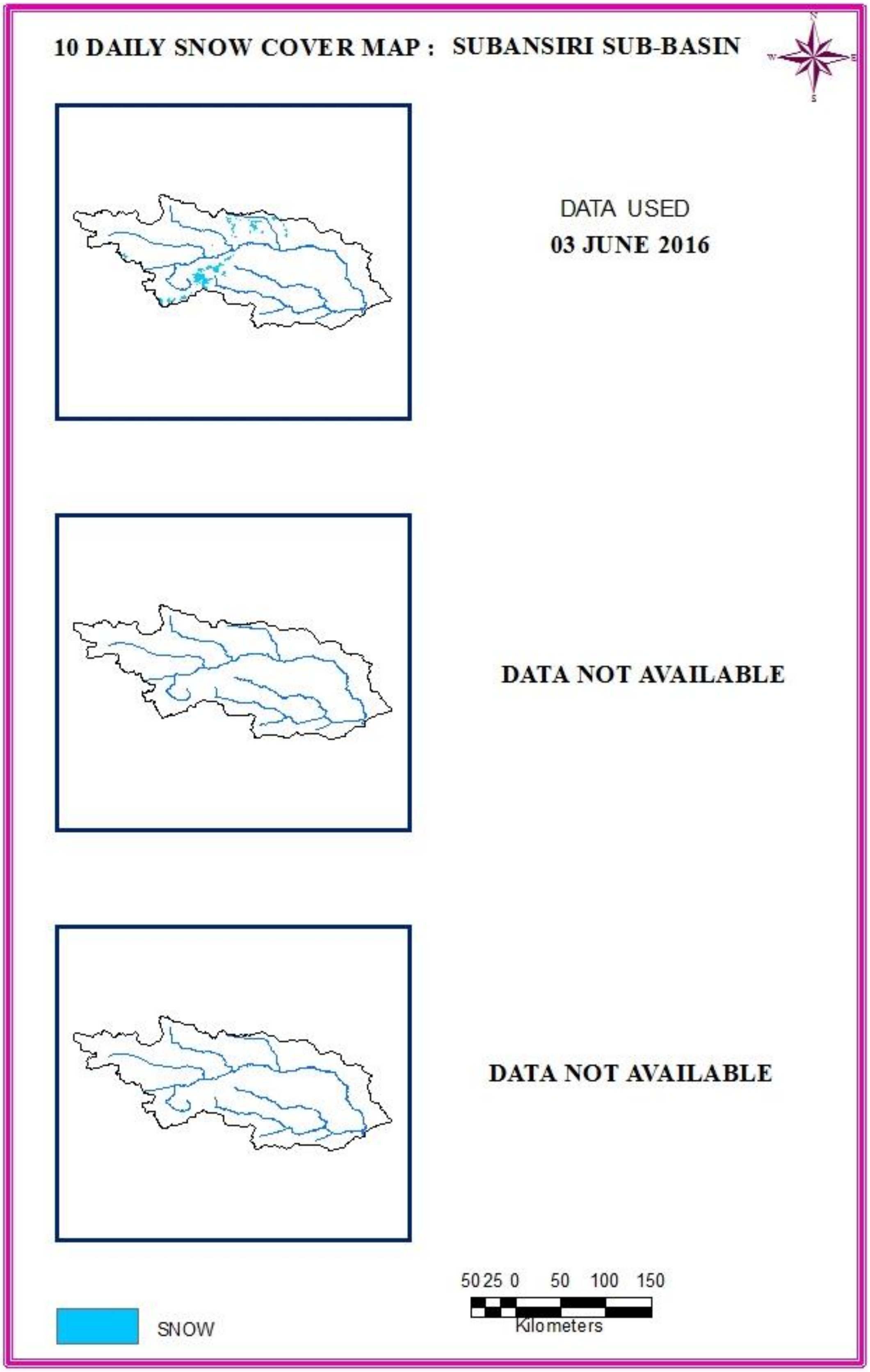
DATA NOT AVAILABLE
DATA NOT AVAILABLE
DATA NOT AVAILABLE
DATA NOT AVAILABLE
SNOW
90 45 0 90 180 270
Kilometers


10 DAILY SNOW COVER MAP : SUBANSIRI SUB-BASIN
DATA USED
03 JUNE 2016
DATA NOT AVAILABLE
DATA NOT AVAILABLE
50 25 0 50 100 150
Kilometers
SNOW

TAWANG SUB-BASIN

AREAL EXTENT OF SNOW (5 DAILY)

BASIN NAME: TAWANG **BASIN AREA: 6656 sq km**

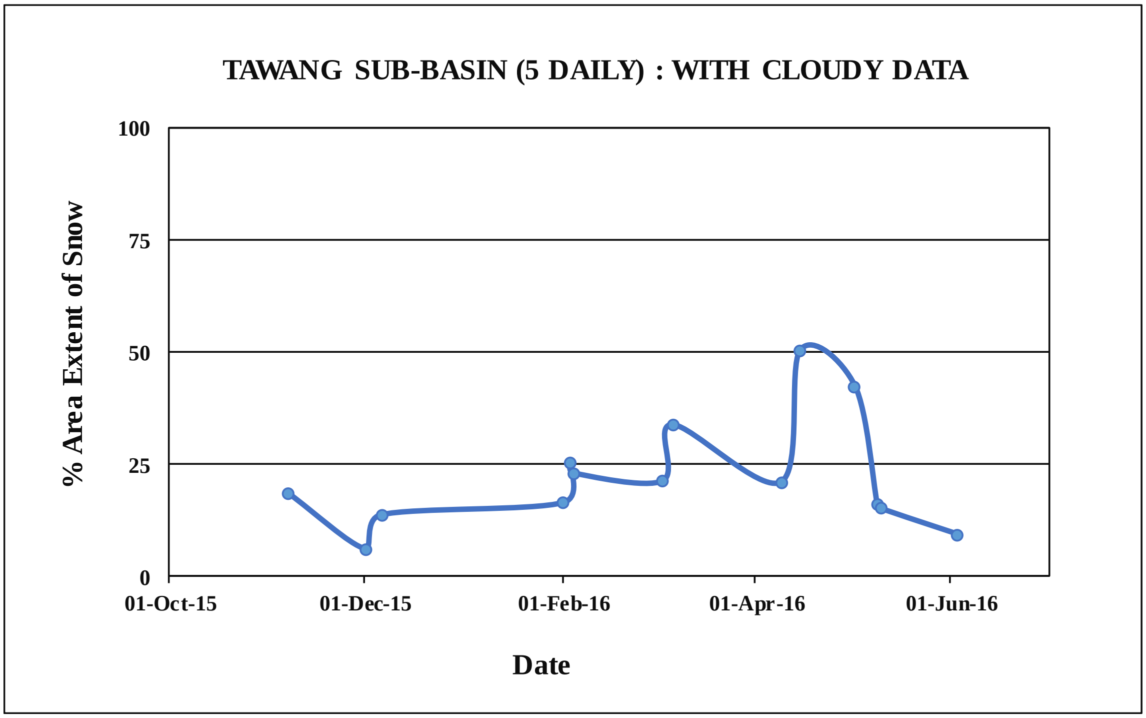
S No	Date	Snow cover (sq km)	Snow cover (%)	S No	Date	Snow cover (sq km)	Snow cover (%)
November 2015							
1	07-Nov-2015	1239 (C)	19				
December 2015							
2	01-Dec-2015	419	6	**3**	06-Dec-2015	918 (C)	14
February 2016							
4	01-Feb-2016	1100 (C)	17	**5**	03-Feb-2016	1687 (C)	25
6	04-Feb-2016	1566	24				
March 2016							
7	03-Mar-2016	1420 (C)	21	**8**	06-Mar-2016	2251 (C)	34
April 2016							
9	09-April-2016	1405 (C)	21	**10**	15-April-2016	3353	50
May 2016							
11	02-May-2016	2831	43	**12**	09-May-2016	1089	16
13	10-May-2016	1017	15				
June 2016							
14	03-June-2016	636	10				

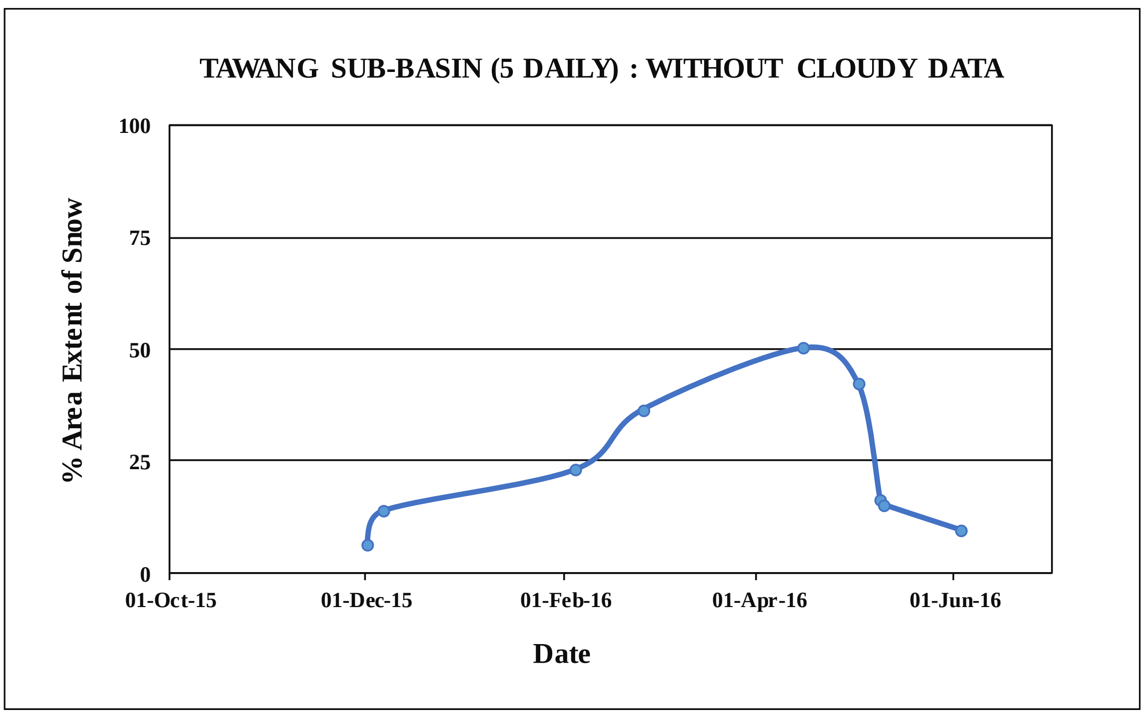
AREAL EXTENT OF SNOW (10 DAILY)

BASIN NAME: TAWANG **BASIN AREA: 6656 sq km**

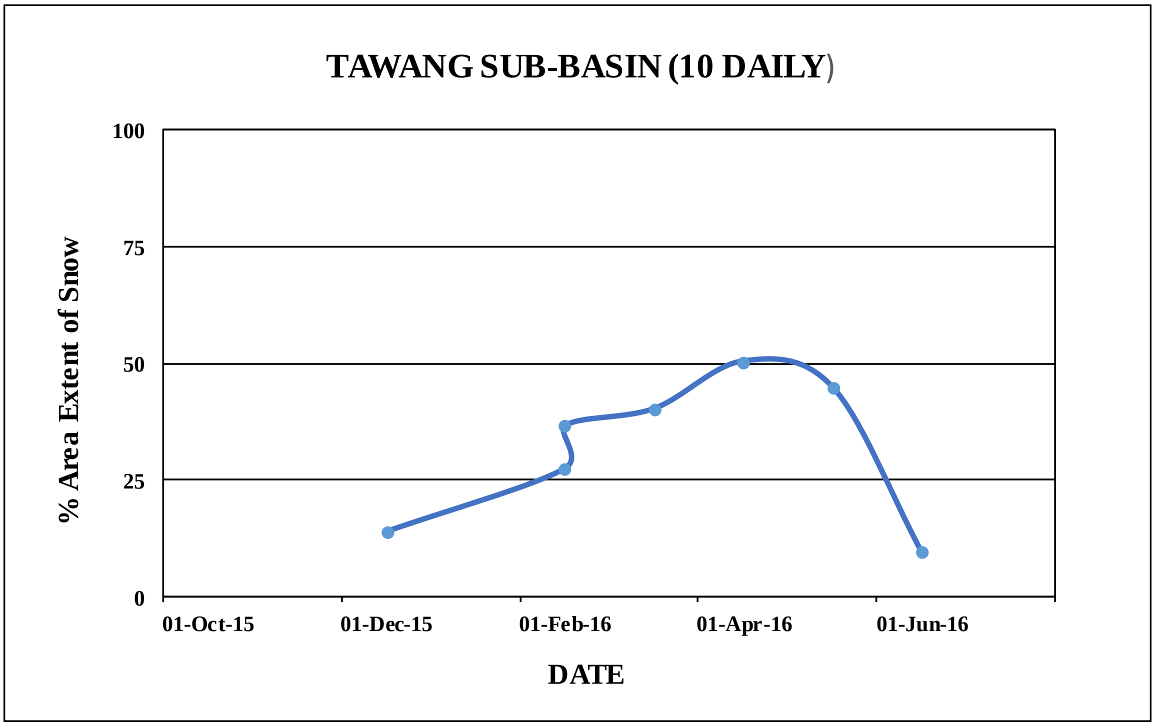
S. No	Date	Snow cover (sq km)	Snow cover (%)	S No	Date	Snow cover (sq km)	Snow cover (%)
December 2015							
1	05-Dec-2015	925	14				
February 2016							
2	05-Feb-2016	1824	27	**3**	25-Feb-2016	2463	37
March 2016							
4	05-Mar-2016	2675	40				
May 2016							
5	05-May-16	2984	45				
June 2016							
6	5-June-2016	666	10				

SNOW COVER DEPLETION CURVE

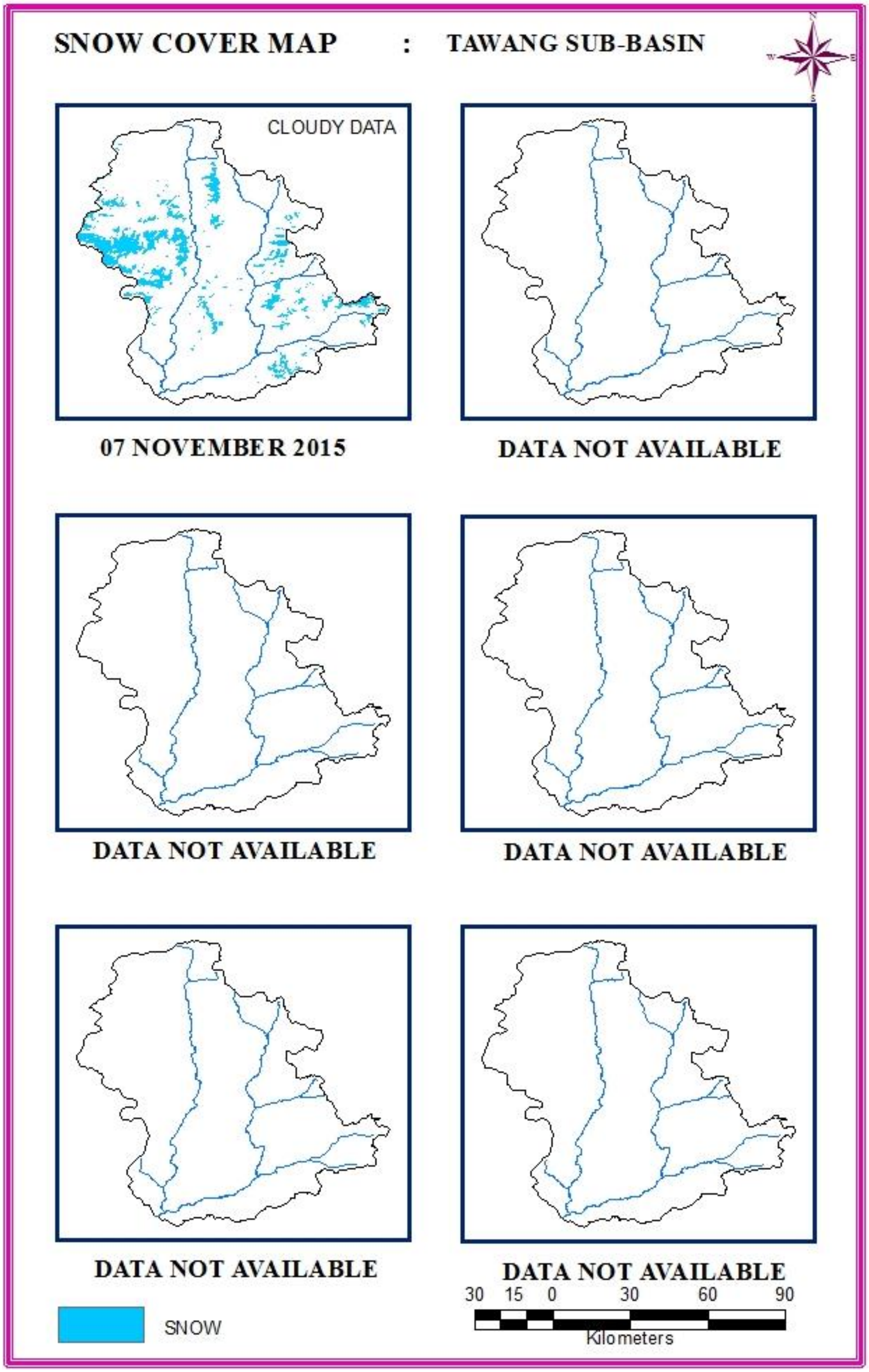


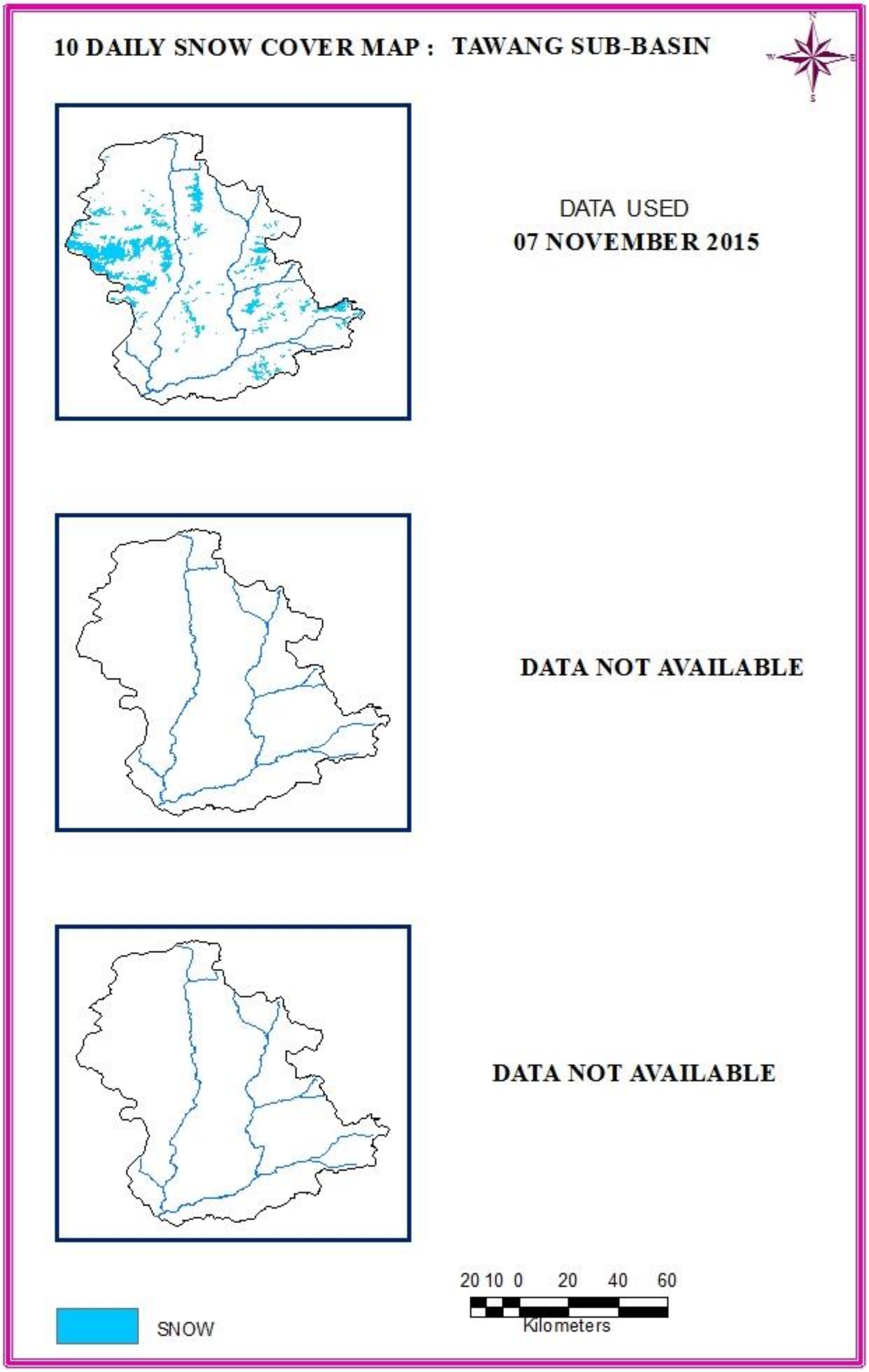


SNOW COVER DEPLETION CURVE



SNOW COVER MAP


SNOW COVER MAP : TAWANG SUB-BASIN
CLOUDY DATA
07 NOVEMBER 2015
DATA NOT AVAILABLE
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 : TAWANG SUB-BASIN
DATA USED
07 NOVEMBER 2015
DATA NOT AVAILABLE
DATA NOT AVAILABLE
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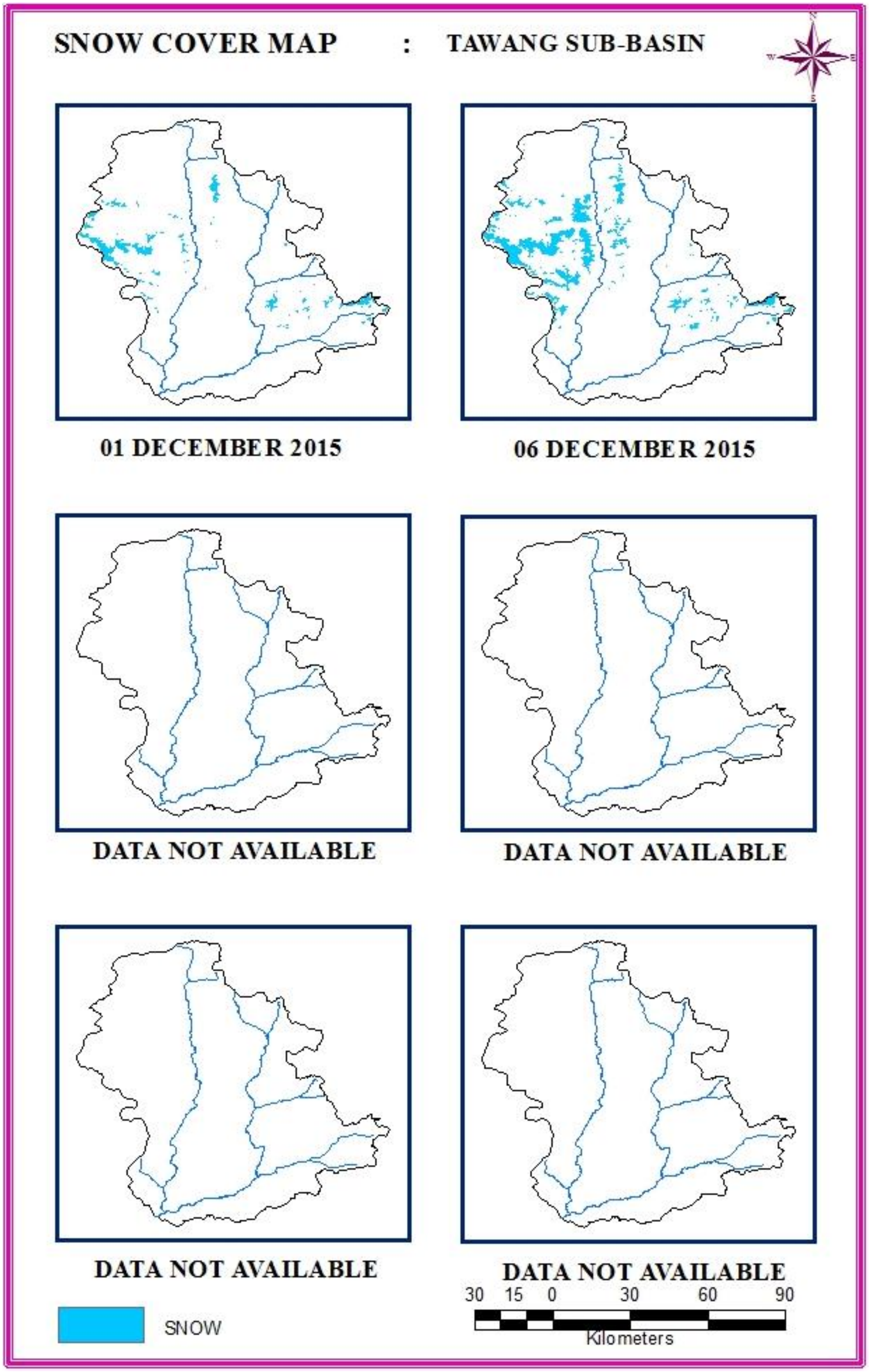
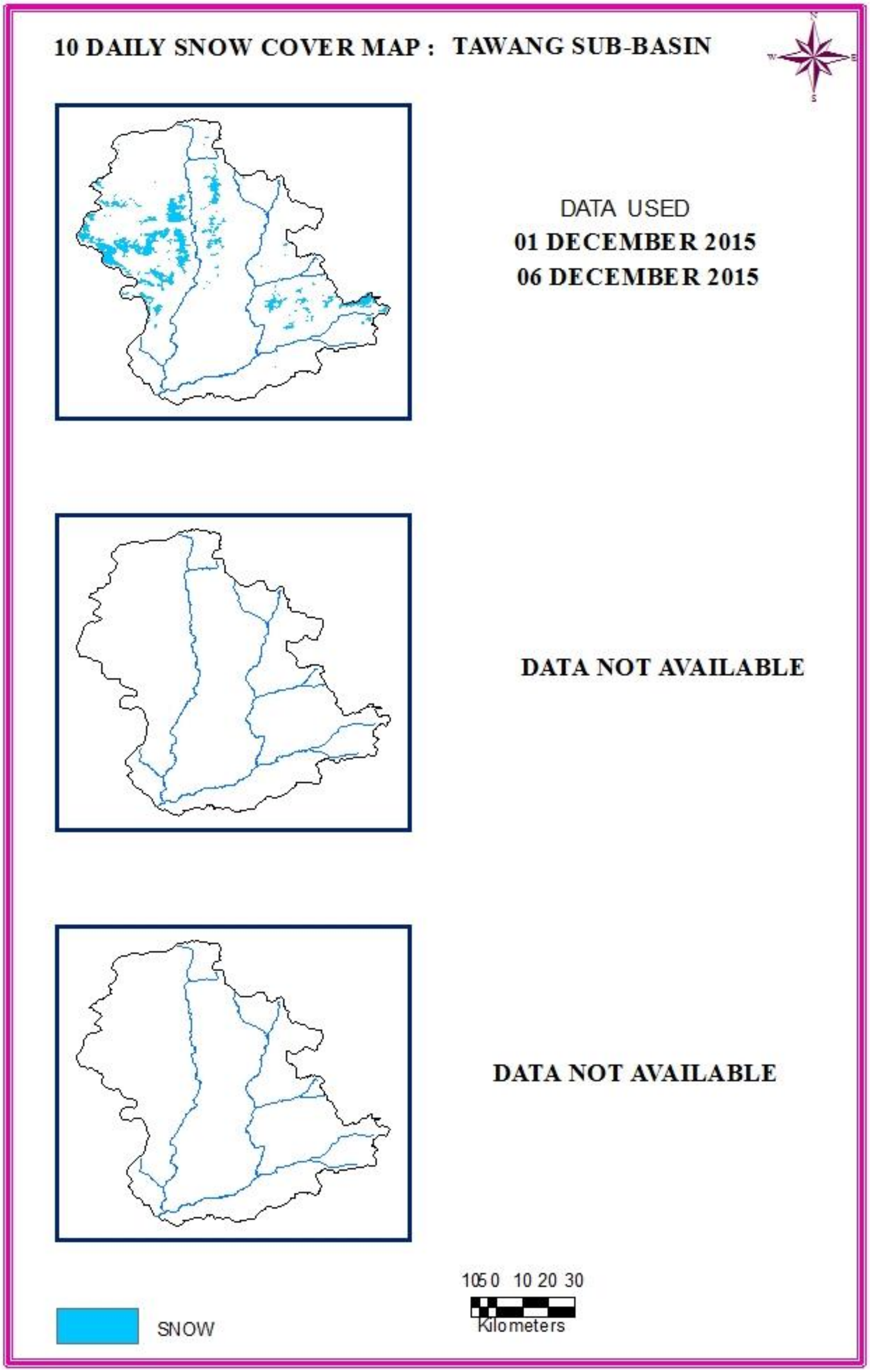
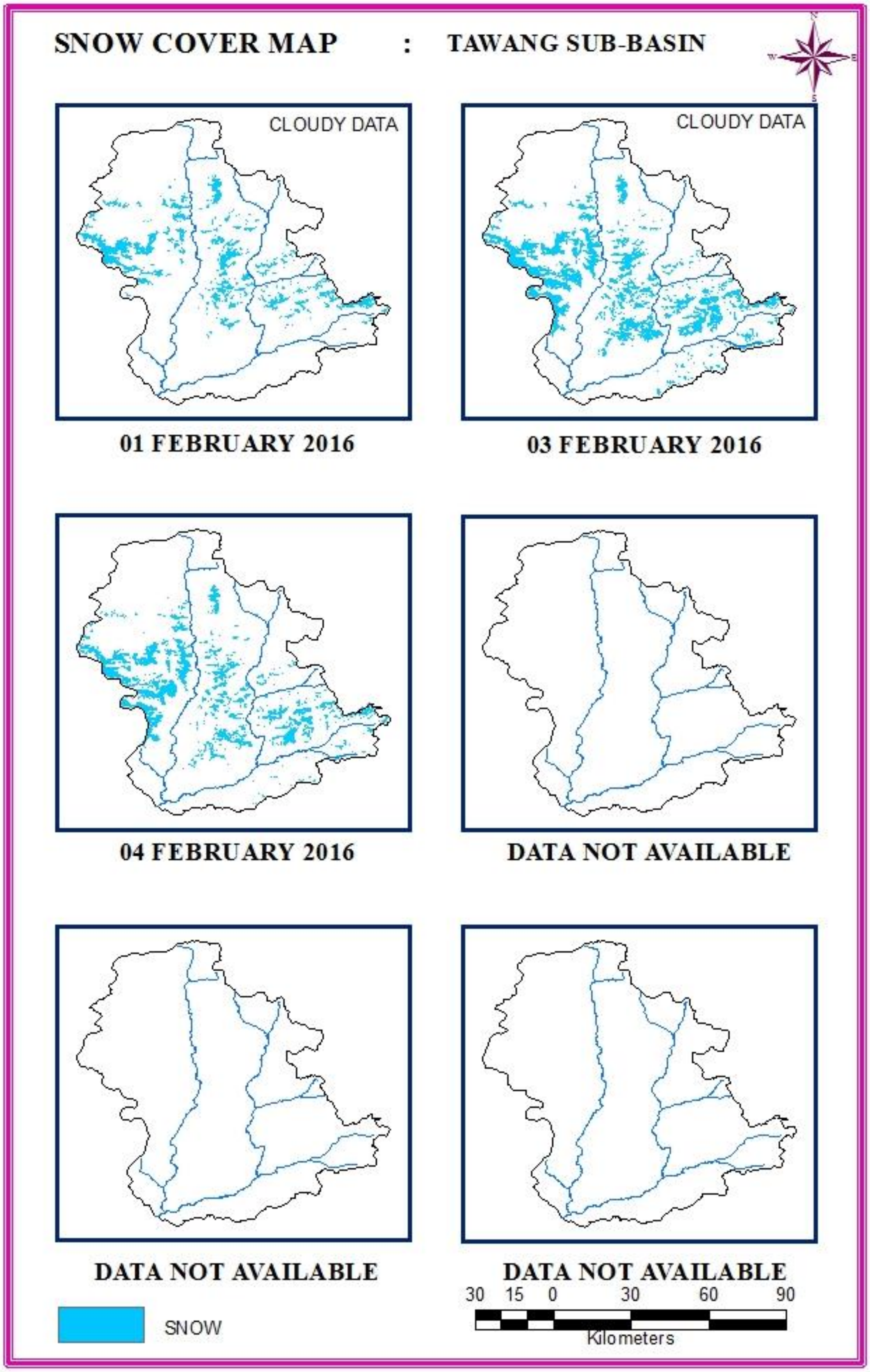
Kilometers
SNOW


SNOW COVER MAP : TAWANG SUB-BASIN
01 DECEMBER 2015
06 DECEMBER 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 : TAWANG SUB-BASIN
DATA USED
01 DECEMBER 2015
06 DECEMBER 2015
DATA NOT AVAILABLE
DATA NOT AVAILABLE
10 5 0 10 20 30
Kilometers
SNOW


SNOW COVER MAP : TAWANG SUB-BASIN
CLOUDY DATA
CLOUDY DATA
01 FEBRUARY 2016
03 FEBRUARY 2016
04 FEBRUARY 2016
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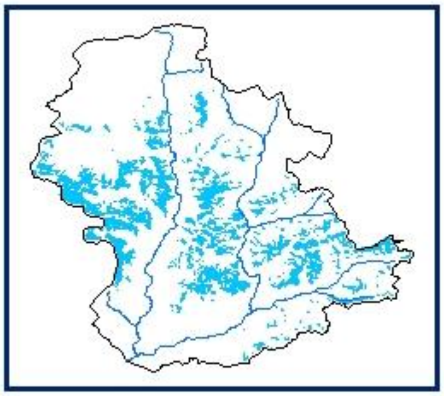
DATA NOT AVAILABLE
DATA NOT AVAILABLE
SNOW
30 15 0 30 60 90
Kilometers

10 DAILY SNOW COVER MAP : TAWANG SUB-BASIN



DATA USED

01 FEBRUARY 2016

03 FEBRUARY 2016

04 FEBRUARY 2016

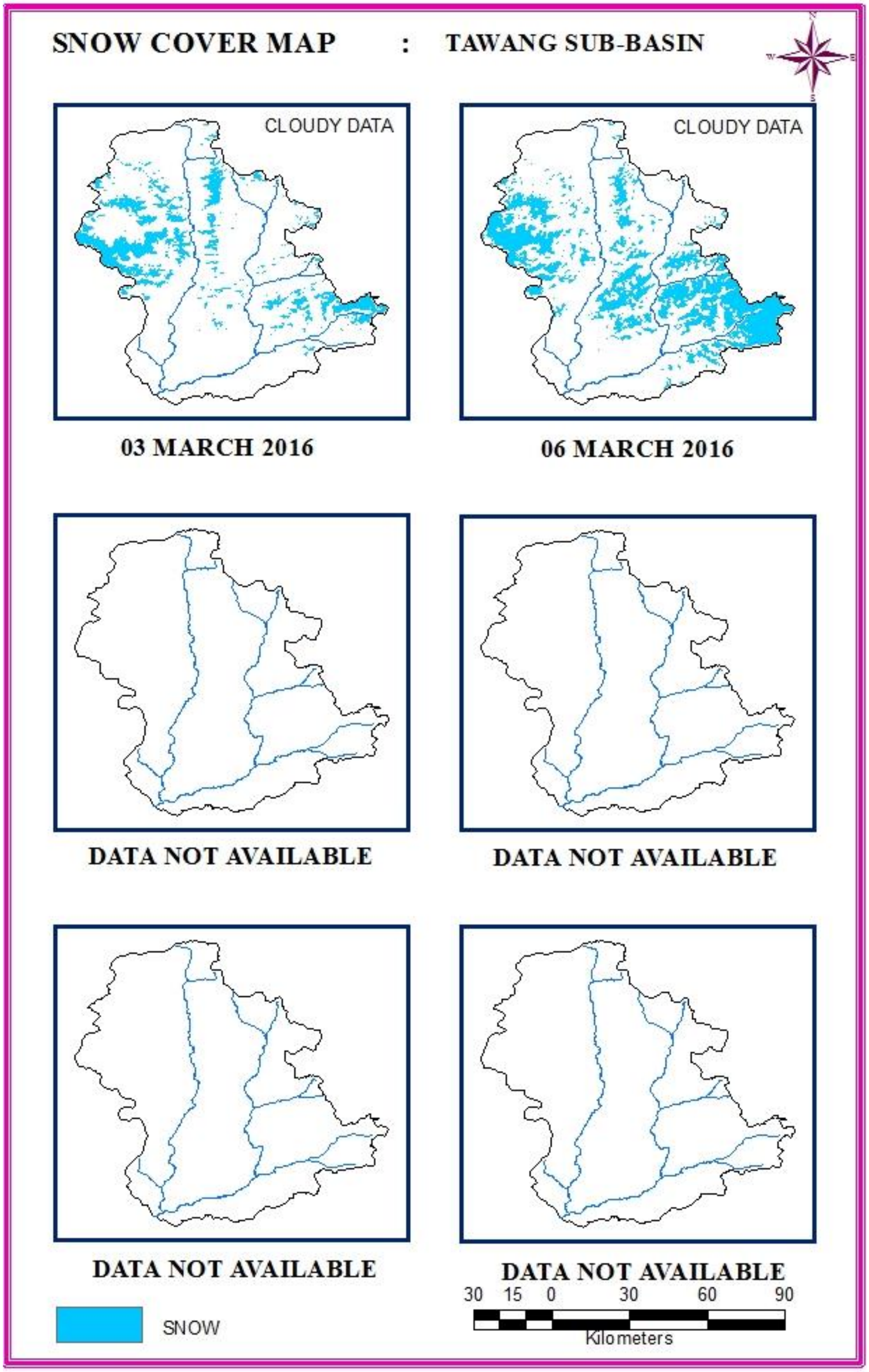
DATA NOT AVAILABLE

DATA NOT AVAILABLE

10 5 0 10 20 30

Kilometers

SNOW


SNOW COVER MAP : TAWANG SUB-BASIN
CLOUDY DATA
03 MARCH 2016
CLOUDY DATA
06 MARCH 2016
DATA NOT AVAILABLE
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DATA NOT AVAILABLE
SNOW
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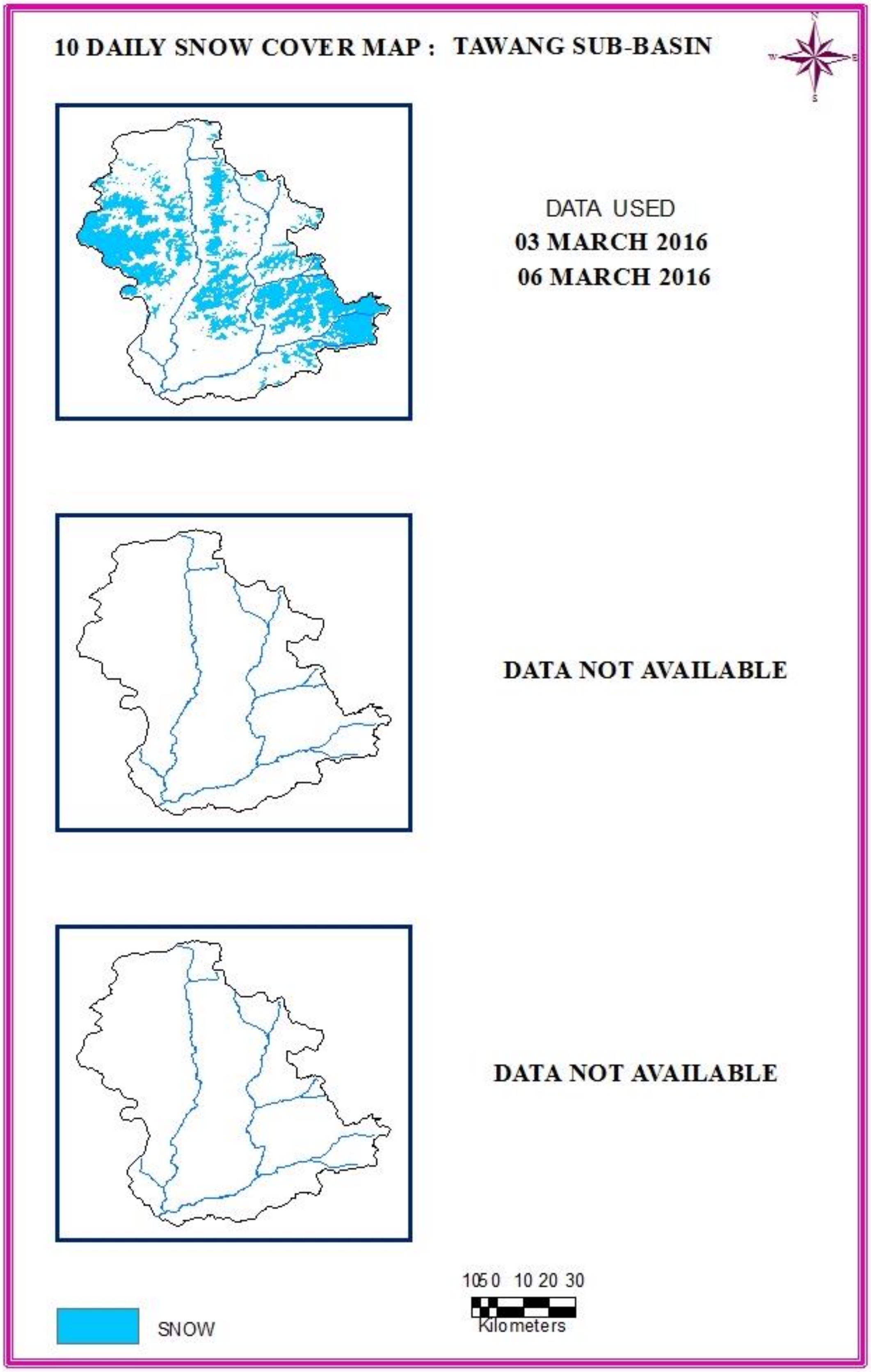
Kilometers


10 DAILY SNOW COVER MAP : TAWANG SUB-BASIN
DATA USED
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06 MARCH 2016
DATA NOT AVAILABLE
DATA NOT AVAILABLE
SNOW
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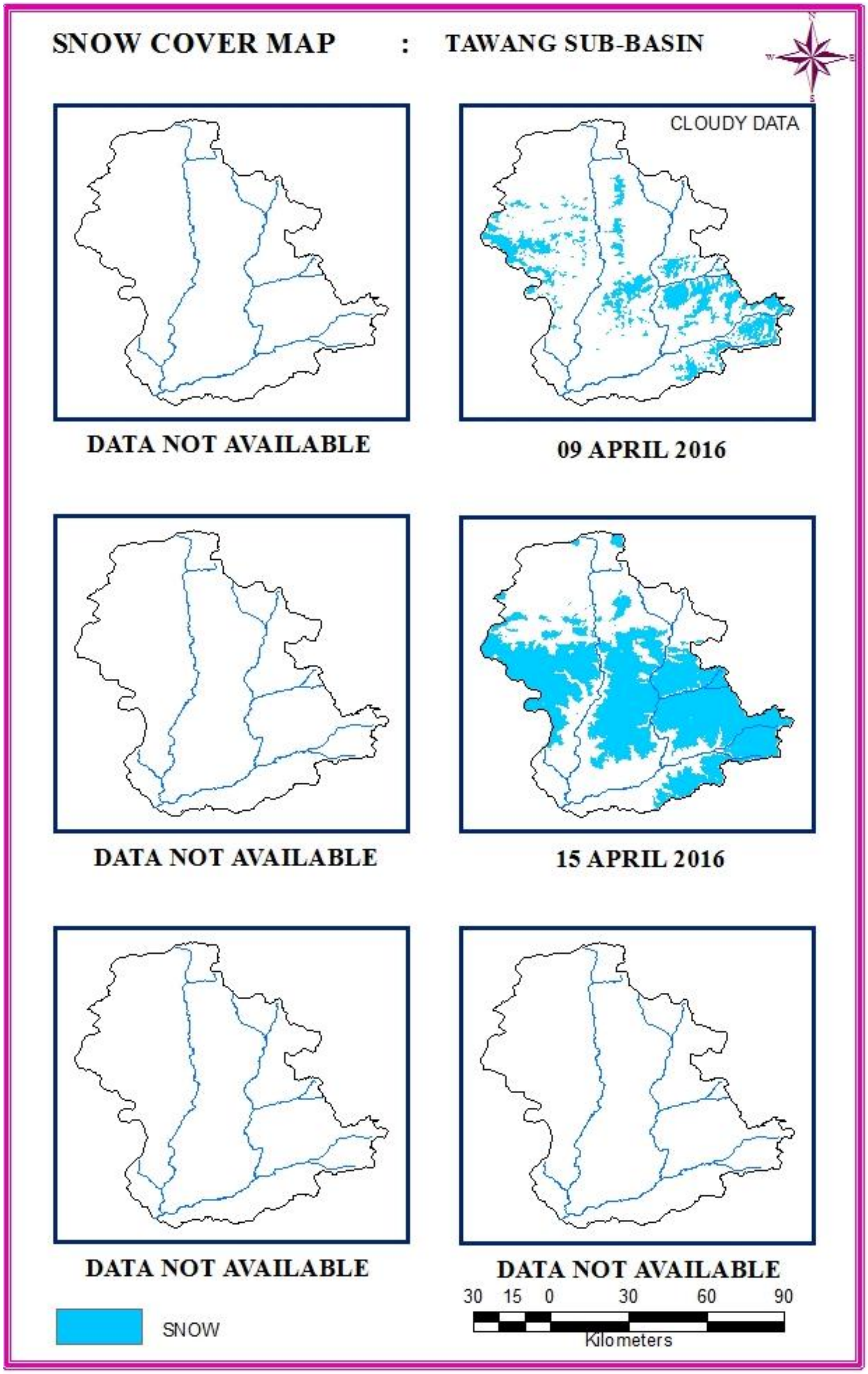
Kilometers



SNOW COVER MAP : TAWANG SUB-BASIN
CLOUDY DATA
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09 APRIL 2016
DATA NOT AVAILABLE
15 APRIL 2016
DATA NOT AVAILABLE
DATA NOT AVAILABLE
SNOW
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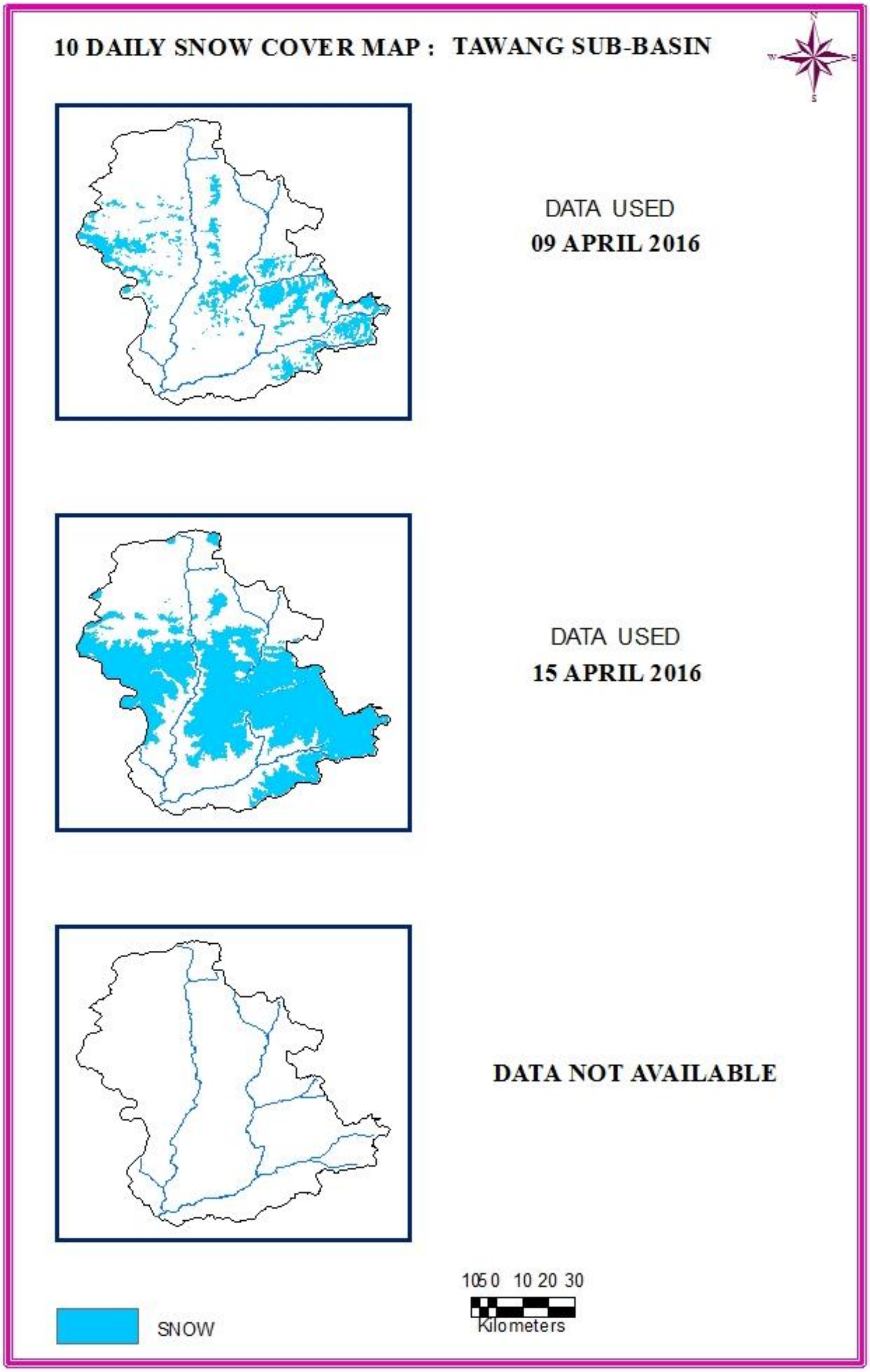
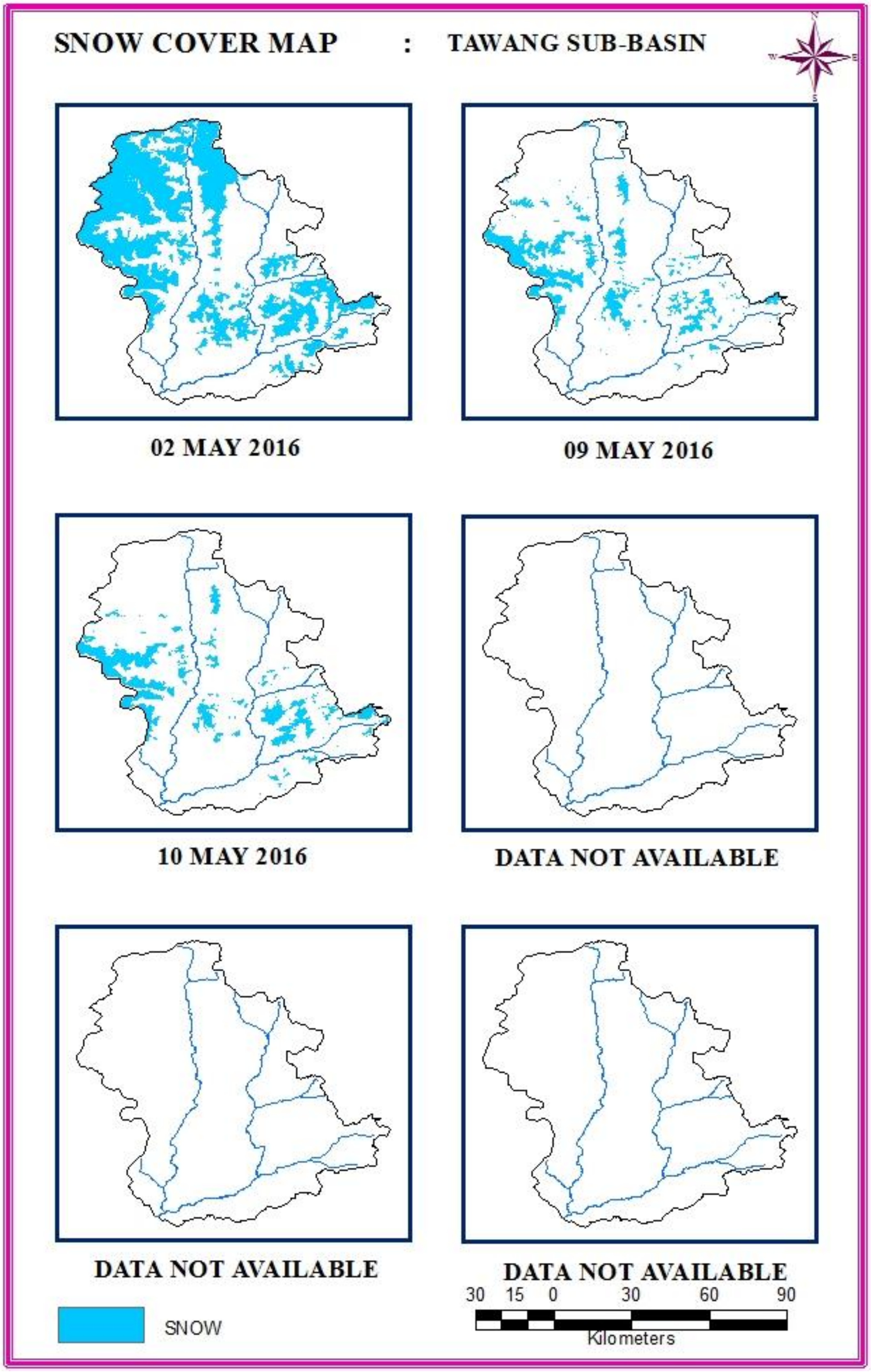
Kilometers


10 DAILY SNOW COVER MAP : TAWANG SUB-BASIN
DATA USED
09 APRIL 2016
DATA USED
15 APRIL 2016
DATA NOT AVAILABLE
10 5 0 10 20 30
Kilometers
SNOW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02 MAY 2016
09 MAY 2016
10 MAY 2016
DATA NOT AVAILABLE
DATA NOT AVAILABLE
DATA NOT AVAILABLE
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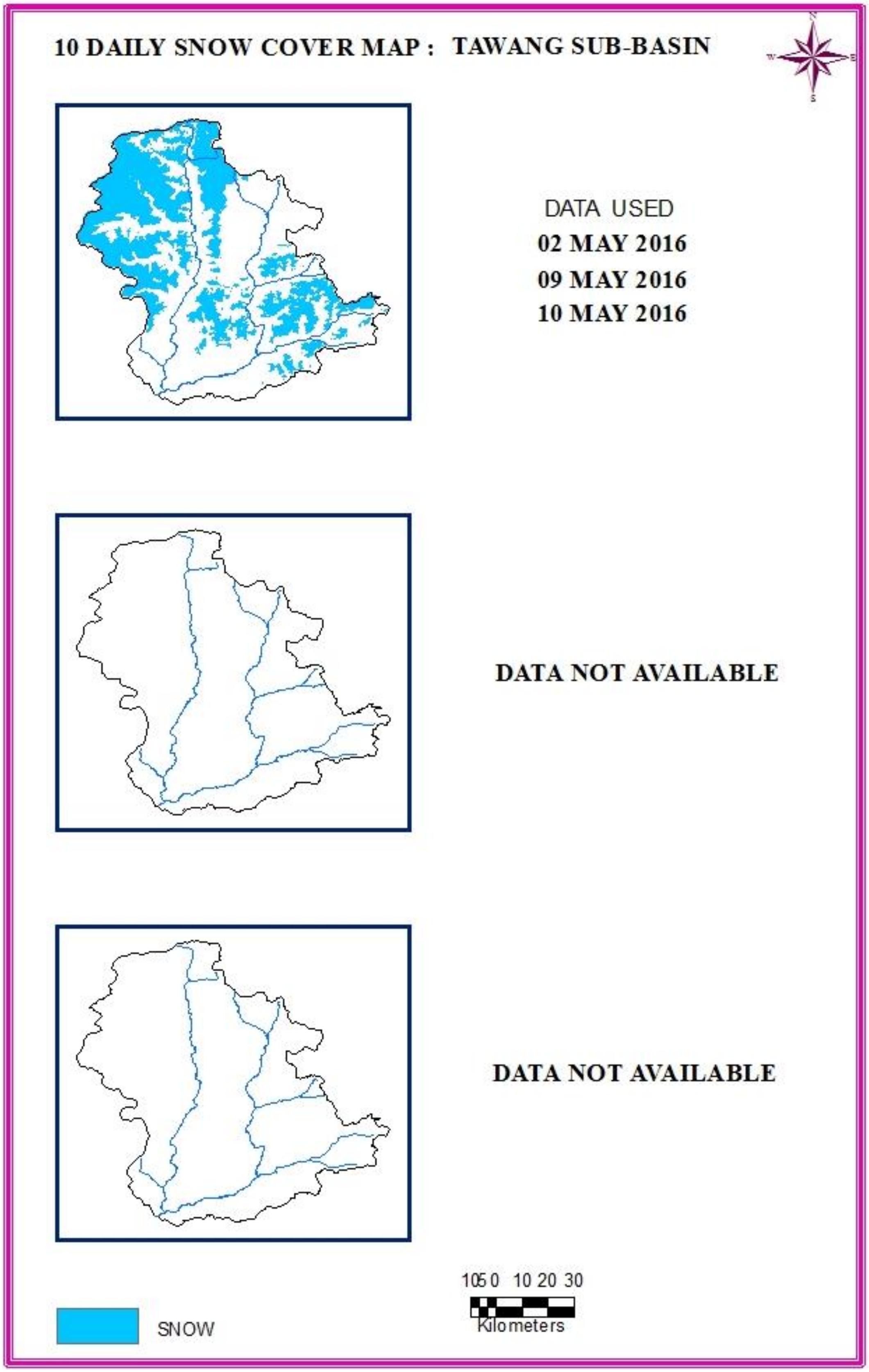
Kilometers
SNOW


10 DAILY SNOW COVER MAP : TAWANG SUB-BASIN
DATA USED
02 MAY 2016
09 MAY 2016
10 MAY 2016
DATA NOT AVAILABLE
DATA NOT AVAILABLE
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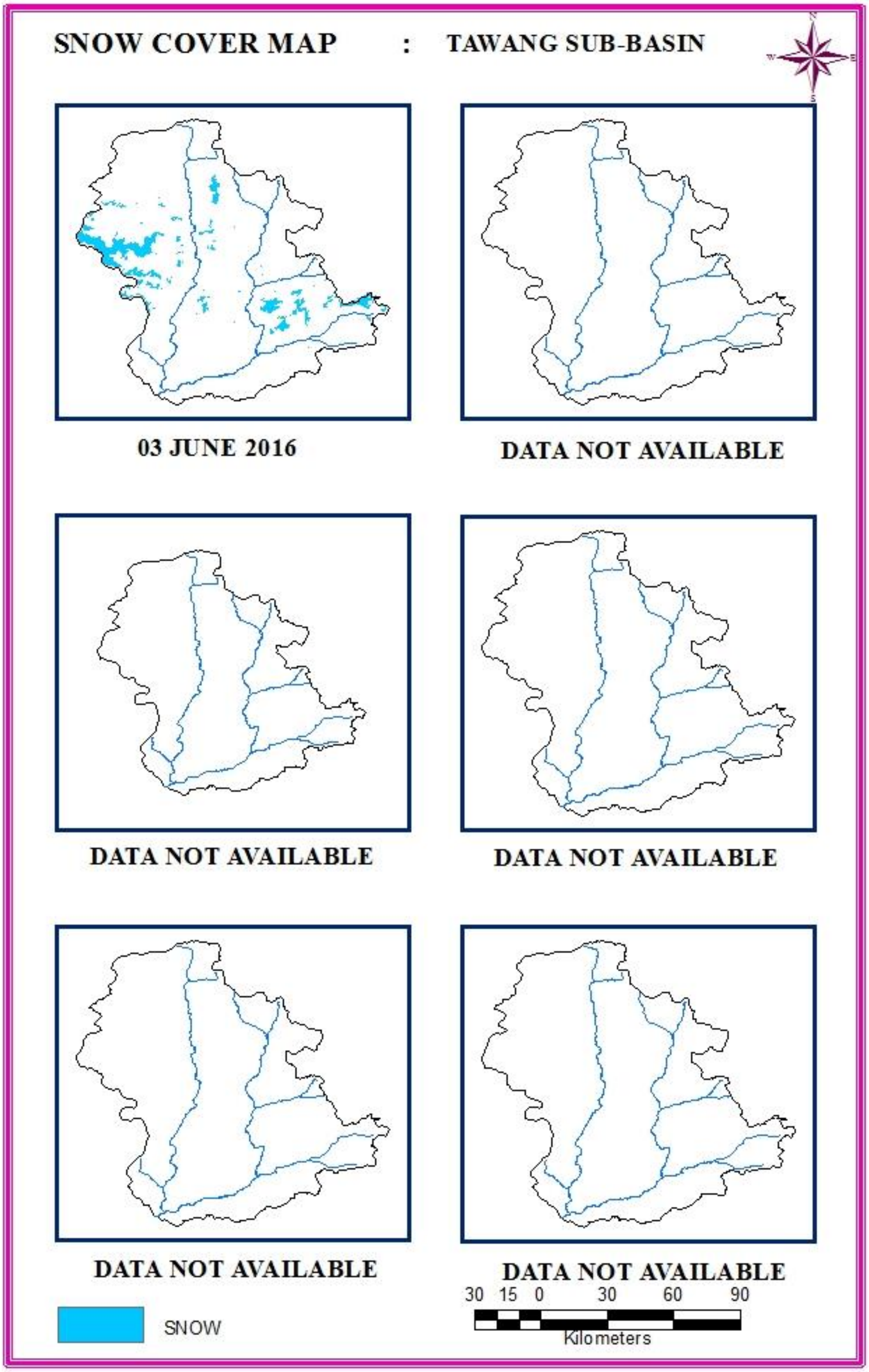
Kilometers
SNOW


SNOW COVER MAP : TAWANG SUB-BASIN
03 JUNE 2016
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DATA NOT AVAILABLE
SNOW
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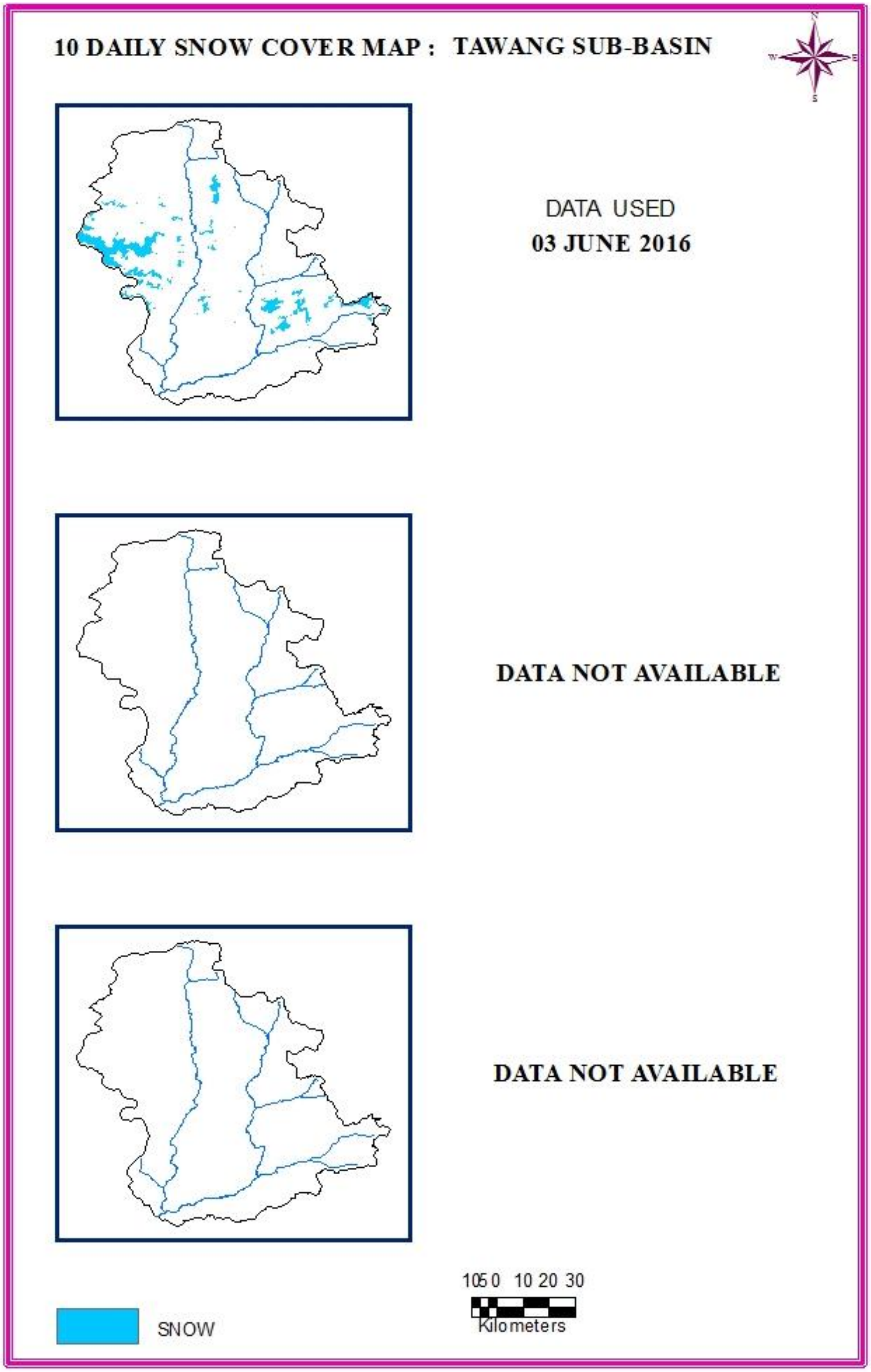
Kilometers


10 DAILY SNOW COVER MAP : TAWANG SUB-BASIN
DATA USED
03 JUNE 2016
DATA NOT AVAILABLE
DATA NOT AVAILABLE
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Kilometers
SNOW