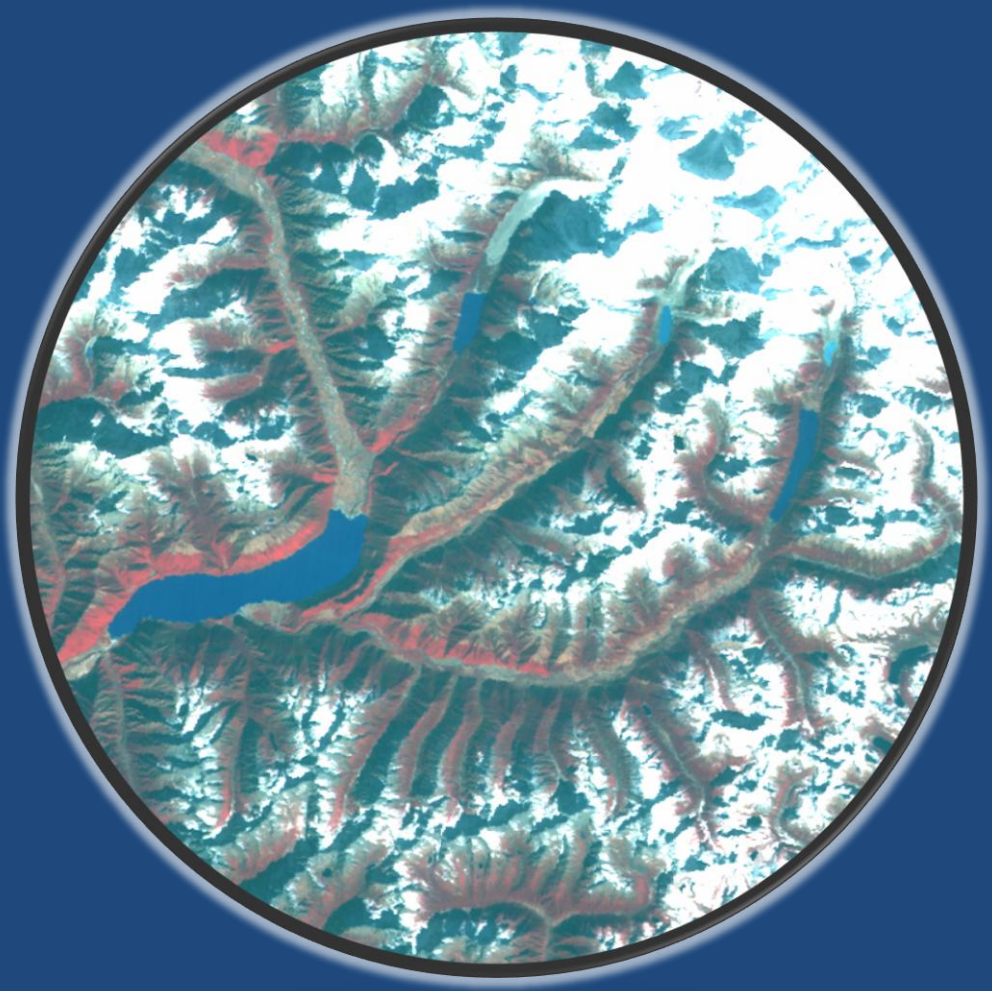
Monitoring of Glacial Lakes/Water Bodies in the Himalayan Region of Indian River Basins during 2011



Submitted by

Water Resources Division, RSAA
National Remote Sensing Centre
Indian Space Research Organisation

Submitted to

Climate Change and IAD Directorate
Central Water Commission
Ministry of Water Resources

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April 2012

Document Control Sheet

1	Security Classification	Restricted		
2	Distribution	This document is for use by Central Water Commission, Ministry of Water Resources, Govt. of India.		
3	Report / Document version	(a) Issue no. 1	(b) Revision & Date	0
4	Report / Document Type	Technical report		
5	Document Control Number	NRSC-RSAA-WRG-Apr12-TR395		
6	Title	Report on **" Monitoring of Glacial Lakes/Water Bodies in the Himalayan Region of Indian River Basins during 2011"**		
7	Particulars of collation	Pages 4+51	Figures 2	Tables 3 / References 6
8	Author(s)	K. Abdul Hakeem and E. Siva Sankar		
9	Affiliation of authors	Water Resources Group, RSAA		
10	Project Team	K. Abdul Hakeem and E. Siva Sankar		
11	Scrutiny mechanism	Compiled by K. Abdul Hakeem	Reviewed by Group Head, WRG	Approved / Controlled by DD (RSAA)
12	Originating unit	Water Resources Division, Water Resources Group, RS & GIS Applications Area		
13	Sponsor(s) / Name and Address	Climate Change and IAD Directorate Central Water Commission, New Delhi Govt. of India		
14	Date of Initiation	01-Jun-11		
15	Date of Publication	16-Apr-12		
16	Abstract (with Keywords) : This document presents the details on monitoring of glacial lakes and water bodies in the Himalayan region of Indian river basins during the months of June, July, August, September and October 2011 using satellite remote sensing technique, including the data used and methodology followed in this study.			

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1. INTRODUCTION

1.1 Background

Glacial lakes are common in the high elevation of glacierised basin. They are formed when glacial ice or moraines impound water. There are varieties of such lakes, ranging from melt water ponds on the surface of glacier to large lakes in side valleys dammed by a glacier in the main valley. These lakes normally drain their water through seepage in front of the retreating glacier. The moraine creates topographic depression in which the melt water is generally accumulated leading to formation of glacial lake. When this lake is watertight, melt waters will accumulate in the basin until seepage or overflow limits the lake level. Such moraine-dammed lakes appear to be the most common type of glacial lakes. The impoundment of the lake may be unstable, leading to sudden release of large quantities of stored water. Failure of these ice or moraine dams as very destructive events has been documented throughout the world. Flash floods caused by the outburst of glacial lakes, called as Glacial Lake Outburst Flood (GLOF), are well known in Himalaya where such lakes had been formed by landslides. The unabated shrinkage of Himalayan glaciers has resulted in the formation of more moraine-dammed lakes. Bursting of such lakes leads to flash floods and these floods redistribute sediments and modify the landscape.

Planning & Development Directorate of Central Water Commission (CWC) desired to use satellite remote sensing techniques to map, inventory and monitor the glacial lakes & water bodies in Himalayan region of Indian river basins. In this connection, CWC approached National Remote Sensing Centre (NRSC) to carry out the study using the latest satellite remote sensing data and requested to submit the project proposal. Accordingly, a proposal was generated (NRSC/RS&GIS-AA/WROG/WRD/Project Proposal-PP01/2009) and submitted to CWC. CWC accepted the proposal and conveyed the same vide order No. 2/17/P&D/2008/173-86 dated 26.02.2009. CWC and NRSC entered into a Memorandum of Understanding (MOU) on 15-Dec-2009. Subsequently, CWC issued an office order No. 2/17/P&D/2008/354-365 dated 29.06.2010 authorizing NRSC to incur expenditure for this project.

1.2 Objectives

The objectives of the study are

1. To carry out inventory of glacial lakes/water bodies in the Himalayan region of Indian River basins using satellite data of the recent past years. Glacial lakes with spatial extent greater than 50 ha (during the inventorying year) will be considered and inventoried.
2. Monitoring the spatial extent of the glacial lakes/water bodies (identified/inventoried under Objective 1 on monthly basis during June to October months for 5 years, succeeding the inventorying year.

3. Monitoring the spatial extent of 2 selected lakes, if required, with high-resolution data on event basis, during the monitoring years of study under Objective 2.

The inventory of glacial lakes/water bodies in the Himalayan region of Indian River basins using satellite data as given under objective 1 has been completed and a comprehensive report (Ref: NRSC Report No. NRSC-RS&GISAA-WRG-CWC-Lakes-May2011-TR255) was submitted to Climate Change and IAD Directorate, Central Water Commission, Ministry of Water Resources, New Delhi in June 2011. Similarly, the monthly monitoring reports were submitted to CWC for the months of June to October 2011 (See References).

This report presents the consolidated results of monitoring of glacial lakes/water bodies in the Himalayan region of Indian River basins using satellite data during the months of June, July, August, September and October 2011.

2. STUDY AREA & MATERIALS

2.1 Study area

The present study is carried out for the area covering Himalayas under the major river basins of Indus, Ganga and Brahmaputra. The study area extends across different countries namely India, Nepal, Bhutan and China. The index map showing study area is given in Figure 1.

2.2 Materials

The inventory of glacial lakes and water bodies was carried out using satellite images of the Advanced Wide Field Sensor (AWiFS) of the Indian remote sensing satellite, Resourcesat-1. The monitoring of these glacial lakes/water bodies was also carried out AWiFS data.

2.2.1 Satellite data

For the purpose of monitoring glacial lakes and water bodies from satellite images, it is preferable to have cloud free satellite images during the time of monitoring. Since the monitoring is carried out during monsoon period, probability of availability of cloud free data is less. Hence all the possible satellite data were browsed and checked for their coverage of the study area and cloud cover. There were a total of 23, 23, 21, 26 and 29 scenes covering the study during the months of June, July, August, September and October 2011 respectively. Out of this, 8, 8, 8, 9 and 7 cloud free or partially cloud free scenes were ordered for the months of June, July, August, September and October 2011 respectively. The list of satellite data used in this study is given in Table 1.

Table 1 List of satellite data used

Path	Row	Date	Path	Row	Date
104	51	02-Jun-11	110	51	19-Aug-11
109	51	03-Jun-11	97	47	26-Aug-11
100	50	06-Jun-11	112	50	29-Aug-11
110	51	08-Jun-11	93	46	30-Aug-11
91	45	09-Jun-11	103	51	1-Sep-11
111	51	13-Jun-11	108	51	2-Sep-11
93	46	19-Jun-11	113	50	3-Sep-11
113	50	23-Jun-11	99	49	5-Sep-11
91	45	3-Jul-11	104	51	6-Sep-11
101	50	5-Jul-11	91	47	13-Sep-11
106	51	6-Jul-11	97	49	19-Sep-11
107	50	11-Jul-11	93	46	23-Sep-11
112	51	12-Jul-11	104	50	30-Sep-11
93	46	13-Jul-11	95	47	3-Oct-11

99	49	19-Jul-11	100	49	4-Oct-11
95	47	23-Jul-11	110	50	6-Oct-11
97	48	2-Aug-11	111	50	11-Oct-11
93	46	6-Aug-11	93	46	17-Oct-11
103	51	8-Aug-11	103	50	19-Oct-11
99	48	12-Aug-11	100	49	28-Oct-11

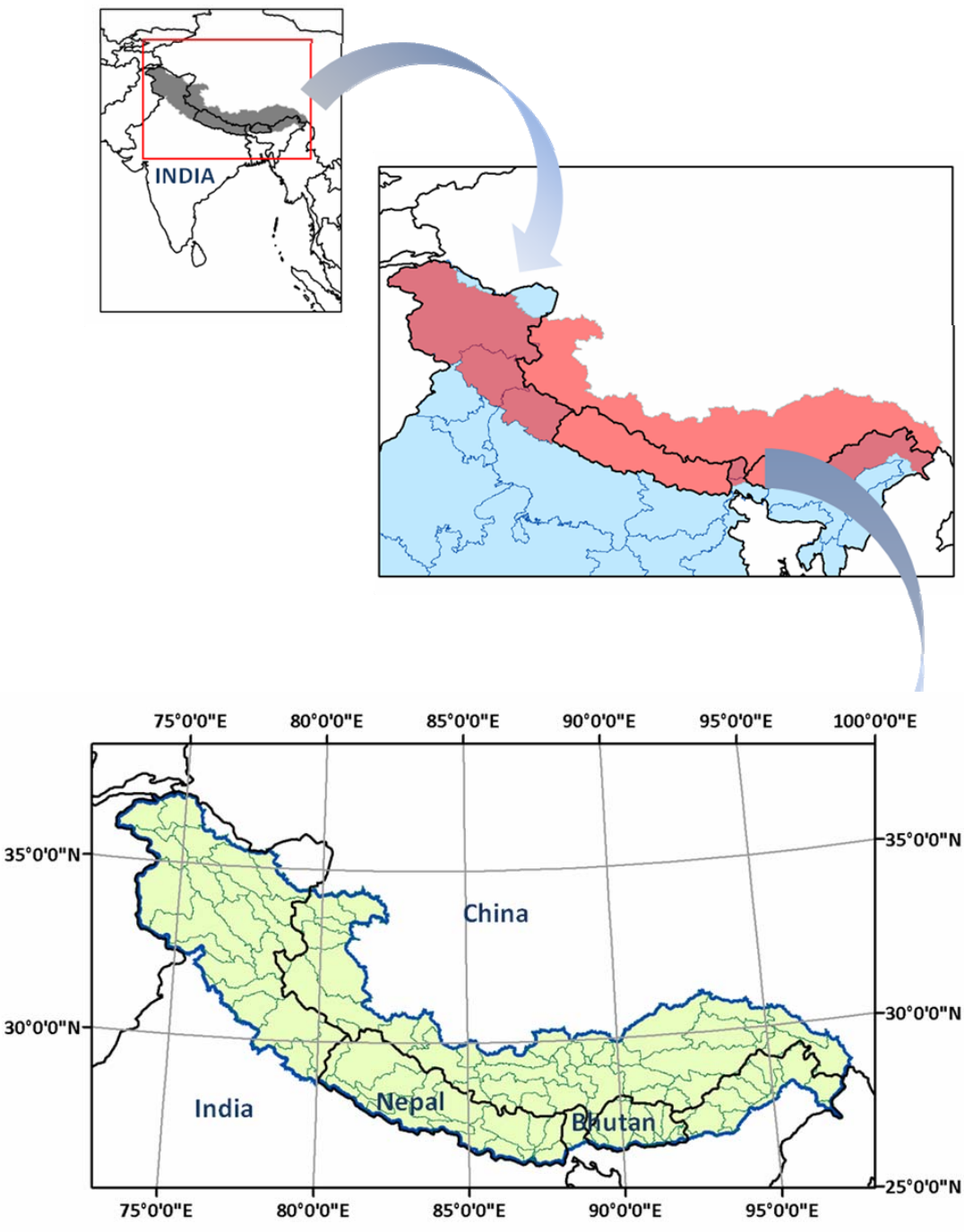

Figure 1 Index map of study area

3 METHODOLOGY

3.1 Overview

The monitoring of glacial lakes and water bodies in the Himalayan region using satellite images involves the following steps.

- Ortho-rectification of satellite data
- Identification & digitization of glacial lakes & water bodies
- Organisation of database

This chapter discusses each of the above steps in detail.

3.2 Orthorectification of satellite data

Orthorectification is the process by which the geometric distortions of the image are modelled and accounted for, resulting in a planimetrically correct image. 3D world is imaged by most sensors in 2D and orthorectification corrects for many of the anomalies resultant from this conversion. Orthorectified imagery is particularly useful in areas of the world with exacerbated terrain features such as mountains, plateaus, etc. The orthorectification process yields map-accurate images which can be highly useful as base maps and may be easily incorporated into a GIS. The success of the orthorectification process depends on the accuracy of the DEM and the correction method.

In this study, orthorectification of AWiFS data was carried out using Projective Transform model available in ERDAS Imagine software. The Projective Transform models are simulation models purely solved by the Ground Control Points (GCPs). The orthorectified Landsat ETM images were used as reference image for collections of GCPs and the elevation values for GCPs were collected from SRTM DEM.

3.3 Monitoring of glacial lakes & water bodies

The glacial lakes & water bodies are delineated based on the visual interpretation of satellite images of Resourcesat AWiFS sensor. Identification of features was done through panchromatic mode and/or different colour combinations of the multi-spectral bands namely green, red, near infrared and shortwave infrared.

To identify the glacial lakes & water bodies, different image enhancement techniques are used to improve the visual interpretation. This method is complimented with the knowledge and experience of the Himalayan terrain conditions for inventorying glacial lakes and water bodies. With different spectral band combinations in false colour composite (FCC) and in individual spectral bands, glacial lakes and water bodies can be identified. The knowledge of image

interpretation keys: colour, tone, texture, pattern, association, shape, shadow, etc. will also enhance the capability of identifying these features.

The water spread area of the lakes in false colour composite images ranges in appearance from light blue to blue to black. The frozen lakes appear white in colour. Sizes of water bodies are generally small, having circular, semi-circular, or irregular shapes with very fine texture. They are generally associated with glaciers in the case of high lying areas, or rivers in the case of low lying areas.

The present study proposed to map all the glacial lakes & water bodies that are larger than 50 ha in area. Even though during inventory, glacial lakes and water bodies having area more than 10 ha were digitised, monitoring was carried out only for the glacial lakes & water bodies that are larger than 50 ha. The boundary of glacial lakes and water bodies are digitized using on-screen digitisation techniques as polygon feature. The polygons are geoprocessed and the water spread area of glacial lakes/water bodies were computed digitally. These steps were repeated for each date of satellite data and water spread area was computed. The maximum water spread area for each water body among the different dates of satellite for the month of October 2011 has been considered for the final analysis of the change in water spread. The following criteria were followed while monitoring the water bodies.

- A Change in water spread area within +/- 5% is considered to be normal (insignificant) in remote sensing derived inventory studies.
- Partly or fully cloud covered or frozen water bodies have not been considered in monitoring
- Only the maximum spatial extent of water spread area during the current month has been mapped and compared with the spatial extent of water spread area mapped for the inventory year (2009).

4 RESULTS

4.1 Results

The monitoring of glacial lakes and water bodies in the Himalayan region of Indian river basins was carried out through visual interpretation of satellite images from AWiFS sensor. The basins covered under this study are Indus, Ganga and Brahmaputra. All the lakes & water bodies those are larger than 50 ha in size are considered. The monthly status of the glacial lakes and water bodies monitored is given below.

June 2011

The monitoring of glacial lakes and water bodies in the Himalayan region of Indian river basins could be carried out using satellite images only for 178 out of 433 water bodies that are inventoried using 2009 satellite data. Out of these, 20 water bodies have shown decrease in water spread area and 49 have shown increase. The remaining 109 water bodies have not changed significantly (+/- 5%).

July 2011

The monitoring of glacial lakes and water bodies in the Himalayan region of Indian river basins could be carried out using satellite images only for 125 out of 433 water bodies that are inventoried using 2009 satellite data. Out of these, 17 water bodies have shown decrease in water spread area and 36 have shown increase. The remaining 72 water bodies have not changed significantly (+/- 5%).

August 2011

The monitoring of glacial lakes and water bodies in the Himalayan region of Indian river basins could be carried out using satellite images only for 153 out of 433 water bodies that are inventoried using 2009 satellite data. Out of these, 23 water bodies have shown decrease in water spread area and 73 have shown increase. The remaining 57 water bodies have not changed significantly (+/- 5%).

September 2011

The monitoring of glacial lakes and water bodies in the Himalayan region of Indian river basins could be carried out using satellite images only for 243 out of 433 water bodies that are inventoried using 2009 satellite data. Out of these, 56 water bodies have shown decrease in water spread area and 93 have shown increase. The remaining 94 water bodies have not changed significantly (+/- 5%).

October 2011

The monitoring of glacial lakes and water bodies in the Himalayan region of Indian river basins could be carried out using satellite images only for 360 out of 433 water

bodies that are inventoried using 2009 satellite data. Out of these, 97 water bodies have shown decrease in water spread area and 114 have shown increase. The remaining 149 water bodies have not changed significantly (+/- 5%).

The consolidated list of glacial lakes/water bodies monitored during the year 2011 is given in Table 2 and the monthly distribution is shown in figure 3.

Table 2 List of glacial lakes/water bodies monitored during the year 2011

Month	No. of glacial lakes/water bodies monitored	Water Spread Area		
		Increased	Decreased	No Change
June 2011	178	49	20	109
July 2011	125	36	17	72
August 2011	153	73	23	57
September 2011	243	93	56	94
October 2011	360	114	97	149
June-Oct, 2011	**391**	**218**	**35**	**138**

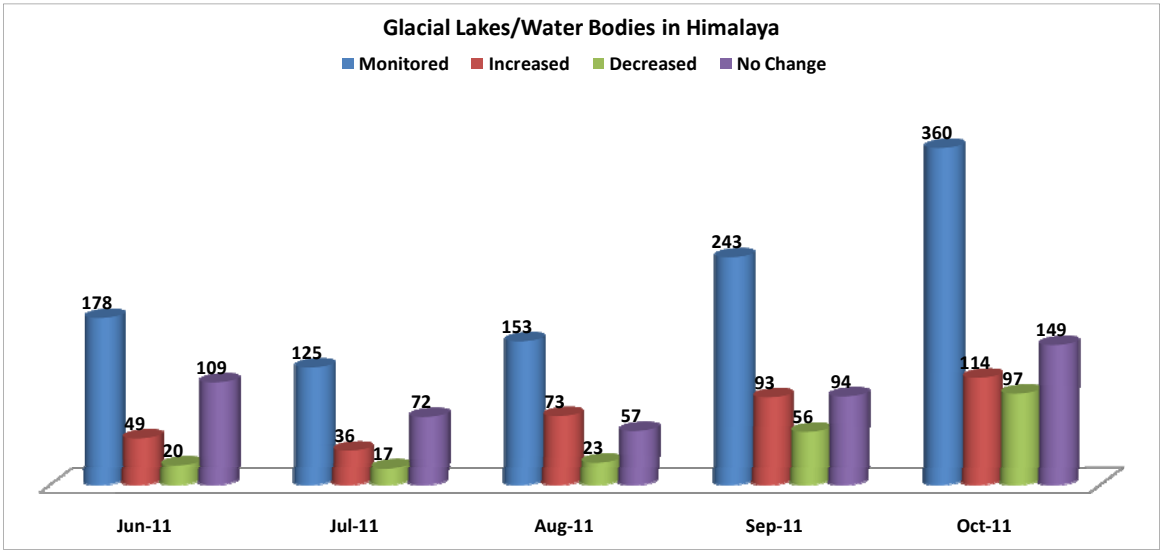

Figure 2 Monthly distribution glacial lakes/water bodies monitored

5 CONCLUSIONS

5.1 Conclusions

The water spread area of glacial lakes/water bodies monitored for each month during the year 2011 is compared and the maximum water spread area is arrived, Based on this area, the change in water spread is analysed for each of the glacial lakes/water bodies. This resulted in monitoring of 391 out of 433 water bodies that are inventoried using 2009 satellite data. Out of these, 35 water bodies have shown decrease in water spread area and 218 have shown increase. The remaining 138 water bodies have not changed significantly (+/- 5%). The list of glacial lakes and water bodies with a change in water spread area by more than 20% are given in Table 3.

The inventory of glacial lakes/water bodies was carried out using the cloud free satellite images during the year 2009. Some of these data sets were pertaining to winter season during which there was possibility of water bodies being in a frozen state. However, during the monitoring phase of the project, satellite data of June to October 2011 were used. This enabled the updating of inventoried glacial lakes/water bodies and also helped in improving the digitisation of actual water spread area during monsoon period. The selected cases of such glacial lakes/water bodies are shown in the Annexure.

Table 3 List of water bodies with extreme change in water spread area

Lake ID	Latitude	Longitude	GL/ WB	Reference Area (ha)	June 2011 area (ha)	July 2011 area (ha)	August 2011 area (ha)	September 2011 area (ha)	October 2011 area (ha)	2011 max area (ha)	% diff	Remarks
Basin Name/Country - Brahmaputra/China												
03_82G_048	29.42	93.29	WB	55.14					37.56	37.56	-31.9	Decrease
03_82K_002	29.99	94.44	WB	74.52					57.34	57.34	-23.1	Decrease
03_62O_019	29.88	83.42	WB	95.39				73.44	41.18	73.44	-23.0	Decrease - Seasonal waterbody
03_62J_021	30.33	82.27	WB	57.71	57.71		63.39	70.47	57.36	70.47	22.1	Increase - not a waterbody, but waterpool along river course d/s of glacier
03_62O_001	29.99	83.27	WB	87.01	87.01			106.74	102.01	106.74	22.7	Increase - not a waterbody, but low lying area near river course
03_62J_015	30.40	82.19	WB	70.30	70.30	86.58	80.18	83.43	81.47	86.58	23.2	Increase - earlier area is based on 19-Dec-2009 AWiFS data.
03_91C_017	29.49	96.70	WB	683.41			848.40	628.94	0.00	848.40	24.1	Increase - Flooded river course
03_91C_018	29.46	96.79	WB	648.61			820.81	751.44	726.41	820.81	26.5	Increase - Flooded river course
03_77P_006	28.66	91.68	WB	4566.44			5924.24		5667.24	5924.24	29.7	Increase
03_62O_039	29.59	83.99	WB	235.59	306.17			310.32	302.88	310.32	31.7	Increase - Zhuisi Cuo
03_71G_011	29.12	85.40	WB	950.81	1191.34			1255.35	1260.62	1260.62	32.6	Increase - Earlier area is based on AWiFS data as on 15-Oct-2009
03_71K_009	29.56	86.27	WB	229.95			307.43	246.78	220.13	307.43	33.7	Increased - Looks like water logged area and not a water body
03_71O_005	29.59	87.05	WB	150.73		177.17		209.61	0.00	209.61	39.1	Error in digitisation based on 30-Oct-2000 ETM data - Actual area is 1,965,307.25 sqm based on 15-Oct-09 AWiFS data
03_91D_081	28.52	96.70	WB	303.79					436.19	436.19	43.6	Increase
03_62O_016	29.89	83.58	WB	91.72	135.67		112.85	100.22	104.77	135.67	47.9	Increase - This water body is in the flood plain of the river and the water spread area varies dynamically.
03_77P_004	28.81	91.15	WB	143.27	143.27		238.07		234.09	238.07	66.2	Increase - earlier area is based on 04-Nov-2009 & 28-Nov-2009 AWiFS data when the water body was partially frozen.
03_71G_014	29.08	85.19	WB	60.08	136.75			136.91	142.65	142.65	137.4	Increase - Earlier area is based on AWiFS data as on 15-Oct-2009
Basin Name/Country - Brahmaputra/India												
03_82O_062	29.01	95.91	WB	52.27					41.60	41.60	-20.4	Decrease
03_78A_009	27.95	88.33	GL	54.89	54.89	68.06		60.66	57.93	68.06	24.0	Increase - earlier area is based on 04-Nov-2009 & 28-Nov-2009 AWiFS data.
03_77D_003	28.01	88.76	WB	83.58	107.86	121.38		88.95	71.35	121.38	45.2	Increase - This was under snow cover partially in the reference satellite data (04-Nov-2009 & 28-Nov-2009)
Basin Name/Country - Ganga/China												
02_62B_001	30.62	80.63	WB	67.04				35.01	48.35	48.35	-27.9	Decrease - Original area is based on 15-Oct-1999 ETM data. The area based on AWiFS data as on 29-Sep-09 is 462,271.15sqm
02_77D_004	28.29	88.12	WB	1874.77		391.13		1366.39	1282.63	1366.39	-27.1	Decrease - earlier area is based on 08-Nov-2000 ETM data.

Lake ID	Latitude	Longitude	GL/ WB	Reference Area (ha)	June 2011 area (ha)	July 2011 area (ha)	August 2011 area (ha)	September 2011 area (ha)	October 2011 area (ha)	2011 max area (ha)	% diff	Remarks
02_71H_029	28.32	85.84	GL	413.24				509.85	457.98	509.85	23.4	Increase - earlier area is based on 15-Oct-2009 AWiFS data where it was partially frozen
02_71P_015	28.58	87.54	WB	838.38	1011.46	971.53		1093.63	1046.08	1093.63	30.4	Increase - earlier area is based on 15-Oct-2009 AWiFS data
Basin Name/Country - Ganga/India												
02_53K_001	29.57	78.76	WB	3879.59	4624.47			6489.49	0.00	6489.49	67.3	Increase - Kalagarh Dam Resorvoir
Basin Name/Country - Indus/China												
01_61G_004	33.51	81.58	WB	68.36					26.77	26.77	-60.8	Dry - Original area is based on 20-Oct-2001 ETM data. The area based on AWiFS data as on 29-Sep-09 is 232,396.02 sqm
01_61F_001	34.34	81.26	WB	57.19		31.92			24.88	31.92	-44.2	Decrease - earlier area is based on 20-Oct-2000 ETM data. The area of water body is 428198 sqm in 29-Sep-09 AWiFS data. Based on this, the decrease is by 25%
01_61D_001	32.80	80.48	WB	63.15		82.06	78.97	82.13	81.96	82.13	30.1	Increase - earlier area is based on 29-Sep-2009 AWiFS data
01_61D_002	32.54	80.23	WB	1216.05		1514.59	1625.10	1739.40	1737.61	1739.40	43.0	Increase
Basin Name/Country - Indus/India												
01_43E_023	35.87	73.75	WB	86.06	88.08	96.99	104.10		0.00	104.10	21.0	Increase - earlier area is based on 16-Sep-2001 ETM data.
01_52D_001	32.61	76.03	WB	724.67	775.30	858.92	800.64	896.12	765.04	896.12	23.7	Increase - Chamera Dam Reservoir Lake
01_52J_009	34.15	78.55	WB	57.24		64.50	72.24	56.78	50.93	72.24	26.2	Increase
01_43K_014	33.51	74.77	WB	111.32		133.67		144.21	123.67	144.21	29.5	Increase - earlier area is based on 30-Sep-2001 ETM data - Actual area is 1,311,106.19 sqm based on 01-Nov-09 AWiFS data
01_53A_002	31.39	76.54	WB	10255.95	10662.51		12756.48	11560.80	13810.10	13810.10	34.7	Increase - Bhakra Reservoir
01_43J_004	34.92	74.52	WB	59.10		66.22	81.30		63.56	81.30	37.6	Increase - earlier area is based on 01-Nov-2009 AWiFS data when the water body was partially frozen. The water body is of size 787192.10 sqm in 11-aug-09 AWiFS data.Increase is by 3%.
01_53A_001	31.99	76.05	WB	16946.16	19671.44	19581.74	23861.65	23796.40	23450.20	23861.65	40.8	Increase
01_43G_001	33.21	73.71	WB	17016.07	19360.22	22667.24	25420.12	23100.90	22313.40	25420.12	49.4	Increase
01_52J_001	34.46	78.14	GL	65.40		110.47	119.21	92.78	94.76	119.21	82.3	Increase - earlier area is based on 31-Jan-2000 ETM data. The water body is of same size 1180247.41 sqm in 29-sep-09 AWiFS data.

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Annexure

Glacial lakes / water bodies that needs updation

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