

## PRINCIPAL BENCH, NEW DELHI

Original Application No. 618/2025

**IN THE MATTER OF:**

IN RE: NEWS ITEM TITLED "TRANSFORMING FOOD LAND AND WATER SYSTEMS TO COMBAT CLIMATE CRISIS IN LADAKH INDIA" APPEARING IN CURRENT SCIENCE VOLUME 129 NUMBER 8 DATED 25.10.2025  
**...Applicant**

**Versus**

MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE (MOEF&CC) Through its Secretary and ors.  
**...Respondent (s)**

**Index**

S. No.	Particular	Page No.
1.	Reply on behalf of respondent no. 2 (Ministry of Jal Shakti)	1-7
2.	Annexure-R-2/1, Copy of detailed inputs from the Central Water Commission regarding its monitoring and risk assessment activities (Comprehensive Trend Analysis Report (2011-2023) of Glacial Lakes in the Himalayan Region of Indian River Basins)	8-303
3.	Annexure-R-2/2, Copy of Criteria for Risk Indexing of Glacial Lakes in the Indian Himalayan Region are annexed herewith and marked	304-340

**Respondent No. 2****Filed by**

New Delhi  
Dated 23-04-2026



**GIGI. C. GEORGE**  
**Advocate**

NATIONAL GREEN TRIBUNAL

Email: gigigeorge.adv42@yahoo.in, M-9810625315

**BEFORE THE NATIONAL GREEN TRIBUNAL,**

**PRINCIPAL BENCH, NEW DELHI**

**ORIGINAL APPLICATION NO. 618 OF 2025**

**IN THE MATTER OF:**

IN RE: NEWS ITEM TITLED "TRANSFORMING FOOD LAND AND WATER SYSTEMS TO COMBAT CLIMATE CRISIS IN LADAKH INDIA" APPEARING IN CURRENT SCIENCE VOLUME 129 NUMBER 8 DATED 25.10.2025

...Applicant

**AND**

MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE (MOEF&CC) Through its Secretary and ors.

...Respondents

**REPLY BY WAY OF AFFIDAVIT ON BEHALF OF RESPONDENT NO. 02, MINISTRY OF JAL SHAKTI, GOVERNMENT OF INDIA**

Most Respectfully Showeth:

I, Nagendra Kumar Singh S/o Late Shri Narayan Singh Rajput Aged 52 Years presently working as Executive Engineer, Central Water Commission do hereby solemnly affirm and state on oath as under:-

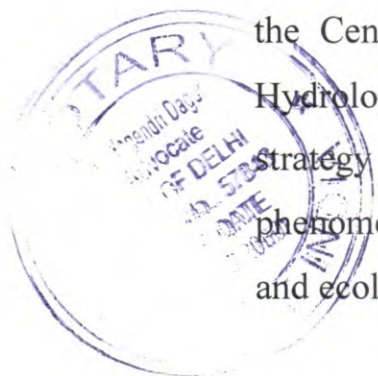
- 1) That I am duly authorised to swear and file the present Counter Affidavit on behalf of Respondent No. 02, Ministry of Jal Shakti, and am conversant with the facts and circumstances of the case based on official records.



- 2) That I represent the Secretary, Ministry of Jal Shakti, Government of India, the Respondent No. 02 in the aforesaid Original Application. I am fully conversant with the facts and circumstances of the case based on official records and am duly authorised and competent to swear this affidavit on behalf of the said Respondent.
- 3) That the present affidavit is being filed in compliance with the order dated 02.12.2025 passed by this Hon'ble Tribunal, placing on record the status of actions taken and the comprehensive framework established by the Respondent No. 2 to address the issues concerning water systems, glacier dynamics, and climate change impacts in the Indian Himalayan Region, with a specific focus on Ladakh.

#### **PRELIMINARY SUBMISSIONS**

- 4) That the Respondent No. 2, Ministry of Jal Shakti (MoJS), is the nodal ministry of the Government of India entrusted with the responsibility of development, conservation, and management of water resources in the country. The Ministry is committed towards the challenges posed by climate change, particularly in ecologically sensitive regions such as Ladakh, through robust scientific monitoring, data-driven policy formulation, and institutional capacity-building.
- 5) That it is submitted that the concerns raised in the suo motu proceedings, based on the article in 'Current Science', are being addressed by the Respondent No. 2 and its attached/subordinate organisations, including the Central Water Commission (CWC) and the National Institute of Hydrology (NIH). The Respondent No. 2 has established a multi-pronged strategy to monitor the cryosphere, assess risks associated with glacial phenomena, and develop mitigation frameworks to ensure water security and ecological sustainability.

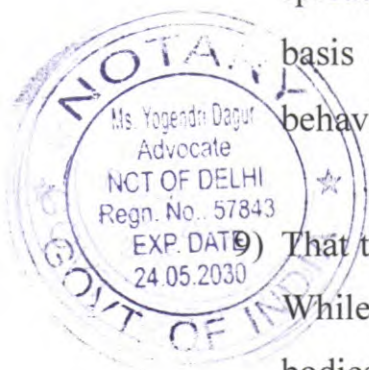


- 6) That the Respondent No. 2 has been implementing scientifically driven monitoring systems for glacial lakes and water bodies, which are critical indicators of climate change impact. The Central Water Commission, under the aegis of the Respondent No. 2, has been regularly monitoring these water bodies to pre-empt and mitigate potential disasters, such as Glacial Lake Outburst Floods (GLOFs).
- 7) That it is humbly submitted that the Respondent No.2 has not only focused on monitoring but has also taken steps to institutionalise the study of the cryosphere and climate change. The establishment of high-level committees and dedicated research centres underscores the Government of India's commitment to safeguarding the fragile Himalayan ecosystem and the communities dependent on it.

### REPLY ON MERIT

- 8) That with respect to the issues of climate crisis, water scarcity, and glacier retreat in Ladakh, it is submitted that the Respondent No.2, through the Central Water Commission, is undertaking extensive and systematic monitoring activities. The CWC monitors a total of 2843 Glacial Lakes (GLs) and Water Bodies (WBs) in the Himalayan Region using advanced Remote Sensing Techniques. Specifically, for Ladakh, the CWC monitors 179 Glacial Lakes and 26 Water Bodies (with a water spread area above 10 Ha). This monitoring is conducted on a monthly basis from June to October each year, providing crucial data on the behaviour of these water bodies.

- 9) That the monitoring program in Ladakh is being progressively expanded. While monitoring of 3 large glacial lakes (size > 50 Ha) and several water bodies commenced in 2011, an additional 12 glacial lakes (size 10-50 Ha) were brought under monitoring in 2022. It is submitted that the

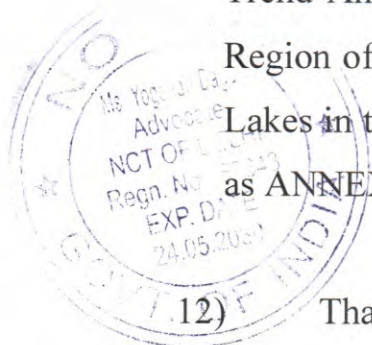


monitoring of the remaining 164 glacial lakes in Ladakh has commenced from June 2025, demonstrating a phased and comprehensive approach to cover the entire region.

- 10) That in response to the need for strengthening water management and monitoring glacier dynamics, the CWC has developed and finalised a "Criteria for Risk Indexing of Glacial Lakes". This scientific framework is designed to identify and rank glacial lakes based on their likelihood of failure and the potential damage from a Glacial Lake Outburst Flood (GLOF) event. The criteria evaluate 12 key factors, including the lake's size, change in size over time, stability of slopes, and downstream vulnerabilities.
- 11) That based on this Risk Indexing, a detailed assessment of 15 glacial lakes in Ladakh was conducted. It is respectfully submitted that the results of this scientific assessment reveal that none of the lakes fall under the high-risk Category-1 (Score > 70) or Category-2 (Score 60-70). Only two lakes fall under the moderate-risk Category-3, and twelve lakes fall under the low-risk Category-4. This data-driven risk assessment allows for targeted and prioritised mitigation and management strategies, ensuring that resources are directed towards areas of genuine concern.

A true copy of the detailed inputs from the Central Water Commission regarding its monitoring and risk assessment activities (Comprehensive Trend Analysis Report (2011-2023) of Glacial Lakes in the Himalayan Region of Indian River Basins) and Criteria for Risk Indexing of Glacial Lakes in the Indian Himalayan Region are annexed herewith and marked as ANNEXURE R-2/1 and R-2/2, respectively.

- 12) That to further standardise the framework for sustainable development and disaster mitigation, the CWC has published two seminal guidelines:

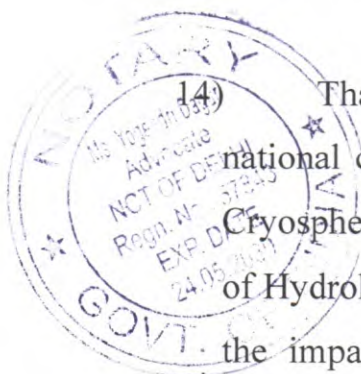


- a. "*Guideline for Assessment of GLOF specific to river valley projects in Indian Himalayan Region (IHR)*", which provides a comprehensive framework for identifying vulnerable glacial lakes and simulating GLOF scenarios to ensure the safety of infrastructure projects.
- b. "*Guideline for Structural measures to mitigate adverse effect of GLOF on Dam/Barrages*", which supports engineers and planners in incorporating GLOF considerations into infrastructure design and risk reduction strategies.

These guidelines are instrumental in ensuring that development activities in the fragile Himalayan region are conducted with the best standards of safety and environmental consideration.

- 13) That the Respondent No.2 has initiated inter-agency coordination to address these complex environmental challenges. A "*Steering Committee for Monitoring of Glaciers*" has been constituted under the Chairmanship of the Secretary, Department of Water Resources, RD & GR, MoJS. This committee brings together key national agencies such as National Institute of Hydrology (NIH), National Remote Sensing Centre (NRSC), Wadia Institute of Himalayan Geology, Geological Survey of India (GSI), and CWC, among others, to unify efforts in glacier studies, consolidate data on a GIS-based web portal, and develop predictive models for the behaviour of Himalayan glaciers. Three meetings of this high-level committee have already been held.

That furthermore, to create a dedicated knowledge base and build national capacity, the Ministry of Jal Shakti established the "Centre for Cryosphere and Climate Change Studies (C4S)" at the National Institute of Hydrology, Roorkee, in May 2023. This Centre is focused on studying the impact of climate change on the water resources of the Indian Himalayan Region and aims to provide best practices through proper



mapping of snow, glaciers, and glacial lakes, thereby directly addressing the core issues raised by this Hon'ble Tribunal.

15) That in light of the aforesaid submissions, it is evident that the Respondent No.2 is not only aware of the challenges in Ladakh but has also implemented a robust, scientifically-grounded, and institutionally-backed framework to monitor, assess, and mitigate the risks associated with climate change and its impact on water resources. The actions of the Respondent No. 2 are in complete alignment with the national commitment to environmental protection and sustainable development.

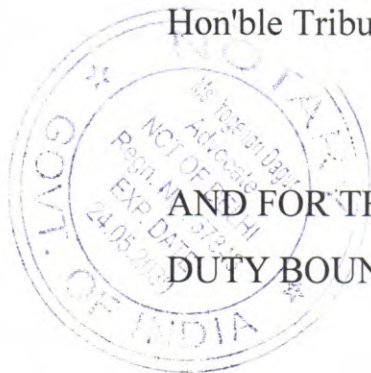
16) That the contents of this affidavit are true and correct to my knowledge and belief, based on the official records. No part of it is false, and nothing material has been concealed therefrom.

### PRAYER

In view of the facts and circumstances stated hereinabove, it is most respectfully prayed that this Hon'ble Tribunal may be pleased to:

a) Take the present Counter Affidavit and the submissions made herein on record; b) Acknowledge the comprehensive measures undertaken by the Respondent No. 2 for the monitoring and management of glacial lakes and water resources in Ladakh; c) Pass such other and further order(s) as this Hon'ble Tribunal may deem fit and proper in the interest of justice.

AND FOR THIS ACT OF KINDNESS, THE RESPONDENT NO. 2, AS IN DUTY BOUND, SHALL EVER PRAY.



*गीतिका*

DEPONENT

अधिसासी अभियंता/Executive Engineer  
ऊपरी यमुना मण्डल/Upper Yamuna Division  
केंद्रीय जल आयोग/Central Water Commission  
नई दिल्ली-110016/New Delhi-110016

'23 APR 2026

VERIFICATION

Verified at New Delhi on 25<sup>th</sup> April 2026 that the contents of the above reply affidavit is true and correct to the best of my knowledge and belief and nothing material has been concealed therefrom.

23 APR 2026



23 APR 2026

**ATTESTED**

**NOTARY PUBLIC  
NCT OF DELHI**

*(Handwritten signature)*

**DEPONENT**

अधिशासी अभियंता/Executive Engineer  
ऊपरी यमुना मण्डल/Upper Yamuna Division  
केंद्रीय जल आयोग/Central Water Commission  
नई दिल्ली-110016/New Delhi-110016



**COMPREHENSIVE TREND ANALYSIS REPORT (2011-2023)  
OF GLACIAL LAKES IN THE HIMALAYAN REGION OF  
INDIAN RIVER BASINS**

**CENTRAL WATER COMMISSION  
DEPARTMENT OF WATER RESOURCES,  
RIVER DEVELOPMENT & GANGA REJUVENATION**

**Comprehensive Trend Analysis Report (2011-2023)  
of Glacial Lakes in the Himalayan Region of Indian River  
Basins**



**Morphology & Climate Change Directorate**

**Planning & Development Organisation**

**Central Water Commission**

**Department of Water Resources, River Development &**

**Ganga Rejuvenation**

**Ministry of Jal Shakti, New Delhi**

**August 2024**

## Document Control Sheet

1.	Report / Document Type	Technical Report			
2.	Document Control Number	CWC/M&CC/GLWB/ 2024/TR-2			
3.	Title	<b>Comprehensive Trend Analysis Report (2011-2023) of Glacial Lakes in the Himalayan Region of Indian River Basins</b>			
4.	Author(s)	Sh. V.D. Roy Sh Piyush Kumar Smt. Archa Raj D. Sh. Rohit Kumar Yadav			
5.	Affiliation of authors	Morphology and Climate Change Directorate, CWC, New Delhi			
6.	Project Team	Sh. V.D. Roy Sh Piyush Kumar Smt. Archa Raj D. Sh. Rohit Kumar Yadav Sh. Chiradip Das			
7.	Scrutiny mechanism	Compiled by Smt. Archa Raj D. Assistant Director  Sh Piyush Kumar Deputy Director	Reviewed by Sh. V.D. Roy, Director  Smt Shobhika Singh Deputy Directors	Controlled by Sh. D.P.Mathuria, Chief Engineer, (P&DO)	Approved by Sh. P. M. Scott, Member (RM), CWC
8.	Originating unit	P&D organization, CWC, New Delhi			
9.	Date of Publication	07.08.2024			
10.	<p>Abstract (with Keywords): CWC monitors 902 Glacial Lakes &amp; Water Bodies in the Himalayan region and Tibetan region, draining to India on monthly basis – June to Oct, every year, using Remote Sensing Data. This document has two sections dedicated to Comprehensive trend analysis of 100 GLs located in India and Mapping of Projects &amp; CWC HO stations along the Flow Path of 100 GLs respectively. The trend analysis of 100 Glacial Lakes within India on the complete data on water spread area as available from monthly reports since monitoring started in 2011 and listing them in three categories ie increasing, no change, decreasing corresponding to <math>\pm 10</math> and <math>\pm 20\%</math> margin has been covered under <b>Section-I. Section-II</b> contains State-wise flow path of above 100 Glacial Lakes along with projects, Hydrological Observation stations in the enroute, to facilitate the visualization of potential impact in the event of GLOF.</p> <p>Keywords: Glacial Lake, Water Bodies, Indian Himalayan Region, Satellite Images, Remote Sensing, Google Earth Engine, Trend Analysis, Flow Path, GLOF</p>				

## Contents

Executive Summary	xi
1 Introduction.....	1
1.1 Glacial Lakes and Water Bodies.....	1
1.2 Glacial Lakes In Indian Himalayan Region.....	1
1.3 Inventory Of Glacial Lakes and Water Bodies 2011.....	1
1.4 Glacial Lake Atlas of Indian Himalayan River Basins in 2023.....	2
1.5 Objectives.....	3
1.6 Limitations, Assumptions and Plans for the future.....	3
2 Monitoring of Glacial Lakes and Water Bodies.....	4
2.1 Study Area .....	4
2.2 Remote Sensing Technology.....	10
2.2.1 Sentinel-2 Multi Spectral Imagery.....	10
2.2.2 Sentinel-1 Synthetic Aperture Radar (Microwave Imagery) .....	10
3 Methodology of Monitoring of Glacial Lakes and Water Bodies using Remote Sensing Techniques - 2011-2023.....	11
3.1 Monitoring 2011-2015.....	11
3.2 Monitoring 2016-2021.....	11
3.3 Monitoring 2022-2023.....	12
SECTION -1 Comprehensive analysis of changes in water spread area of 100 GLs since 2009/2011.....	14
4 Cumulative Change in Water spread Area of Glacial Lakes.....	15
4.1 Introduction.....	15
4.2 Cumulative Statistics of Monitored Glacial Lakes.....	15
4.3 Cumulative Statistics of Glacial Lakes located in India.....	15
4.4 Trend Analysis of Change in Water spread Area of Glacial Lakes.....	17
4.5 Methodology for Trend Analysis.....	18
4.6 Result of Trend Analysis.....	24

4.6.1	Trend analysis of 15 GL of size greater than 50 Ha (2011 to 2023) for $\pm 10\%$ variation w.r.t. Base Year data of 2009.....	24
4.6.2	Trend analysis of 15 GL of size greater than 50 Ha (2011 to 2023) for $\pm 20\%$ variation w.r.t. Base Year data of 2009.....	26
4.6.3	Trend analysis of 15 GL of size greater than 50 Ha (2022 - 2023) for $\pm 10\%$ variation w.r.t. Base Year data June 2022.....	46
4.6.4	Trend analysis of 15 GL of size greater than 50 Ha (2022 to 2023) for $\pm 20\%$ variation Base Year data June 2022.....	47
4.6.5	Trend analysis of 85 Glacial Lakes of size between 10 Ha to 50 Ha for change in Water spread area (2011-2023) for $\pm 10\%$ variation w.r.t. base year data of 2011.....	67
4.6.6	Trend analysis of 85 Glacial Lakes of size between 10 Ha to 50 Ha (2011-2023) for $\pm 20\%$ variation w.r.t. base year data of 2011.....	69
4.6.7	Trend analysis of 85 Glacial Lakes of size between 10 Ha to 50 Ha (2022-2023) for $\pm 10\%$ variation Base Year data June 2022.....	162
4.6.8	Trend analysis of 85 Glacial Lakes of size between 10 Ha to 50 Ha (2022-2023) for $\pm 20\%$ variation Base Year data June 2022.....	165
4.7	Abstract of Trend Analysis.....	257
4.8	Conclusion of Trend Analysis.....	261
SECTION -II Mapping of Projects & CWC HO stations enroute flow path of 100 GLs within India		263
5	Mapping of anticipated GLOF (Glacial Lake Outburst Flood) Damage centres of Glacial Lakes located in India.....	264
5.1	Introduction.....	264
5.2	Impacts of GLOF.....	264
5.3	Delineation of Flow Path of Glacial Lake.....	264
5.4	Methodology for Delineation of Flow Path of Glacial Lake.....	264
5.5	Mapping of Damage Centre.....	265
5.6	Usefulness of Mapping of Damage Centre.....	265
6.	References.....	272

## List of Figures

Figure 2.1	Lake Type Distribution.....	5
Figure 2.2	Index Map of Study Area.....	6
Figure 2.3	Location Map of Study Area showing Glacial Lakes and Water Bodies being monitored by CWC.....	7
Figure 2.4	Relief Map of the Study Area.....	7
Figure 2.5	Elevation Range of GL&WB within Indian Himalayan Region being monitored by CWC.....	8
Figure 2.6	Country-wise Distribution of GL/WB in Indian Himalayan Region being monitored By CWC.....	8
Figure 2.7	State-wise Distribution of Glacial Lakes within India being monitored by CWC.....	9
Figure 2.8	State-wise Distribution of Water Bodies being monitored by CWC.....	9
Figure 3.1	Methodology of automatic monitoring of Glacial Lakes & Water Bodies using Satellite Image.....	13
Figure 4.1	Comparison of total Inventory area (2011) and total area of October 2023 of 495 GLs.....	15
Figure 4.2	Comparison of total Inventory area (2011) and total area of October 2023 of 58 GLs located in India.....	16
Figure 4.3	Comparison of total Inventory area (2011) and total area of October 2023 of 14 GLs (size> 50Ha) located in India.....	16
Figure 4.4	Comparison of total Inventory area (2011) and total area of October 2023 of 44 GLs (size 10 Ha to 50Ha) located in India.....	17
Figure 4.5(i)	Trend Analysis plot of South Lhonak Lake (Lake ID: 03_78A_014), Sikkim, for $\pm 10\%$ variation w.r.t. Base Year data of 2009.....	20
Figure 4.5(ii)	Trend Analysis plot of South Lhonak Lake (Lake ID: 03_78A_014), Sikkim, for $\pm 20\%$ variation w.r.t. Base Year data of 2009.....	20
Figure 4.6(i)	Trend Analysis plot of South Lhonak Lake (Lake ID: 03_78A_014), Sikkim, for $\pm 10\%$ variation w.r.t. Base data of June 2022.....	21
Figure 4.6(ii)	Trend Analysis plot of South Lhonak Lake (Lake ID: 03_78A_014), Sikkim, for $\pm 20\%$ variation w.r.t. Base data of June 2022.....	21
Figure 4.7(i)	Trend Analysis plot of Glacial Lake of Lake ID: 03_83A_003, Arunachal Pradesh, for $\pm 10\%$ variation w.r.t. Base Year data of 2009.....	22
Figure 4.7(ii)	Trend Analysis plot Lake (Lake ID: 03_83A_003), Arunachal Pradesh, for $\pm 20\%$ variation w.r.t. Base Year data of 2009.....	22
Figure 4.8(i)	Trend Analysis plot of Lake (Lake ID: 03_83A_003), Arunachal Pradesh, for $\pm 10\%$ variation w.r.t. Base data of June 2022.....	23
Figure 4.8(ii)	Trend Analysis plot of Lake (Lake ID: 03_83A_003), Arunachal Pradesh, for $\pm 20\%$ variation w.r.t. Base data of June 2022.....	23
Figure 4.9(i)- 4.11(ii):-	Trend Analysis of <sup>vi</sup> “Change in Water spread area of Glacial Lakes (>50 Ha) (2011-2023) of Ladakh”.....	29-31

Figure 4.12(i)- 4.13(ii):-	Trend Analysis of “Change in Water spread area of Glacial Lakes (>50 Ha) (2011-2023) of Himachal Pradesh”.....	33-34
Figure 4.14(i)- 4.23(ii):-	Trend Analysis of “Change in Water spread area of Glacial Lakes (>50 Ha) (2011-2023) of Sikkim”.....	35-45
Figure 4.24(i)- 4.26(ii):-	Trend Analysis of “Change in Water spread area of Glacial Lakes (>50 Ha) (2022-2023) of Ladakh”.....	50-52
Figure 4.27(i)- 4.28(ii):-	Trend Analysis of “Change in Water spread area of Glacial Lakes (>50 Ha) (2022-2023) of Himachal Pradesh”.....	54-55
Figure 4.29(i)- 4.38(ii):-	Trend Analysis of “Change in Water spread area of Glacial Lakes (>50 Ha) (2022-2023) of Sikkim”.....	57-66
Figure 4.39(i)- 4.50(ii):-	Trend Analysis of “Change in Water spread area of Glacial Lakes between 10 Ha to 50 Ha (2011-2023) of Ladakh”.....	74-85
Figure 4.51(i)- 4.65(ii):-	Trend Analysis of “Change in Water spread area of Glacial Lakes between 10 Ha to 50 Ha (2011-2023) of Jammu & Kashmir”.....	87-101
Figure 4.66(i)- 4.73(ii):-	Trend Analysis of “Change in Water spread area of Glacial Lakes between 10 Ha to 50 Ha (2011-2023) of Himachal Pradesh”.....	102-110
Figure 4.74(i)- 4.80(ii):-	Trend Analysis of “Change in Water spread area of Glacial Lakes between 10 Ha to 50 Ha (2011-2023) of Uttarakhand”.....	112-118
Figure 4.81(i)- 4.112(ii):-	Trend Analysis of “Change in Water spread area of Glacial Lakes between 10 Ha to 50 Ha (2011-2023) of Sikkim”.....	119-141
Figure 4.113(i)- 4.121(ii):-	Trend Analysis of “Change in Water spread area of Glacial Lakes between 10 Ha to 50 Ha (2011-2023) of Arunachal Pradesh”.....	143-151
Figure 4.122(i)- 4.133(ii):-	Trend analysis of “Change in water spread area of Glacial Lakes between 10 Ha to 50 Ha of Ladakh (2022-2023)”.....	169-180
Figure 4.134(i)- 4.148(ii):-	Trend analysis of “Change in water spread area of Glacial Lakes between 10 Ha to 50 Ha of Jammu and Kashmir (2022-2023)”.....	182-197
Figure 4.149(i)- 4.156(ii):-	Trend analysis of “Change in water spread area of Glacial Lakes between 10 Ha to 50 Ha of Himachal Pradesh (2022-2023)”.....	199-206
Figure 4.157(i)- 4.163(ii):-	Trend analysis of “Change in water spread area of Glacial Lakes between 10 Ha to 50 Ha of Uttarakhand (2022-2023)”.....	208-214
Figure 4.164(i)- 4.195(ii):-	Trend analysis of “Change in water spread area of Glacial Lakes between 10 Ha to 50 Ha of Sikkim (2022-2023)”.....	216-247
Figure 4.196(i)- 4.204(ii):-	Trend analysis of “Change in water spread area of Glacial Lakes between 10 Ha to 50 Ha of Arunachal Pradesh (2022-2023)”.....	248-256
Figure 4.205(i):	Trend Analysis carried out for Change in Waterspread area of 15 GL (>50 Ha) w.r.t. Base year Data 2009 for $\pm 10\%$ variation.....	257
Figure 4.205(ii):	Trend Analysis carried out for Change in Waterspread area of 15 GL (>50 Ha) w.r.t. Base year Data 2009 for $\pm 20\%$ variation.....	257

Figure 4.206(i):	Trend Analysis carried out for Change in Waterspread area of 15 GL (>50 Ha) w.r.t. Base year Data 2022 for $\pm 10\%$ variation.....	258
Figure 4.206(ii):	Trend Analysis carried out for Change in Waterspread area of 15 GL (>50 Ha) w.r.t. Base year Data 2022 for $\pm 20\%$ variation.....	258
Figure 4.207(i):	Trend Analysis carried out for Change in Waterspread area of 85 GL (10-50 Ha) w.r.t. Base year Data 2011 for $\pm 10\%$ variation.....	259
Figure 4.207(ii):	Trend Analysis carried out for Change in Waterspread area of 85 GL (10-50 Ha) w.r.t. Base year Data 2011 for $\pm 20\%$ variation.....	259
Figure 4.208(i):	Trend Analysis carried out for Change in Waterspread area of 85 GL (10-50 Ha) w.r.t. Base year Data 2022 for $\pm 10\%$ variation.....	260
Figure 4.208(ii):	Trend Analysis carried out for Change in Waterspread area of 85 GL (10-50 Ha) w.r.t. Base year Data 2022 for $\pm 10\%$ variation.....	260

## List of Tables

Table 1.1	Country-wise details of Glacial Lakes & Water Bodies of Inventory – 2011.....	2
Table 1.2	Basin wise details of Glacial Lakes & Water Bodies of Inventory 2011.....	2
Table 1.3	The abstract of Glacial Lakes as per Glacial Atlas of IHR of NRSC 2023.....	2
Table 2.1	State-wise and Basin-wise details of the 477 GLs/WBs above 50 Ha.....	4
Table 2.2	State-wise and basin-wise details of the 425 GLs/WBs of water spread area between 10Ha to 50 ha.....	5
Table 2.3	Abstract of State-wise & Basin-wise details of GL&WBs being monitored monthly by CWC.....	6
Table 4.1	Criteria for Trend Analysis.....	18
Table 4.2	Data set of South Lhonak Lake (Lake ID: 03_78A_014), Sikkim, for $\pm 10\%$ & $\pm 20\%$ variation w.r.t. Base Year data of 2009.....	19
Table 4.3	Data set of South Lhonak Lake (Lake ID: 03_78A_014), Sikkim, for $\pm 10\%$ & $\pm 20\%$ variation w.r.t. Base Year data of June 2022.....	20
Table 4.4	Data set of Glacial Lake of Lake ID: 03_83A_003, Arunachal Pradesh, for $\pm 10\%$ & $\pm 20\%$ variation w.r.t. Base Year data of 2009.....	21
Table 4.5	Data set of Lake (Lake ID: 03_83A_003), Arunachal Pradesh, for $\pm 10\%$ & $\pm 20\%$ variation w.r.t. Base Year data of June 2022.....	22
Table 4.6	State wise distribution of Glacial Lakes of size greater than 50Ha analysed for trend for $\pm 10\%$ variation in water spread area w.r.t. base year data 2009.....	25
Table 4.7	Trend Analysis of Glacial Lakes of size greater than 50 Ha in size located in India analysed for $\pm 10\%$ variation in water spread area based on 13 years data (in addition to that of 2009).....	25
Table 4.8	State wise distribution of Glacial Lakes of size greater than 50Ha analysed for trend for $\pm 20\%$ variation in water spread area w.r.t. base year data 2009.....	26
Table 4.9	Trend Analysis of Glacial Lakes of size greater than 50 Ha in size located in India analysed for $\pm 20\%$ variation in water spread area based on 13 years data (in addition to that of 2009).....	26
Table 4.10	State wise details of trend analysis of Glacial Lakes of size greater than 50Ha for a $\pm 10\%$ variation in water spread area based on June 2022 data.....	46
Table 4.11	Trend Analysis of Glacial Lakes of size greater than 50 Ha in size located in India analysed for $\pm 10\%$ variation in water spread area based on June data 2022.....	46

Table 4.12	State wise details of trend analysis of Glacial Lakes of size greater than 50Ha for a $\pm 20\%$ variation in water spread area w.r.t. June 2022 data.....	47
Table 4.13	Trend Analysis of Glacial Lakes of size greater than 50 Ha in size located in India analysed for $\pm 20\%$ variation in water spread area based on 2 Years data (2022-2023).....	47
Table 4.14	State wise details of trend analysis of Glacial Lakes of water spread area of 10 Ha to 50 Ha for a $\pm 10\%$ variation in water spread area w.r.t. base year data 2011.....	67
Table 4.15	Trend Analysis of Glacial Lakes 10- 50 Ha in size located in India analysed for 10% variation in water spread area based on 2 years data (in addition to that of 2011).....	70
Table 4.16	Trend Analysis of Glacial Lakes 10- 50 Ha in size located in India analyzed For 20% variation in water spread area based on 2 years data (in addition to that of 2011).....	70
Table 4.17	Trend Analysis of Glacial Lakes 10- 50 Ha in size located in India analysed for 20% variation in water spread area based on 2 years data (in addition to that of 2011).....	70
Table 4.18	State wise details of trend analysis of Glacial Lakes of water spread area of 10 Ha to 50 Ha for a $\pm 10\%$ variation in water spread area w.r.t June 2022	162
Table 4.19	Trend Analysis of Glacial Lakes 10- 50 ha in size located in India analysed for 10% variation in water spread area based on 2 years data (2022-2023) w.r.t. June 2022	162
Table 4.20	State wise details of trend analysis of Glacial Lakes of water spread area of 10 Ha to 50 Ha for a $\pm 20\%$ variation in water spread area w.r.t June 2022 data.....	165
Table 4.21	Trend Analysis of Glacial Lakes 10- 50 ha in size located in India analysed for $\pm 20\%$ variation in water spread area based on 2 years data (2022-2023).....	165

<b>ABBREVIATIONS</b>	
AR	Arunachal Pradesh
CWC	Central Water Commission
DoWR, RD & GR	Department of Water Resources, River Development & Ganga Rejuvenation
DWRIS	Development of Water Resources Information System
GEE	Google Earth Engine
GL(s)	Glacial Lake(s)
GLOF	Glacial Lake Outburst Flood
FCC	False Color Composite
ha	Hectare
HP	Himachal Pradesh
J&K	Jammu & Kashmir
LAT	Latitude
LONG	Longitude
LU/LC	Land Use /Land Cover
NDWI	Normalized Difference Water Index
NDMA	National Disaster Management Authority
NIR	Near-Infrared
NRSC	National Remote Sensing Centre
SAR	Synthetic Aperture Radar
SDC	Swiss Agency for Development and Cooperation
SK	Sikkim
TAR	Tibet Autonomous Region
UID	Unique Identification
UK	Uttarakhand
WB(s)	Water Body(ies)

## Executive Summary

The Himalayan Region (HR) is facing important challenges in coping with the adverse effects of climate change. Physically, the shrinking of mountain glaciers and expansion of Glacial Lakes are amongst the most recognizable and dynamic impacts of climate warming in this environment. In combination with this, altered stability of surrounding rock and ice walls, the potential threat from Glacial Lake Outburst Flood (GLOF) is evolving over time. Therefore, under such changing environment, a close watch on the relative change in water spread area of even smaller lakes has become very crucial in this region.

Analysis of worldwide literature on the outburst of glacial lakes and the field and theoretical experience have led to the conclusion that it is not feasible to make a reliable prediction of a specific occurrence on the basis of our existing knowledge. As direct predictions cannot be made, there is an urgent need to monitor a careful selection of prioritized lakes on a regular basis. This should be carried out in collaboration with other institutions, both nationally and internationally.

The work of monitoring of Glacial Lakes/Water Bodies (GLs/WBs) using remote sensing technique was taken up by CWC, DoWR, RD&DR, Ministry of Jal Shakti, during XI Plan period in the year 2009 under DWRIS Plan scheme. The inventory of GLs/WBs was published in June, 2011 in association with National Remote Sensing Centre (NRSC), Hyderabad based on the satellite data of Advanced Wide Field Sensor (AWiFS) of the Indian Remote Sensing Satellite, Resourcesat-1 collected from May-Nov, 2009. This inventory is therefore hereafter referred as *Inventory of Glacial Lakes & Water Bodies (2011)*. As per this inventory, there are 2028 GLs/WBs with size more than 10 ha in the Himalayan Region draining towards India. The country wise & basin wise details of the inventory are given in **Table ES.1**.

**Table ES.1: Country wise & Basin wise Distribution of Glacial lakes and Water bodies above 10 Ha(in Nos.)**

Country-wise Distribution				Basin-wise Distribution			
Country	Glacial Lakes (>10 Ha)	Water Bodies (>10 Ha)	Total (>10 Ha)	Basin Name	Glacial Lakes	Water Bodies	Total
India	60	448	508	Brahmaputra	294	1099	1393
Bhutan	77	124	201	Ganga	178	105	283
Nepal	57	45	102	Indus	31	321	352
China	309	904	1213	<b>Total</b>	<b>503</b>	<b>1525</b>	<b>2028</b>
Myanmar	-	4	4				
<b>Total</b>	<b>503</b>	<b>1525</b>	<b>2028</b>				

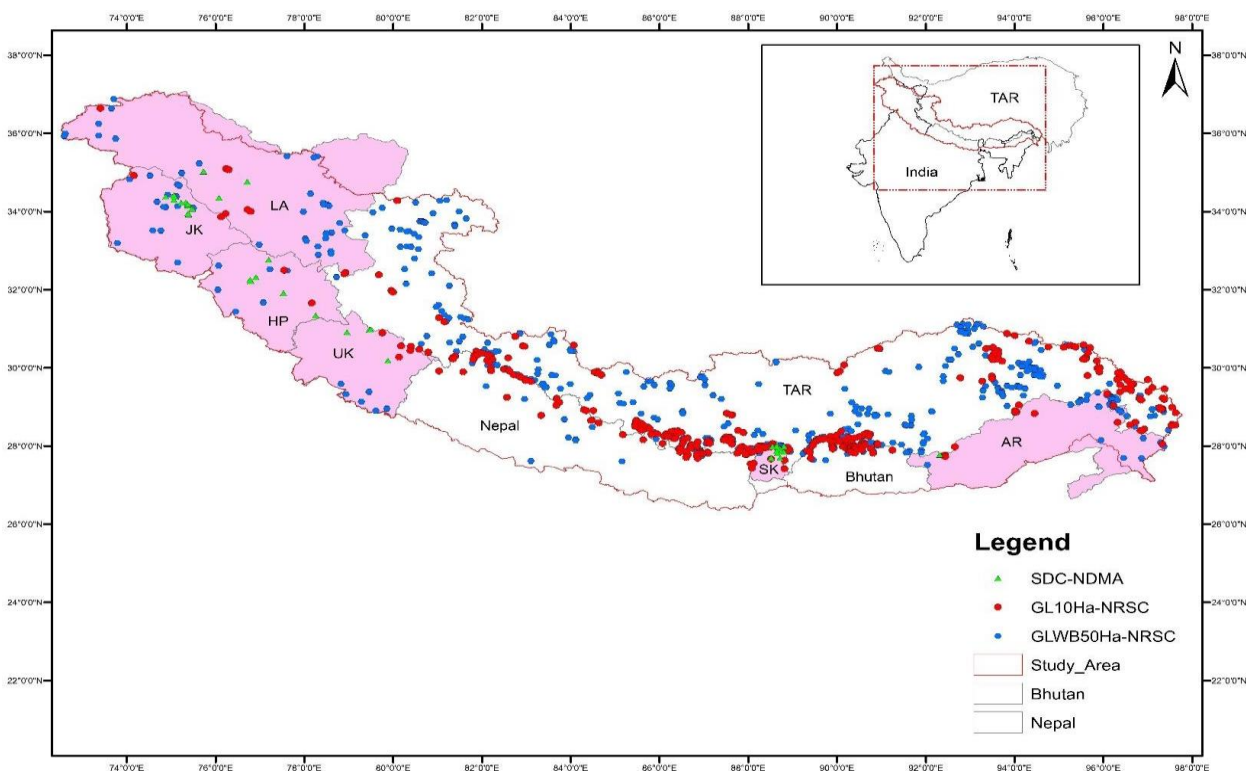
Monitoring of 477 GLs/WBs with size more than 50 ha, sourced from Glacial Lake Inventory 2011, for change in water spread area, was carried out during monsoon season (June to October) every year since 2011. The monitoring activity initiated in NRSC was continued till 2015. CWC has taken up monitoring during 2016 and the work was undertaken by downloading and manually digitising Advanced Wide Field Sensor (AWiFS) Satellite imageries procured/ downloaded from NRSC and processing them in Arc GIS. This continued till 2021. From 2022, monitoring of additional 425 GLs with sizes of 10ha to 50ha was also included. This includes 385 Glacial Lakes with water spread area between 10-50 Ha from Glacial Lake Inventory (2011) and 40 high priority Glacial Lakes identified by Swiss Agency for Development and Cooperation (SDC) for NDMA. Thus, currently CWC is monitoring a total of 902 GLs/WBs. High resolution multi-spectral and microwave (SAR) images of foreign satellites

at 10 m resolution have been processed and analysed in open-source cloud computing platform Google Earth Engine using automatic algorithm which has been developed in-house. Visual inspection & manual digitisation has been used to supplement the automatic algorithm to complete the task. The Monthly Monitoring Report is shared with all stakeholders through email for further necessary action. The reports are also e-published on CWC website for any time access by the concerned (<https://cwc.gov.in/glacial-lakeswater-bodies-himalayan-region>). The abstract of 902 GL/WB is given in **Table ES.2**.

**Table ES.2: Abstract of 902 GLs/WBs**

Country/ Area	State/ Union Territory	No of Glacial Lakes				No of Water Bodies				Grand Total
		Indus Basin	Ganga Basin	Brahma- putra Basin	Total	Indus Basin	Ganga Basin	Brahma- putra Basin	Total	
India	Ladakh	15	0	0	15	26	0	0	26	41
	Jammu & Kashmir	15	0	0	15	16	0	0	16	31
	Himachal Pradesh	10	0	0	10	5	0	0	5	15
	Uttarakhand	0	9	0	9	0	6	0	6	15
	Sikkim	0	0	42	42	0	0	1	1	42
	Arunachal Pradesh	0	0	9	9	0	0	25	25	35
	<b>Total</b>	<b>40</b>	<b>9</b>	<b>51</b>	<b>100</b>	<b>47</b>	<b>6</b>	<b>26</b>	<b>79</b>	<b>179</b>
	<b>India Total</b>	<b>100</b>				<b>79</b>				<b>179</b>
Transboundary	China	12	110	187	309	49	19	191	259	568
	Bhutan	0	0	71	71	0	0	11	11	82
	Nepal	0	64	0	64	0	9	0	9	73
	<b>Total</b>	<b>12</b>	<b>174</b>	<b>258</b>	<b>444</b>	<b>49</b>	<b>28</b>	<b>202</b>	<b>279</b>	<b>723</b>
	<b>Transboundary Total</b>	<b>444</b>				<b>279</b>				<b>723</b>
<b>Grand Total</b>		<b>544</b>				<b>358</b>				<b>902</b>

**Map of Study Area showing Glacial Lakes and Water Bodies being monitored by CWC**



## Limitations, Assumptions and Plans for the future:

### Limitations:

- Glacial lake identification can be done either using visual interpretation or automatic mapping methods. The automatic mapping procedures have limitations due to varying terrain conditions like lakes situated in the shadow portions of mountains, presence of snow cover, cloud cover, lakes being partly frozen, foreshortening, layover etc. As lake water absorbs the incident radiation making it appear in darker tone and colour in the standard FCC of satellite data, similar response also prevails over shadow region of clouds or mountains on surface, which may lead to incorrect mapping. Moreover, a mountain shadow covering a lake partly/completely within its vicinity, also make it difficult to accurately map the lake boundary.
- 40 Glacial Lakes, which have been listed as high priority lakes, as per “Synthesis report on GLOF hazard and risk across the Indian Himalayan Region” prepared by Swiss Agency for Development and Cooperation (SDC) for NDMA, was included for monitoring during the year 2022. But the baseline data/inventory for these lakes are unavailable.
- Trend analysis under Section I has been carried out on the monthly monitoring data. It is observed that in several cases, there are wide variations in two successive data. This is perhaps the erroneous water spread area extracted from remote sensing data due to limitations in availability of cloud free images or in processing of remote sensing data.
- Monthly monitoring data of 13 years (2011-2022) is available for 15 Glacial Lakes with water spread area above 50 ha at the time of inventory. For the remaining 85 lakes only two year data (2022-23) is available.
- Trend analysis of 100 Glacial Lakes located within India has only been carried out.

### Assumptions:

- Inclusion or exclusion of water pixels near lake boundaries depending on more than or less than certain fraction of its area falling within the lake boundary.
- Linear trend analysis was assumed in Section-I.

### Plans for Future:

- Similar Trend Analysis of Transboundary Glacial Lakes(444 Nos.) in the forthcoming reports.
- Mapping of damage centres like habitation and their population, vital infrastructures, landslide susceptible area etc. enroute flow path.

This document has two sections dedicated to Comprehensive trend analysis of 100 GLs located in India and Mapping of Projects & CWC HO stations along the Flow Path of 100 GLs respectively.

## Section –I:

Section –I presents the trend analysis of “**Change in Water spread area of 100 Glacial Lakes within India being monitored monthly by CWC**”. This has been carried out over the available monthly monitoring data with a view to prioritize lakes for close monitoring & planning of mitigation measures. The analysis has been done for  $\pm 10\%$  &  $\pm 20\%$  Variation w.r.t base year of 2009/2011 as well as June 2022. Abstract of the same is given in following **Table ES.3**.

**Table ES.3. Criteria for comprehensive trend analysis of change in water spread area of glacial lakes.**

Sl. No.	Trend Analysis carried out for Change in Water spread area of			Trend
1	15 GL (>50 Ha) w.r.t. Base year Data 2009	±10% Variation	±20% Variation	Long Term (13 Years)
2	15 GL (>50 Ha) w.r.t. June 2022 Monitoring Data	±10% Variation	±20% Variation	Recent Trend (Last two years)
3	85 GL (10 Ha - 50 Ha) w.r.t. Base year Data 2011	±10% Variation	±20% Variation	Long Term (2 years in addition to base year)
4	85 GL (10 Ha - 50 Ha) w.r.t. June 2022 Monitoring Data	±10% Variation	±20% Variation	Recent Trend (Last two years)

Trend analysis helped in categorizing the 100 Glacial lakes into the lakes depicting increasing trend, no change trend and decreasing trend. This was done state/UT wise. The abstract of Glacial Lakes showing Increasing Trend on the above criteria are given in the following **Tables ES.4 & ES.5.**

**Table ES.4** Abstract of Results of comprehensive trend analysis of changes of water spread area of 15 GL (>50 Ha) for increasing trend

State	No of Lakes showing Increasing Trend out of 15 GLs(>50Ha)			
	w.r.t. Base year Data 2009		w.r.t. June 2022 Monitoring Data	
	± 10% Variation	± 20% Variation	± 10% Variation	± 20% Variation
Laddakh	1	1	0	0
Himachal Pradesh	2	2	0	0
Sikkim	7	5	0	0
<b>Total</b>	<b>10</b>	<b>8</b>	<b>0</b>	<b>0</b>

**Table ES.5** Abstract of Results of comprehensive trend analysis of changes of water spread area of 85 GL (10-50 Ha) for increasing trend

State	No of Lakes showing Increasing Trend out of 85 GLs(10-50Ha)			
	w.r.t. Base year Data 2011		w.r.t. June 2022 Monitoring Data	
	± 10% Variation	± 20% Variation	± 10% Variation	± 20% Variation
Ladakh	3	3	1	1
Jammu & Kashmir	5	5	4	4
Himachal Pradesh	4	4	2	2
Uttarakhand	1	1	1	1
Sikkim	8	8	6	5
Arunachal Pradesh	3	3	4	4
<b>Total</b>	<b>24</b>	<b>24</b>	<b>18</b>	<b>17</b>

**Conclusion of Trend Analysis:**

The abstract of comprehensive trend analysis is presented in table ES.6.

**Table ES.6: Abstract of comprehensive trend analysis**

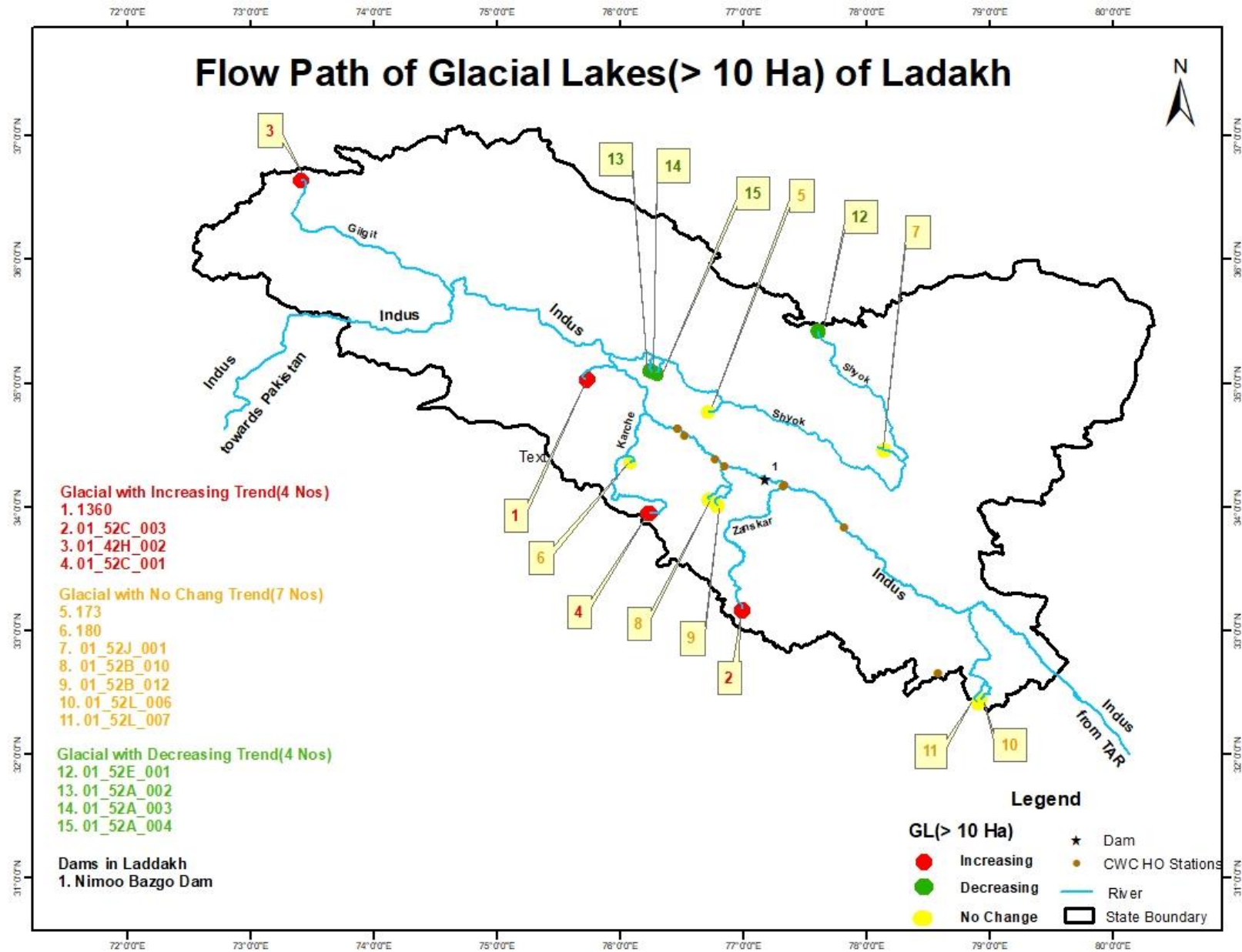
Sl. No.	Trend Analysis carried out for Change in Water spread area of	Lakes showing Increasing Trend		Lakes showing No Change Trend		Lakes showing Decreasing Trend		Lakes with No Analysis	Total no. of Lakes
		±10% Variation	±20% Variation	±10% Variation	±20% Variation	±10% Variation	±20% Variation		
1	15 GL (>50 Ha) w.r.t. Base year Data 2009 (Long Term)	10	8	2	6	3	1	0	15
2	15 GL (>50 Ha) w.r.t. June 2022 Monitoring Data (Recent)	0	0	14	14	1	1	0	15
3	85 GL (10 Ha - 50 Ha) w.r.t. Base year Data 2011 (Long Term)	24	24	42	42	17	17	2	85
4	85 GL (10 Ha - 50 Ha) w.r.t. June 2022 Monitoring Data (Recent)	18	17	46	47	19	19	2	85

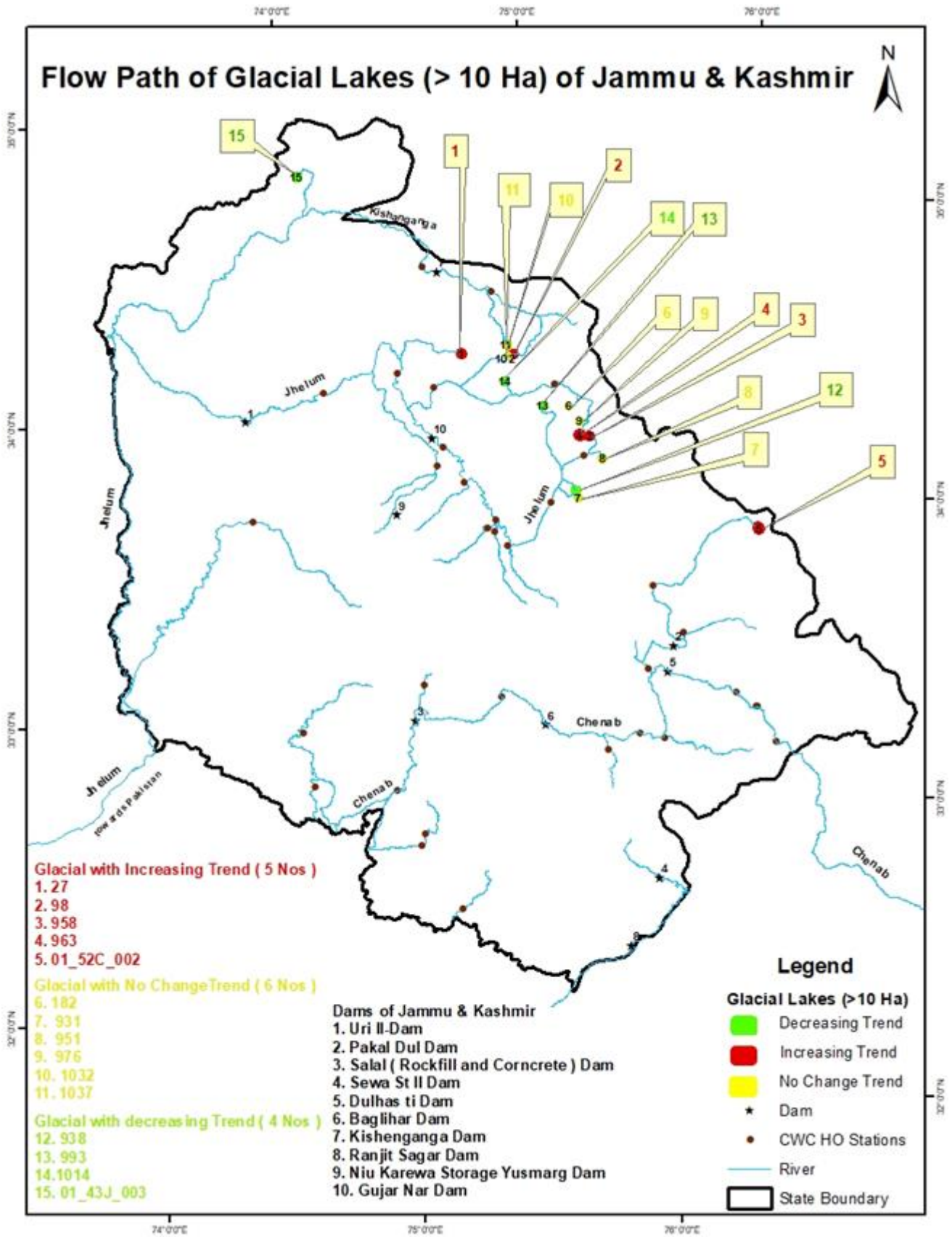
- The number of increasing lakes under  $\pm 10\%$  and  $\pm 20\%$  are more or less the same, which indicates that the Glacial Lakes showing increasing trend has increased more than 20% with reference to baseline data.
- Almost 50% of larger lakes (size >50 Ha) has increase more than 20% whereas 28% of the medium sized lakes (size 10-50 Ha) have increase more than 20%. The interpretation of trend line of individual lakes shows that the medium sized lakes are increasing at a faster pace than larger lakes.
- It is seen that none of the larger lakes have shown increase more than 20% in the recent term, whereas about 20% of the medium sized lakes shown increase more than 20% in recent years.

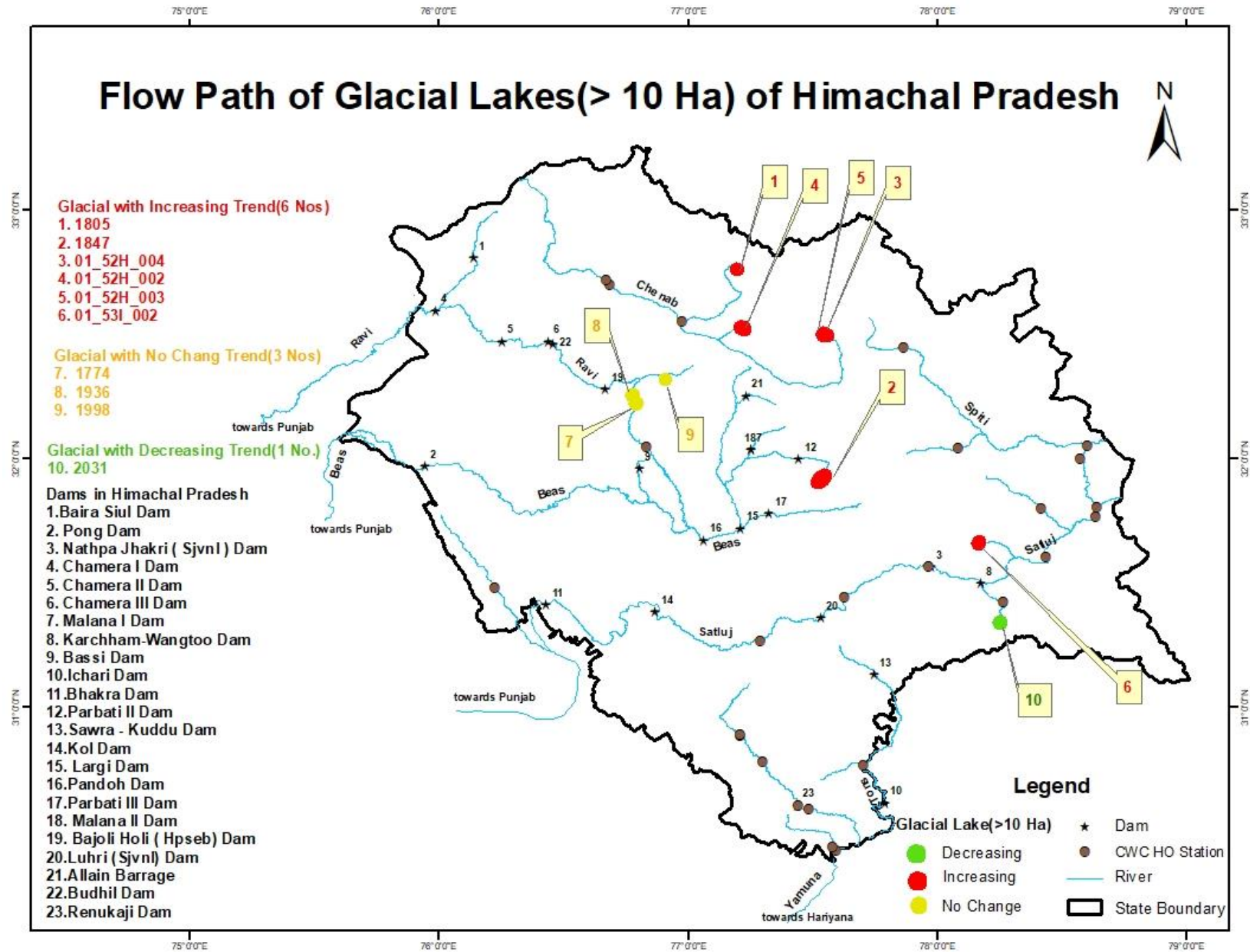
**Section-II:**

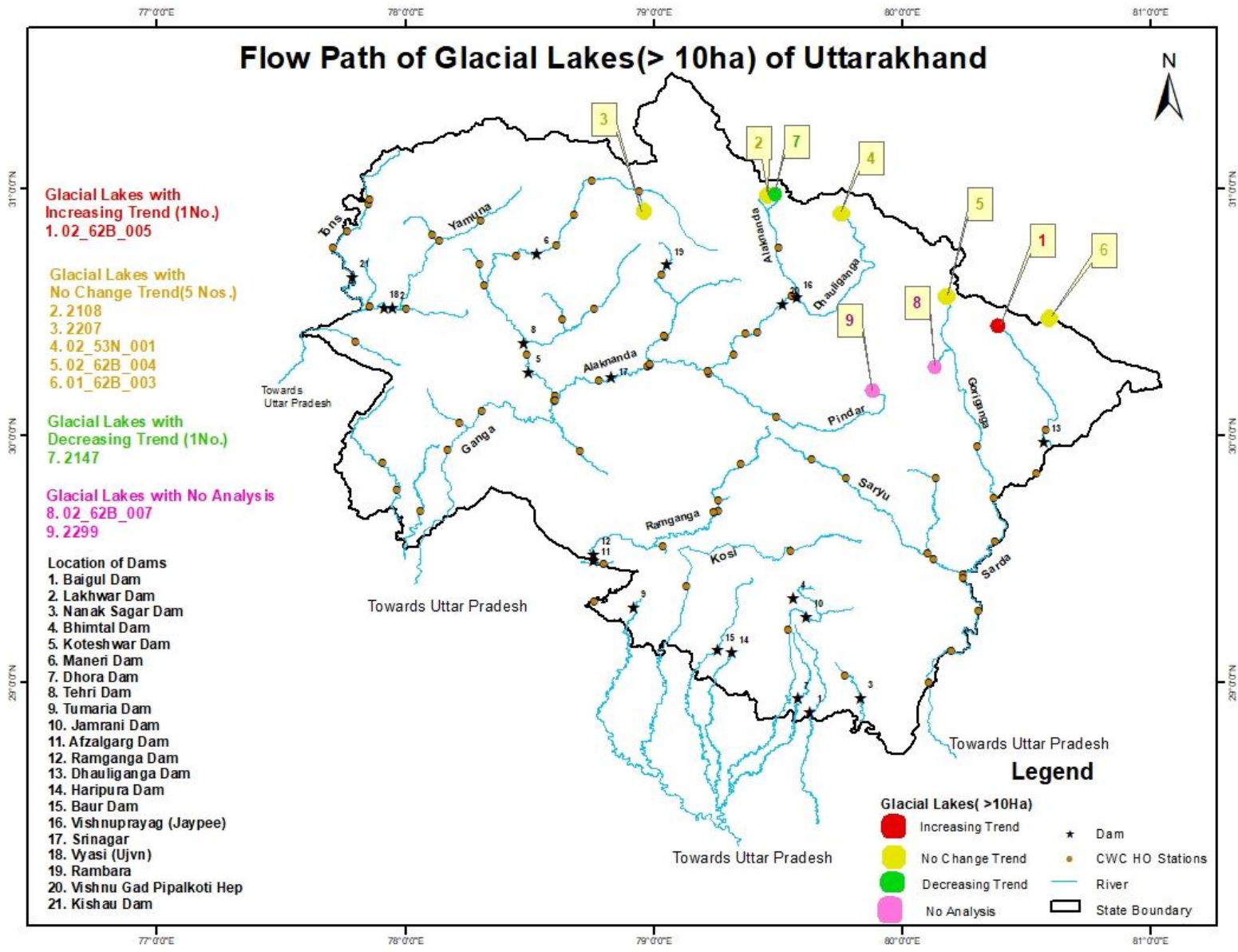
Finally to have knowledge in advance about the impact of damage on settlements, infrastructures, Projects, etc due to breach of Glacial Lake resulting in GLOF, the **flow path for all the 100 Glacial Lakes** have been mapped along with projects and CWC HO stations enroute. This is presented in **Section –II**.

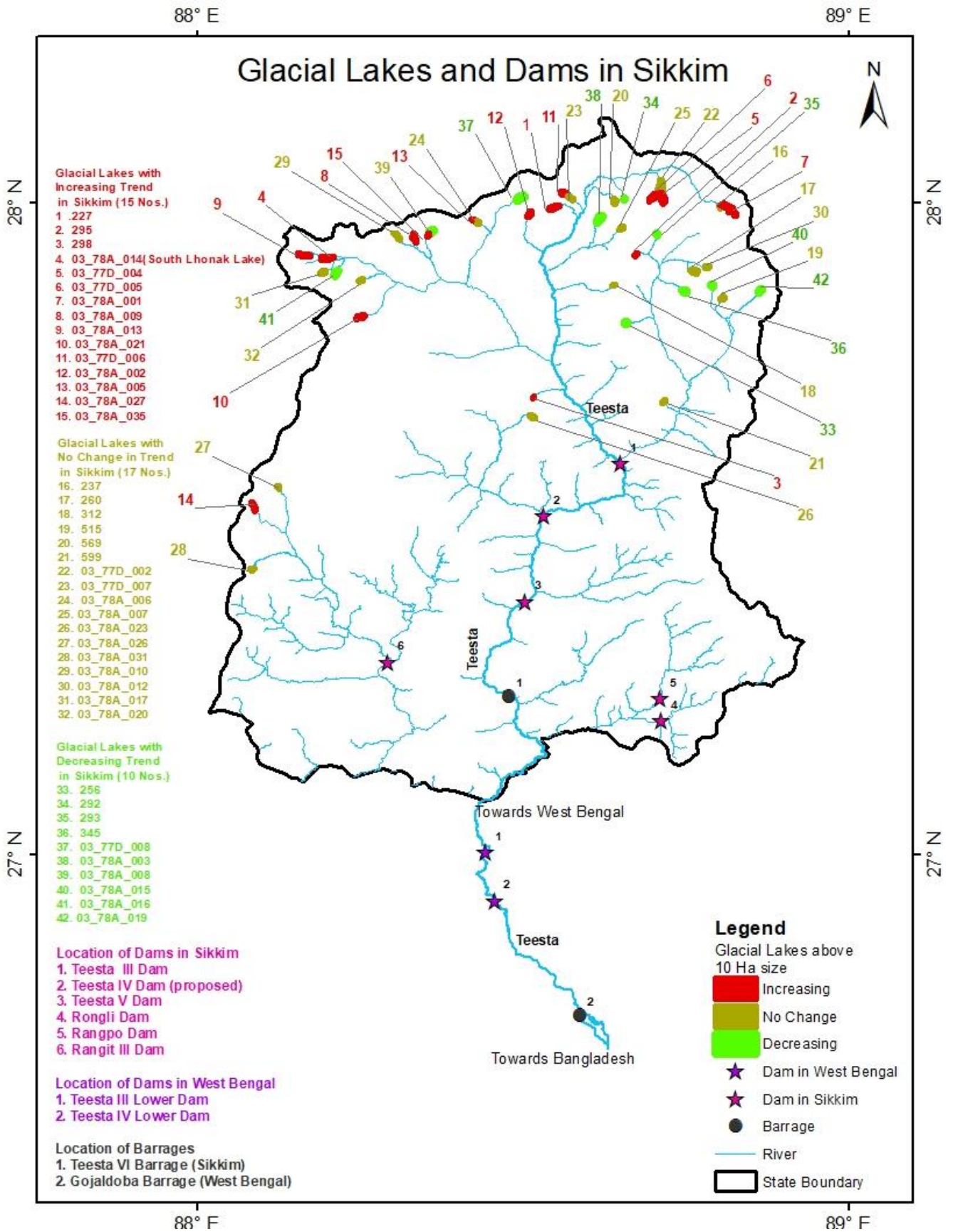
Further mapping of settlements, various infrastructures are in progress. State wise maps are given below.

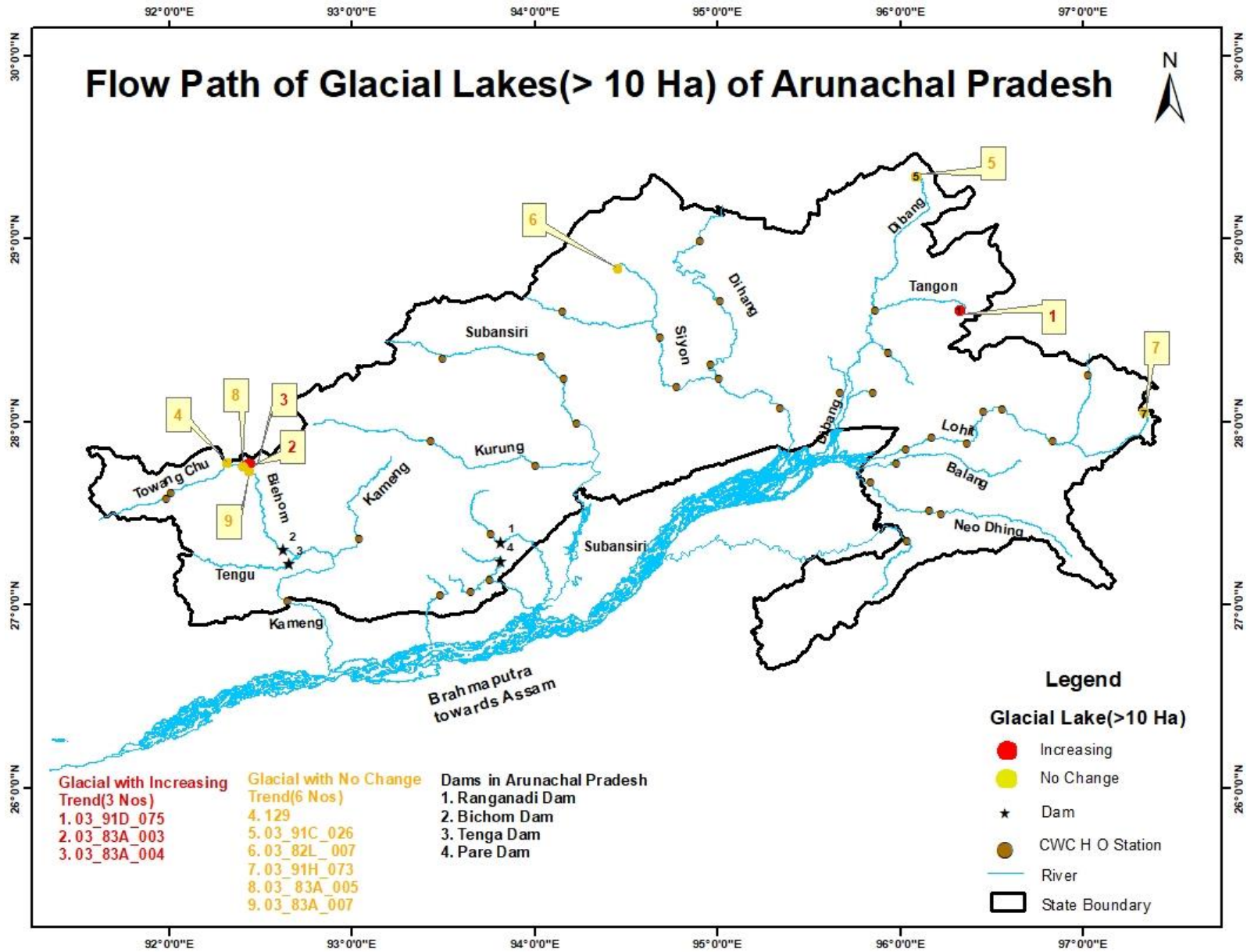












## 1. Introduction

### 1.1 Glacial Lakes and Water Bodies

A glacial lake is a body of water with origins from a glacier. It is formed when a glacier erodes the surface before melting and the melt water fills the resulting depression. The water in Glacial Lakes accumulates behind loose naturally formed 'glacial/moraine dams' made of ice, sand, pebbles and ice residue as the glaciers melt. Various types of lakes may have different levels of hazard potential depending upon many factors such as the nature of damming materials, position of the lake, volume of the water, the nature and position of the associated mother glacier, physical and topographical conditions, and other physical conditions of the surroundings. Interaction between the risk factors and triggering processes such as ice avalanches, debris flows, rock fall, earthquake or landslides reaching a lake strongly affect the risk of a lake outburst. Moraine-dammed lakes located at the snout of a glacier have a high probability of breaching with high hazard potential and can breach suddenly leading to catastrophic floods. Such outburst floods are known as Glacial Lake Outburst Flood (GLOF).

A water Body referred in this report is the body of water retained permanently due to obstruction created naturally or artificially but not directly associated with Glaciers.

### 1.2 Glacial Lakes in Indian Himalayan Region

The Indian Himalayan Region (IHR) contains the world's largest number of glaciers and snow outside the Polar Regions and are aptly called Third Pole of the world. It consist of three major river systems, ie, Indus, Ganga and Brahmaputra stretching over five countries viz. India, China, Nepal, Pakistan and Bhutan.

### 1.3 Inventory of Glacial Lakes & Water Bodies 2011

The work of monitoring of Glacial Lakes/Water Bodies (GLs/WBs) was taken up by CWC, DoWR, RD&DR, Ministry of Jal Shakti, during XI Plan period in the year 2009, under DWRIS Plan scheme. The inventory of glacial lakes and water bodies of the Himalayan region of Indian river basins published in June, 2011 was done in association with National Remote Sensing Centre (NRSC), Hyderabad based on the satellite data of Advanced Wide Field Sensor (AWiFS) of the Indian Remote Sensing Satellite, Resourcesat-1 collected from May to November, 2009. The inventory consisted of a total of 2028 glacial lakes and water bodies with water spread area greater than 10 Ha. The country-wise and basin-wise details of the Inventory are furnished in **Table No. 1.1** and **Table No. 1.2**

**Table 1.1: Country-wise details of Glacial Lakes & Water Bodies of Inventory (2011)**

Country	Glacial Lakes >10 Ha (Nos.)	Water Bodies >10 Ha (Nos.)	Total >10 Ha (Nos.)
India	60	448	508
Bhutan	77	124	201
Nepal	57	45	102
China	309	904	1213
Myanmar	-	4	4
<b>Total</b>	<b>503</b>	<b>1525</b>	<b>2028</b>

**Table 1.2: Basin-wise details of Glacial Lakes & Water Bodies of Inventory (2011)**

Basin Name	Glacial Lakes (Nos.)	Water Bodies (Nos.)	Total (Nos.)
Brahmaputra	294	1099	1393
Ganga	178	105	283
Indus	31	321	352

#### 1.4 Glacial Lake Atlas of Indian Himalayan River Basins in 2023

NRSC has published Glacial Lake Atlas of Indian Himalayan River Basins in the year 2023. The atlas depicts distribution of 28,043 glacial lakes of size greater than 0.25 ha mapped using high resolution Resourcesat-2 LISS4 MX satellite data of 2016-17. The atlas presents the details of glacial lakes in terms of area, type and elevation and administrative unit wise for all three river basins i.e. Indus, Ganga and Brahmaputra. Ten different types of glacial lakes are identified and categorized into four major classes, viz., Moraine-dammed Lake, Ice-dammed lake, Glacier Erosion lake, and Other Glacial lake.

The abstract of Glacial Lakes as per Glacial Atlas of IHR of NRSC 2023 is given in following **Table No. 1.3**

<b>Table 1.3: Abstract of Glacial Lakes as per Glacial Lake Atlas of IHR of NRSC 2023</b>			
<b>Size(Ha)</b>	<b>No of Glacial Lakes</b>		<b>Total</b>
	<b>India</b>	<b>Transboundary</b>	
0.25-1	3342	9194	12536
1-5	2862	7769	10631
5-10	712	1733	2445
10-50	596	1536	2132
>50	58	241	299
<b>Total</b>	<b>7570</b>	<b>20473</b>	<b>28043</b>

## 1.5 Objectives

The broad objectives of the study are

- To detect temporal changes in water spread area of Glacial Lakes & Water Bodies over the monitoring period.
- To do the trend analysis on the changes in water spread area of Glacial lakes located in India with respect to different base data and to classify the Glacial Lakes into three types
  - (i) Glacial Lakes displaying Increasing Trend
  - (ii) Glacial Lakes displaying No Change in Trend
  - (iii) Glacial Lakes displaying Decreasing Trend
- To identify the Glacial lakes showing a consistent increase in water spread area for the period from 2011 to 2023 and to identify the vulnerable Glacial Lakes based on increasing trend.
- To delineate the flow path of all Glacial Lakes in India above 10 ha area and to map the likely damage centre like infrastructure, projects, habitation, etc enroute.
- To share the report with concerned stakeholders including National Disaster Management Authority / State Disaster Management Authority for suitable action.

## 1.6 Limitations, Assumptions and Plans for the future:

### **Limitations:**

- Glacial lake identification can be done either using visual interpretation or automatic mapping methods. The automatic mapping procedures have limitations due to varying terrain conditions like lakes situated in the shadow portions of mountains, presence of snow cover, cloud cover, lakes being partly frozen, foreshortening, layover etc. As lake water absorbs the incident radiation making it appear in darker tone and colour in the standard FCC of satellite data, similar response also prevails over shadow region of clouds or mountains on surface, which may lead to incorrect mapping. Moreover, a mountain shadow covering a lake partly/completely within its vicinity, also make it difficult to accurately map the lake boundary.
- 40 Glacial Lakes, which have been listed as high priority lakes, as per “Synthesis report on GLOF hazard and risk across the Indian Himalayan Region” prepared by Swiss Agency for Development and Cooperation (SDC) for NDMA, was included for monitoring during the year 2022. But the baseline data/inventory for these lakes are unavailable.
- Trend analysis under Section I has been carried out on the monthly monitoring data. It is observed that in several cases, there are wide variations in two successive data. This is perhaps the erroneous water spread area extracted from remote sensing data due to limitations in availability of cloud free images or in processing of remote sensing data.
- Monthly monitoring data of 13 years (2011-2022) is available for 15 Glacial Lakes with water spread area above 50 ha at the time of inventory. For the remaining 85 lakes only two year data (2022-23) is available.
- Trend analysis of 100 Glacial Lakes located within India has only been carried out.

### **Assumptions:**

- Inclusion or exclusion of water pixels near lake boundaries depending on more than or less than certain fraction of its area falling within the lake boundary.
- Linear trend analysis was assumed in Section-I.

### **Plans for Future:**

- Similar Trend Analysis of Transboundary Glacial Lakes(444 Nos.) in the forthcoming reports.
- Mapping of damage centres like habitation and their population, vital infrastructures, landslide susceptible area etc. enroute flow path.

## 2. Monitoring of Glacial Lakes and Water Bodies

### 2.1 Study Area

The present study area covers the Glacial Lakes & Water Bodies (GLs & WBs) lying in the region of Himalaya and TAR, that drain to India, based on 2011 Inventory of NRSC. The study area extends across the countries of India, Nepal, Bhutan and China.

The Glacial Lakes and Water Bodies taken up for monitoring in the study area are as follows:

- (i) **477** Glacial Lakes/Water Bodies, with water spread area greater than 50Ha which have been sourced from the inventory of Glacial Lakes & Water Bodies in the Indian Himalayan region(2011) (Ref: NRSC Report No. NRSC-RS&GISAA-WRG-CWC-Lakes- May2011-TR255).

The state-wise and basin-wise details of the 477 GLs/WBs above 50 Ha are shown in **Table.2.1**

**Table 2.1: State-wise and Basin-wise details of the 477 GLs/WBs above 50 Ha (Nos.)**

Country/ Area	State/UT	Glacial Lake>50Ha				Water Body >50Ha				Grand Total
		Indus Basin	Ganga Basin	Brahma- putra Basin	Total	Indus Basin	Ganga Basin	Brahma- putra Basin	Total	
India	Ladakh	3	0	0	3	26	0	0	26	26
	Jammu & Kashmir	0	0	0	0	16	0	0	16	16
	Himachal Pradesh	2	0	0	2	5	0	0	5	7
	Uttarakhand	0	0	0	0	0	6	0	6	6
	Sikkim	0	0	10	10	0	0	1	1	11
	Arunachal Pradesh	0	0	0	0	0	0	25	25	25
	<b>Total</b>	<b>5</b>	<b>0</b>	<b>10</b>	<b>15</b>	<b>47</b>	<b>6</b>	<b>26</b>	<b>79</b>	<b>94</b>
	<b>India Total</b>	<b>15</b>				<b>79</b>				<b>94</b>
Transboundary	China	1	36	40	77	49	19	191	259	336
	Bhutan	0	0	15	15	0	0	11	11	26
	Nepal	0	12	0	12	0	9	0	9	21
	<b>Total</b>	<b>1</b>	<b>48</b>	<b>55</b>	<b>104</b>	<b>49</b>	<b>28</b>	<b>202</b>	<b>279</b>	<b>383</b>
	<b>Total Transboundary</b>	<b>104</b>				<b>279</b>				<b>383</b>
<b>Grand Total</b>		<b>Total Glacial Lakes = 119</b>				<b>Total Water Bodies = 358</b>				<b>477</b>

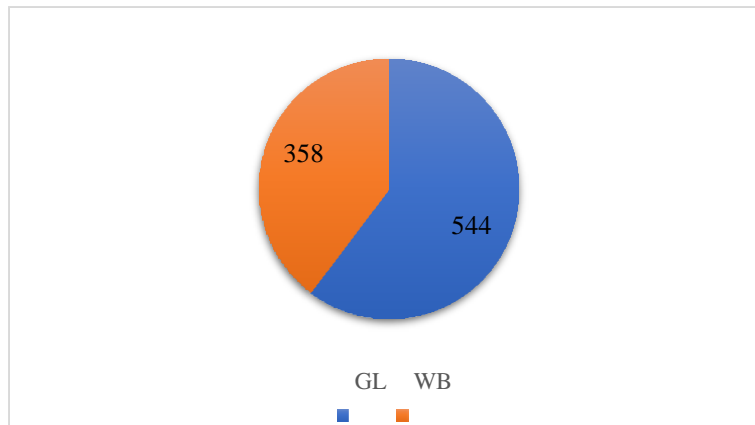
- (ii) **385** Glacial Lakes, with spatial extent greater than 10 ha, have been taken from the inventory of Glacial Lakes & Water Bodies in the Indian Himalayan region(2011) (Ref: NRSC Report No. NRSC-RS&GISAA-WRG-CWC-Lakes-May2011-TR255).
- (iii) **40** Glacial Lakes, which have been listed as high priority lakes, as per “Synthesis report on GLOF hazard and risk across the Indian Himalayan Region” prepared by Swiss Agency for Development and Cooperation (SDC) for NDMA.

This adds up to a total of **425 Glacial Lakes of water spread area between 10Ha and 50Ha**. The state-wise and basin-wise details of these lakes are shown in **Table No. 2.2**.

**Table 2.2: State-wise and Basin-wise details of the 425 GLs/WBs with water spread area between 10Ha and 50 Ha**

Country/Area	Glacial Lake of size 10Ha -50 Ha			Grand Total (Nos.)	
	State/UT	Indus Basin (Nos.)	Ganga Basin (Nos.)		Brahmaputra Basin (Nos.)
India	Ladakh	12	0	0	12
	Jammu & Kashmir	15	0	0	15
	Himachal Pradesh	8	0	0	8
	Uttarakhand	0	9	0	9
	Sikkim	0	0	32	32
	Arunachal Pradesh	0	0	9	9
	<b>Total</b>	<b>35</b>	<b>9</b>	<b>41</b>	<b>85</b>
	<b>India Total</b>	<b>85</b>			
Transboundary	China	11	74	147	232
	Bhutan	0	0	56	56
	Nepal	0	52	0	52
	<b>Total</b>	<b>11</b>	<b>126</b>	<b>203</b>	<b>340</b>
	<b>Total Transboundary</b>	<b>340</b>			
<b>Grand Total</b>		<b>425</b>			

Currently, a total of **902 Glacial Lakes and Water Bodies** are being monitored by CWC. Of these, 544 are Glacial Lakes and 358 are Water Bodies. The break-up of Glacial Lakes and Water Bodies is shown in **Figure 2.1**. The abstract of state-wise and basin-wise details of the 902 GLs & WBs being monitored by CWC on monthly basis are furnished in **Table no. 2.3**.

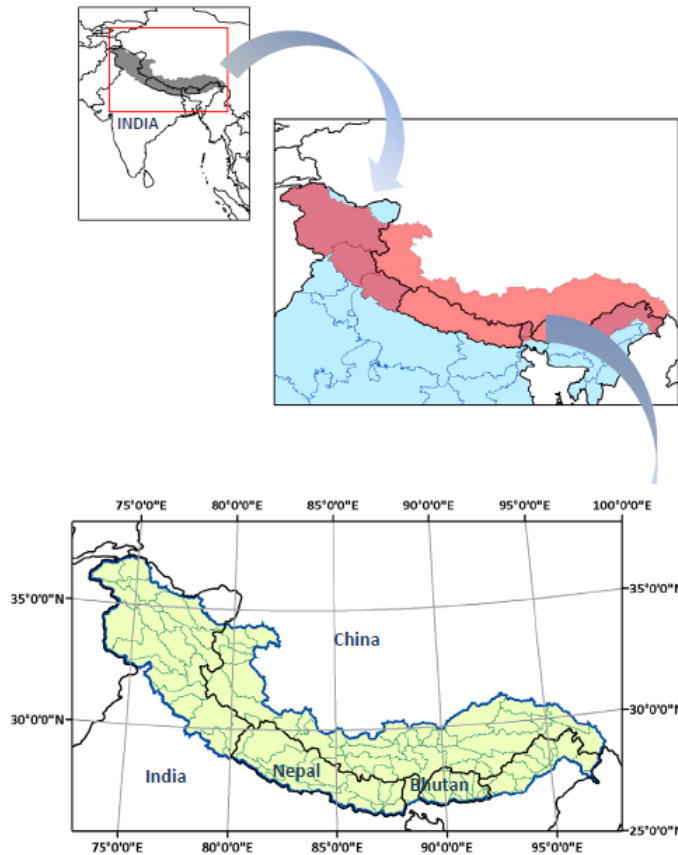


**Figure 2.1: Lake Type Distribution**

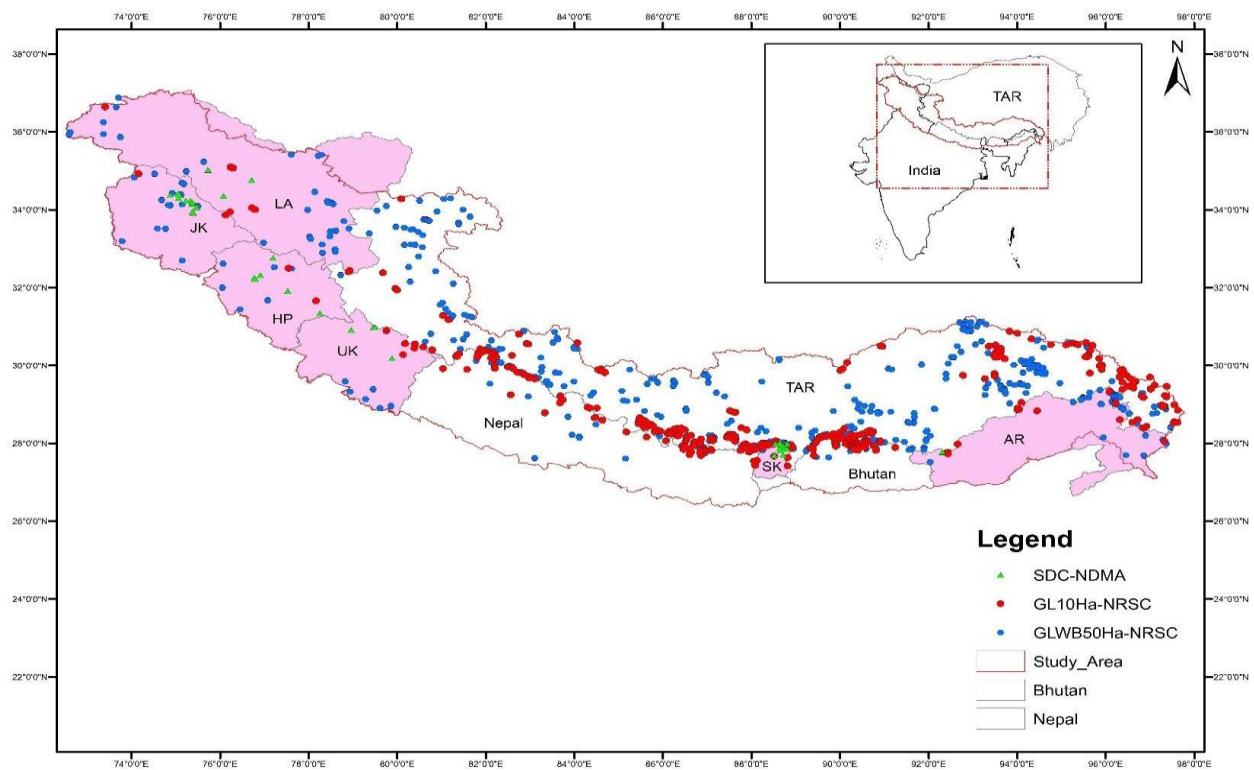
**Table 2.3: Abstract of State-wise & Basin-wise details of GLs&WBs being monitored monthly by CWC**

Country/ Area	State/ Union Territory	No of Glacial Lakes				No of Water Bodies				Grand Total
		Indus Basin	Ganga Basin	Brahma- putra Basin	Total	Indus Basin	Ganga Basin	Brahma- putra Basin	Total	
India	Ladakh	15	0	0	15	26	0	0	26	41
	Jammu & Kashmir	15	0	0	15	16	0	0	16	31
	Himachal Pradesh	10	0	0	10	5	0	0	5	15
	Uttarakhand	0	9	0	9	0	6	0	6	15
	Sikkim	0	0	42	42	0	0	1	1	42
	Arunachal Pradesh	0	0	9	9	0	0	25	25	35
	<b>Total</b>	<b>40</b>	<b>9</b>	<b>51</b>	<b>100</b>	<b>47</b>	<b>6</b>	<b>26</b>	<b>79</b>	<b>179</b>
	<b>India Total</b>	<b>100</b>				<b>79</b>				<b>179</b>
Transboundary	China	12	110	187	309	49	19	191	259	568
	Bhutan	0	0	71	71	0	0	11	11	82
	Nepal	0	64	0	64	0	9	0	9	73
	<b>Total</b>	<b>12</b>	<b>174</b>	<b>258</b>	<b>444</b>	<b>49</b>	<b>28</b>	<b>202</b>	<b>279</b>	<b>723</b>
	<b>Transboundary Total</b>	<b>444</b>				<b>279</b>				<b>723</b>
<b>Grand Total</b>	<b>544</b>				<b>358</b>				<b>902</b>	

The index map of the study area is shown in **Figure. 2.2**, and the location map of the study area showing the glacial lakes and Water Bodies being monitored by CWC is shown in **Figure.2.3**.



**Figure 2.2: Index Map of Study Area**



**Figure 2.3: Map of Study Area showing Glacial Lakes and Water Bodies being monitored by CWC**

The GLs & WBs are mostly located at an elevation range of 3000m to 5500m. A few of them are located above elevation of 5500m and some below 3000m. The elevation of Waterbodies range from 200 m to 5000m. This can be visualized by comparing the location map of study area (**Figure 2.3**) with the relief map of the study area shown in **Figure 2.4**. The elevation range of GLs & WBs being monitored by CWC is shown in **Figure 2.5**



**Figure 2.4: Relief Map of the Study Area**

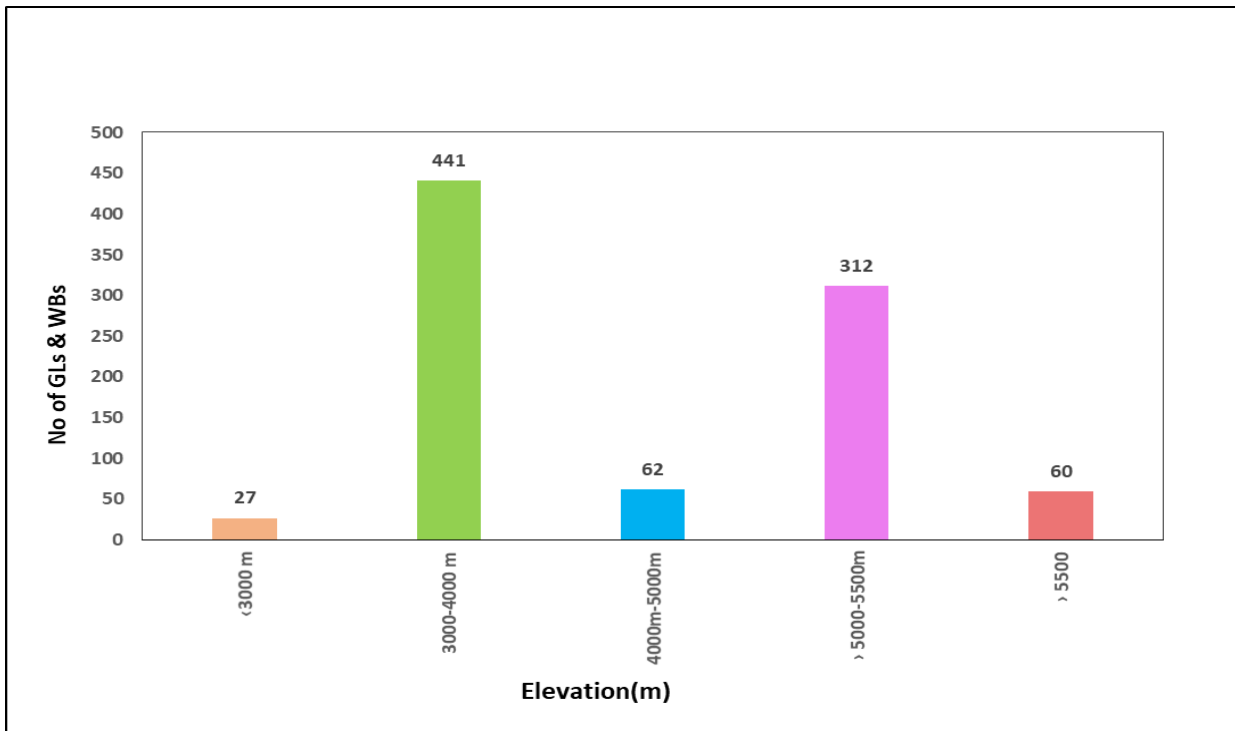


Figure 2.5: Elevation Range of GLs&WBs within Indian Himalayan Region being monitored by CWC

The country-wise distribution of Glacial Lakes & Water Bodies being monitored by CWC is shown in Figure 2.6.

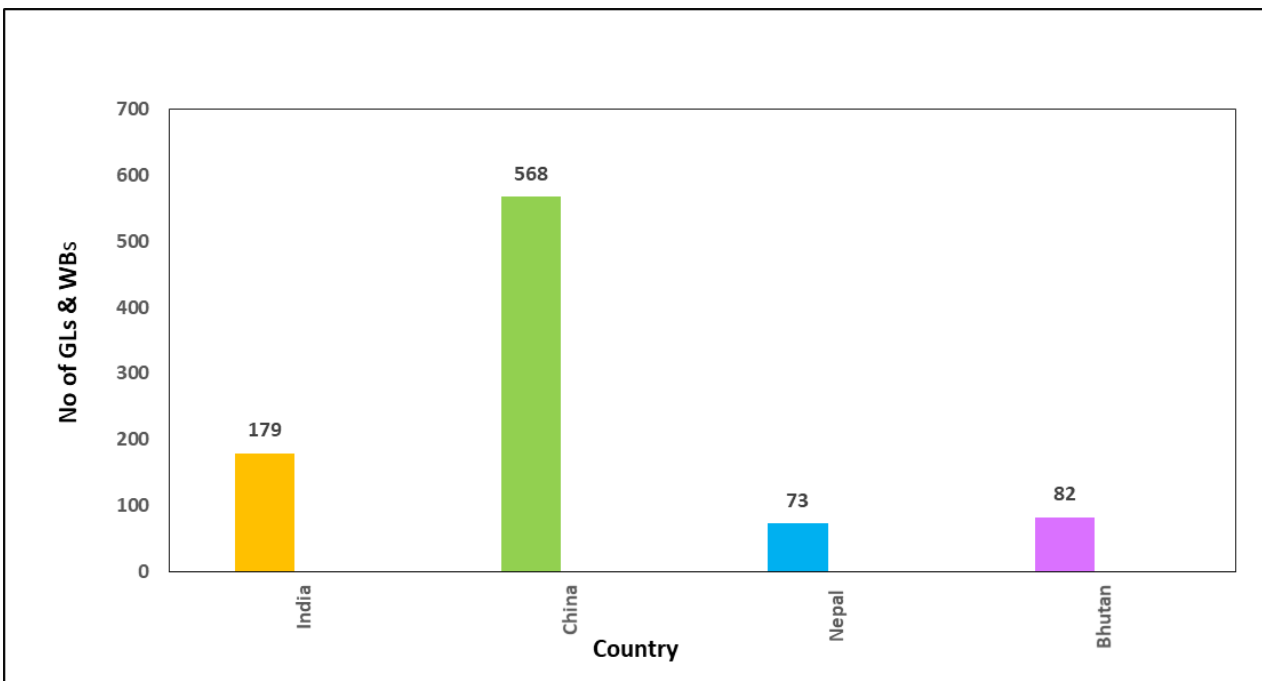
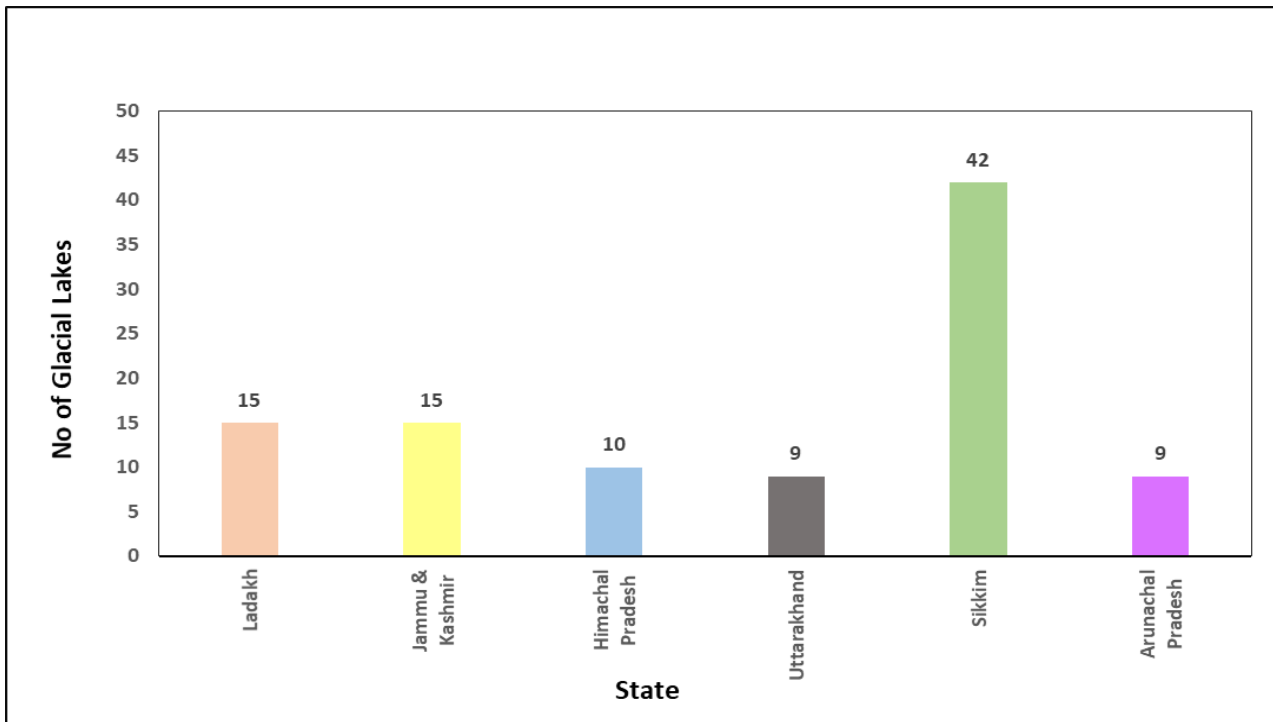


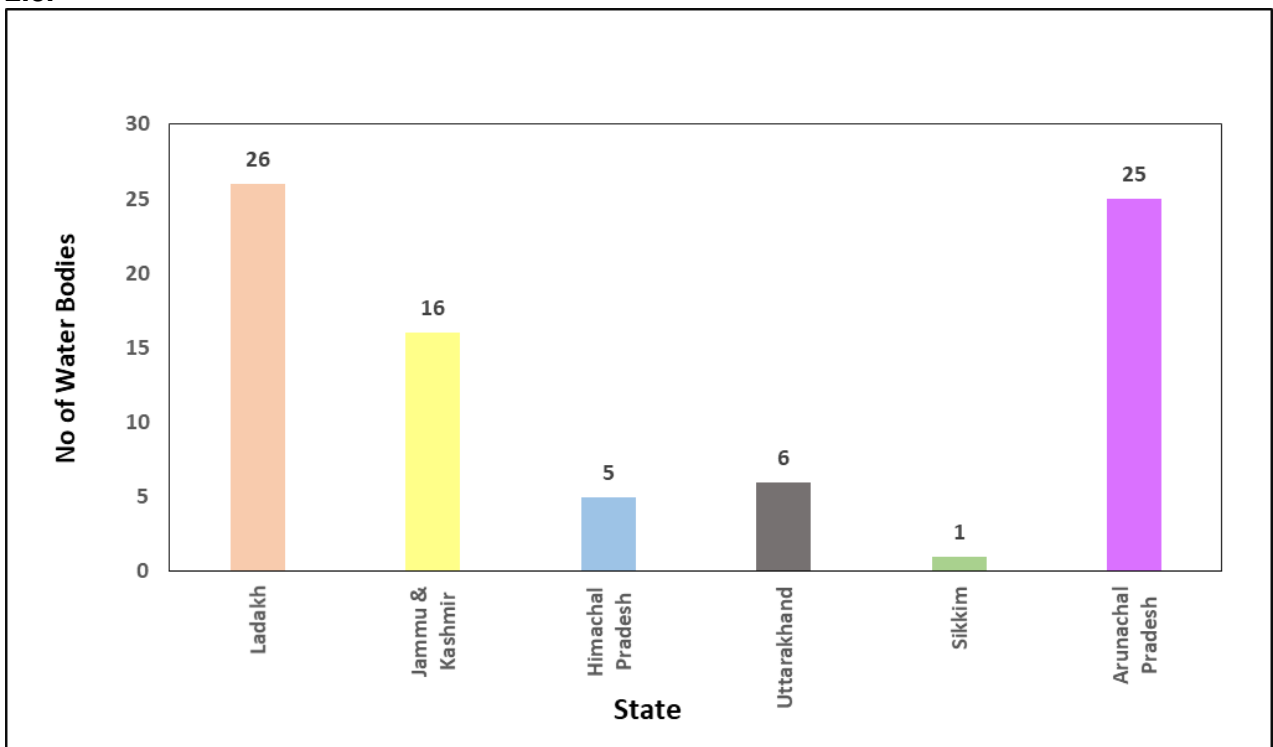
Figure 2.6:Country-wise distribution of GLs & WBs in Indian Himalayan Region being monitored by CWC

The state-wise distribution of Glacial Lakes being monitored by CWC within India is shown in Figure 2.7.



**Figure: 2.7: State-wise Distribution of Glacial Lakes within India being monitored by CWC**

The State-wise distribution of Water Bodies within India being monitored by CWC is shown in **Figure 2.8.**



**Figure: 2.8 State-wise Distribution of Water Bodies being monitored by CWC**

## 2.2 Remote Sensing Technology

Remote sensing is the science of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analysing, and applying that information. Satellite remote sensing technology has contributed significantly to the acquisition of Earth's resources, thus helping in their better management. They also play a complementary role to the conventional data collection procedures. Satellite remote sensing offers several unique advantages like quick and repetitive data collection, reliability, accuracy, geometric integrity and digital storage, which makes it an ideal tool for mapping, inventorying and monitoring the natural resources.

Monitoring of glacial lakes located in remote mountain areas with rugged terrain and inclement weather by traditional means is very tedious and difficult. Hence Remote Sensing data plays a greater role in generating information on glacial lakes. Satellites with high spatial, spectral and temporal resolution sensors are useful in deriving lake information with better accuracy at regular intervals. Visual and digital image processing and analysis techniques integrated with Geographic Information Systems (GIS) are very useful for the study and monitoring of Glacial Lakes and Water Bodies.

The monitoring was done by downloading and manually digitising Advanced Wide Field Sensor (AWiFS) Satellite imagery procured/ downloaded from NRSC till 2021. The SENTINEL-2 Multispectral Imagery (MSI) and Sentinel-1 Synthetic Aperture Radar (SAR) data (Microwave Imagery) have been utilized for the study thereafter.

### 2.2.1 Sentinel-2 Multi Spectral Imagery

The Sentinel-2 mission comprises of a constellation of two polar-orbiting satellites placed in the same sun-synchronous orbit, phased at 180° to each other. It is a wide-swath, high-resolution, multi-spectral imaging mission for monitoring of vegetation, soil and water cover, inland waterways and coastal areas. The SENTINEL-2 payload has visible, near infrared and shortwave infrared sensors sampling 13 spectral bands - 4 bands at 10 m, 6 bands at 20 m and 3 bands at 60 m spatial resolution with a swath width of 290 km. The revisit frequency of each single SENTINEL-2 satellite is 10 days and the combined constellation revisit is 5 days. The Green, Red and NIR bands have been utilized for this study.

### 2.2.2 Sentinel-1 Synthetic Aperture Radar (Microwave Imagery)

The Sentinel-1 mission comprises a constellation of two polar-orbiting satellites, Sentinel-1A and Sentinel-1B, sharing the same orbital plane. It has C-band synthetic aperture radar (SAR) active sensor. Synthetic Aperture Radar (SAR) has the advantage of operating at wavelengths not impeded by cloud cover or a lack of illumination and can acquire data over a site during day or night time under all weather conditions. SAR actively transmits microwave signals towards the Earth and receives a portion of transmitted energy as backscatter from the ground. The SAR instrument provides radar backscatter measurements influenced by the terrain structure and surface roughness. Generally, the more roughness or structure on the ground, the greater the backscatter. Rough surfaces will scatter the energy and return a significant amount back to the antenna resulting in a bright feature. The C-band imaging operates in four exclusive imaging modes with different resolution (down to 5 m) and coverage (up to 400 km). It provides dual polarisation capability, very short revisit times and rapid product delivery. It can transmit a signal in either horizontal (H) or vertical (V) polarisation, and then receive in both H and V polarisations. For each observation, precise measurements of spacecraft position and altitude are available. The repeat orbit cycle of each Sentinel-1 satellite is 12-day. The backscatter intensity of vertical transmit-vertical receive (X) band (VV band) data has been utilized for the study.

### 3. Methodology of Monitoring of Glacial Lakes and Water Bodies using Remote Sensing Techniques - 2011-2023

#### 3.1 Monitoring 2011-2015

The monitoring of glacial lakes and water bodies of size greater than 50 Ha, for the period from 2011 to 2015, was carried out at NRSC, using satellite images of the Advanced Wide Field Sensor (AWiFS) of the Indian remote sensing satellites, Resourcesat -1 & 2. The cloud free images of the study area were selected and orthorectified. Orthorectification is the process by which the geometric distortions of the image are modelled and accounted for, resulting in a planimetrically correct image.

Orthorectification of AWiFS data was carried out using Projective Transform model of 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.

The glacial lakes & water bodies were delineated from orthorectified images through visual interpretation. Identification of features was done using panchromatic mode and/or different colour combinations of the multi-spectral bands namely green, red, near infrared and shortwave infrared in False Colour Composite(FCC).

The boundary of glacial lakes and water bodies were digitized using on-screen digitisation techniques as polygon feature. The polygons were 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 glacial lake/water body among the different dates of satellite for the monitoring month has been considered for the final analysis of the change in water spread.

The criteria followed for monitoring were

- A Change in water spread area within +/- 5% was considered normal in remote sensing derived inventory studies.
- Partly or fully cloud covered or frozen water bodies were not considered in monitoring
- The maximum spatial extent of water spread area during the monitoring month was mapped and compared with the spatial extent of water spread area of the corresponding glacial lake/water body in the inventory, 2011.

#### 3.2 Monitoring 2016-2021

CWC took over monitoring of glacial lakes and water bodies of size greater than 50 Ha during the year 2016. The same methodology as detailed above was followed. Advanced Wide Field Sensor (AWiFS) Satellite imageries were procured/ downloaded from NRSC and were processed in Arc GIS.

### 3.3 Monitoring 2022-2023

The work of monitoring of Glacial Lakes and WaterBodies was expanded during the year 2022. All glacial lakes with size between 10 ha to 50 ha (385 Nos) as per NRSC Inventory 2011 and 40 Glacial lakes identified as high priority lakes by SDC, was included for monitoring, in addition to the 477 GLs&WBs(size>50 Ha). This add up to 902 Glacial Lakes & Water Bodies. Multispectral and Microwave imageries of foreign satellites (Sentinal 1 & 2) was utilized for the study.

Use of a combination of Microwave satellite images in conjunction with multispectral satellite images (MSI) has largely overcome the short-comings due to obscurity from cloud cover and this has led to almost all-time and all-weather monitoring of all 902 Lakes. This has increased availability of satellite images at shorter frequency interval and will facilitate in reducing the monitoring interval in future. Moreover, the use of Sentinel satellite images has brought the improvement of spatial resolution from 56m to10m leading to enhancement of monitoring accuracy. Sentinel images have also aided in improving temporal resolution.

Google Earth Engine(GEE) has been used to process the Multispectral and Microwave Sentinel image data for the monitoring of Glacial Lakes & Water Bodies. Google Earth Engine (GEE) is a cloud-based geospatial analysis platform that enables users to visualize and analyze satellite images. The Microwave and Multispectral Satellite works on different principle, and hence separate methodology has been adopted to compute the water spread area of GL&WBs in an automatic manner.

Multispectral data consist of visible and infrared bands. The spectral combination of NIR, red & green bands is used to generate false colour composite (FCC). The Normalised Difference Water Index (NDWI) is computed using green and NIR band. The process of calculation of NDWI and FCC is repeated for each GL&WB. The OTSU algorithm is further used to identify the threshold of NDWI for segregating water pixels from other types of features. The detected water pixels are further summed to calculate water spread area in the region of interest.

Microwave data of Sentinel-1 is a phase-preserving dual polarisation SAR system. The backscatter intensity of vertical transmit vertical receive (X) band has been used to distinguish water pixels from other types of features. The OTSU algorithm is further used to identify the threshold of backscatter intensity for segregation. The water spread area of each lake has been calculated by summation of water pixels in the region of interest.

The automated area of the GL&WBs are then manually verified in GEE. The lakes which show discrepancy in automated area extraction are required to be delineated manually based on the visual interpretation. This is required as the region being monitored is rugged terrain with steep mountains and valleys, which may lead to effects like foreshortening, layover, mountain shadows etc in the microwave/SAR data. Cloud cover hinders the performance of Multispectral Satellite images.

The change detection in water spread area of Lake has been calculated for following three cases in each month.

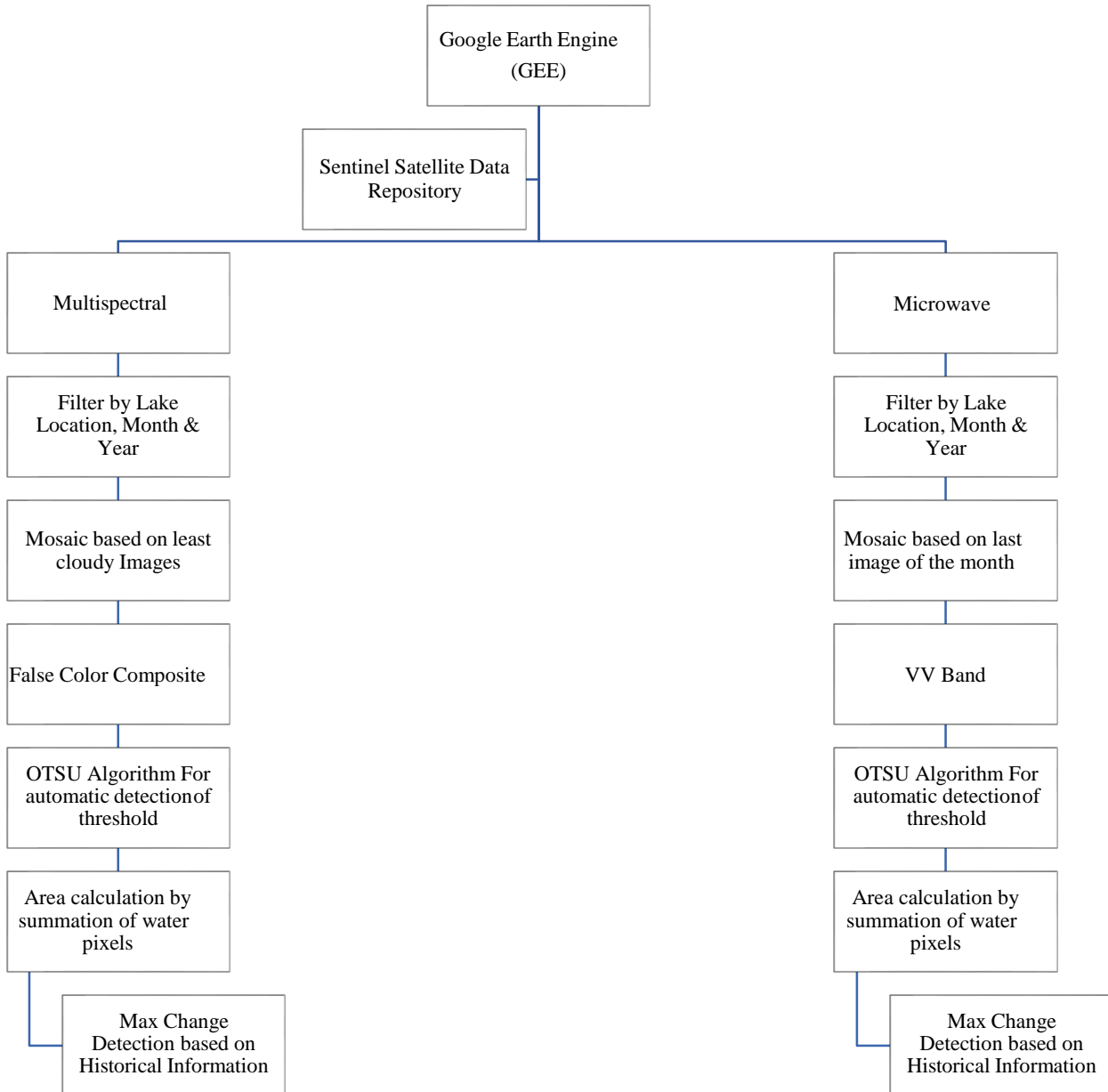
- Difference between the current area of lake and base year(2009)
- Difference between the current area of lake and Last five years average area
- Difference between the current area of lake and Last ten years average area

The minimum of change observed in three cases has been adopted to identify increase, decrease and no change in water spread area.

Then the lakes have been categorized as lakes with increase in water spread area greater than

40%, increase in water spread area up to 40%, no change in water spread area, decrease in water spread area and lakes for which analysis could not be performed due to limitations in remote sensing technology such as cloud cover, frozen condition, dried up condition etc.

The detailed flow-chart of methodology for automatic monitoring of Glacial Lakes and Water Bodies using satellite images is given below in **Figure 3.1**



**Figure 3.1: Methodology of automatic monitoring of Glacial Lakes & Water Bodies using Satellite Image**

# Section-I

Comprehensive analysis of changes in water spread area of 100 GLs since 2009/2011

## 4. Cumulative Change in Water spread Area of Glacial Lakes

### 4.1 Introduction

Climate change pose a profound impact on snow, ice and glaciers worldwide, causing them to recede at an unprecedented rate. As global temperatures rise, glaciers melt more rapidly than they can accumulate new snow, leading to a net loss in glacier mass, known as glacier recession. Glacier recession can lead to the formation of new glacial lakes and increase in water spread area of existing Glacial Lakes in mountainous terrains. As glacial lakes grow, the likelihood of glacial lake outburst floods (GLOFs) in high altitude areas increases.

CWC has started the work of monitoring Glacial Lakes of Indian Himalayan region draining to India, since 2011. **119 Glacial Lakes** of size greater than 50 Ha, of NRSC inventory 2011, was being monitored till 2021. During 2022, the additional 385 GL, of NRSC inventory 2011, and 40 GL identified by SDC, has been included for monitoring. Thus a total of **544 Glacial Lakes** are being monitored presently.

### 4.2. Cumulative Statistics of Monitored Glacial Lakes

The total Inventory area of Glacial Lakes was **20,647 Ha** during the year 2011 which has increased to **23,329 Ha** during the year 2023(October data). This is shown in the figure 4.1. There is a **12.99%** increase in area. *(This includes only 495 lakes out of 544 GL. 40 SDC lakes which have no inventory details as well as lakes which were not analysed during the year 2023 have been excluded.)*

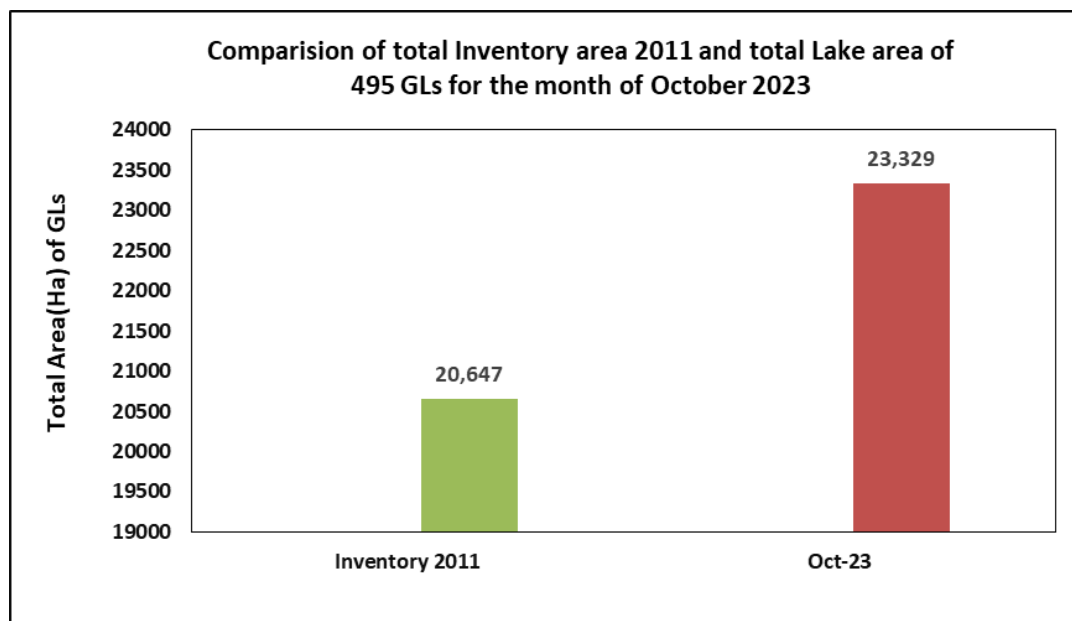
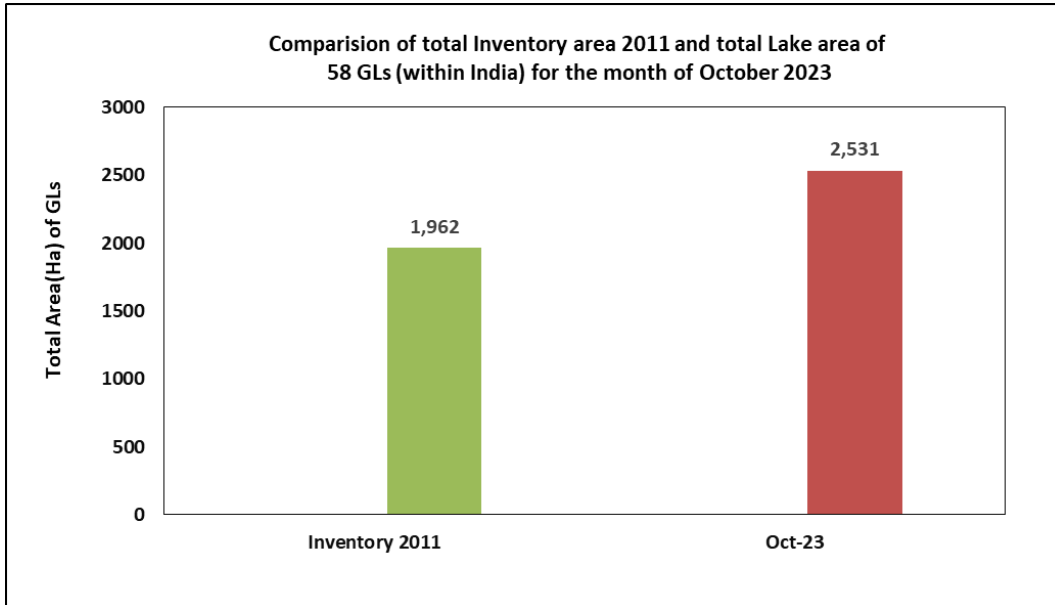


Figure 4.1: Comparison of total Inventory area (2011) and total area of October 2023 of 495 GLs

### 4.3. Cumulative Statistics of Glacial Lakes located in India

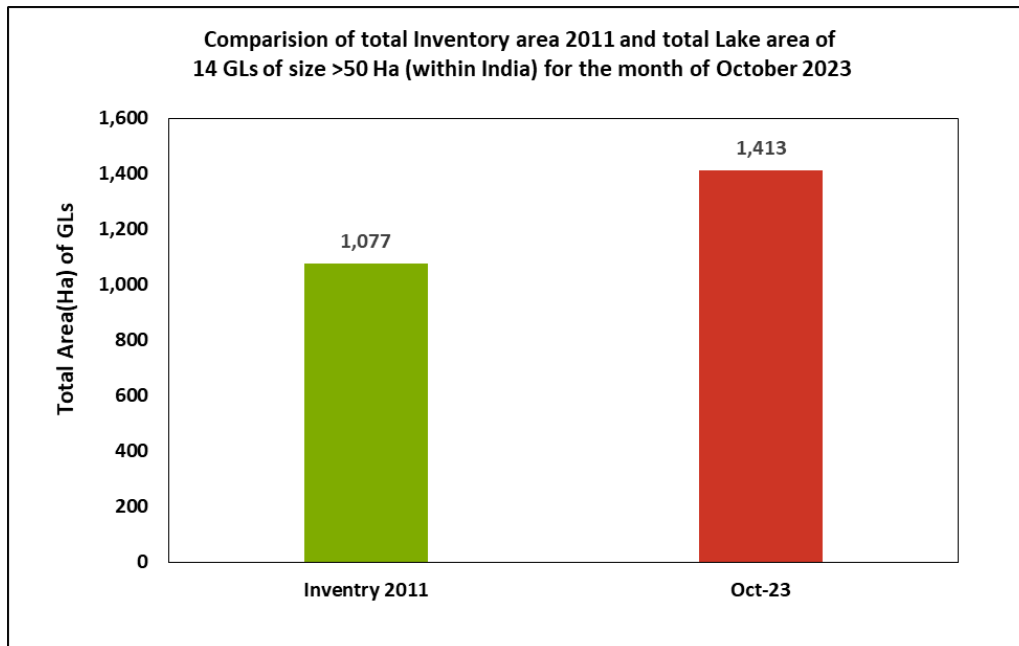
There are a total of **100 Glacial Lakes** in India being monitored by Central Water Commission. Out of this, 15 Glacial Lakes have a water spread area greater than 50 Ha being monitored from 2011, and 85 Glacial Lakes have a water spread area between 10 ha to 50 ha, being monitored from 2022. They are spread across the states of Himachal Pradesh, Uttarakhand, Sikkim & Arunachal Pradesh and union territories of Jammu & Kashmir and Ladakh.

The total Inventory area of Glacial Lakes within India was **1,962 Ha** during the year 2011 which has increased to **2,531 Ha** during the year 2023(October data). There is a **29%** increase in area. This is shown in the figure 4.2. *(This includes only 58 lakes out of 100 GL. 40 SDC lakes which have no inventory details as well as lakes which were not analysed during the year 2023 have been excluded.)*



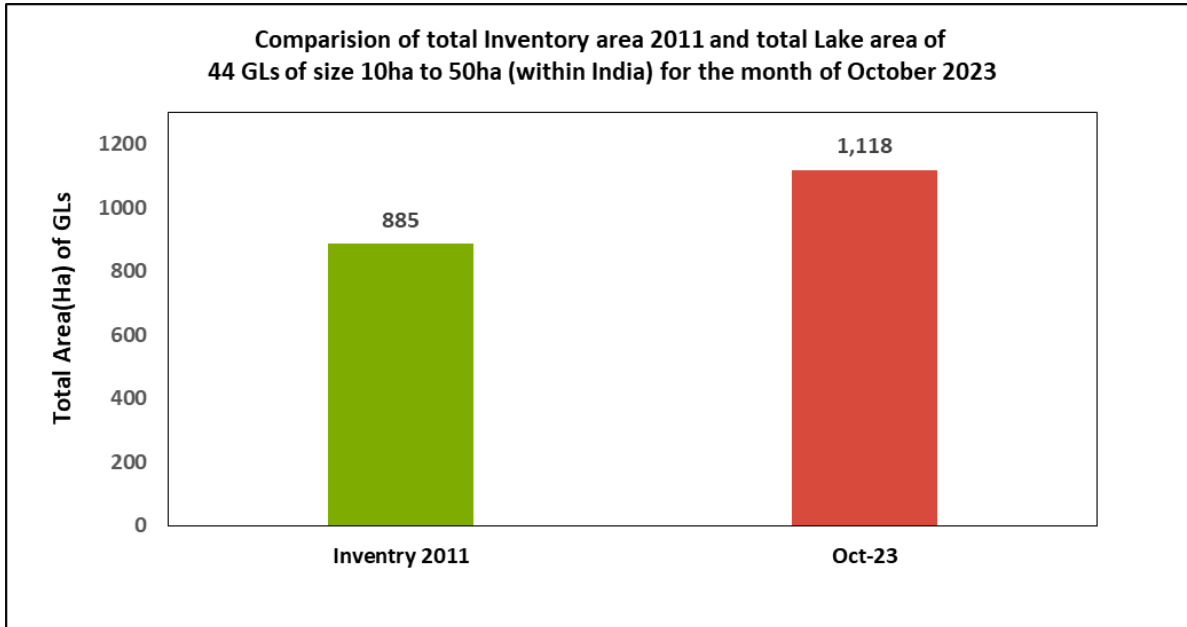
**Figure 4.2: Comparison of total Inventory area (2011) and total area of October 2023 of 58 GLs located in India**

**4.3.1** The total Inventory area of **15 Glacial Lakes of area > 50Ha** was **1077 Ha** during the year 2011 which has increased to **1413 Ha** during the year 2023(October data). There is a **31.2%** increase in area. This is shown in the figure 4.3. *(This includes only 14 lakes out of 15 GL. One lake which was not analysed during the year 2023 have been excluded)*



**Figure 4.3: Comparison of total Inventory area (2011) and total area of October 2023 of 14 GLs (size > 50Ha) located in India**

**4.3.2** The total Inventory area of **85 Glacial Lakes of area 10- 50Ha** was **885 Ha** during the year 2011 which has increased to **1118 Ha** during the year 2023(October data). There is a **26.3%** increase in area. This is shown in the figure below. *(This includes only 45 lakes out of 85 GL. 40 SDC lakes which have no inventory details have been excluded)*



**Figure 4.4: Comparison of total Inventory area (2011) and total area of October 2023 of 44 GLs (size 10 Ha to 50Ha) located in India**

The statistics of increasing water spread area of Glacial Lakes highlights the urgent need for risk assessment and mitigation planning in high risk mountainous communities that may be exposed to GLOFs, as the planet warms. Hence, a need had arisen to analyse the trend of change in water spread area of Glacial Lakes in detail through the timeline using the available monthly monitoring data.

#### **4.4 Trend Analysis of Change in Waterspread Area of Glacial Lakes**

Trend analysis is a quantitative review of what happens over a period of time. It entails the collection of data from multiple time periods and plotting the information on a line graph for further analysis. It predicts future behaviour on the basis of past data.

Trend analysis of Glacial Lakes for change in Waterspread area based on monthly monitoring data provides an idea on the behavior of the lake in respect to growth or decline in area. Linear trend analysis was adopted as linear trends are easier to interpret. Initially it was decided to carry out trend analysis of 100 Glacial Lakes located within India. The criteria adopted for trend analysis is given in **table 4.1**.

Table 4.1: Criteria for Trend Analysis

Sl. No.	Trend Analysis carried out for Change in Water spread area of			Trend
1	15 GL (>50 Ha) w.r.t. Base year Data 2009	±10% Variation	±20% Variation	Long Term (13 Years)
2	15 GL (>50 Ha) w.r.t. June 2022 Monitoring Data	±10% Variation	±20% Variation	Recent Trend (Last two years)
3	85 GL (10 Ha - 50 Ha) w.r.t. Base year Data 2011	±10% Variation	±20% Variation	Long Term (2 years in addition to base year)
4	85 GL (10 Ha - 50 Ha) w.r.t. June 2022 Monitoring Data	±10% Variation	±20% Variation	Recent Trend (Last two years)

#### 4.5 Methodology for Trend Analysis

Linear trend analysis was carried out for 100 Glacial Lakes within India for change in Water spread area under two categories—15 Glacial Lakes of water spread area greater than 50 Ha and 85 Glacial Lakes of water spread area between 10 Ha to 50 ha considering variation of  $\pm 10\%$  &  $\pm 20\%$ . The inventory area of the year 2009 / 2011 along with monthly monitoring data for 13 / 2 years (2011 to 2023 / 2022 to 2023) in chronological order has been plotted with **Time** along the X-axis and **Water-spread area** along the Y-axis depicting the periodic variation in water spread area for each of the lakes. The unavailable data due to cloud cover, frozen lake condition, etc. were not considered for the analysis. A band has been created with base data(2009 /2011/June 2022)  $\pm 10\%$ / $\pm 20\%$  of base data. A Linear trend line was generated for each of the lakes. The trend line was used to categorize the lakes into three classes - lakes with increasing trend, no change trend and decreasing trend, depending on the last point of trend line lying above, within or below the band respectively.

A sample data set of South Lhonak Lake (Lake ID: 03\_78A\_014), Sikkim, **with water spread area > 50 Ha**, considered for linear trend analysis for change in Water spread area for  $\pm 10\%$  &  $\pm 20\%$  variation w.r.t. base year data of 2009 & 2022 are shown in table 4.2(i & ii) & 4.3(i & ii) respectively. The respective trend analysis plots are shown in Figure 4.5(i & ii) & 4.6 (i & ii).

Similarly, a sample data set of Lake ID: 03\_83A\_003, Arunachal Pradesh, **with water spread area between 10 Ha to 50 Ha**, considered for linear trend analysis for change in Water spread area for  $\pm 10\%$  &  $\pm 20\%$  variation w.r.t. base year data of 2011 & 2022 are shown in table 4.4(i & ii) & 4.5(i & ii) respectively. The respective trend analysis plots are shown in Figure 4.7(i & ii) & 4.8 (i & ii).

**Table 4.2: Data set of South Lhonak Lake (Lake ID: 03\_78A\_014), Sikkim, for  $\pm 10\%$  &  $\pm 20\%$  variation w.r.t. Base Year data of 2009**

**(i)  $\pm 10\%$  variation**

Month	Area (Ha)	+ 10 % variation w.r.t base data (Inventory 2009)	-10 % variation w.r.t base data (Inventory 2009)
Inventory 2009	94	103.4	84.6
Inventory 2011	132	103.4	84.6
Jun-11	136	103.4	84.6
Jul-11	136	103.4	84.6
Aug-11	136	103.4	84.6
Sep-11	134	103.4	84.6
Oct-11	126	103.4	84.6
Jun-12	100	103.4	84.6
Jul-12	100	103.4	84.6
Aug-12	100	103.4	84.6
Sep-12	102	103.4	84.6
Oct-12	99	103.4	84.6
Jun-13	117	103.4	84.6
Jul-13	113	103.4	84.6
Aug-13	113	103.4	84.6
Sep-13	115	103.4	84.6
Oct-13	109	103.4	84.6
Jun-14	100	103.4	84.6
Jul-14	100	103.4	84.6
Aug-14	100	103.4	84.6
Sep-14	117	103.4	84.6
Oct-14	128	103.4	84.6
Jun-16	128	103.4	84.6
Jul-16	128	103.4	84.6
Aug-16	128	103.4	84.6
Sep-16	99	103.4	84.6
Oct-16	99	103.4	84.6
Jun-17	99	103.4	84.6
Jul-17	99	103.4	84.6
Aug-17	99	103.4	84.6
Sep-17	99	103.4	84.6
Oct-17	131	103.4	84.6
Jun-18	138	103.4	84.6
Jul-18	138	103.4	84.6
Aug-18	138	103.4	84.6
Sep-18	156	103.4	84.6
Oct-18	156	103.4	84.6
Jun-19	156	103.4	84.6
Jul-19	156	103.4	84.6
Aug-19	156	103.4	84.6
Sep-19	156	103.4	84.6
Oct-19	156	103.4	84.6
Jun-20	156	103.4	84.6
Jul-20	156	103.4	84.6
Aug-20	148	103.4	84.6
Sep-20	148	103.4	84.6
Oct-20	150	103.4	84.6
Jun-21	150	103.4	84.6
Jul-21	150	103.4	84.6
Aug-21	145	103.4	84.6
Sep-21	154	103.4	84.6
Oct-21	146	103.4	84.6
Jun-22	154	103.4	84.6
Jul-22	156	103.4	84.6
Aug-22	166	103.4	84.6
Sep-22	169	103.4	84.6
Oct-22	149	103.4	84.6
Jun-23	142	103.4	84.6
Jul-23	156	103.4	84.6
Aug-23	155	103.4	84.6
Sep-23	171	103.4	84.6
5th October-23	130	103.4	84.6
Oct-23	147	103.4	84.6

**(ii)  $\pm 20\%$  variation**

Month	Area (Ha)	+ 20 % variation w.r.t base data (Inventory 2009)	-20 % variation w.r.t base data (Inventory 2009)
Inventory 2009	94	112.8	75.2
Inventory 2011	132	112.8	75.2
Jun-11	136	112.8	75.2
Jul-11	136	112.8	75.2
Aug-11	136	112.8	75.2
Sep-11	134	112.8	75.2
Oct-11	126	112.8	75.2
Jun-12	100	112.8	75.2
Jul-12	100	112.8	75.2
Aug-12	100	112.8	75.2
Sep-12	102	112.8	75.2
Oct-12	99	112.8	75.2
Jun-13	117	112.8	75.2
Jul-13	113	112.8	75.2
Aug-13	113	112.8	75.2
Sep-13	115	112.8	75.2
Oct-13	109	112.8	75.2
Jun-14	100	112.8	75.2
Jul-14	100	112.8	75.2
Aug-14	100	112.8	75.2
Sep-14	117	112.8	75.2
Oct-14	128	112.8	75.2
Jun-16	128	112.8	75.2
Jul-16	128	112.8	75.2
Aug-16	128	112.8	75.2
Sep-16	99	112.8	75.2
Oct-16	99	112.8	75.2
Jun-17	99	112.8	75.2
Jul-17	99	112.8	75.2
Aug-17	99	112.8	75.2
Sep-17	99	112.8	75.2
Oct-17	131	112.8	75.2
Jun-18	138	112.8	75.2
Jul-18	138	112.8	75.2
Aug-18	138	112.8	75.2
Sep-18	156	112.8	75.2
Oct-18	156	112.8	75.2
Jun-19	156	112.8	75.2
Jul-19	156	112.8	75.2
Aug-19	156	112.8	75.2
Sep-19	156	112.8	75.2
Oct-19	156	112.8	75.2
Jun-20	156	112.8	75.2
Jul-20	156	112.8	75.2
Aug-20	148	112.8	75.2
Sep-20	148	112.8	75.2
Oct-20	150	112.8	75.2
Jun-21	150	112.8	75.2
Jul-21	150	112.8	75.2
Aug-21	145	112.8	75.2
Sep-21	154	112.8	75.2
Oct-21	146	112.8	75.2
Jun-22	154	112.8	75.2
Jul-22	156	112.8	75.2
Aug-22	166	112.8	75.2
Sep-22	169	112.8	75.2
Oct-22	149	112.8	75.2
Jun-23	142	112.8	75.2
Jul-23	156	112.8	75.2
Aug-23	155	112.8	75.2
Sep-23	171	112.8	75.2
5th October-23	130	112.8	75.2
Oct-23	147	112.8	75.2

Note: Glacial Lake Outburst Flood(GLOF) of South Lhonak Lake, Sikkim, on 04<sup>th</sup> October 2023, leading to a decrease in water level on 05<sup>th</sup> October 2023.

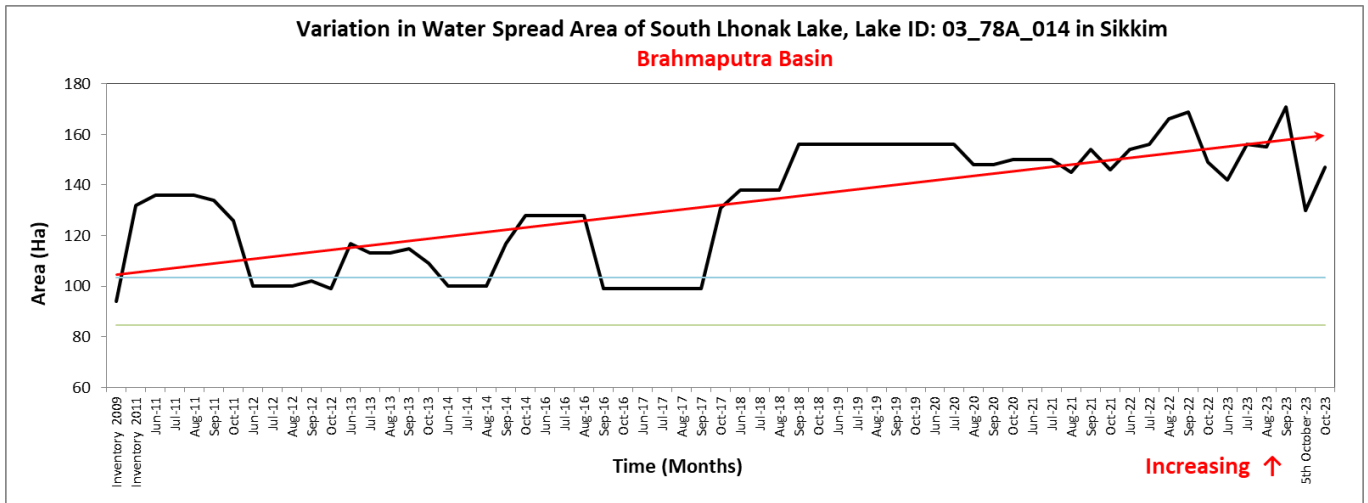


Figure 4.5(i): Trend Analysis plot of South Lhonak Lake (Lake ID: 03\_78A\_014), Sikkim, for ± 10% variation w.r.t. Base Year data of 2009

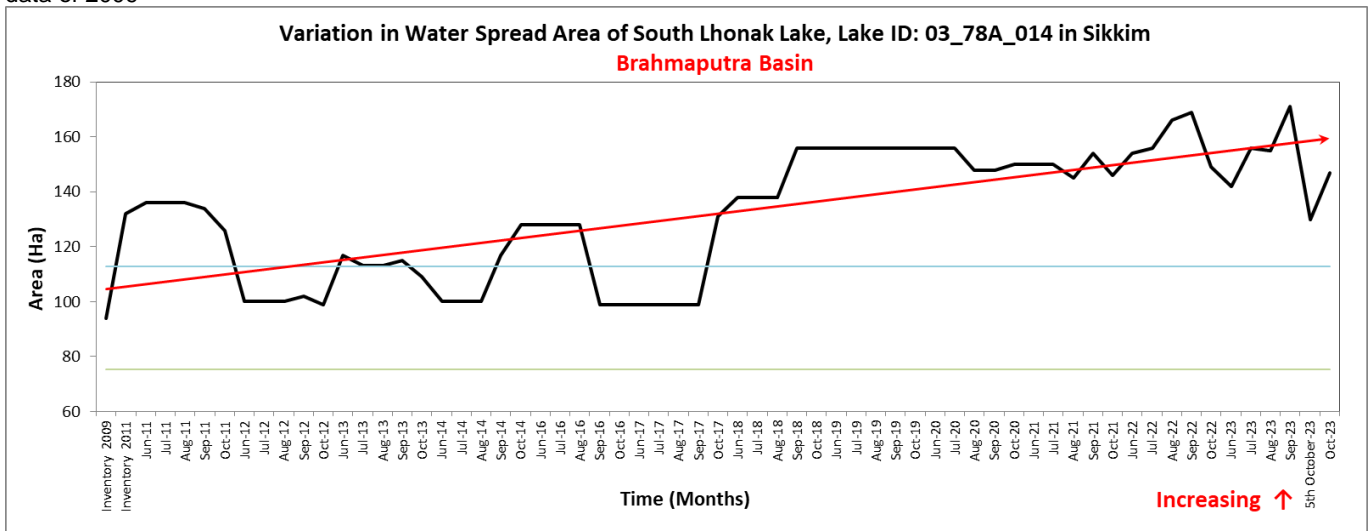


Figure 4.5(ii): Trend Analysis plot of South Lhonak Lake (Lake ID: 03\_78A\_014), Sikkim, for ± 20% variation w.r.t. Base Year data of 2009

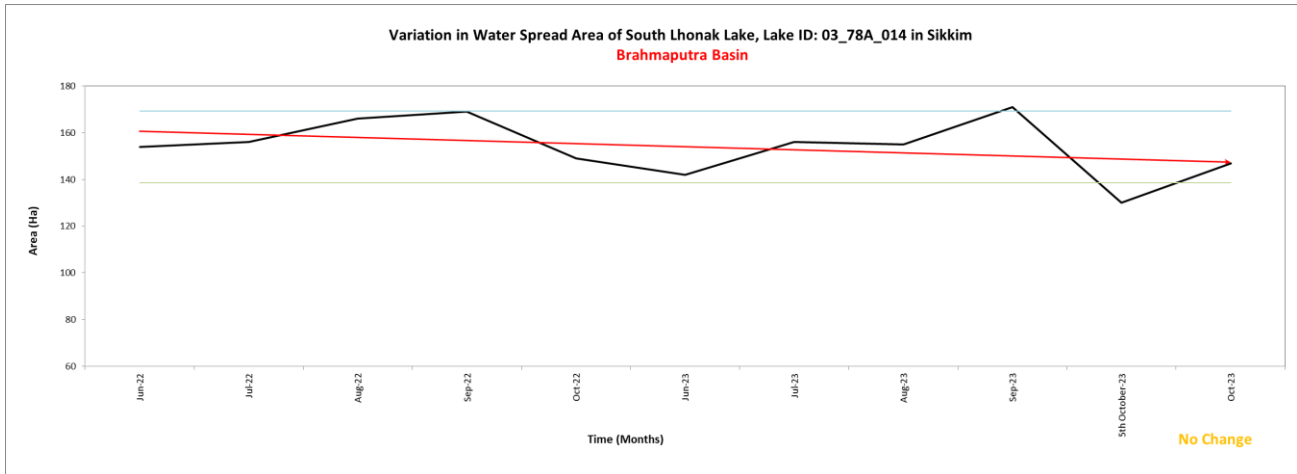
Table 4.3: Data set of South Lhonak Lake (Lake ID: 03\_78A\_014), Sikkim, for ± 10% & ± 20% variation w.r.t. Base Year data of June 2022

(i) ± 10% variation

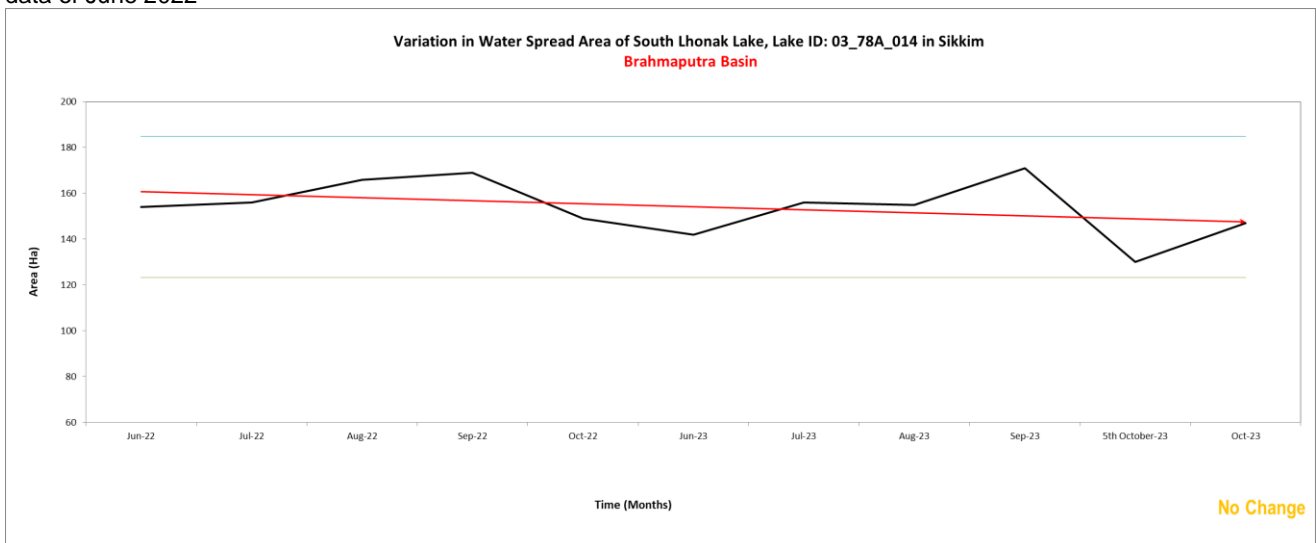
Month	Area (Ha)	+ 10% variation w.r.t base data (June 2022)	- 10% variation w.r.t base data (June 2022)
Jun-22	154	169.4	138.6
Jul-22	156	169.4	138.6
Aug-22	166	169.4	138.6
Sep-22	169	169.4	138.6
Oct-22	149	169.4	138.6
Jun-23	142	169.4	138.6
Jul-23	156	169.4	138.6
Aug-23	155	169.4	138.6
Sep-23	171	169.4	138.6
5th October-23	130	169.4	138.6
Oct-23	147	169.4	138.6

(ii) ± 20% variation

Month	Area (Ha)	+ 20% variation w.r.t base data (Inventory 2009)	- 20% variation w.r.t base data (Inventory 2009)
Jun-22	154	184.8	123.2
Jul-22	156	184.8	123.2
Aug-22	166	184.8	123.2
Sep-22	169	184.8	123.2
Oct-22	149	184.8	123.2
Jun-23	142	184.8	123.2
Jul-23	156	184.8	123.2
Aug-23	155	184.8	123.2
Sep-23	171	184.8	123.2
5th October-23	130	184.8	123.2
Oct-23	147	184.8	123.2



**Figure 4.6(i):** Trend Analysis plot of South Lhonak Lake (Lake ID: 03\_78A\_014), Sikkim, for  $\pm 10\%$  variation w.r.t. Base data of June 2022



**Figure 4.6(ii):** Trend Analysis plot of South Lhonak Lake (Lake ID: 03\_78A\_014), Sikkim, for  $\pm 20\%$  variation w.r.t. Base data of June 2022

**Table 4.4:** Data set of Glacial Lake of Lake ID: 03\_83A\_003, Arunachal Pradesh, for  $\pm 10\%$  &  $\pm 20\%$  variation w.r.t. Base Year data of 2009

**(i)  $\pm 10\%$  variation**

Month	Area (Ha)	+ 10 % variation w.r.t base data (Inventory 2009)	-10 % variation w.r.t base data (Inventory 2009)
Inventory 2011	24	26.4	21.6
Jun-22	82	26.4	21.6
Jul-22	82	26.4	21.6
Aug-22	82	26.4	21.6
Sep-22	81	26.4	21.6
Jun-23	81	26.4	21.6
Jul-23	87	26.4	21.6
Aug-23	82	26.4	21.6
Sep-23	79	26.4	21.6
Oct-23	87	26.4	21.6

**(ii)  $\pm 20\%$  variation**

Month	Area (Ha)	+ 20 % variation w.r.t base data (Inventory 2009)	-20 % variation w.r.t base data (Inventory 2009)
Inventory 2011	24	28.8	19.2
Jun-22	82	28.8	19.2
Jul-22	82	28.8	19.2
Aug-22	82	28.8	19.2
Sep-22	81	28.8	19.2
Jun-23	81	28.8	19.2
Jul-23	87	28.8	19.2
Aug-23	82	28.8	19.2
Sep-23	79	28.8	19.2
Oct-23	87	28.8	19.2

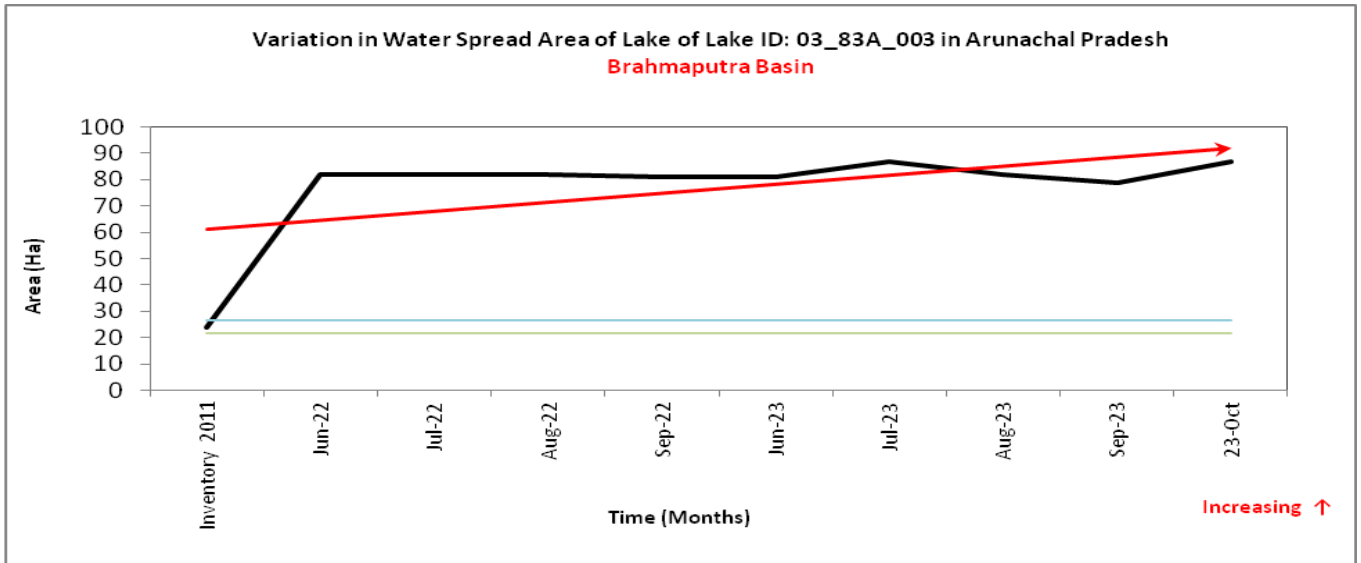


Figure 4.7(i): Trend Analysis plot of Glacial Lake of Lake ID: 03\_83A\_003, Arunachal Pradesh, for ± 10% variation w.r.t. Base Year data of 2009

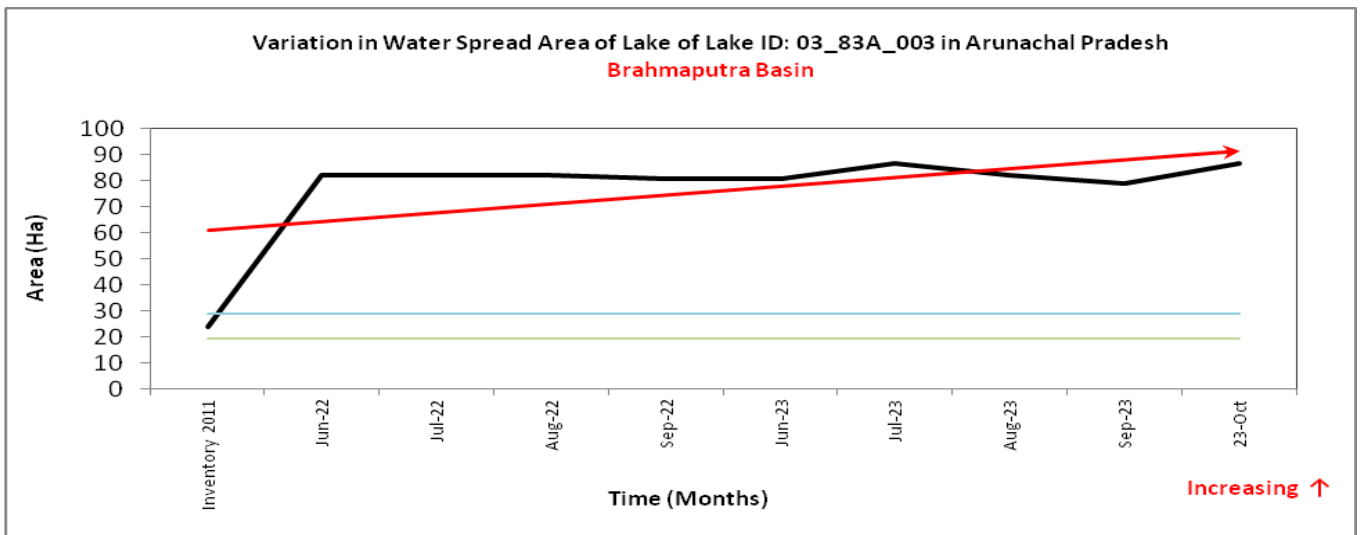


Figure 4.7(ii): Trend Analysis plot Lake (Lake ID: 03\_83A\_003), Arunachal Pradesh, for ± 20% variation w.r.t. Base Year data of 2009

Table 4.5: Data set of Lake (Lake ID: 03\_83A\_003), Arunachal Pradesh, for ± 10% & ± 20% variation w.r.t. Base Year data of June 2022

(i) ± 10% variation

Month	Area (Ha)	+ 10 % variation w.r.t base data (June 2022)	- 10 % variation w.r.t base data (June 2022)
Jun-22	82	90.2	73.8
Jul-22	82	90.2	73.8
Aug-22	82	90.2	73.8
Sep-22	81	90.2	73.8
Jun-23	81	90.2	73.8
Jul-23	87	90.2	73.8
Aug-23	82	90.2	73.8
Sep-23	79	90.2	73.8
Oct-23	87	90.2	73.8

(ii) ± 20% variation

Month	Area (Ha)	+ 20 % variation w.r.t base data (Inventory 2009)	-20 % variation w.r.t base data (Inventory 2009)
Jun-22	82	98.4	65.6
Jul-22	82	98.4	65.6
Aug-22	82	98.4	65.6
Sep-22	81	98.4	65.6
Jun-23	81	98.4	65.6
Jul-23	87	98.4	65.6
Aug-23	82	98.4	65.6
Sep-23	79	98.4	65.6
Oct-23	87	98.4	65.6

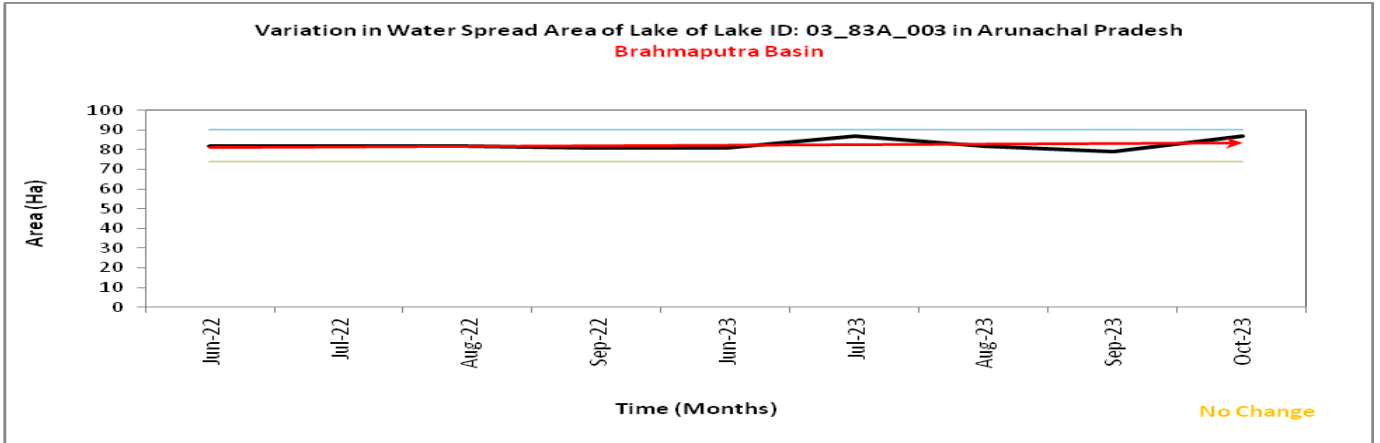


Figure 4.8(i): Trend Analysis plot of Lake (Lake ID: 03\_83A\_003), Arunachal Pradesh, for  $\pm 10\%$  variation w.r.t. Base data of June 2022

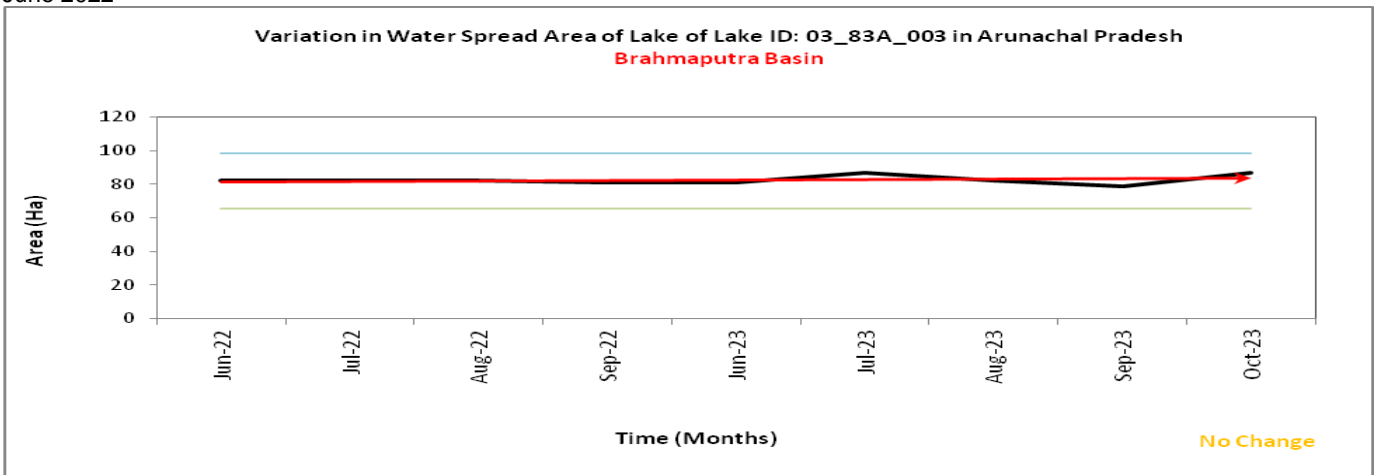


Figure 4.8(ii): Trend Analysis plot of Lake (Lake ID: 03\_83A\_003), Arunachal Pradesh, for  $\pm 20\%$  variation w.r.t. Base data of June 2022

## 4.6 Result of Trend Analysis

### 4.6.1 Trend analysis of 15 GL of size greater than 50 Ha (2011 to 2023) for $\pm 10\%$ variation w.r.t. Base Year data of 2009

As per the analysis, 10 GLs exhibit an increasing trend, 2 GLs exhibit no change trend and 3GLs exhibit decreasing trend, assuming +/-10 % variation in last data w.r.t base year (2009) data of water spread area. The state-wise distribution of these lakes is given in Table No. 7.4. The details are furnished in Table No. 7.5.

Sikkim has the maximum number of Glacial Lakes (7 Nos.) with ***increasing trend*** followed by Himachal Pradesh (2 Nos.) and Ladakh (1No). One lake each in Ladakh and Sikkim show ***no change in trend*** throughout the period of 13 years. Two lakes in Sikkim and One lake in Ladakh show a ***decreasing trend***.

**Table No. 4.6: State wise distribution of Glacial Lakes of size greater than 50Ha analysed for trend for  $\pm 10\%$  variation in water spread area w.r.t. base year data 2009**

Sl. No.	States	Increasing Trend	No Change in Trend	Decreasing Trend	Total
1	Ladakh	1	1	1	3
2	Himachal Pradesh	2	0	0	2
3	Sikkim	7	1	2	10
	<b>Total</b>	<b>10</b>	<b>2</b>	<b>3</b>	<b>15</b>

**Table No. 4.7: Trend Analysis of Glacial Lakes of size greater than 50 Ha in size located in India analysed for  $\pm 10\%$  variation in water spread area based on 13 years data (in addition to that of 2009)**

Sl. No.	Lake ID	Latitude (N)	Longitude (E)	UID	Elevation (m)	Basin	River	Country	State	Inventory 2009 (Area in Ha)	Trend (10%)
1	01_52C_003	33.1573	76.9843	JK_187	4512	Indus	Indus	India	Ladakh	45	Increasing
2	01_52J_001	34.4577	78.1351	JK_197	5311	Indus	Shyok	India	Ladakh	97	No Change
3	01_52E_001	35.418	77.6046	JK_188	5116	Indus	Shyok	India	Ladakh	51	Decreasing
4	01_52H_004	32.4964	77.5516	HP_5	4155	Indus	Chenab	India	Himachal Pradesh	46	Increasing
5	01_52H_002	32.5247	77.2183	HP_3	4101	Indus	Chenab	India	Himachal Pradesh	62	Increasing
6	03_78A_021	27.8245	88.2492	SK_26	5431	Brahmaputra	Teesta	India	Sikkim	56	Increasing
7	03_77D_005	28.0091	88.6979	SK_5	5249	Brahmaputra	Teesta	India	Sikkim	79	Increasing
8	03_78A_014	27.9119	88.1986	SK_20	5234	Brahmaputra	Teesta	India	Sikkim	94	Increasing
9	03_78A_009	27.9477	88.3313	SK_16	5044	Brahmaputra	Teesta	India	Sikkim	54	Increasing
10	03_78A_001	27.9917	88.8155	SK_9	5371	Brahmaputra	Teesta	India	Sikkim	156	Increasing
11	03_77D_004	28.0071	88.7128	SK_4	5287	Brahmaputra	Teesta	India	Sikkim	106	Increasing
12	03_78A_013	27.9188	88.161	SK_19	5470	Brahmaputra	Teesta	India	Sikkim	63	Increasing
13	03_77D_002	28.0261	88.71	SK_2	5156	Brahmaputra	Teesta	India	Sikkim	105	No Change
14	03_78A_003	27.9753	88.6164	SK_11	4977	Brahmaputra	Teesta	India	Sikkim	58	Decreasing
15	03_77D_008	28.0073	88.4949	SK_8	5039	Brahmaputra	Teesta	India	Sikkim	46	Decreasing

#### 4.6.2 Trend analysis of 15 GL of size greater than 50 Ha (2011 to 2023) for $\pm 20\%$ variation w.r.t. Base Year data of 2009

As the analysis was carried out for  $\pm 20\%$  variation in last data w.r.t base year (2009) data, only 8 GLs showed an increasing trend, 6 showed no change in trend and One GL showed a decreasing trend. The state-wise distribution of these lakes is given in Table no. 7.6. The details are furnished in Table No. 4.8.

**Table No.4.8 State wise distribution of Glacial Lakes of size greater than 50Ha analysed for trend for  $\pm 20\%$  variation in water spread area w.r.t. base year data 2009**

Sl. No.	States	Increasing Trend	No Change Trend	Decreasing Trend	Total
1	Ladakh	1	1	1	3
2	Himachal Pradesh	2	0	0	2
3	Sikkim	5	5	0	10
	<b>Total</b>	8	6	1	15

**Table No. 4.9 Trend Analysis of Glacial Lakes of size greater than 50 Ha in size located in India analysed for  $\pm 20\%$  variation in water spread area based on 13 years data (in addition to that of 2009)**

Sl. No.	Lake ID	Latitude (N)	Longitude (E)	UID	Elevation (m)	Basin	River	Country	State	Inventory 2009 (Area in Ha)	Trend (20%)
1	01_52C_003	33.1573	76.9843	JK_187	4512	Indus	Indus	India	Ladakh	45	Increasing
2	01_52J_001	34.4577	78.1351	JK_197	5311	Indus	Shyok	India	Ladakh	97	No Change
3	01_52E_001	35.418	77.6046	JK_188	5116	Indus	Shyok	India	Ladakh	51	Decreasing
4	01_52H_004	32.4964	77.5516	HP_5	4155	Indus	Chenab	India	Himachal Pradesh	46	Increasing
5	01_52H_002	32.5247	77.2183	HP_3	4101	Indus	Chenab	India	Himachal Pradesh	62	Increasing
6	03_78A_021	27.8245	88.2492	SK_26	5431	Brahmaputra	Teesta	India	Sikkim	56	Increasing
7	03_77D_005	28.0091	88.6979	SK_5	5249	Brahmaputra	Teesta	India	Sikkim	79	Increasing
8	03_78A_014	27.9119	88.1986	SK_20	5234	Brahmaputra	Teesta	India	Sikkim	94	Increasing
9	03_78A_001	27.9917	88.8155	SK_9	5371	Brahmaputra	Teesta	India	Sikkim	156	Increasing
10	03_78A_013	27.9188	88.161	SK_19	5470	Brahmaputra	Teesta	India	Sikkim	63	Increasing
11	03_78A_009	27.9477	88.3313	SK_16	5044	Brahmaputra	Teesta	India	Sikkim	54	No Change
12	03_77D_004	28.0071	88.7128	SK_4	5287	Brahmaputra	Teesta	India	Sikkim	106	No Change
13	03_77D_002	28.0261	88.71	SK_2	5156	Brahmaputra	Teesta	India	Sikkim	105	No Change
14	03_78A_003	27.9753	88.6164	SK_11	4977	Brahmaputra	Teesta	India	Sikkim	58	No Change
15	03_77D_008	28.0073	88.4949	SK_8	5039	Brahmaputra	Teesta	India	Sikkim	46	No Change

Lake-wise plot are appended as given below.

<i>Trend analysis for Change in Water spread area of Glacial Lakes (&gt;50 Ha) for <math>\pm 10\%</math> &amp; <math>\pm 20\%</math> w.r.t base year data 2009</i>		
<b>S.No.</b>	<b>States</b>	<b>Figure No.</b>
1	Ladakh	Figure 4.9(i)-Figure 4.11(ii)
2	Himachal Pradesh	Figure 4.12(i)-Figure 4.13(ii)
3	Sikkim	Figure 4.14(i)-Figure 4.23(ii)

Trend Analysis of “Change in Water spread area of Glacial Lakes (>50 Ha) of Ladakh”

Figure 4.9(i) Trend Analysis Plot  $\pm 10\%$

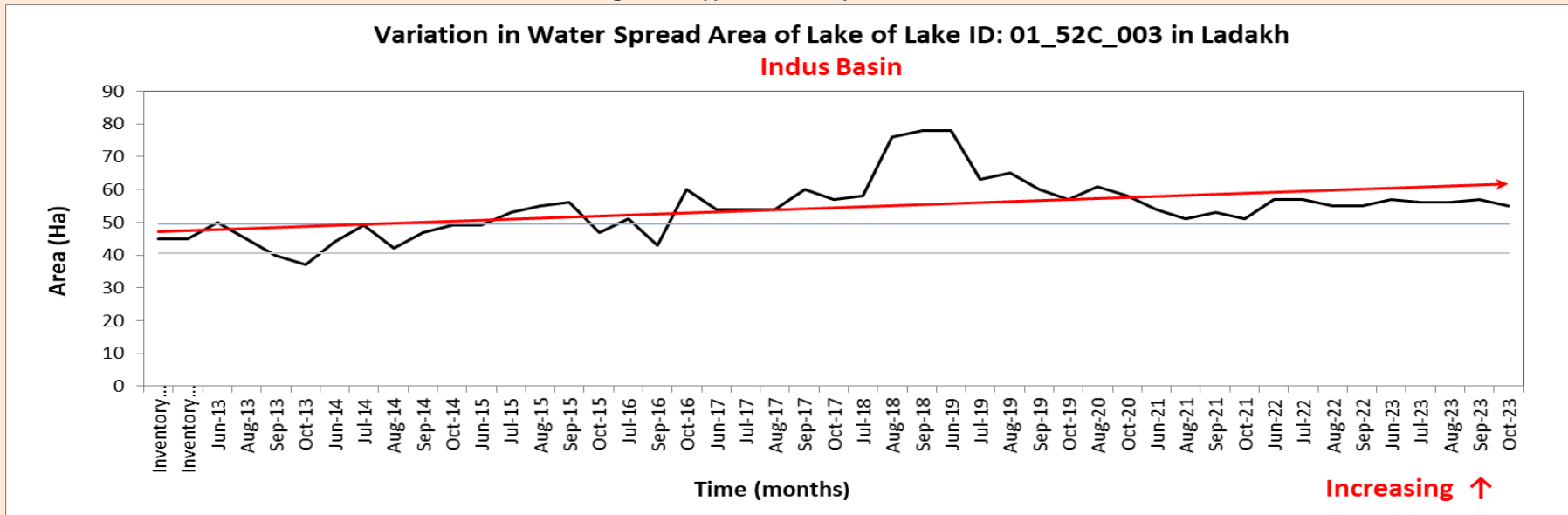


Figure 4.9(ii) Trend Analysis Plot  $\pm 20\%$

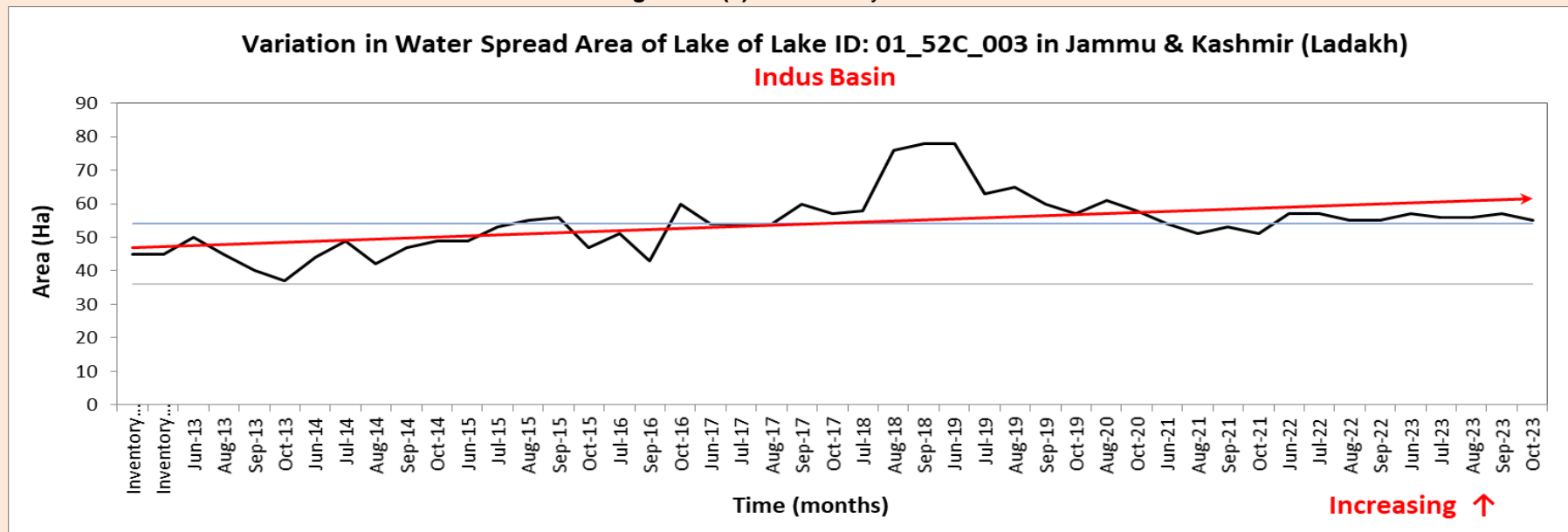


Figure 4.10(i) Trend Analysis Plot  $\pm 10\%$

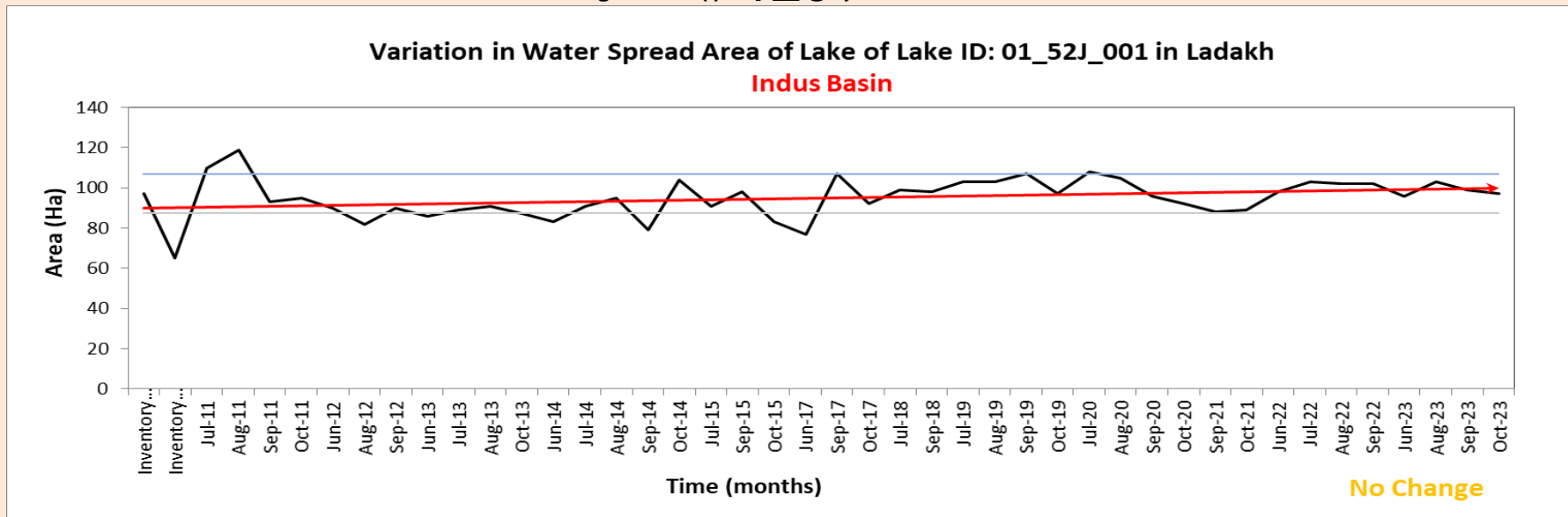


Figure 4.10(ii) Trend Analysis Plot  $\pm 20\%$

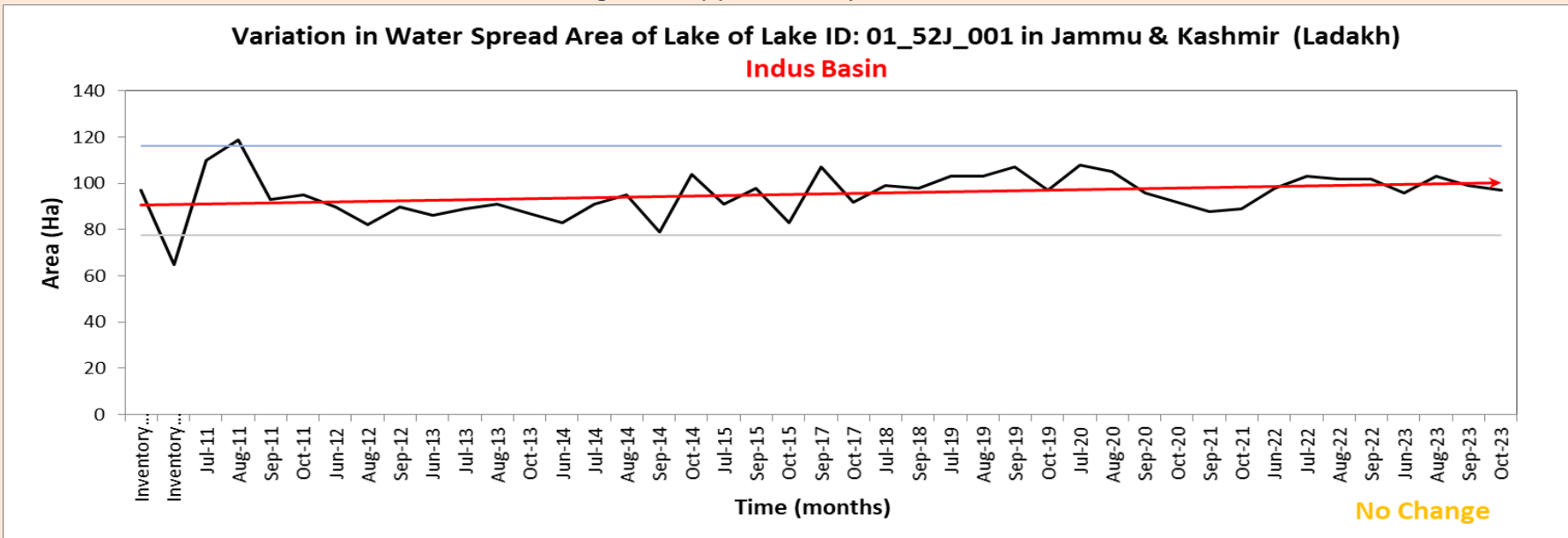


Figure 4.11(i) Trend Analysis Plot  $\pm 10\%$

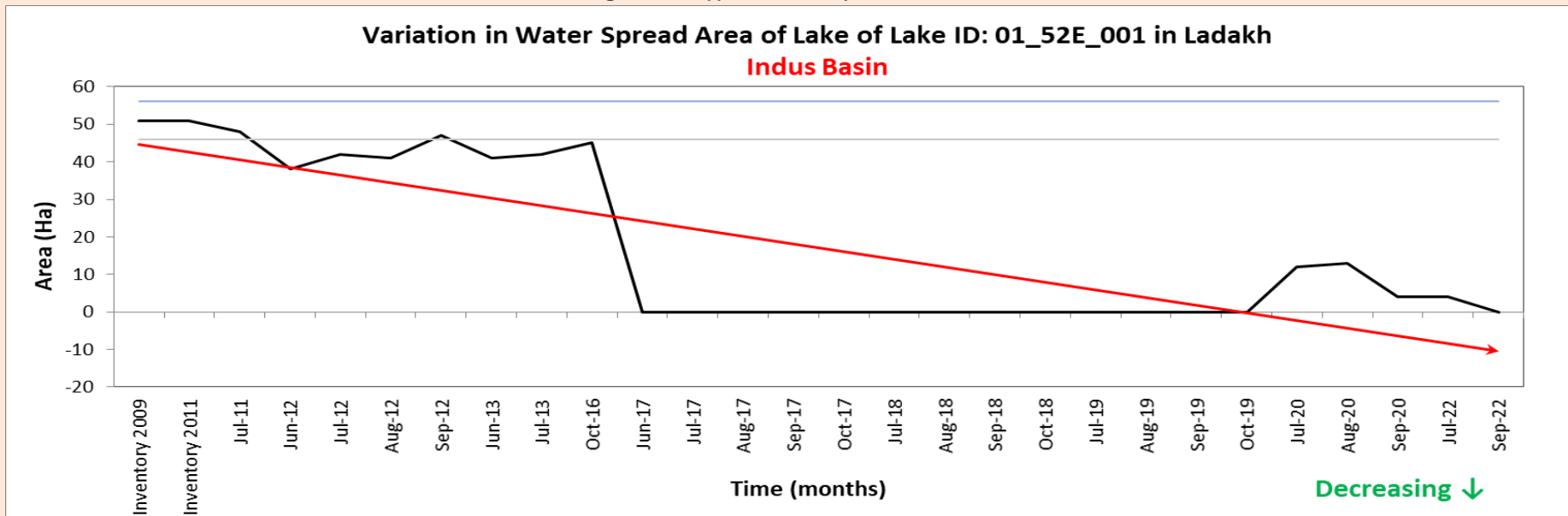
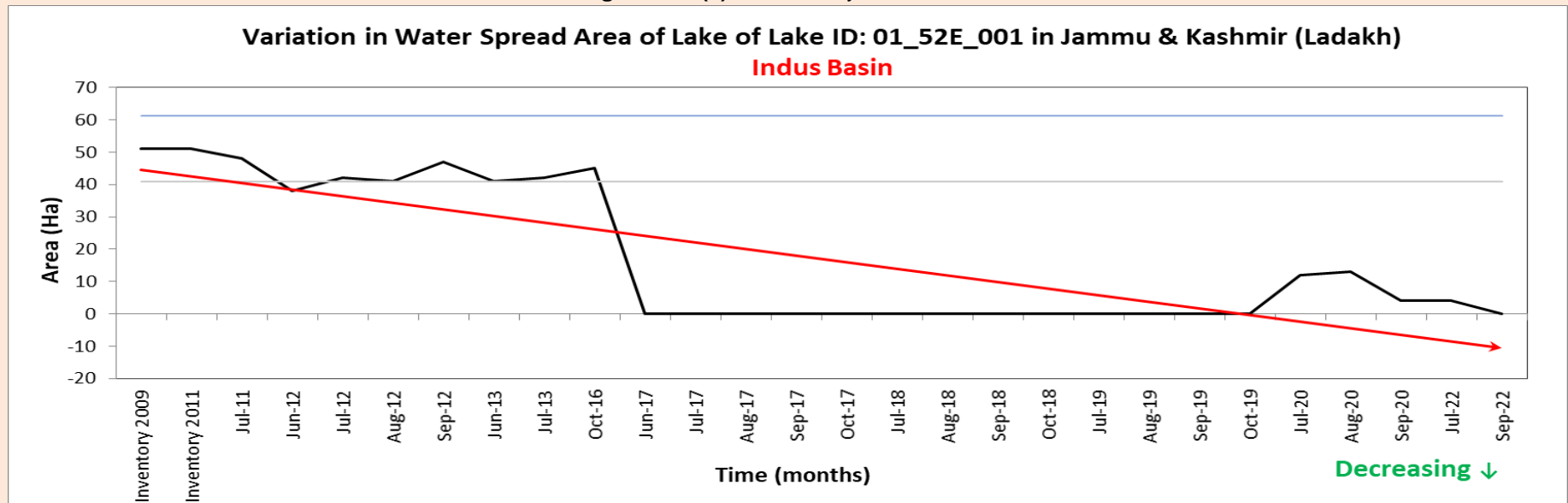


Figure 4.11(ii) Trend Analysis Plot  $\pm 20\%$



Trend Analysis of “Change in Water spread area of Glacial Lakes (>50 Ha) of Himachal Pradesh”

Figure 4.12(i) Trend Analysis Plot  $\pm 10\%$

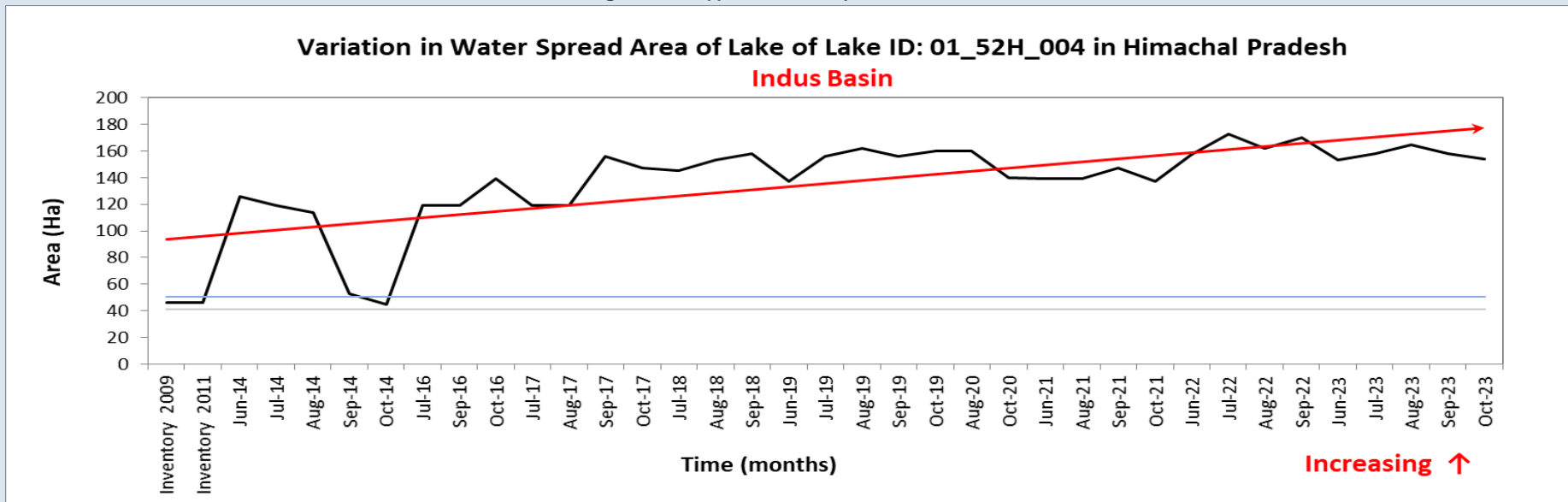
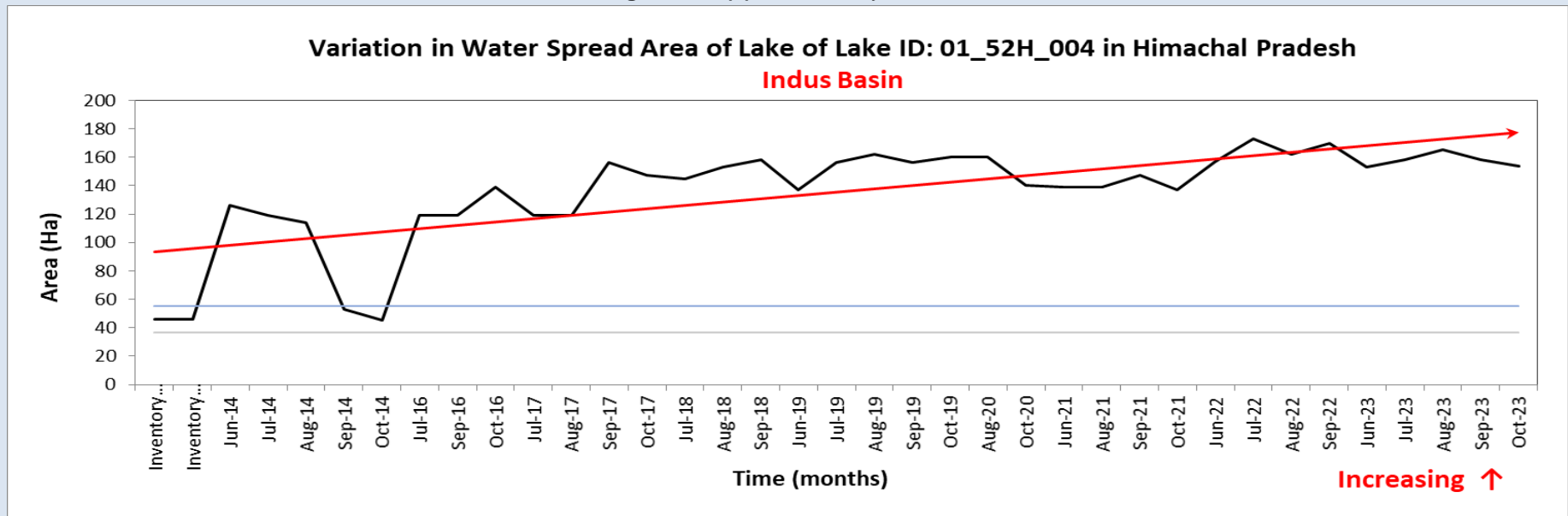


Figure 4.12(ii) Trend Analysis Plot  $\pm 20\%$



133  
Figure 4.13(i) Trend Analysis Plot  $\pm 10\%$

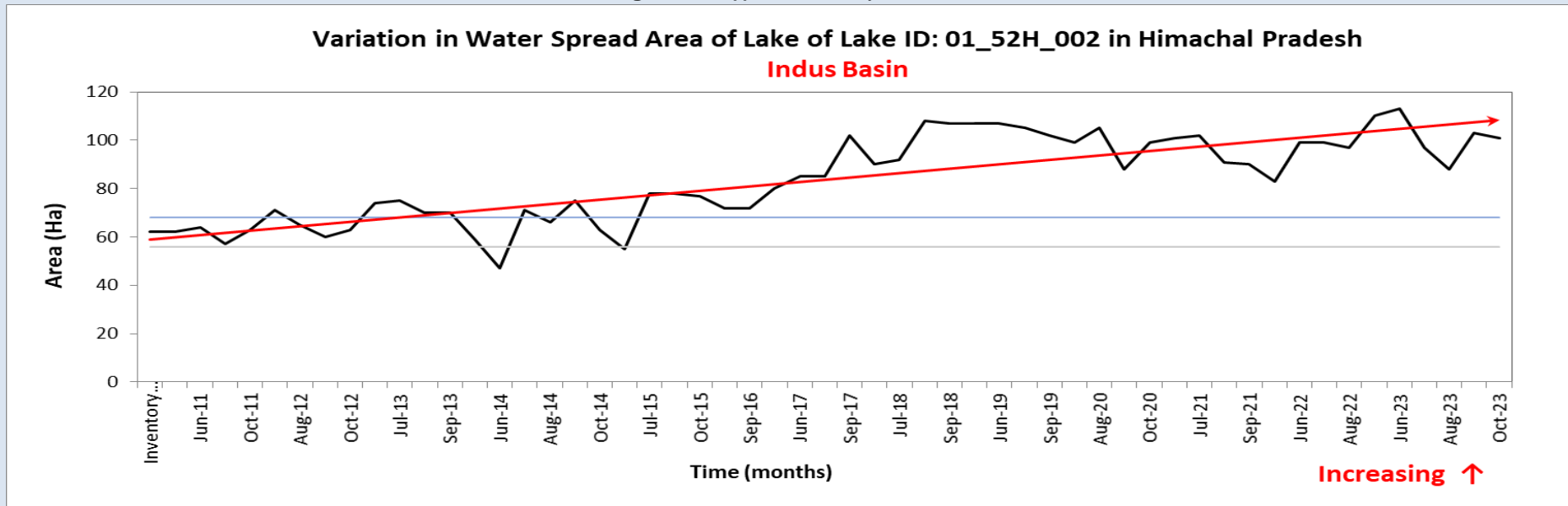
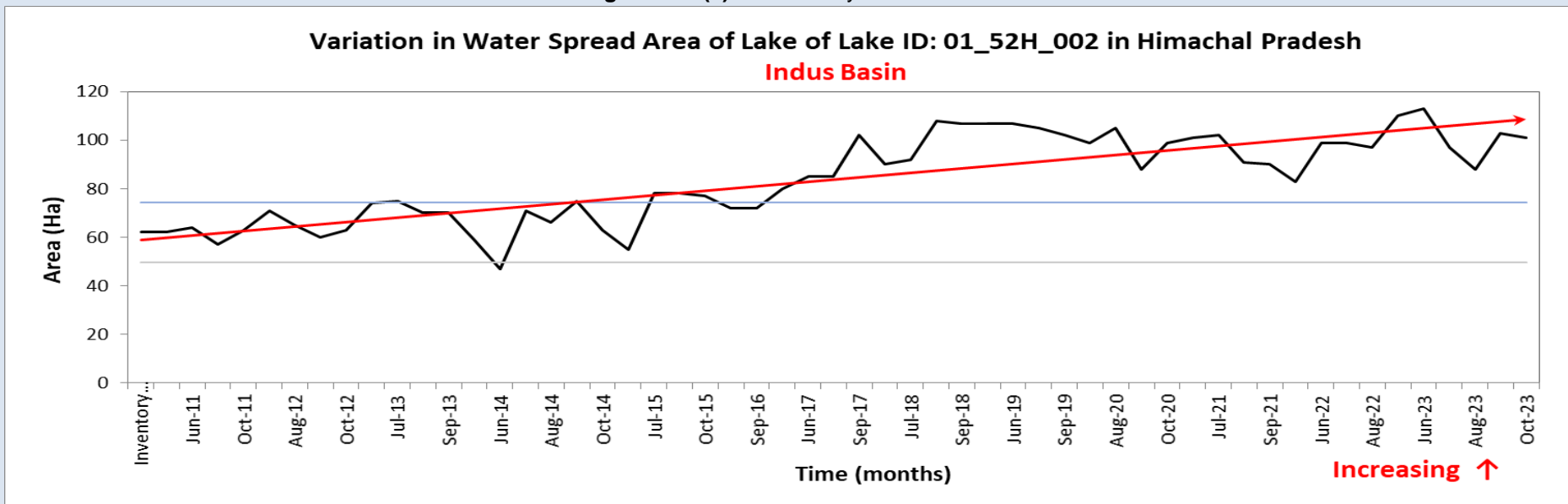


Figure 4.13(ii) Trend Analysis Plot  $\pm 20\%$



**Trend Analysis of “Change in Water spread area of Glacial Lakes (>50 Ha) of Sikkim”**

Figure 4.14(i) Trend Analysis Plot  $\pm 10\%$

135

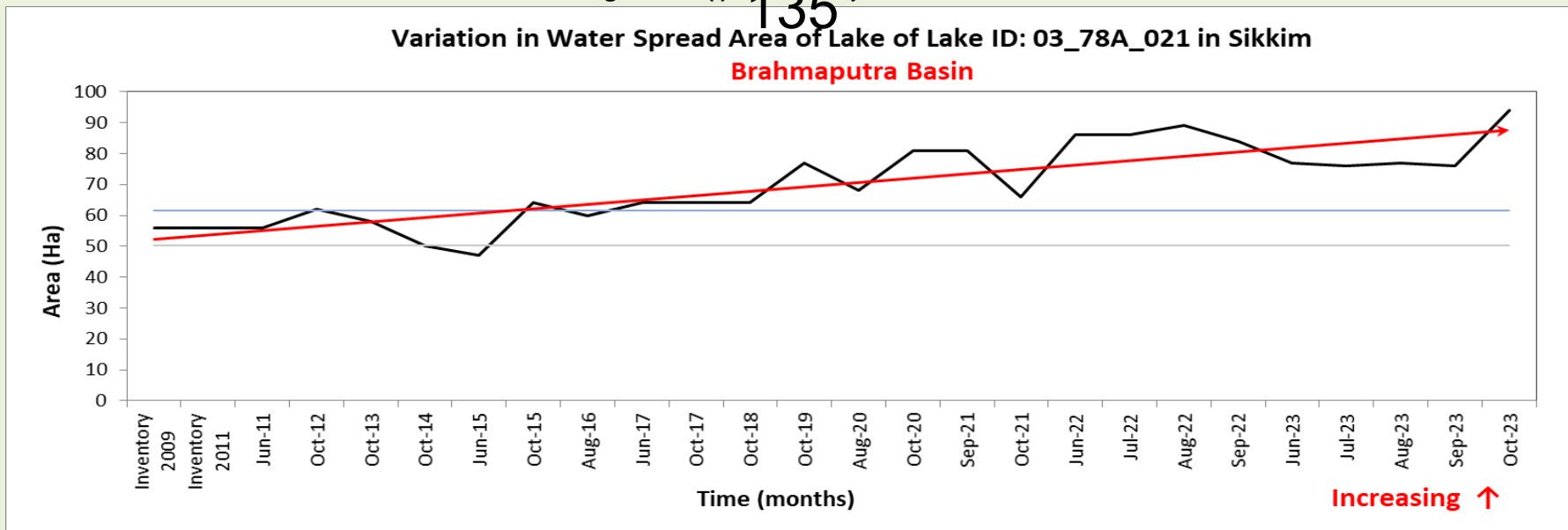
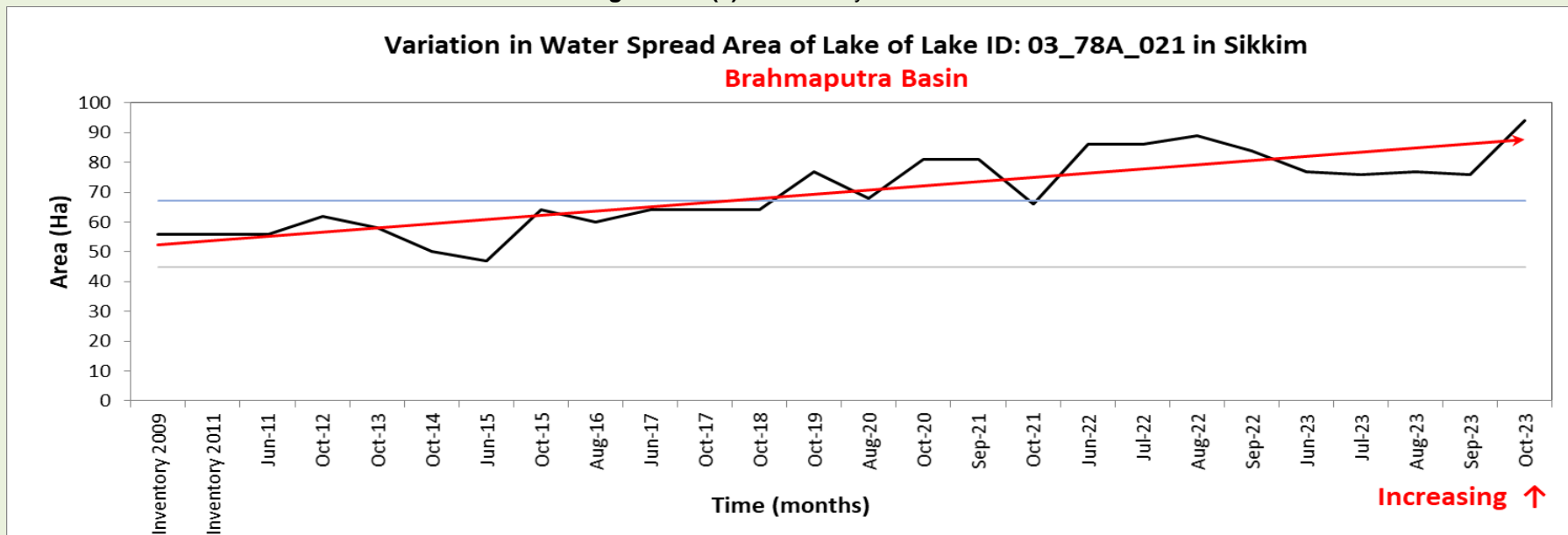


Figure 4.14(ii) Trend Analysis Plot  $\pm 20\%$



136  
Figure 4.15(i) Trend Analysis Plot  $\pm 10\%$

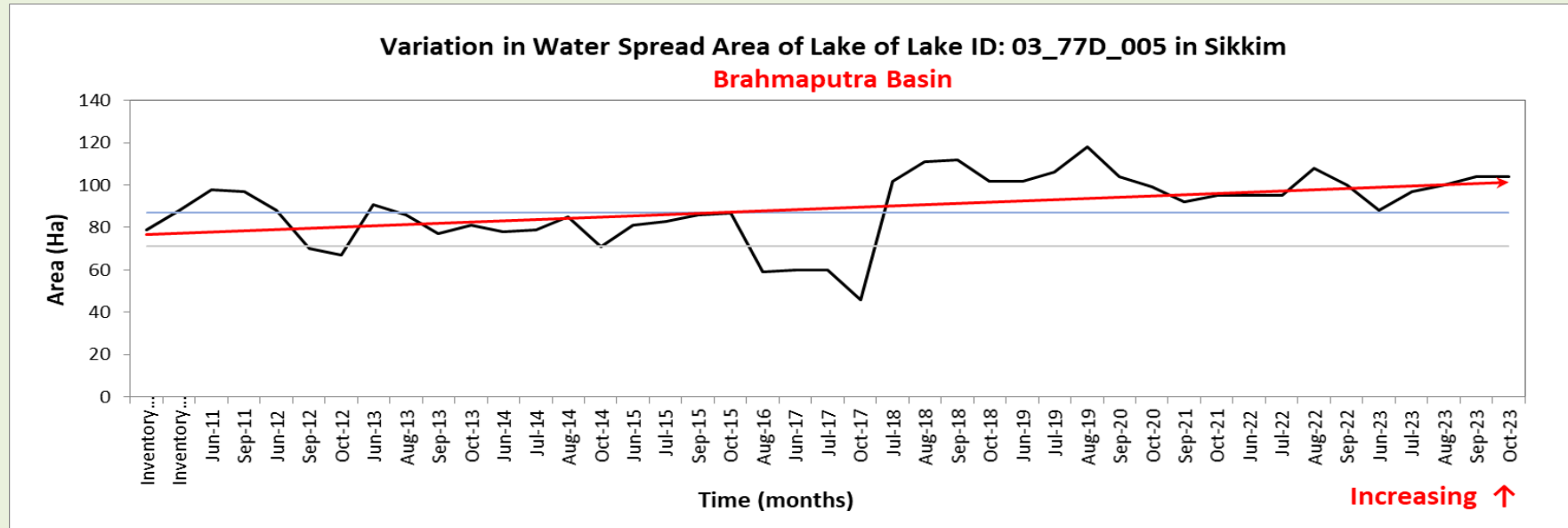


Figure 4.15(ii) Trend Analysis Plot  $\pm 20\%$

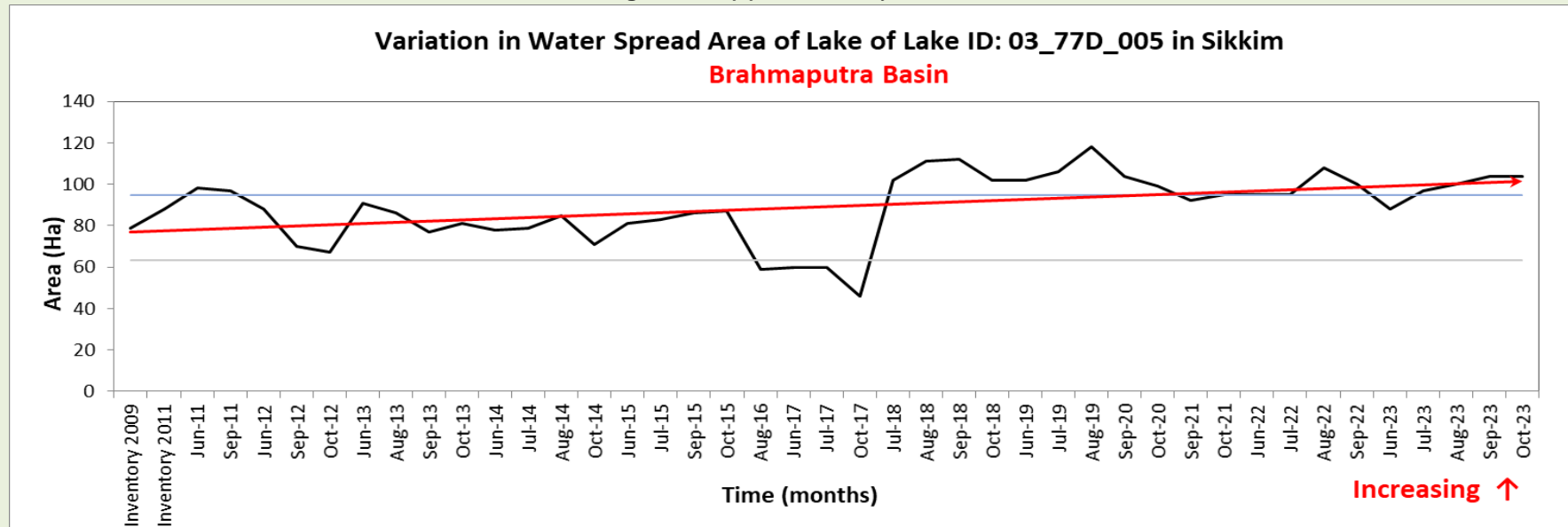


Figure 4.16(i) Trend Analysis Plot  $\pm 10\%$

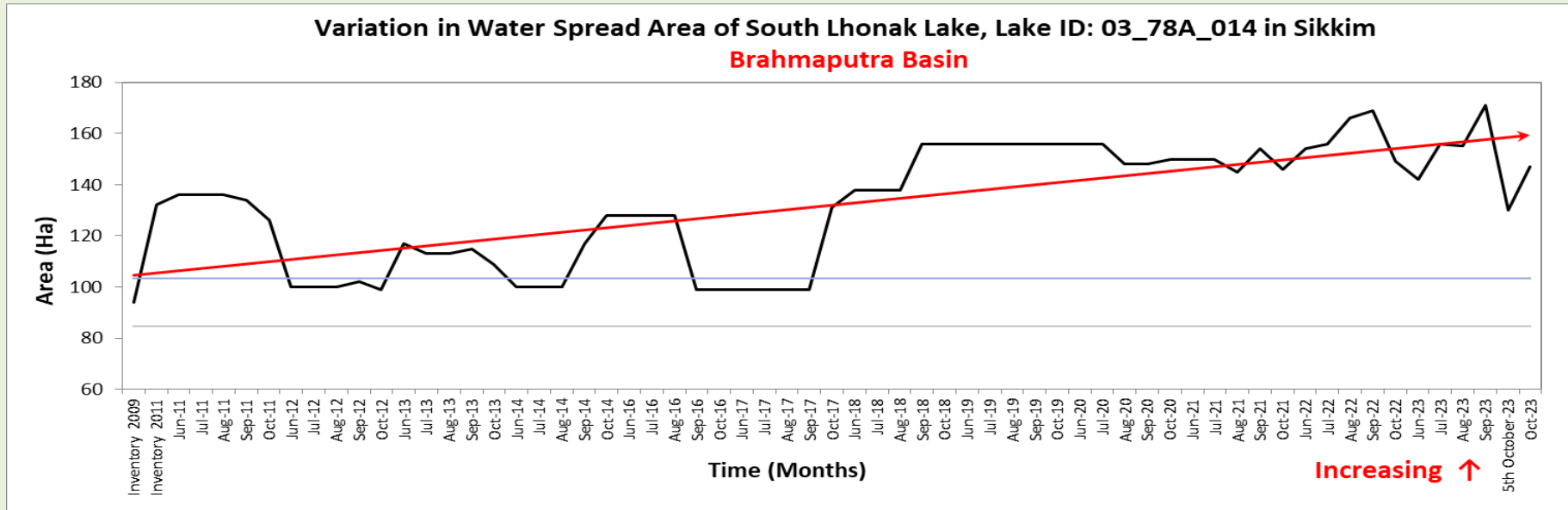


Figure 4.16(ii) Trend Analysis Plot  $\pm 20\%$

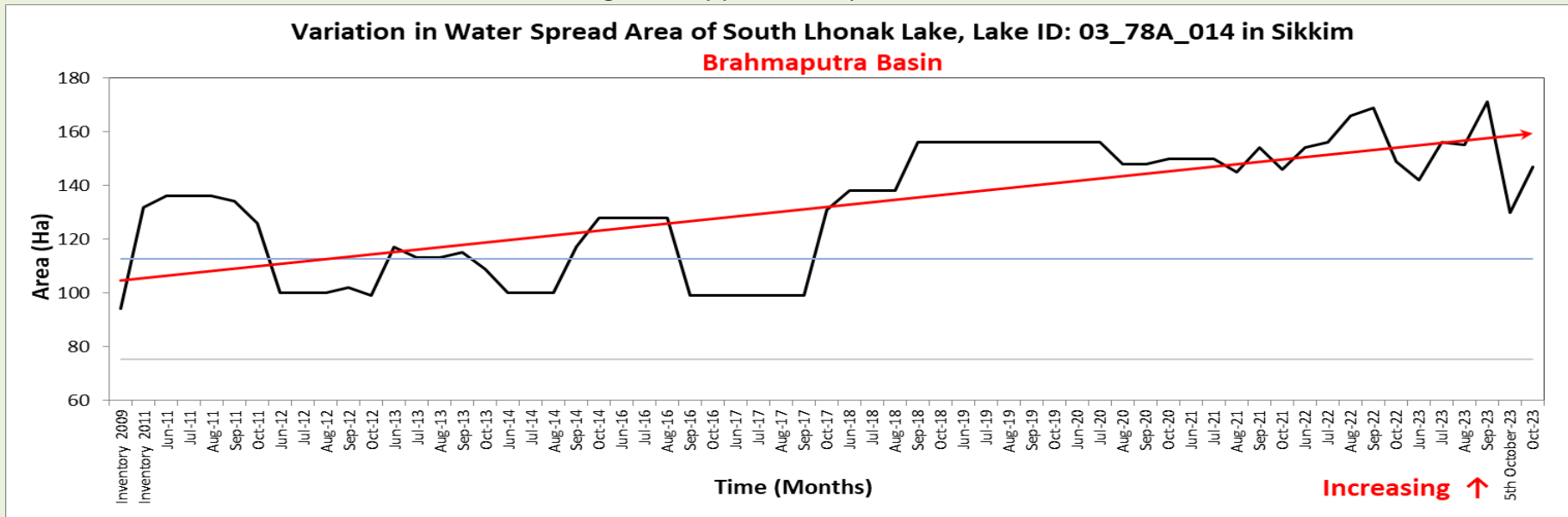


Figure 4.17(i) Trend Analysis Plot  $\pm 10\%$

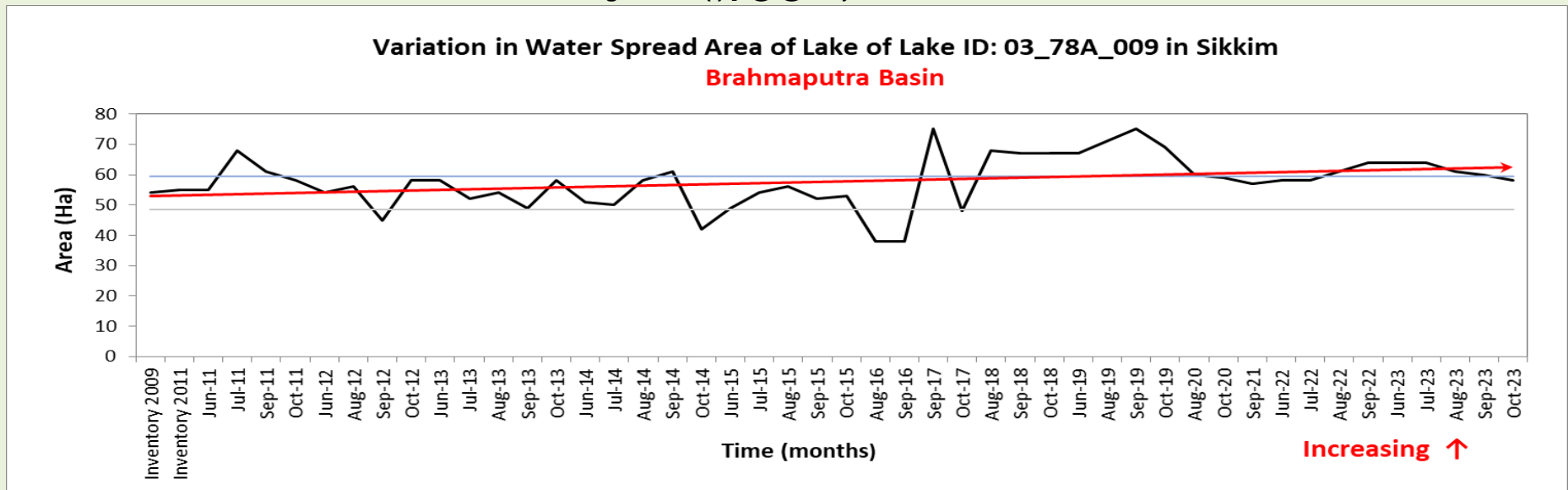


Figure 4.17(i) Trend Analysis Plot  $\pm 20\%$

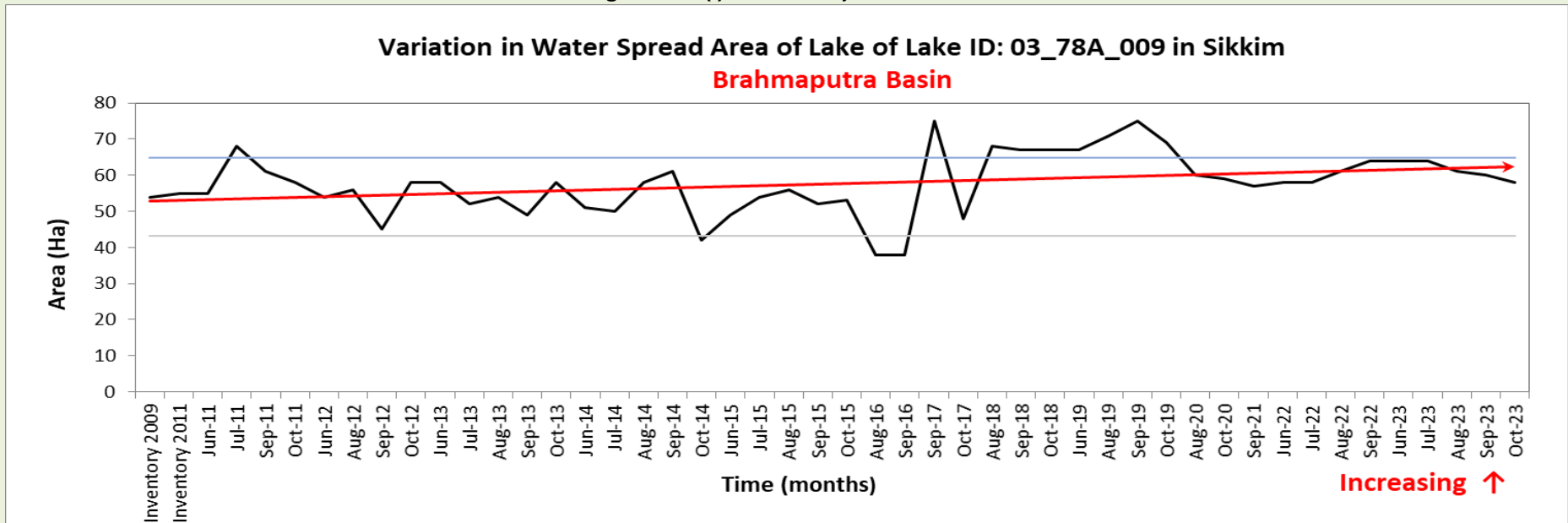


Figure 4.18(i) Trend Analysis Plot  $\pm 10\%$

139

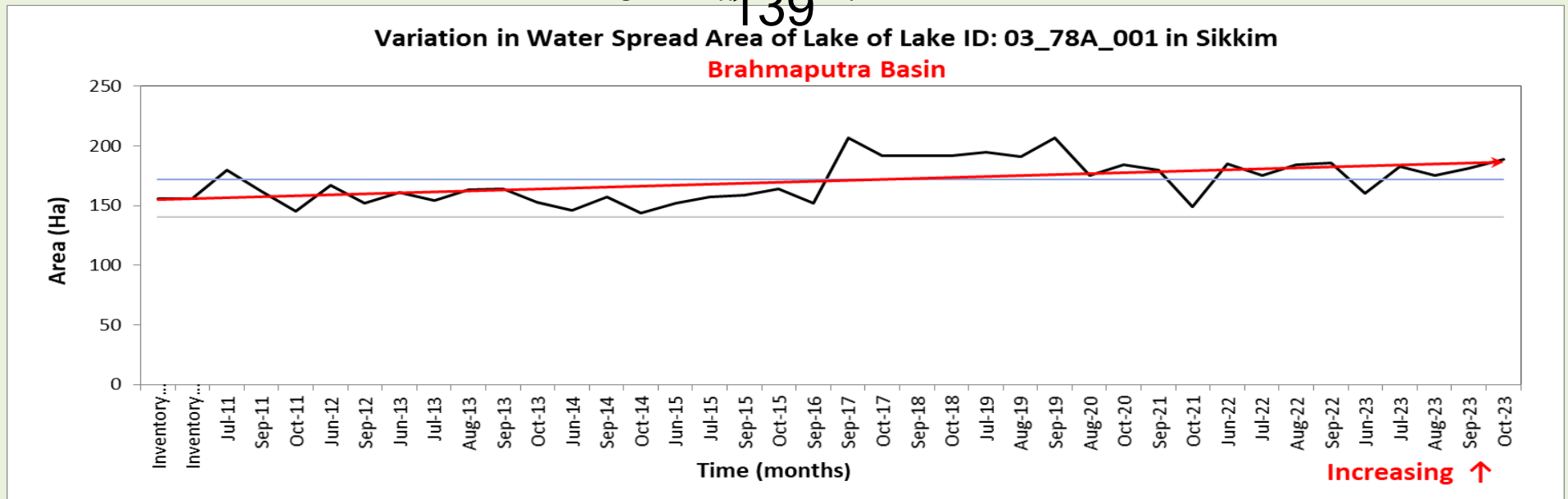


Figure 4.18(ii) Trend Analysis Plot  $\pm 20\%$

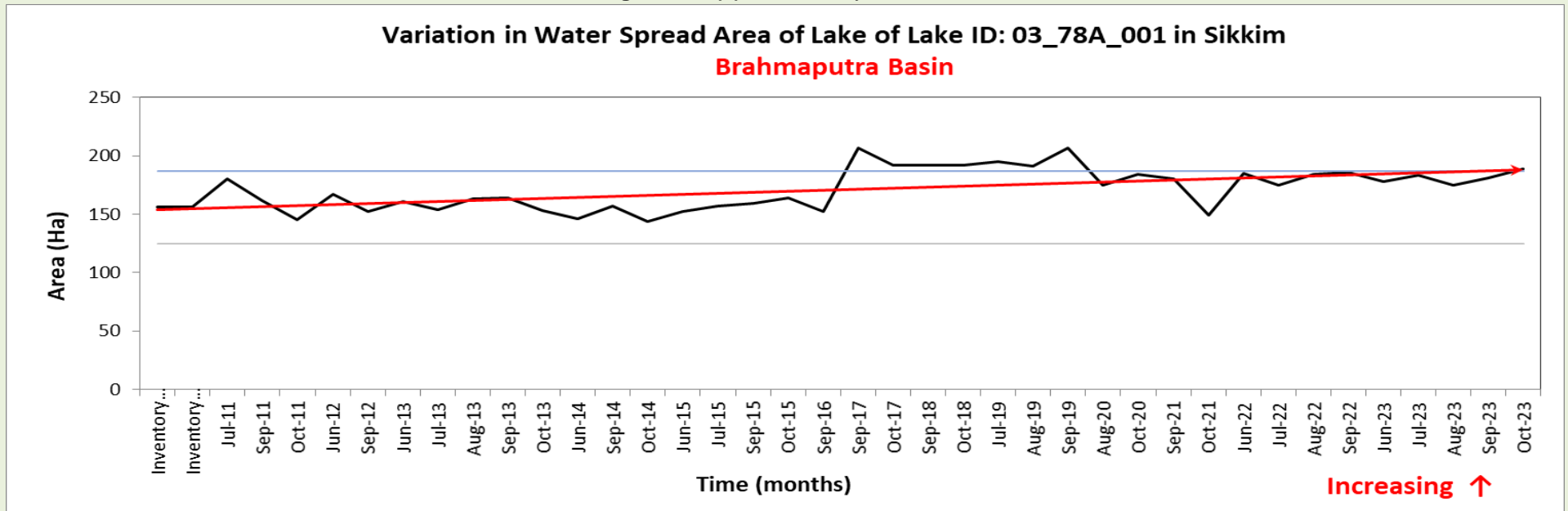


Figure 4.19(i) Trend Analysis Plot  $\pm 10\%$

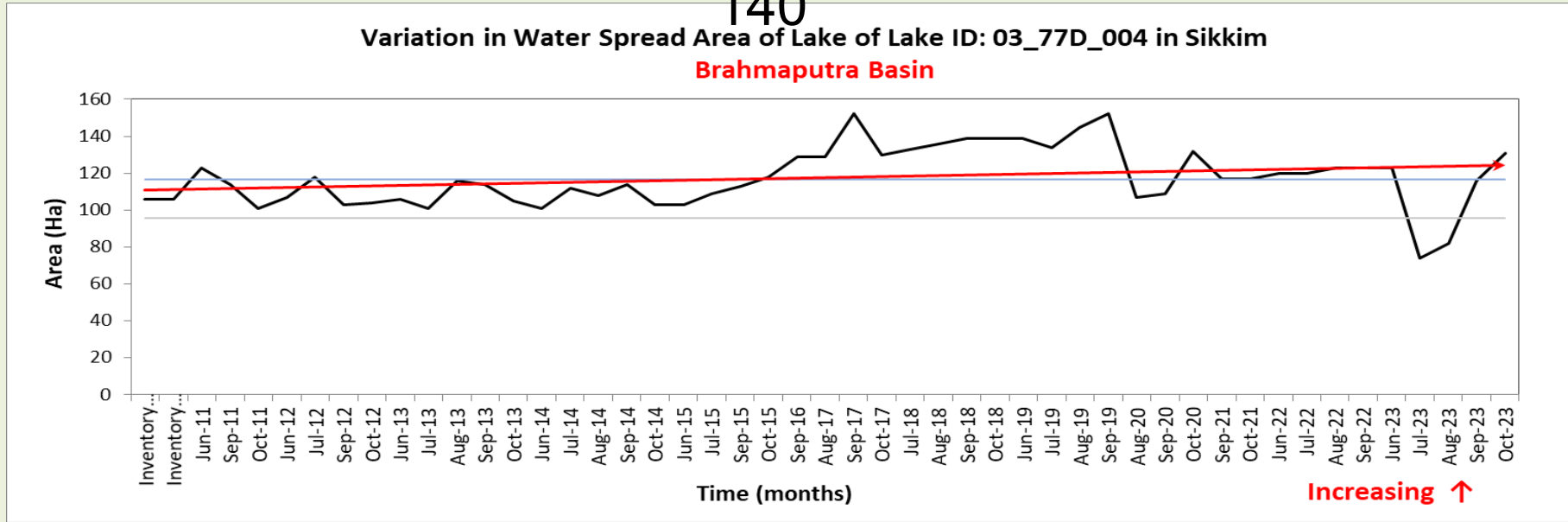


Figure 4.19(ii) Trend Analysis Plot  $\pm 20\%$

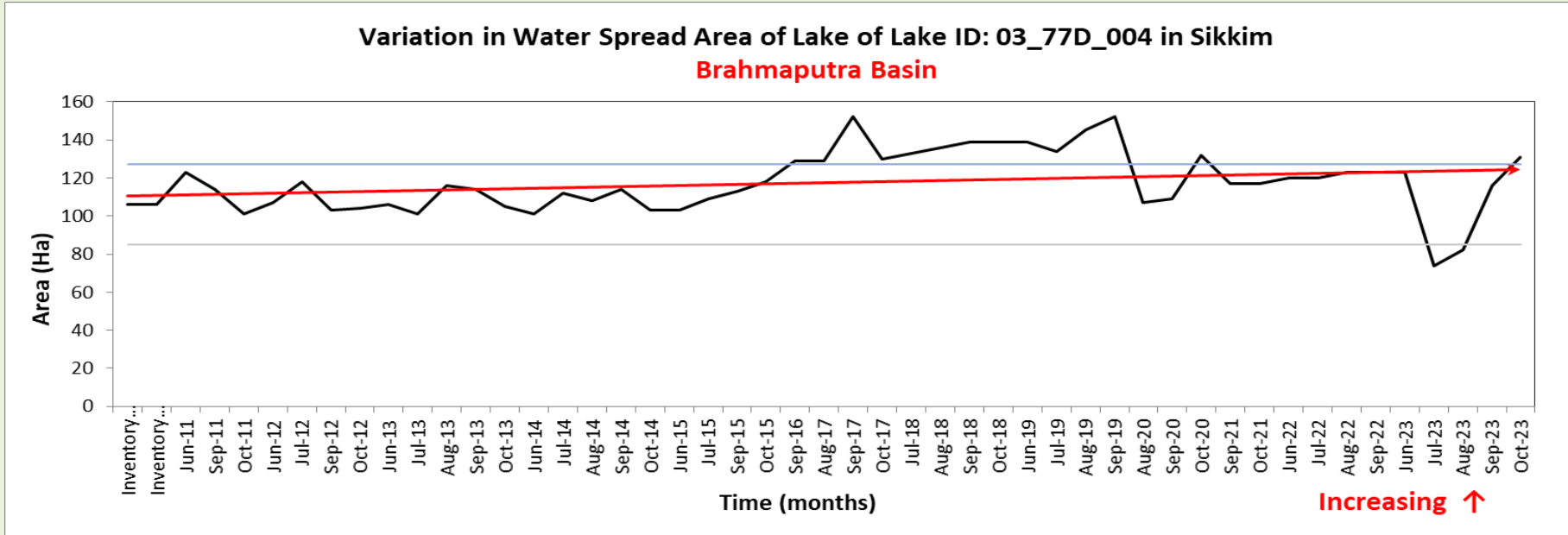


Figure 4.20(i) Trend Analysis Plot  $\pm 10\%$

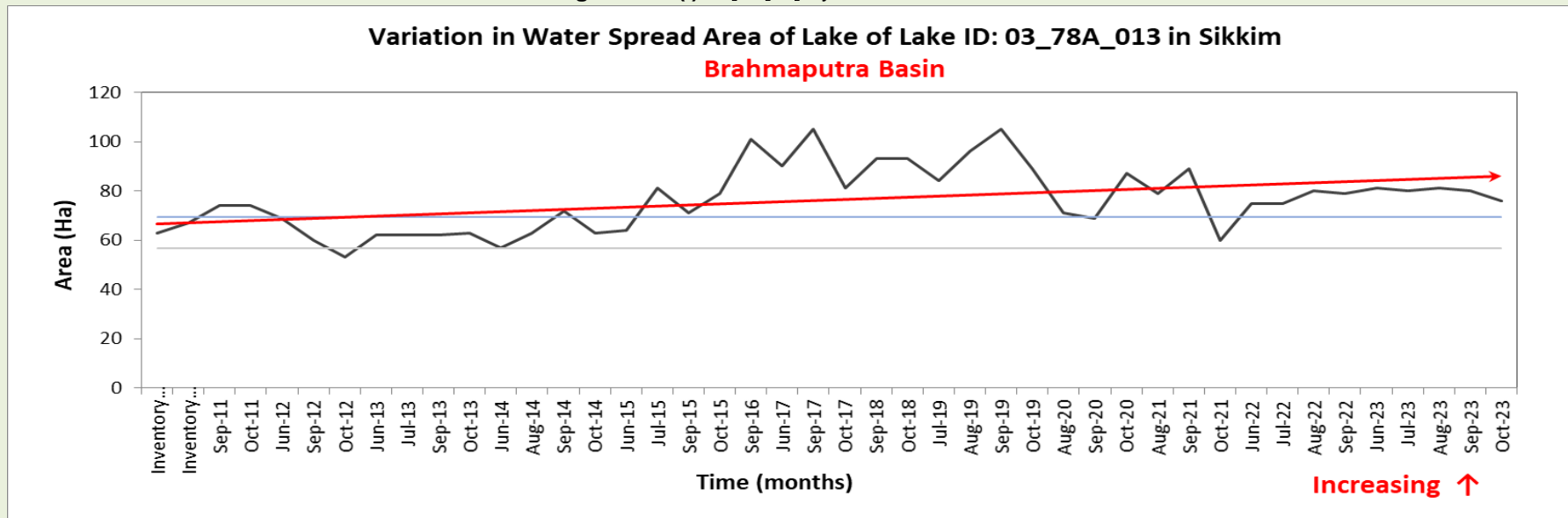


Figure 4.20(ii) Trend Analysis Plot  $\pm 20\%$

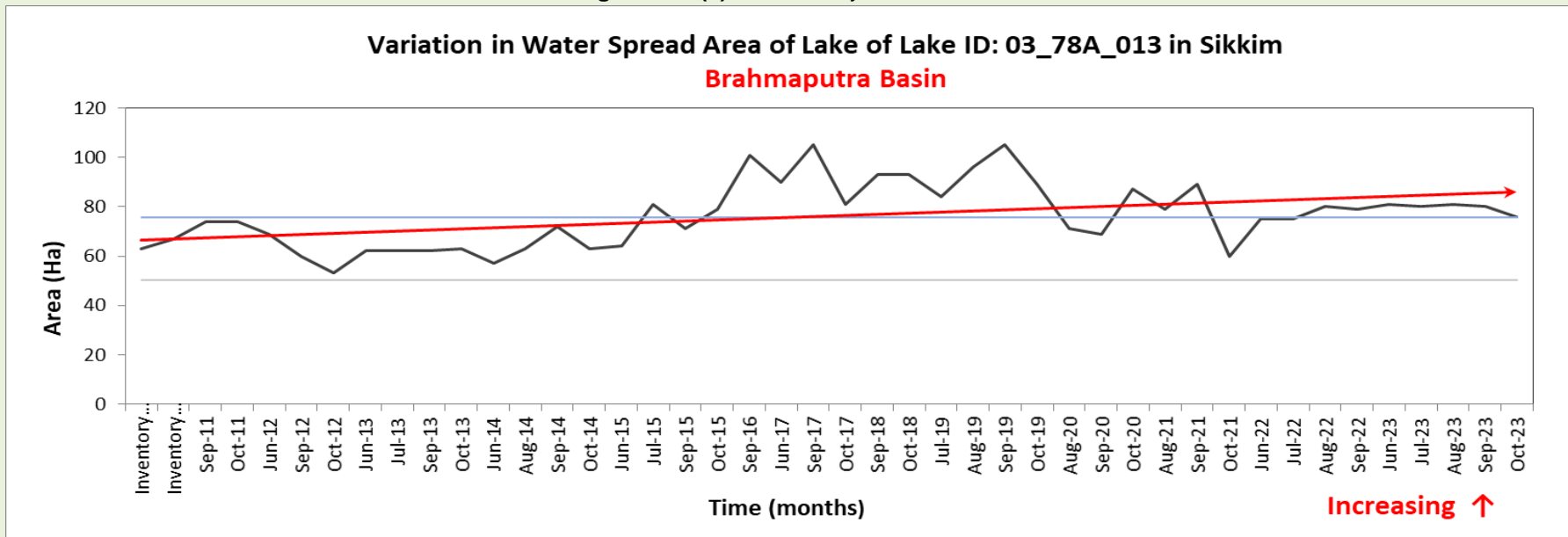


Figure 4.21(i) Trend Analysis Plot  $\pm 10\%$

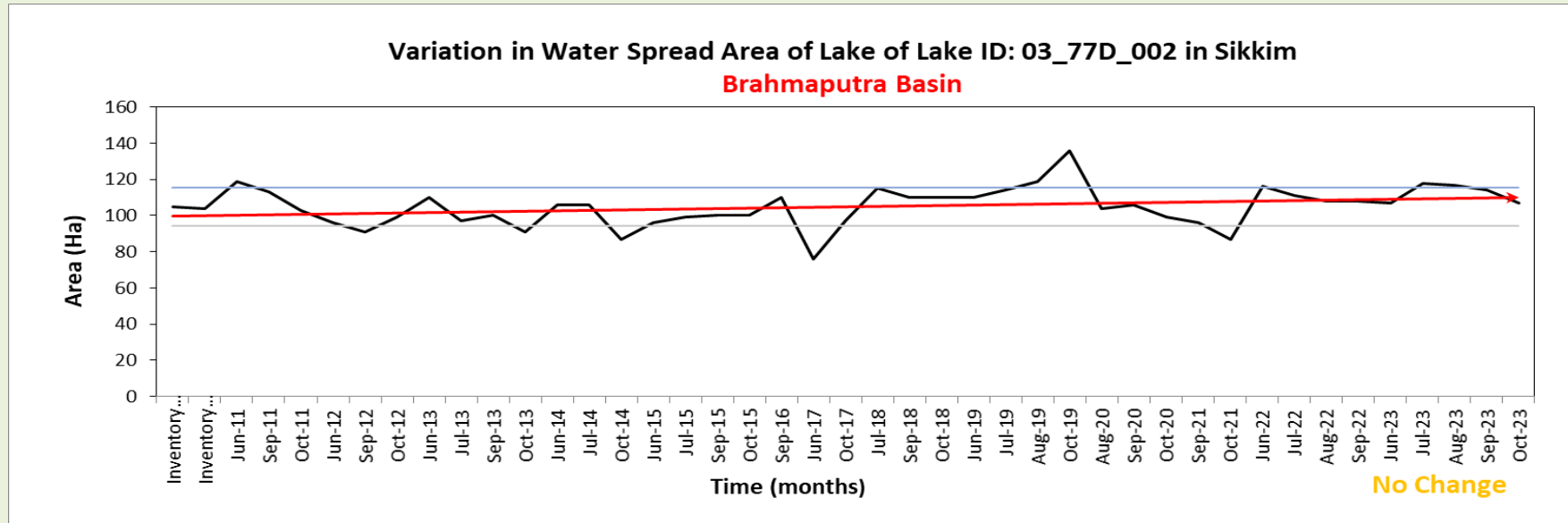


Figure 4.21(ii) Trend Analysis Plot  $\pm 20\%$

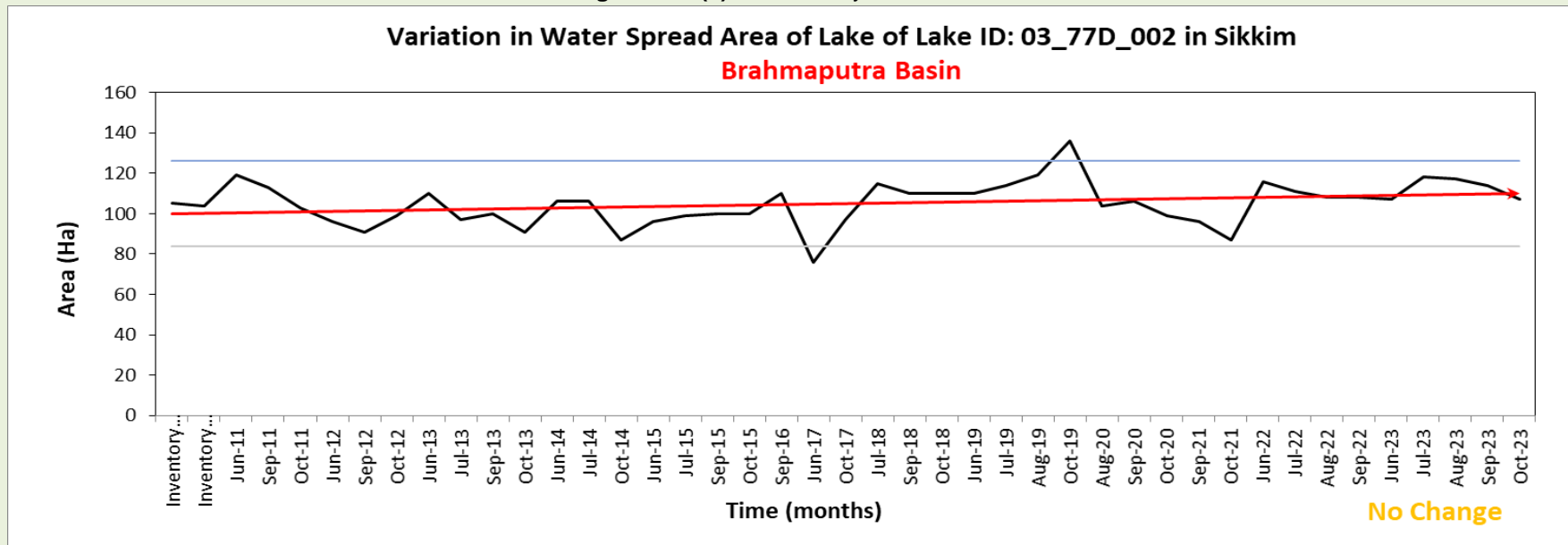


Figure 4.22(i) Trend Analysis Plot  $\pm 10\%$

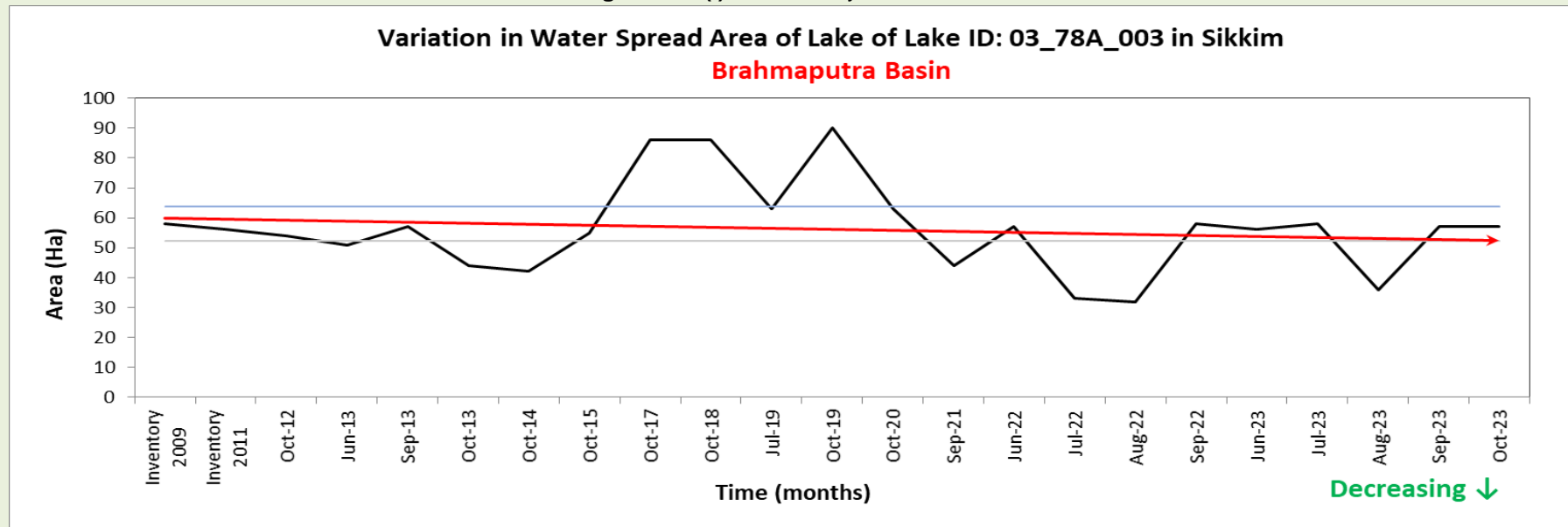


Figure 4.22(ii) Trend Analysis Plot  $\pm 20\%$

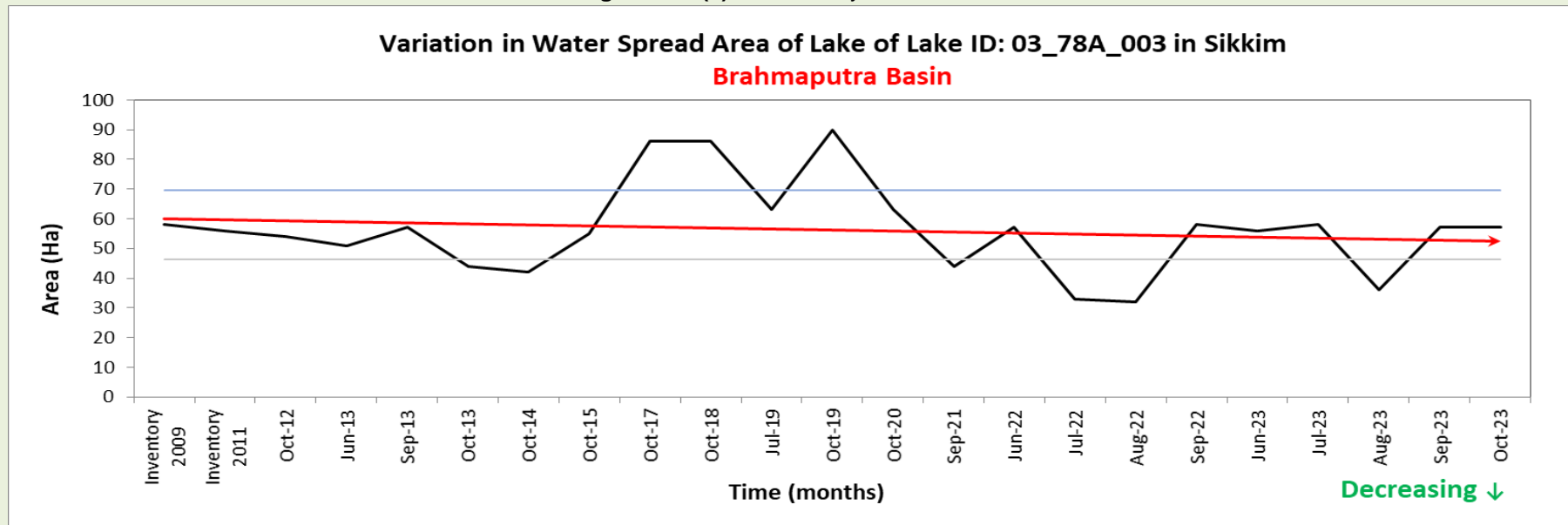


Figure 4.23(i) Trend Analysis Plot  $\pm 10\%$

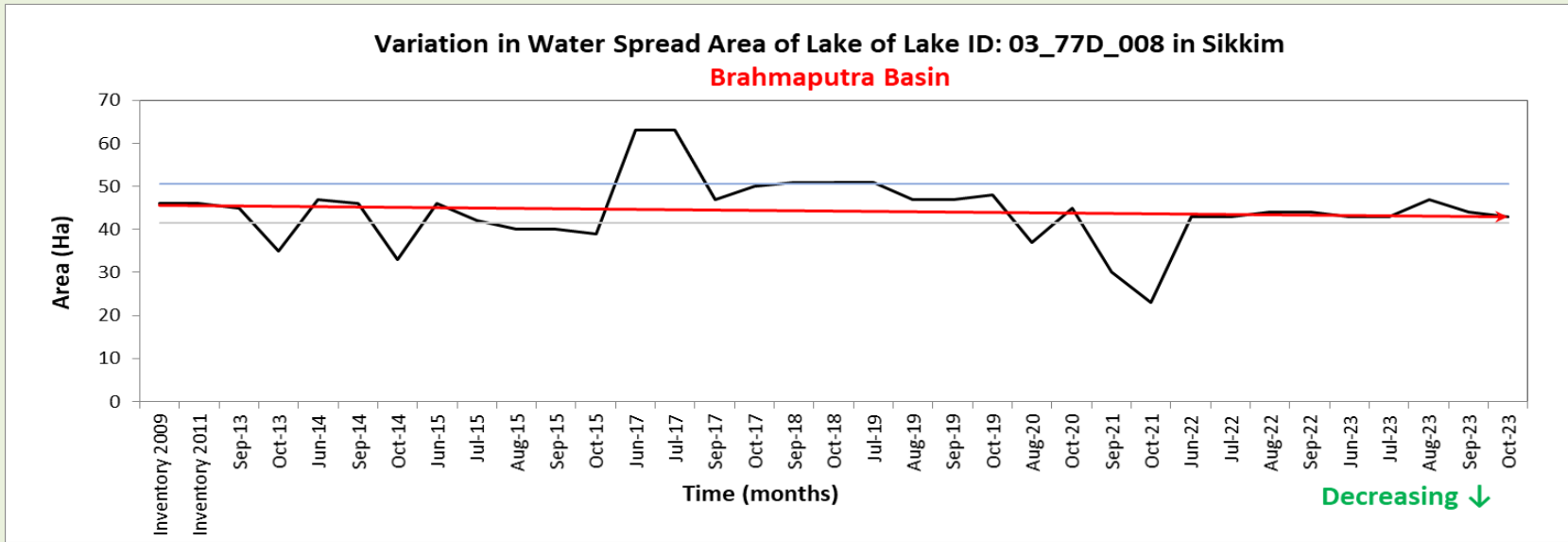
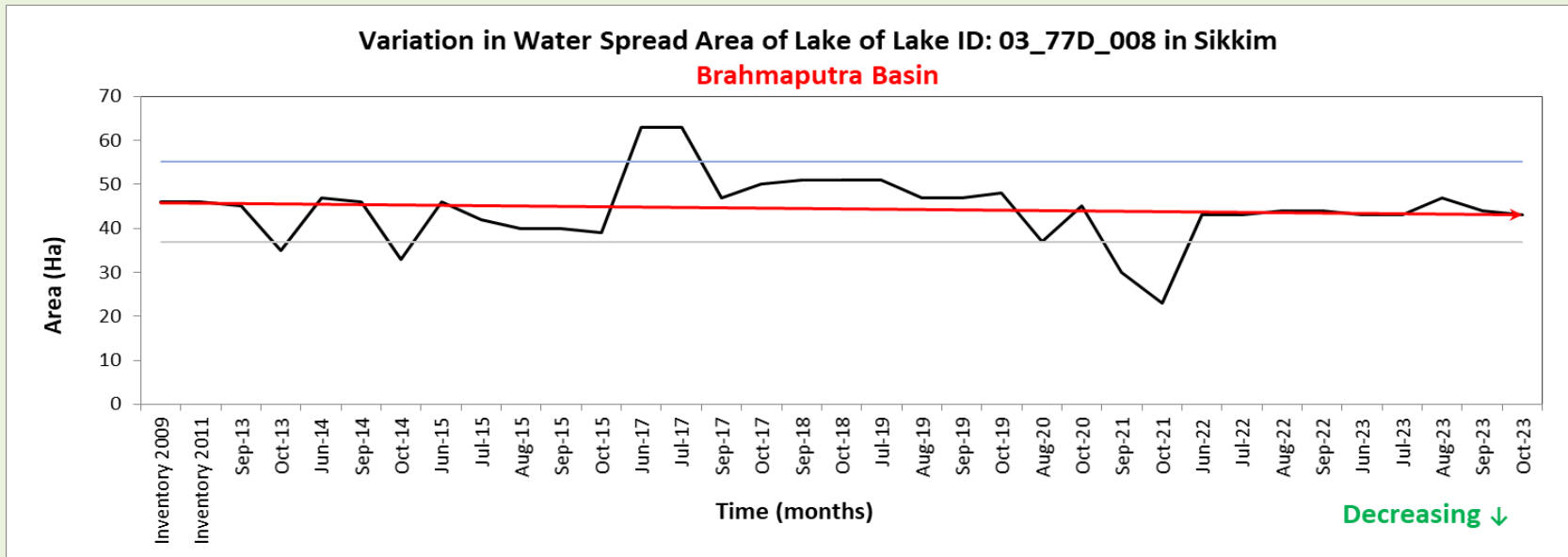


Figure 4.23(ii) Trend Analysis Plot  $\pm 20\%$



#### 4.6.3 Trend analysis of 15 GL of size greater than 50 Ha (2022 - 2023) for $\pm 10\%$ variation w.r.t. Base Year data June 2022

This was done to analyse the recent trend of Glacial lakes. As per the analysis, no Glacial Lake exhibited an increasing trend. The Glacial Lakes showing long term increasing trend has shifted to a stable condition exhibiting No change in trend. The state-wise distribution of these lakes is given in Table No. 7.8. The details are furnished in Table No. 7.9.

**Table No.4.10: State wise details of trend analysis of Glacial Lakes of size greater than 50Ha for a  $\pm 10\%$  variation in water spread area based on June 2022 data**

Sl. No.	States	Increasing Trend	No Change in Trend	Decreasing Trend	Total
1	Ladakh	0	2	1	3
2	Himachal Pradesh	0	2	0	2
3	Sikkim	0	10	0	10
	<b>Total</b>	<b>0</b>	<b>14</b>	<b>1</b>	<b>15</b>

**Table No.4.11: Trend Analysis of Glacial Lakes of size greater than 50 Ha in size located in India analysed for  $\pm 10\%$  variation in water spread area based on June data 2022**

Sl. No	Lake ID	Latitude (N)	Longitude (E)	UID	Elevation (m)	Basin	River	Country	State	Inventory 2009 (Area in Ha)	Trend (10%)
1	01_52C_003	33.1573	76.9843	JK_187	4512	Indus	Indus	India	Ladakh	45	No Change
2	01_52J_001	34.4577	78.1351	JK_197	5311	Indus	Shyok	India	Ladakh	97	No Change
3	01_52E_001	35.418	77.6046	JK_188	5116	Indus	Shyok	India	Ladakh	51	Decreasing
4	01_52H_004	32.4964	77.5516	HP_5	4155	Indus	Chenab	India	Himachal Pradesh	46	No Change
5	01_52H_002	32.5247	77.2183	HP_3	4101	Indus	Chenab	India	Himachal Pradesh	62	No Change
6	03_78A_021	27.8245	88.2492	SK_26	5431	Brahmaputra	Teesta	India	Sikkim	56	No Change
7	03_77D_005	28.0091	88.6979	SK_5	5249	Brahmaputra	Teesta	India	Sikkim	79	No Change
8	03_78A_014	27.9119	88.1986	SK_20	5234	Brahmaputra	Teesta	India	Sikkim	94	No Change
9	03_78A_009	27.9477	88.3313	SK_16	5044	Brahmaputra	Teesta	India	Sikkim	54	No Change
10	03_78A_001	27.9917	88.8155	SK_9	5371	Brahmaputra	Teesta	India	Sikkim	156	No Change
11	03_77D_004	28.0071	88.7128	SK_4	5287	Brahmaputra	Teesta	India	Sikkim	106	No Change
12	03_78A_013	27.9188	88.161	SK_19	5470	Brahmaputra	Teesta	India	Sikkim	63	No Change
13	03_77D_002	28.0261	88.71	SK_2	5156	Brahmaputra	Teesta	India	Sikkim	105	No Change
14	03_78A_003	27.9753	88.6164	SK_11	4977	Brahmaputra	Teesta	India	Sikkim	58	No Change
15	03_77D_008	28.0073	88.4949	SK_8	5039	Brahmaputra	Teesta	India	Sikkim	46	No Change

#### 4.6.4 Trend analysis of 15 GL of size greater than 50 Ha (2022 to 2023) for $\pm 20\%$ variation w.r.t. Base Year data June 2022

Analysis showed same result for 20% variation also. The state-wise distribution of these lakes is given in Table No. 7.10. The details are furnished in Table No. 7.11.

**Table No. 4.12: State wise details of trend analysis of Glacial Lakes of size greater than 50Ha for a  $\pm 20\%$  variation in water spread area w.r.t. June 2022 data**

Sl. No.	States	Increasing Trend	No Change in Trend	Decreasing Trend	Total
1	Ladakh	0	2	1	3
2	Himachal Pradesh	0	2	0	2
3	Sikkim	0	10	0	10
	<b>Total</b>	<b>0</b>	<b>14</b>	<b>1</b>	<b>15</b>

**Table No. 4.13: Trend Analysis of Glacial Lakes of size greater than 50 Ha in size located in India analysed for  $\pm 20\%$  variation in water spread area based on 2 Years data (2022-2023)**

Sl. No.	Lake ID	Latitude (N)	Longitude (E)	UID	Elevation (m)	Basin	River	Country	State	Inventory 2009 (Area in Ha)	Trend (20%)
1	01_52C_003	33.1573	76.9843	JK_187	4512	Indus	Indus	India	Ladakh	45	No Change
2	01_52J_001	34.4577	78.1351	JK_197	5311	Indus	Shyok	India	Ladakh	97	No Change
3	01_52E_001	35.418	77.6046	JK_188	5116	Indus	Shyok	India	Ladakh	51	Decreasing
4	01_52H_004	32.4964	77.5516	HP_5	4155	Indus	Chenab	India	Himachal Pradesh	46	No Change
5	01_52H_002	32.5247	77.2183	HP_3	4101	Indus	Chenab	India	Himachal Pradesh	62	No Change
6	03_78A_021	27.8245	88.2492	SK_26	5431	Brahmaputra	Teesta	India	Sikkim	56	No Change
7	03_77D_005	28.0091	88.6979	SK_5	5249	Brahmaputra	Teesta	India	Sikkim	79	No Change
8	03_78A_014	27.9119	88.1986	SK_20	5234	Brahmaputra	Teesta	India	Sikkim	94	No Change
9	03_78A_001	27.9917	88.8155	SK_9	5371	Brahmaputra	Teesta	India	Sikkim	156	No Change
10	03_78A_013	27.9188	88.161	SK_19	5470	Brahmaputra	Teesta	India	Sikkim	63	No Change
11	03_78A_009	27.9477	88.3313	SK_16	5044	Brahmaputra	Teesta	India	Sikkim	54	No Change
12	03_77D_004	28.0071	88.7128	SK_4	5287	Brahmaputra	Teesta	India	Sikkim	106	No Change
13	03_77D_002	28.0261	88.71	SK_2	5156	Brahmaputra	Teesta	India	Sikkim	105	No Change
14	03_78A_003	27.9753	88.6164	SK_11	4977	Brahmaputra	Teesta	India	Sikkim	58	No Change
15	03_77D_008	28.0073	88.4949	SK_8	5039	Brahmaputra	Teesta	India	Sikkim	46	No Change

Lake-wise plot are appended as given below.

<i>Trend analysis for Change in Water spread area of Glacial Lakes (&gt;50 Ha) for <math>\pm 10\%</math> &amp; <math>\pm 20\%</math> w.r.t base year data of June 2022</i>		
<b>S.No.</b>	<b>States</b>	<b>Figure No.</b>
1	Ladakh	Figure 4.24(i)-Figure 4.26(ii)
2	Himachal Pradesh	Figure 4.27(i)-Figure 4.28(ii)
3	Sikkim	Figure 4.29(i)-Figure 4.38(ii)

**Trend Analysis of “Change in Water spread area of Glacial Lakes (>50 Ha) of Ladakh”**

Figure 4.24(i) Trend Analysis Plot  $\pm 10\%$

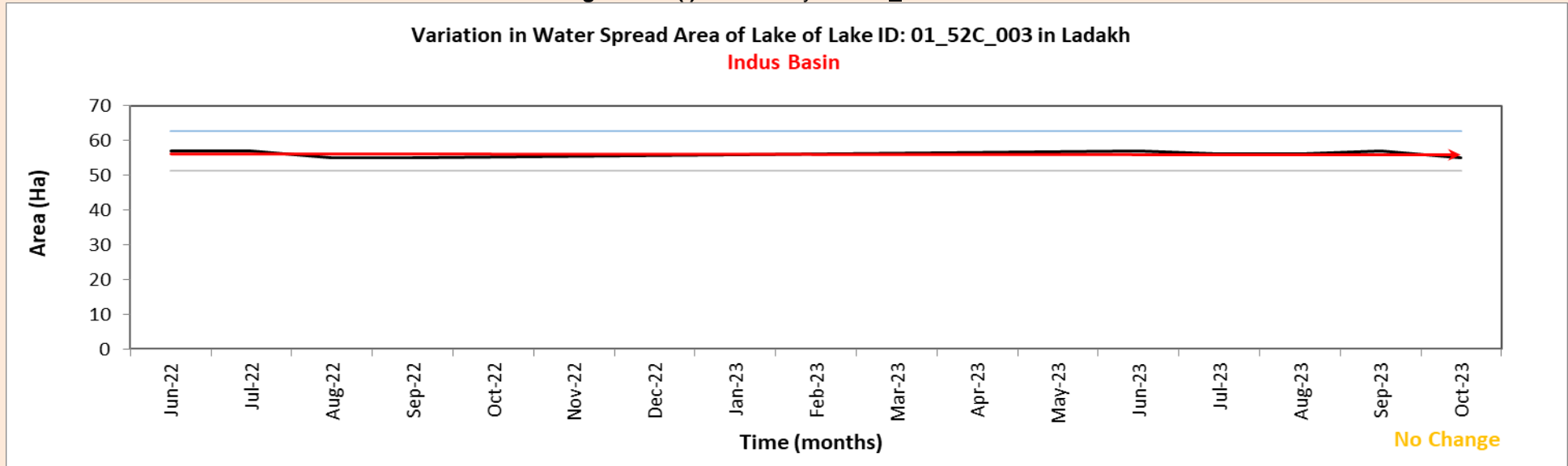
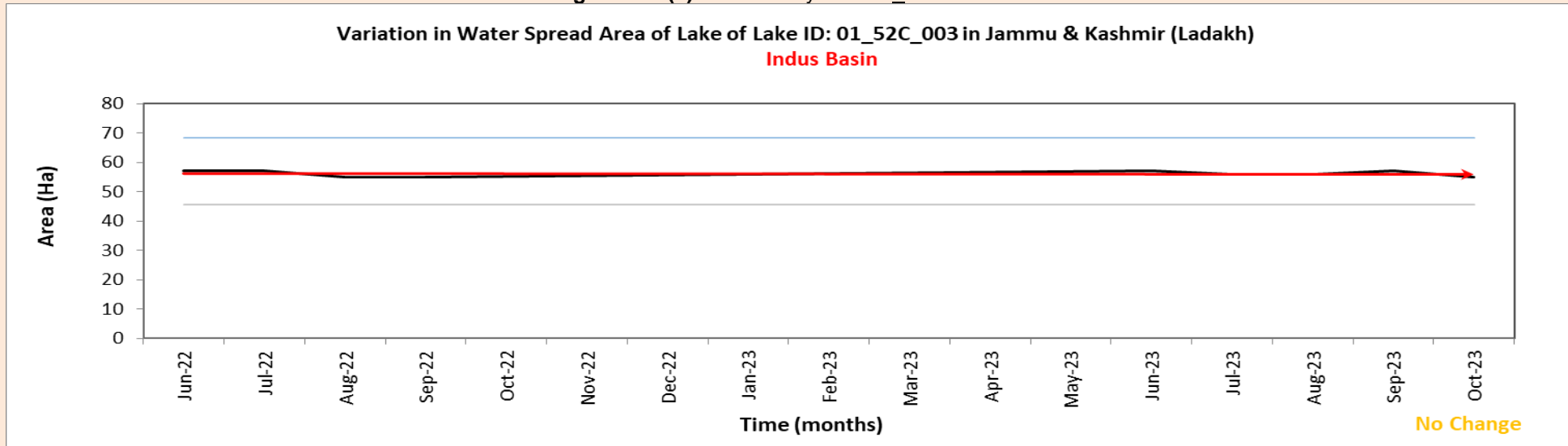
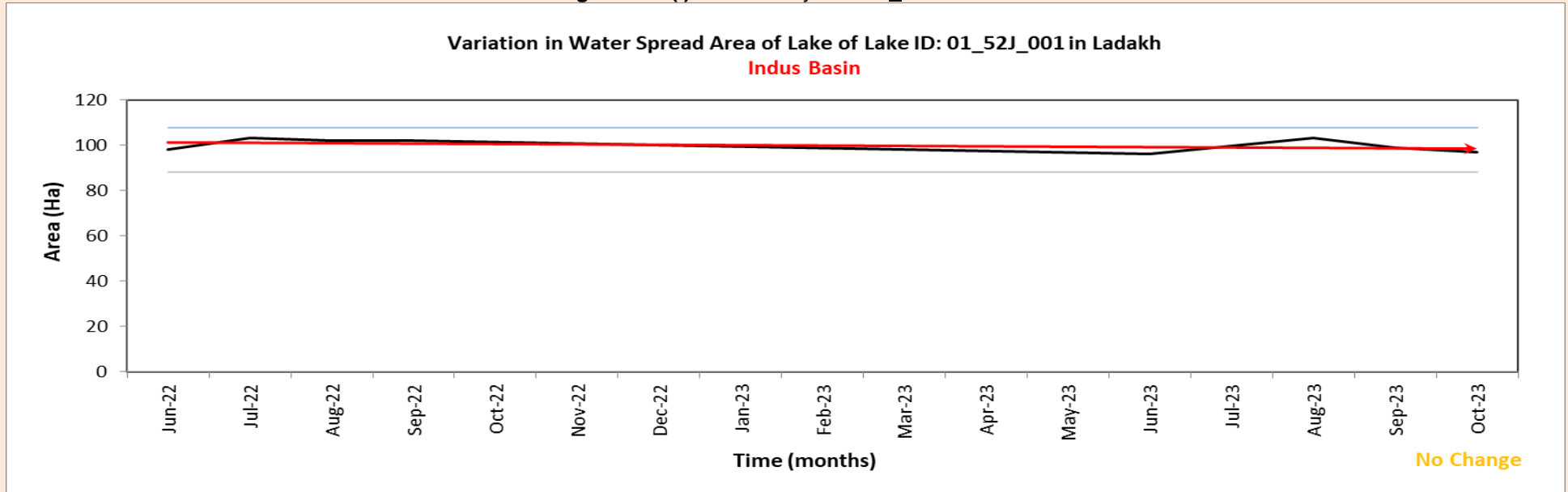


Figure 4.24(ii) Trend Analysis Plot  $\pm 20\%$



**Figure 4.25(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.25(ii)** Trend Analysis Plot  $\pm 20\%$

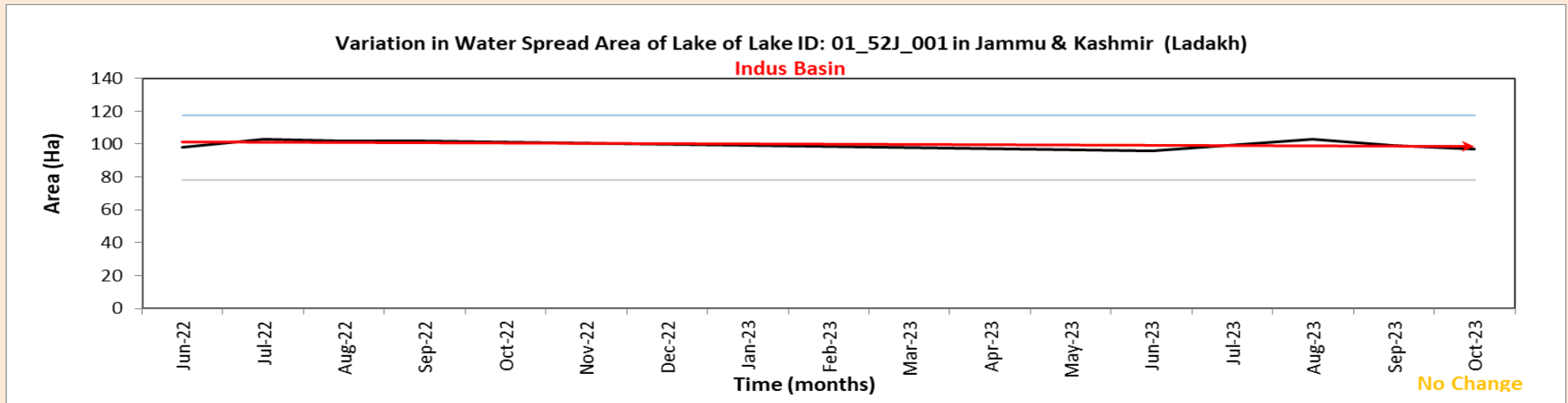


Figure 4.26(i) Trend Analysis Plot  $\pm 10\%$

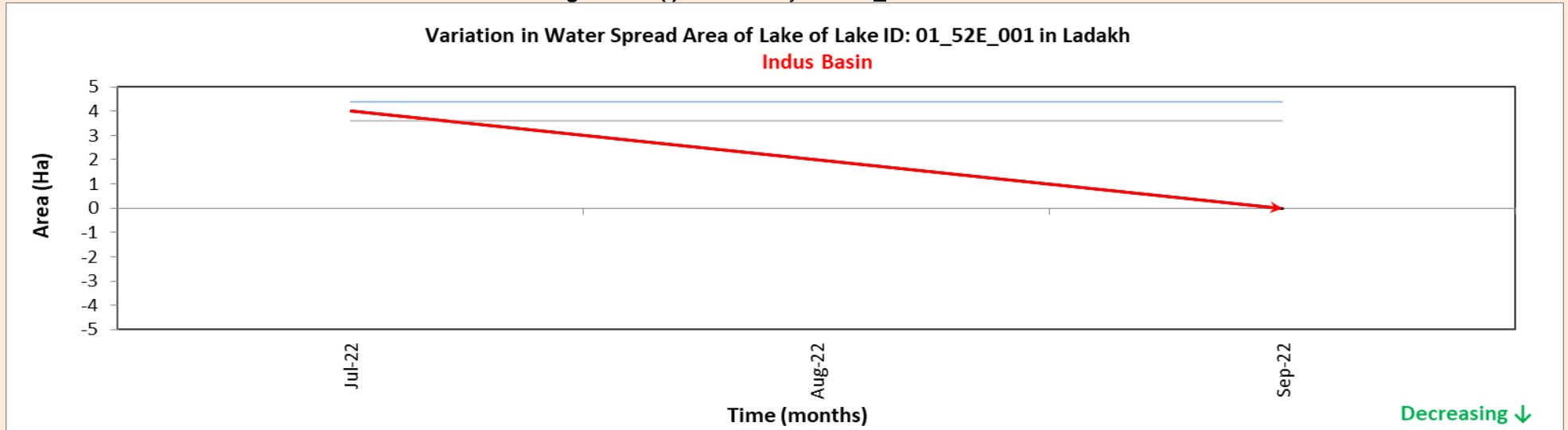
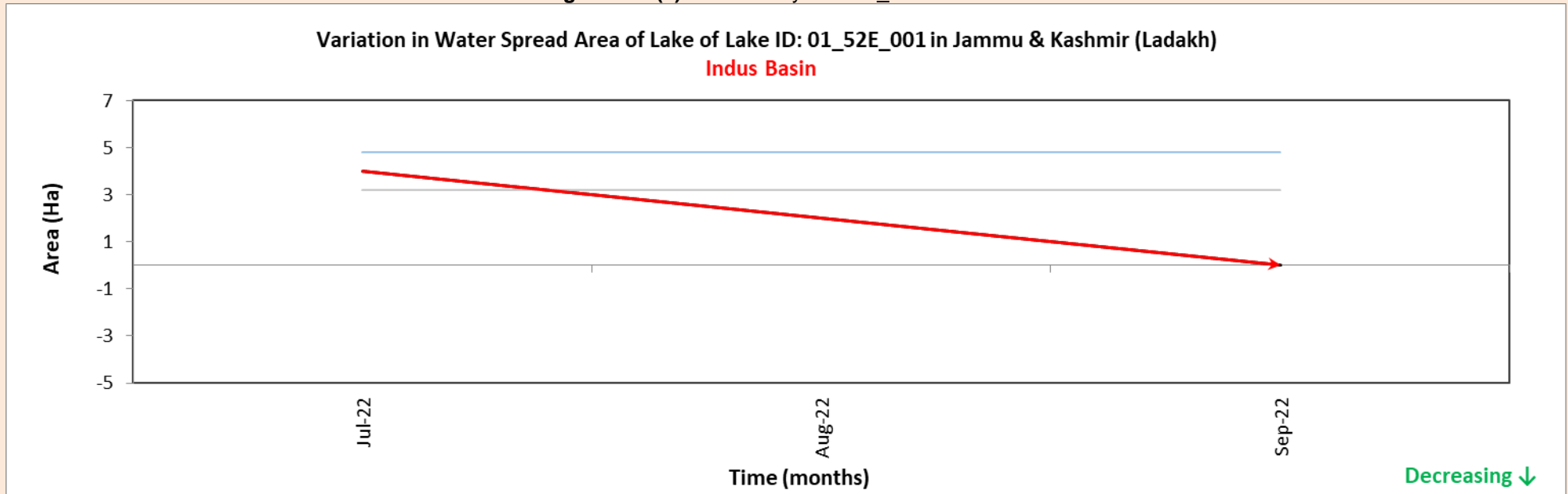


Figure 4.26(ii) Trend Analysis Plot  $\pm 20\%$



**Trend Analysis of “Change in Water spread area of Glacial Lakes (>50 Ha) of Himachal Pradesh”**

Figure 4.27(i) Trend Analysis Plot  $\pm 10\%$

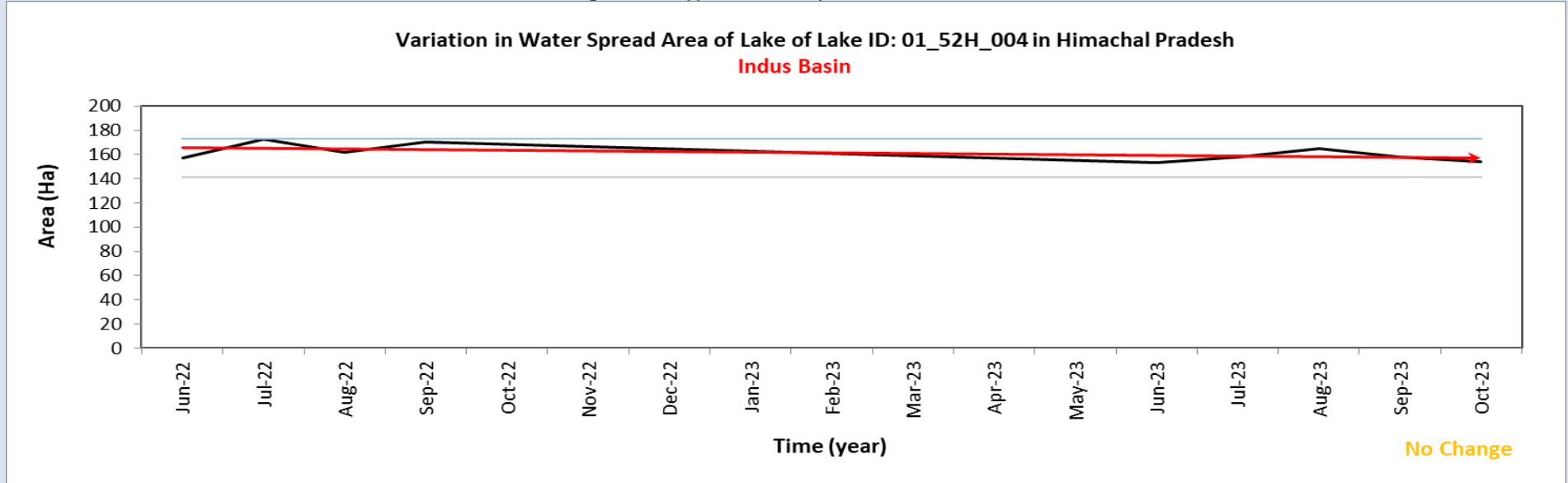
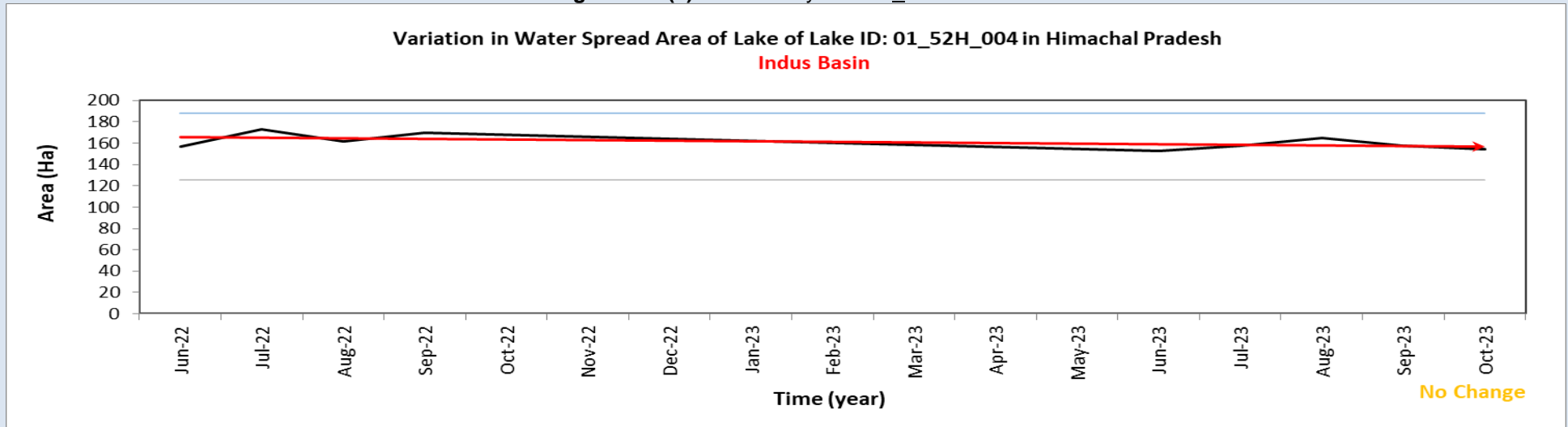
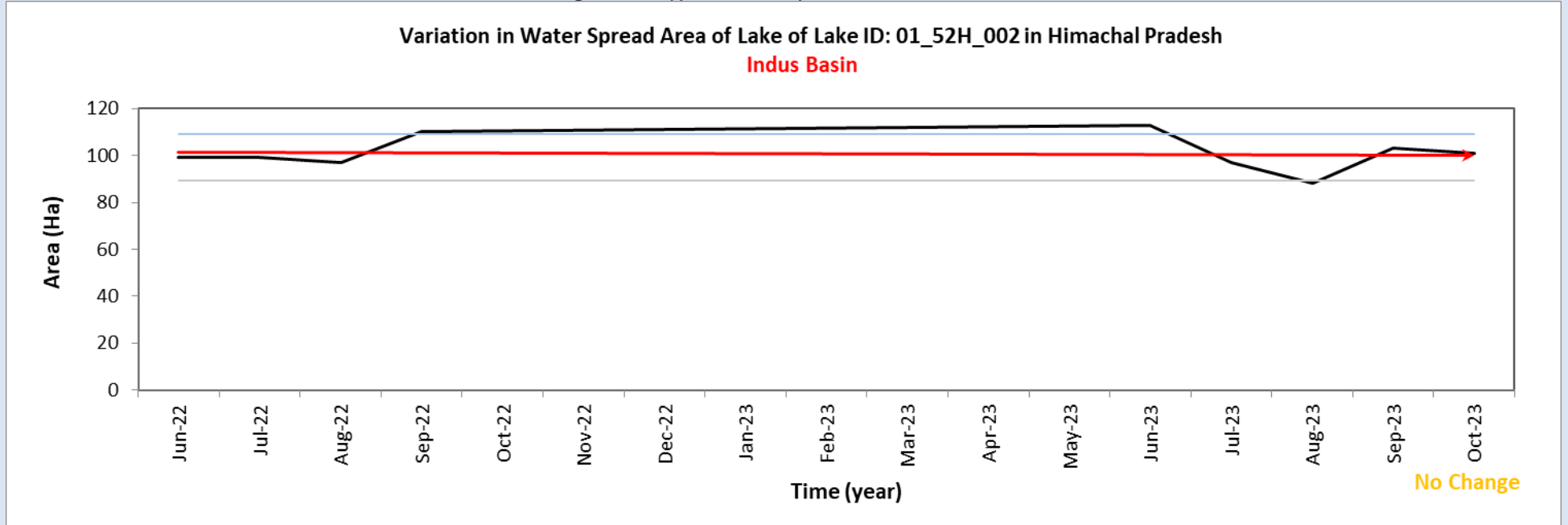


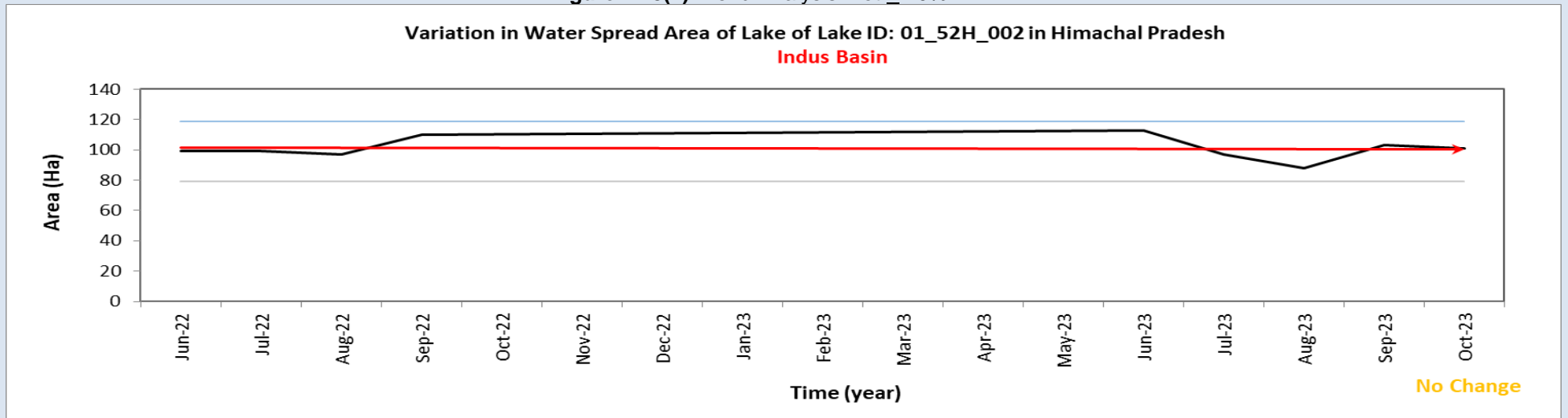
Figure 4.27(ii) Trend Analysis Plot  $\pm 20\%$



**Figure 4.28(i)** Trend Analysis Plot  $\pm 10\%$

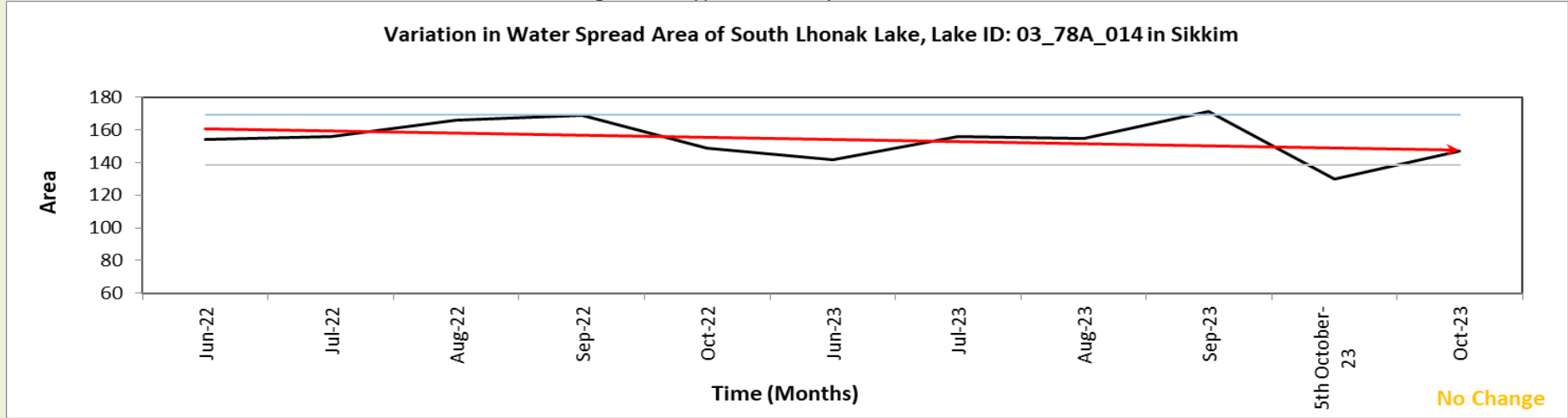


**Figure 4.28(ii)** Trend Analysis Plot  $\pm 20\%$

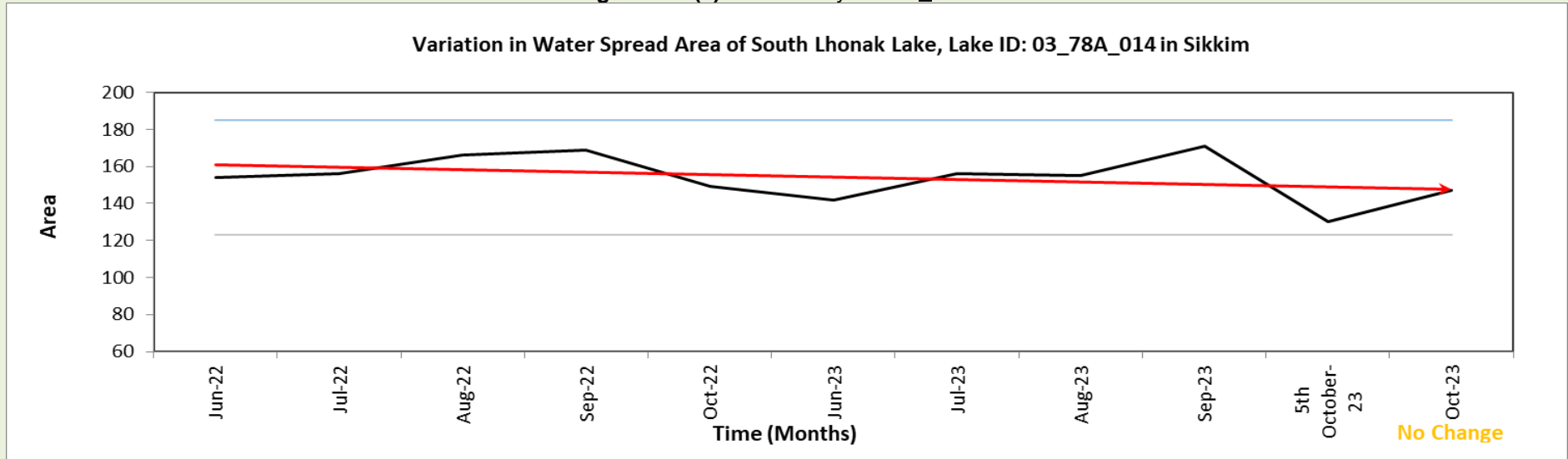


**Trend Analysis of “Change in Water spread area of Glacial Lakes (>50 Ha) of Sikkim”**

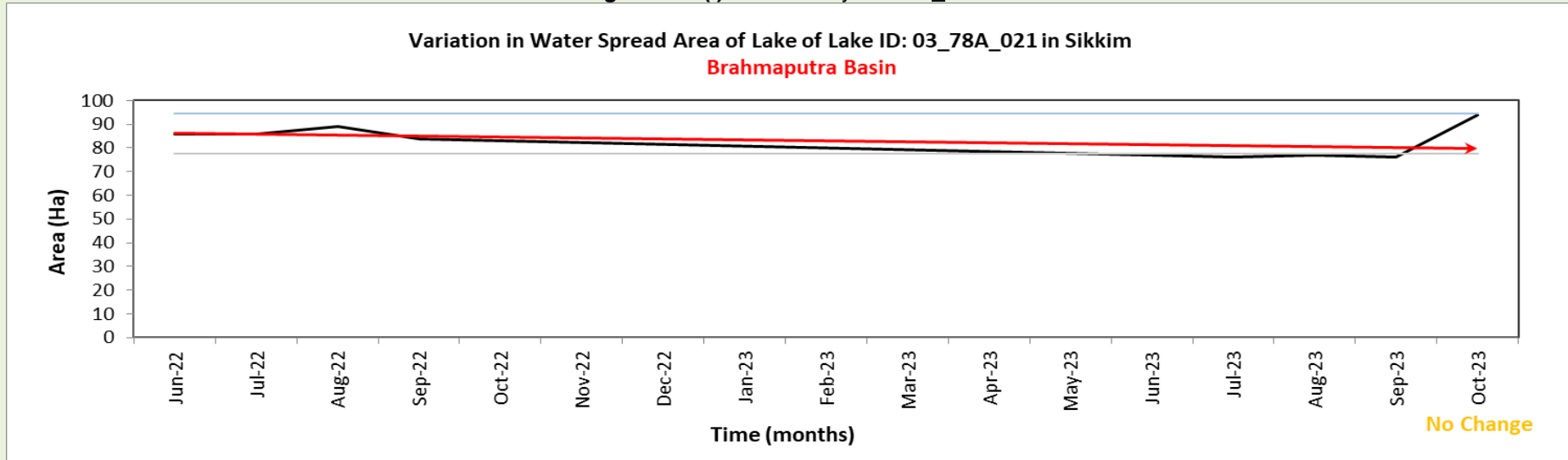
**Figure 4.29(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.29(ii)** Trend Analysis Plot  $\pm 20\%$



**Figure 4.30(i) Trend Analysis Plot  $\pm 10\%$**



**Figure 4.30(ii) Trend Analysis Plot  $\pm 20\%$**

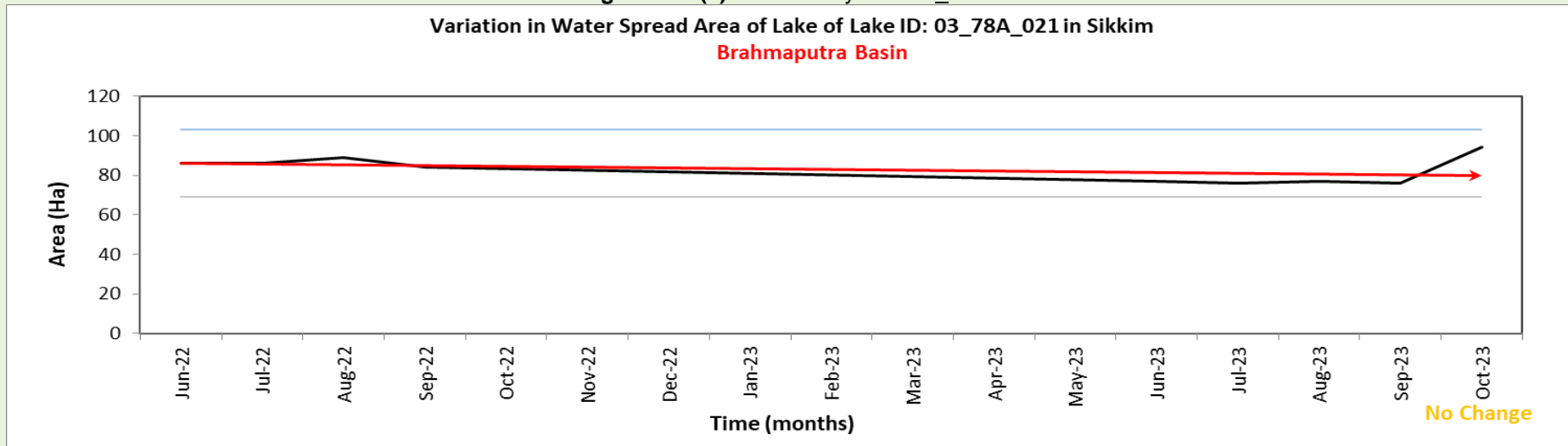


Figure 4.31(i) Trend Analysis Plot  $\pm 10\%$

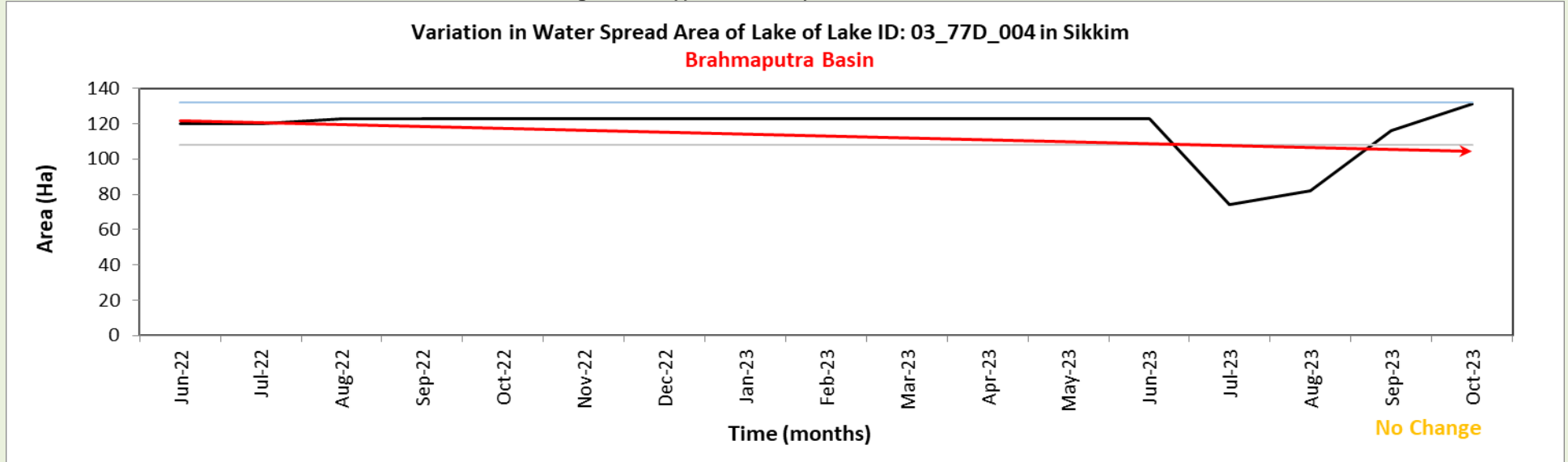
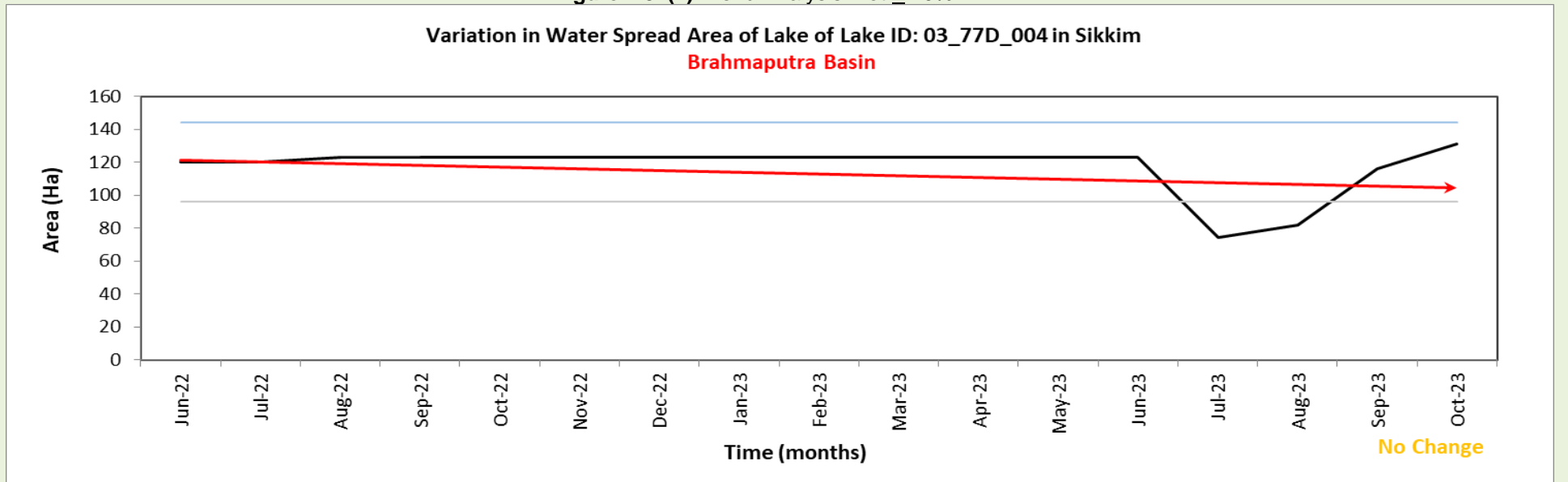
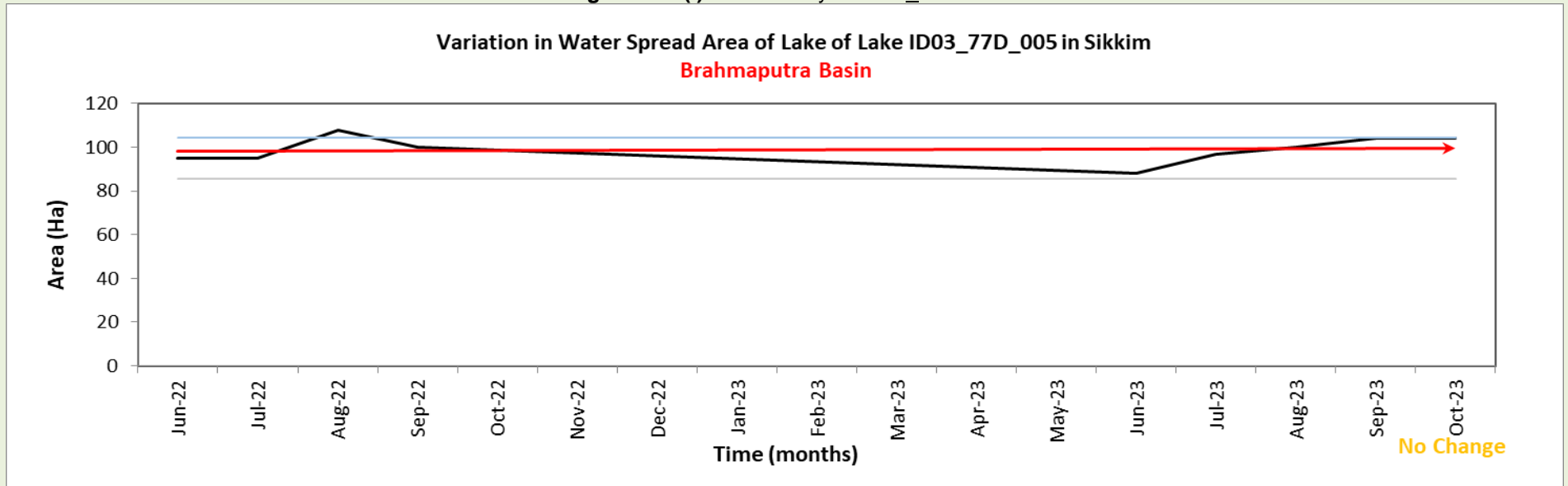


Figure 4.31(ii) Trend Analysis Plot  $\pm 20\%$



**Figure 4.32(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.32(ii)** Trend Analysis Plot  $\pm 20\%$

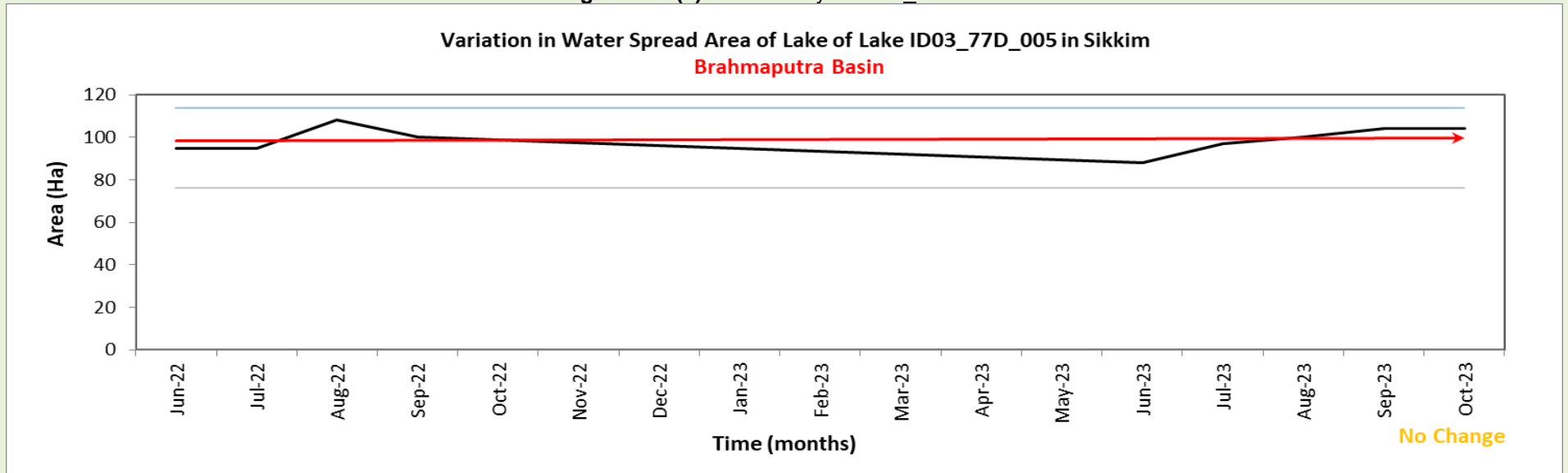


Figure 4.33(i) Trend Analysis Plot + 10%

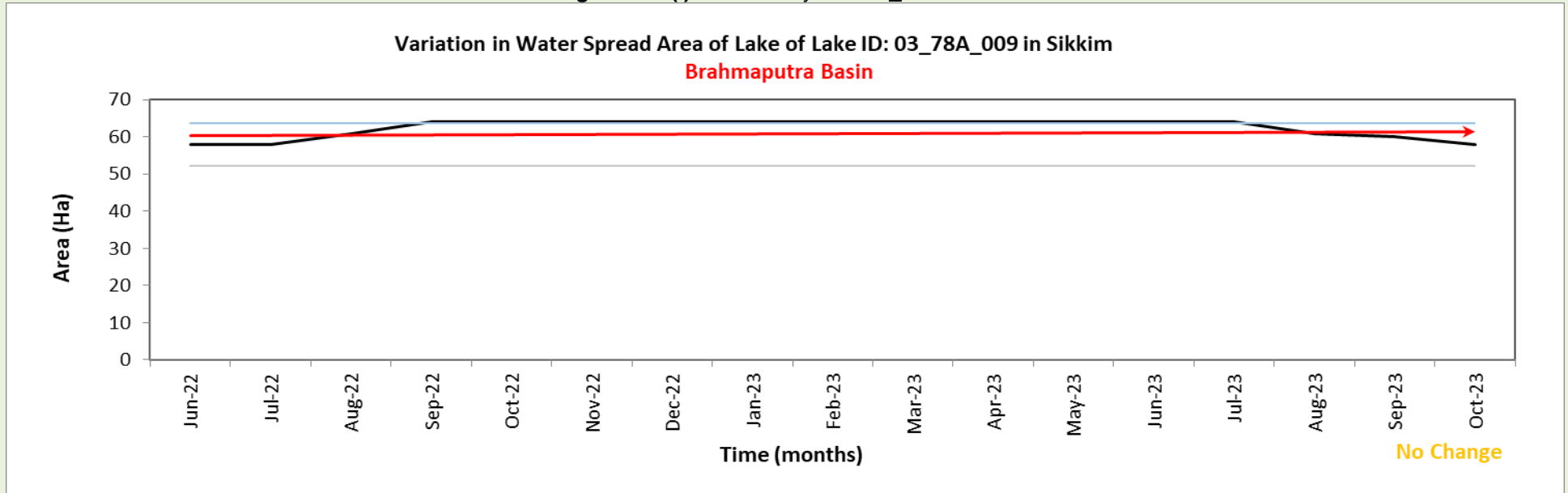


Figure 4.33(ii) Trend Analysis Plot + 20%

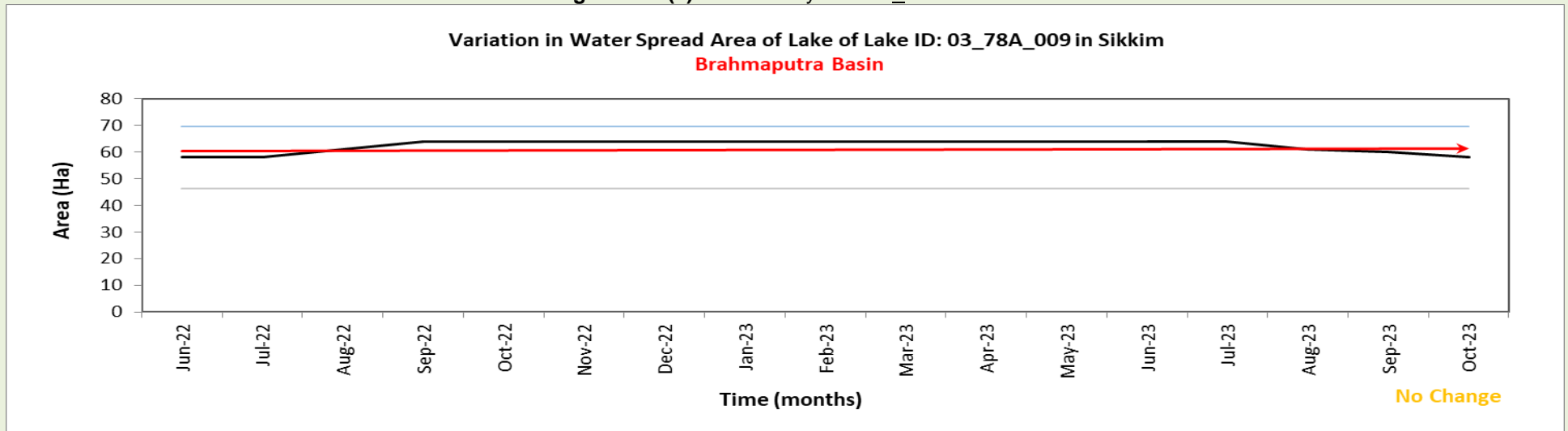


Figure 4.34(i) Trend Analysis Plot  $\pm 10\%$

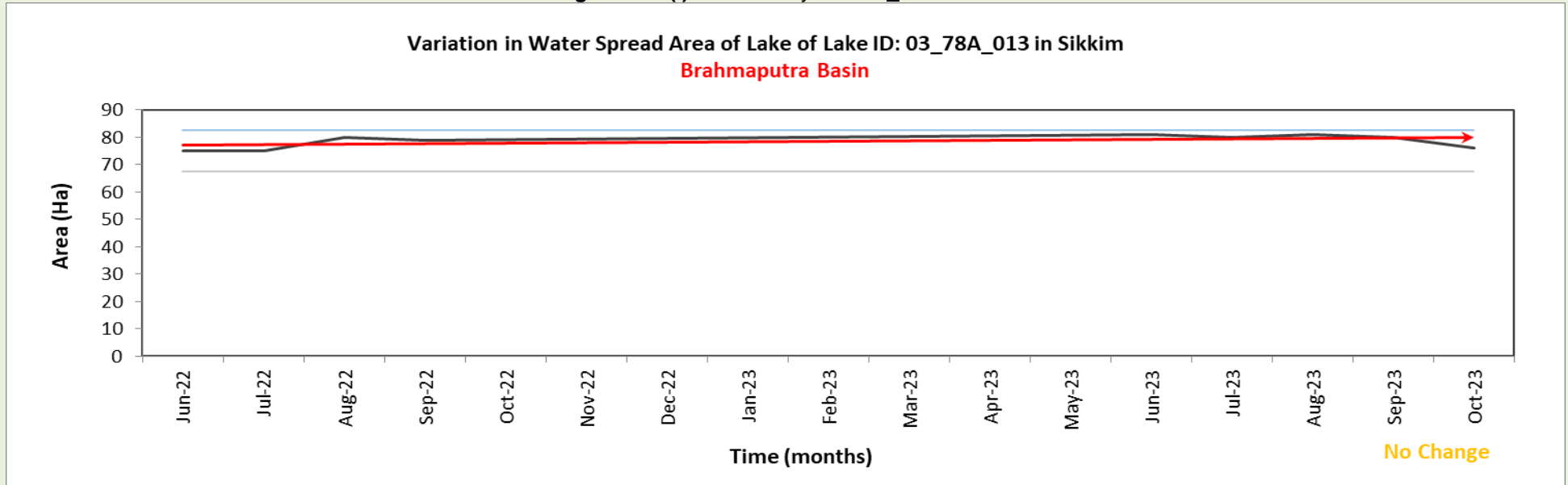
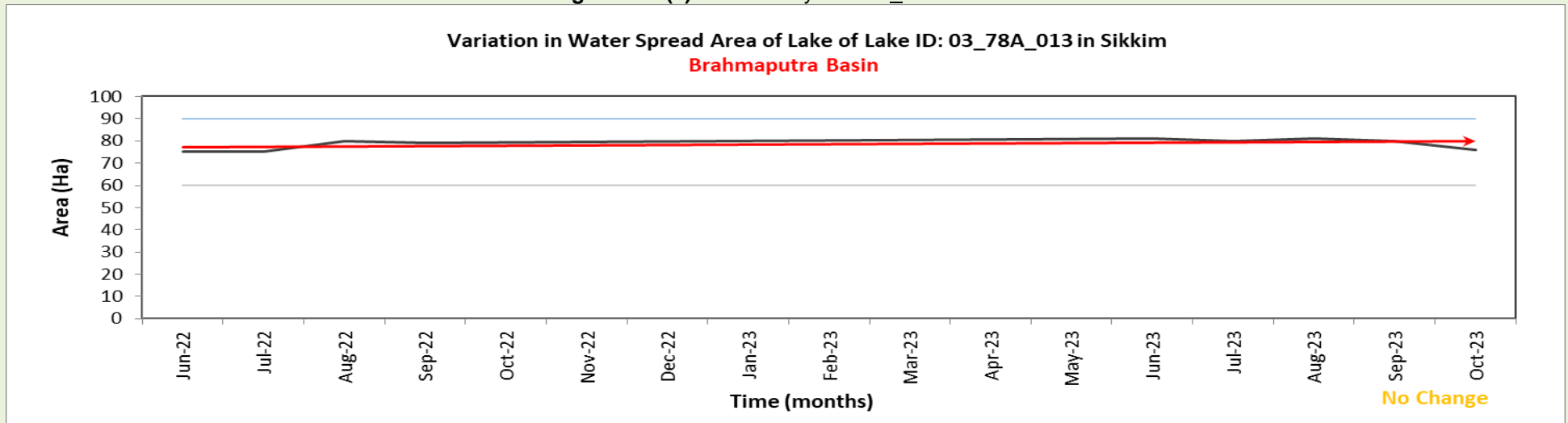
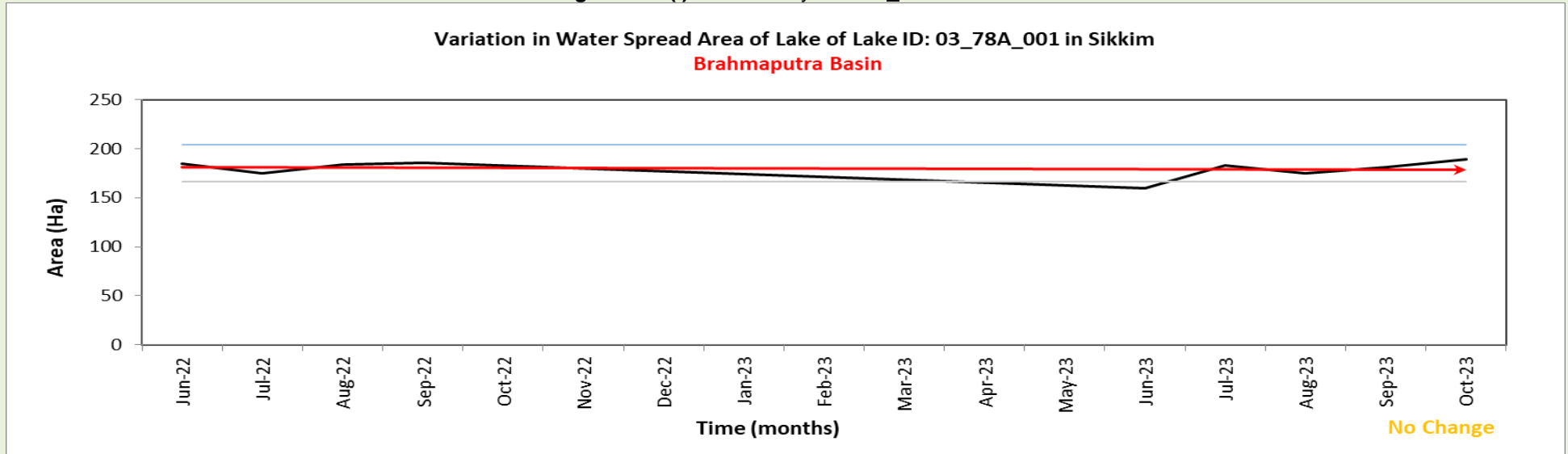


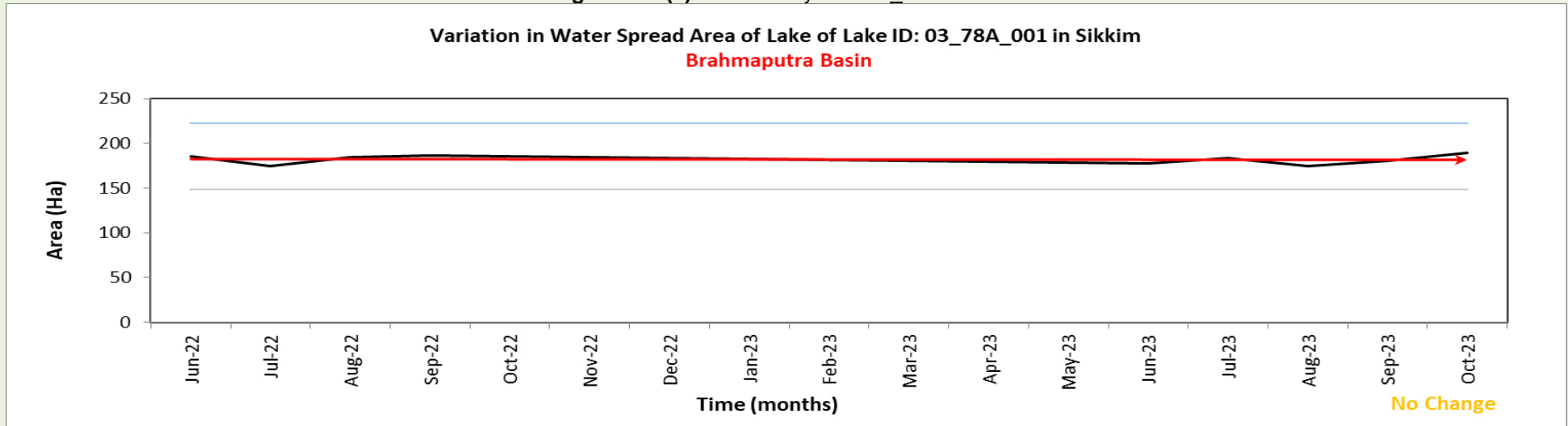
Figure 4.34(ii) Trend Analysis Plot  $\pm 20\%$



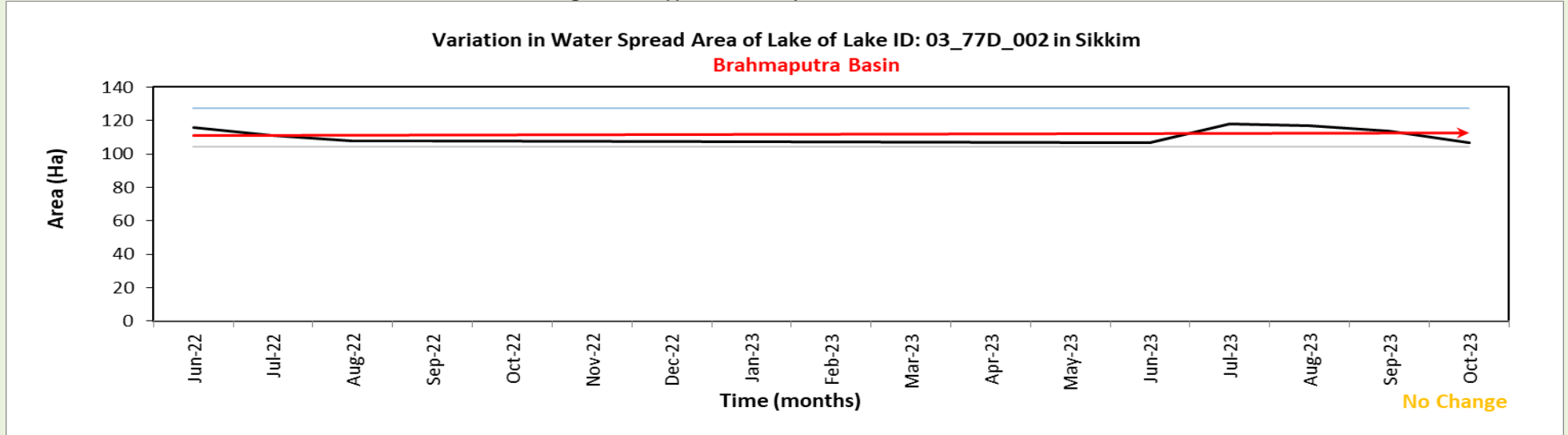
**Figure 4.35(i)** Trend Analysis Plot  $\pm 10\%$



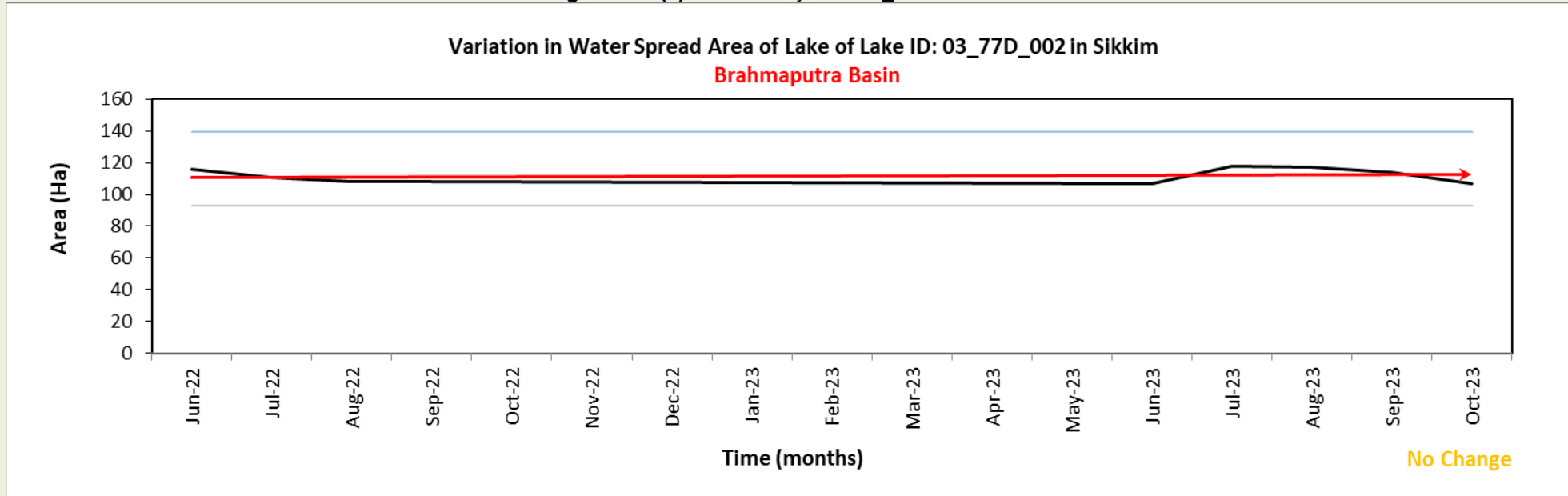
**Figure 4.35(ii)** Trend Analysis Plot  $\pm 20\%$



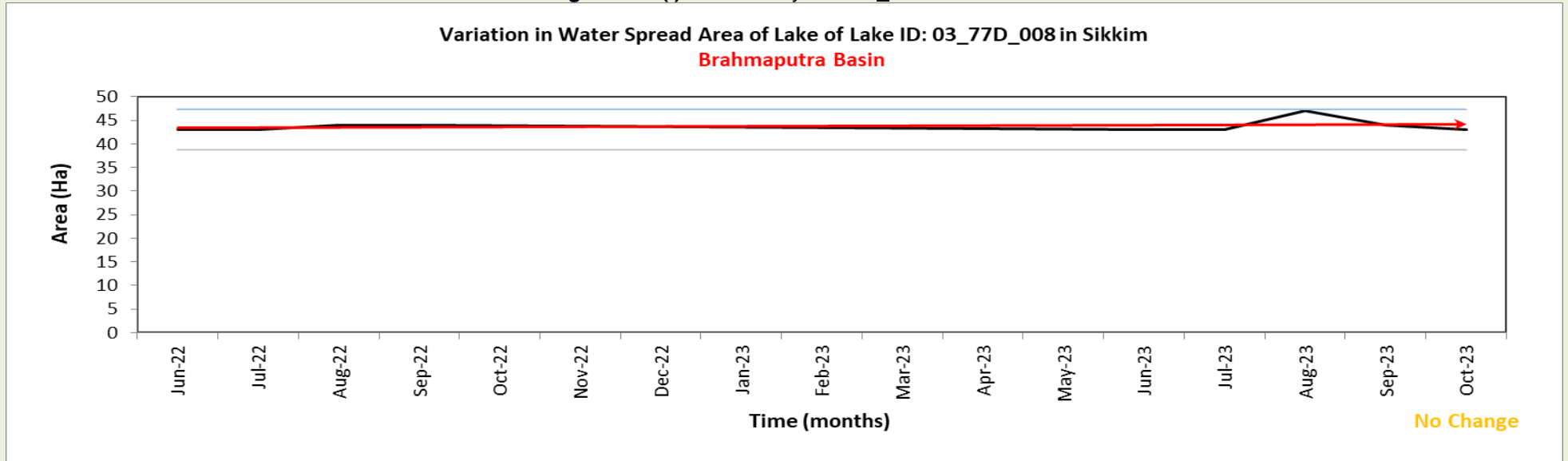
**Figure 4.36(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.36(ii)** Trend Analysis Plot  $\pm 20\%$



**Figure 4.37(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.37(ii)** Trend Analysis Plot  $\pm 20\%$

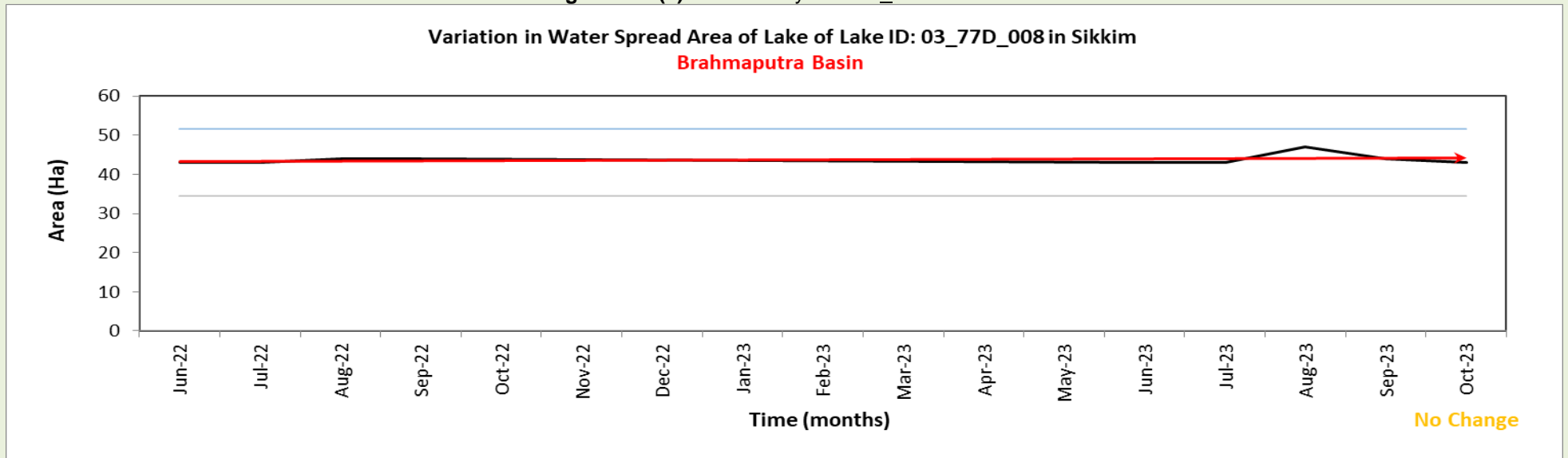


Figure 4.38(i) Trend Analysis Plot  $\pm 10\%$

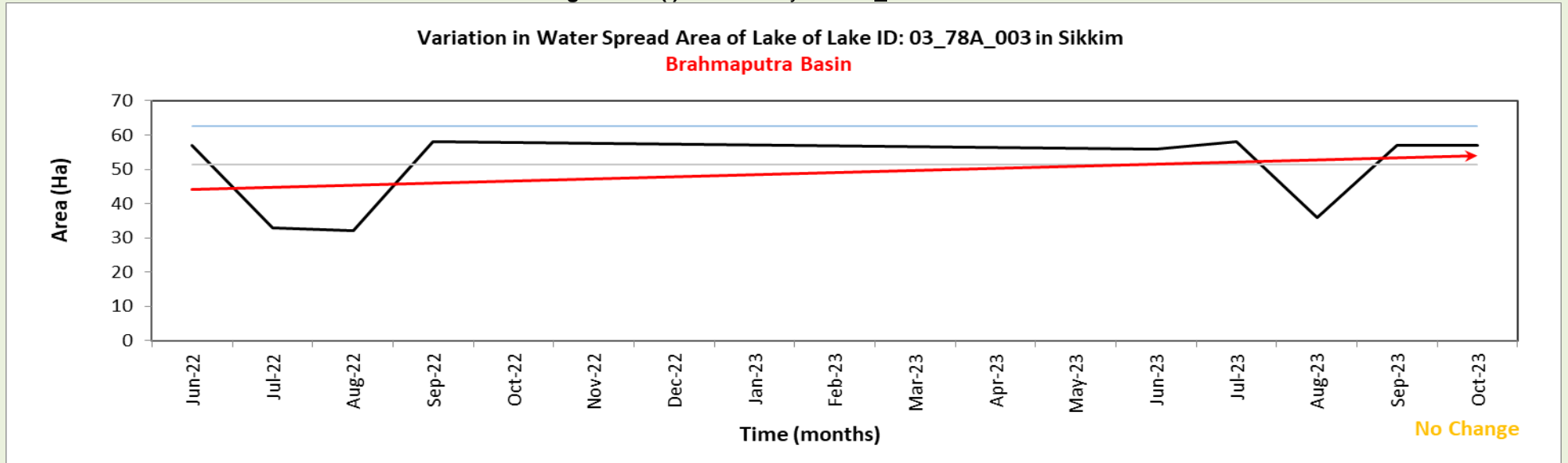
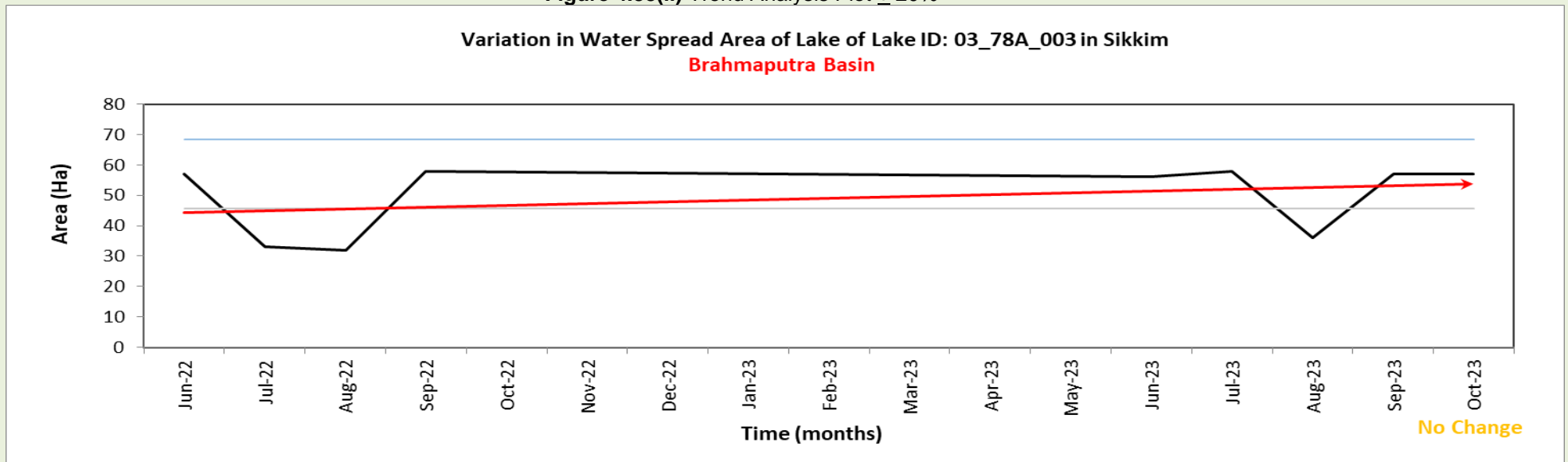


Figure 4.38(ii) Trend Analysis Plot  $\pm 20\%$



#### 4.6.5 Trend analysis of 85 Glacial Lakes of size between 10 Ha to 50 Ha for change in Water spread area (2011-2023) for $\pm 10\%$ variation w.r.t. base year data of 2011

As per the analysis for trend of Glacial Lakes assuming a  $\pm 10\%$  variation in last data wrt base year data (2011) of water spread area, 24 GLs exhibit an increasing trend, 42 GLs exhibit no change in trend and 17GLs, a decreasing trend. Analysis of 2 GLs located in Uttarakhand could not be done due to non-availability of cloud free data. The state-wise distribution of location these lakes are given in table No.7.12. The details are furnished in table No. 7.13.

Sikkim has the maximum number of glacial lakes with increasing trend (8 Nos.), followed by Jammu & Kashmir (5 Nos.), Himachal Pradesh (4 Nos.), Arunachal Pradesh and Ladakh (3 Nos. each) and Uttarakhand (1 No.)

**Table No. 4.14: State wise details of trend analysis of Glacial Lakes of water spread area of 10 Ha to 50 Ha for a  $\pm 10\%$  variation in water spread area w.r.t. base year data 2011**

S.No.	States	Increasing	No Change	Decreasing	No Analysis	Total
1	Ladakh	3	6	3	0	12
2	Jammu & Kashmir	5	6	4	0	15
3	Himachal Pradesh	4	3	1	0	8
4	Uttarakhand	1	5	1	2	9
5	Sikkim	8	16	8	0	32
6	Arunachal Pradesh	3	6	0	0	9
	<b>Total</b>	<b>24</b>	<b>42</b>	<b>17</b>	<b>2</b>	<b>85</b>

**Table No. 4.15: Trend Analysis of Glacial Lakes 10- 50 Ha in size located in India analysed for 10% variation in water spread area based on 2 years data (in addition to that of 2011)**

Sl. No	Lake ID	Latitude(N)	Longitude (E)	Elevation (m)	River	Basin	Country	State	Inventory 2011 (Area in Ha)	Trend (10%)
1	01_42H_002	36° 38' 34.8"	73° 24' 26.64"	2763	Gilgit	Indus	India	Ladakh	13	Increasing
2	01_52C_001	33° 56' 44.52"	76° 13' 53.76"	4394	Shingo (Indus)	Indus	India	Ladakh	36	Increasing
3	1360	35° 1' 40.87"	75° 43' 36.84"	4667		Indus	India	Ladakh		Increasing
4	01_52L_006	32° 26' 27.24"	78° 55' 29.28"	5727	Indus	Indus	India	Ladakh	12	No Change
5	01_52B_012	34° 0' 19.8"	76° 47' 12.84"	5137	Indus	Indus	India	Ladakh	17	No Change
6	01_52L_007	32° 24' 36.36"	78° 53' 56.4"	5498	Indus	Indus	India	Ladakh	32	No Change
7	01_52B_010	34° 3' 6.48"	76° 43' 5.16"	5122	Indus	Indus	India	Ladakh	18	No Change
8	173	34° 46' 12.35"	76° 42' 31.20"	5150		Indus	India	Ladakh		No Change
9	180	34° 21' 13.694"	76° 4' 35.57"	4442		Indus	India	Ladakh		No Change
10	01_52A_002	35° 5' 48.12"	76° 14' 0.6"	4537	Shyok	Indus	India	Ladakh	23	Decreasing
11	01_52A_004	35° 4' 28.2"	76° 17' 33.72"	4619	Shyok	Indus	India	Ladakh	11	Decreasing
12	01_52A_003	35° 5' 33.36"	76° 15' 7.2"	4586	Shyok	Indus	India	Ladakh	24	Decreasing
13	01_52C_002	33° 52' 10.2"	76° 7' 9.48"	4092	Chenab	Indus	India	Jammu & Kashmir	26	Increasing
14	27	34° 22' 40.837"	74° 52' 34.23"	3775		Indus	India	Jammu & Kashmir		Increasing

15	98	34°23'30.053"	75°5'6.93"	4103		Indus	India	Jammu & Kashmir		Increasing
16	958	34°8'15.508"	75°24'59.64"	4103		Indus	India	Jammu & Kashmir		Increasing
17	963	34°8'13.5"	75°22'33.06"	3725		Indus	India	Jammu & Kashmir		Increasing
18	182	34°14'1.589"	75°19'25.60"	4304		Indus	India	Jammu & Kashmir		No Change
19	931	33°55'55.346"	75°23'33.77"	4082		Indus	India	Jammu & Kashmir		No Change
20	951	34°3'58.769"	75°28'31.00"	3762		Indus	India	Jammu & Kashmir		No Change
21	976	34°11'2.939"	75°22'24.77"	4314		Indus	India	Jammu & Kashmir		No Change
22	1032	34°23'8.758"	75°3'55.60"	4007		Indus	India	Jammu & Kashmir		No Change
23	1037	34°25'28.86"	75°3'48.35"	3603		Indus	India	Jammu & Kashmir		No Change
24	01_43J_003	34° 55' 36.12"	74° 9' 19.44"	3954	Jhelum	Indus	India	Jammu & Kashmir	20	Decreasing
25	938	33°57'13.97"	75°22'40.33"	3683		Indus	India	Jammu & Kashmir		Decreasing
26	993	34°13'39.02"	75°13'19.29"	4148		Indus	India	Jammu & Kashmir		Decreasing
27	1014	34°17'51.96"	75°3'40.49"	3989		Indus	India	Jammu & Kashmir		Decreasing
28	01_53I_002	31° 39' 38.52"	78° 10' 1.92"	4273	Satluj	Indus	India	Himachal Pradesh	23	Increasing
29	01_52H_003	32° 29' 54.6"	77° 32'37.32"	4165	Chenab	Indus	India	Himachal Pradesh	28	Increasing
30	1805	32°45'44.51"	77°11'41.17"	4775		Indus	India	Himachal Pradesh		Increasing
31	1847	31°55'1.289"	77°32'17.84"	4570		Indus	India	Himachal Pradesh		Increasing
32	1774	32°13'19.45"	76°47'16.97"	4593		Indus	India	Himachal Pradesh		No Change
33	1936	32°15'17.28"	76°46'37.13"	4606		Indus	India	Himachal Pradesh		No Change
34	1998	32°19'12.49"	76°54'26.81"	3857		Indus	India	Himachal Pradesh		No Change
35	2031	31°20'14.094"	78°15'17.03"	4702		Indus	India	Himachal Pradesh		Decreasing
36	02_62B_005	30° 26' 44.52"	80°23'16.08"	4314	Sarda	Ganga	India	Uttarakhand	12	Increasing
37	01_62B_003	30° 28' 36.48"	80°35'35.16"	5288	Satluj	Indus	India	Uttarakhand	12	No Change
38	02_53N_001	30° 54' 7.92"	79° 45' 12.6"	4688	Ganga	Ganga	India	Uttarakhand	21	No Change
39	02_62B_004	30° 33' 52.2"	80° 10'41.16"	4918	Sarda	Ganga	India	Uttarakhand	19	No Change
40	2108	30°58'30.65"	79°27'32.41"	5587		Ganga	India	Uttarakhand		No Change
41	2207	30°54'40.89"	78°57'31.16"	4707		Ganga	India	Uttarakhand		No Change
42	2147	30°58'44.98"	79°29'8.99"	5688		Ganga	India	Uttarakhand		Decreasing
43	02_62B_007	30° 16' 42.96"	80° 7' 49.8"	4839	Sarda	Ganga	India	Uttarakhand	19	No Analysis
44	2299	30°10'59.57"	79°52'52.3"	4490		Ganga	India	Uttarakhand		No Analysis
45	03_78A_035	27° 57' 3.24"	88° 21'15.48"	4998	Teesta	Brahmaputra	India	Sikkim	N.A.	Increasing
46	03_78A_027	27° 32' 0.6"	88° 5' 8.52"	4888	Teesta	Brahmaputra	India	Sikkim	33	Increasing
47	03_77D_006	28° 0' 51.84"	88° 33'41.76"	5084	Teesta	Brahmaputra	India	Sikkim	22	Increasing
48	03_78A_005	27° 58' 31.44"	88° 25'20.64"	5201	Teesta	Brahmaputra	India	Sikkim	11	Increasing
49	03_78A_002	27° 58' 56.28"	88° 30'28.08"	4952	Teesta	Brahmaputra	India	Sikkim	22	Increasing
50	227	27°59'32.62"	88°32'49.54"	5176		Brahmaputra	India	Sikkim		Increasing
51	295	27°55'16.42"	88°40'21.86"	4850		Brahmaputra	India	Sikkim		Increasing
52	298	27°42'3.09"	88°30'55.99"	4508		Brahmaputra	India	Sikkim		Increasing
53	03_78A_007	27° 57' 38.88"	88° 38'57.48"	4977	Teesta	Brahmaputra	India	Sikkim	17	No Change
54	03_78A_023	27° 40' 17.04"	88° 30'46.44"	4547	Teesta	Brahmaputra	India	Sikkim	33	No Change
55	03_78A_031	27° 26' 15"	88° 5' 9.6"	4305	Teesta	Brahmaputra	India	Sikkim	14	No Change
56	03_78A_010	27° 57' 0.72"	88° 18'16.92"	5078	Teesta	Brahmaputra	India	Sikkim	36	No Change

57	03_78A_017	27° 53' 34.8"	88° 11'31.92"	5545	Teesta	Brahmaputra	India	Sikkim	19	No Change
58	03_78A_006	27° 58' 15.6"	88° 25'45.84"	5004	Teesta	Brahmaputra	India	Sikkim	11	No Change
59	03_77D_007	28° 0' 26.28"	88° 34'18.48"	5015	Teesta	Brahmaputra	India	Sikkim	24	No Change
60	03_78A_012	27° 54' 4.32"	88° 46'54.84"	5130	Teesta	Brahmaputra	India	Sikkim	26	No Change
61	03_78A_020	27° 52' 49.44"	88° 15' 4.68"	5219	Teesta	Brahmaputra	India	Sikkim	14	No Change
62	03_78A_026	27° 33' 44.28"	88° 7' 24.96"	4736	Teesta	Brahmaputra	India	Sikkim	11	No Change
63	237	27°59'39.437"	88°48'7.87"	5322		Brahmaputra	India	Sikkim		No Change
64	260	27°53'42.16"	88°45'40.71"	5253		Brahmaputra	India	Sikkim		No Change
65	312	27°52'27.53"	88°38'18.65"	5137		Brahmaputra	India	Sikkim		No Change
66	515	27°51'14.44"	88°48'31.30"	5063		Brahmaputra	India	Sikkim		No Change
67	569	28°0'9.23"	88°38'17.48"	5450		Brahmaputra	India	Sikkim		No Change
68	599	27°41'40.45"	88°42'56.53"	4251		Brahmaputra	India	Sikkim		No Change
69	03_78A_019	27° 51' 52.2"	88° 51'46.44"	4809	Teesta	Brahmaputra	India	Sikkim	15	Decreasing
70	03_78A_015	27° 52' 23.88"	88° 47' 22.2"	4970	Teesta	Brahmaputra	India	Sikkim	12	Decreasing
71	03_78A_016	27° 53' 33.72"	88° 12'47.16"	5451	Teesta	Brahmaputra	India	Sikkim	14	Decreasing
72	03_78A_008	27° 57' 3.24"	88° 21'15.48"	4998	Teesta	Brahmaputra	India	Sikkim	44	Decreasing
73	256	27°48'58.33"	88°39'19.44"	4615		Brahmaputra	India	Sikkim		Decreasing
74	292	28°0'20.43"	88°39'20.18"	5577		Brahmaputra	India	Sikkim		Decreasing
75	293	27°57'7.01"	88°42'18.24"	5048		Brahmaputra	India	Sikkim		Decreasing
76	345	27°51'49.12"	88°44'44.29"	5108		Brahmaputra	India	Sikkim		Decreasing
77	03_83A_004	27° 45' 47.16"	92°25'29.64"	5109	Dangme Chu	Brahmaputra	India	Arunachal Pradesh	17	Increasing
78	03_83A_003	27° 46' 12.72"	92° 25'56.64"	5188	Dangme Chu	Brahmaputra	India	Arunachal Pradesh	24	Increasing
79	03_91D_075	28° 36' 28.8"	96° 19'14.16"	4274	Dibang	Brahmaputra	India	Arunachal Pradesh		Increasing
80	03_91H_073	28° 3' 15.48"	97° 19'47.64"	4481	Luhit	Brahmaputra	India	Arunachal Pradesh	25	No Change
81	03_91C_026	29° 20' 18.24"	96° 4' 57.72"	4305	Dibang	Brahmaputra	India	Arunachal Pradesh	28	No Change
82	03_82L_007	28° 50' 15"	94° 27' 5.04"	4163	Ding	Brahmaputra	India	Arunachal Pradesh	16	No Change
83	03_83A_005	27° 45' 20.52"	92° 24' 2.52"	4994	Dangme Chu	Brahmaputra	India	Arunachal Pradesh	13	No Change
84	03_83A_007	27° 43' 39.36"	92° 26'12.48"	5028	JiaBrali	Brahmaputra	India	Arunachal Pradesh	14	No Change
85	129	27°46'24.165"	92°19'1.10"	4895		Brahmaputra	India	Arunachal Pradesh		No Change

#### 4.6.6 Trend analysis of 85 Glacial Lakes of size between 10 Ha to 50 Ha (2011-2023) $\pm$ 20% variation w.r.t. base year data of 2011

The output of trend analysis assuming a  $\pm$ 20 % variation in last data w.r.t base year data (2011) of water spread area, was exactly the same as that of  $\pm$ 20 %. A total of 24 Glacial Lakes showed an increasing trend.

The state-wise distribution of location of lakes are given in table No.7.14. The details are furnished in table No. 7.15.

**Table No. 4.16: State wise details of trend analysis of Glacial Lakes of water spread area of 10 Ha to 50 Ha for a  $\pm 20\%$  variation in water spread area w.r.t base year data 2011**

S.No.	States	Increasing	No Change	Decreasing	No Analysis	Total
1	Ladakh	3	6	3	0	12
2	Jammu & Kashmir	5	6	4	0	15
3	Himachal Pradesh	4	3	1	0	8
4	Uttarakhand	1	5	1	2	9
5	Sikkim	8	16	8	0	32
6	Arunachal Pradesh	3	6	0	0	9
	<b>Total</b>	24	42	17	2	85

**Table No. 4.17: Trend Analysis of Glacial Lakes 10- 50 Ha in size located in India analysed for 20% variation in water spread area based on 2 years data (in addition to that of 2011)**

Sl. No	Lake ID	Latitude(N)	Longitude (E)	Elevation (m)	River	Basin	Country	State	Inventory 2011 (Area in Ha)	Trend (20%)
1	01_42H_002	36° 38' 34.8"	73° 24' 26.64"	2763	Gilgit	Indus	India	Ladakh	13	Increasing
2	01_52C_001	33° 56' 44.52"	76° 13' 53.76"	4394	Shingo (Indus)	Indus	India	Ladakh	36	Increasing
3	1360	35° 1' 40.87"	75° 43' 36.84"	4667		Indus	India	Ladakh		Increasing
4	01_52L_006	32° 26' 27.24"	78° 55' 29.28"	5727	Indus	Indus	India	Ladakh	12	No Change
5	01_52B_012	34° 0' 19.8"	76° 47' 12.84"	5137	Indus	Indus	India	Ladakh	17	No Change
6	01_52L_007	32° 24' 36.36"	78° 53' 56.4"	5498	Indus	Indus	India	Ladakh	32	No Change
7	01_52B_010	34° 3' 6.48"	76° 43' 5.16"	5122	Indus	Indus	India	Ladakh	18	No Change
8	173	34° 46' 12.35"	76° 42' 31.20"	5150		Indus	India	Ladakh		No Change
9	180	34° 21' 13.694"	76° 4' 35.57"	4442		Indus	India	Ladakh		No Change
10	01_52A_002	35° 5' 48.12"	76° 14' 0.6"	4537	Shyok	Indus	India	Ladakh	23	Decreasing
11	01_52A_004	35° 4' 28.2"	76° 17' 33.72"	4619	Shyok	Indus	India	Ladakh	11	Decreasing
12	01_52A_003	35° 5' 33.36"	76° 15' 7.2"	4586	Shyok	Indus	India	Ladakh	24	Decreasing
13	01_52C_002	33° 52' 10.2"	76° 7' 9.48"	4092	Chenab	Indus	India	Jammu & Kashmir	26	Increasing
14	27	34° 22' 40.837"	74° 52' 34.23"	3775		Indus	India	Jammu & Kashmir		Increasing
15	98	34° 23' 30.053"	75° 5' 6.93"	4103		Indus	India	Jammu & Kashmir		Increasing
16	958	34° 8' 15.508"	75° 24' 59.64"	4103		Indus	India	Jammu & Kashmir		Increasing
17	963	34° 8' 13.5"	75° 22' 33.06"	3725		Indus	India	Jammu & Kashmir		Increasing
18	182	34° 14' 1.589"	75° 19' 25.60"	4304		Indus	India	Jammu & Kashmir		No Change
19	931	33° 55' 55.346"	75° 23' 33.77"	4082		Indus	India	Jammu & Kashmir		No Change
20	951	34° 3' 58.769"	75° 28' 31.00"	3762		Indus	India	Jammu & Kashmir		No Change
21	976	34° 11' 2.939"	75° 22' 24.77"	4314		Indus	India	Jammu & Kashmir		No Change
22	1032	34° 23' 8.758"	75° 3' 55.60"	4007		Indus	India	Jammu & Kashmir		No Change
23	1037	34° 25' 28.86"	75° 3' 48.35"	3603		Indus	India	Jammu & Kashmir		No Change
24	01_43J_003	34° 55' 36.12"	74° 9' 19.44"	3954	Jhelum	Indus	India	Jammu & Kashmir	20	Decreasing
25	938	33° 57' 13.97"	75° 22' 40.33"	3683		Indus	India	Jammu & Kashmir		Decreasing
26	993	34° 13' 39.02"	75° 13' 19.29"	4148		Indus	India	Jammu &		Decreasing

								Kashmir		
27	1014	34°17'51.96"	75°3'40.49"	3989		Indus	India	Jammu & Kashmir		Decreasing
28	01_53I_002	31° 39' 38.52"	78° 10' 1.92"	4273	Satluj	Indus	India	Himachal Pradesh	23	Increasing
29	01_52H_003	32° 29' 54.6"	77° 32'37.32"	4165	Chenab	Indus	India	Himachal Pradesh	28	Increasing
30	1805	32°45'44.51"	77°11'41.17"	4775		Indus	India	Himachal Pradesh		Increasing
31	1847	31°55'1.289"	77°32'17.84"	4570		Indus	India	Himachal Pradesh		Increasing
32	1774	32°13'19.45"	76°47'16.97"	4593		Indus	India	Himachal Pradesh		No Change
33	1936	32°15'17.28"	76°46'37.13"	4606		Indus	India	Himachal Pradesh		No Change
34	1998	32°19'12.49"	76°54'26.81"	3857		Indus	India	Himachal Pradesh		No Change
35	2031	31°20'14.094"	78°15'17.03"	4702		Indus	India	Himachal Pradesh		Decreasing
36	02_62B_005	30° 26' 44.52"	80°23'16.08"	4314	Sarda	Ganga	India	Uttarakhand	12	Increasing
37	01_62B_003	30° 28' 36.48"	80°35'35.16"	5288	Satluj	Indus	India	Uttarakhand	12	No Change
38	02_53N_001	30° 54' 7.92"	79° 45' 12.6"	4688	Ganga	Ganga	India	Uttarakhand	21	No Change
39	02_62B_004	30° 33' 52.2"	80° 10'41.16"	4918	Sarda	Ganga	India	Uttarakhand	19	No Change
40	2108	30°58'30.65"	79°27'32.41"	5587		Ganga	India	Uttarakhand		No Change
41	2207	30°54'40.89"	78°57'31.16"	4707		Ganga	India	Uttarakhand		No Change
42	2147	30°58'44.98"	79°29'8.99"	5688		Ganga	India	Uttarakhand		Decreasing
43	02_62B_007	30° 16' 42.96"	80° 7' 49.8"	4839	Sarda	Ganga	India	Uttarakhand	19	No Analysis
44	2299	30°10'59.57"	79°52'52.3"	4490		Ganga	India	Uttarakhand		No Analysis
45	03_78A_035	27° 57' 3.24"	88° 21'15.48"	4998	Teesta	Brahmaputra	India	Sikkim	N.A.	Increasing
46	03_78A_027	27° 32' 0.6"	88° 5' 8.52"	4888	Teesta	Brahmaputra	India	Sikkim	33	Increasing
47	03_77D_006	28° 0' 51.84"	88° 33'41.76"	5084	Teesta	Brahmaputra	India	Sikkim	22	Increasing
48	03_78A_005	27° 58' 31.44"	88° 25'20.64"	5201	Teesta	Brahmaputra	India	Sikkim	11	Increasing
49	03_78A_002	27° 58' 56.28"	88° 30'28.08"	4952	Teesta	Brahmaputra	India	Sikkim	22	Increasing
50	227	27°59'32.62"	88°32'49.54"	5176		Brahmaputra	India	Sikkim		Increasing
51	295	27°55'16.42"	88°40'21.86"	4850		Brahmaputra	India	Sikkim		Increasing
52	298	27°42'3.09"	88°30'55.99"	4508		Brahmaputra	India	Sikkim		Increasing
53	03_78A_007	27° 57' 38.88"	88° 38'57.48"	4977	Teesta	Brahmaputra	India	Sikkim	17	No Change
54	03_78A_023	27° 40' 17.04"	88° 30'46.44"	4547	Teesta	Brahmaputra	India	Sikkim	33	No Change
55	03_78A_031	27° 26' 15"	88° 5' 9.6"	4305	Teesta	Brahmaputra	India	Sikkim	14	No Change
56	03_78A_010	27° 57' 0.72"	88° 18'16.92"	5078	Teesta	Brahmaputra	India	Sikkim	36	No Change
57	03_78A_017	27° 53' 34.8"	88° 11'31.92"	5545	Teesta	Brahmaputra	India	Sikkim	19	No Change
58	03_78A_006	27° 58' 15.6"	88° 25'45.84"	5004	Teesta	Brahmaputra	India	Sikkim	11	No Change
59	03_77D_007	28° 0' 26.28"	88° 34'18.48"	5015	Teesta	Brahmaputra	India	Sikkim	24	No Change
60	03_78A_012	27° 54' 4.32"	88° 46'54.84"	5130	Teesta	Brahmaputra	India	Sikkim	26	No Change
61	03_78A_020	27° 52' 49.44"	88° 15' 4.68"	5219	Teesta	Brahmaputra	India	Sikkim	14	No Change
62	03_78A_026	27° 33' 44.28"	88° 7' 24.96"	4736	Teesta	Brahmaputra	India	Sikkim	11	No Change
63	237	27°59'39.437"	88°48'7.87"	5322		Brahmaputra	India	Sikkim		No Change
64	260	27°53'42.16"	88°45'40.71"	5253		Brahmaputra	India	Sikkim		No Change
65	312	27°52'27.53"	88°38'18.65"	5137		Brahmaputra	India	Sikkim		No Change
66	515	27°51'14.44"	88°48'31.30"	5063		Brahmaputra	India	Sikkim		No Change
67	569	28°0'9.23"	88°38'17.48"	5450		Brahmaputra	India	Sikkim		No Change
68	599	27°41'40.45"	88°42'56.53"	4251		Brahmaputra	India	Sikkim		No Change
69	03_78A_019	27° 51' 52.2"	88° 51'46.44"	4809	Teesta	Brahmaputra	India	Sikkim	15	Decreasing
70	03_78A_015	27° 52' 23.88"	88° 47' 22.2"	4970	Teesta	Brahmaputra	India	Sikkim	12	Decreasing
71	03_78A_016	27° 53' 33.72"	88° 12'47.16"	5451	Teesta	Brahmaputra	India	Sikkim	14	Decreasing
72	03_78A_008	27° 57' 3.24"	88° 21'15.48"	4998	Teesta	Brahmaputra	India	Sikkim	44	Decreasing

73	256	27°48'58.33"	88°39'19.44"	4615		Brahmaputra	India	Sikkim		Decreasing
74	292	28°0'20.43"	88°39'20.18"	5577		Brahmaputra	India	Sikkim		Decreasing
75	293	27°57'7.01"	88°42'18.24"	5048		Brahmaputra	India	Sikkim		Decreasing
76	345	27°51'49.12"	88°44'44.29"	5108		Brahmaputra	India	Sikkim		Decreasing
77	03_83A_004	27° 45' 47.16"	92°25'29.64"	5109	Dangme Chu	Brahmaputra	India	Arunachal Pradesh	17	Increasing
78	03_83A_003	27° 46' 12.72"	92° 25'56.64"	5188	Dangme Chu	Brahmaputra	India	Arunachal Pradesh	24	Increasing
79	03_91D_075	28° 36' 28.8"	96° 19'14.16"	4274	Dibang	Brahmaputra	India	Arunachal Pradesh		Increasing
80	03_91H_073	28° 3' 15.48"	97° 19'47.64"	4481	Luhit	Brahmaputra	India	Arunachal Pradesh	25	No Change
81	03_91C_026	29° 20' 18.24"	96° 4' 57.72"	4305	Dibang	Brahmaputra	India	Arunachal Pradesh	28	No Change
82	03_82L_007	28° 50' 15"	94° 27' 5.04"	4163	Ding	Brahmaputra	India	Arunachal Pradesh	16	No Change
83	03_83A_005	27° 45' 20.52"	92° 24' 2.52"	4994	Dangme Chu	Brahmaputra	India	Arunachal Pradesh	13	No Change
84	03_83A_007	27° 43' 39.36"	92° 26'12.48"	5028	JiaBrali	Brahmaputra	India	Arunachal Pradesh	14	No Change
85	129	27°46'24.165"	92°19'1.10"	4895		Brahmaputra	India	Arunachal Pradesh		No Change

Lake-wise plot are appended as given below.

<i>Trend analysis for Change in Water spread area of Glacial Lakes (10-50 Ha) for <math>\pm 10\%</math> &amp; <math>\pm 20\%</math> w.r.t base year data 2011</i>		
<b>S.No.</b>	<b>States</b>	<b>Figure No.</b>
1	Ladakh	Figure 4.39(i)-Figure 4.50(ii)
2	Jammu & Kashmir	Figure 4.51(i)-Figure 4.65(ii)
3	Himachal Pradesh	Figure 4.66(i)-Figure 4.73(ii)
4	Uttarakhand	Figure 4.74(i)-Figure 4.80(ii)
5	Sikkim	Figure 4.81(i)-Figure 4.112(ii)
6	Arunachal Pradesh	Figure 4.113(i)-Figure 4.121(ii)

**Trend Analysis of “Change in Water spread area of Glacial Lakes between 10 Ha to 50 Ha (2011-2023) of Ladakh”**

Figure 4.39(i) Trend Analysis Plot  $\pm 10\%$

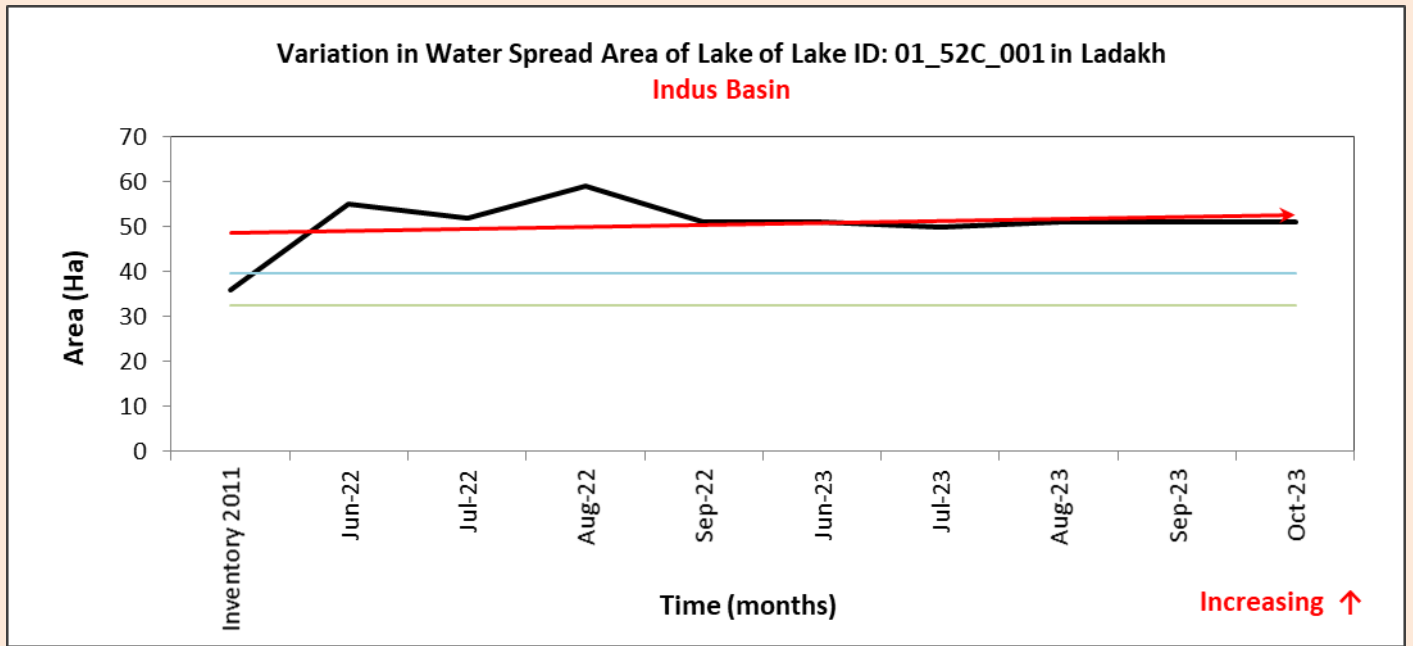


Figure 4.39(ii) Trend Analysis Plot  $\pm 20\%$

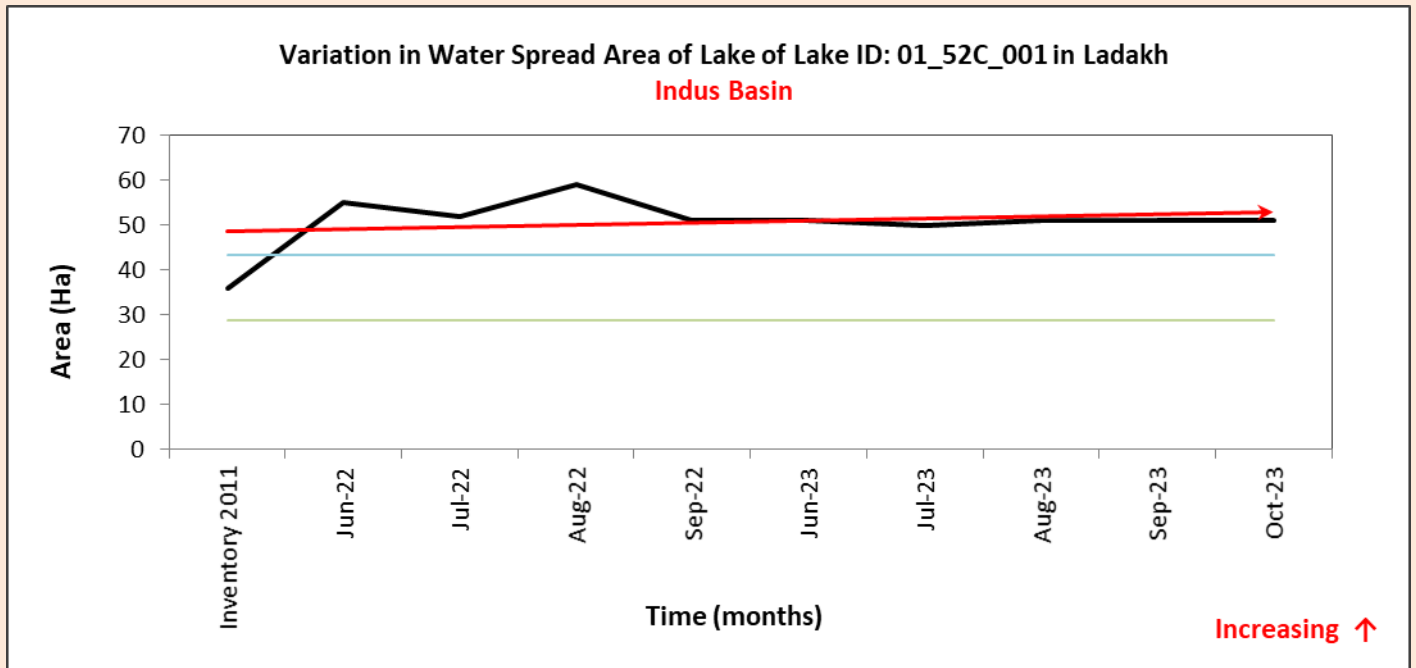


Figure 4.40(i) Trend Analysis Plot  $\pm 10\%$

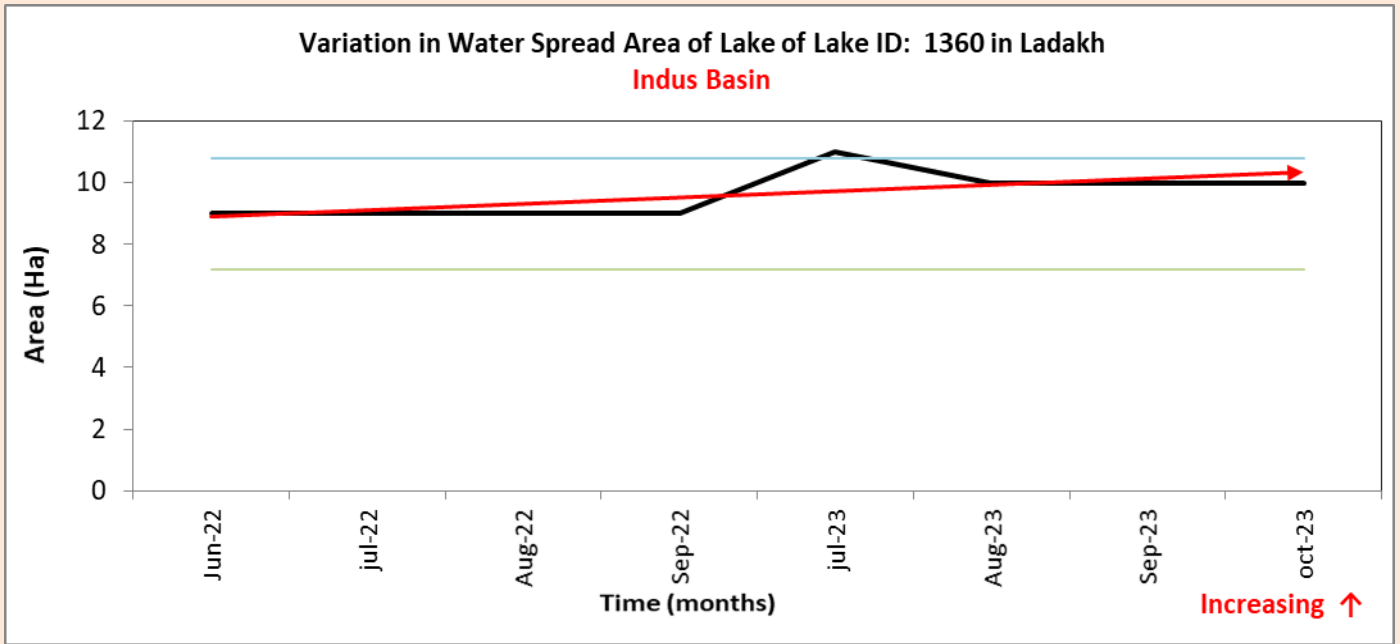


Figure 4.40(ii) Trend Analysis Plot  $\pm 20\%$

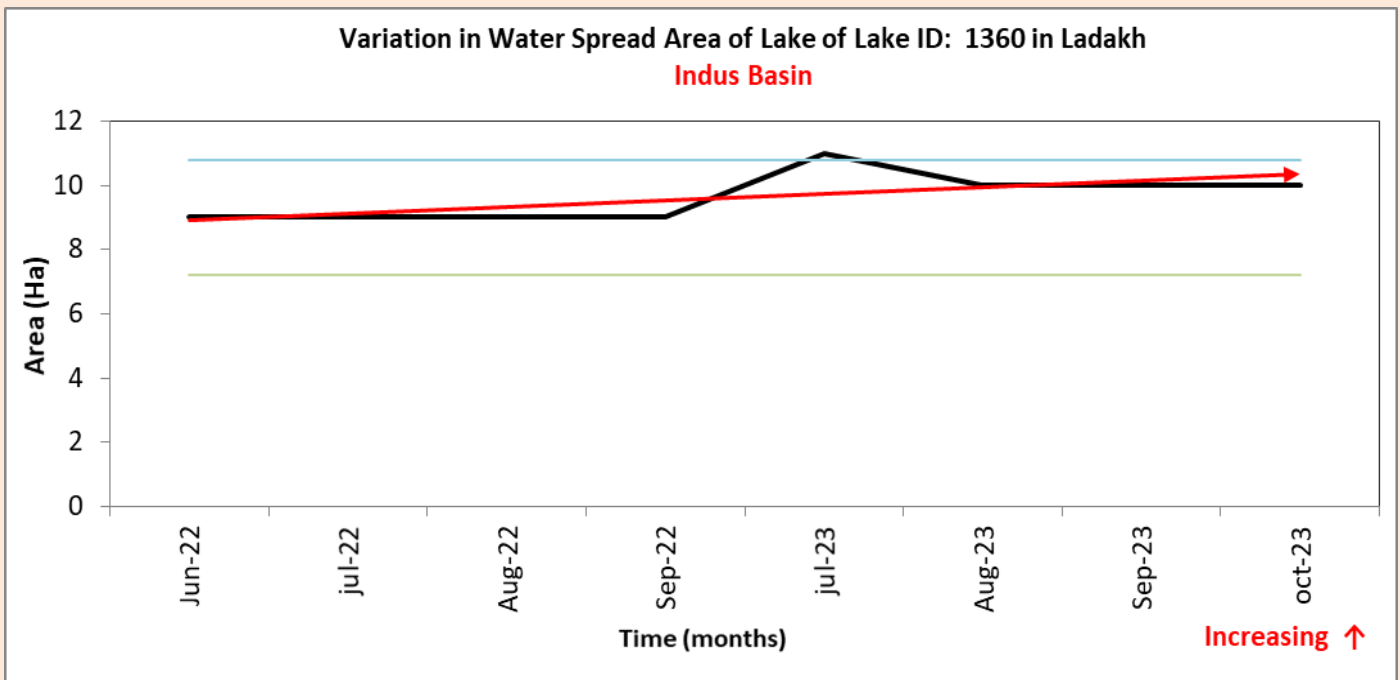


Figure 4.41(i) Trend Analysis Plot  $\pm 10\%$

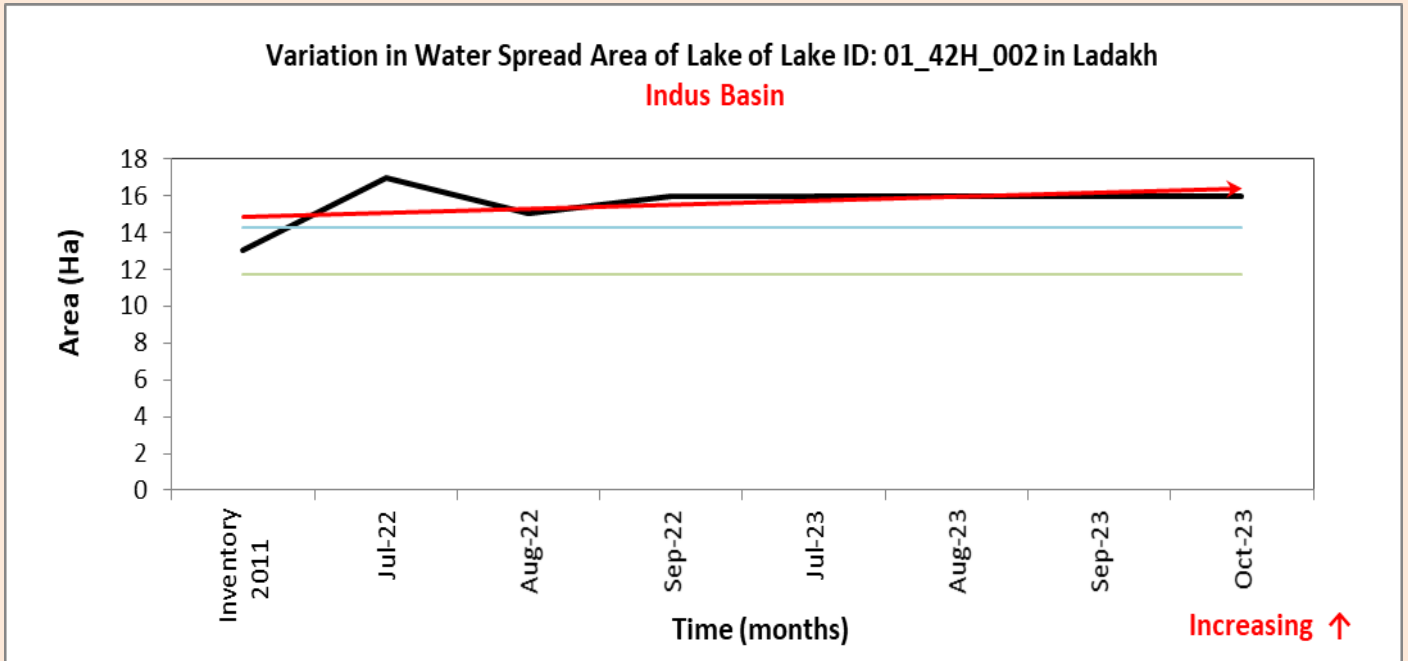


Figure 4.41(ii) Trend Analysis Plot  $\pm 20\%$

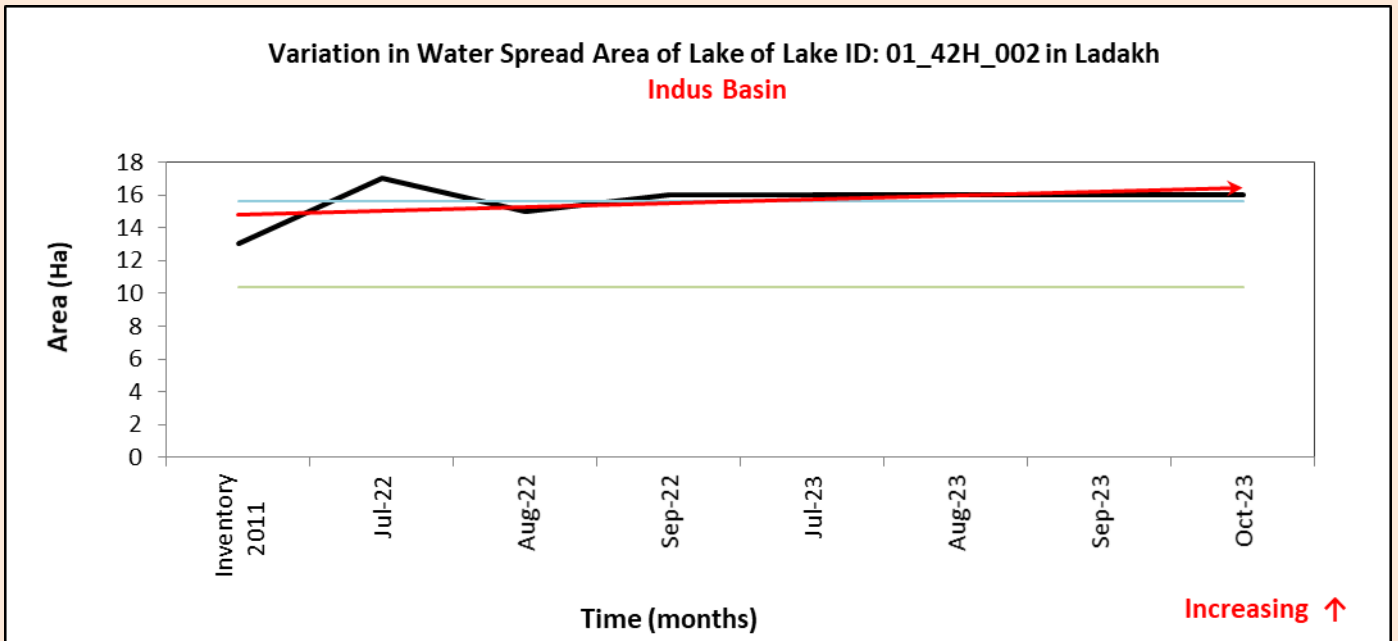


Figure 4.42(i) Trend Analysis Plot  $\pm 10\%$

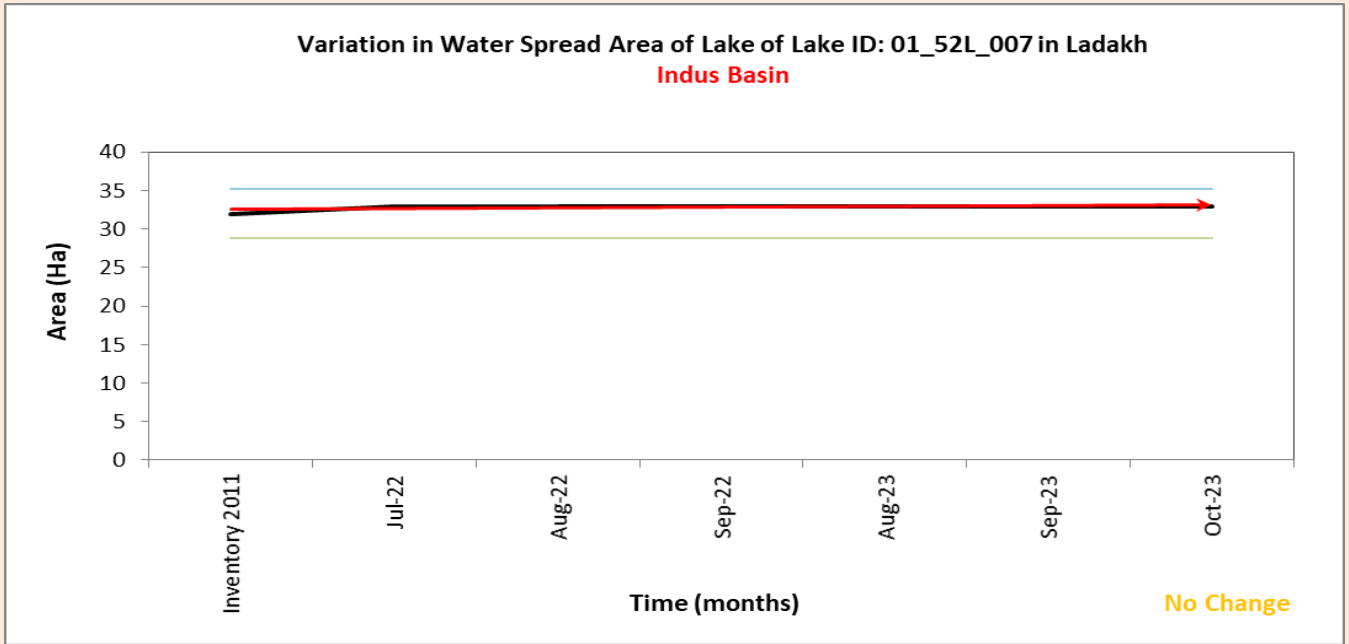


Figure 4.42(ii) Trend Analysis Plot  $\pm 20\%$

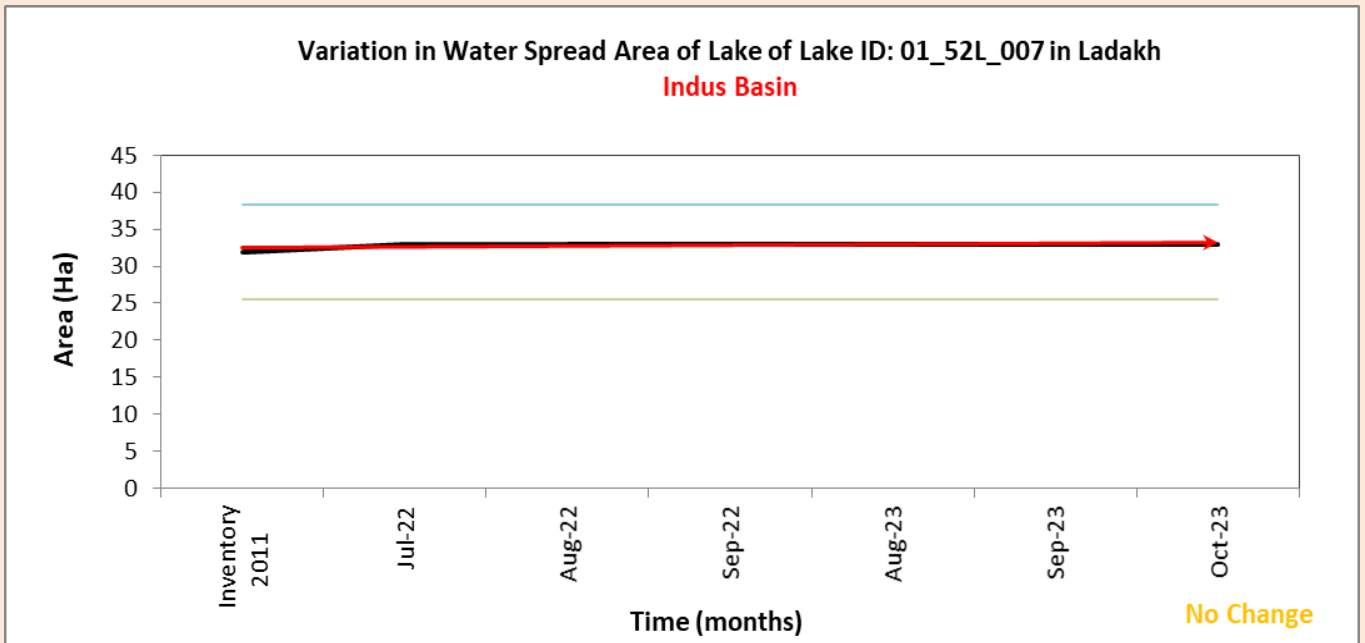


Figure 4.43(i) Trend Analysis Plot  $\pm 10\%$

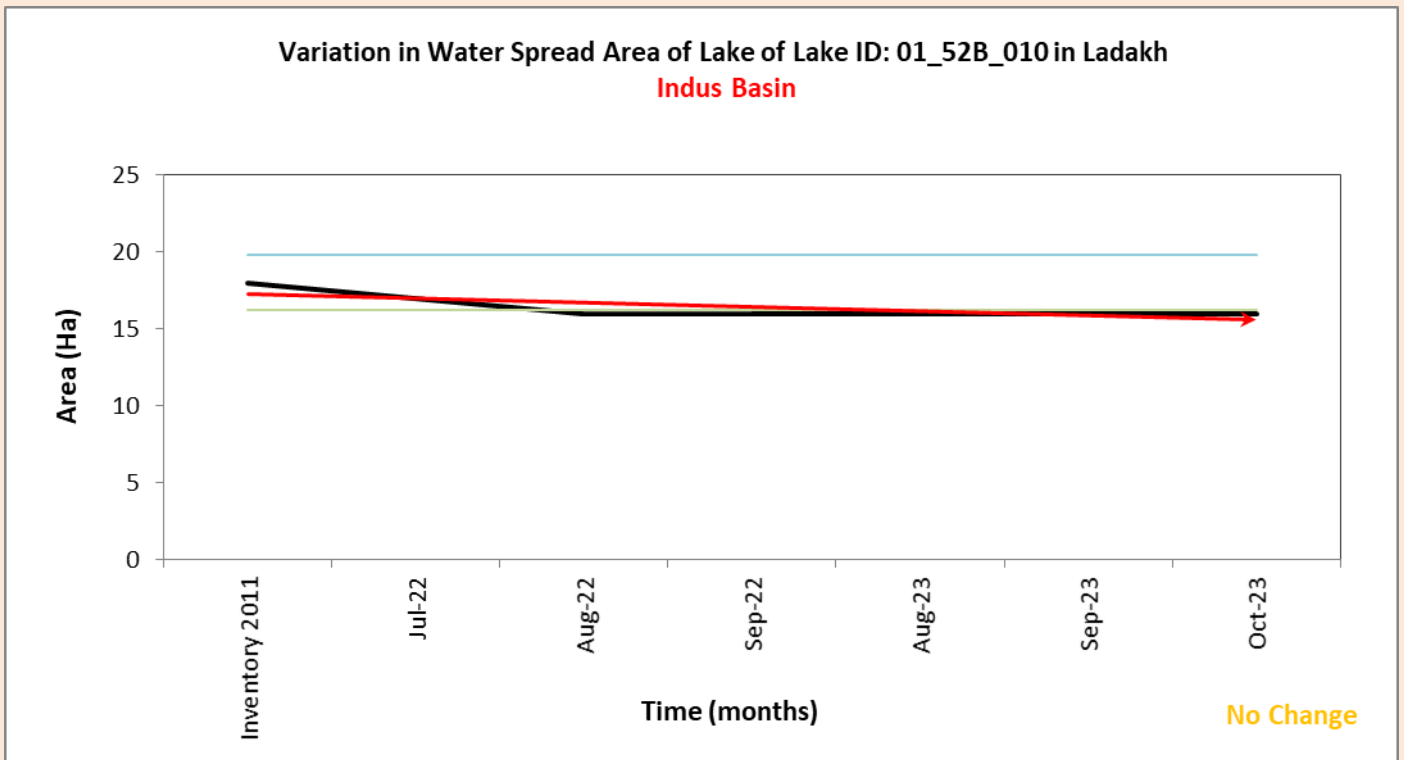


Figure 4.43(ii) Trend Analysis Plot  $\pm 20\%$

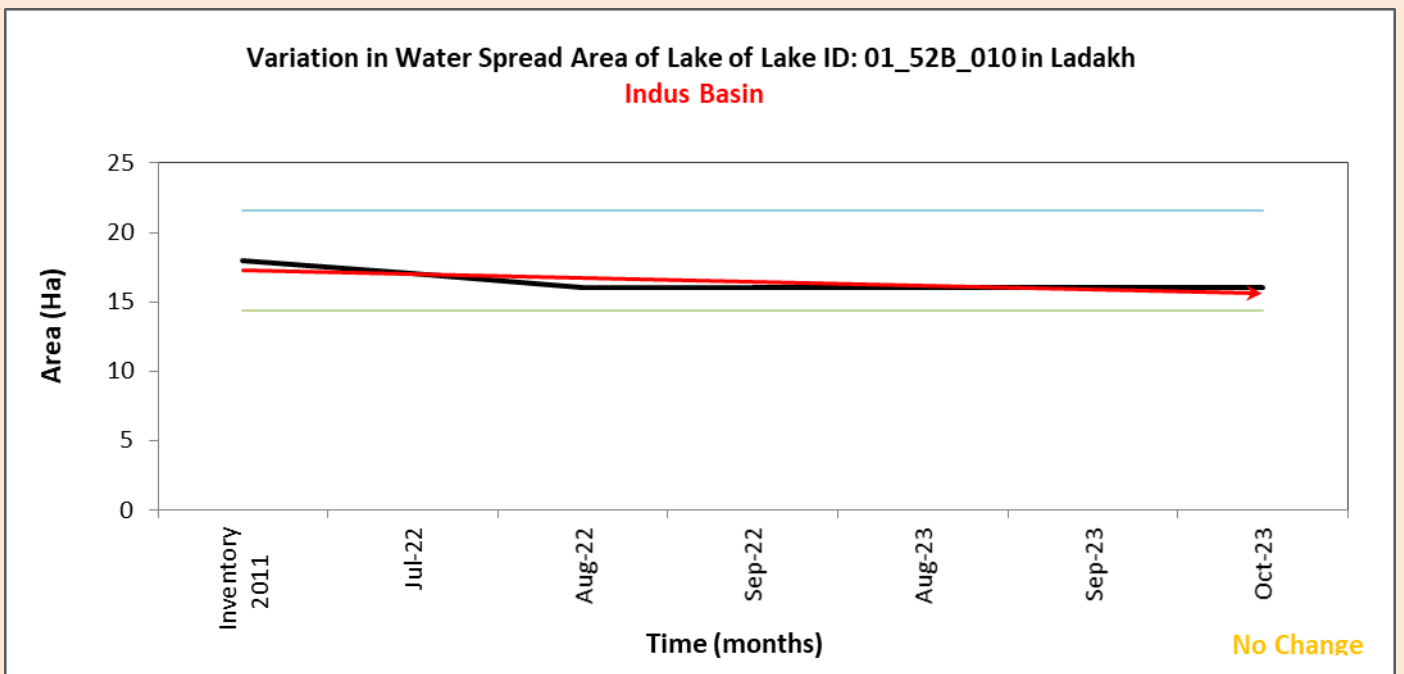


Figure 4.44(i) Trend Analysis Plot  $\pm 10\%$

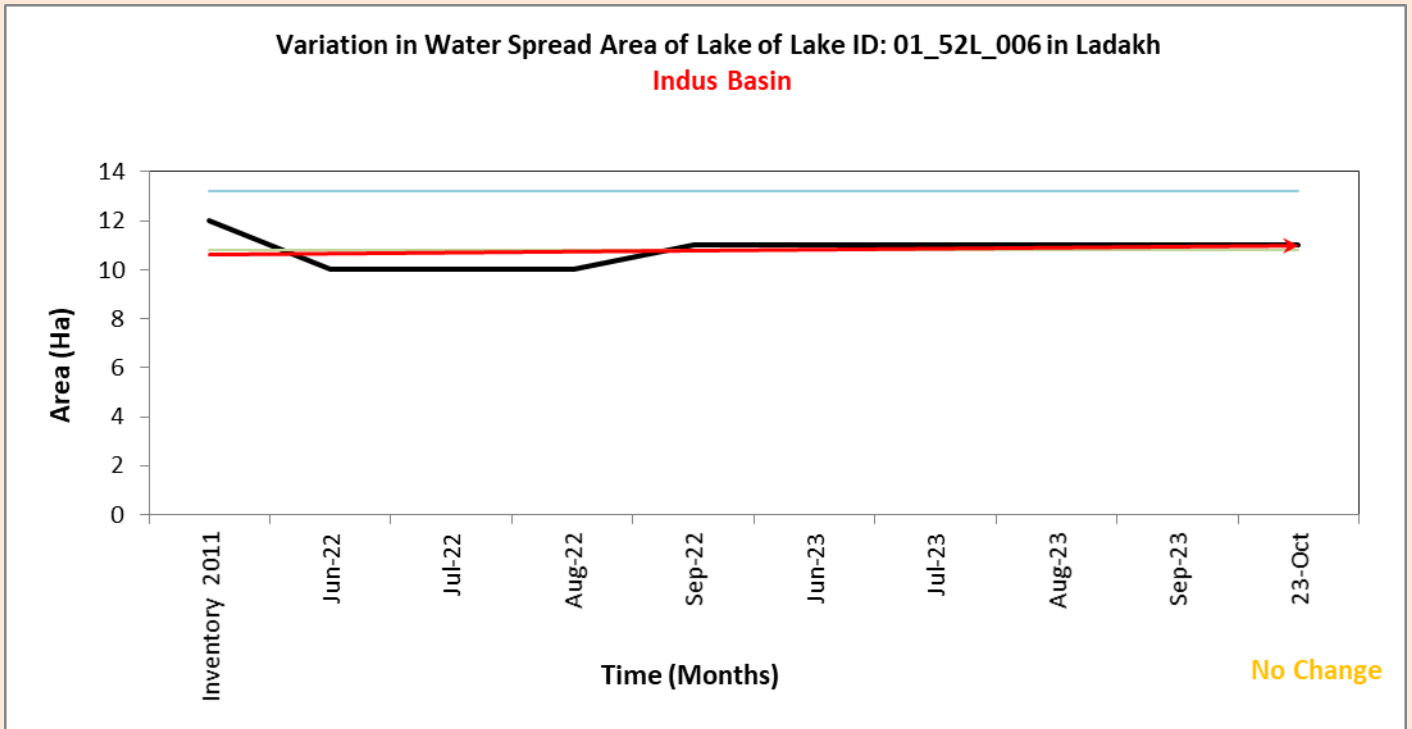


Figure 4.44(ii) Trend Analysis Plot  $\pm 20\%$

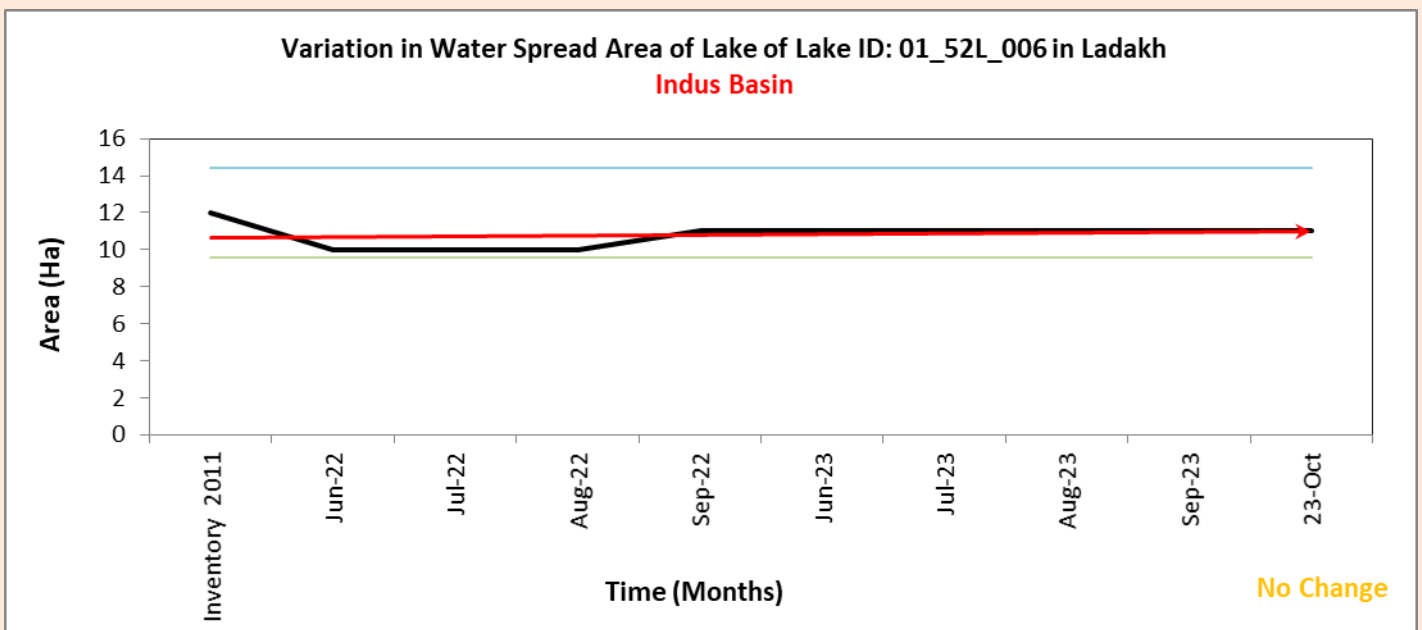


Figure 4.45(i) Trend Analysis Plot  $\pm 10\%$

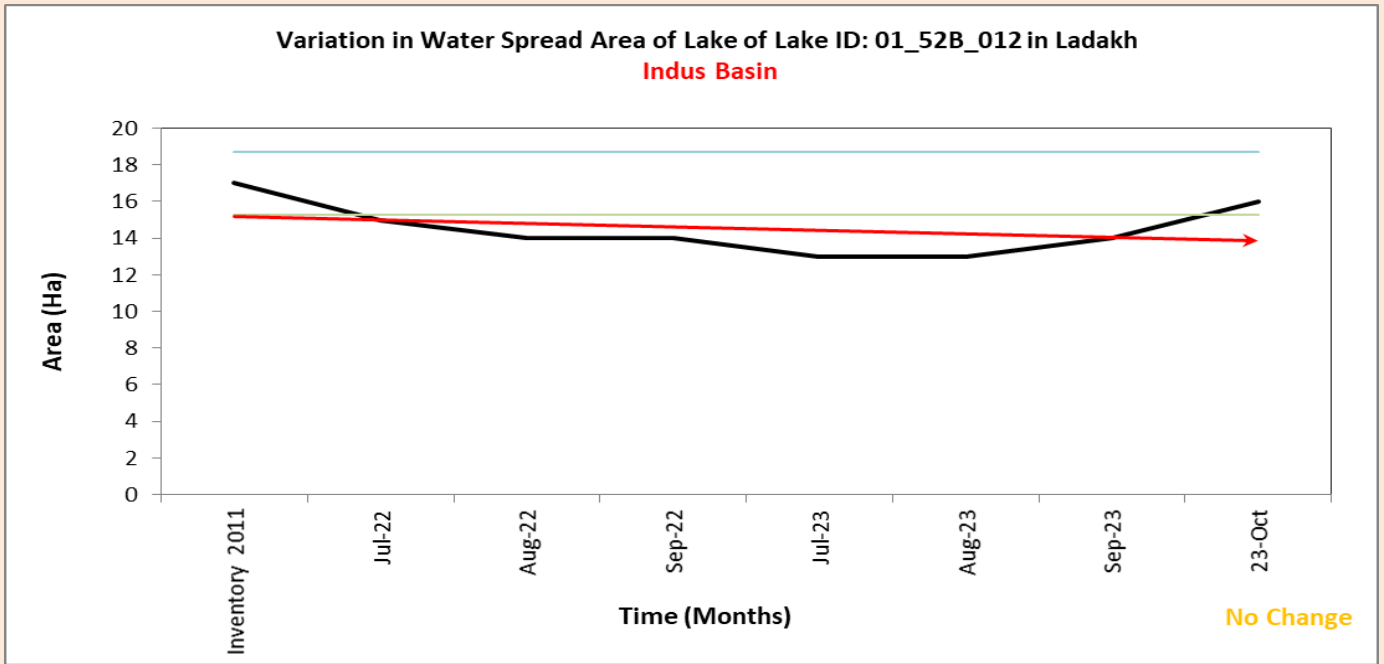


Figure 4.45(ii) Trend Analysis Plot  $\pm 20\%$

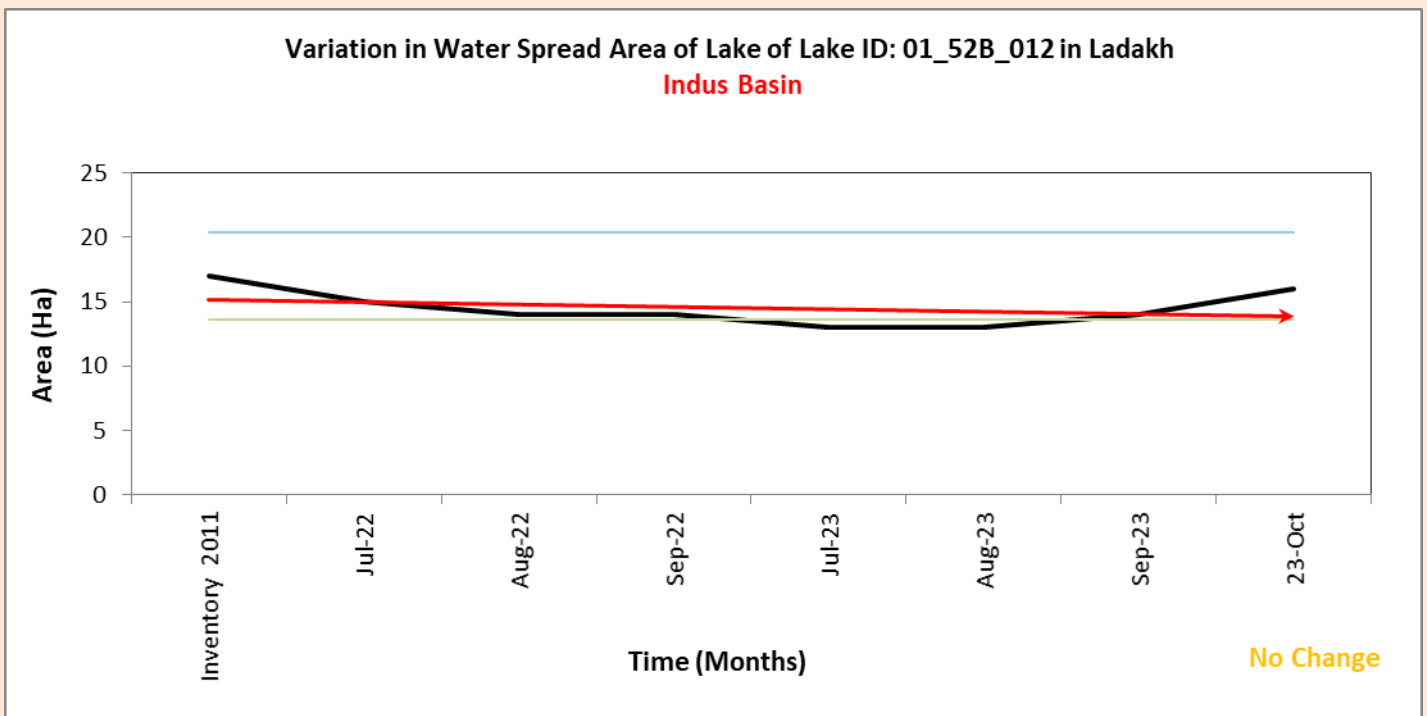


Figure 4.46(i) Trend Analysis Plot  $\pm 10\%$

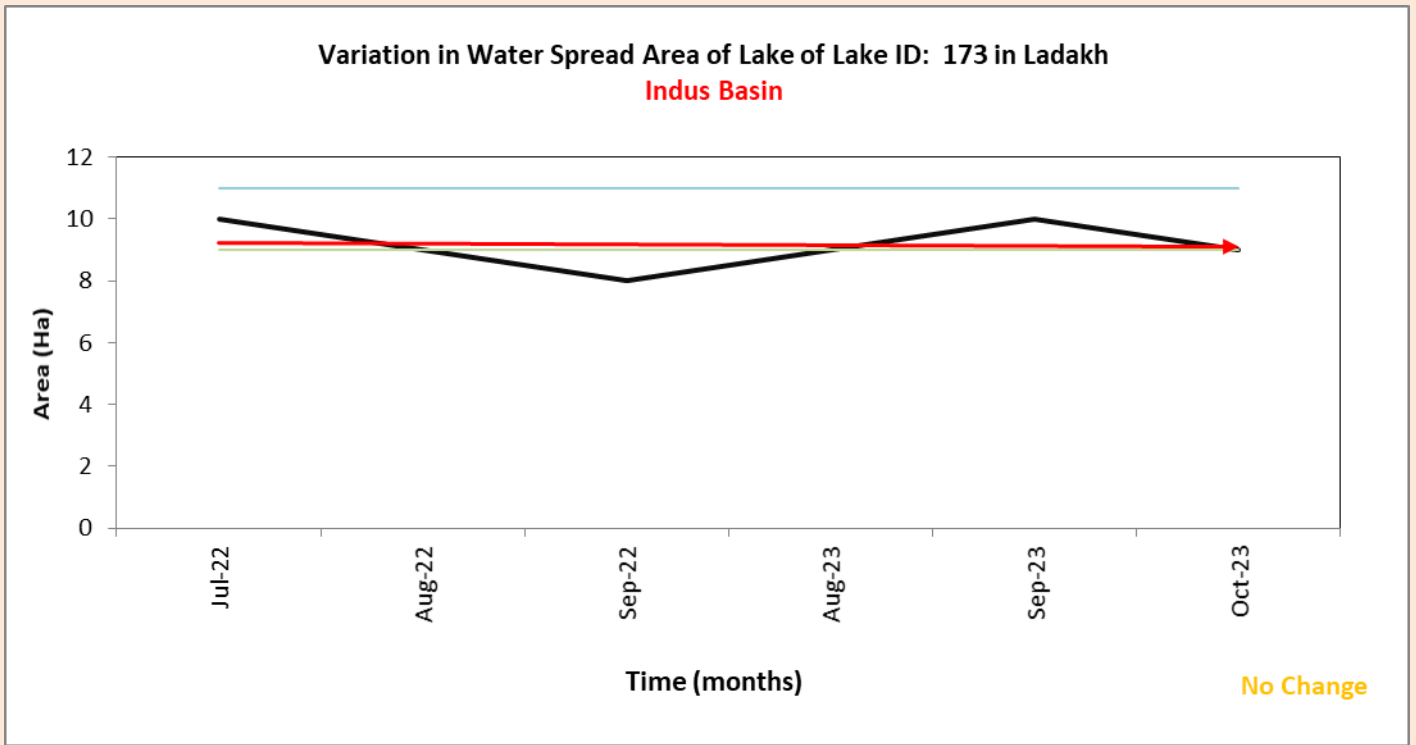


Figure 4.46(ii) Trend Analysis Plot  $\pm 10\%$

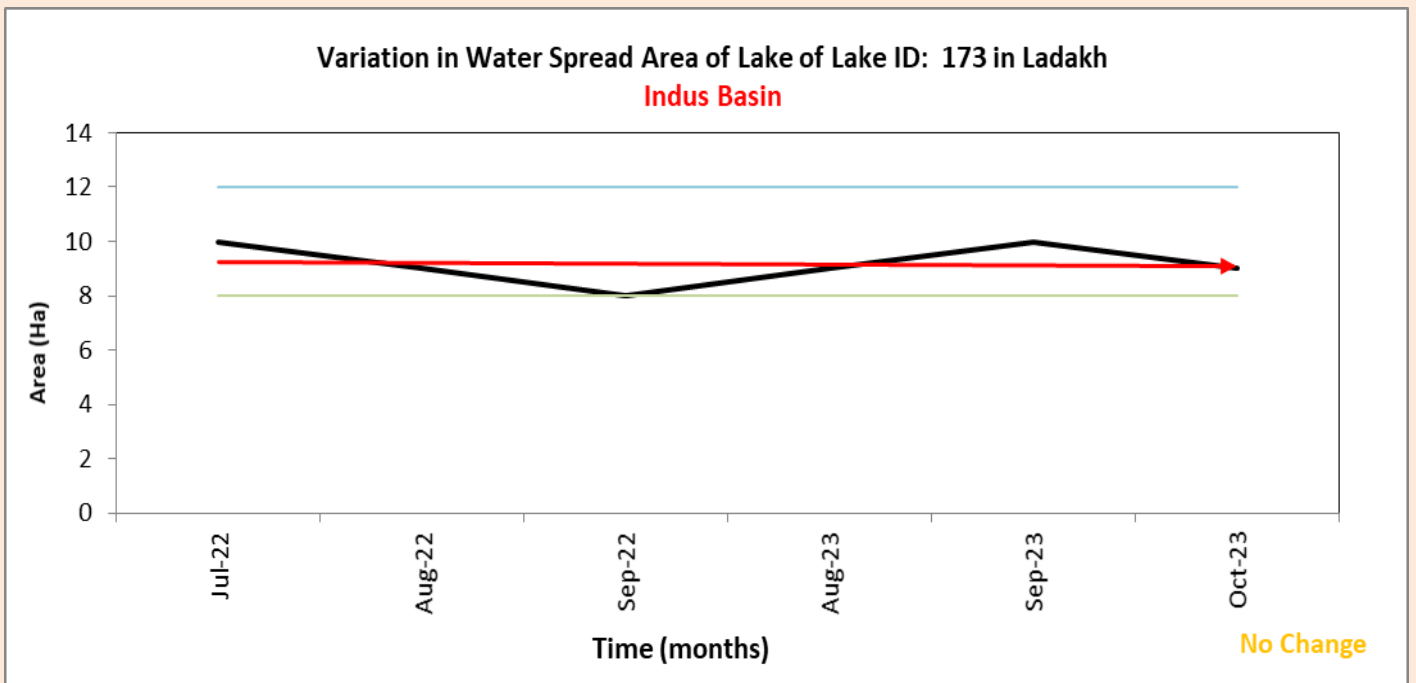


Figure 4.47(i) Trend Analysis Plot  $\pm 10\%$

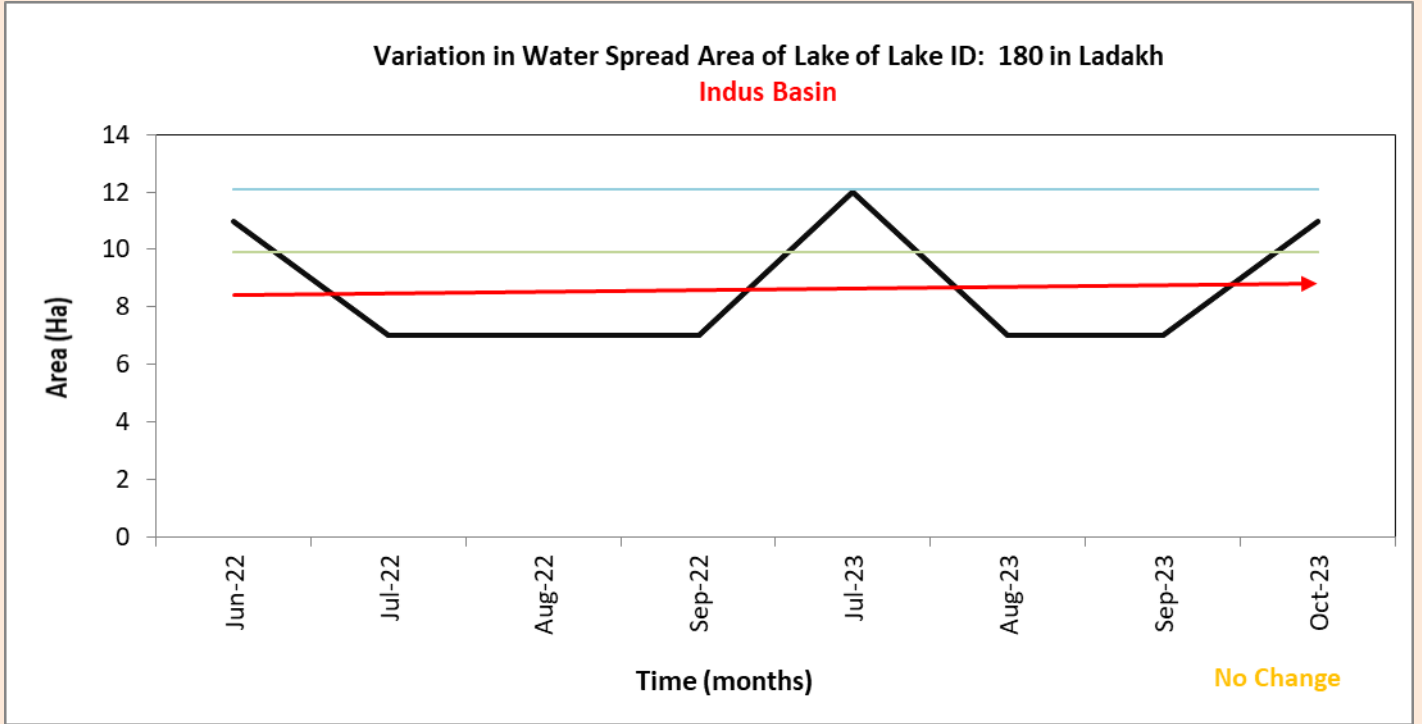


Figure 4.47(ii) Trend Analysis Plot  $\pm 20\%$

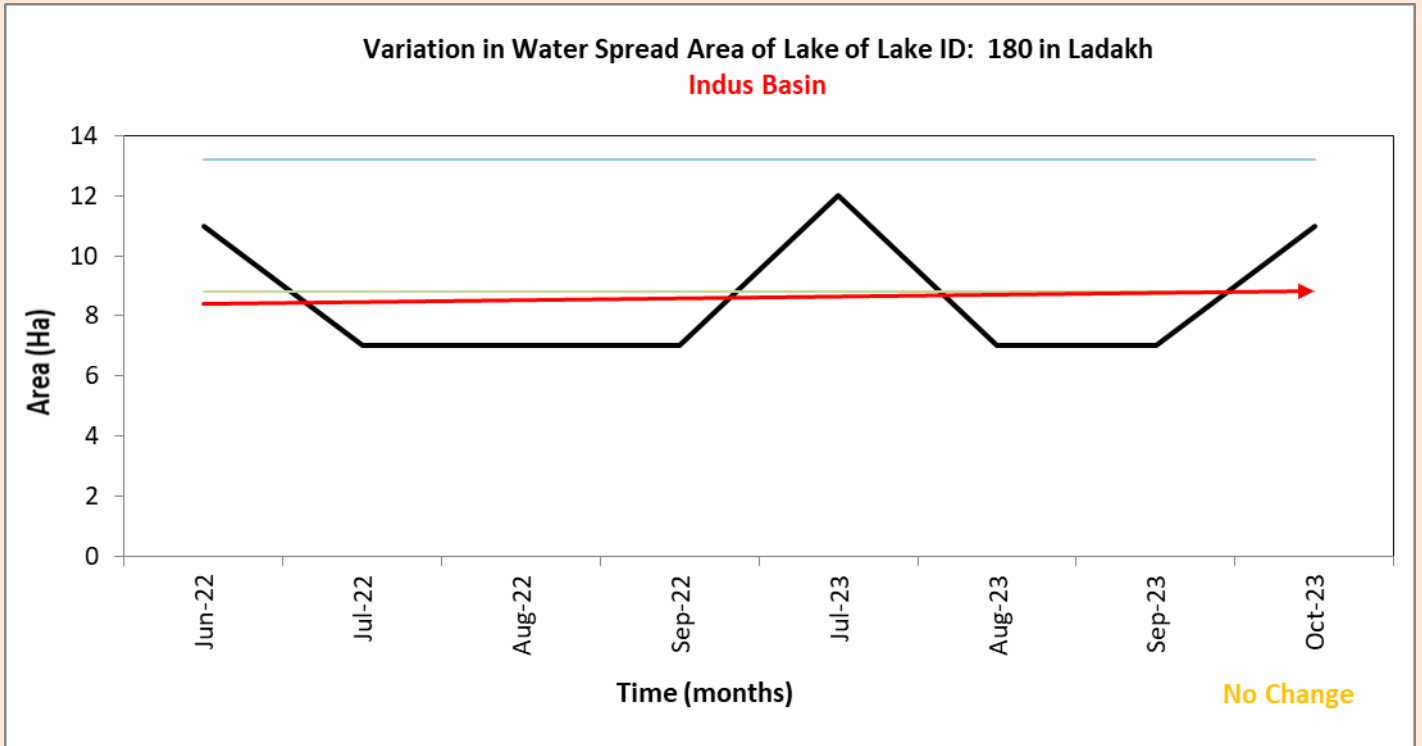


Figure 4.48(i) Trend Analysis Plot  $\pm 10\%$

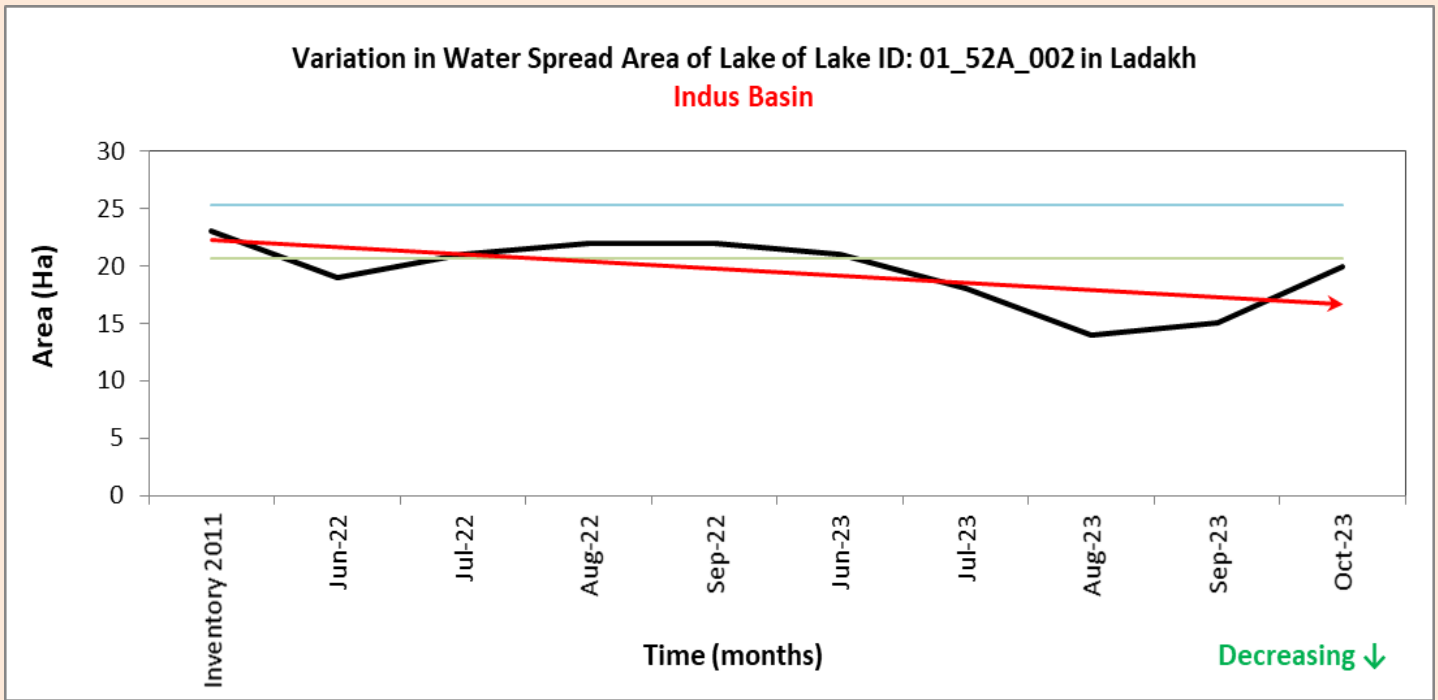


Figure 4.48(ii) Trend Analysis Plot  $\pm 20\%$

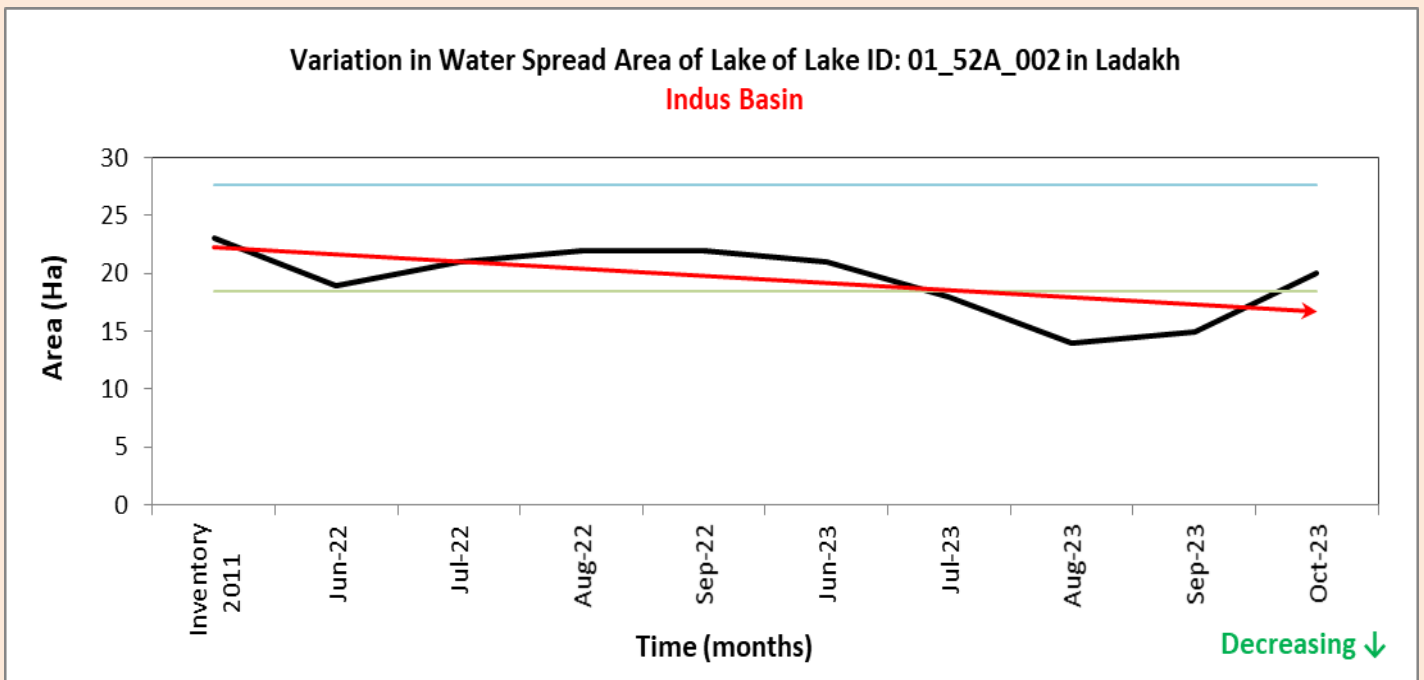


Figure 4.49(i) Trend Analysis Plot  $\pm 10\%$

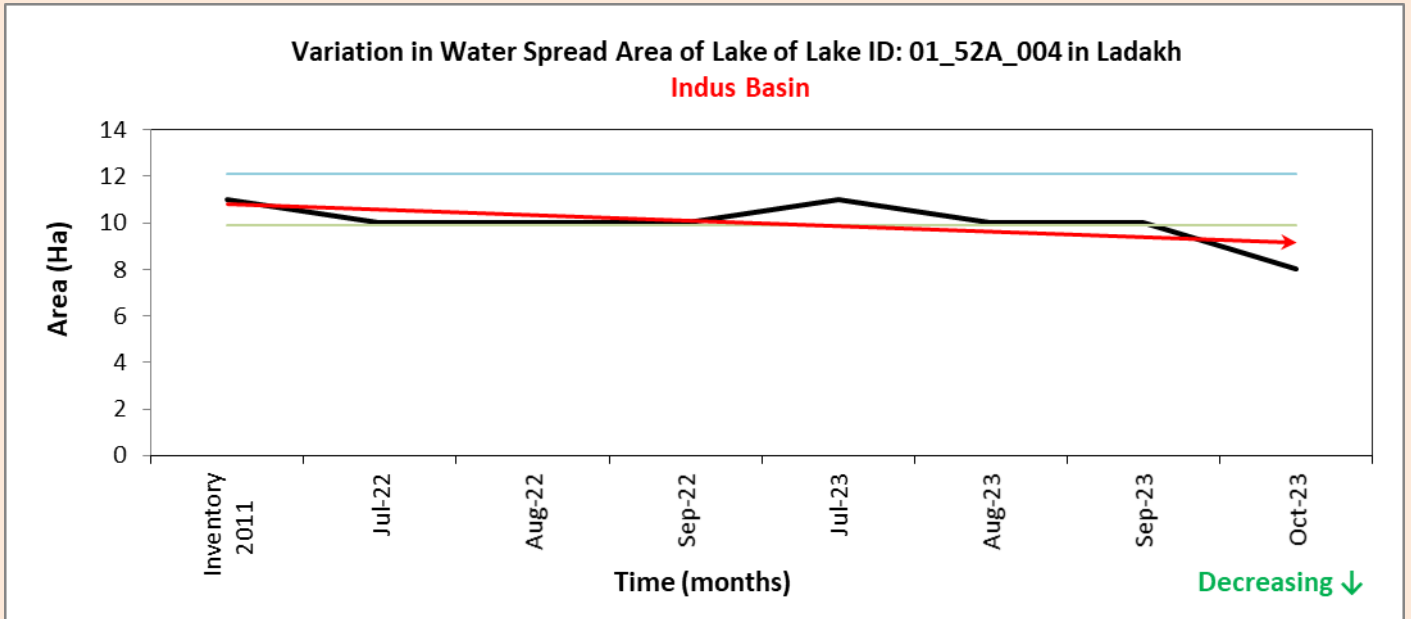


Figure 4.49(ii) Trend Analysis Plot  $\pm 20\%$

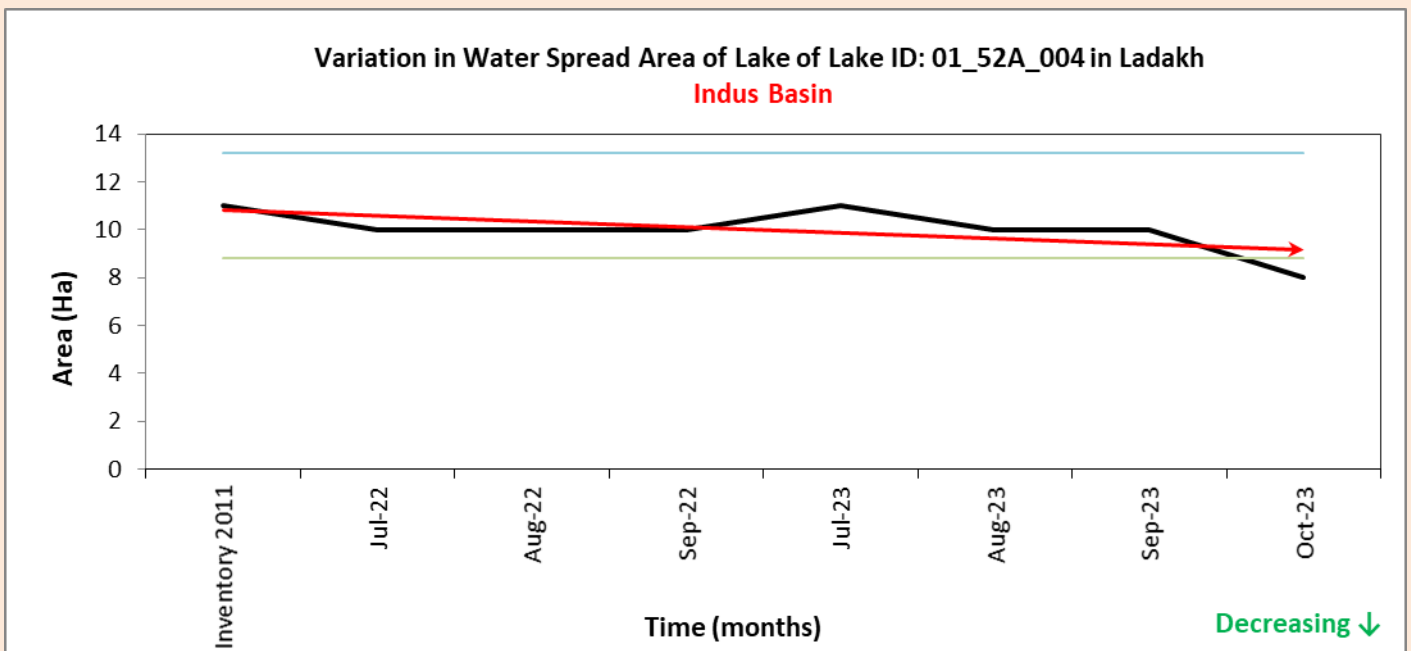


Figure 4.50(i) Trend Analysis Plot  $\pm 10\%$

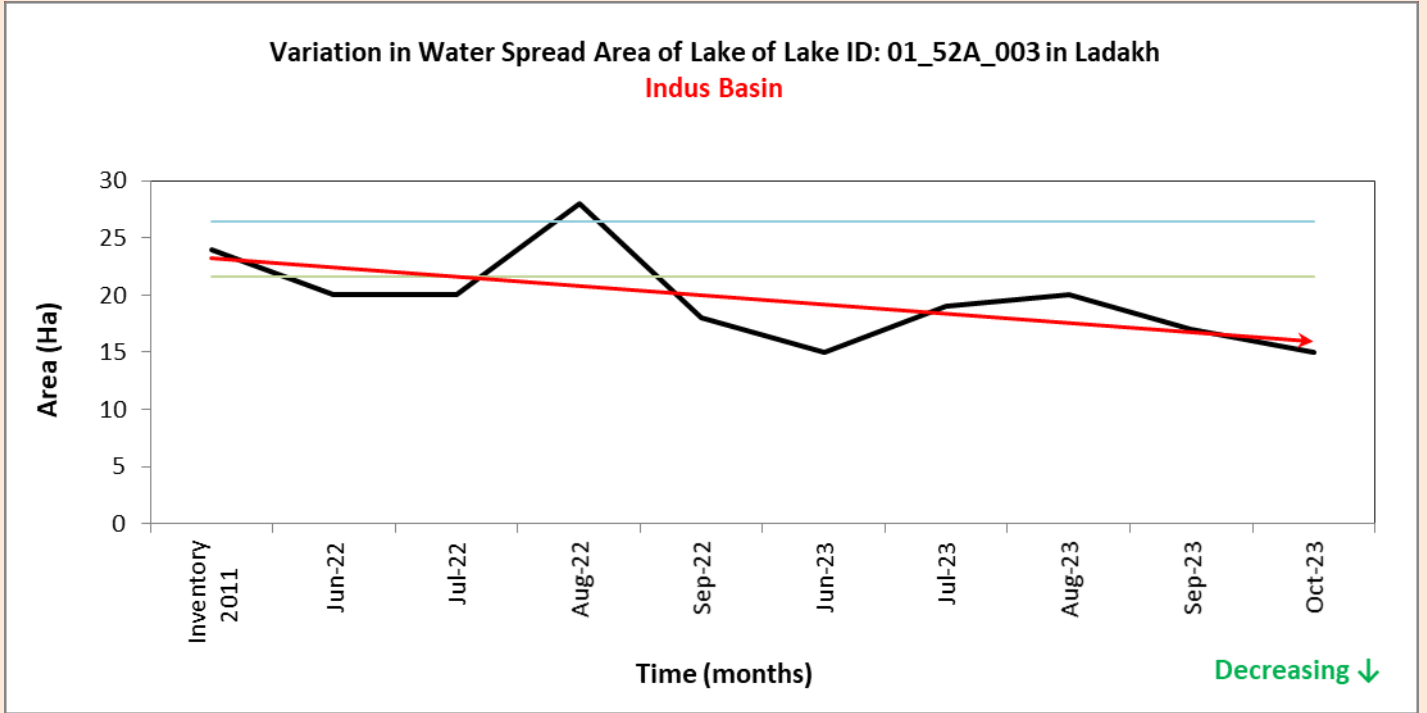
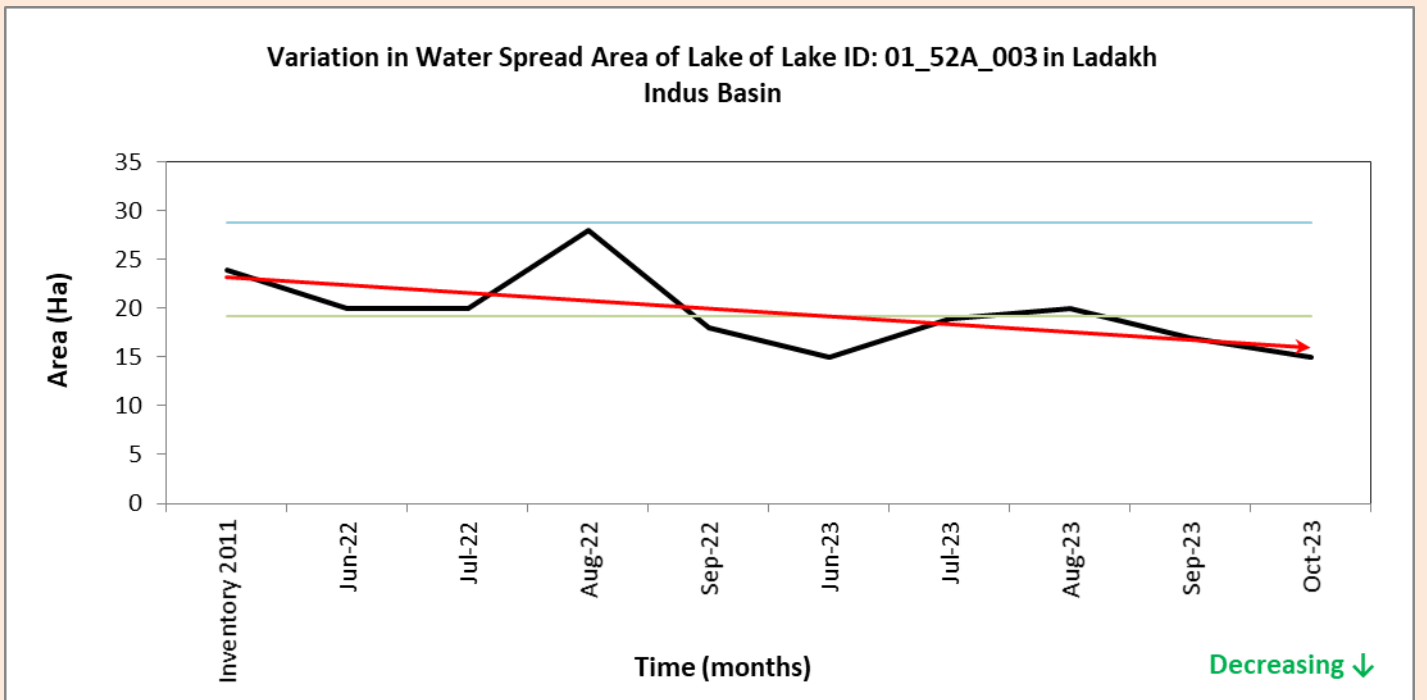


Figure 4.50(ii) Trend Analysis Plot  $\pm 20\%$



**Trend analysis of “Change in water spread area of Glacial Lakes between 10 Ha to 50 Ha of Jammu & Kashmir (2011-2023)”**

Figure 4.51(i) Trend Analysis Plot  $\pm 10\%$

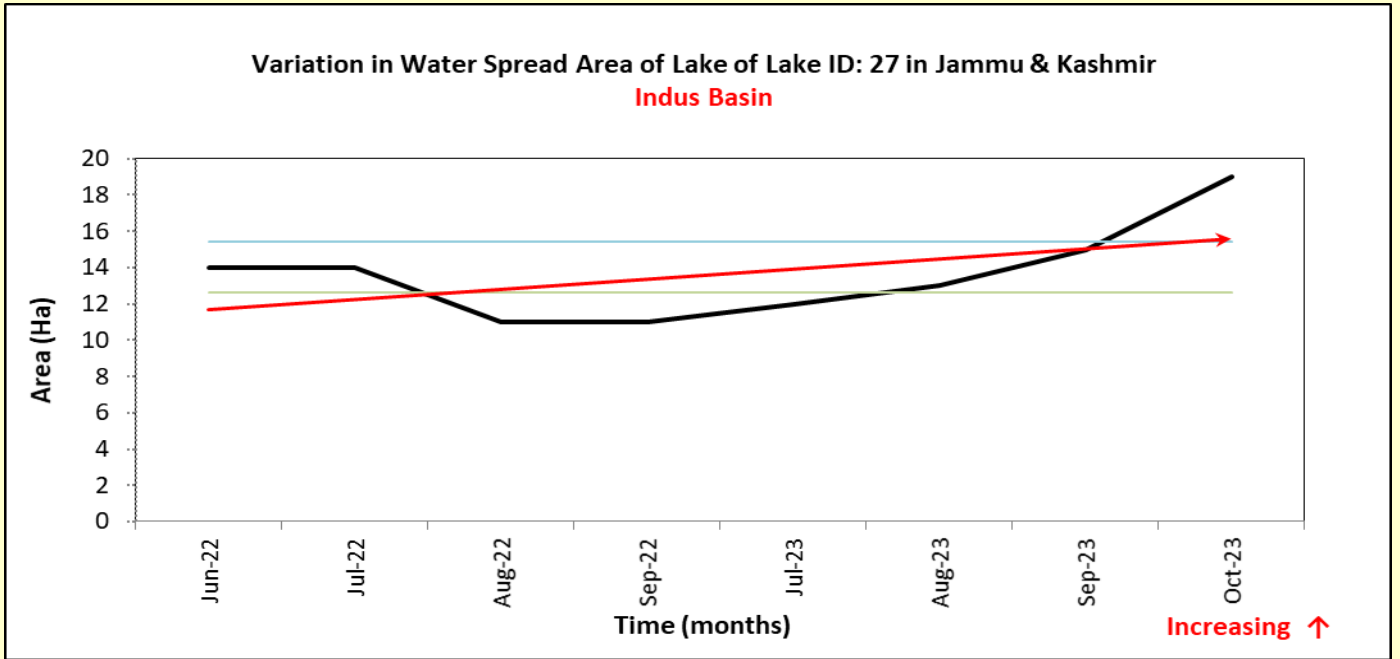


Figure 4.51(ii) Trend Analysis Plot  $\pm 10\%$

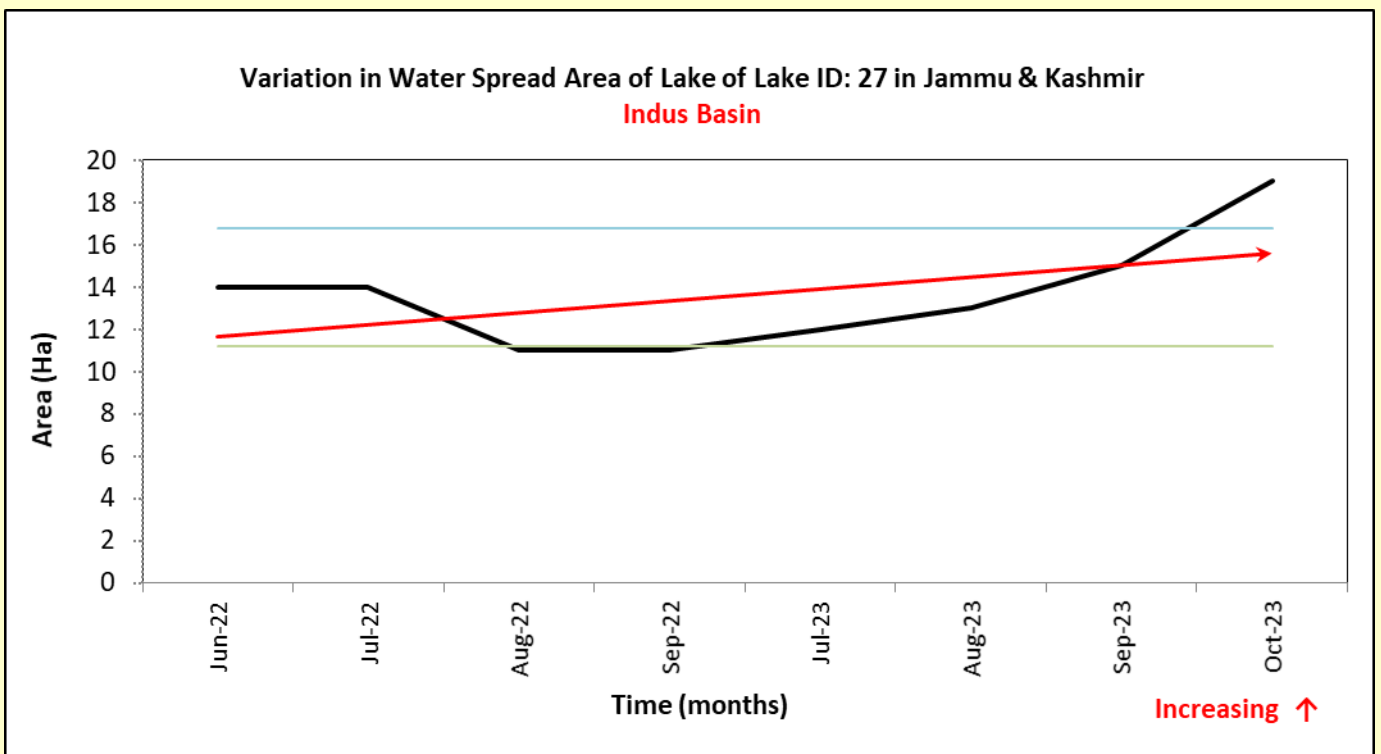


Figure 4.52(i) Trend Analysis Plot  $\pm 10\%$

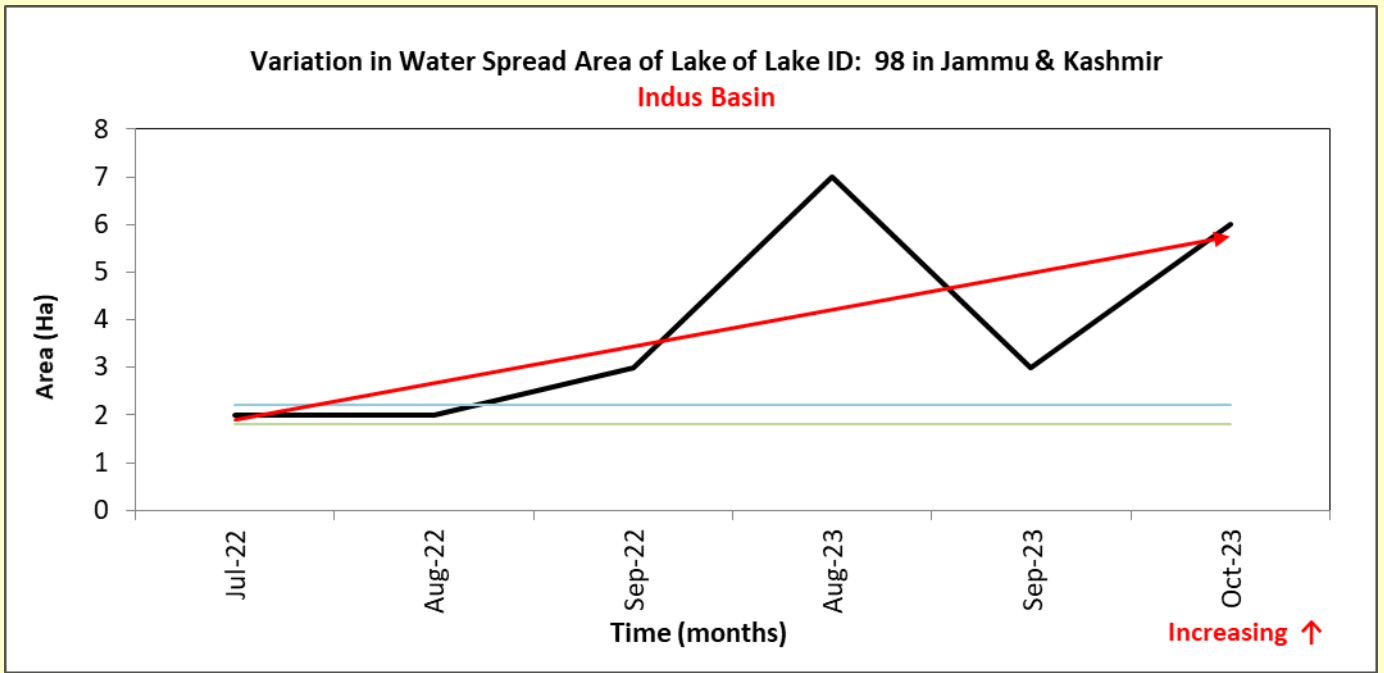


Figure 4.52(ii) Trend Analysis Plot  $\pm 20\%$

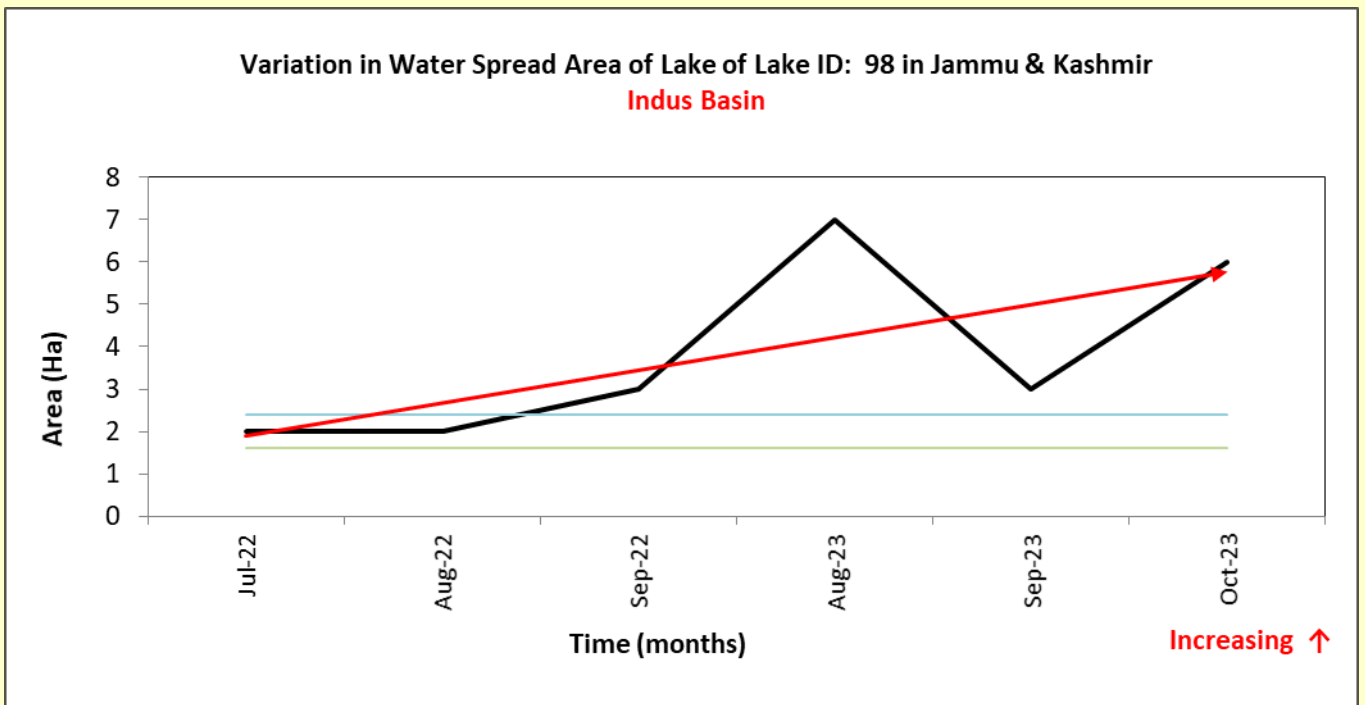


Figure 4.53(i) Trend Analysis Plot  $\pm 10\%$

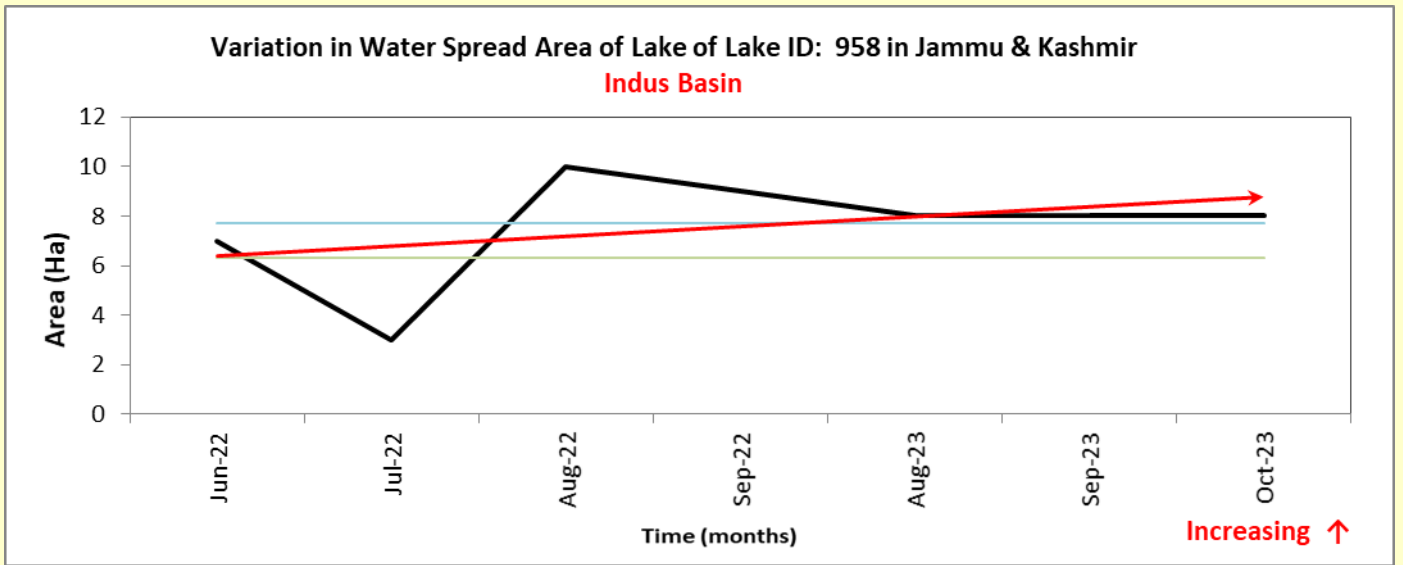


Figure 4.53(ii) Trend Analysis Plot  $\pm 20\%$

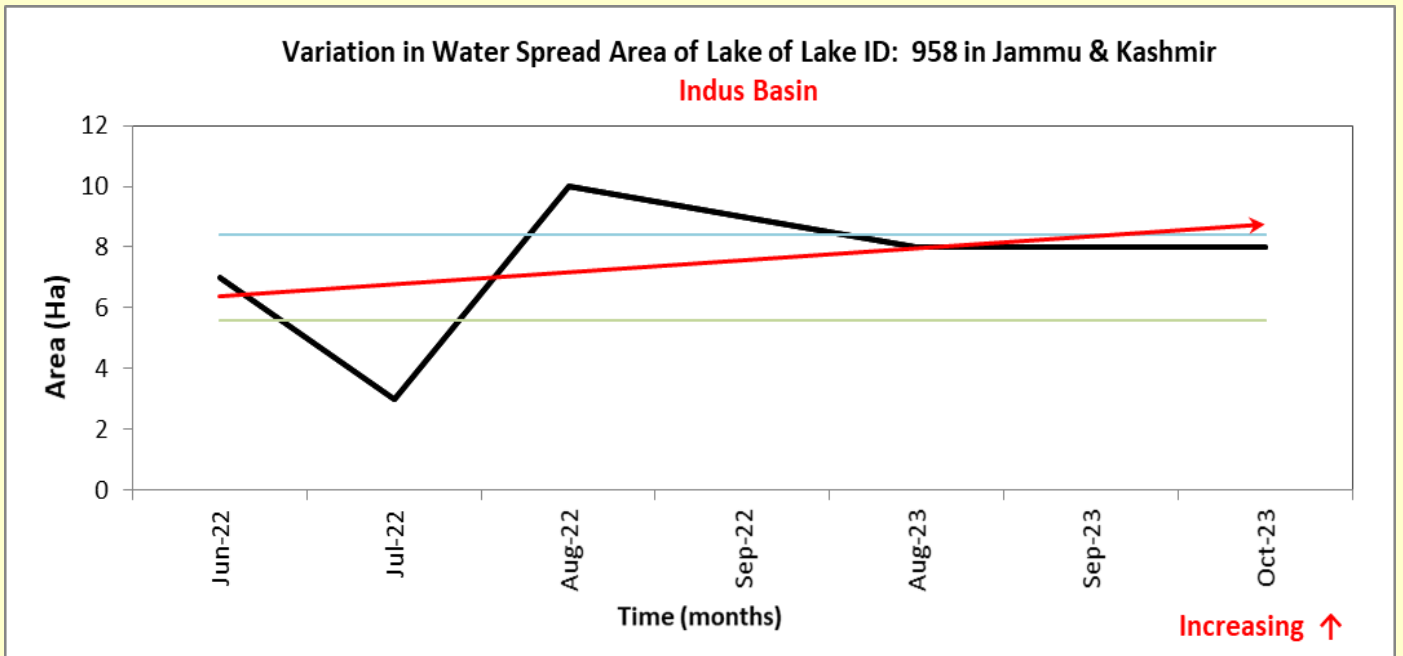


Figure 4.54(i) Trend Analysis Plot  $\pm 10\%$

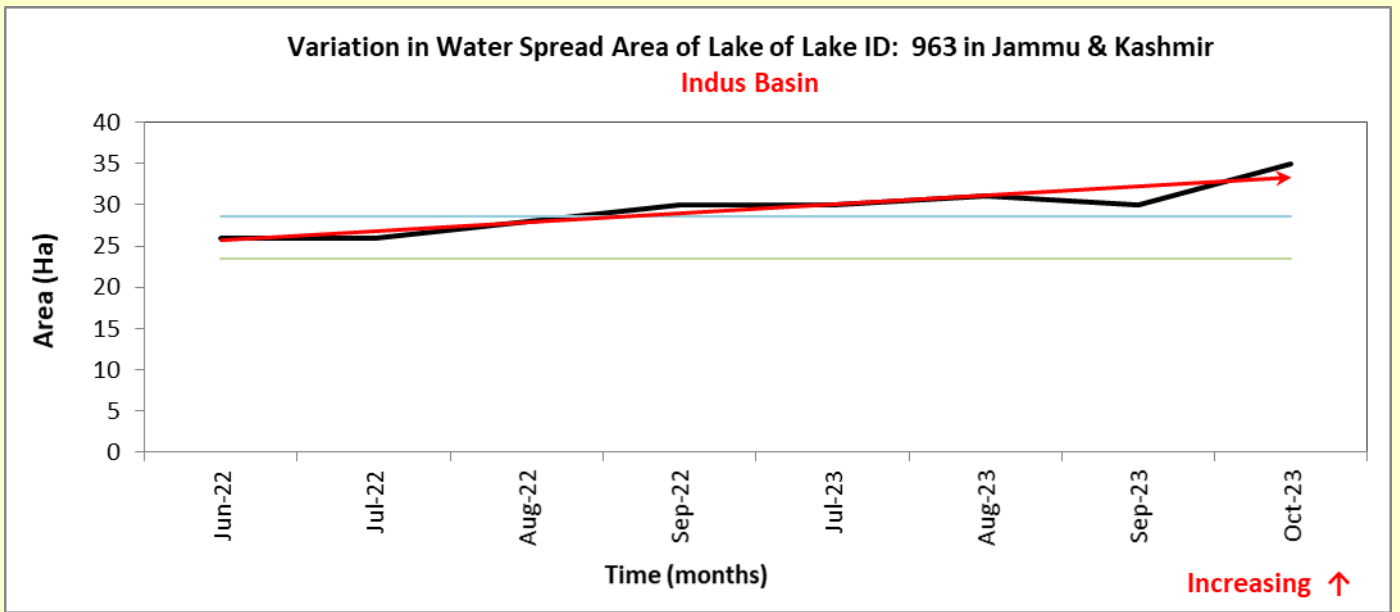


Figure 4.54(ii) Trend Analysis Plot  $\pm 20\%$

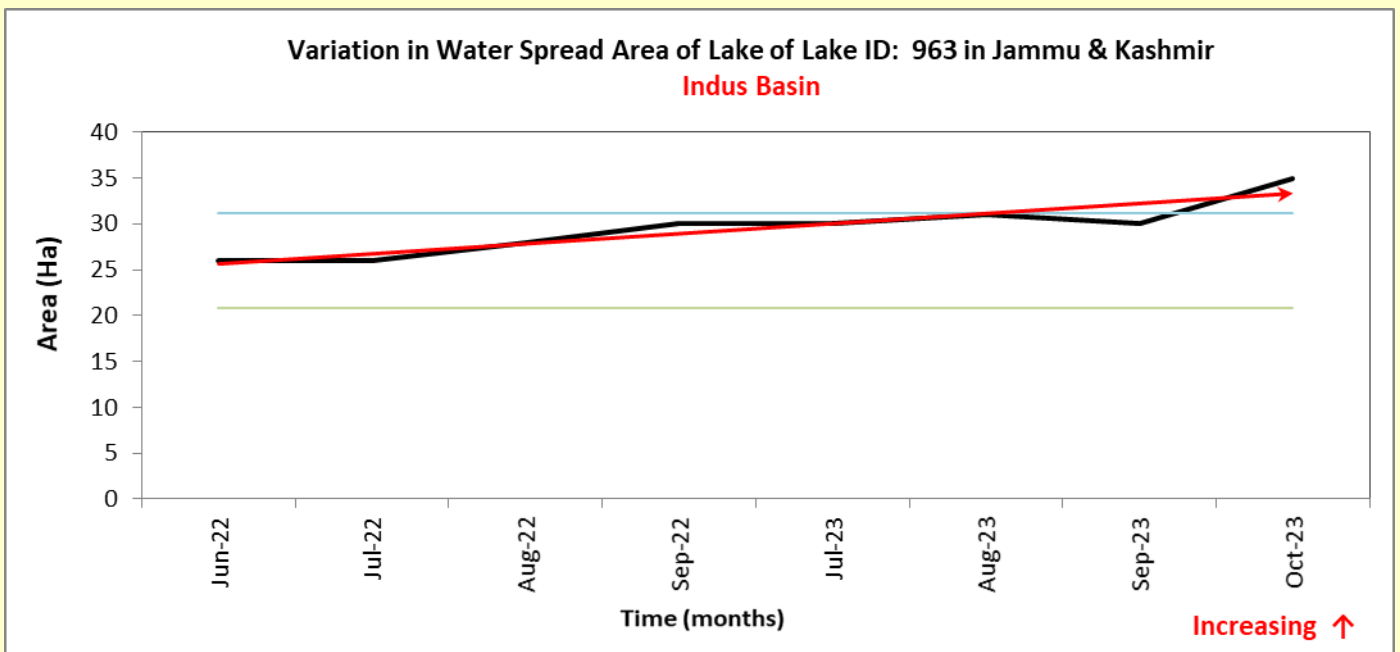


Figure 4.55(i) Trend Analysis Plot  $\pm 10\%$

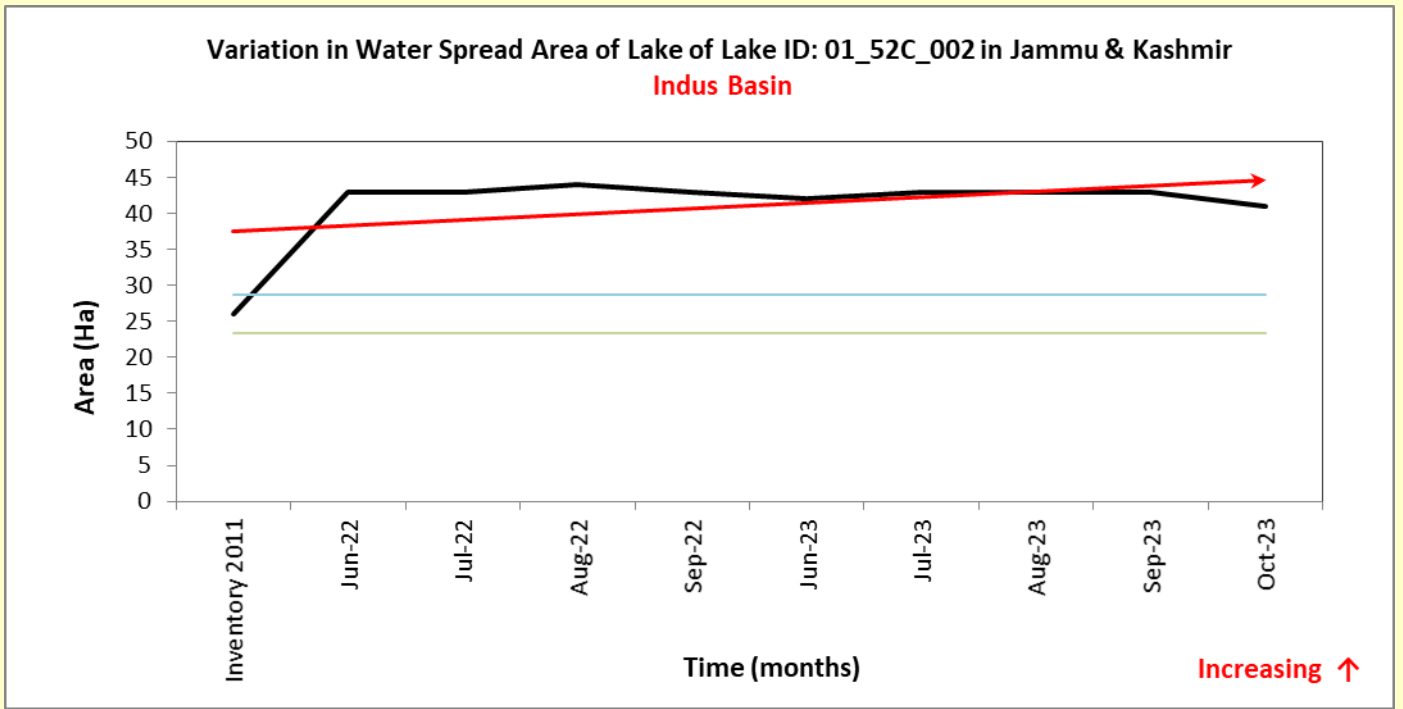


Figure 4.55(ii) Trend Analysis Plot  $\pm 20\%$

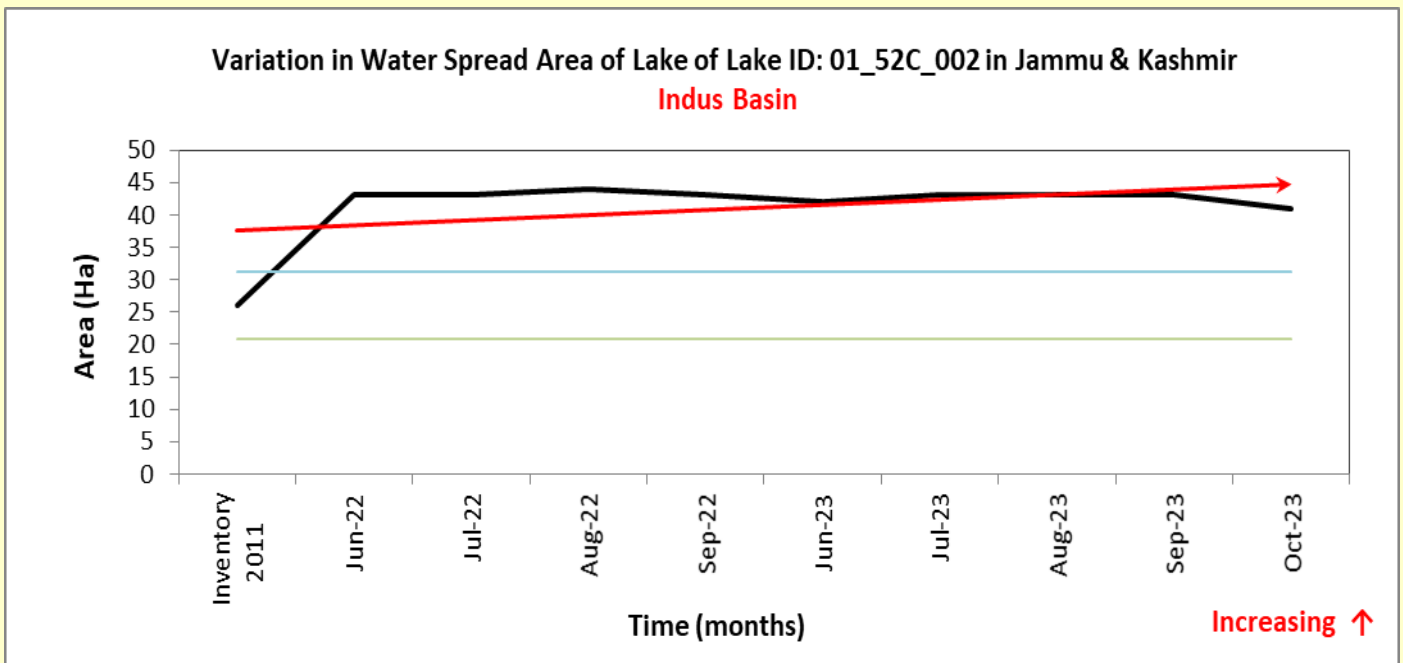


Figure 4.56(i) Trend Analysis Plot  $\pm 10\%$

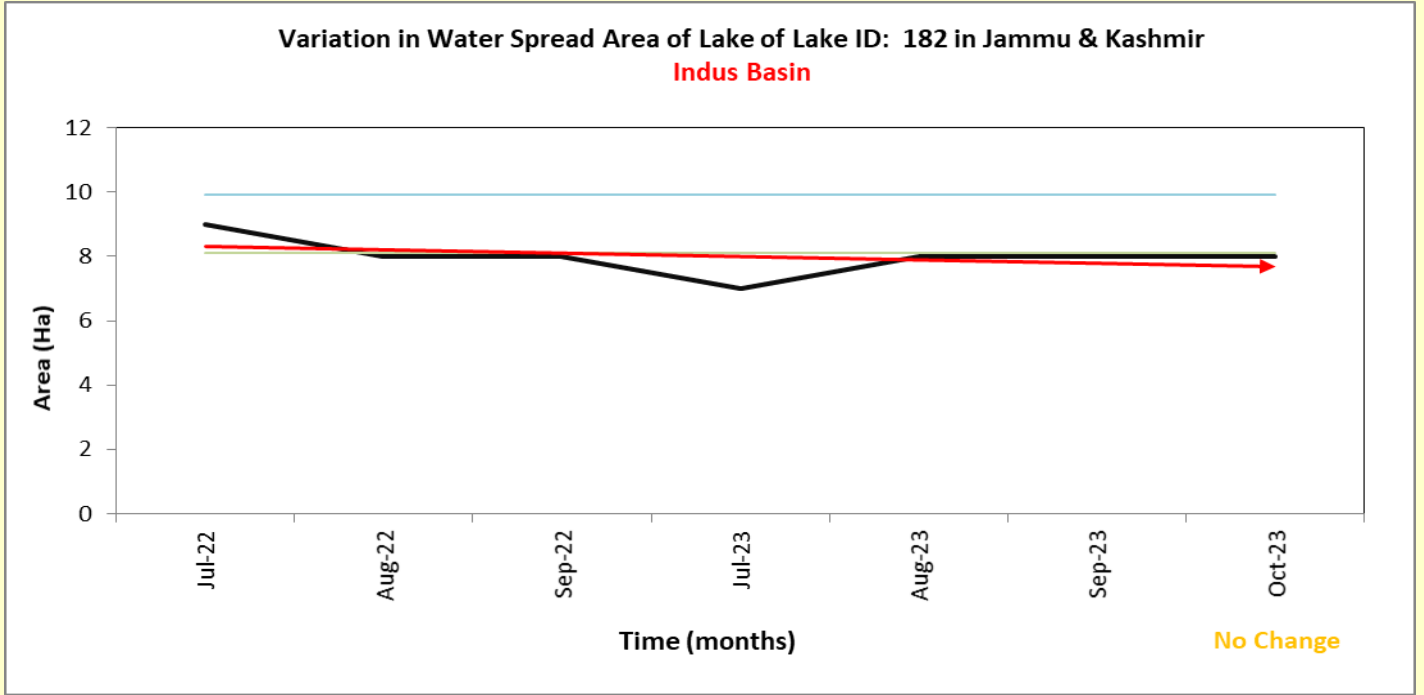


Figure 4.56(ii) Trend Analysis Plot  $\pm 20\%$

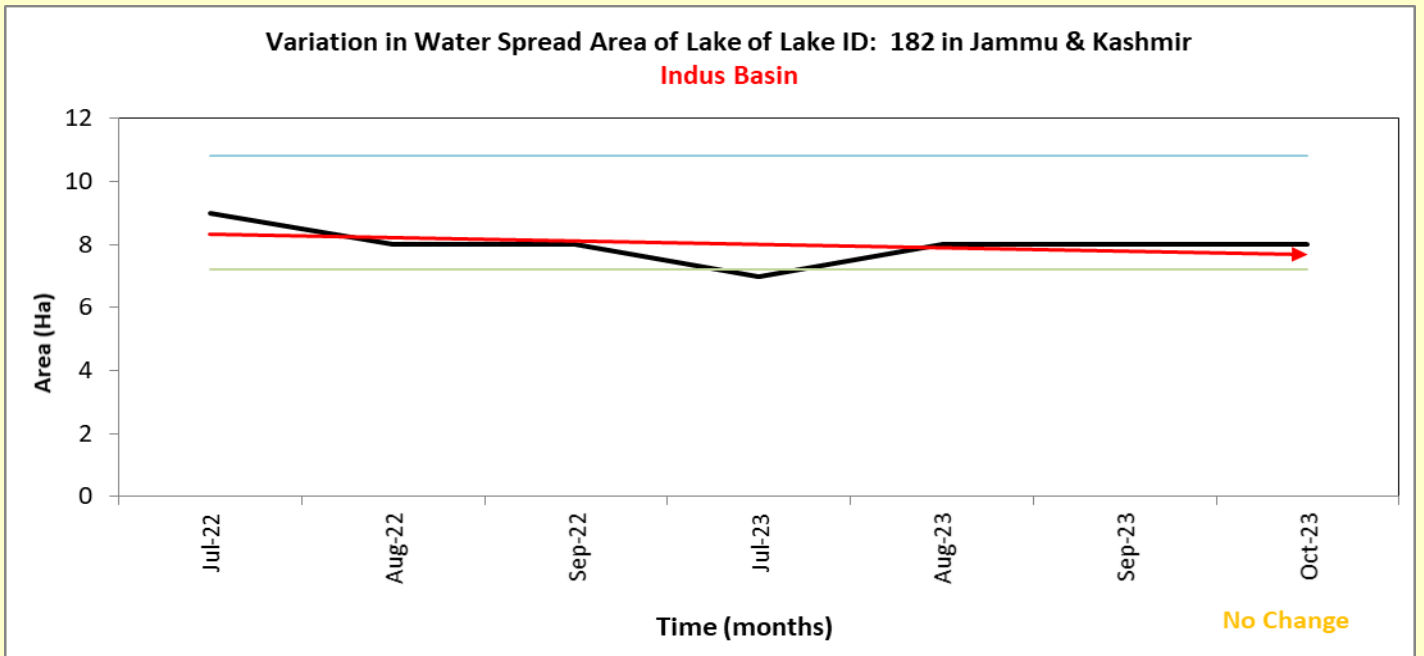


Figure 4.57(i) Trend Analysis Plot  $\pm 10\%$

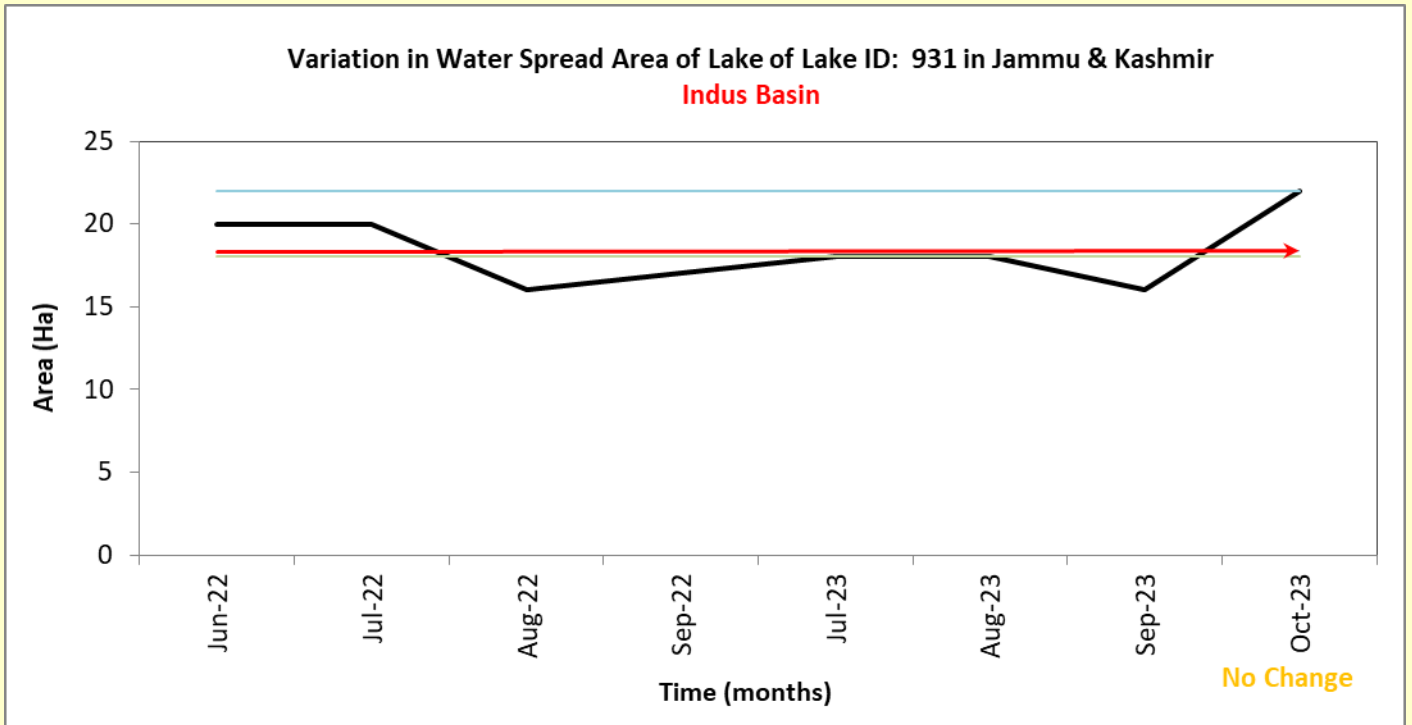


Figure 4.57(ii) Trend Analysis Plot  $\pm 20\%$

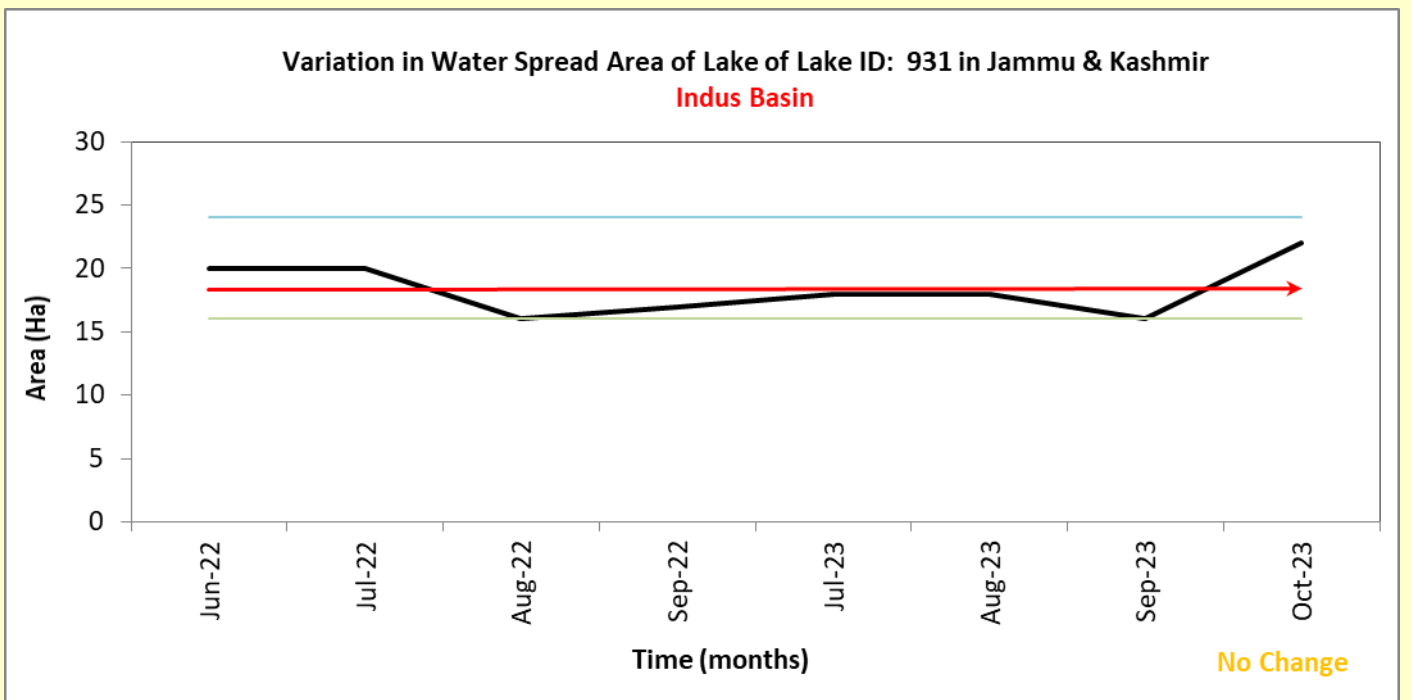


Figure 4.58(i) Trend Analysis Plot  $\pm 10\%$

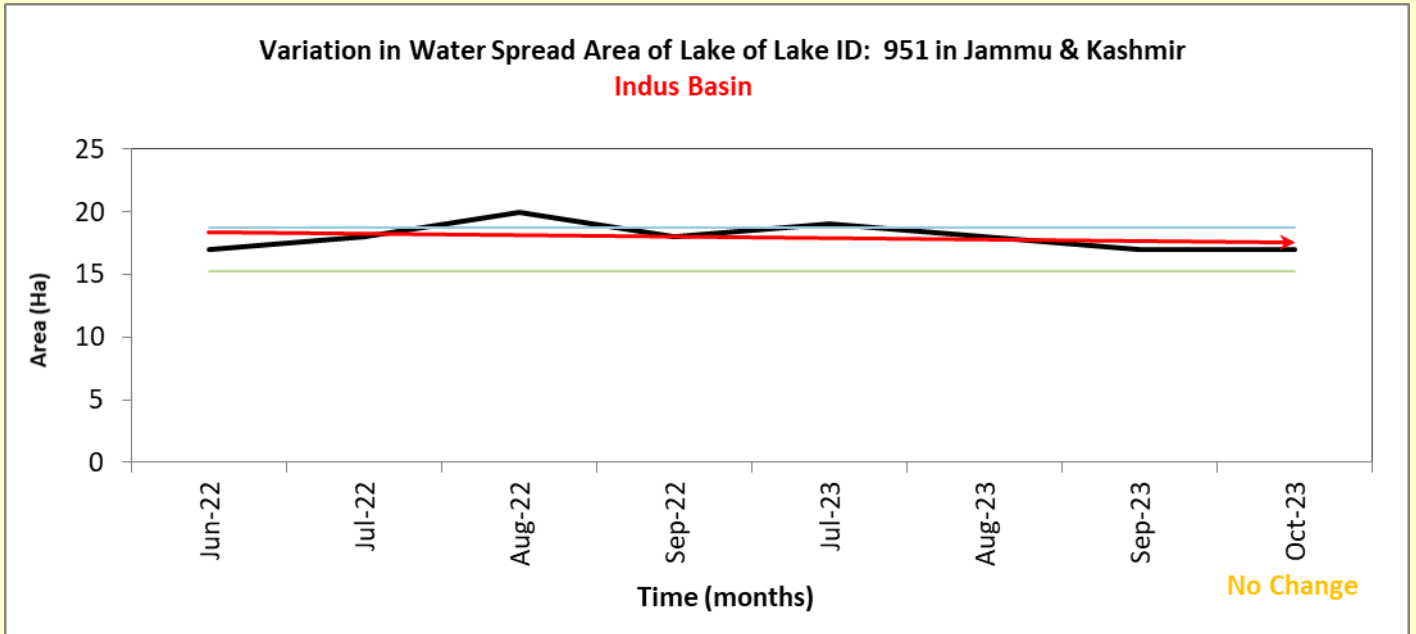


Figure 4.58(ii) Trend Analysis Plot  $\pm 20\%$

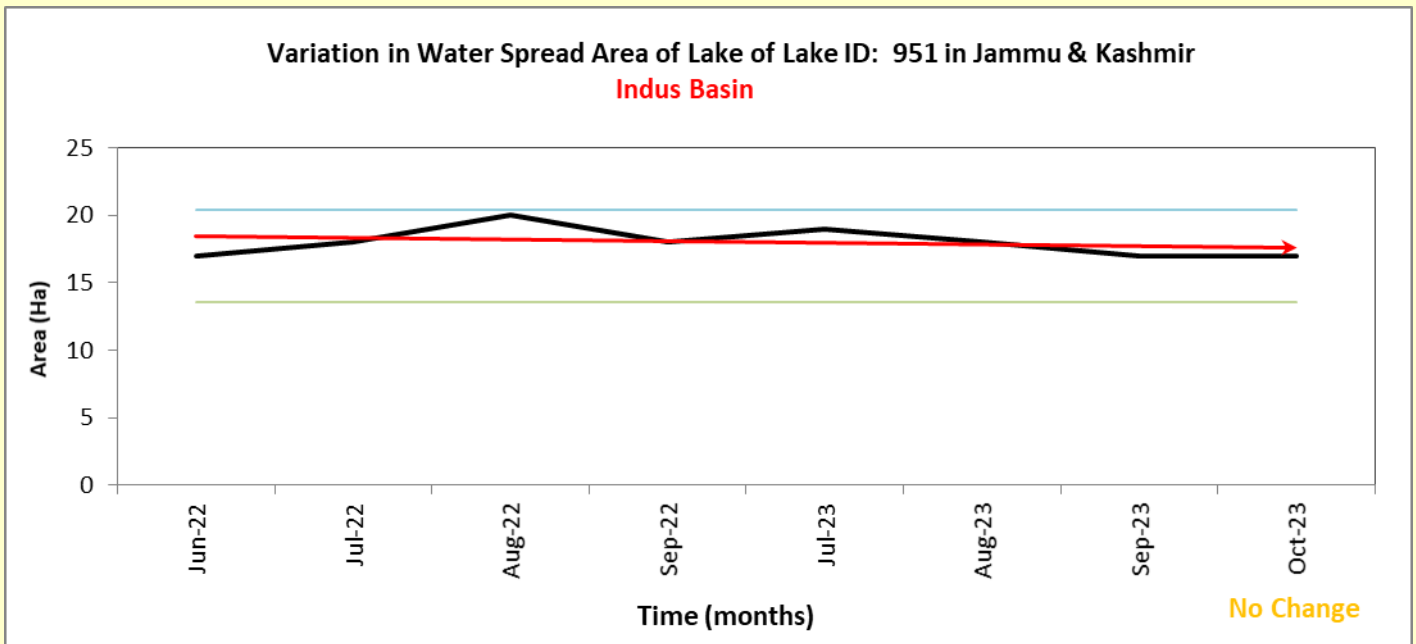


Figure 4.59(i) Trend Analysis Plot  $\pm 10\%$

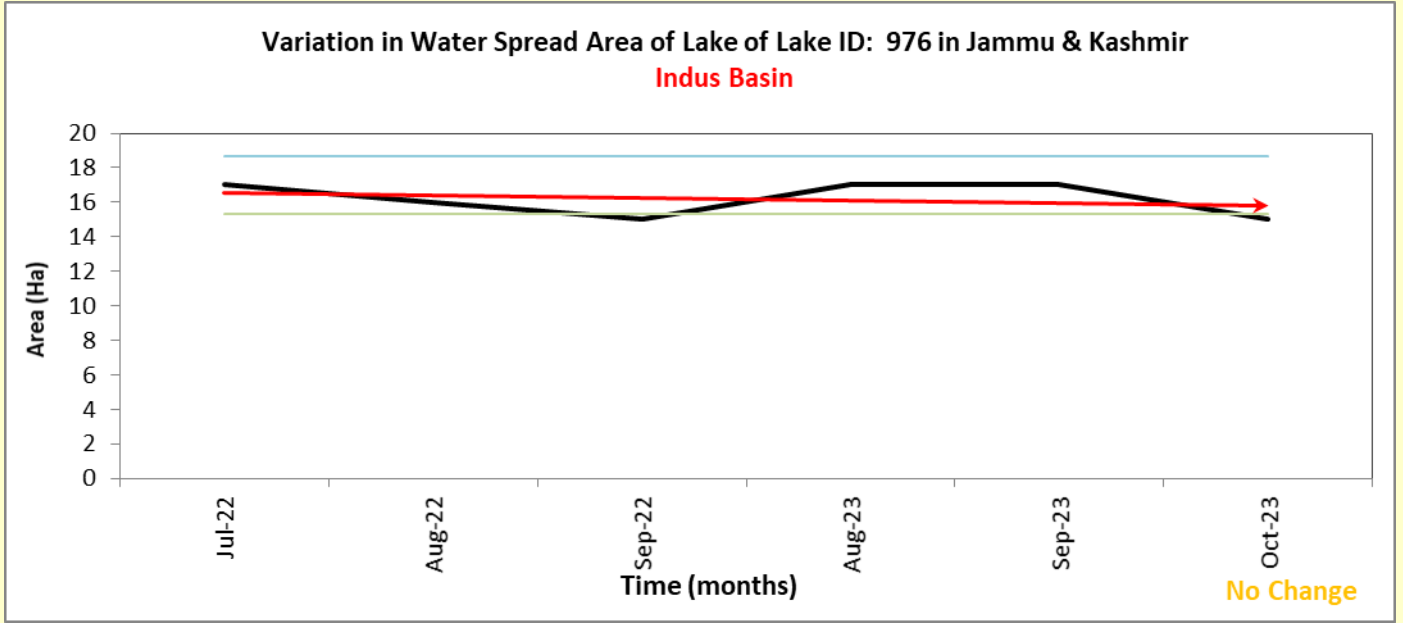


Figure 4.59(ii) Trend Analysis Plot  $\pm 20\%$

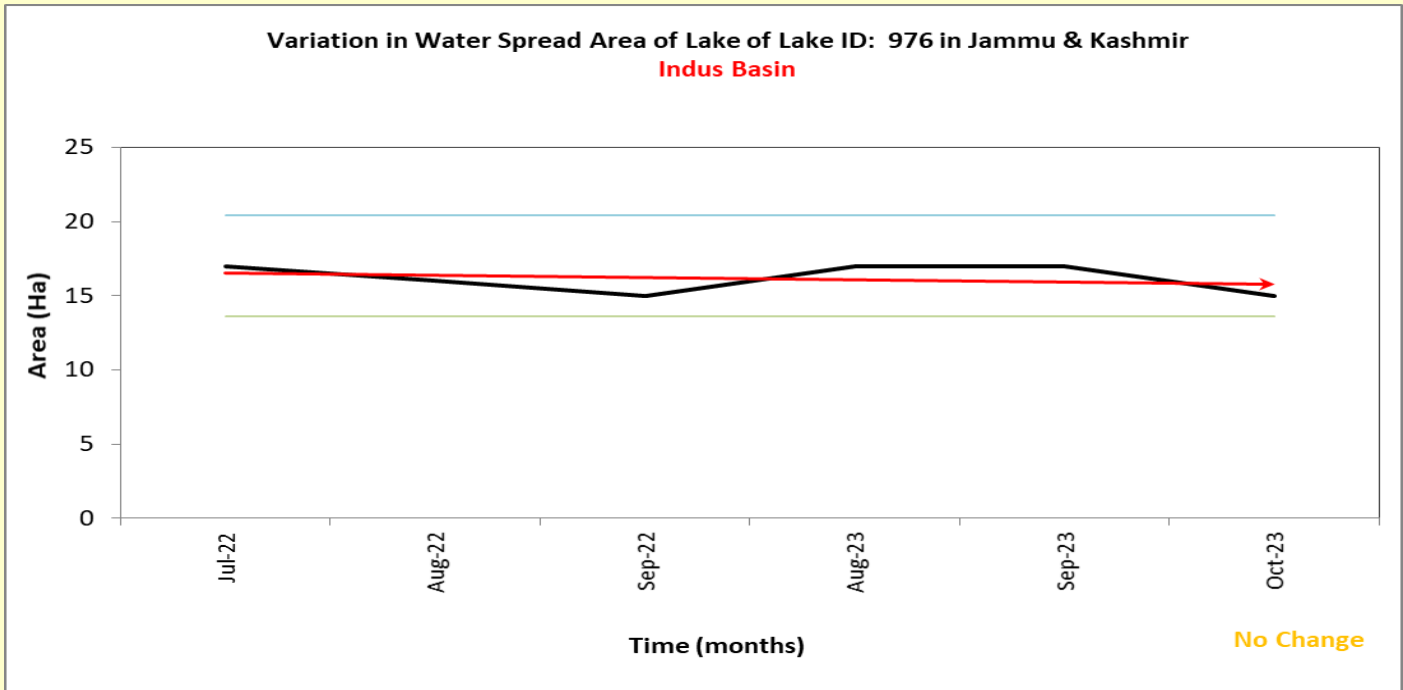


Figure 4.60(i) Trend Analysis Plot  $\pm 10\%$

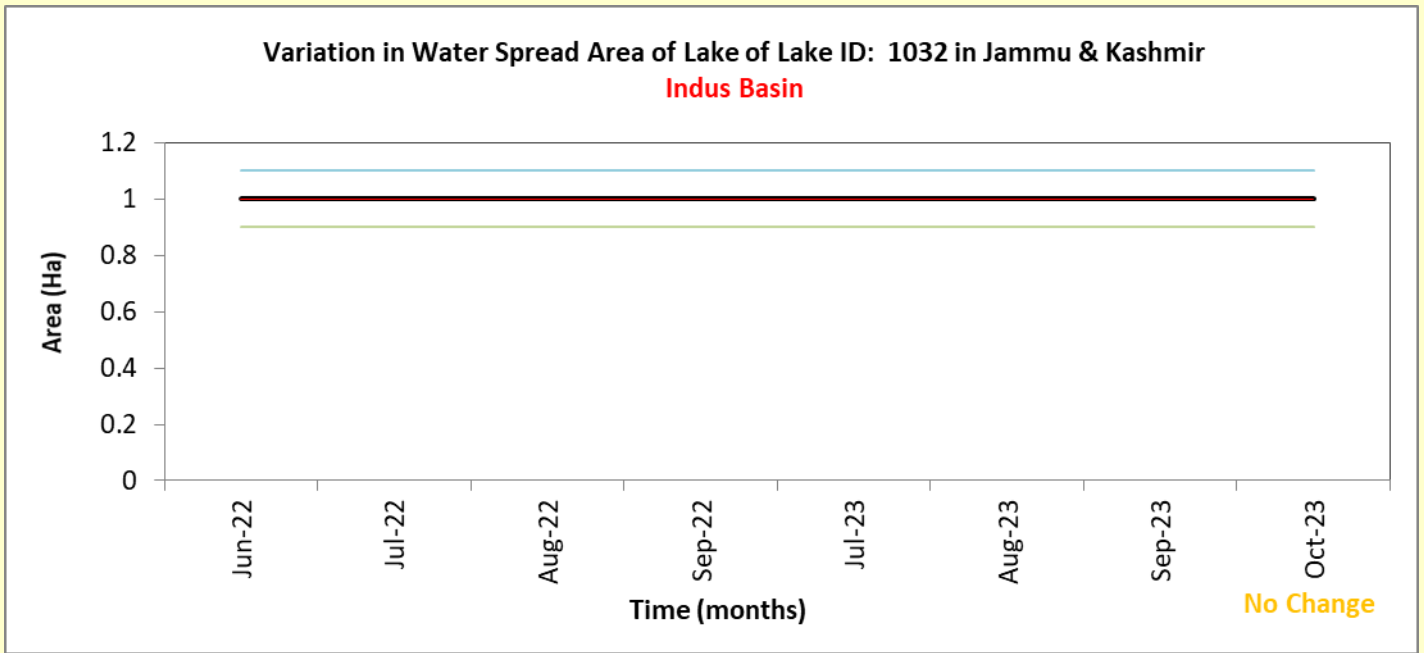


Figure 4.60(ii) Trend Analysis Plot  $\pm 10\%$

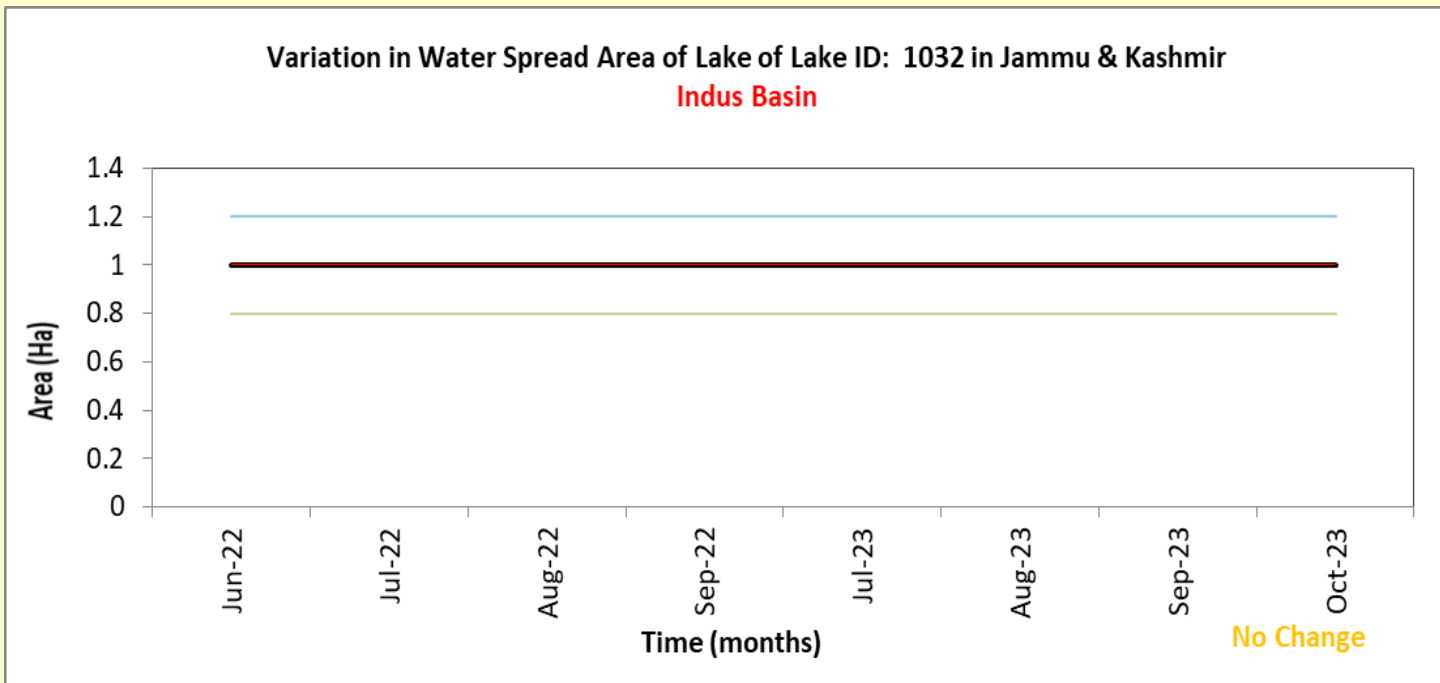


Figure 4.61(i) Trend Analysis Plot  $\pm 10\%$

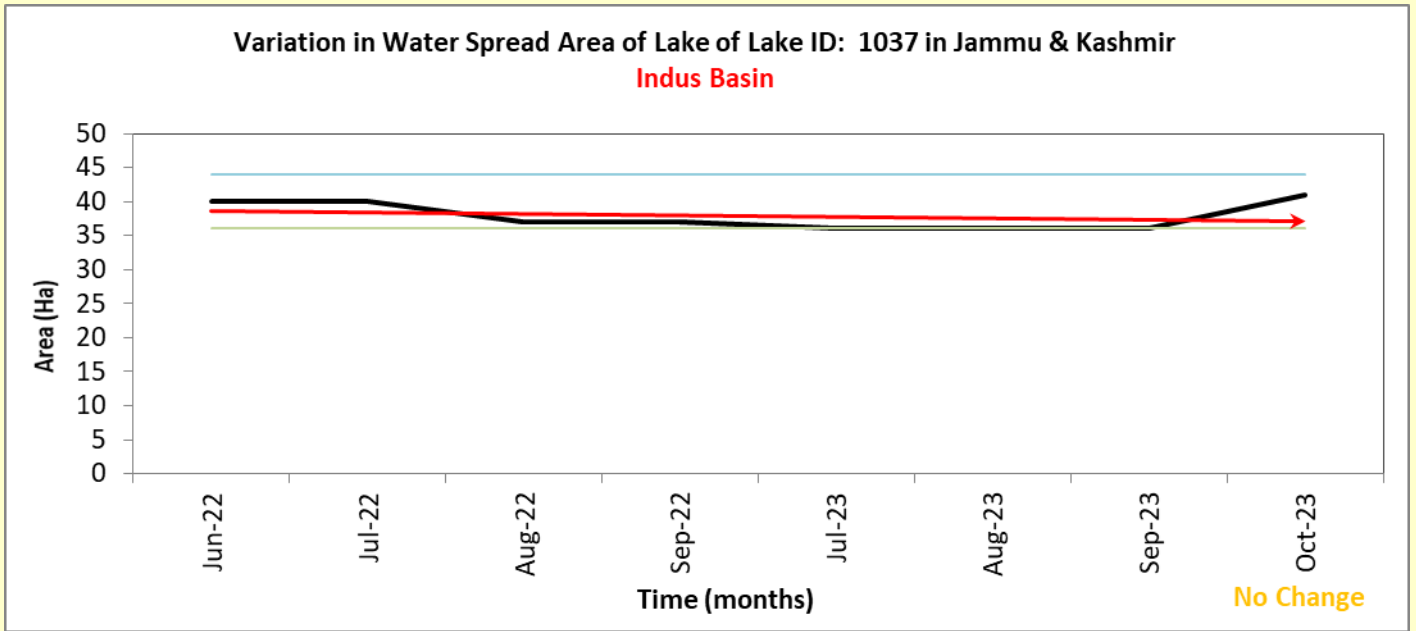


Figure 4.61(ii) Trend Analysis Plot  $\pm 20\%$

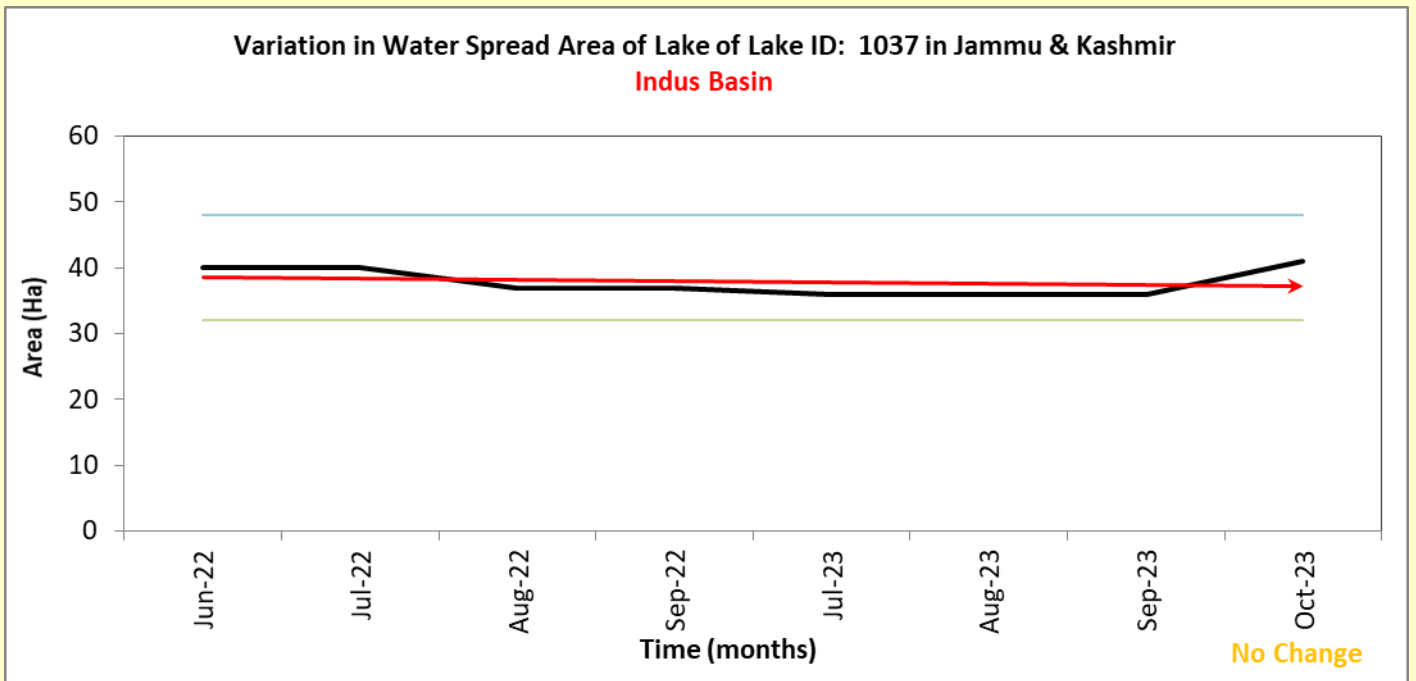


Figure 4.62(i) Trend Analysis Plot  $\pm 10\%$

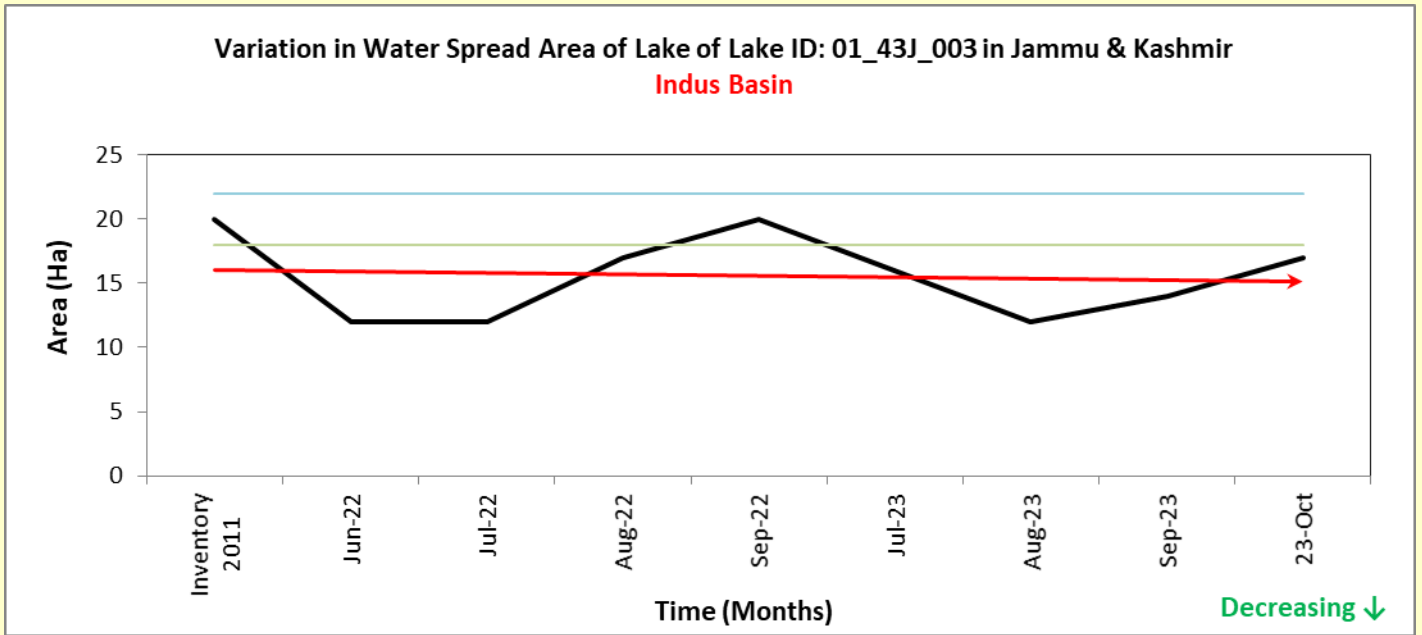


Figure 4.62(ii) Trend Analysis Plot  $\pm 20\%$

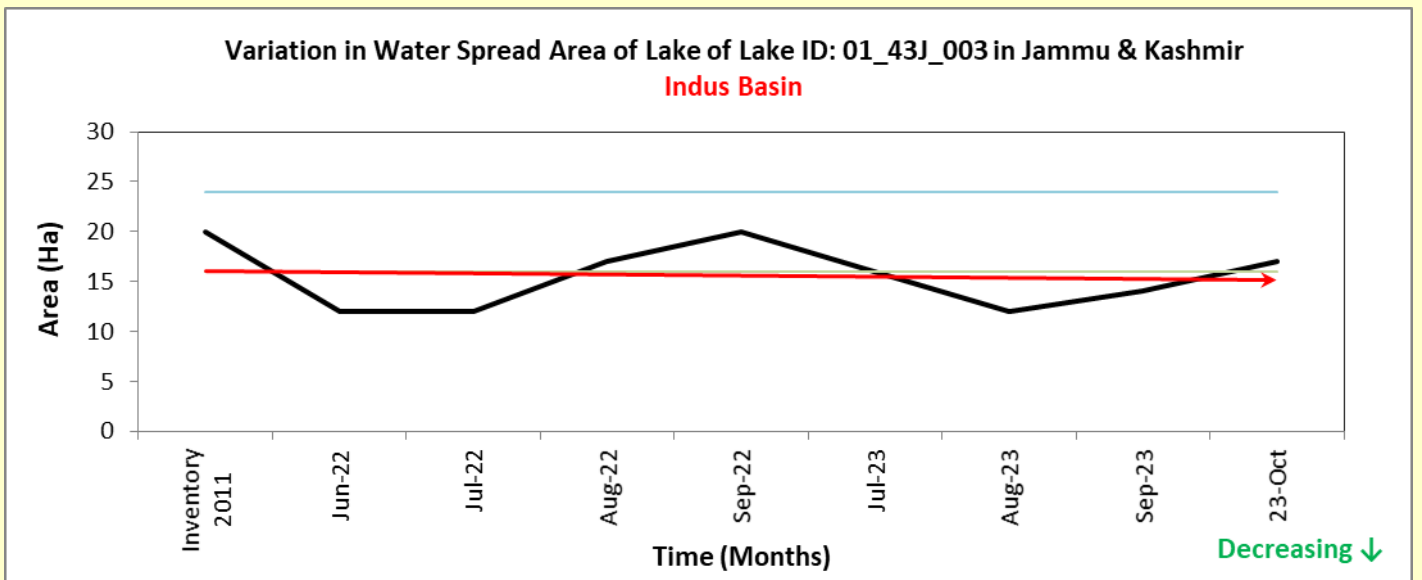


Figure 4.63(i) Trend Analysis Plot  $\pm 10\%$

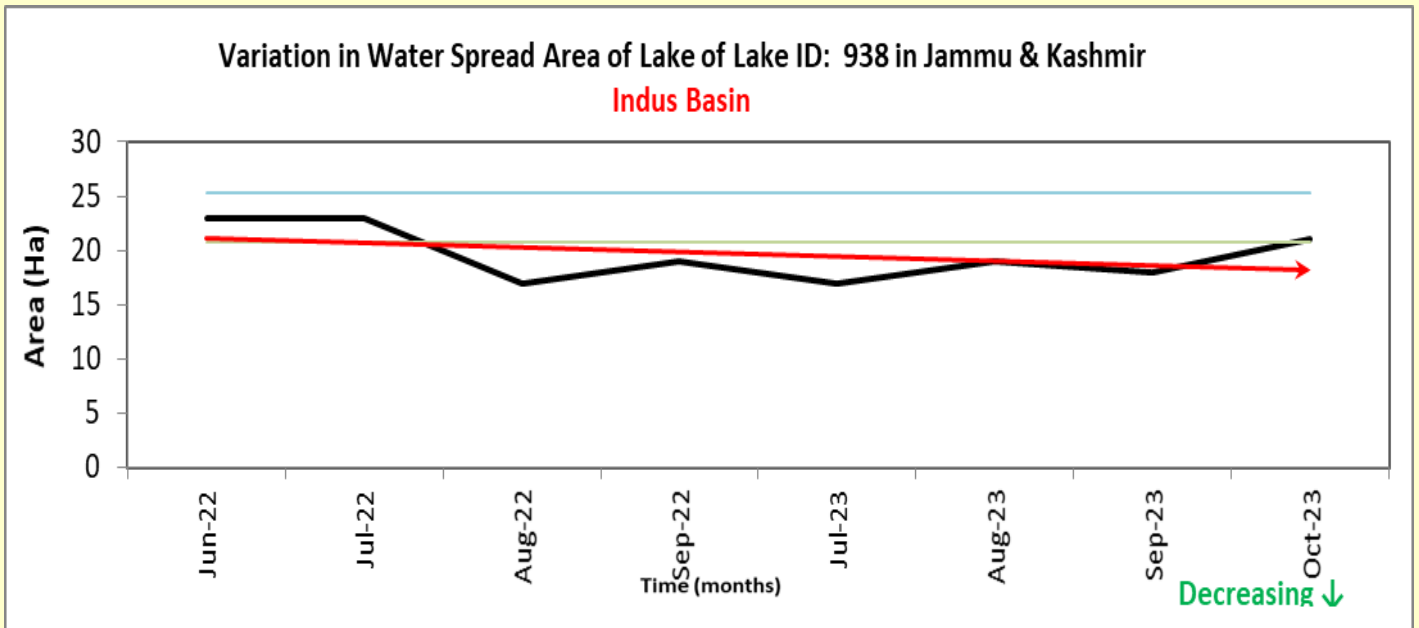


Figure 4.63(ii) Trend Analysis Plot  $\pm 20\%$

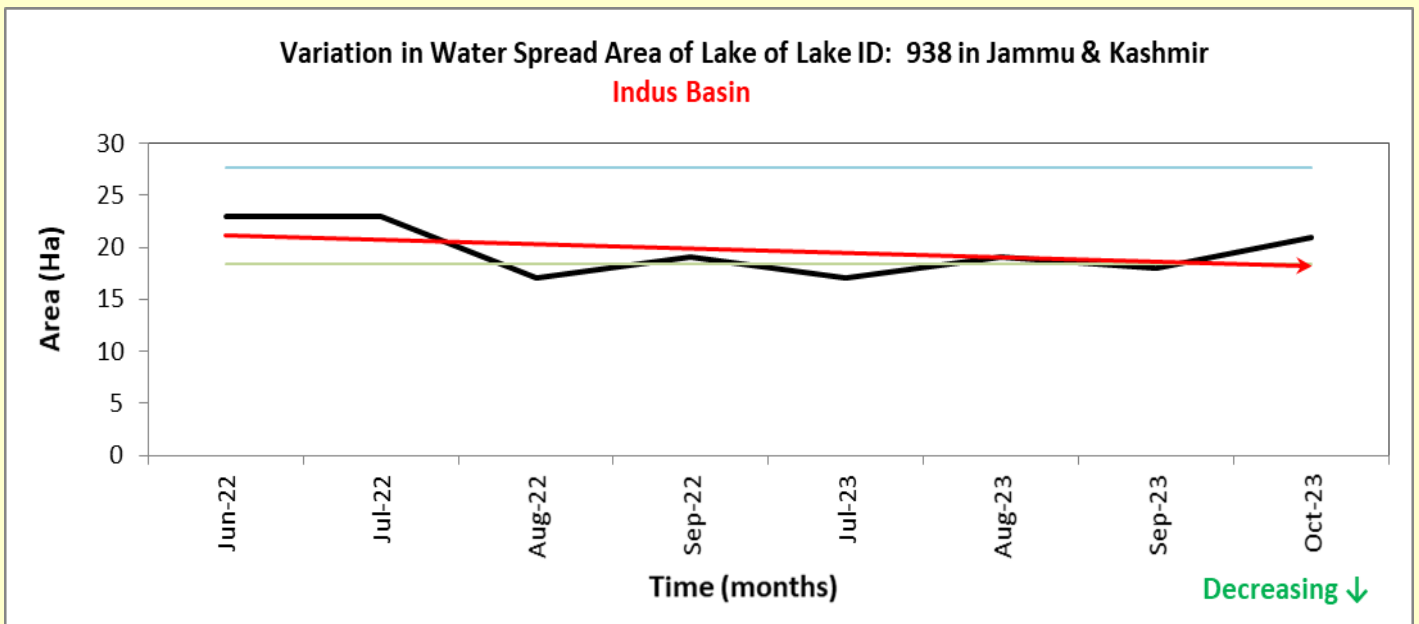


Figure 4.64(i) Trend Analysis Plot  $\pm 10\%$

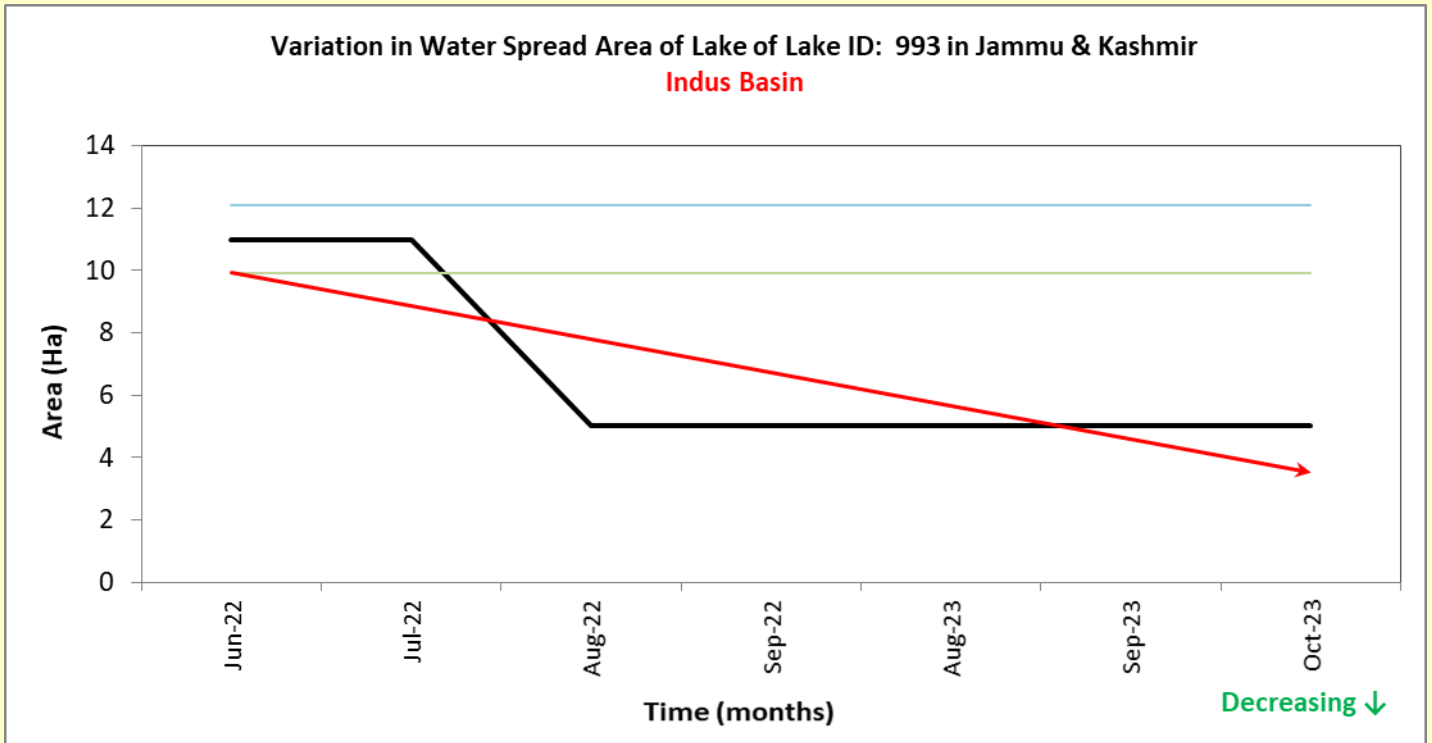


Figure.64(ii) Trend Analysis Plot  $\pm 20\%$

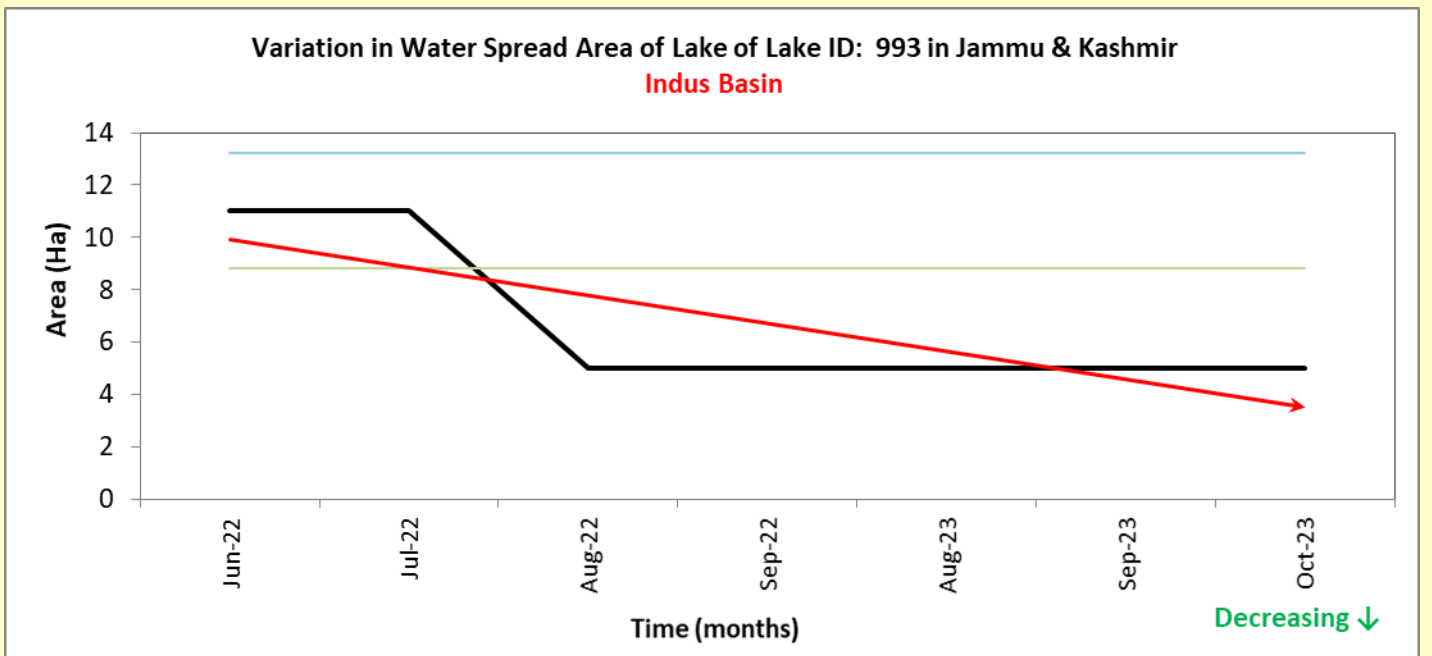


Figure 4.65(i) Trend Analysis Plot  $\pm 10\%$

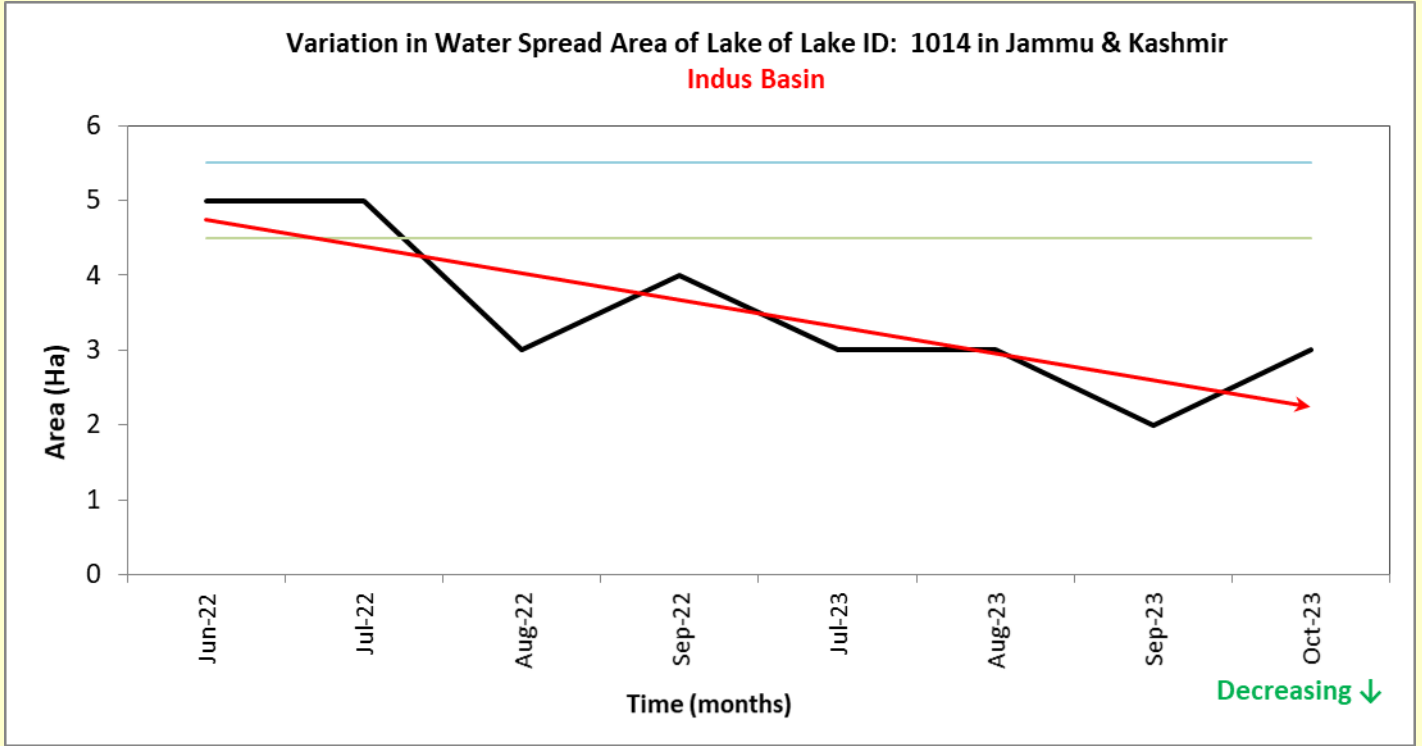
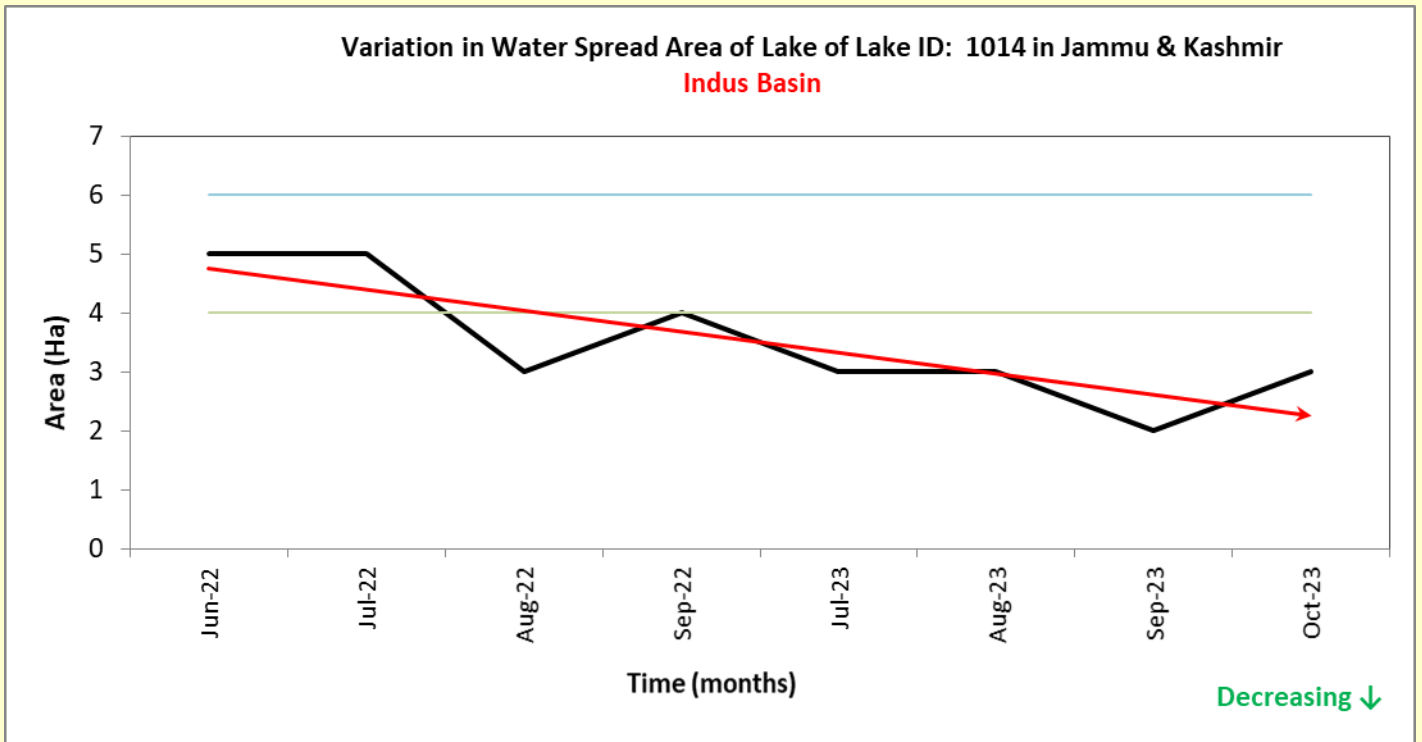


Figure 4.65(ii) Trend Analysis Plot  $\pm 20\%$



**Trend analysis of “Change in water spread area of Glacial Lakes between 10 Ha to 50 Ha of Himachal Pradesh (2011-2023)”**

Figure 4.66(i) Trend Analysis Plot  $\pm 10\%$

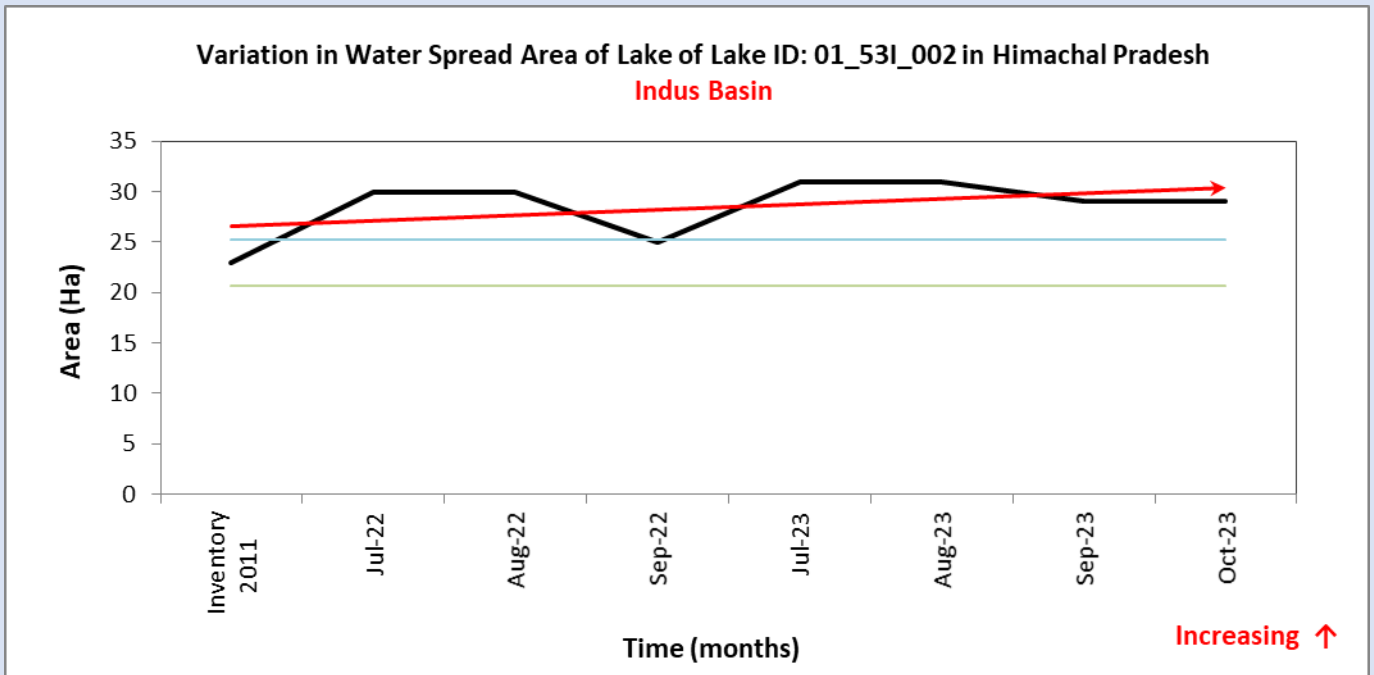


Figure 4.66(ii) Trend Analysis Plot  $\pm 10\%$

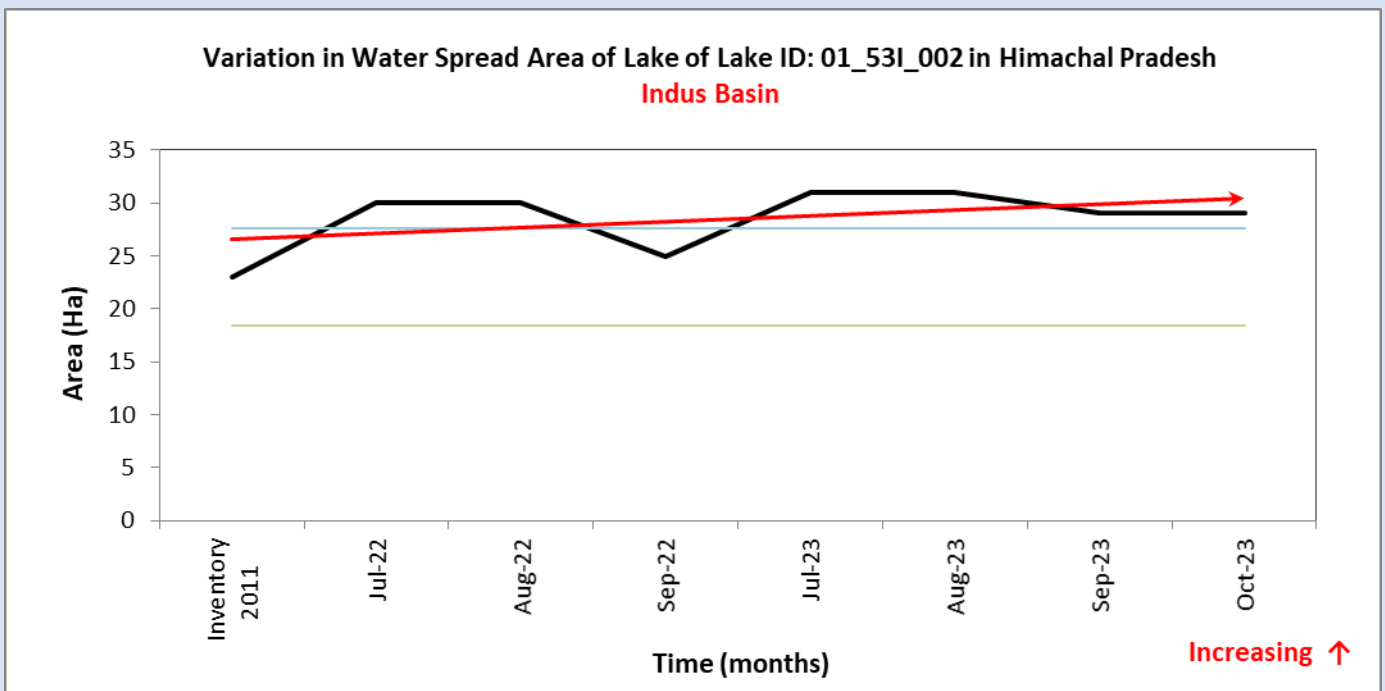


Figure 4.67(i) Trend Analysis Plot  $\pm 10\%$

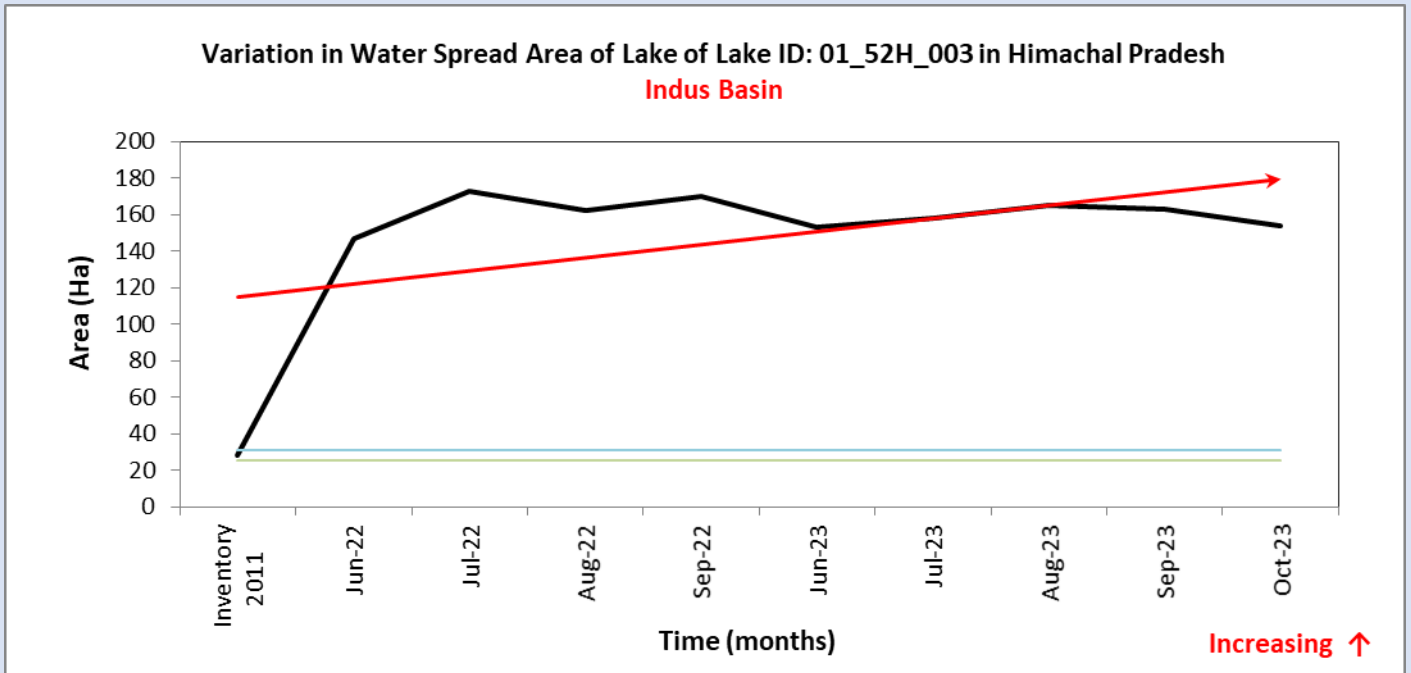


Figure 4.67(ii) Trend Analysis Plot  $\pm 20\%$

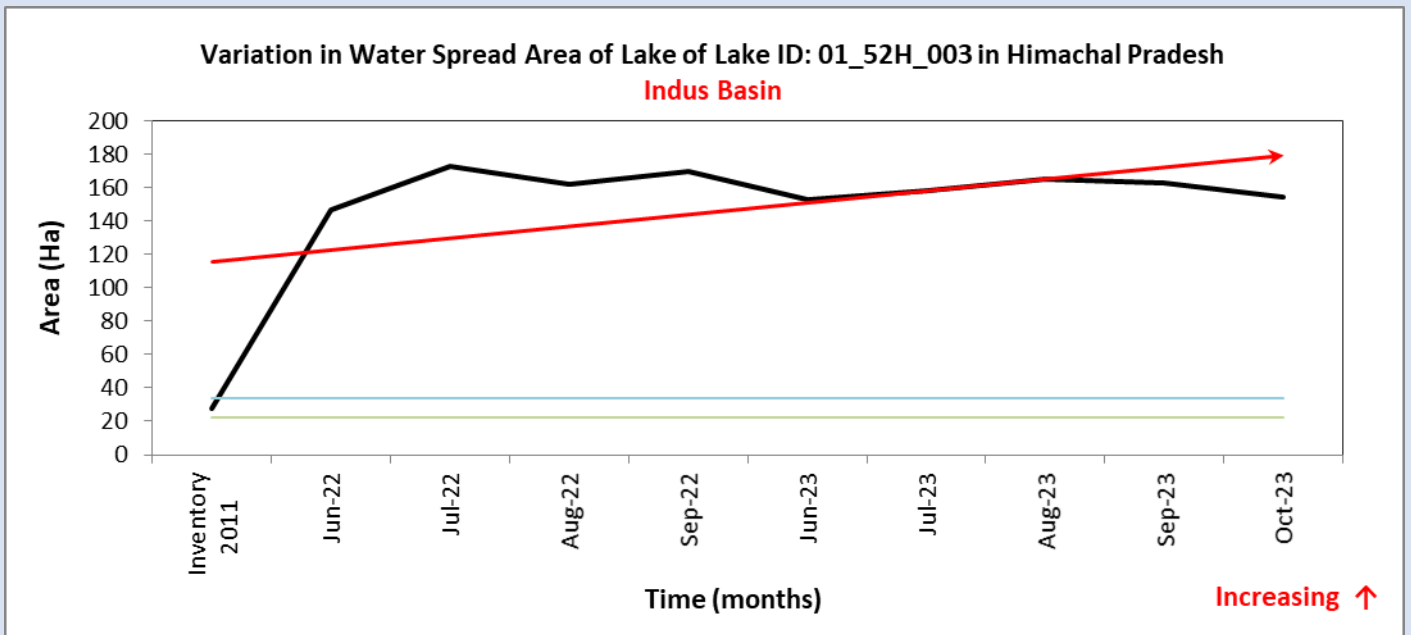


Figure 4.68(i) Trend Analysis Plot  $\pm 10\%$

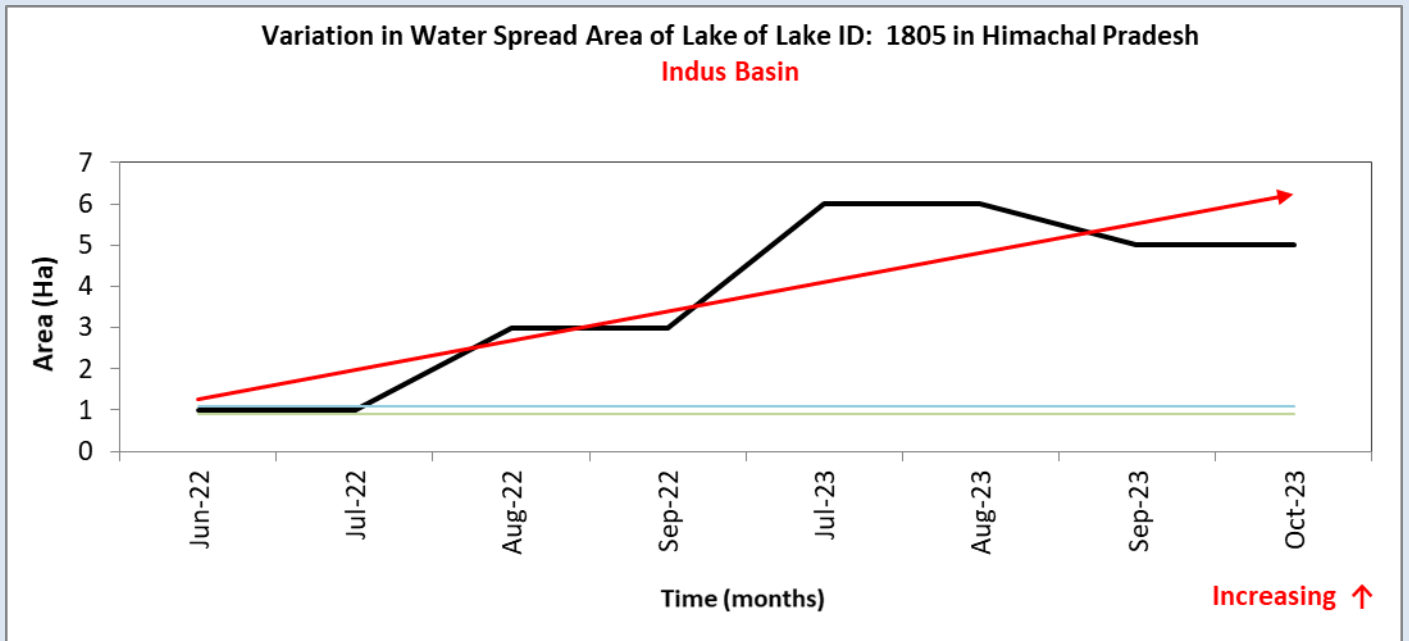


Figure 4.68(ii) Trend Analysis Plot  $\pm 20\%$

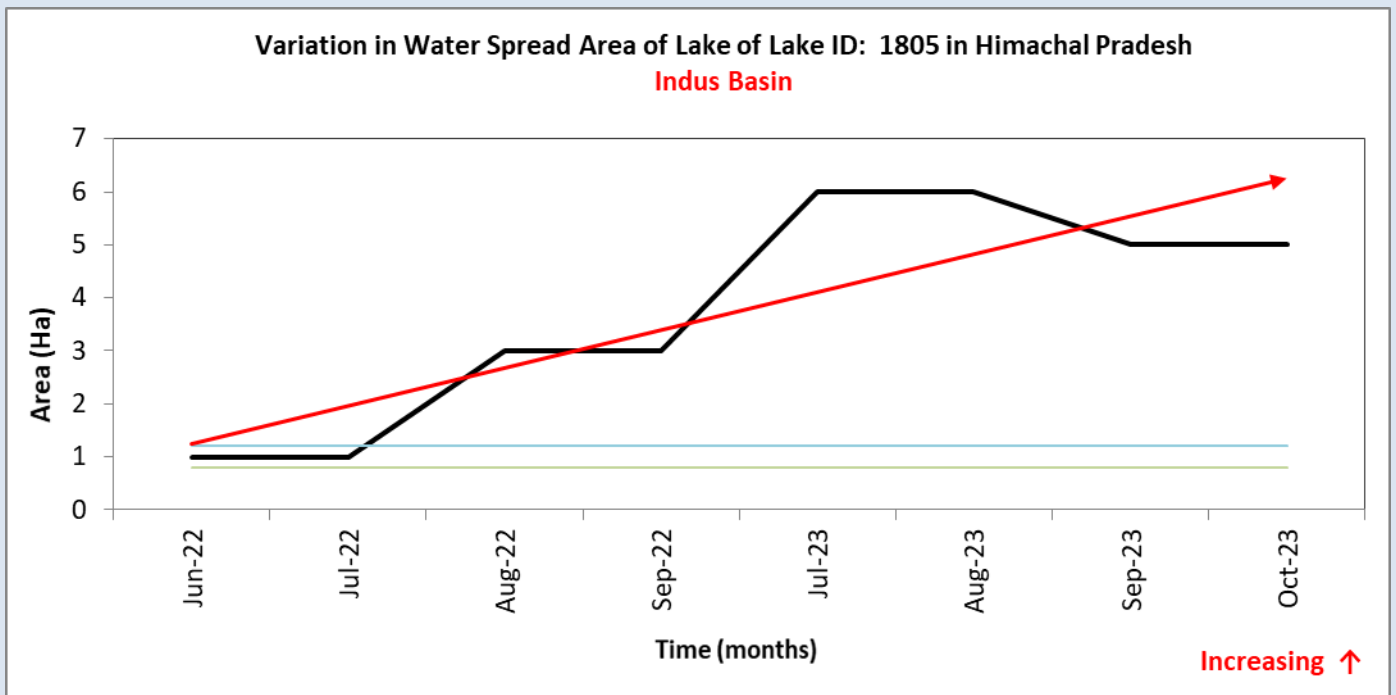


Figure 4.69(i) Trend Analysis Plot  $\pm 10\%$

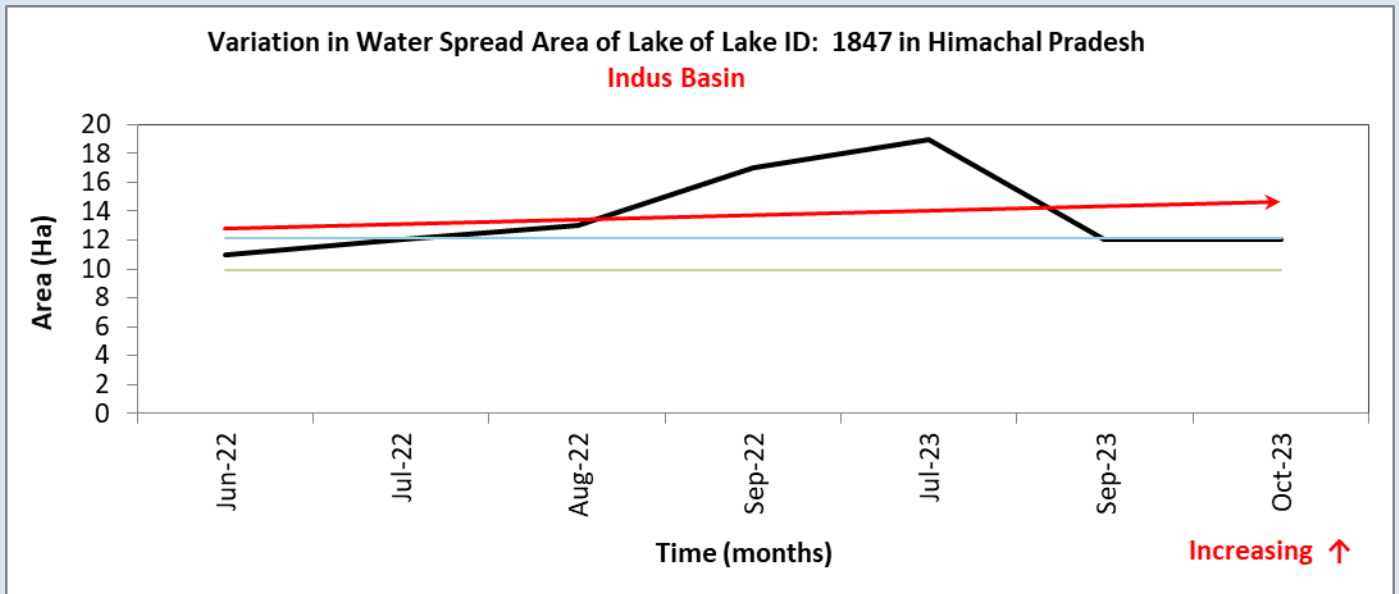


Figure 4.69(ii) Trend Analysis Plot  $\pm 20\%$

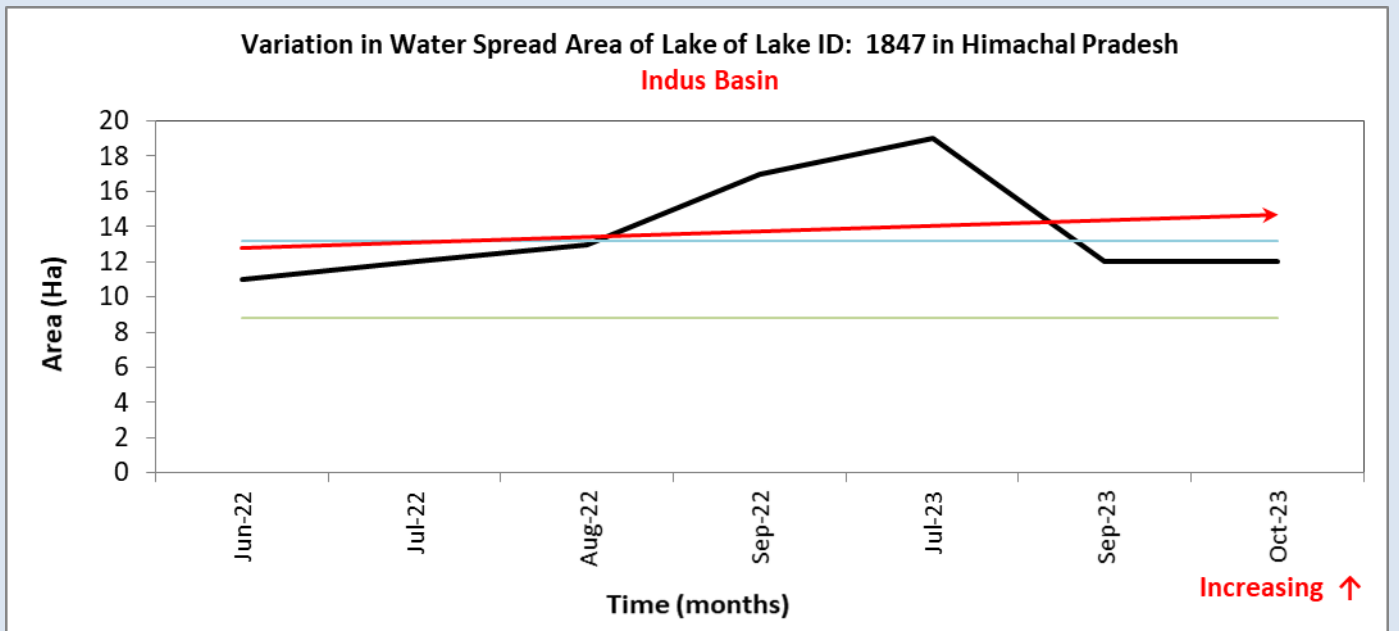


Figure 4.70(i) Trend Analysis Plot  $\pm 10\%$

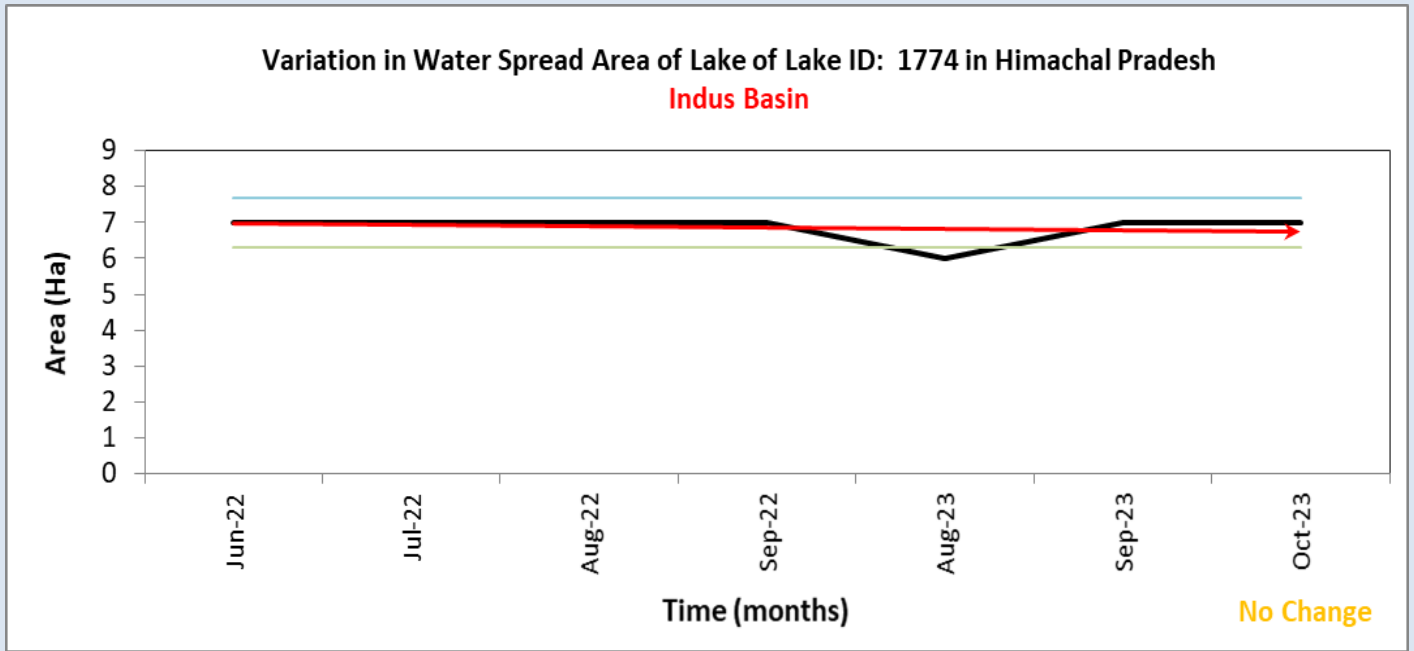


Figure 4.70(ii) Trend Analysis Plot  $\pm 20\%$

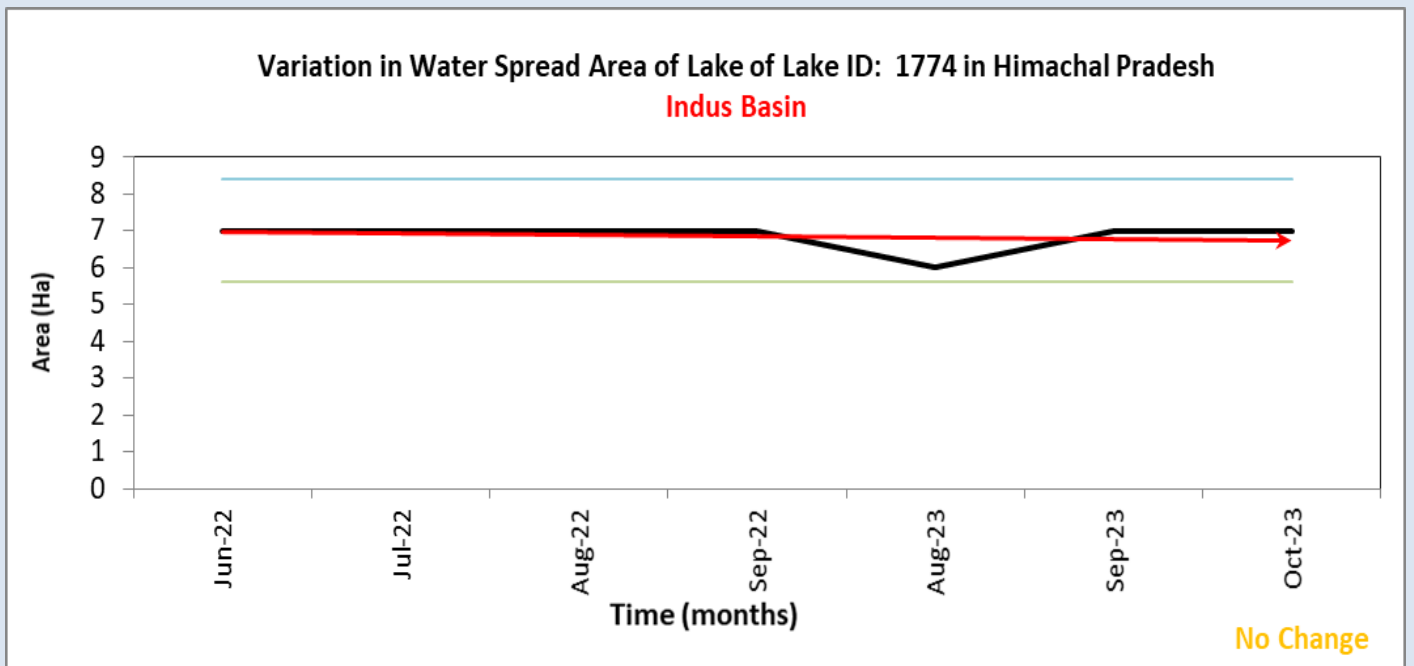


Figure 4.71(i) Trend Analysis Plot  $\pm 10\%$

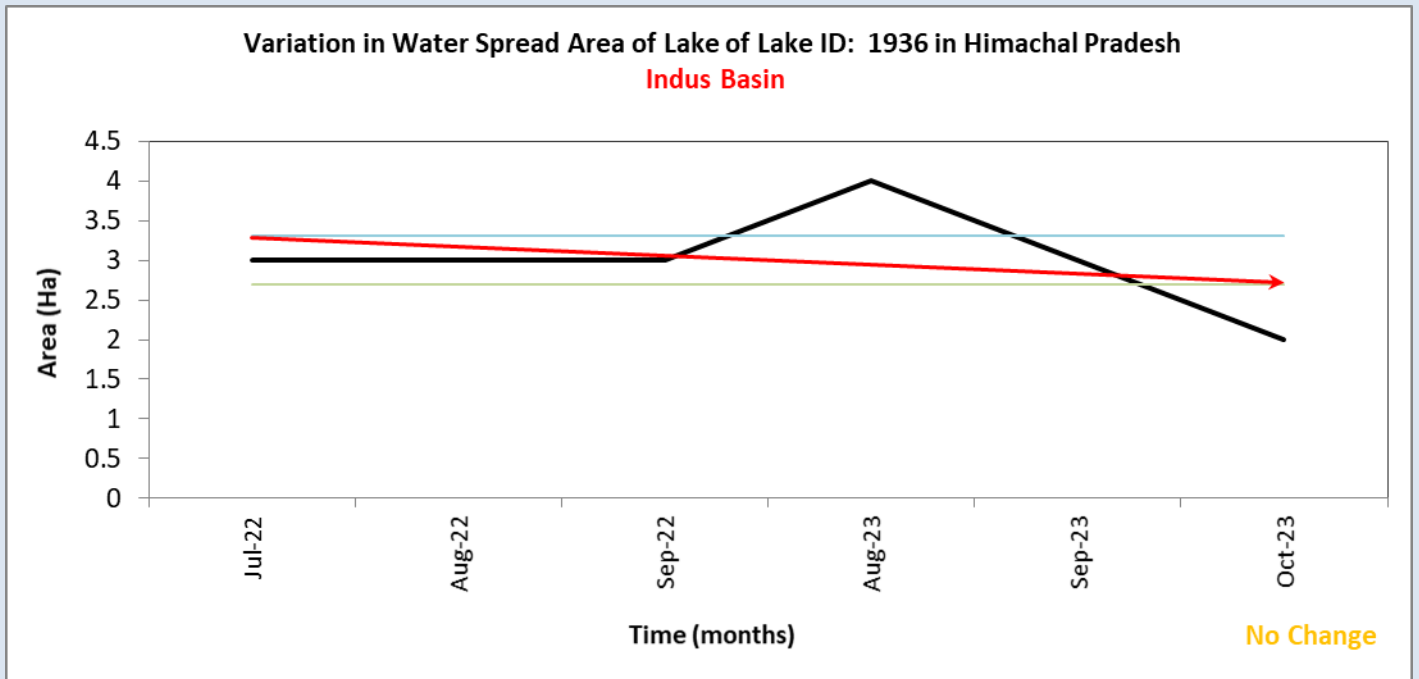


Figure 4.71(ii). Trend Analysis Plot  $\pm 20\%$

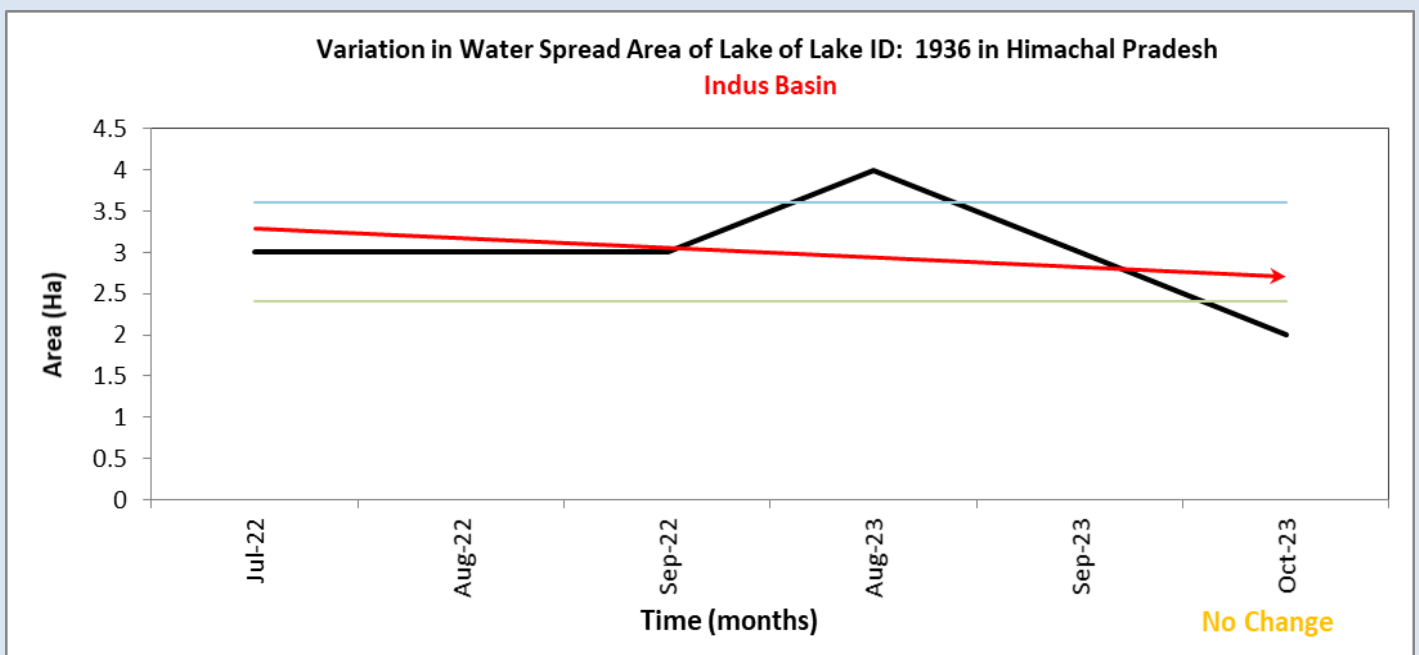


Figure 4.72(i) Trend Analysis Plot  $\pm 10\%$

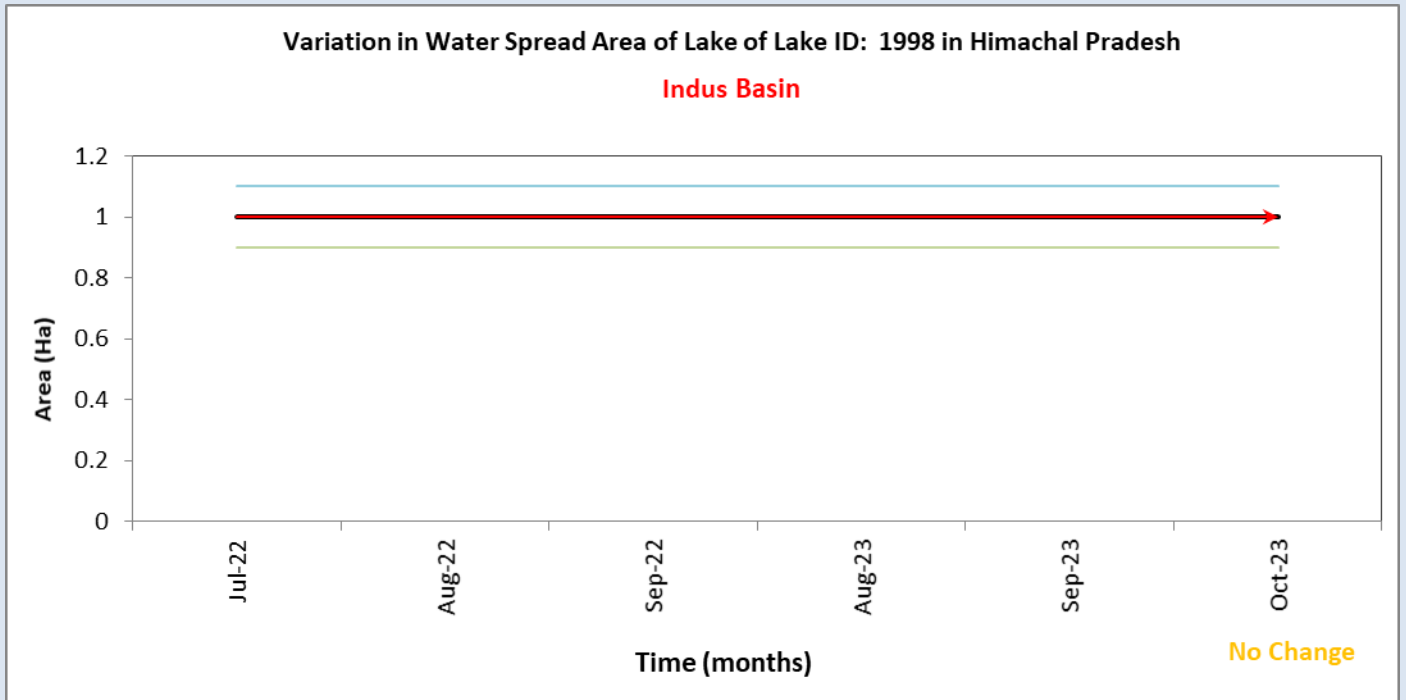


Figure 4.72(ii) Trend Analysis Plot  $\pm 20\%$

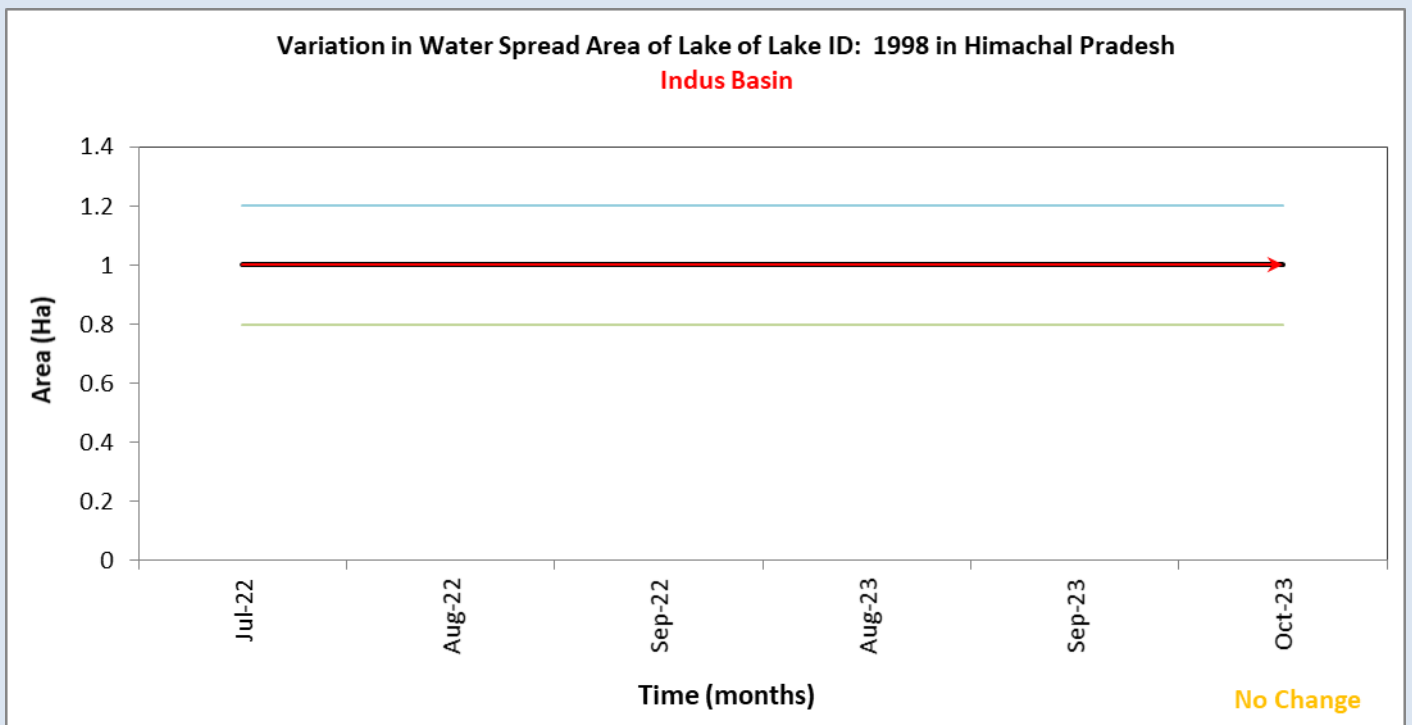


Figure 4.73(i) Trend Analysis Plot  $\pm 10\%$

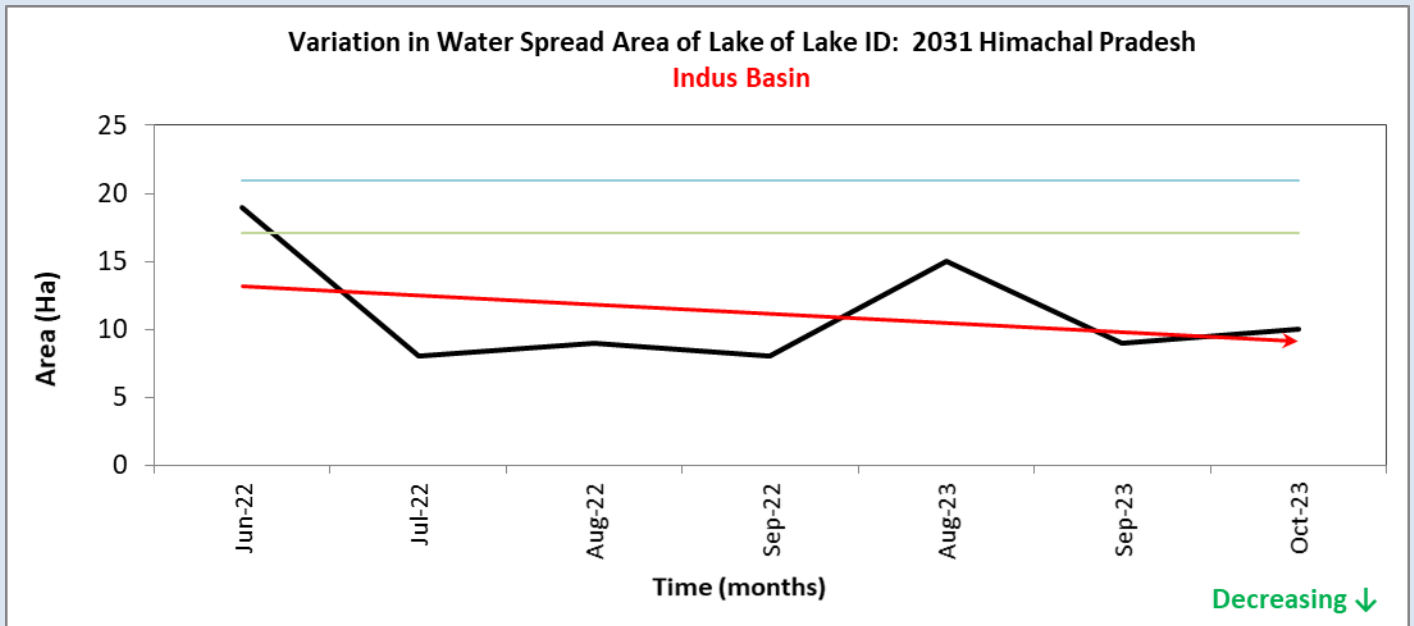
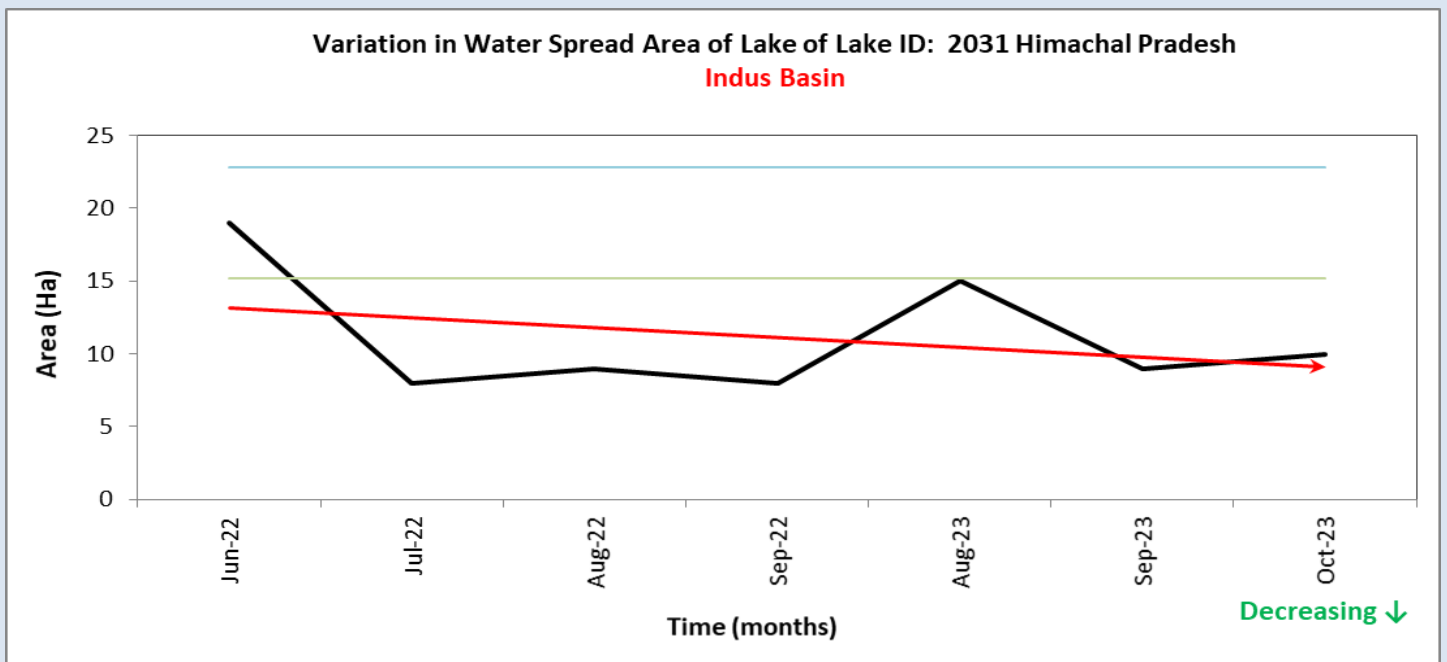


Figure 4.73(ii). Trend Analysis Plot  $\pm 20\%$



**Trend analysis of “Change in water spread area of Glacial Lakes between 10 Ha to 50 Ha of Uttarakhand (2011-2023)”**

Figure 4.74(i) Trend Analysis Plot  $\pm 10\%$

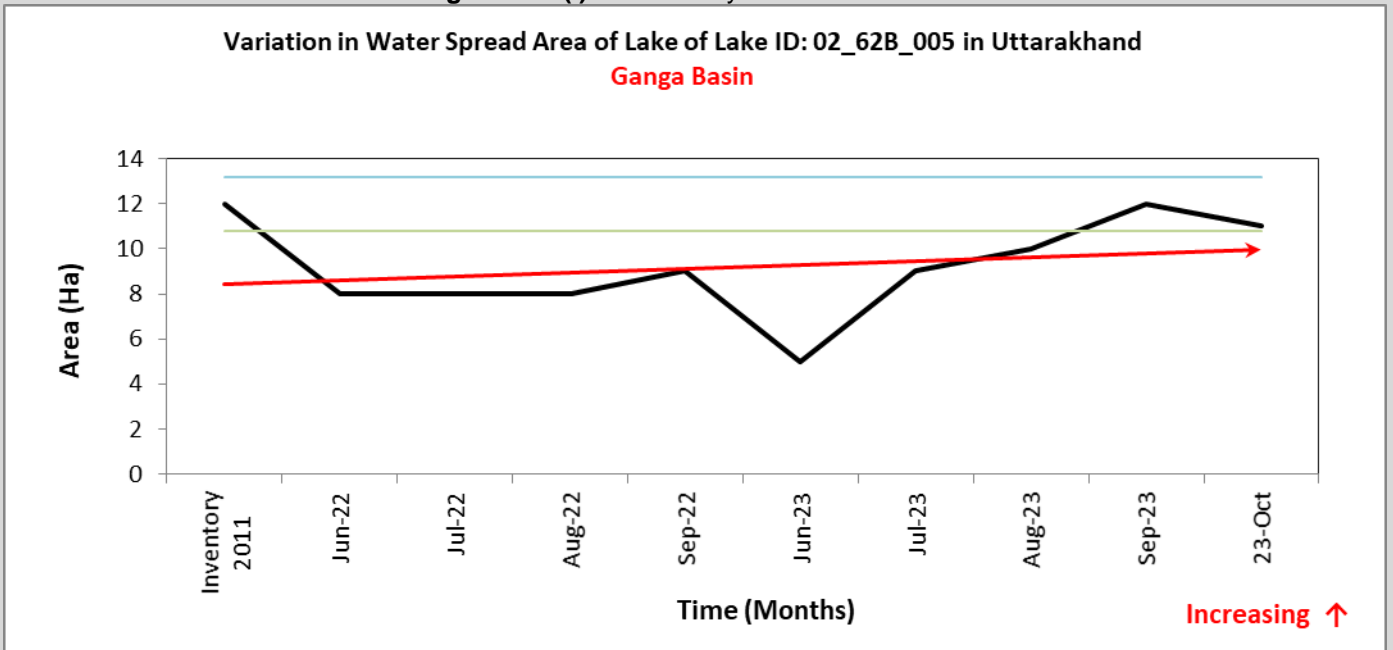


Figure 4.74(ii) Trend Analysis Plot  $\pm 20\%$

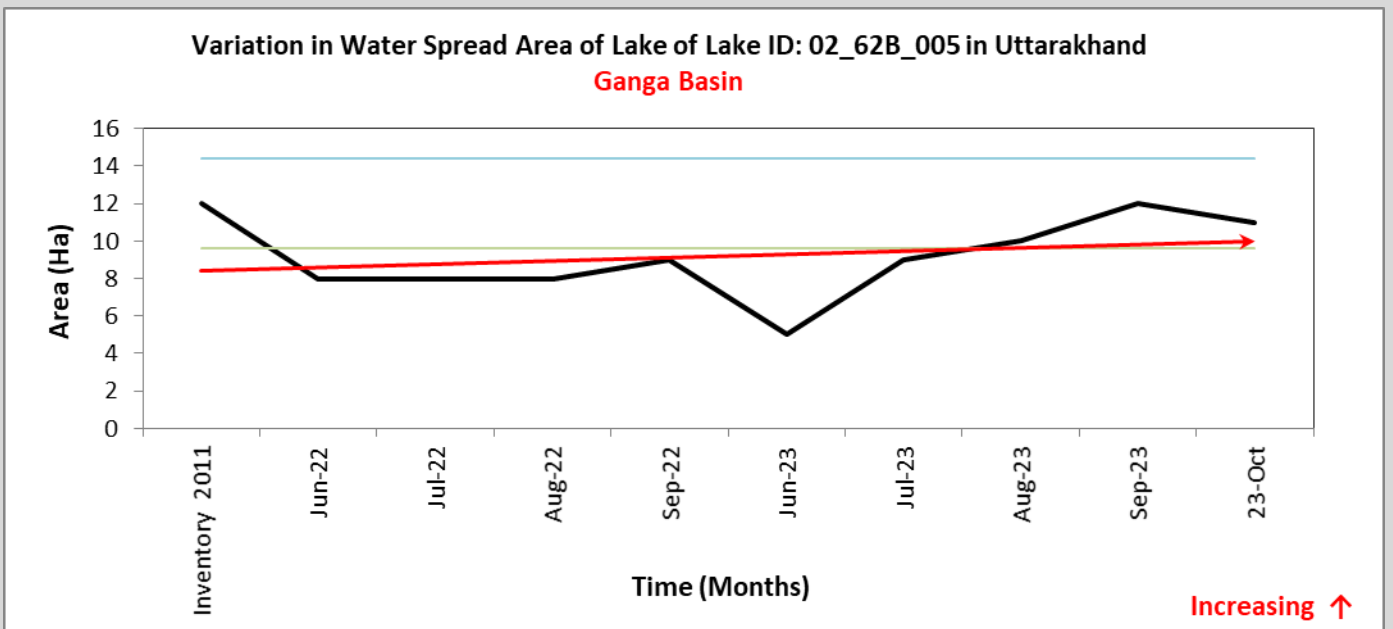


Figure 4.75(i) Trend Analysis Plot  $\pm 10\%$

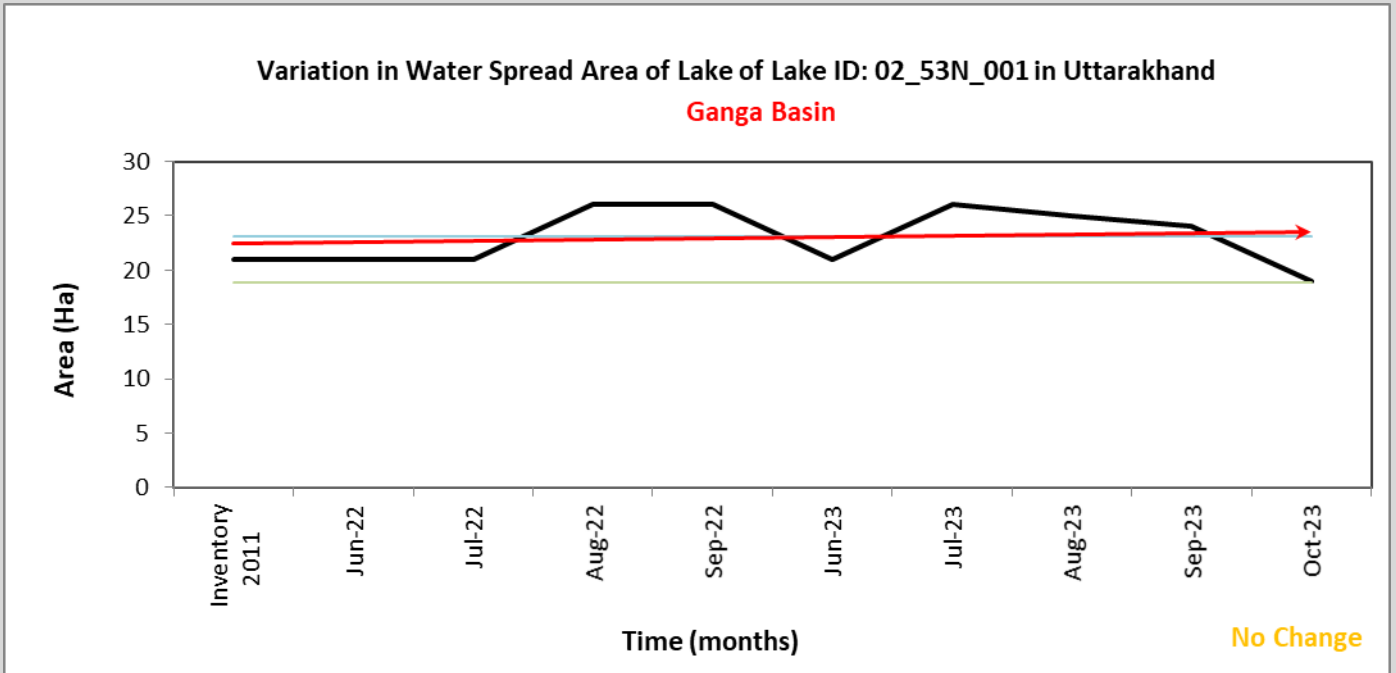


Figure 4.75(ii) Trend Analysis Plot  $\pm 20\%$

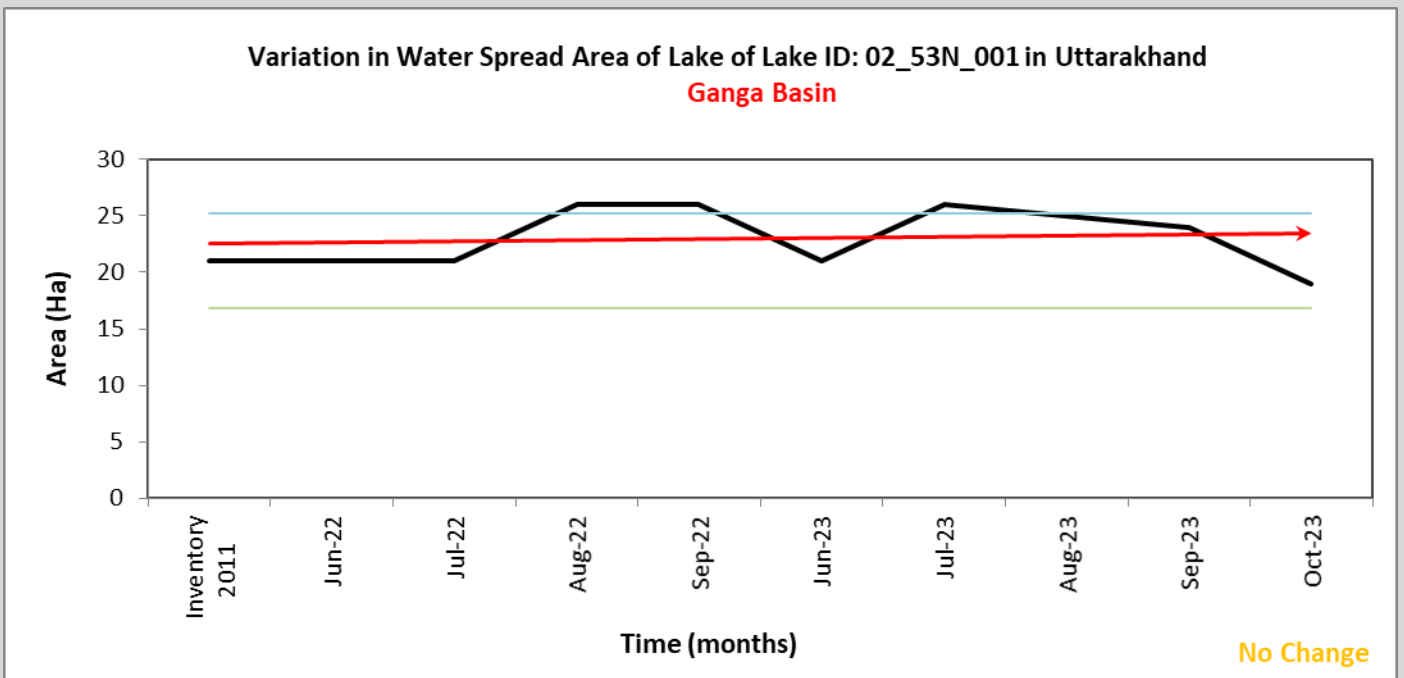


Figure 4.76(i) Trend Analysis Plot  $\pm 10\%$

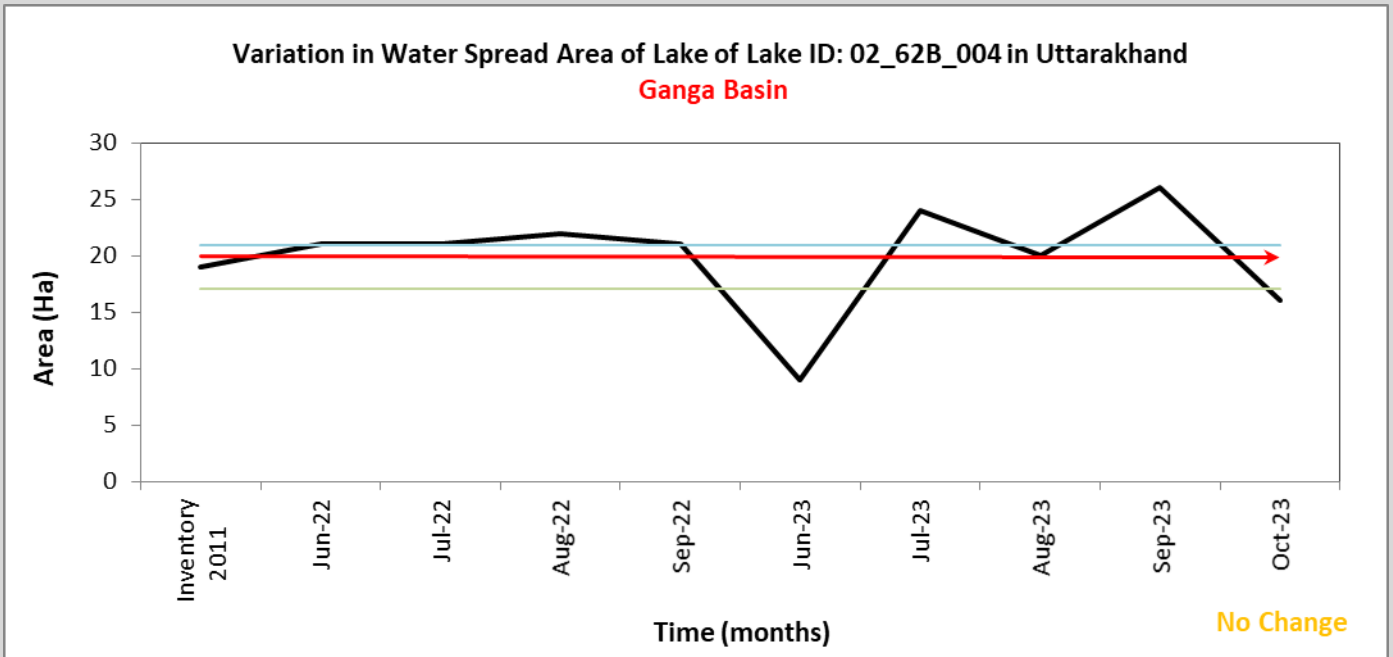


Figure 4.76(ii) Trend Analysis Plot  $\pm 20\%$

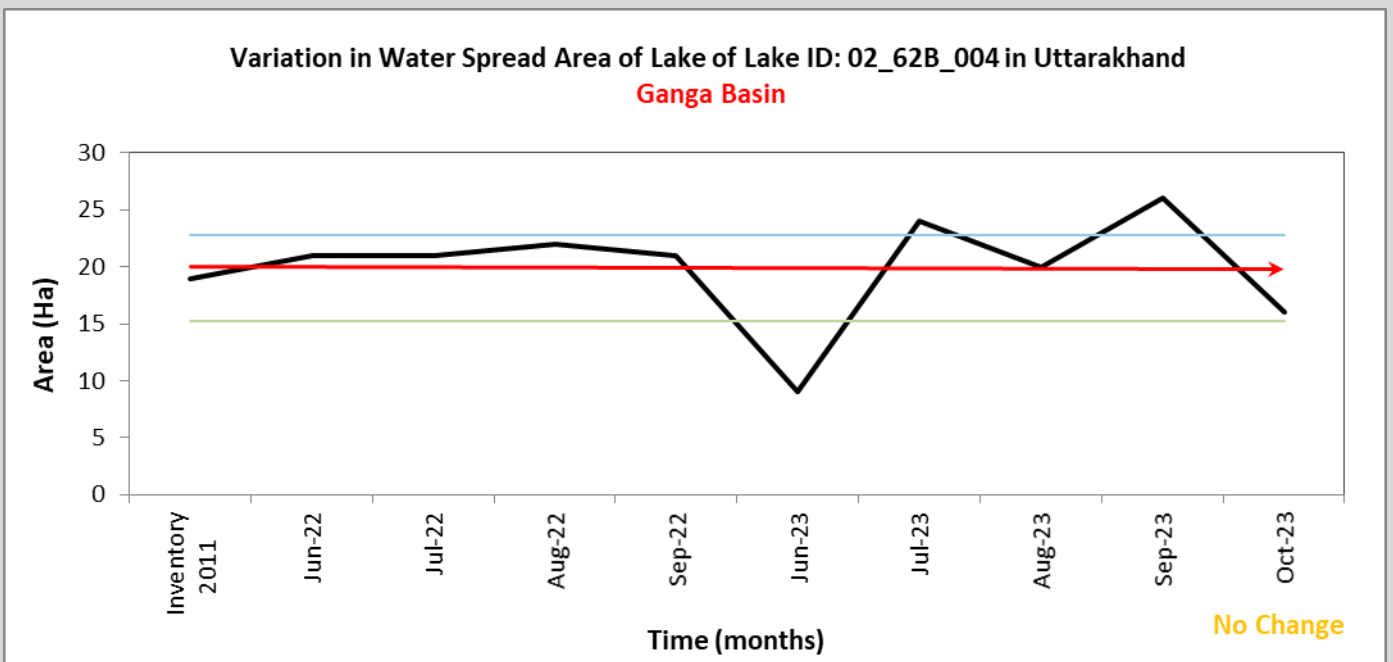


Figure 4.77(i) Trend Analysis Plot  $\pm 10\%$

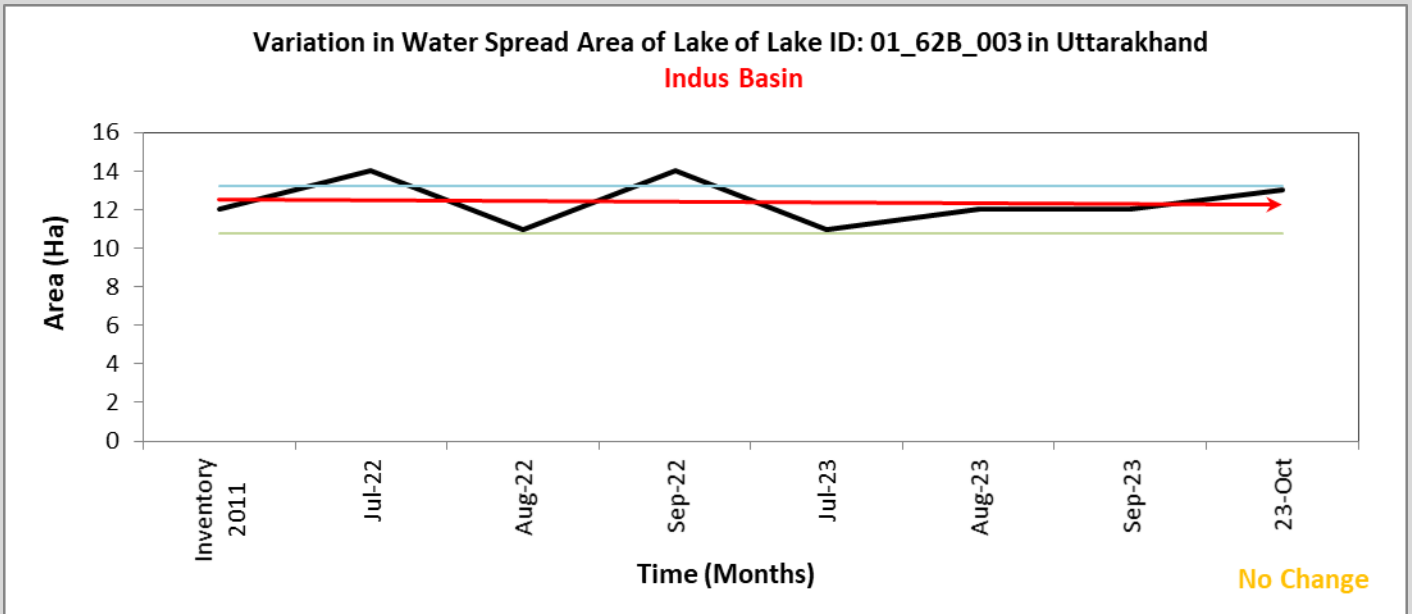
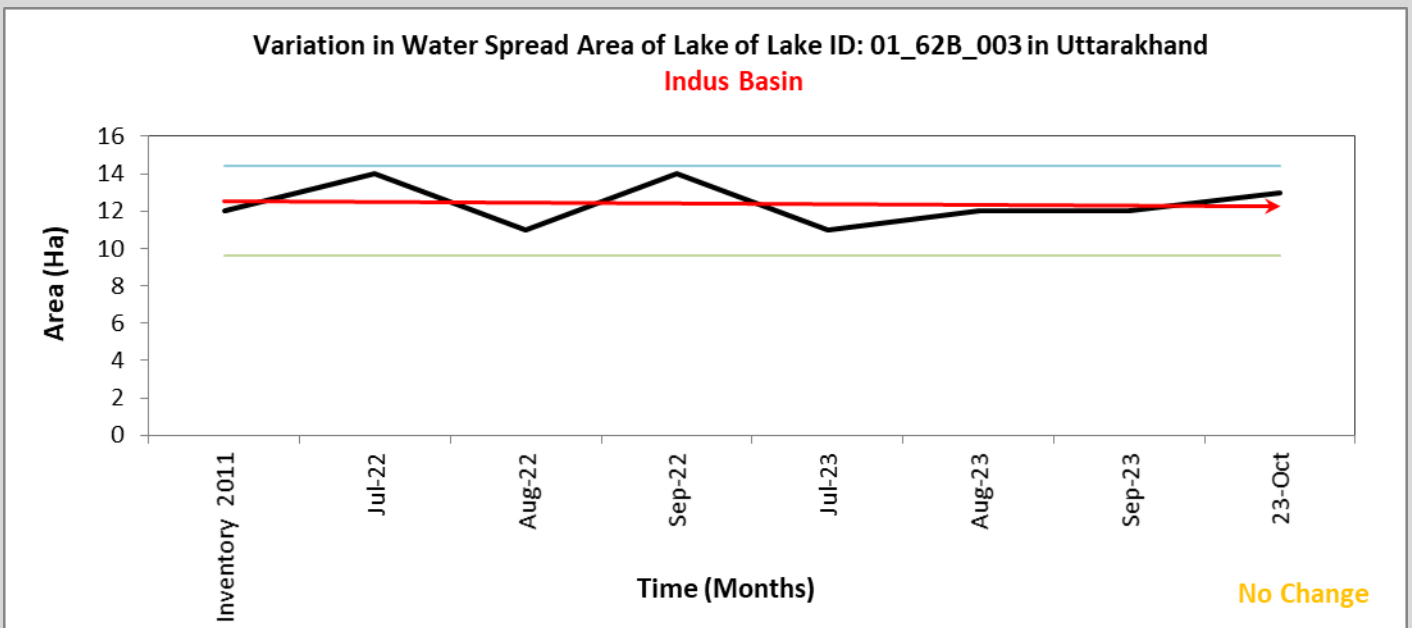
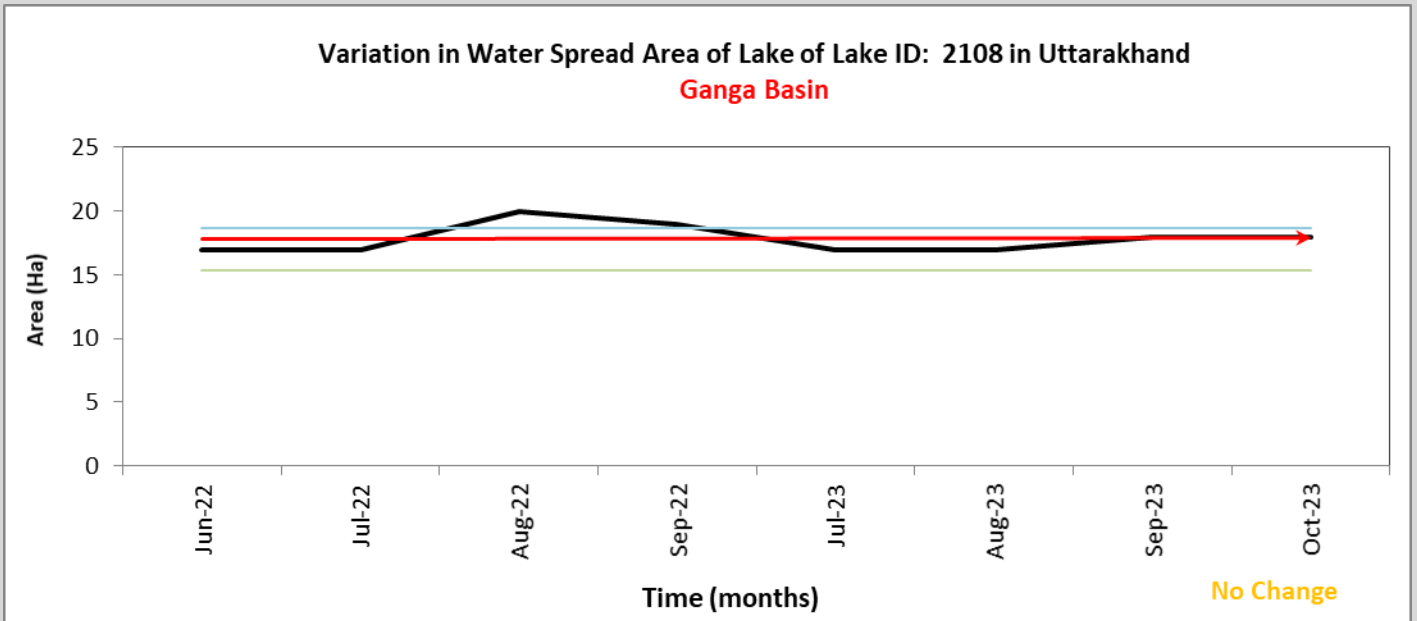


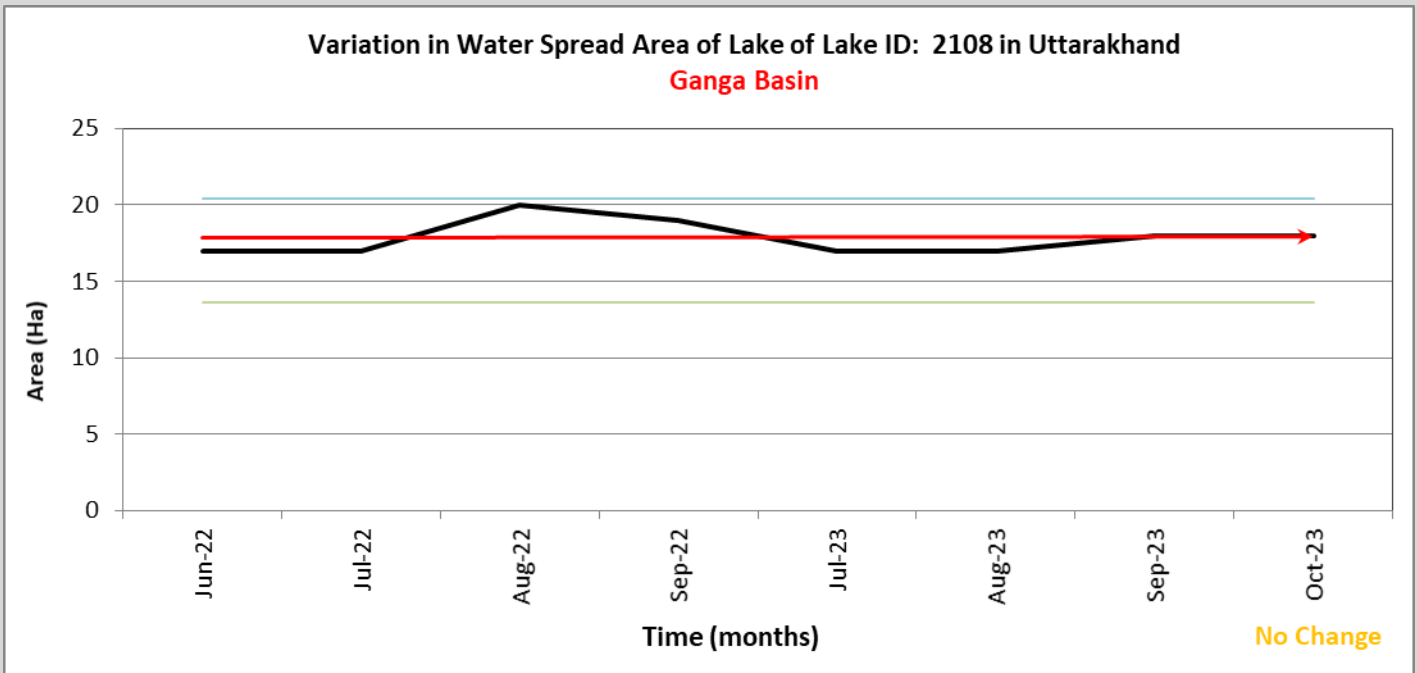
Figure 4.77(ii) Trend Analysis Plot  $\pm 20\%$



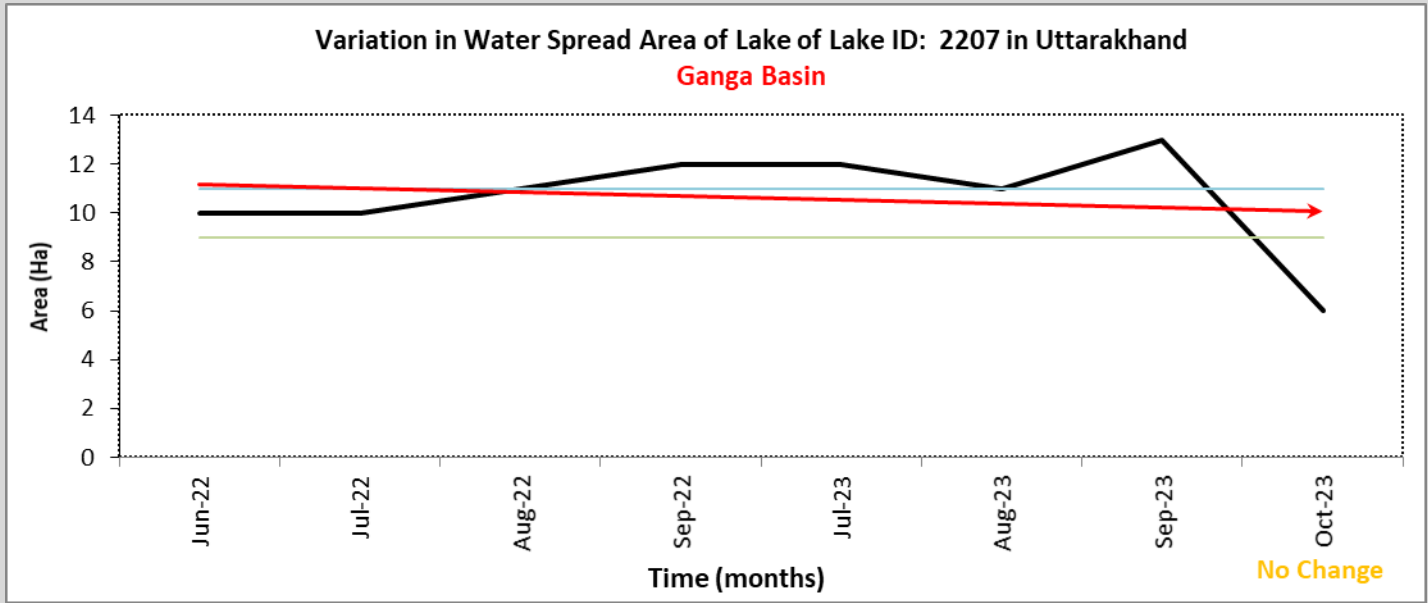
**Figure 4.78(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.78(ii)** Trend Analysis Plot  $\pm 20\%$



**Figure 4.79(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.79(ii)** Trend Analysis Plot  $\pm 20\%$

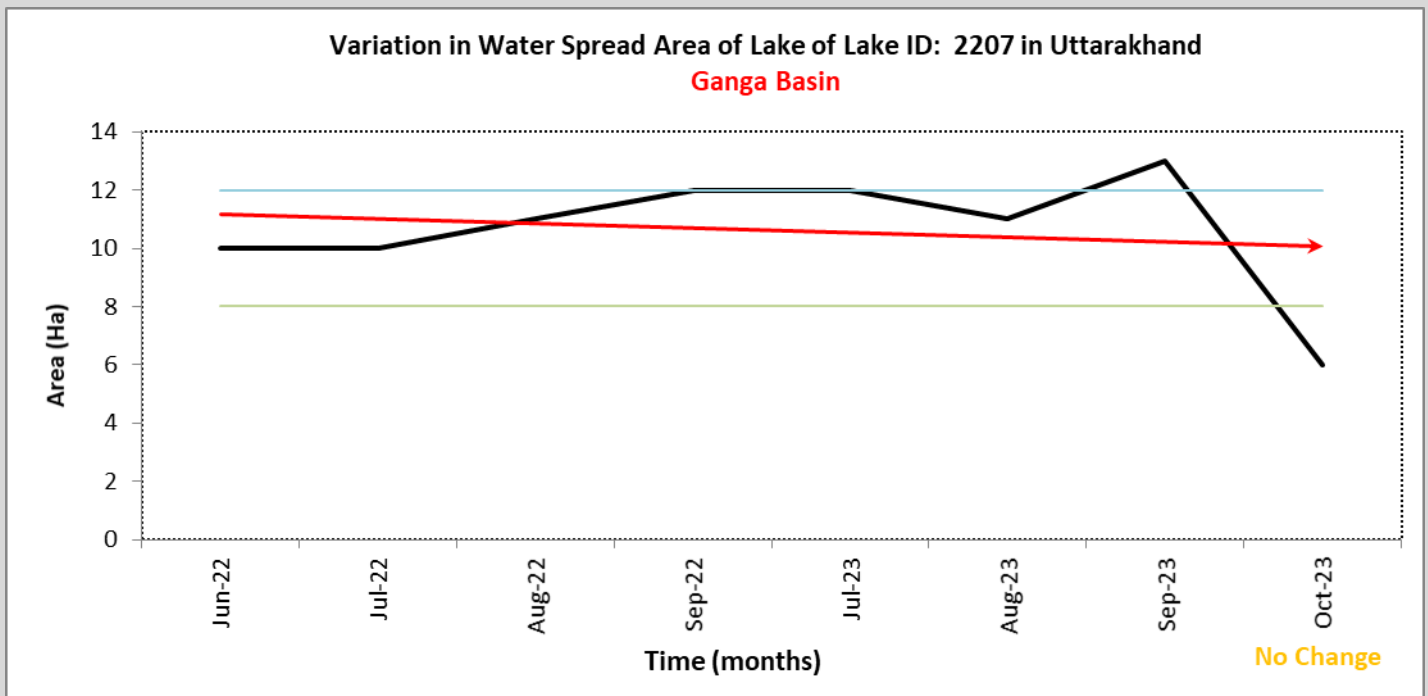


Figure 4.80(i) Trend Analysis Plot  $\pm 10\%$

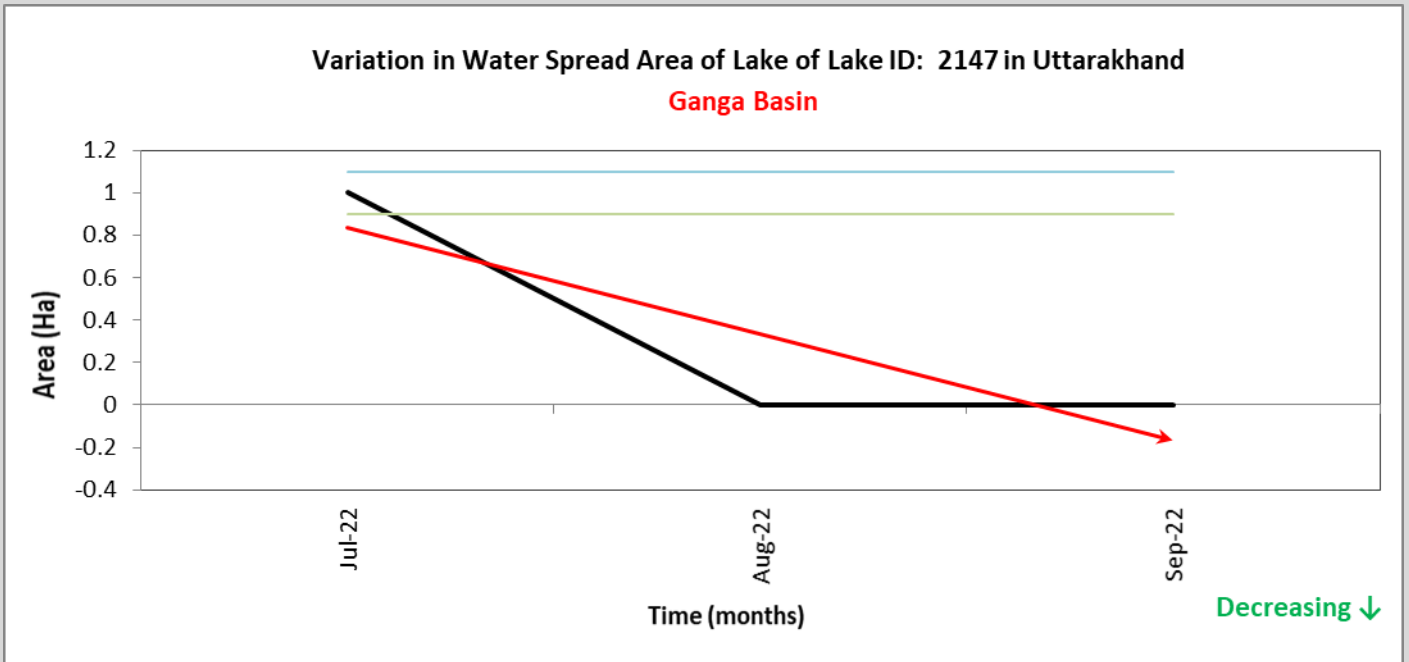
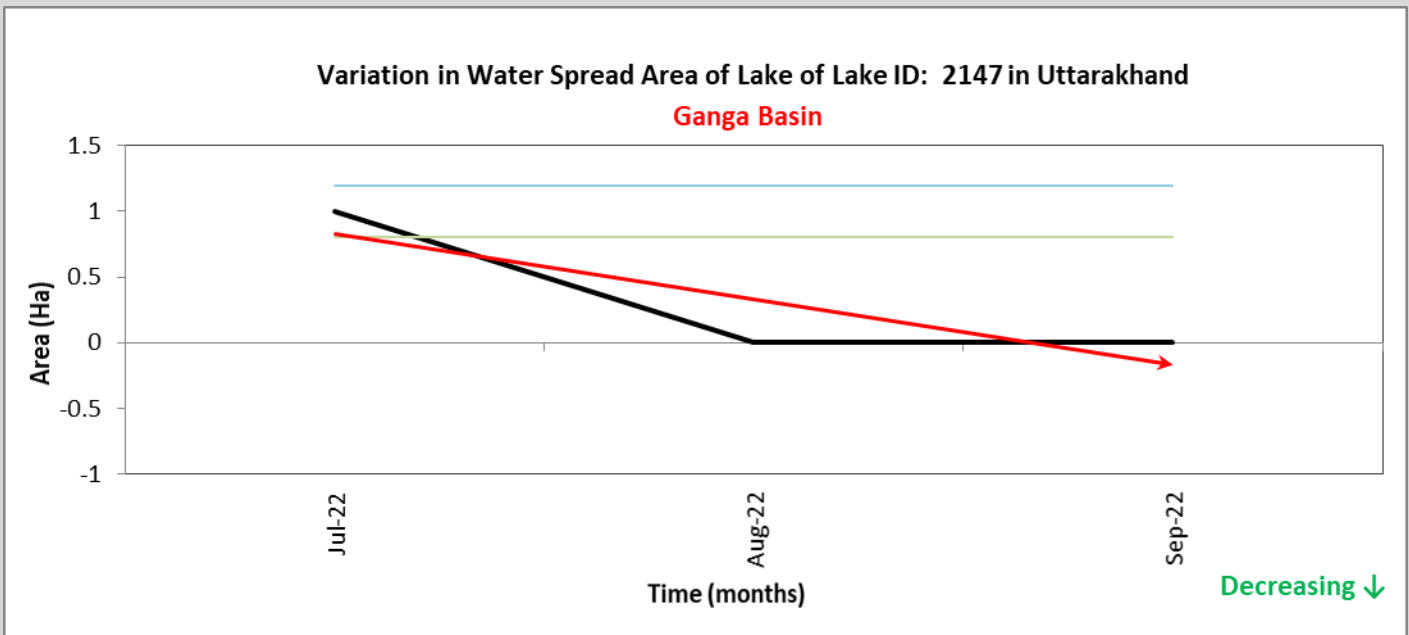


Figure 4.80(ii) Trend Analysis Plot  $\pm 20\%$



**Trend analysis of “Change in water spread area of Glacial Lakes between  
10 Ha to 50 Ha of Sikkim (2011-2023)”**

Figure 4.81(i) Trend Analysis Plot  $\pm 10\%$

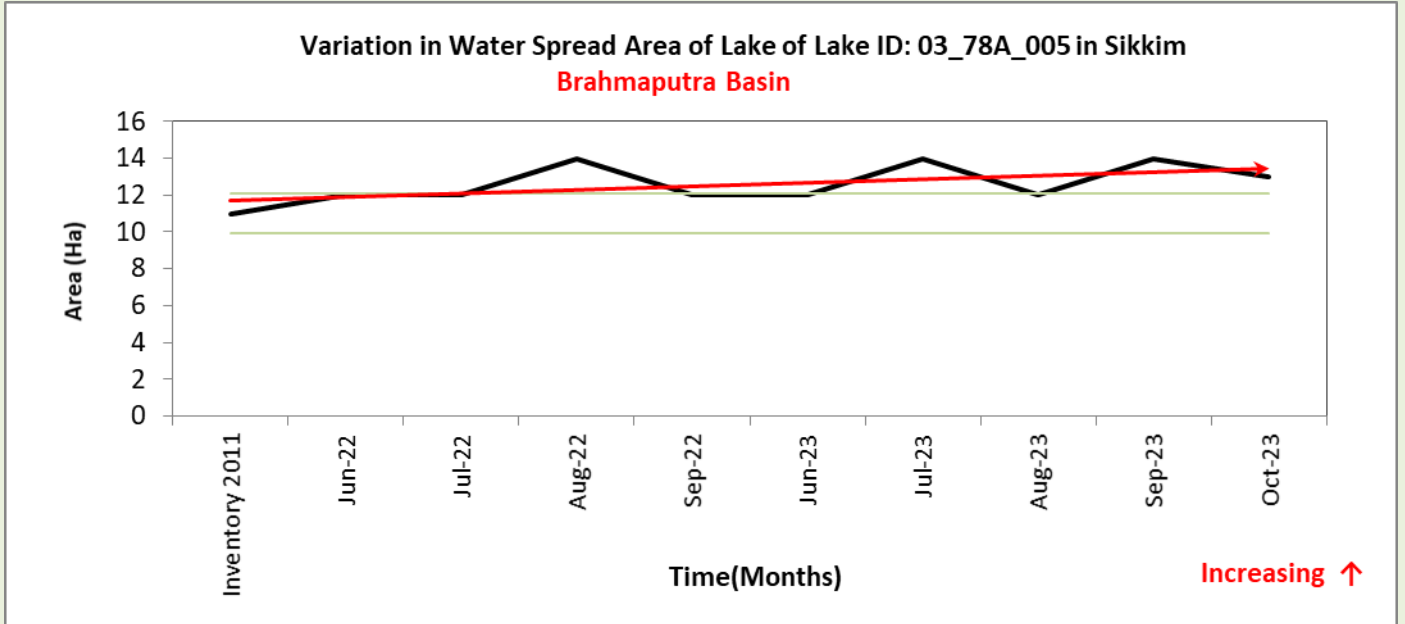


Figure 4.81(ii). Trend Analysis Plot  $\pm 20\%$

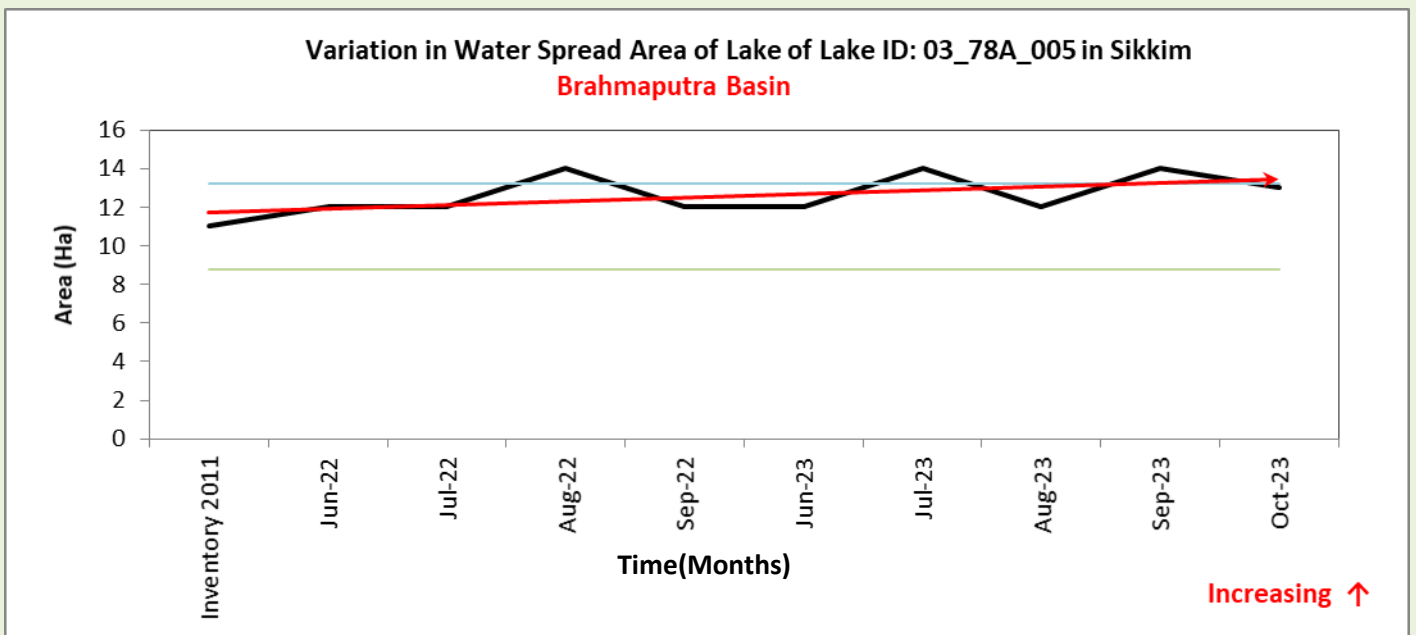


Figure 4.82(i) Trend Analysis Plot  $\pm 10\%$

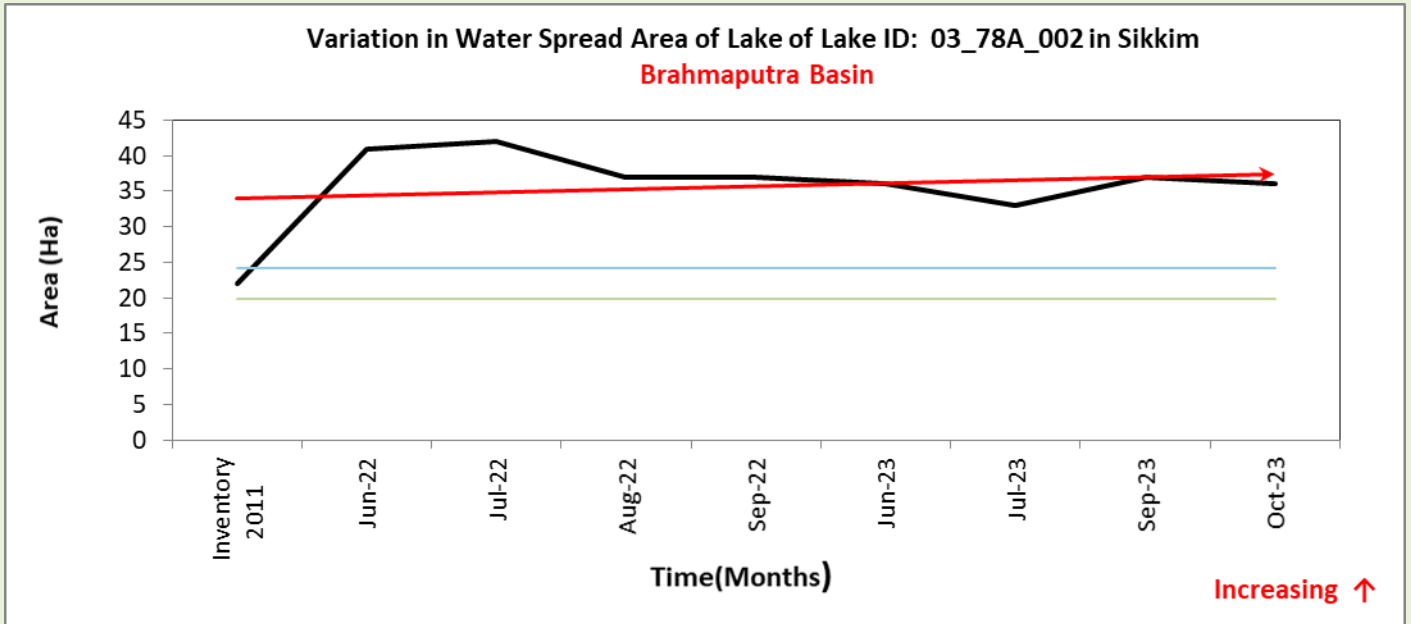


Figure 4.82(ii) Trend Analysis Plot  $\pm 20\%$

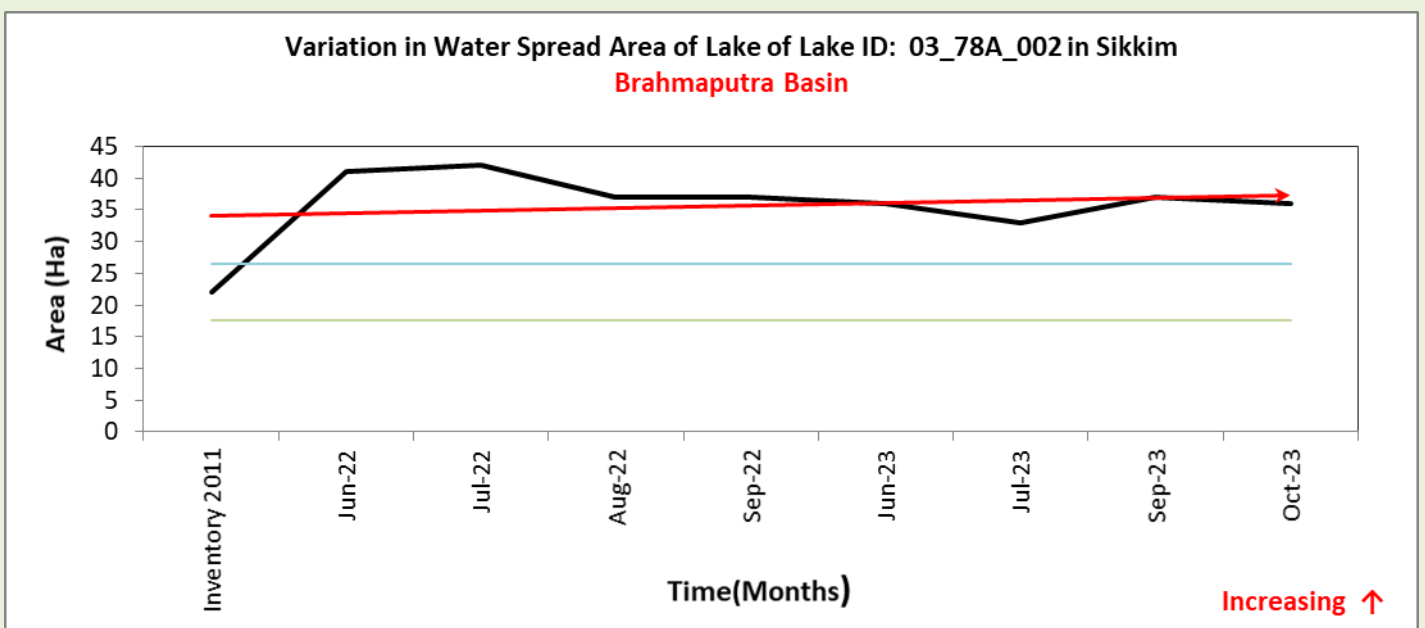


Figure 4.83(i) Trend Analysis Plot  $\pm 10\%$

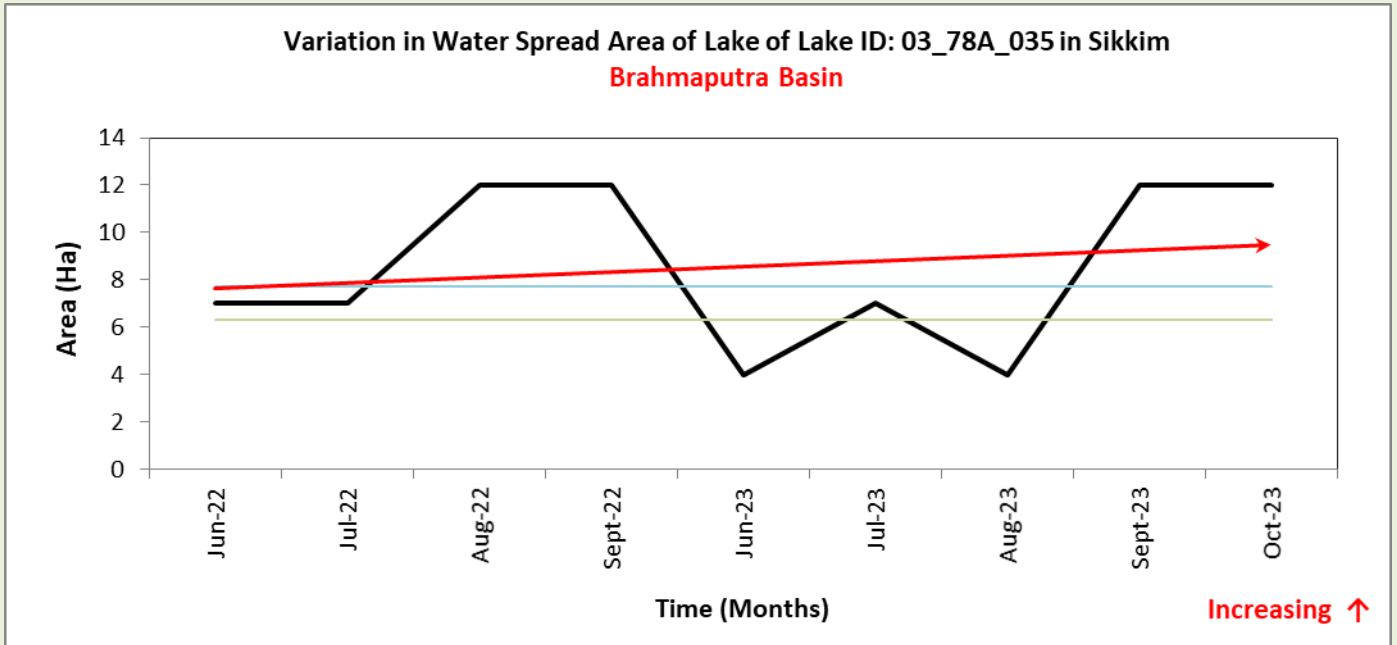


Figure 4.83(ii) Trend Analysis Plot  $\pm 20\%$

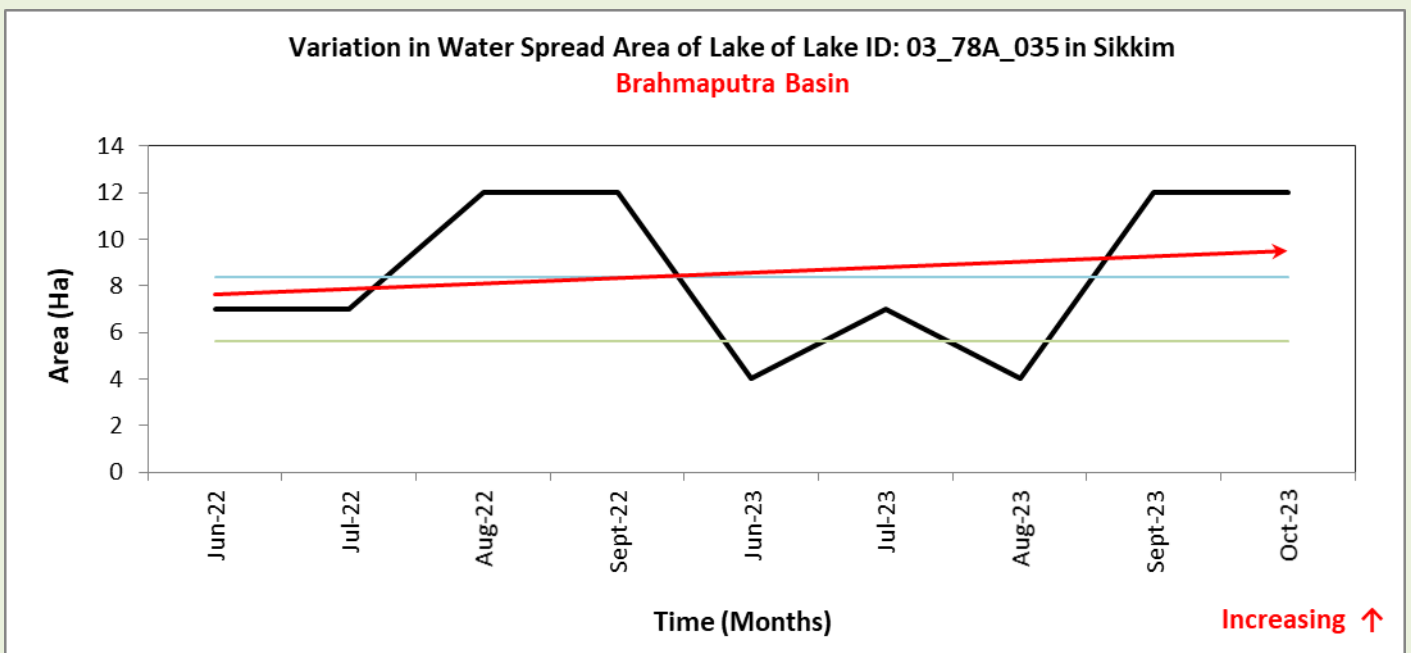


Figure 4.84(i) Trend Analysis Plot  $\pm 10\%$

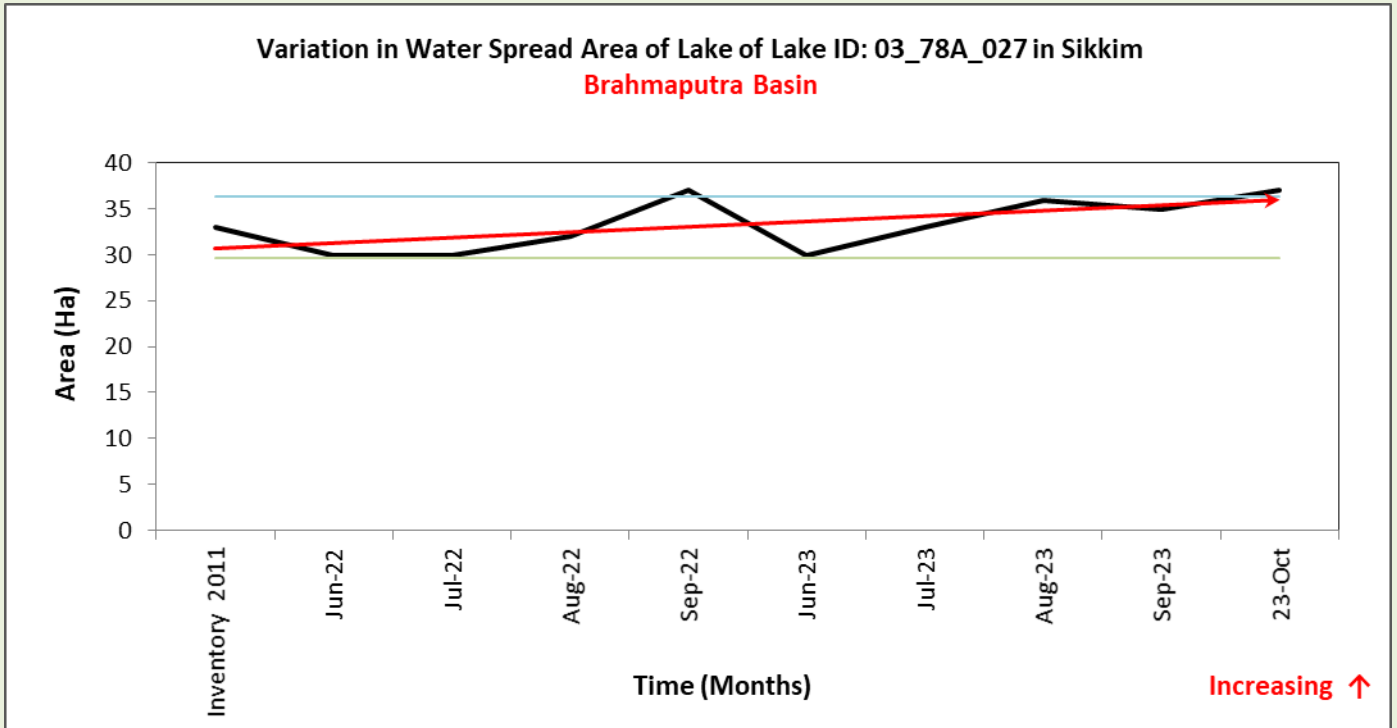


Figure 4.84(ii) Trend Analysis Plot  $\pm 20\%$

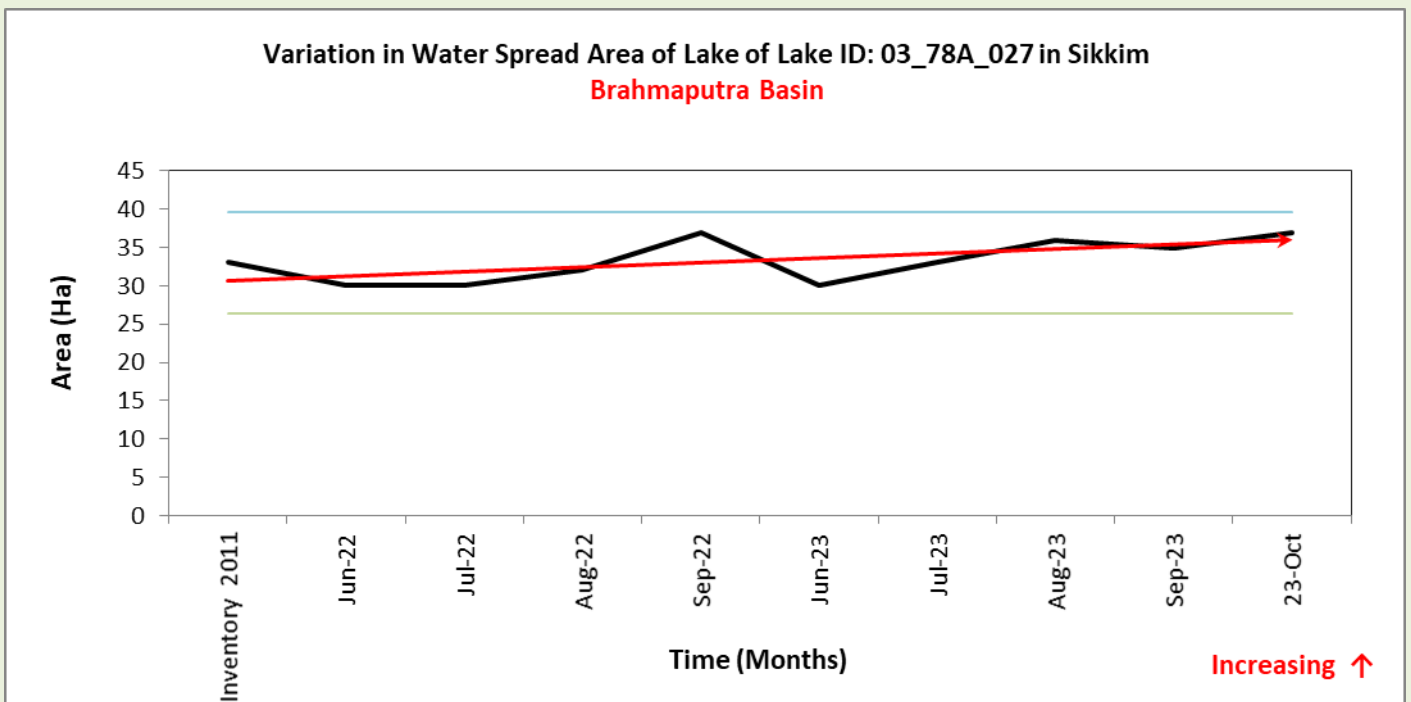


Figure 4.85(i) Trend Analysis Plot  $\pm 10\%$

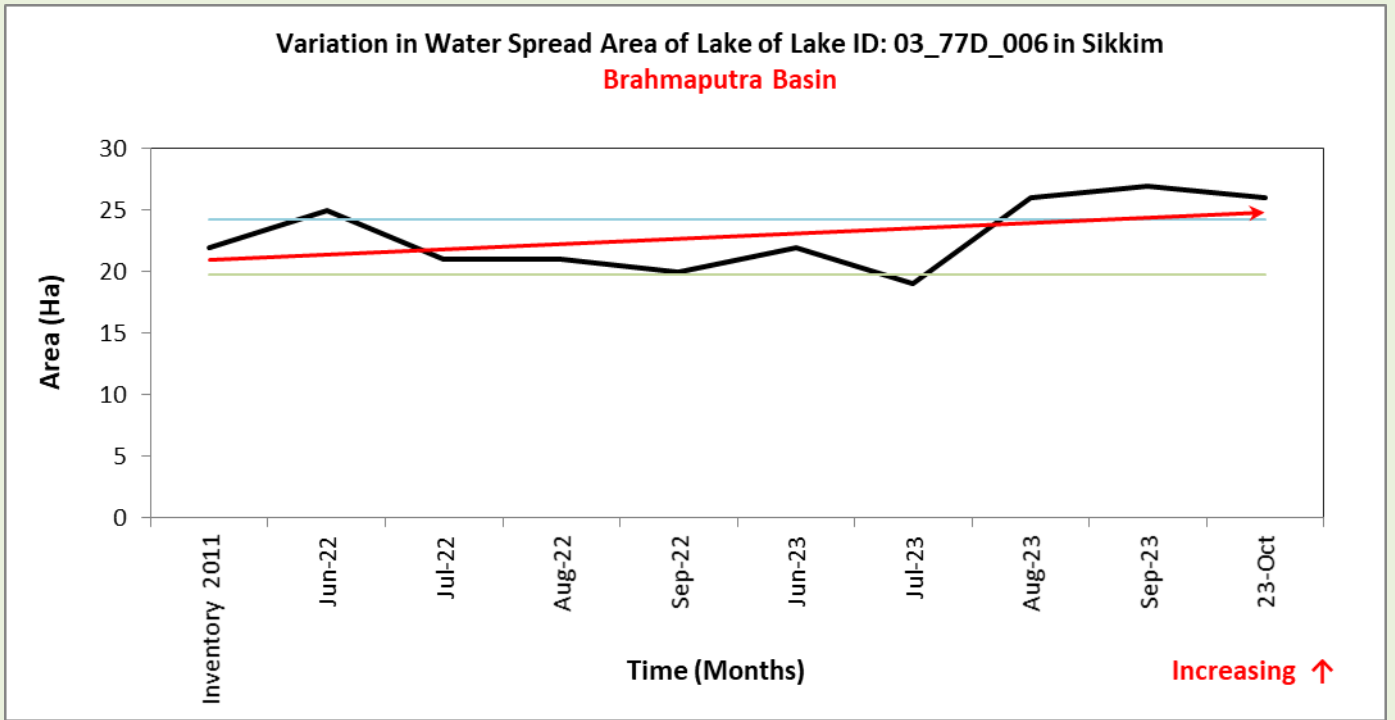


Figure 4.85(ii) Trend Analysis Plot  $\pm 10\%$

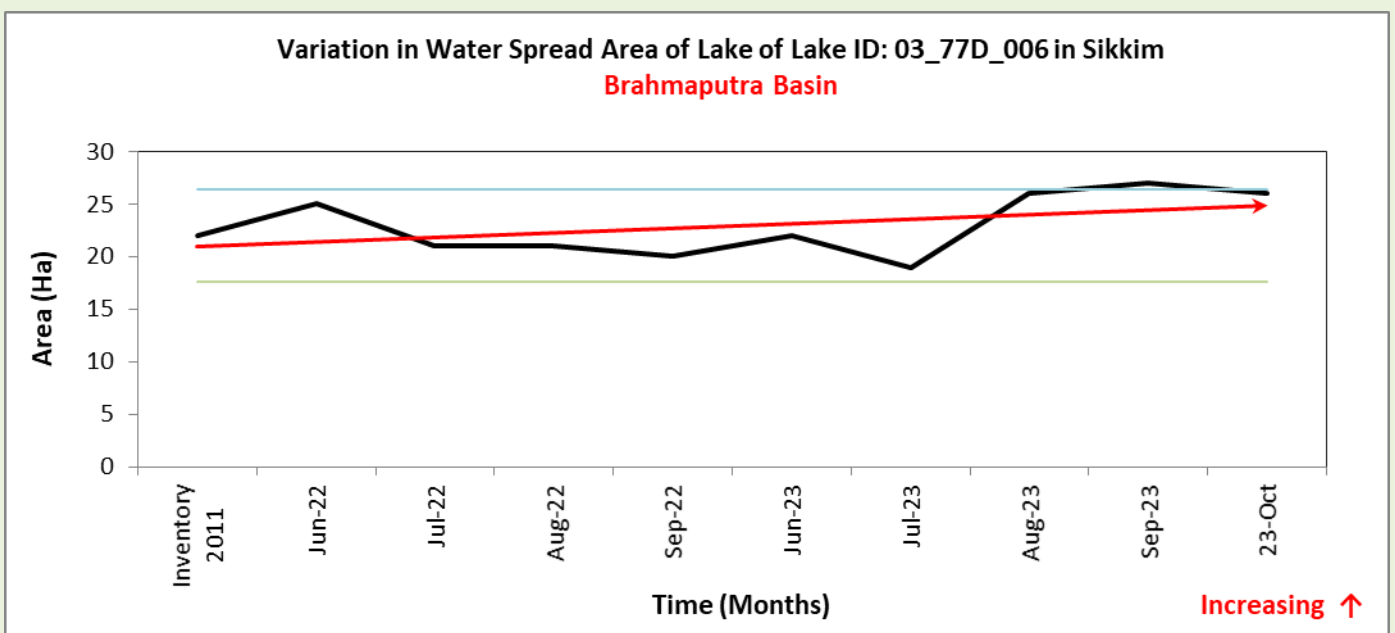


Figure 4.86(i) Trend Analysis Plot  $\pm 10\%$

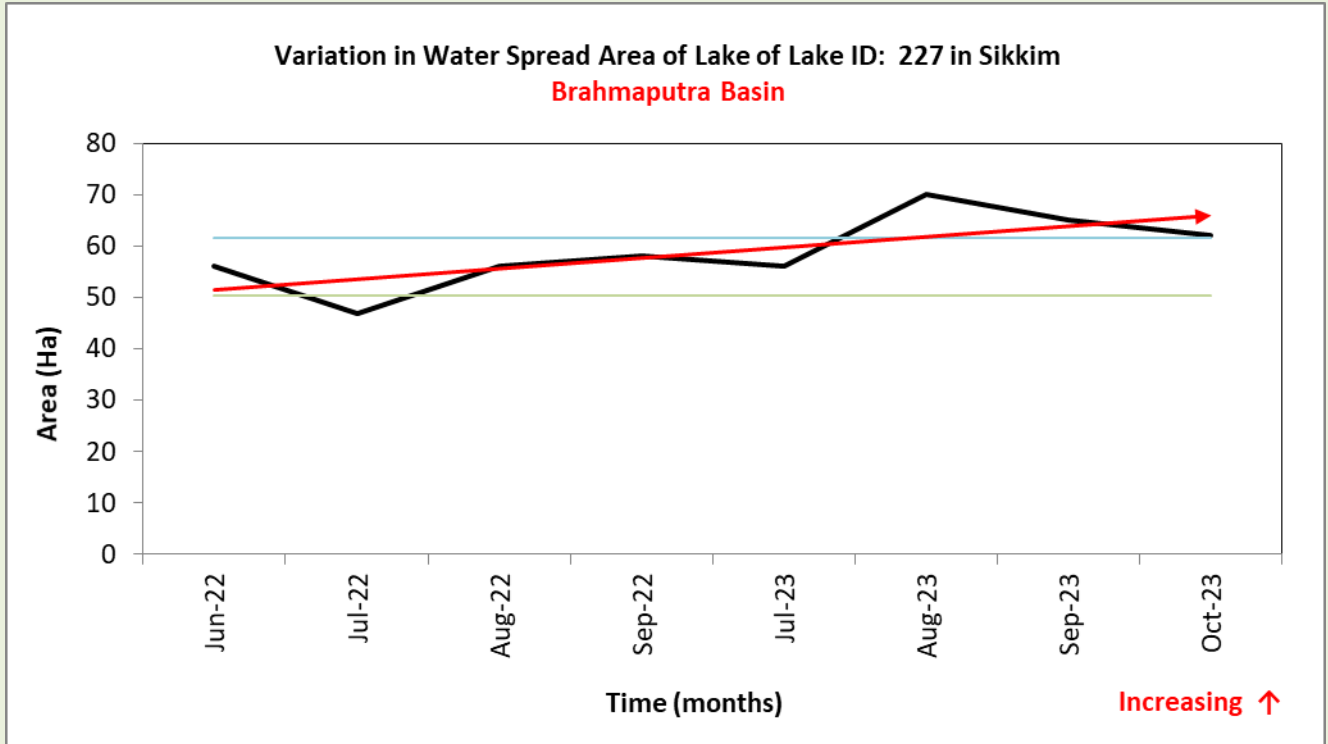


Figure 4.86(ii) Trend Analysis Plot  $\pm 20\%$

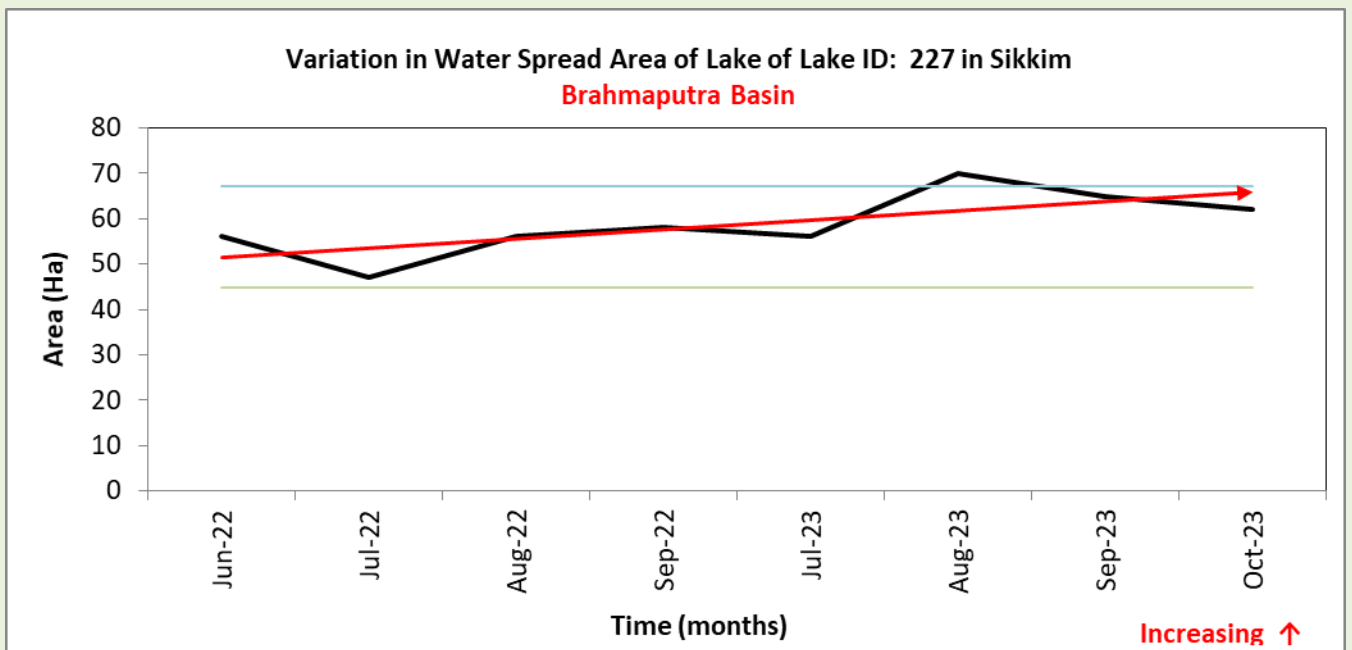


Figure 4.87(i) Trend Analysis Plot  $\pm 10\%$

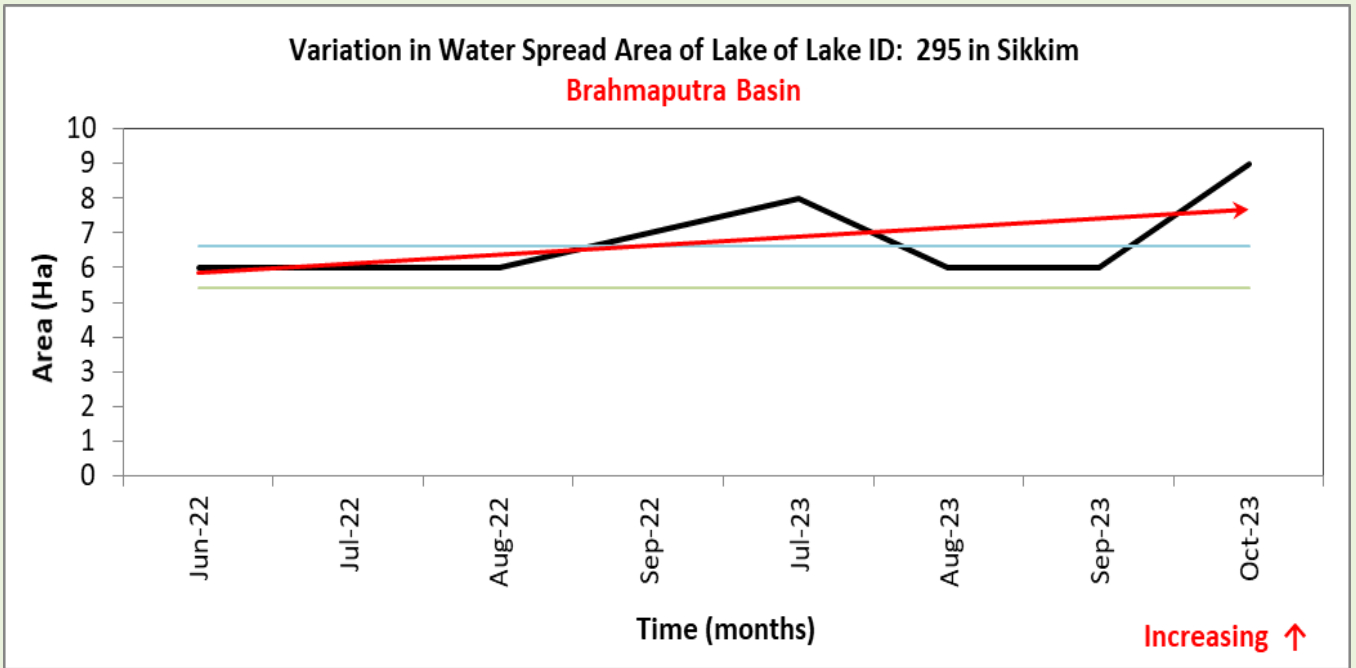


Figure 4.87(ii) Trend Analysis Plot  $\pm 10\%$

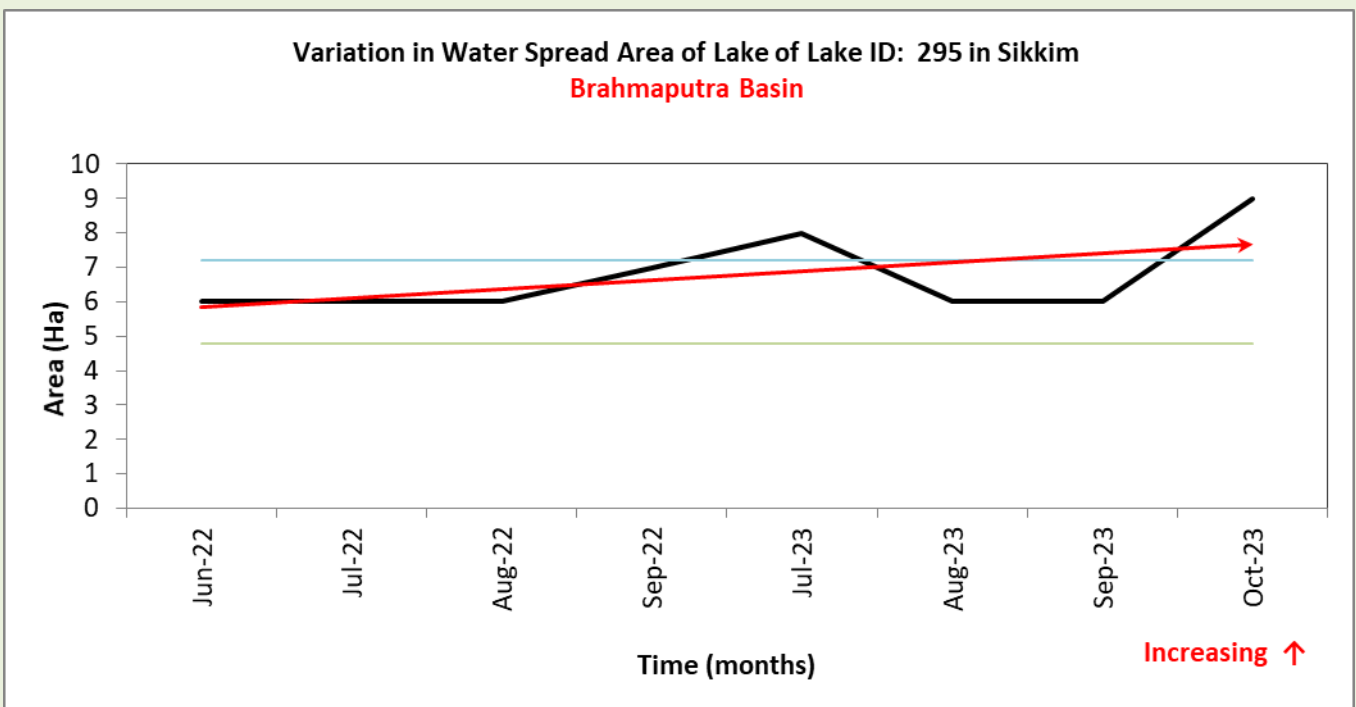


Figure 4.88(i) Trend Analysis Plot  $\pm 10\%$

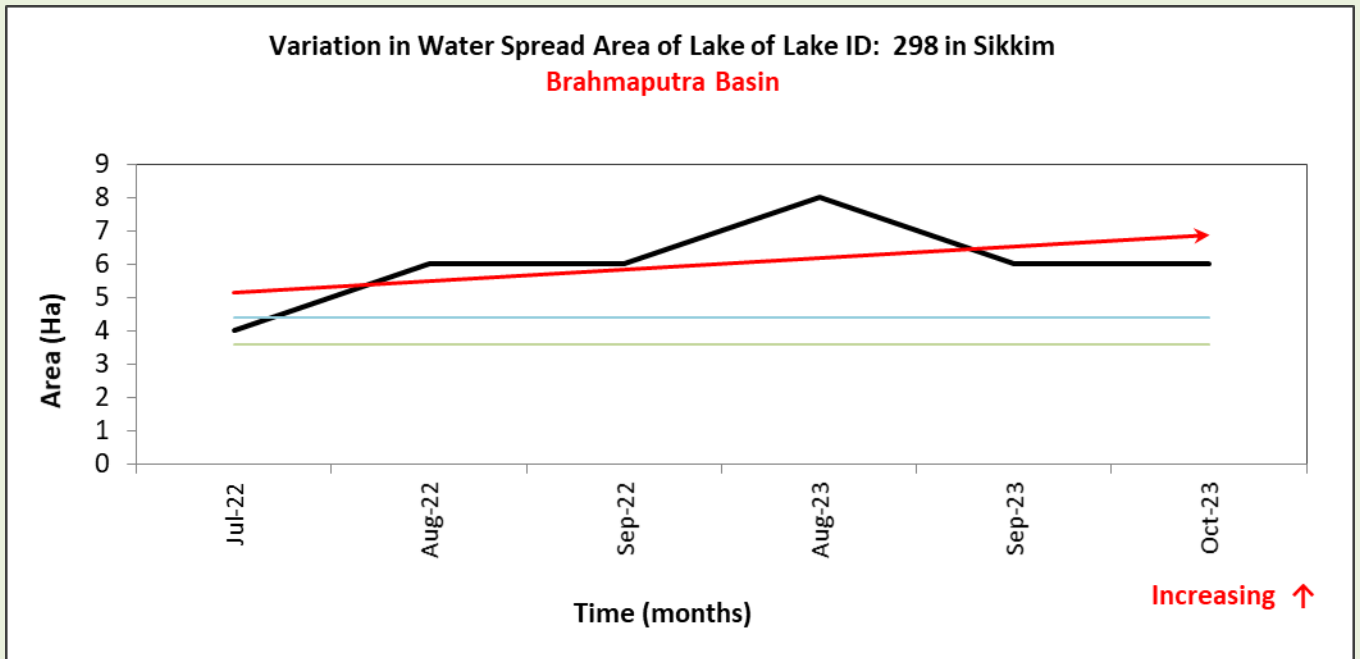


Figure 4.88(ii) Trend Analysis Plot  $\pm 20\%$

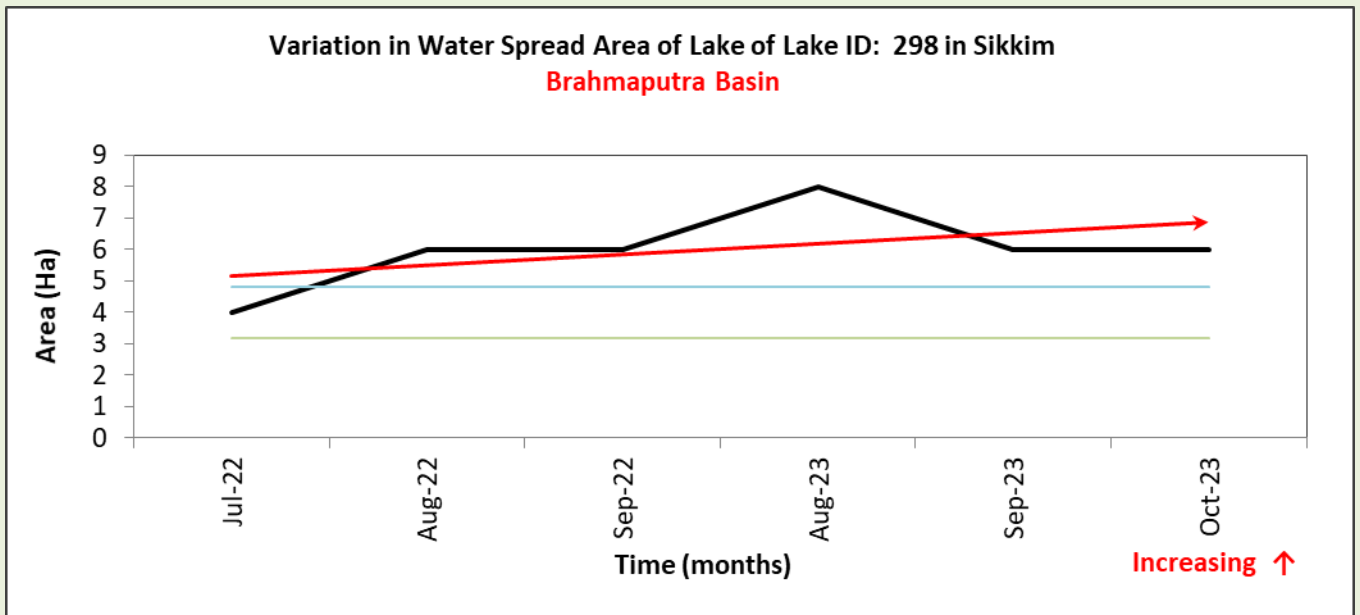


Figure 4.89(i) Trend Analysis Plot  $\pm 10\%$

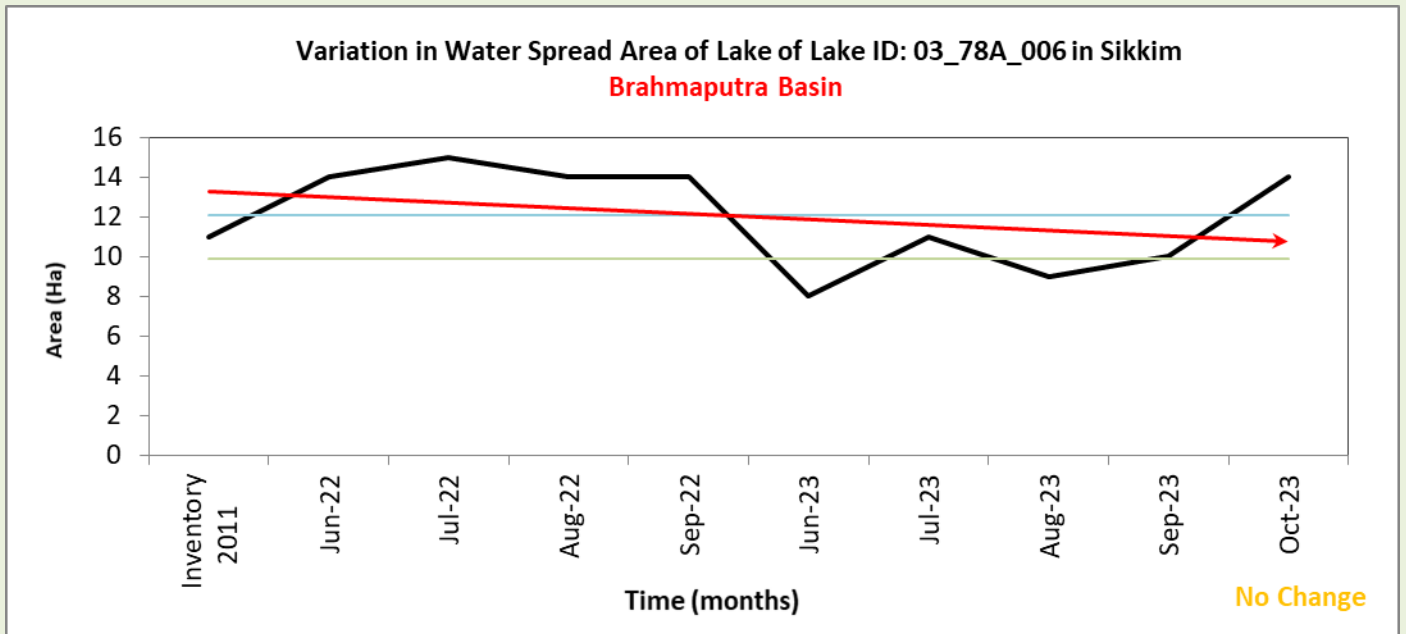


Figure 4.89(ii) Trend Analysis Plot  $\pm 20\%$

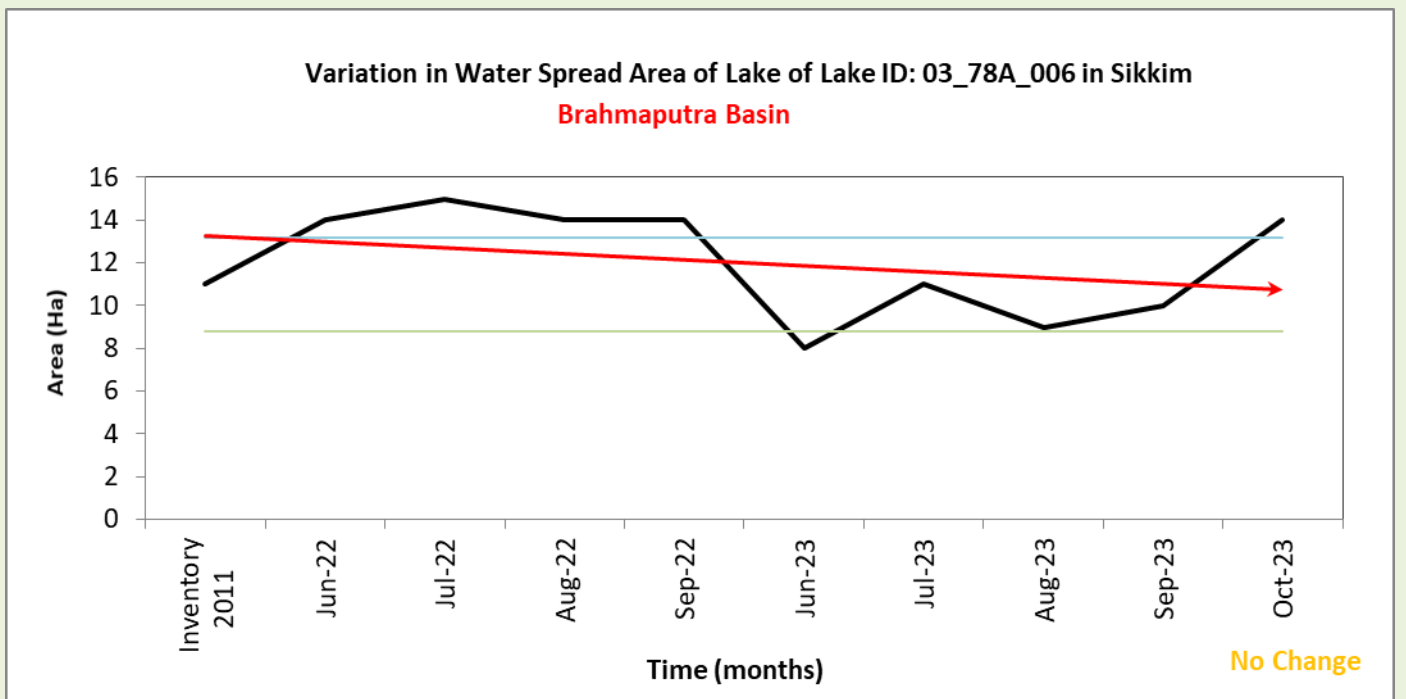


Figure 4.90(i) Trend Analysis Plot  $\pm 10\%$

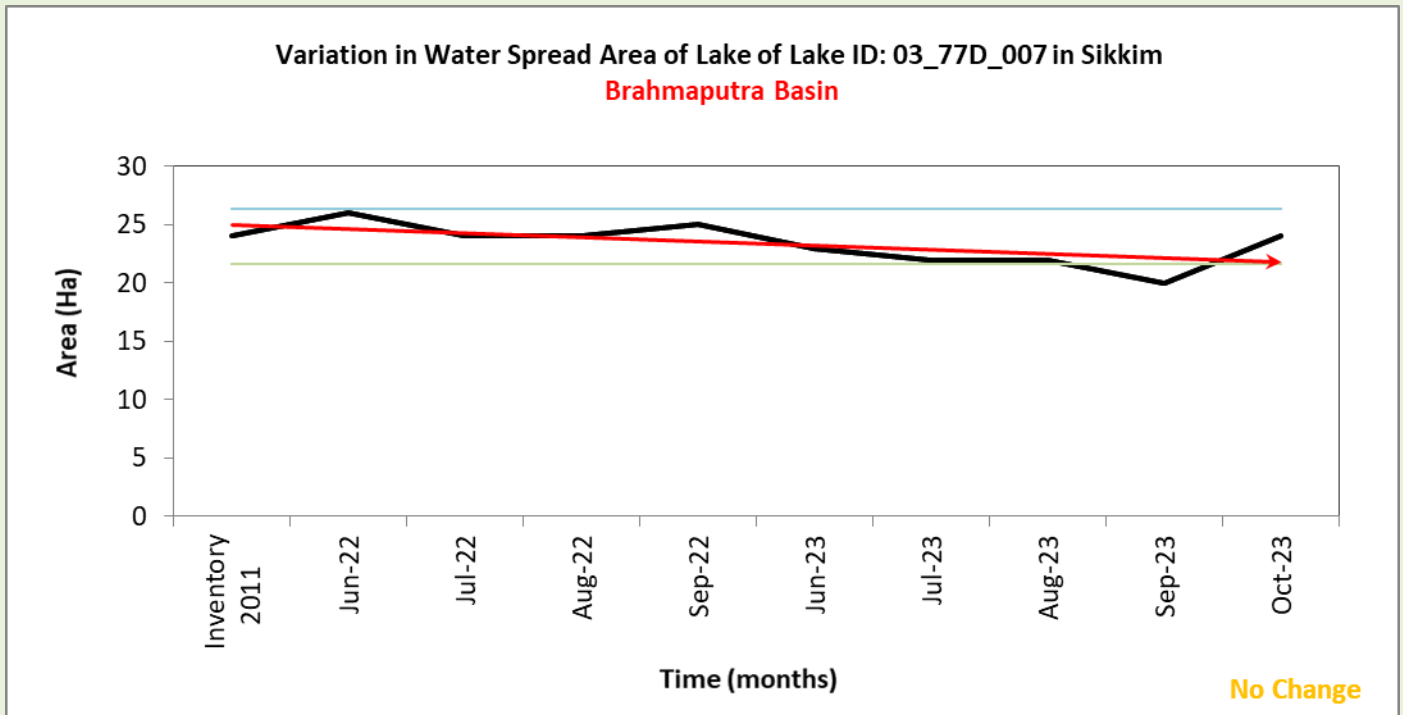


Figure 4.90(ii) Trend Analysis Plot  $\pm 20\%$

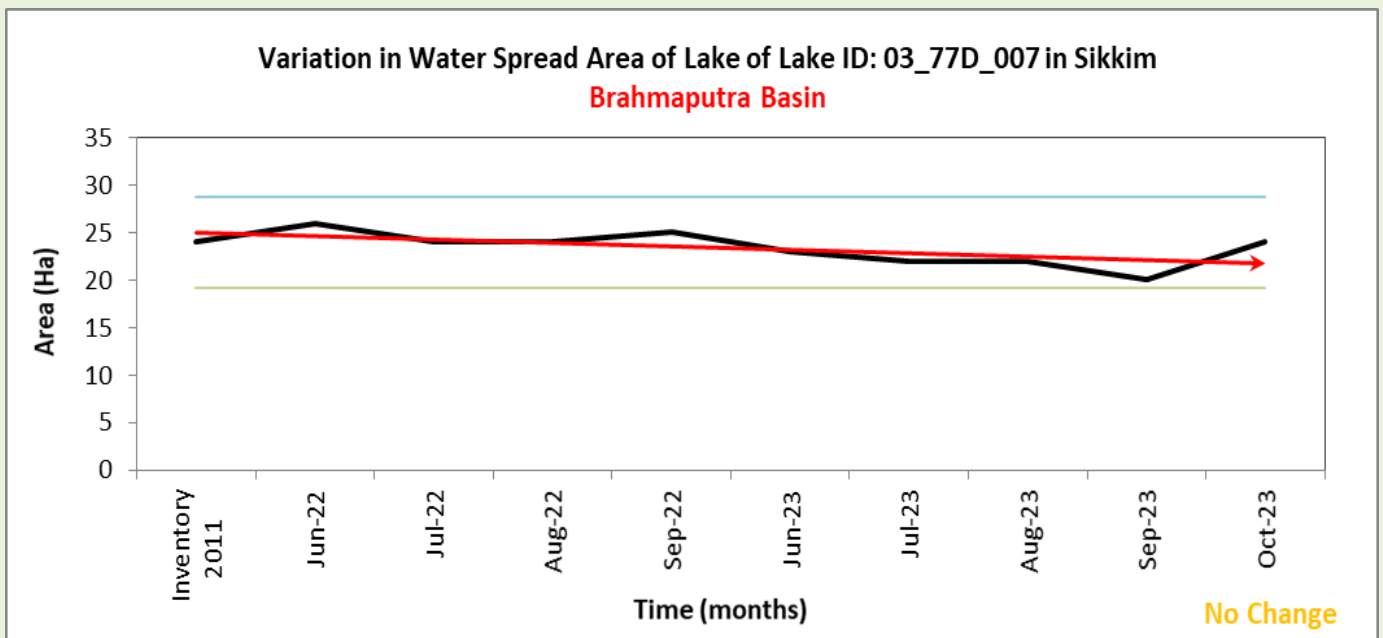


Figure 4.91(i) Trend Analysis Plot  $\pm 10\%$

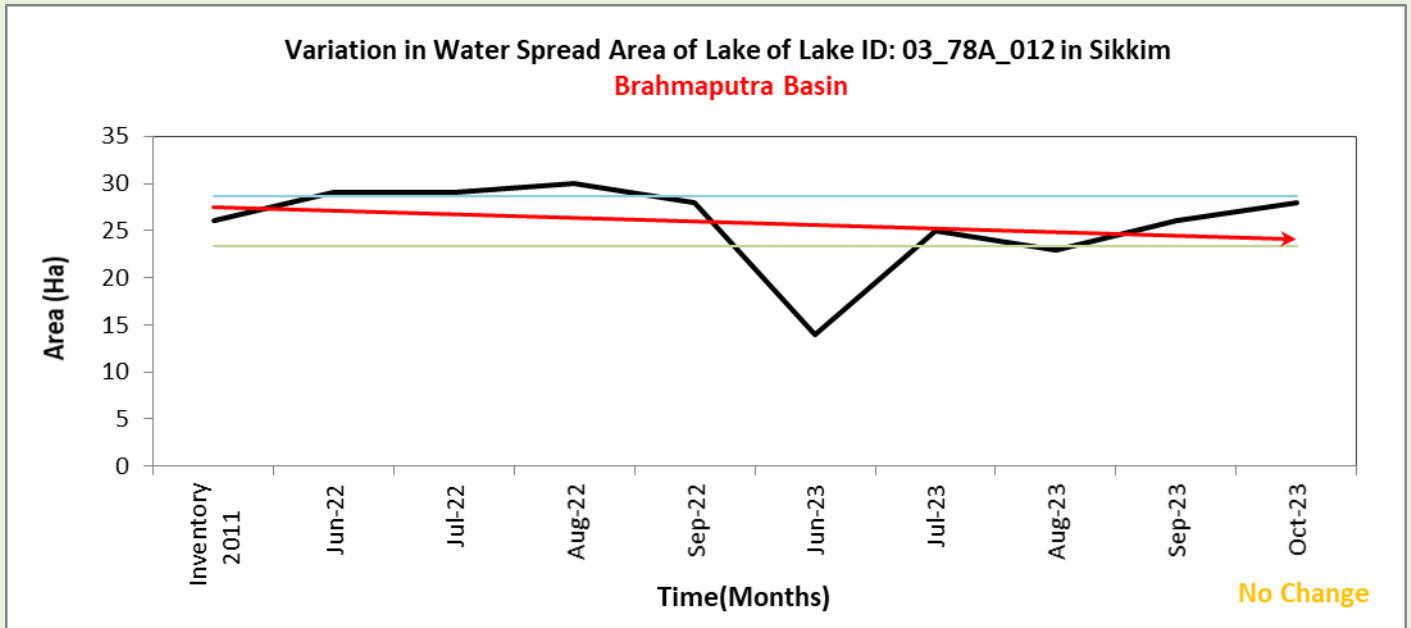


Figure 4.91(ii) Trend Analysis Plot  $\pm 10\%$

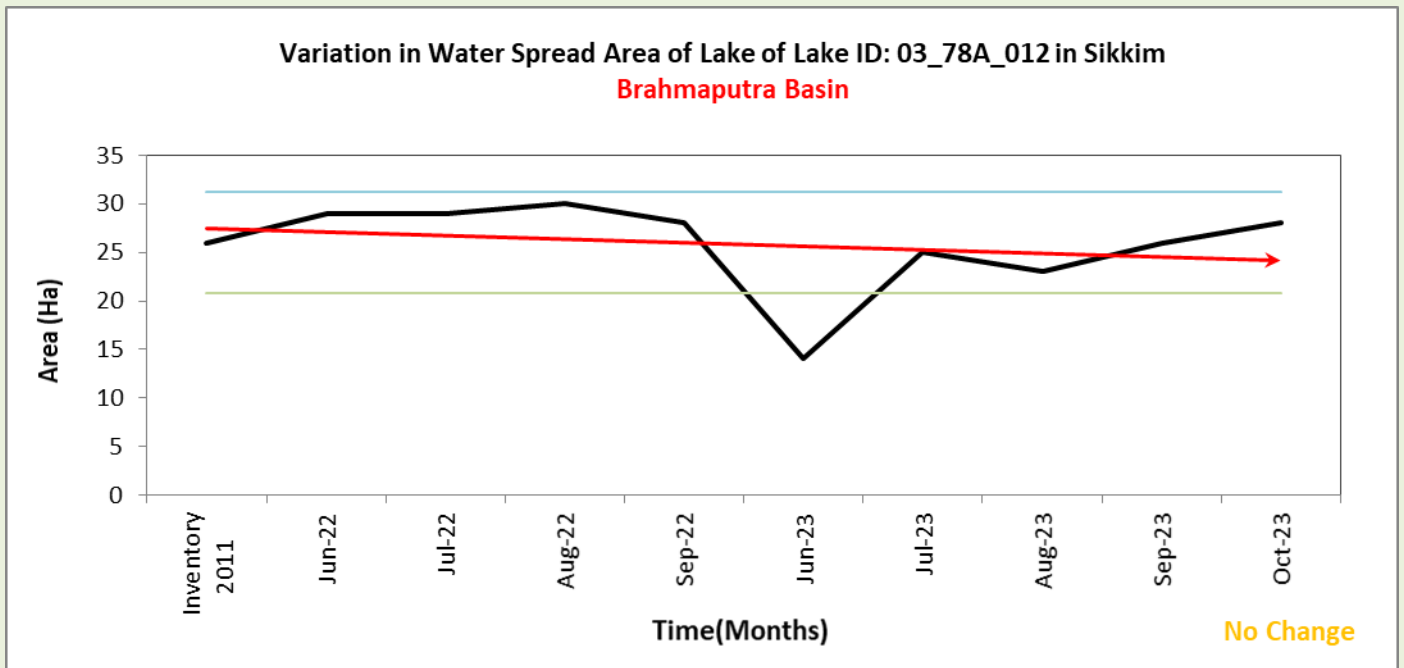


Figure 4.92(i) Trend Analysis Plot  $\pm 10\%$

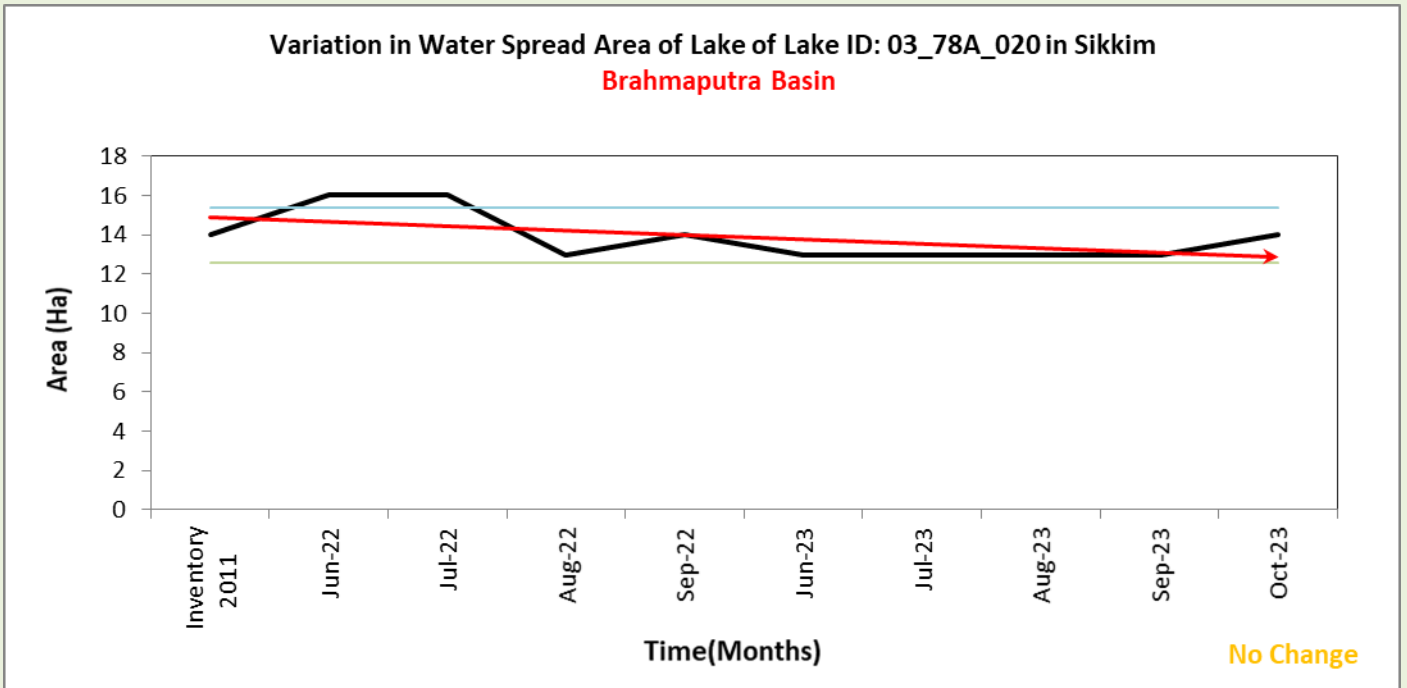
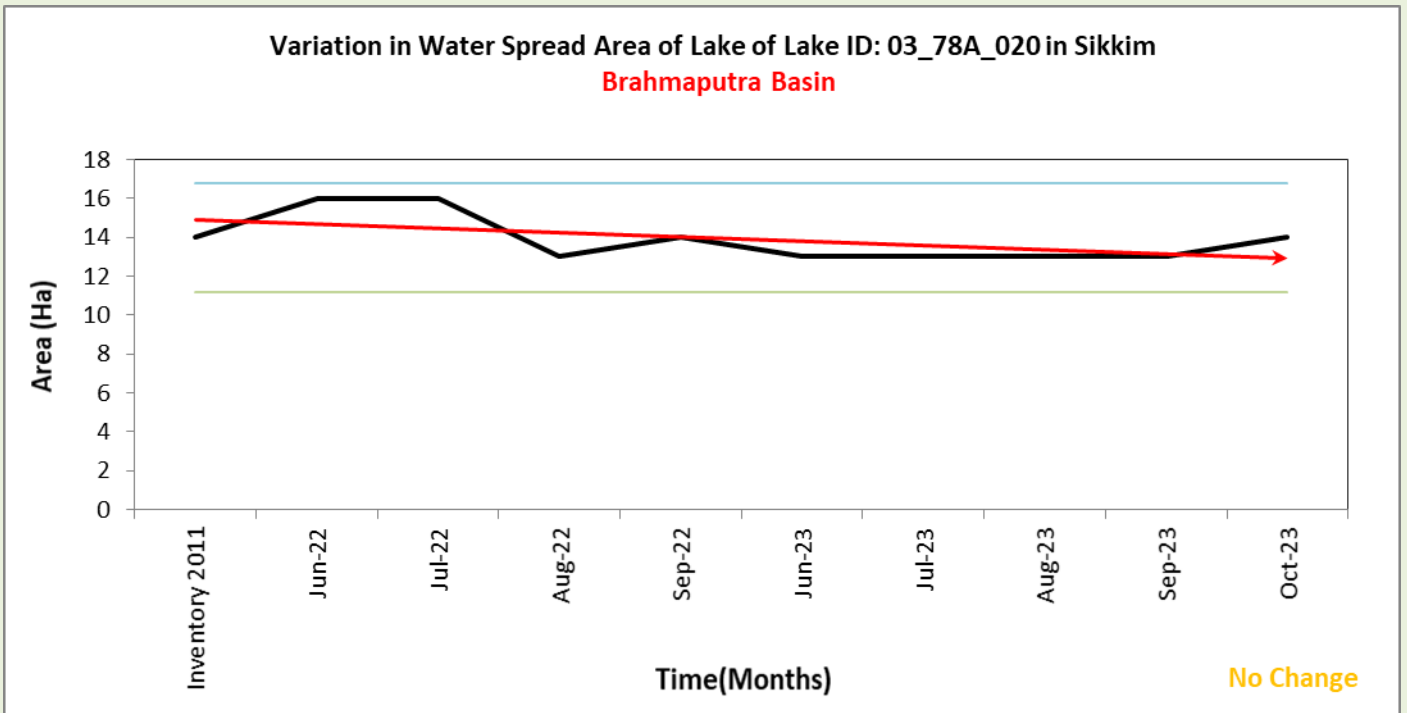
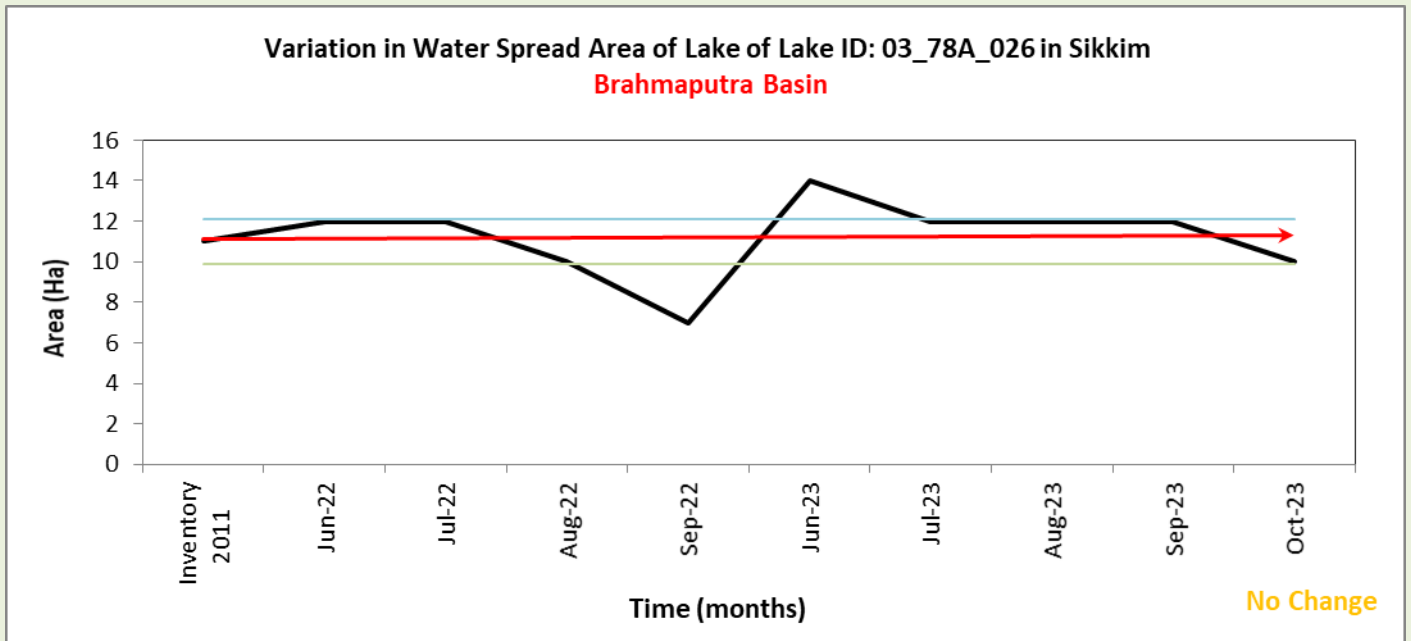


Figure 4.92(ii) Trend Analysis Plot  $\pm 20\%$



**Figure 4.93(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.93(ii)** Trend Analysis Plot  $\pm 20\%$

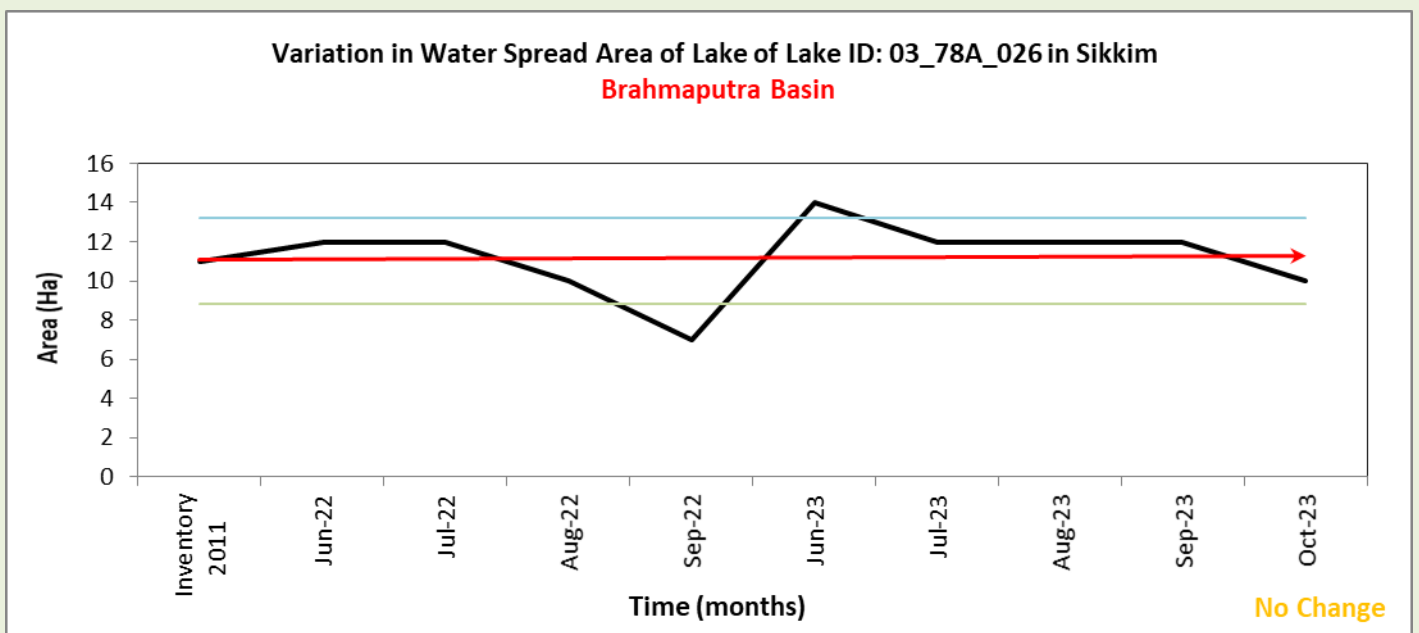


Figure 4.94(i) Trend Analysis Plot  $\pm 10\%$

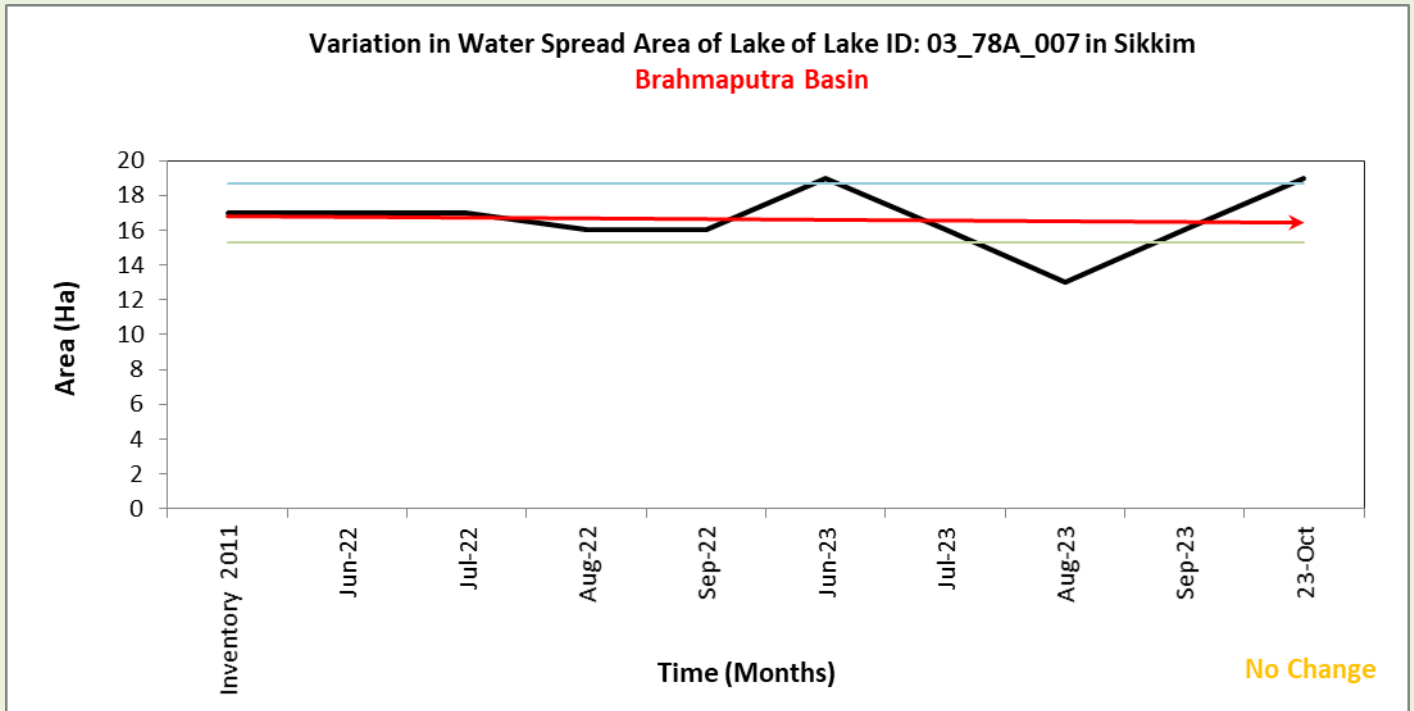


Figure 4.94(ii) Trend Analysis Plot  $\pm 20\%$

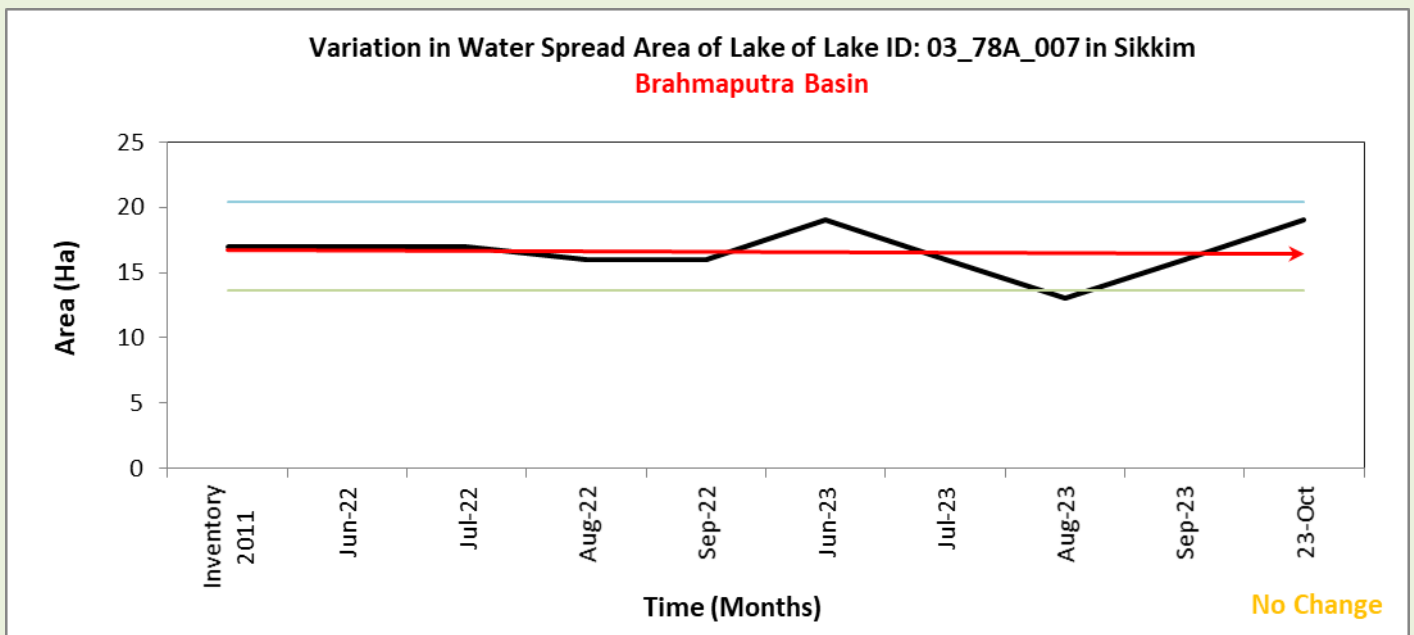


Figure 4.95(i) Trend Analysis Plot  $\pm 10\%$

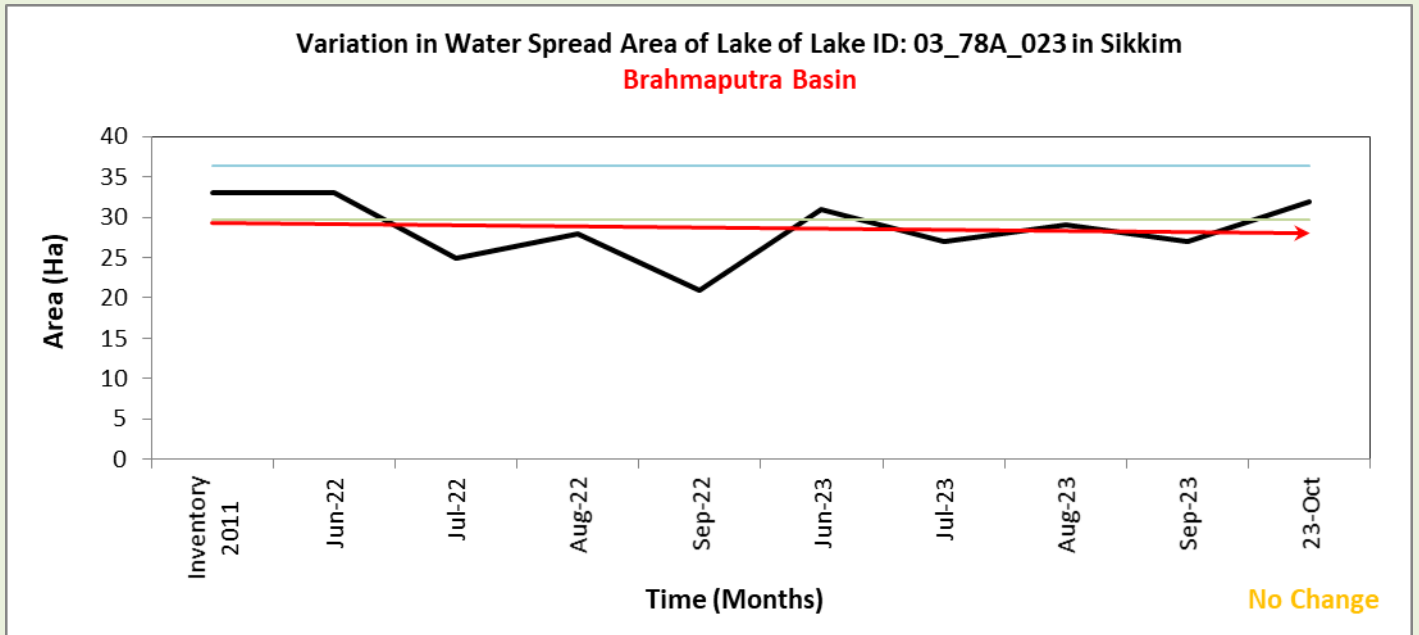
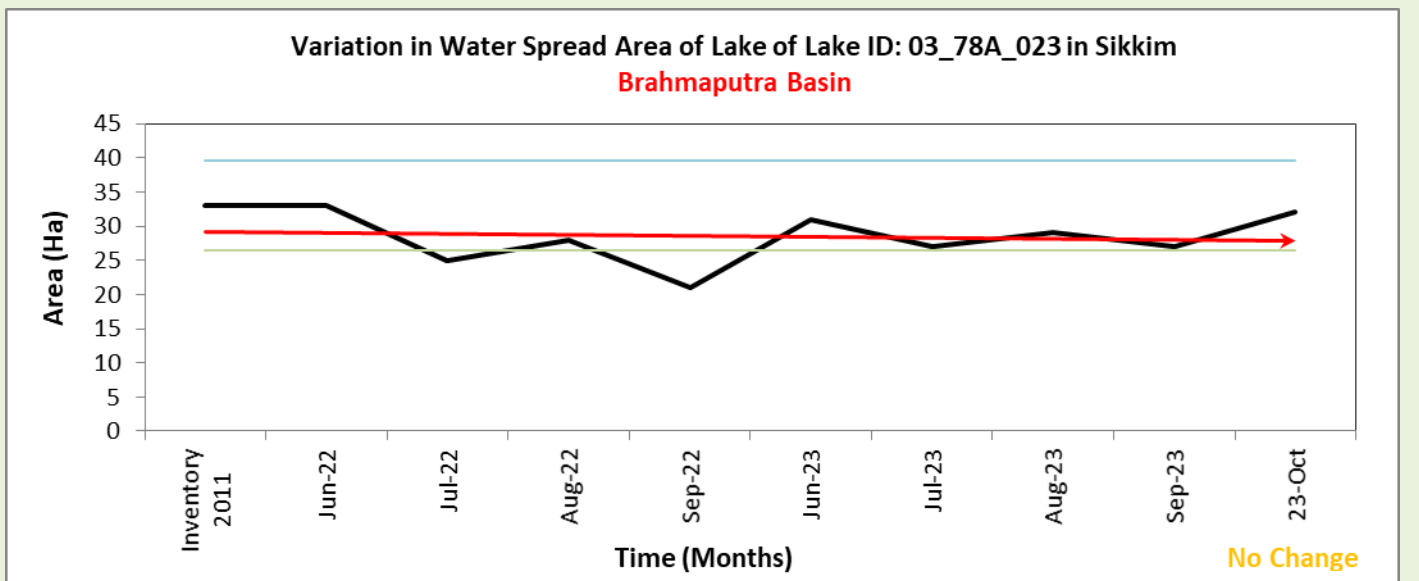
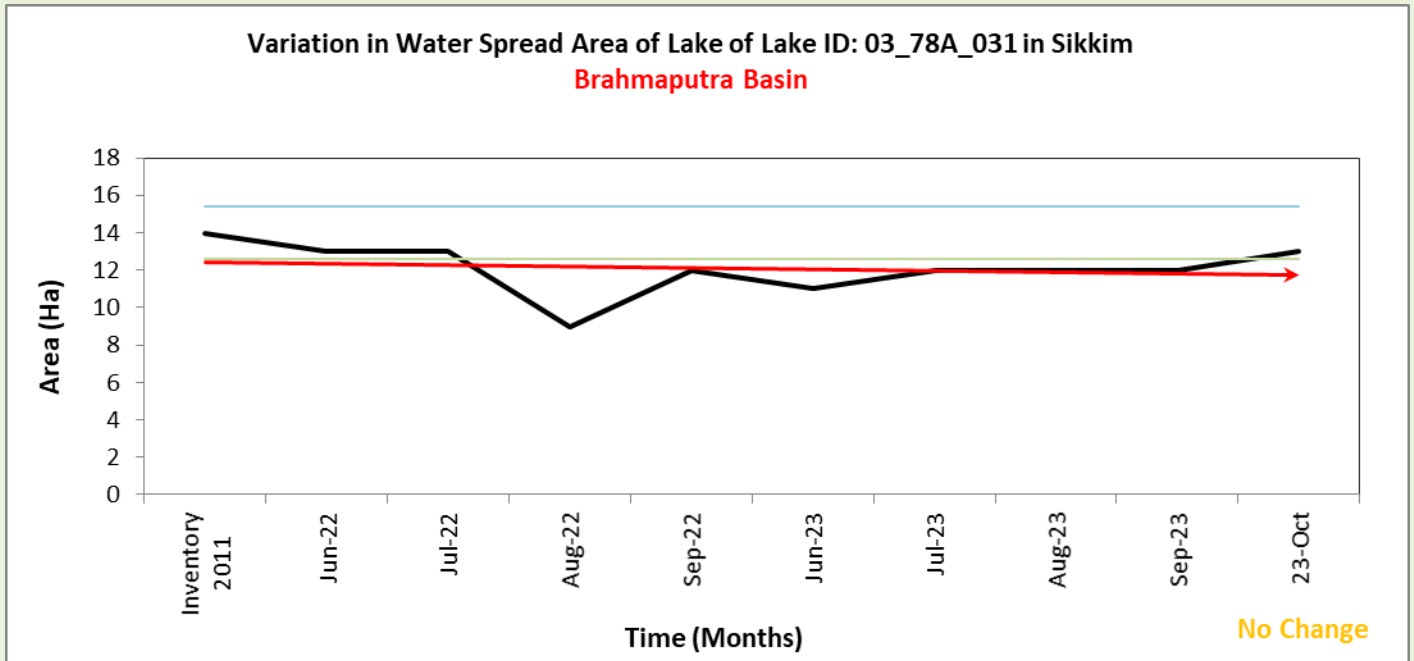


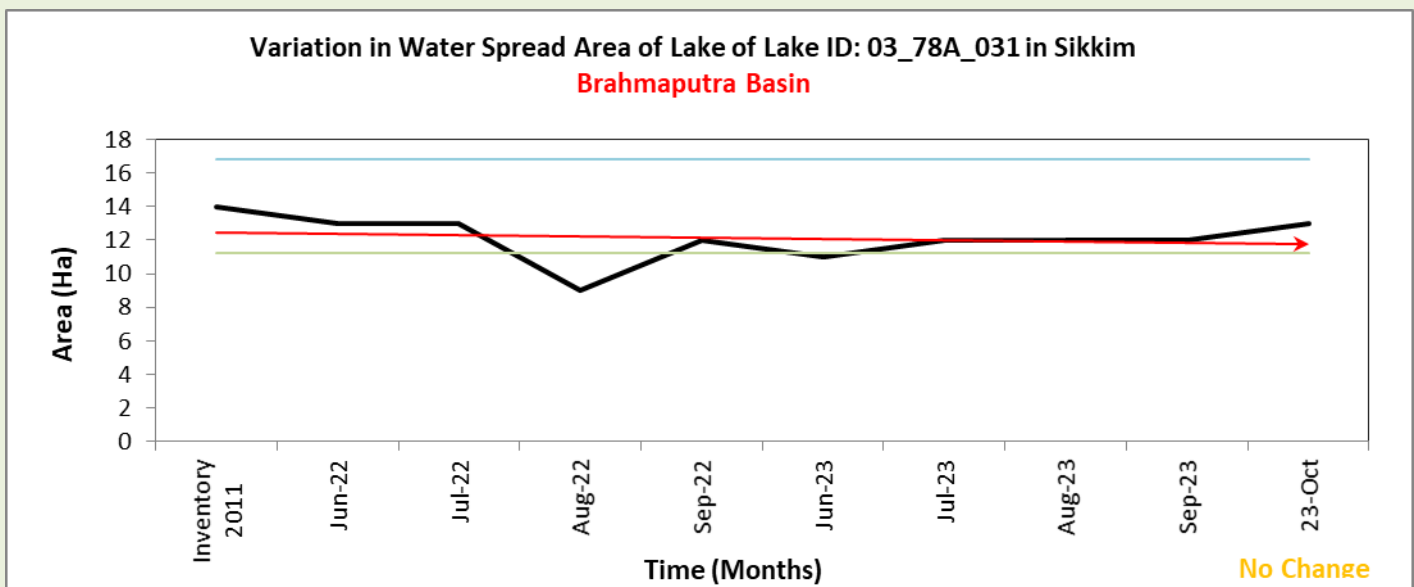
Figure 4.95(ii) Trend Analysis Plot  $\pm 20\%$



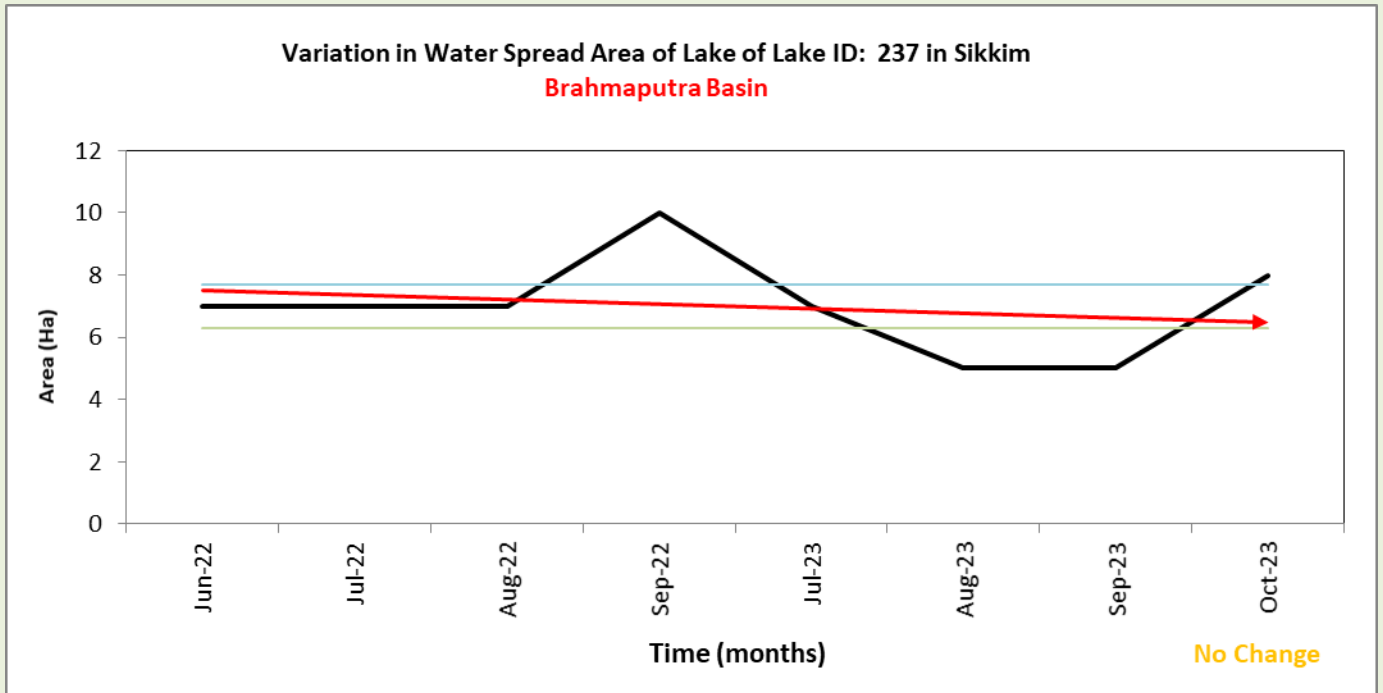
**Figure 4.96(i)** Trend Analysis Plot  $\pm 10\%$



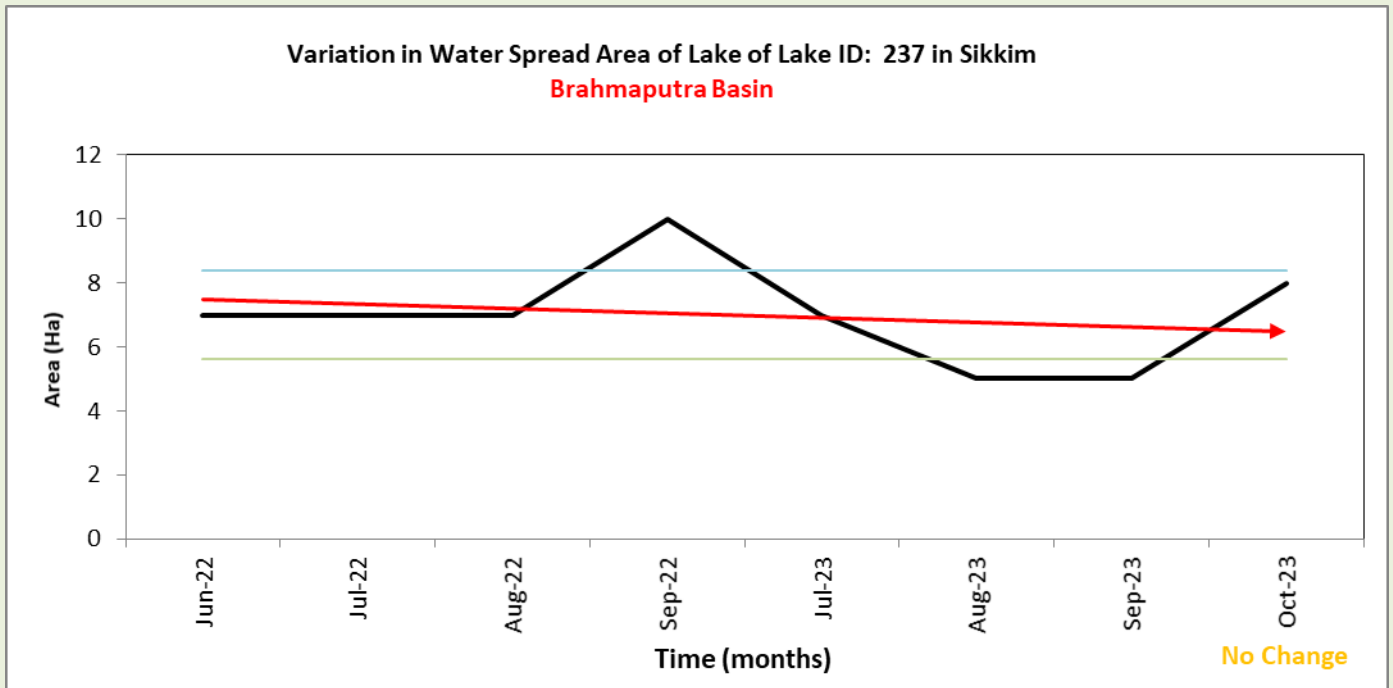
**Figure 4.96(ii)** Trend Analysis Plot  $\pm 20\%$



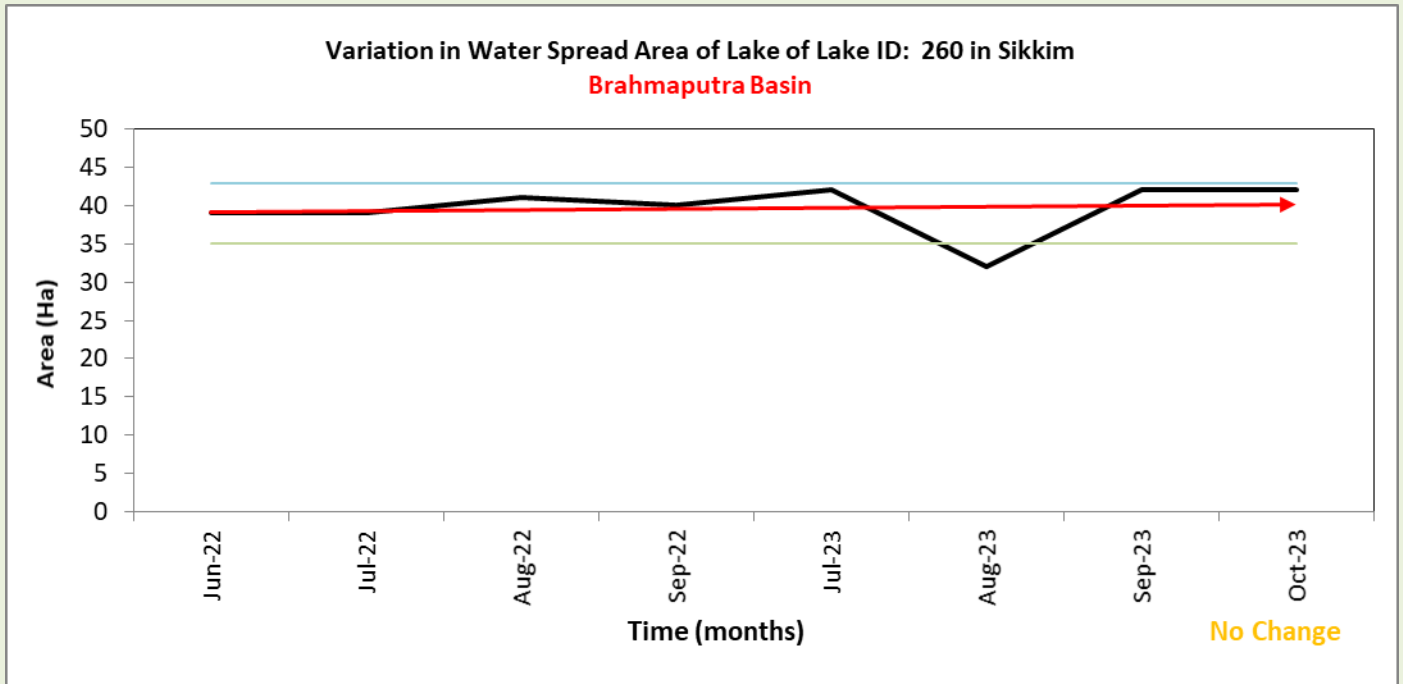
**Figure 4.97(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.97(ii)** Trend Analysis Plot  $\pm 20\%$



**Figure 4.98(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.98(ii)** Trend Analysis Plot 20%

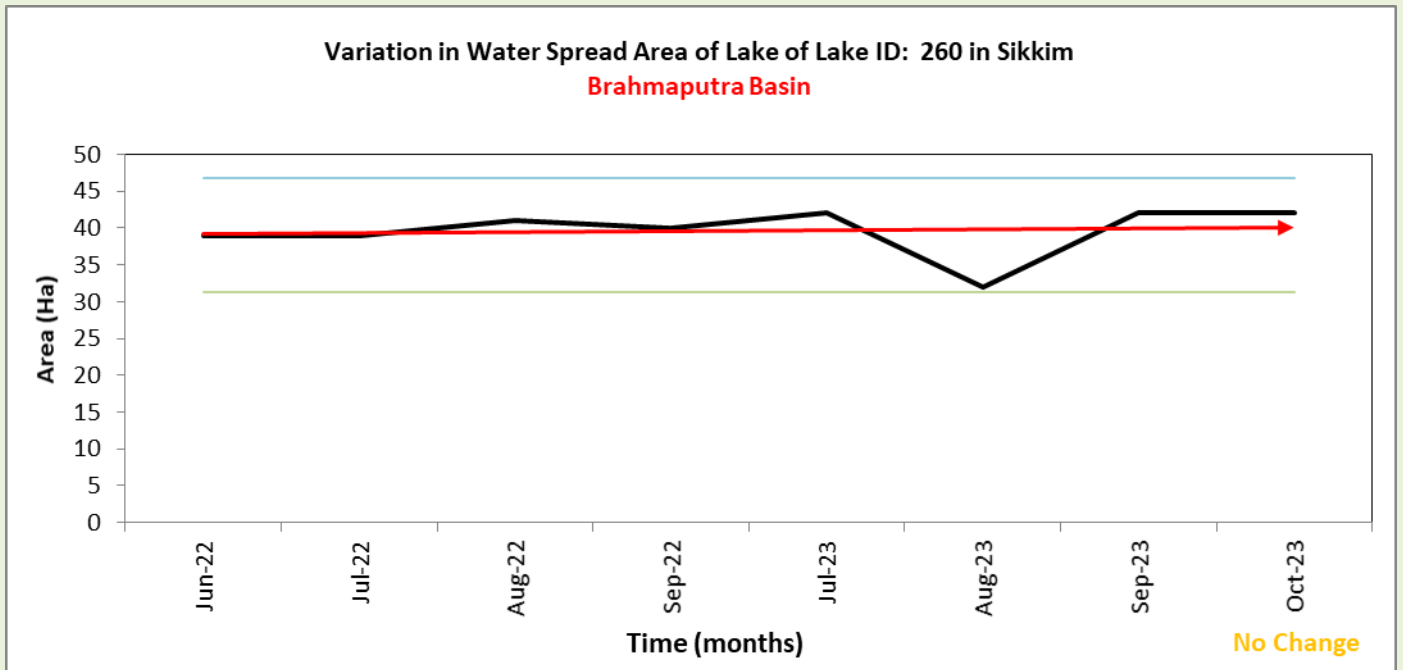


Figure 4.99(i) Trend Analysis Plot  $\pm 10\%$

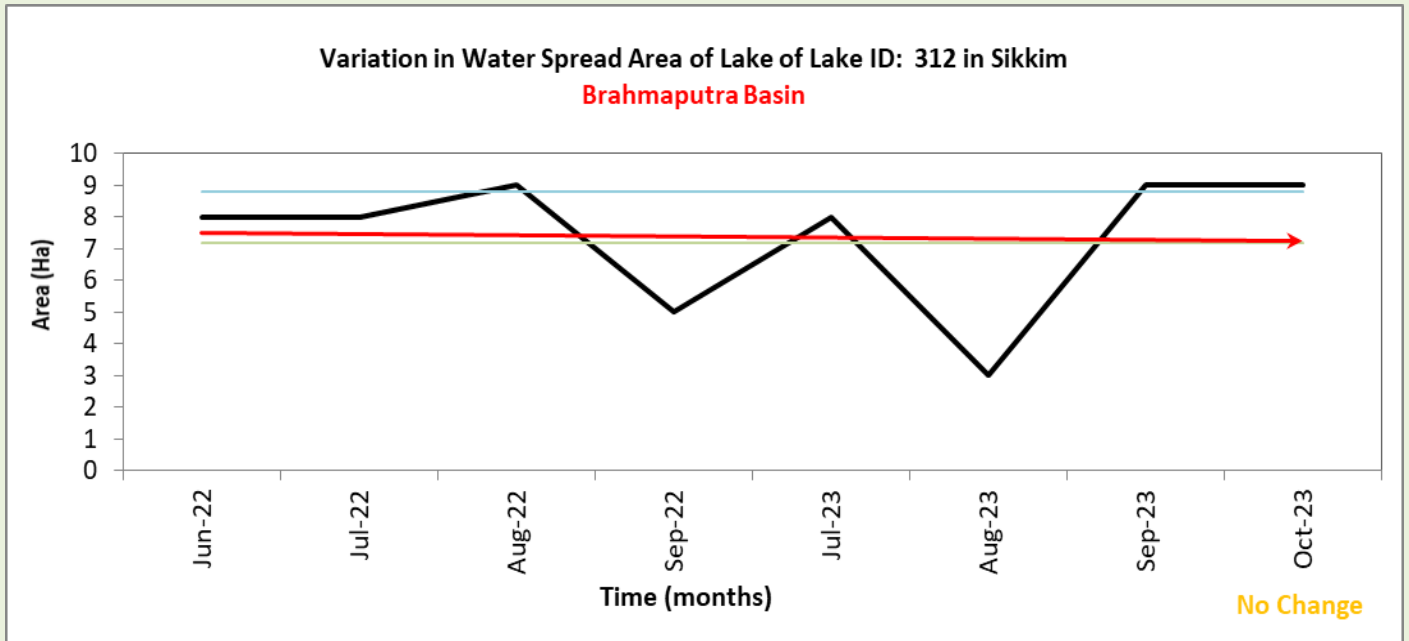


Figure 4.99(ii) Trend Analysis Plot  $\pm 20\%$

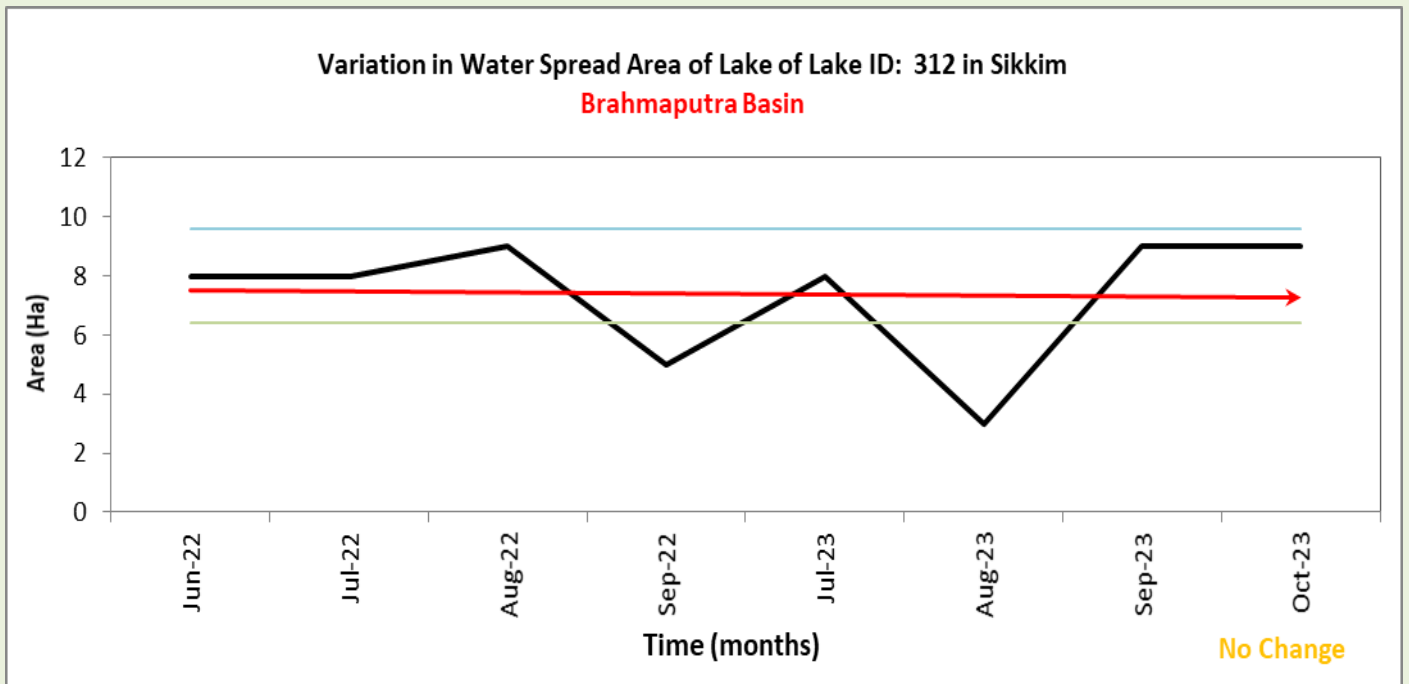


Figure 4.100(i) Trend Analysis Plot  $\pm 10\%$

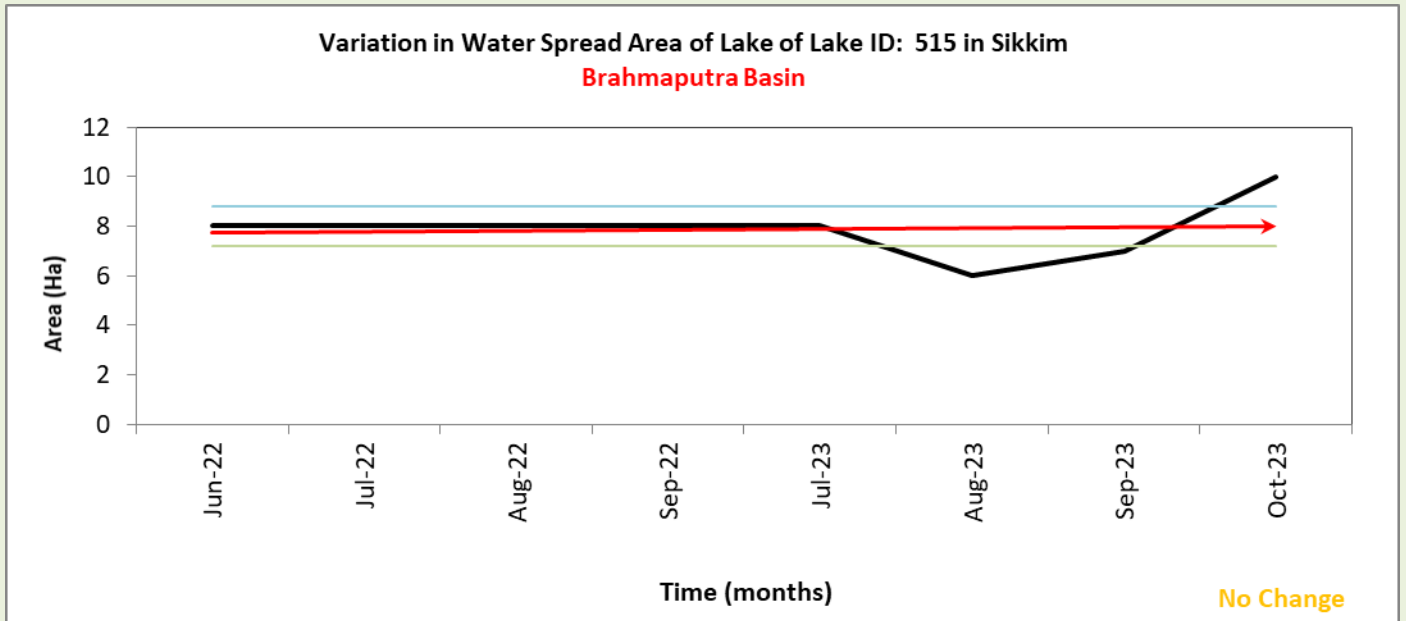
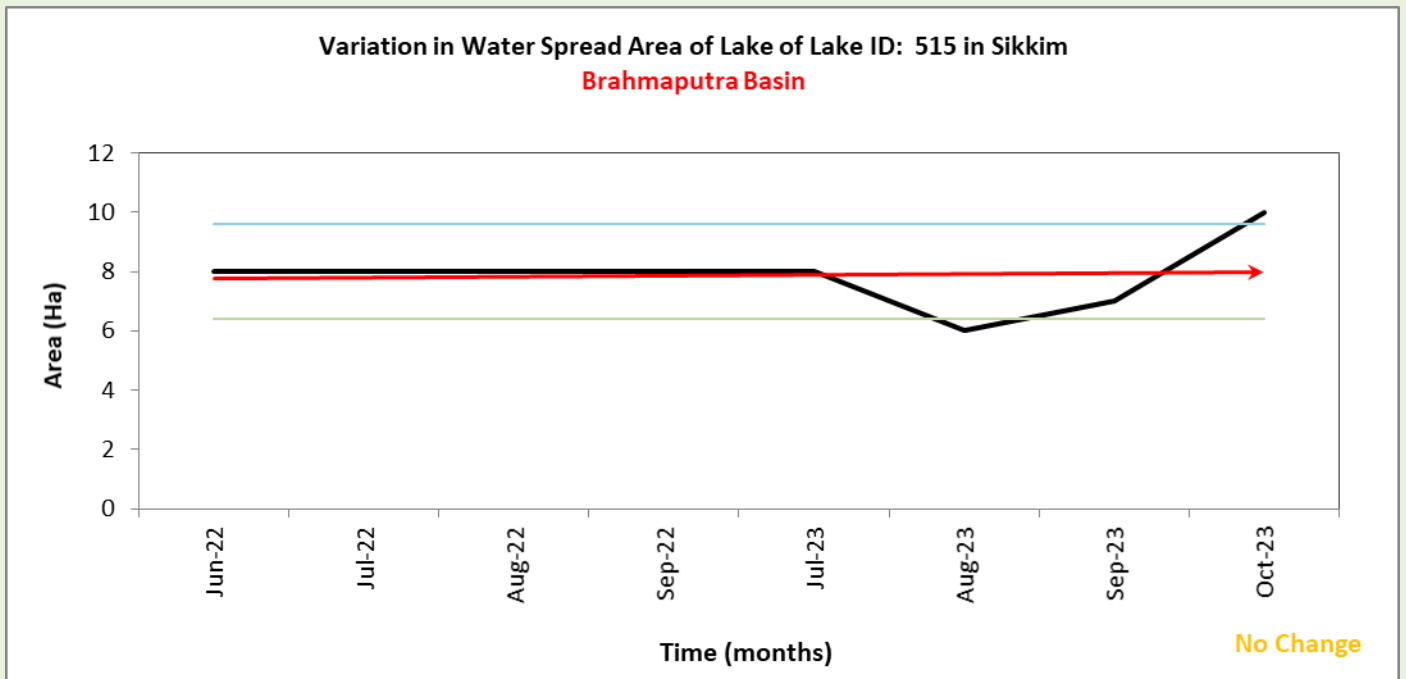
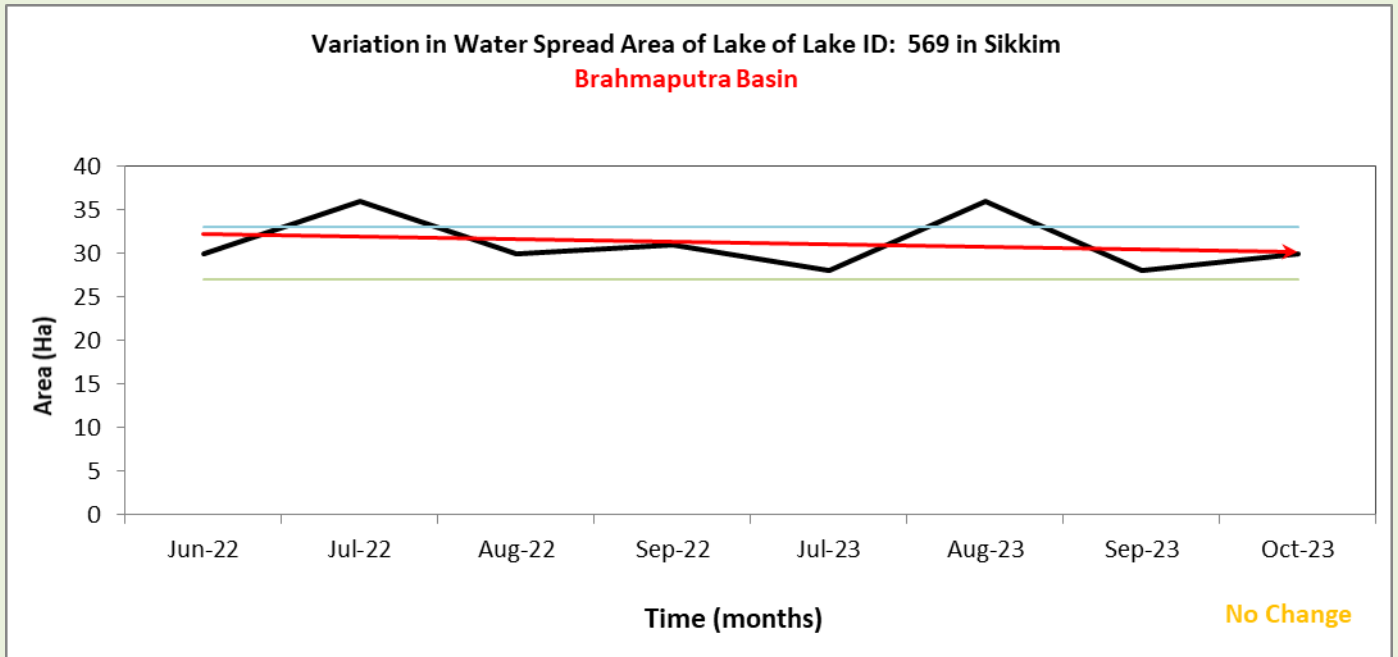


Figure 4.100(ii) Trend Analysis Plot  $\pm 20\%$



**Figure 4.101(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.101(ii)** Trend Analysis Plot 20%

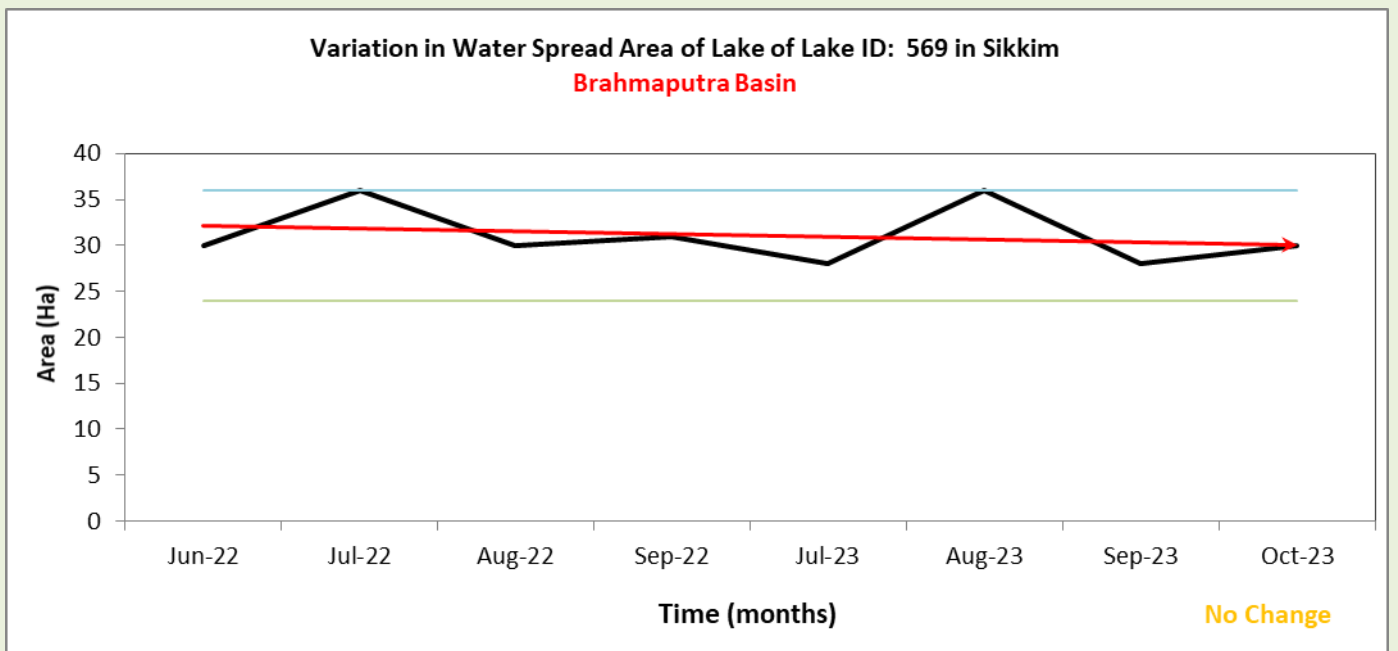


Figure 4.102(i) Trend Analysis Plot  $\pm 10\%$

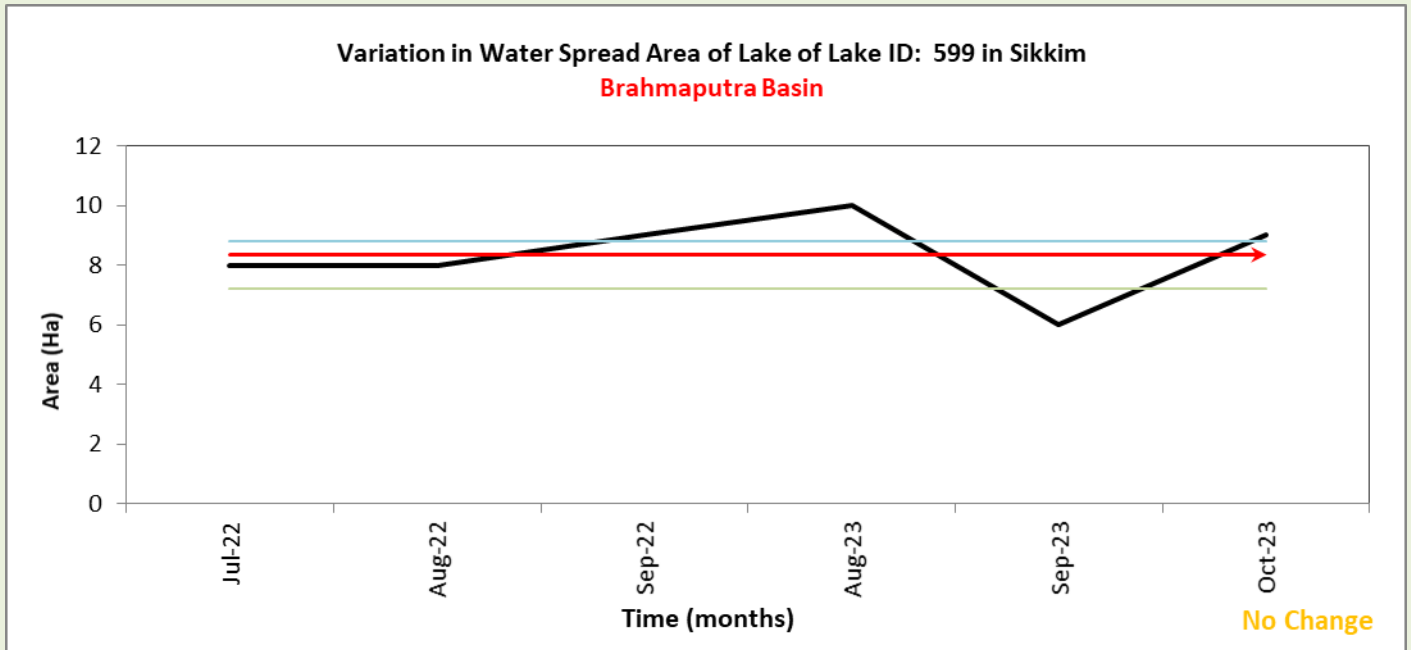
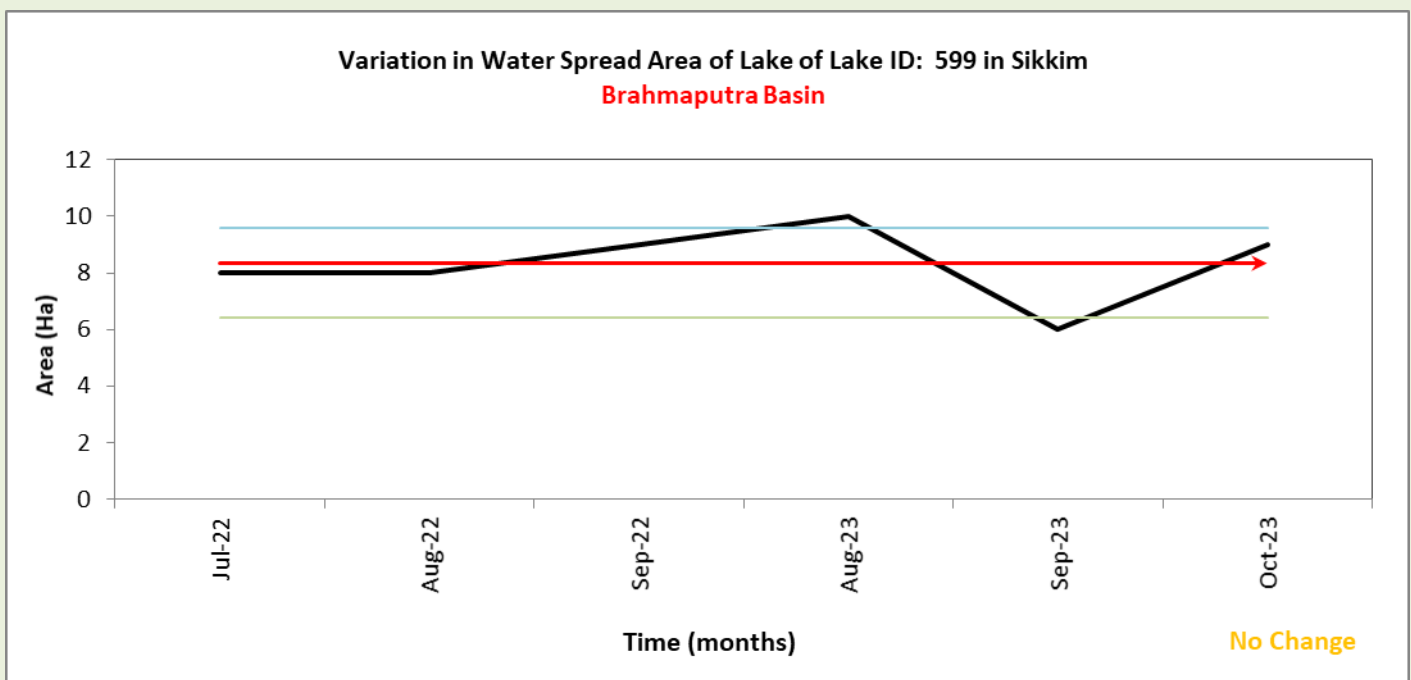
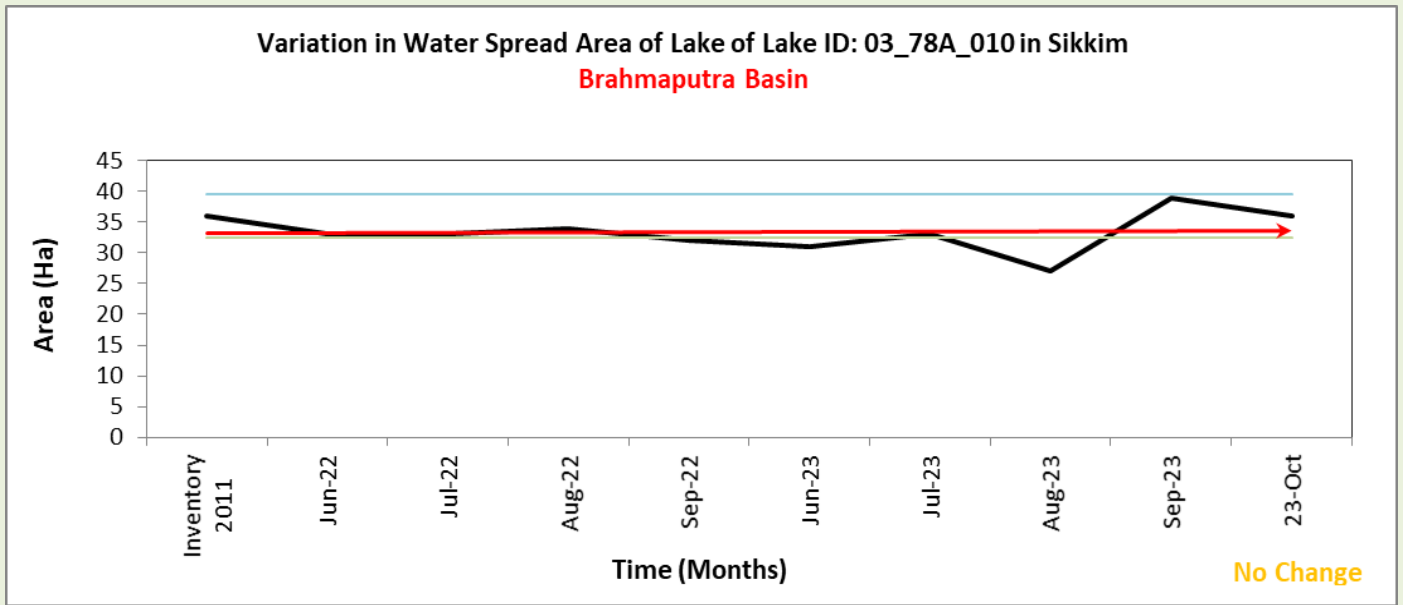


Figure 4.102(ii) Trend Analysis Plot  $\pm 20\%$



**Figure 4.103(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.103(ii)** Trend Analysis Plot  $\pm 20\%$

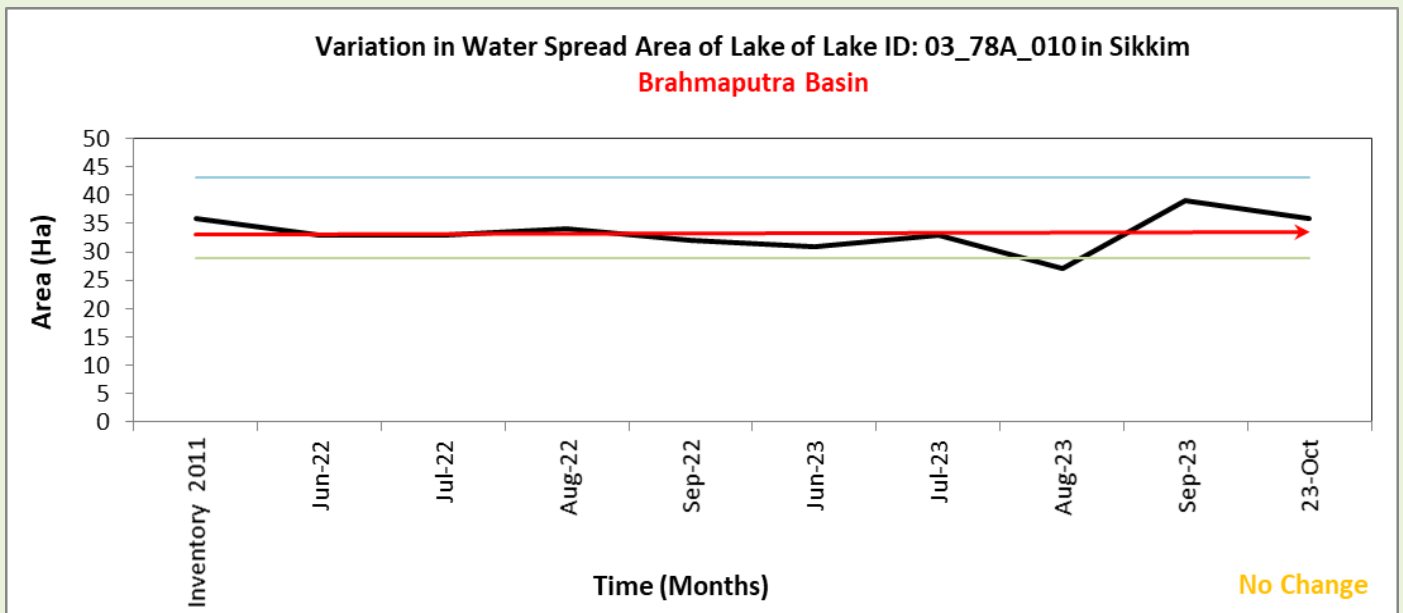


Figure 4.104(i) Trend Analysis Plot  $\pm 10\%$

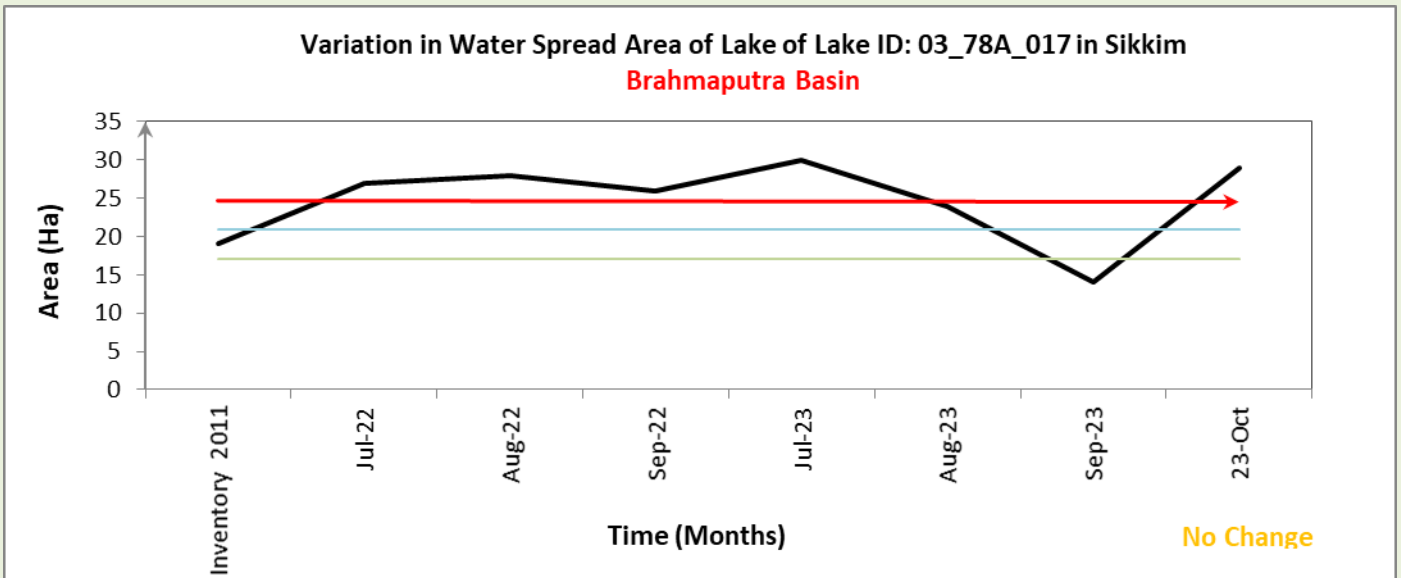


Figure 4.104(ii) Trend Analysis Plot  $\pm 20\%$

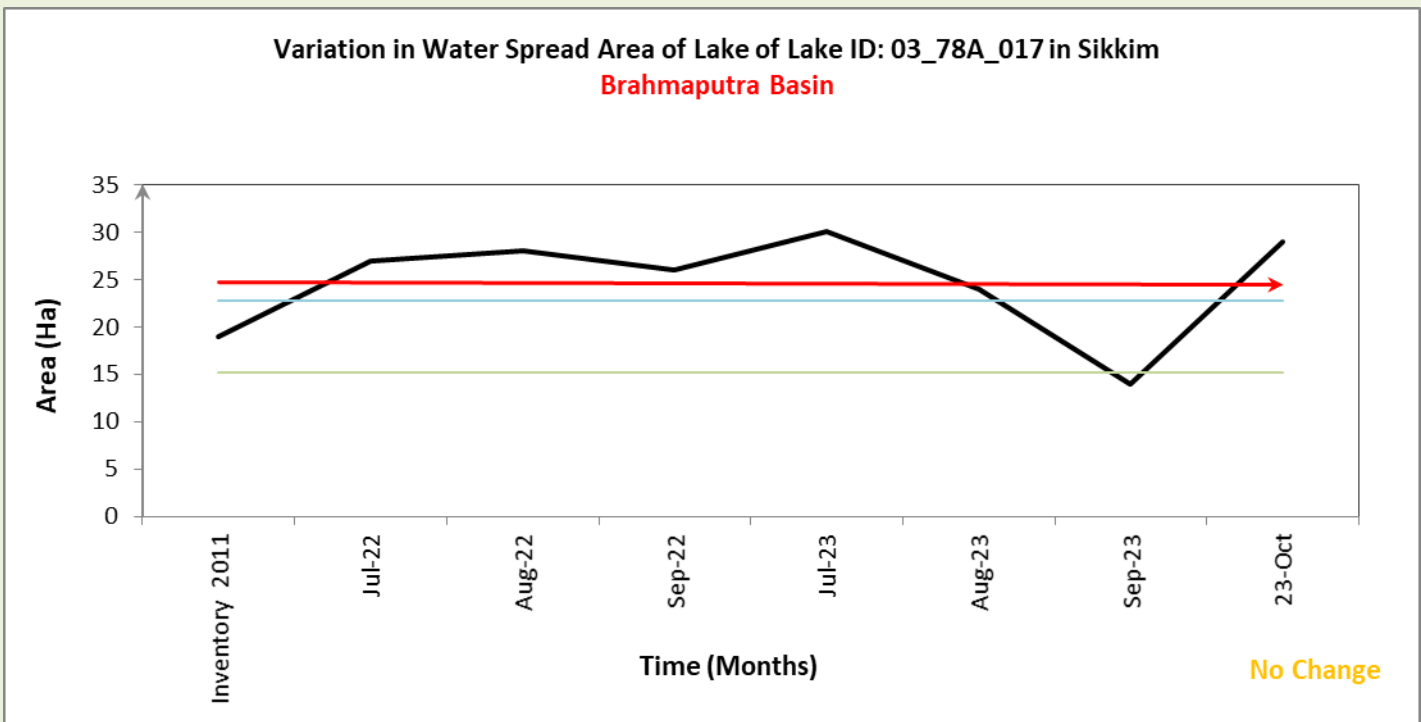


Figure 4.105(i) Trend Analysis Plot  $\pm 10\%$

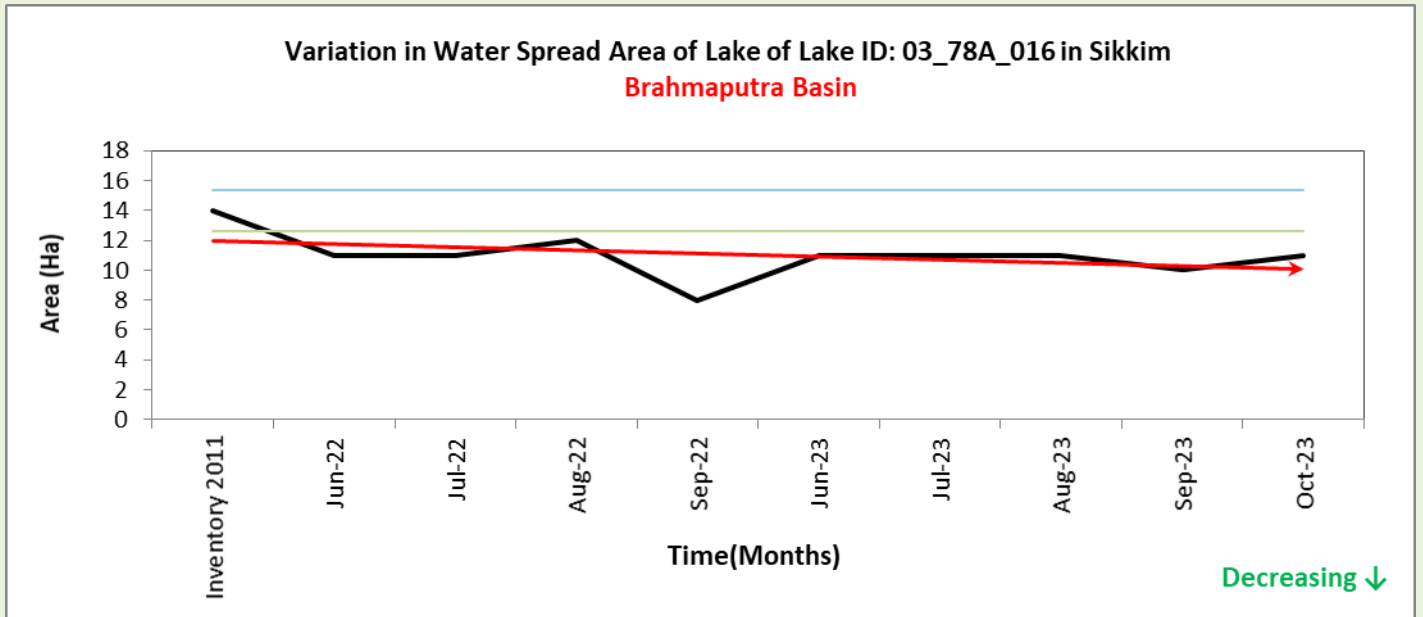


Figure 4.105(ii) Trend Analysis Plot  $\pm 20\%$

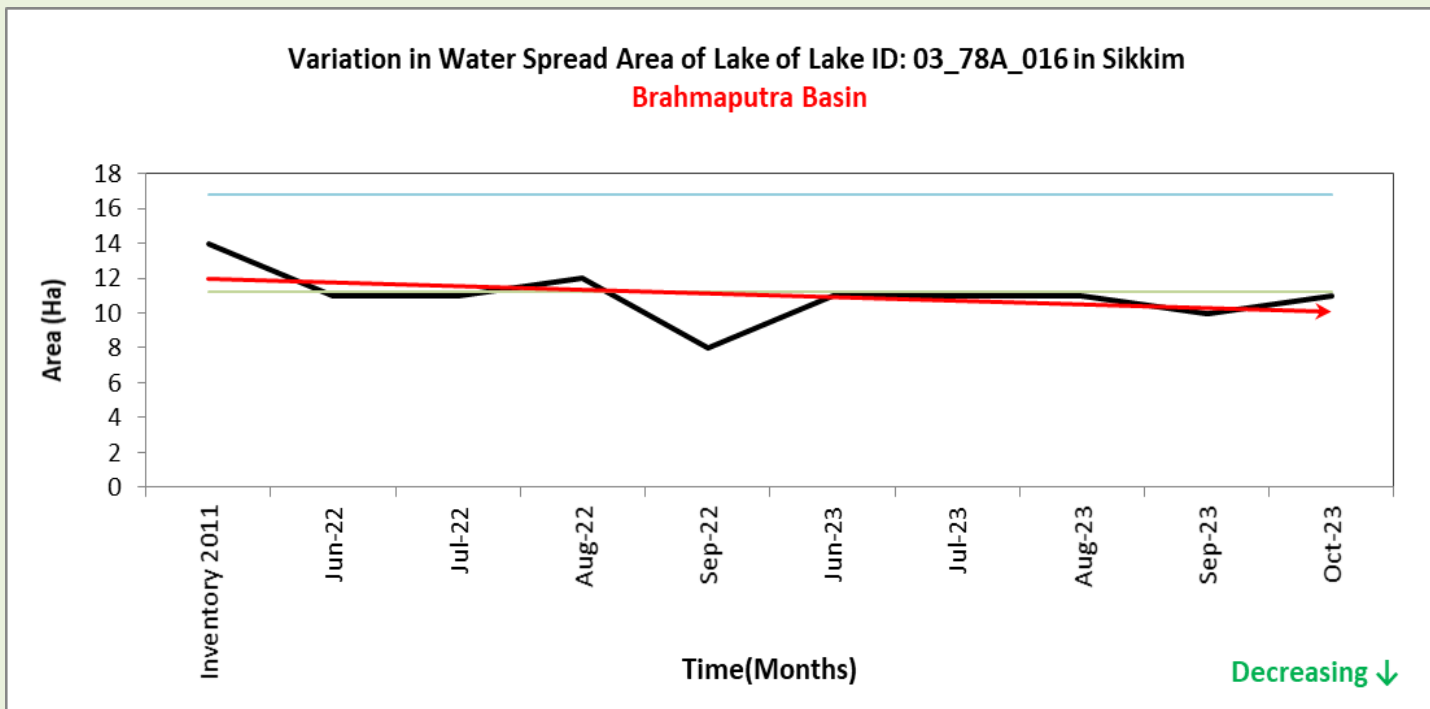


Figure 4.106(i) Trend Analysis Plot  $\pm 10\%$

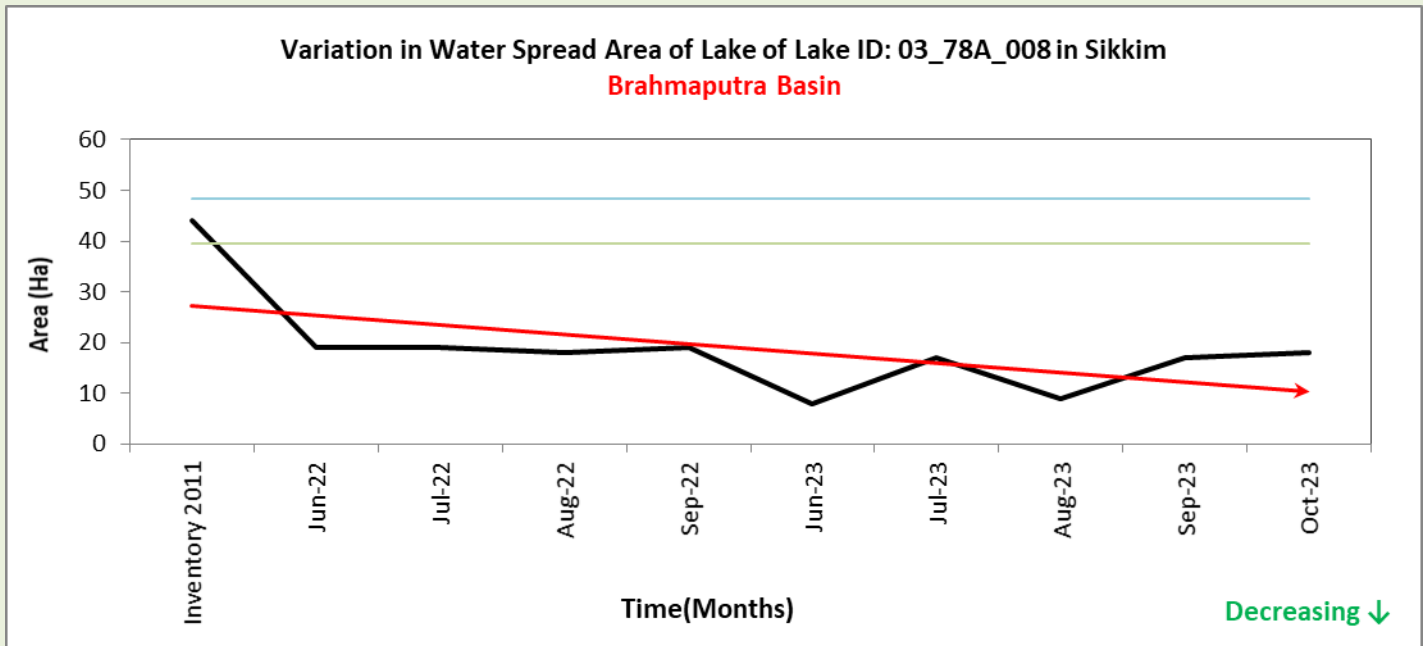


Figure 4.106(ii) Trend Analysis Plot  $\pm 20\%$

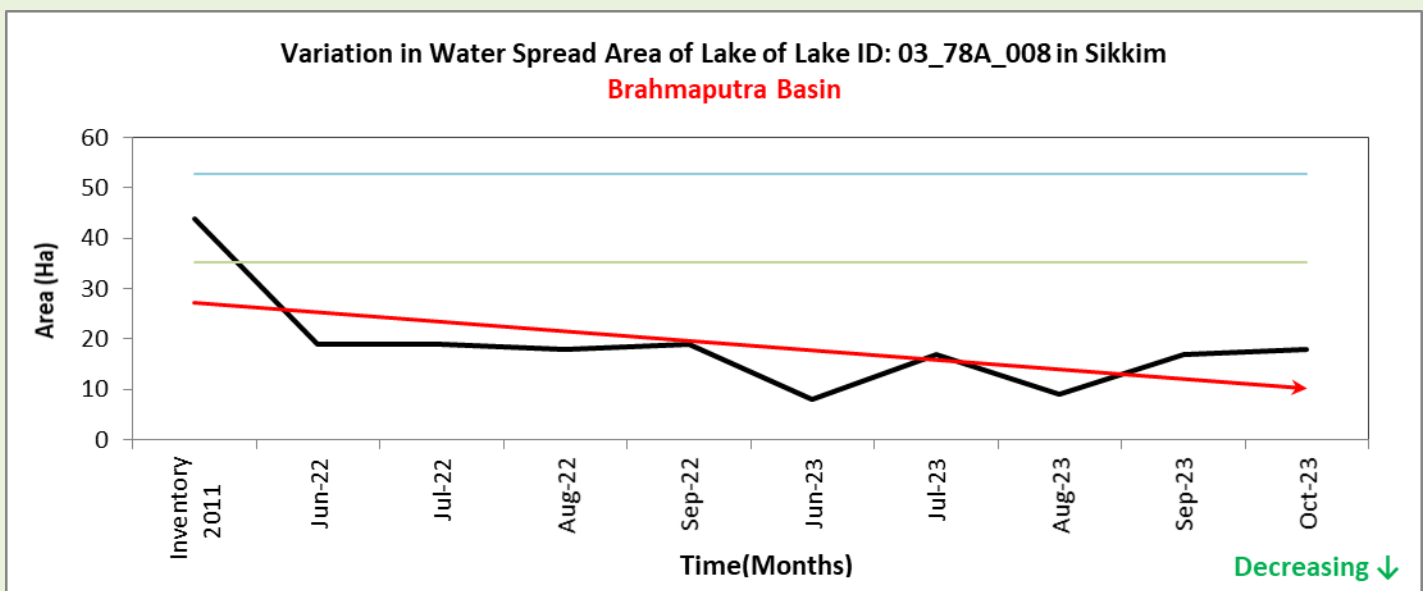


Figure 4.107(i) Trend Analysis Plot  $\pm 10\%$

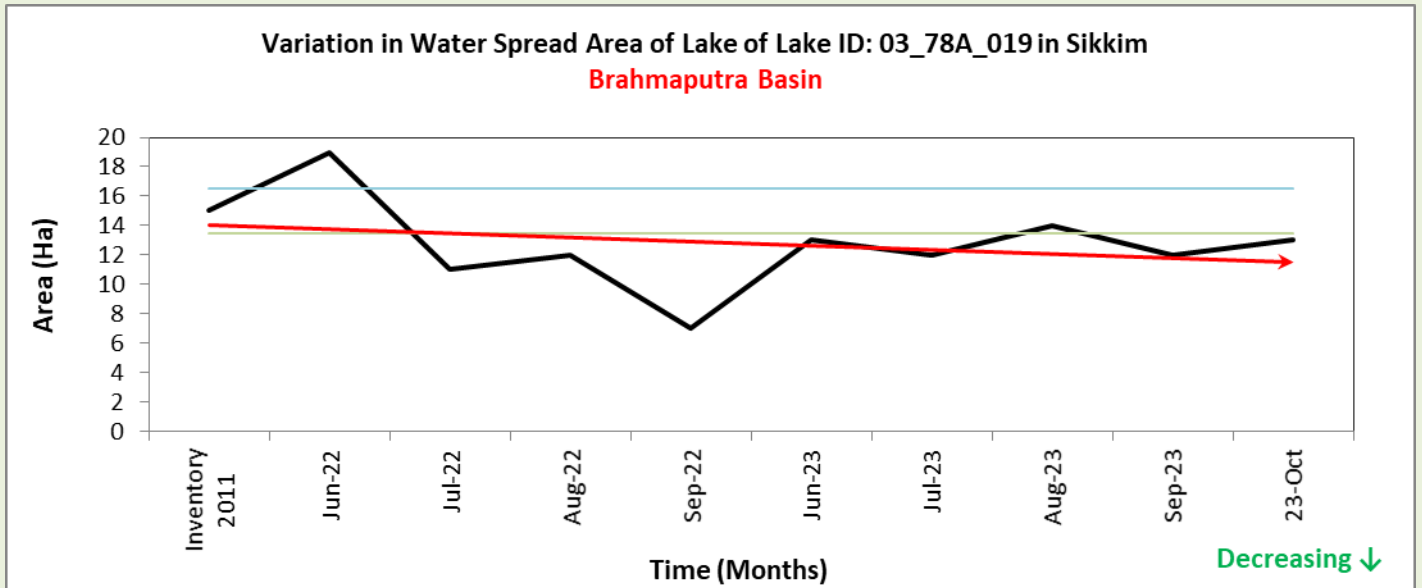


Figure 4.107(ii) Trend Analysis Plot 20%

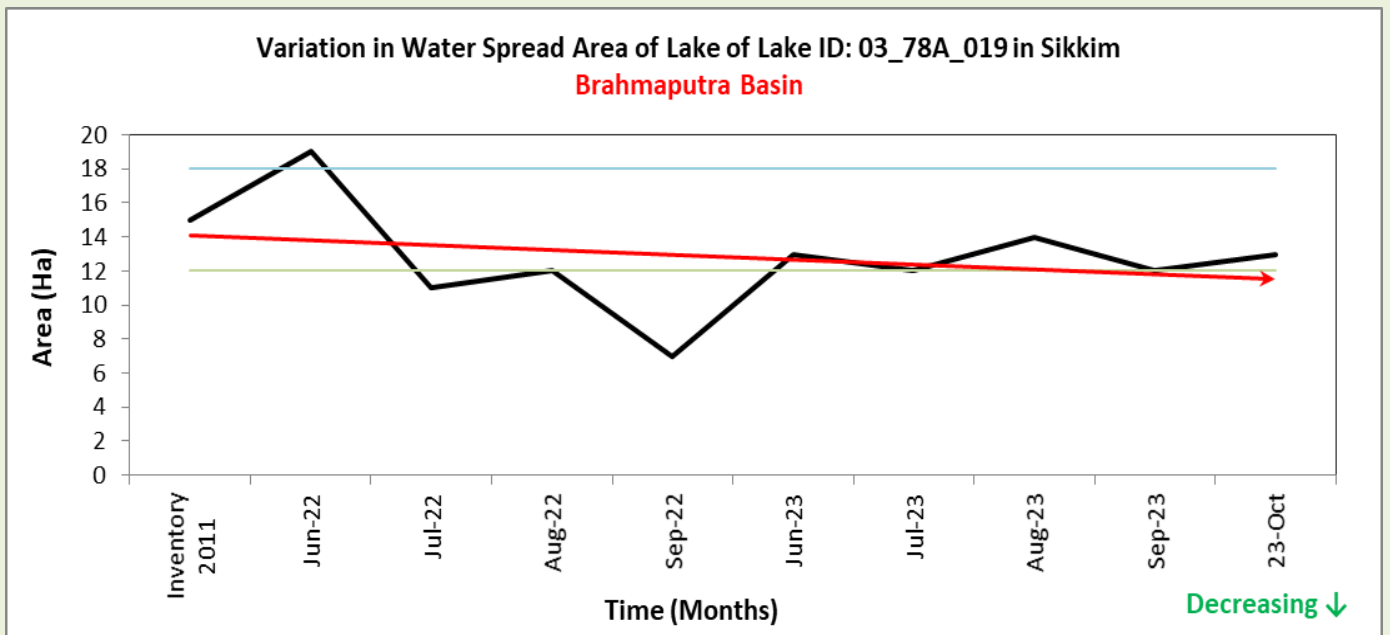


Figure 4.108(i) Trend Analysis Plot  $\pm 10\%$

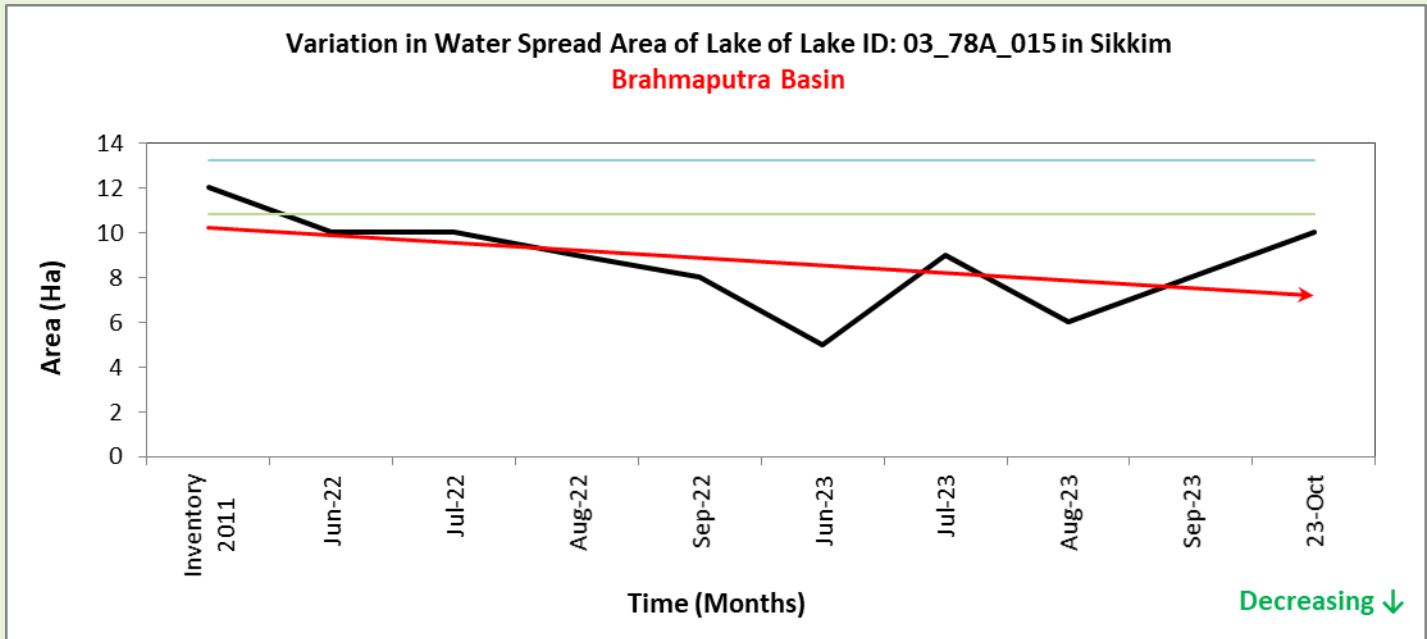


Figure 4.108(ii) Trend Analysis Plot  $\pm 20\%$

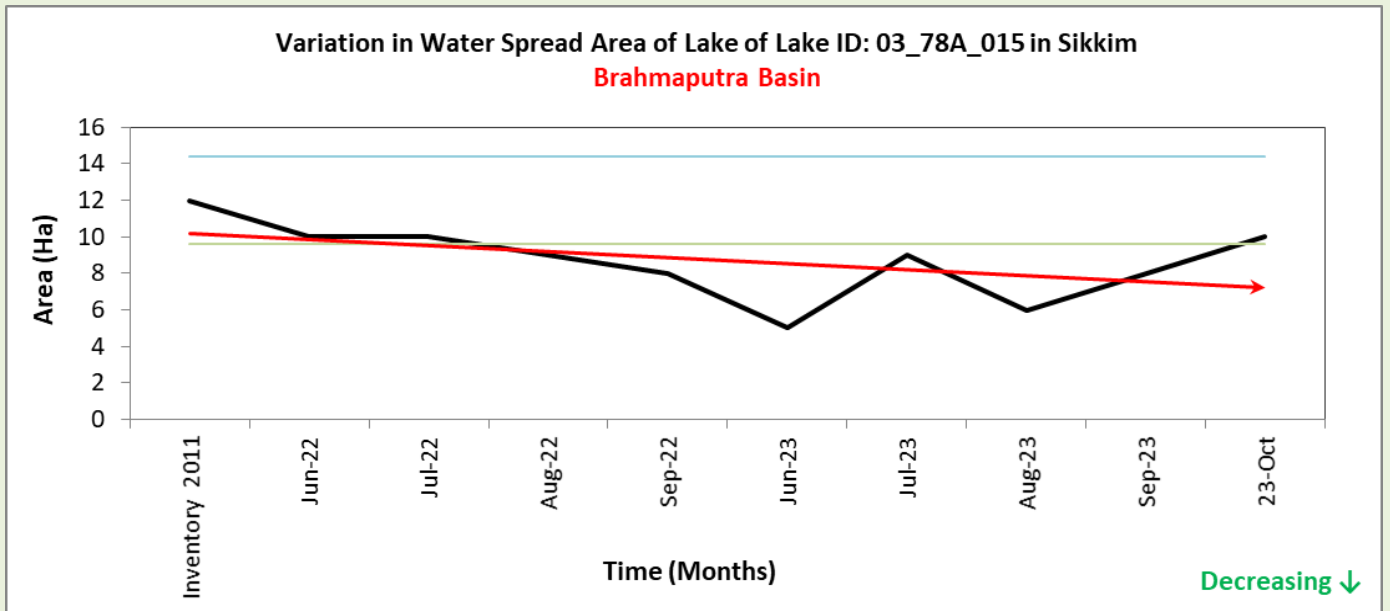


Figure 4.109(i) Trend Analysis Plot  $\pm 10\%$

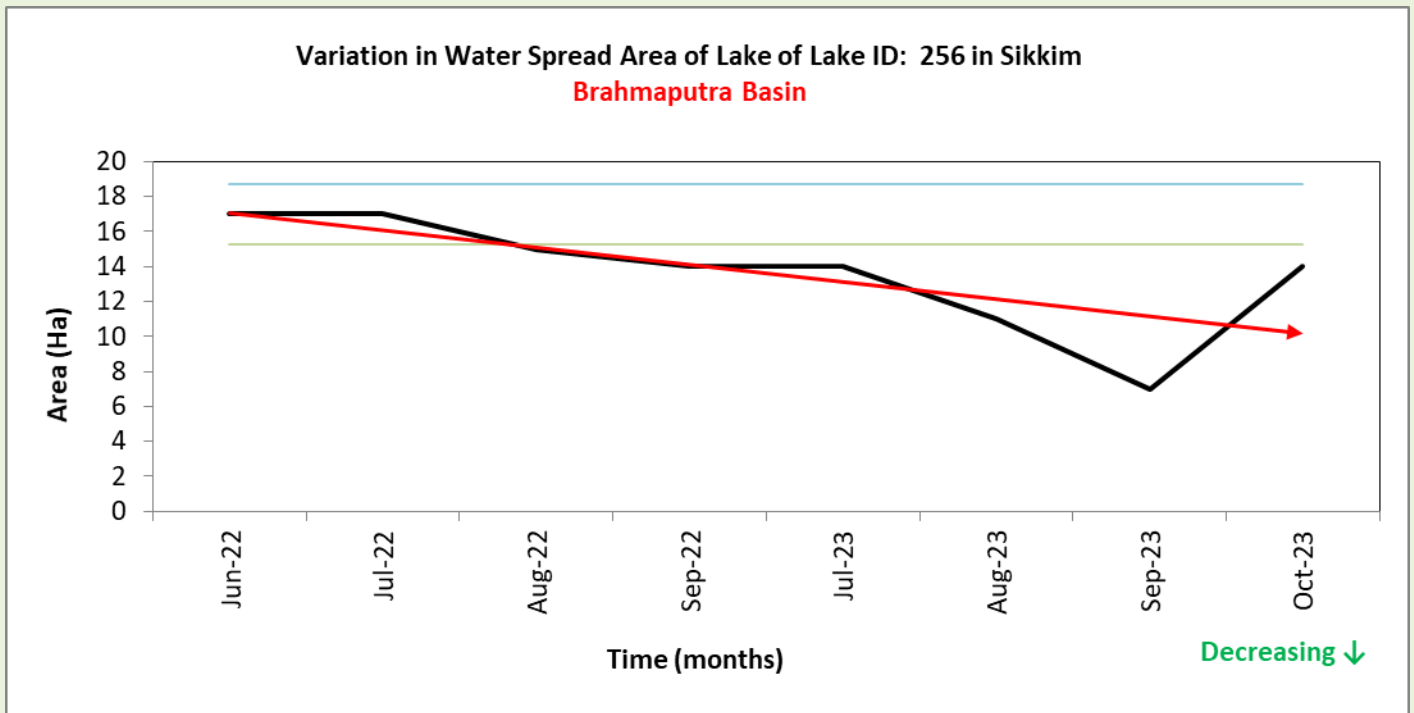


Figure 4.109(ii) Trend Analysis Plot  $\pm 20\%$

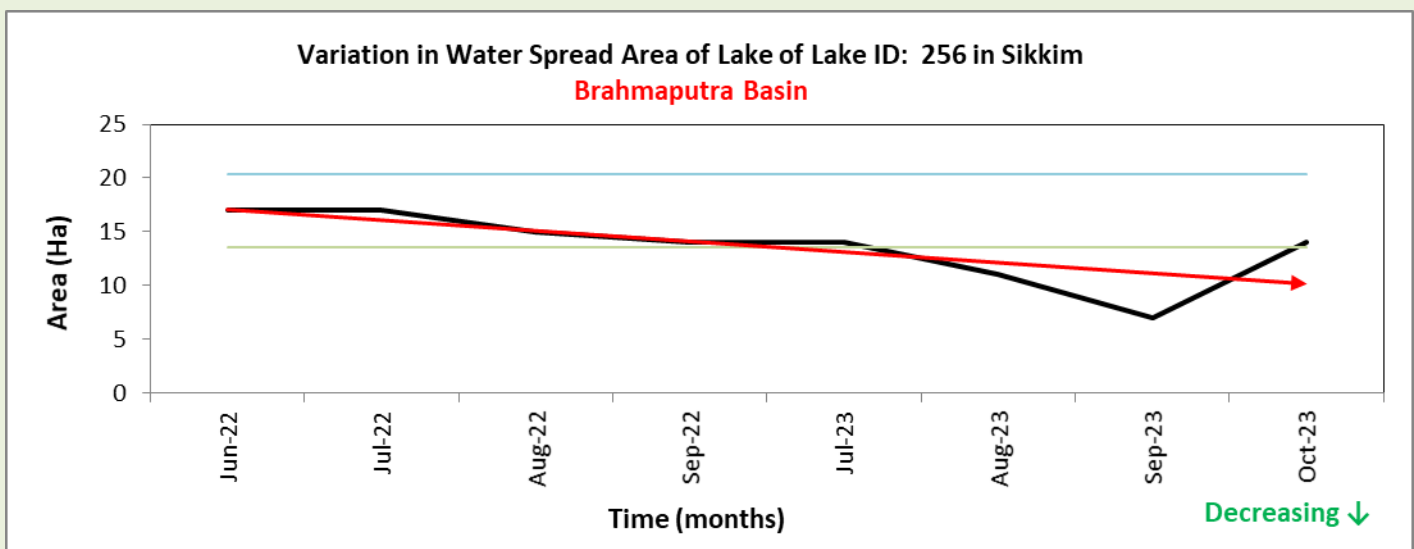


Figure 4.110(i) Trend Analysis Plot  $\pm 10\%$

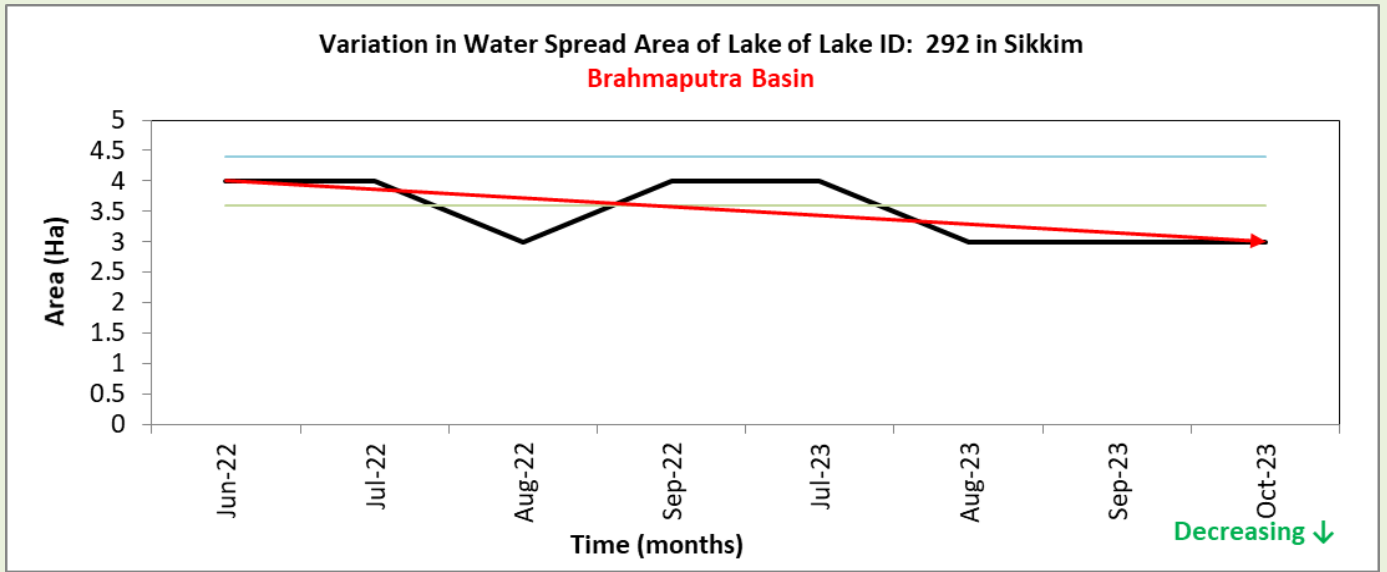


Figure 4.110(ii) Trend Analysis Plot  $\pm 20\%$

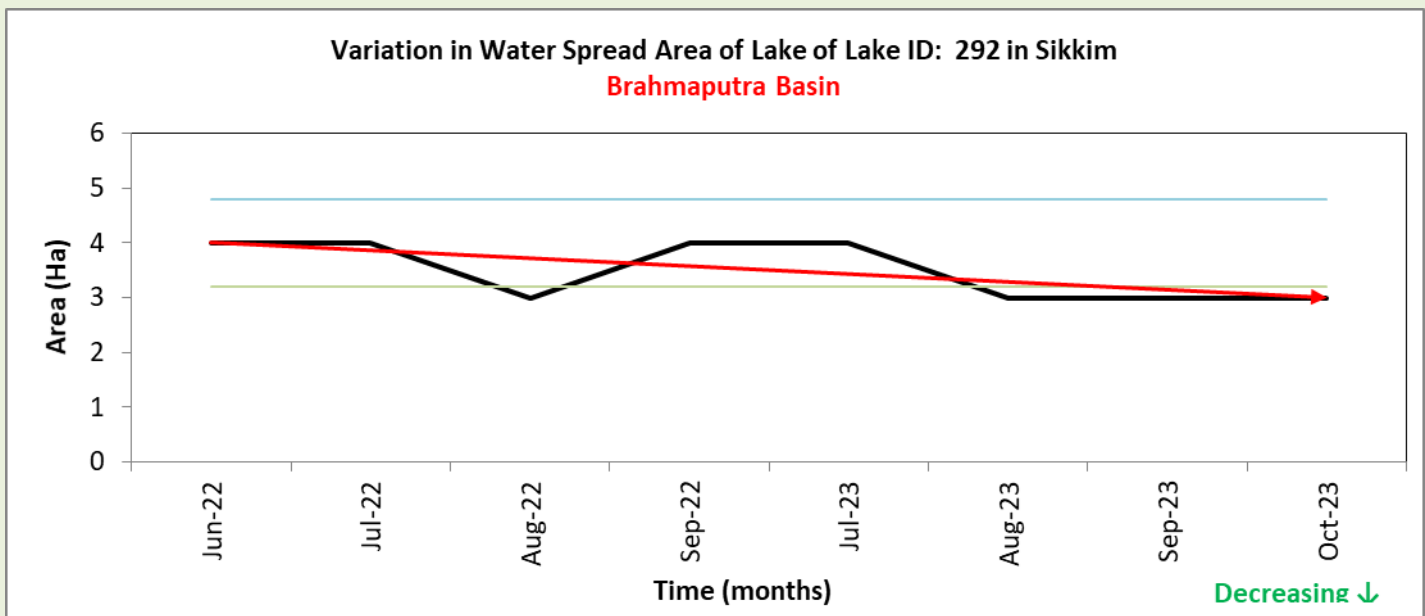


Figure 4.111(i) Trend Analysis Plot  $\pm 10\%$

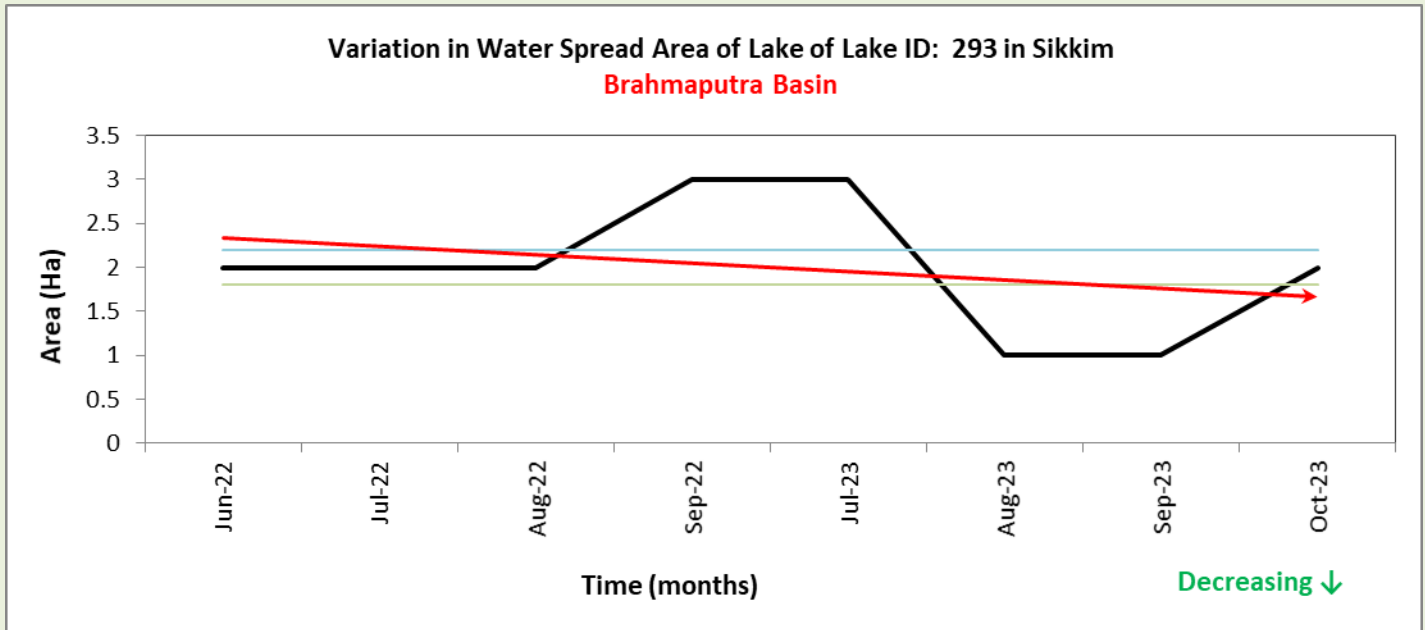


Figure 4.111(ii) Trend Analysis Plot  $\pm 20\%$

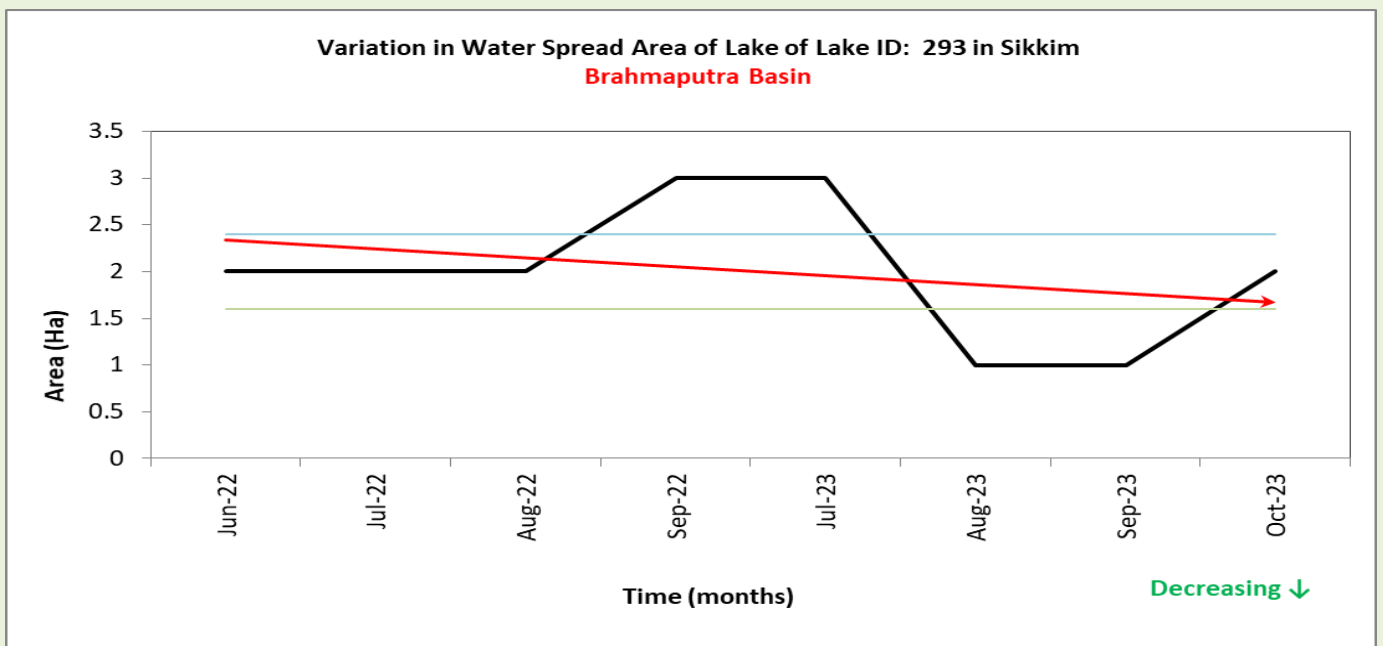


Figure 4.112(i) Trend Analysis Plot  $\pm 10\%$

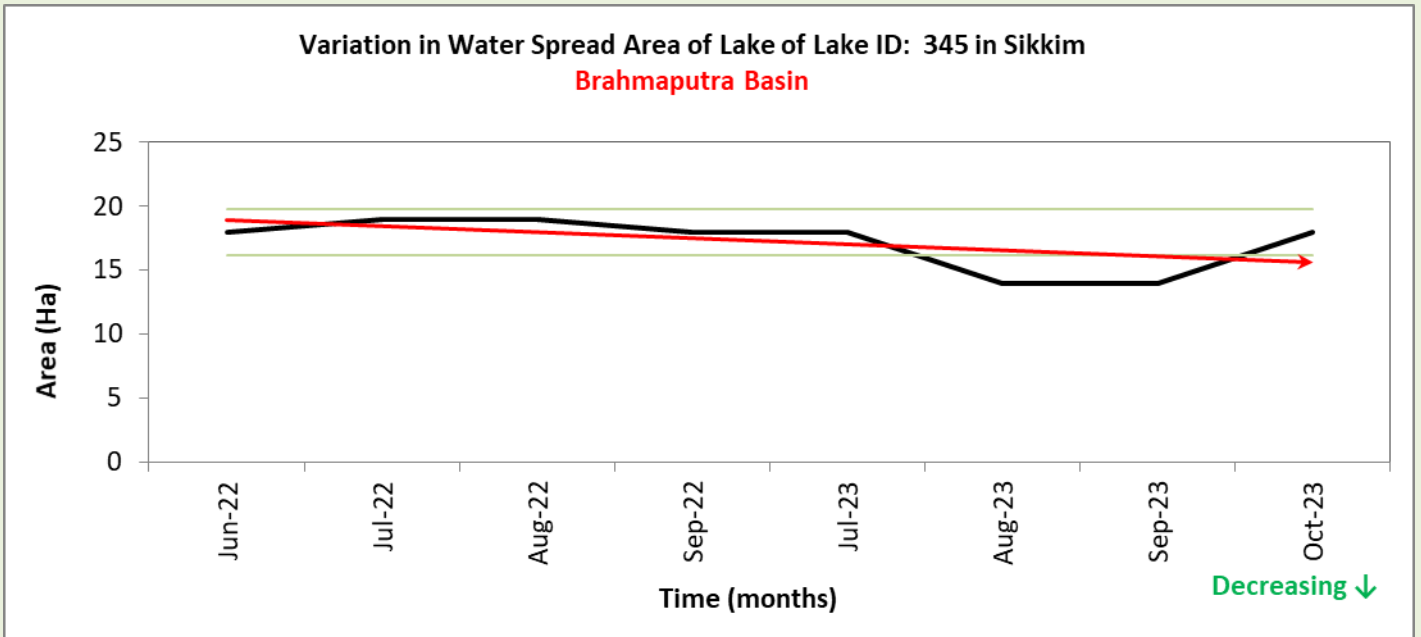
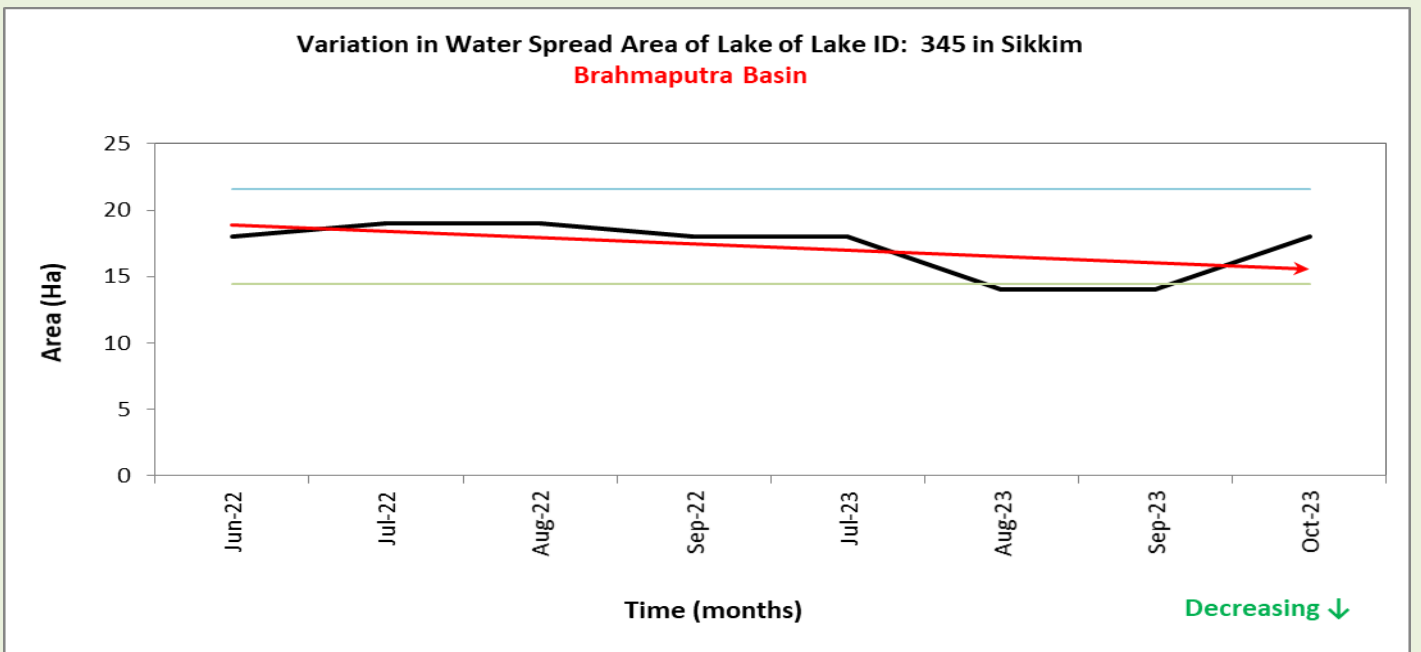


Figure 4.112(ii) Trend Analysis Plot  $\pm 20\%$



**Trend analysis of “Change in water spread area of Glacial Lakes between 10 Ha to 50 Ha of Arunachal Pradesh (2011-2023)”**

Figure 4.113(i) Trend Analysis Plot 10%

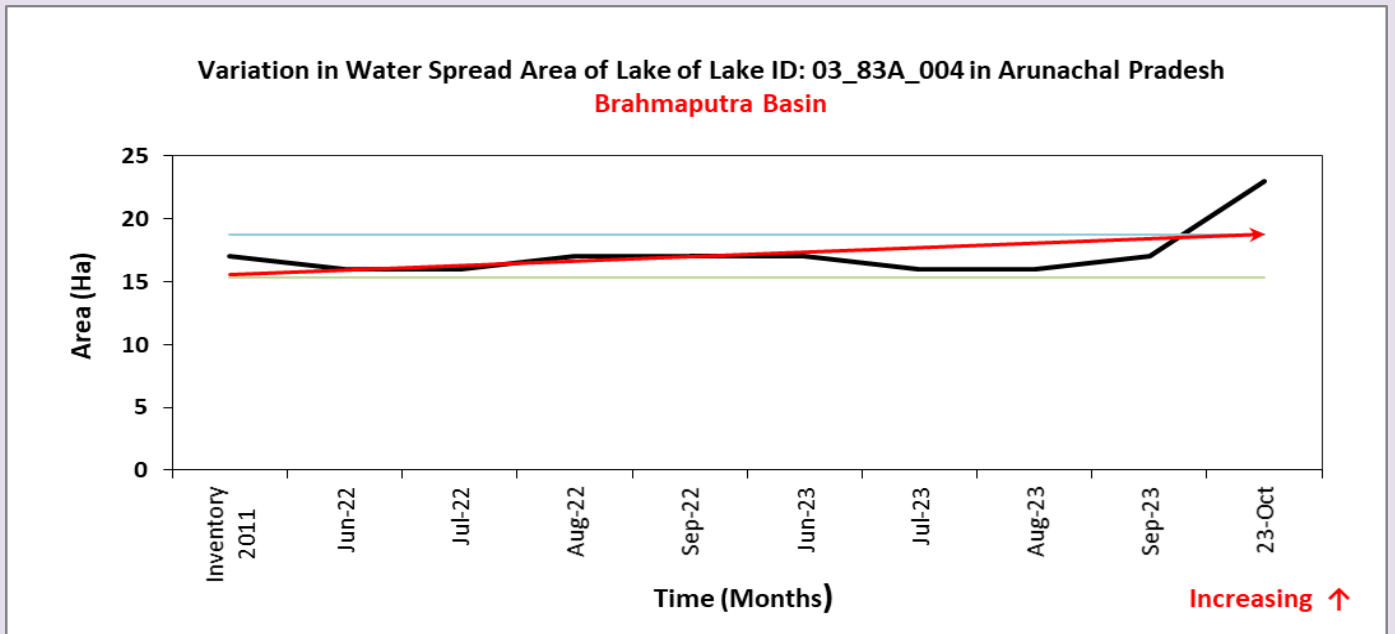


Figure 4.113(ii) Trend Analysis Plot 20%

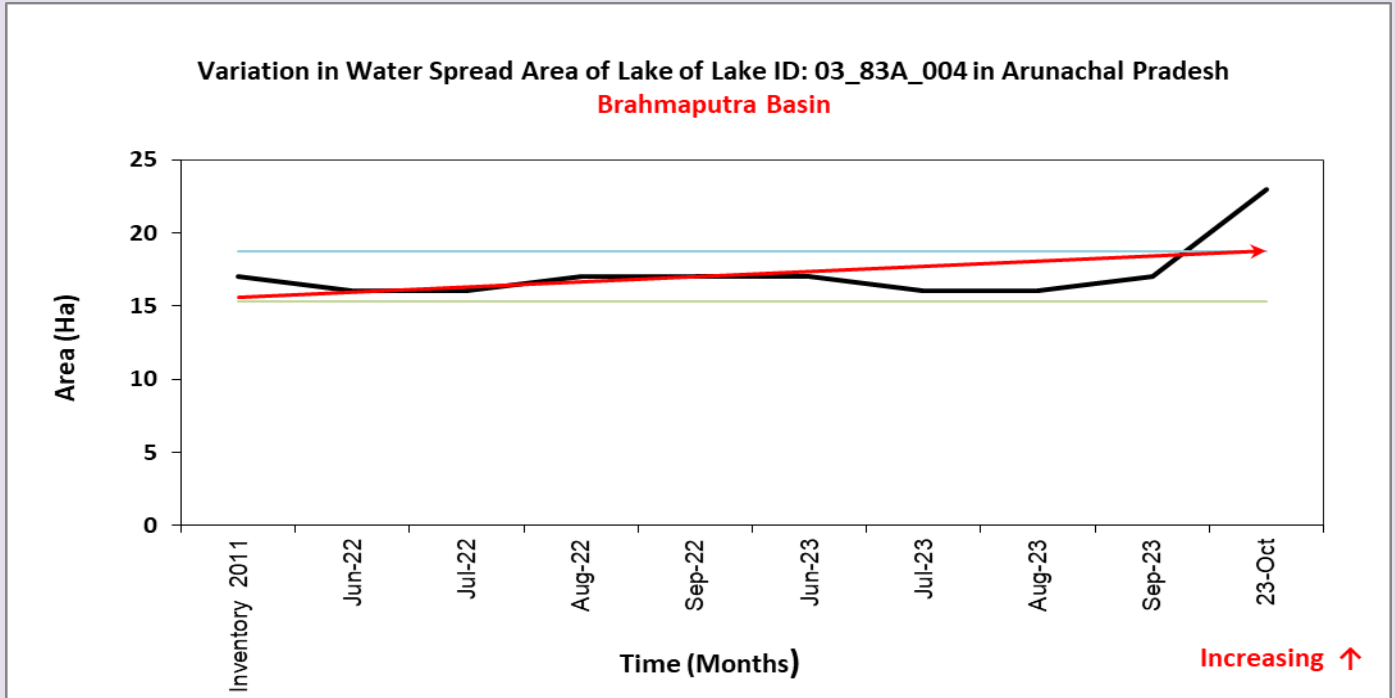


Figure 4.114(i) Trend Analysis Plot  $\pm 10\%$

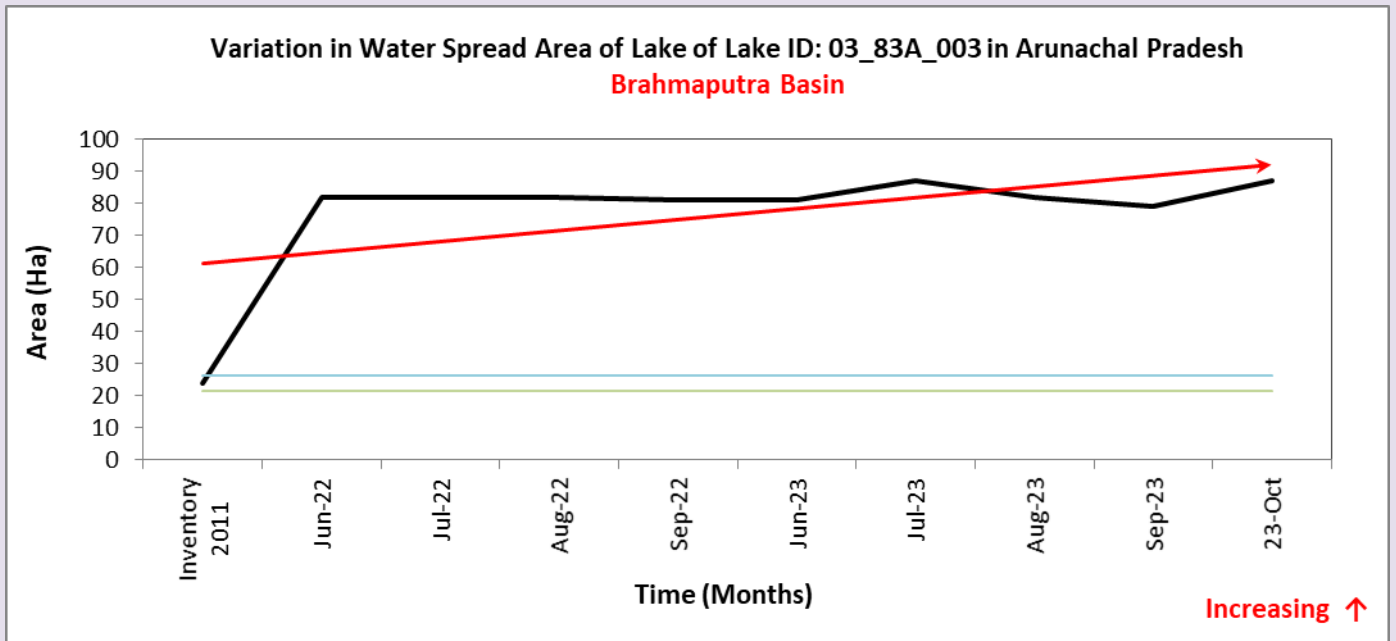


Figure 4.114(ii) Trend Analysis Plot  $\pm 20\%$

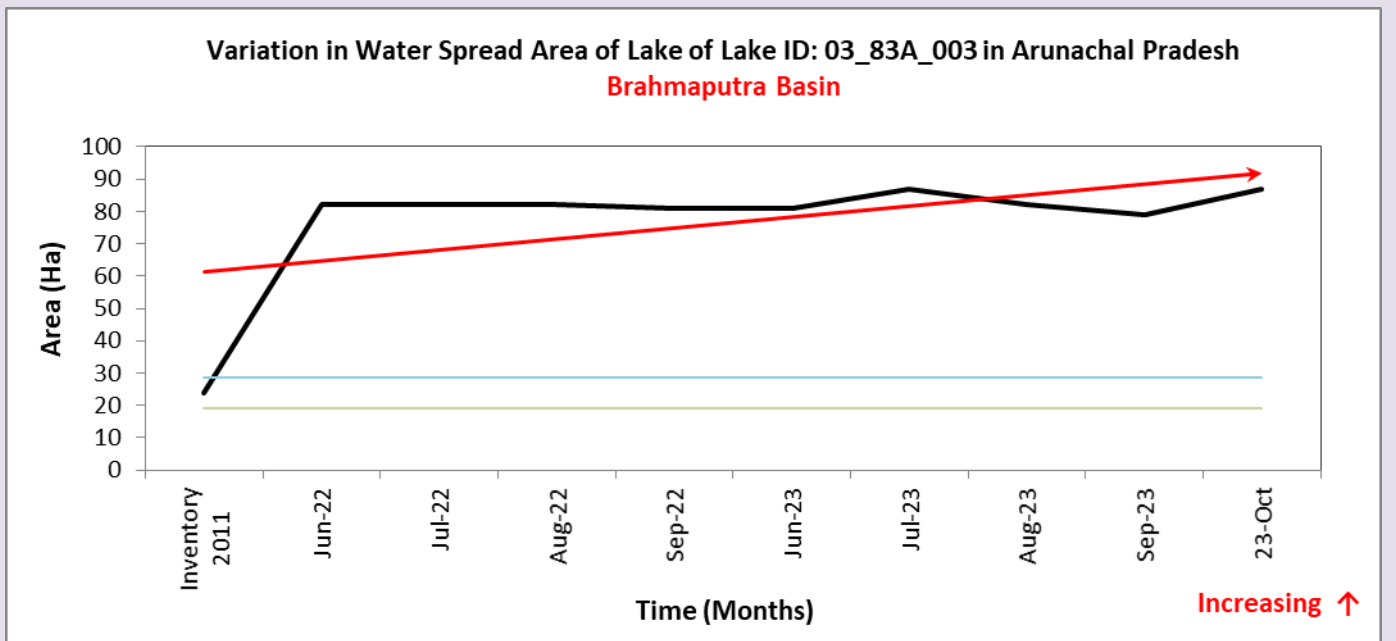


Figure 4.115(i) Trend Analysis Plot  $\pm 10\%$

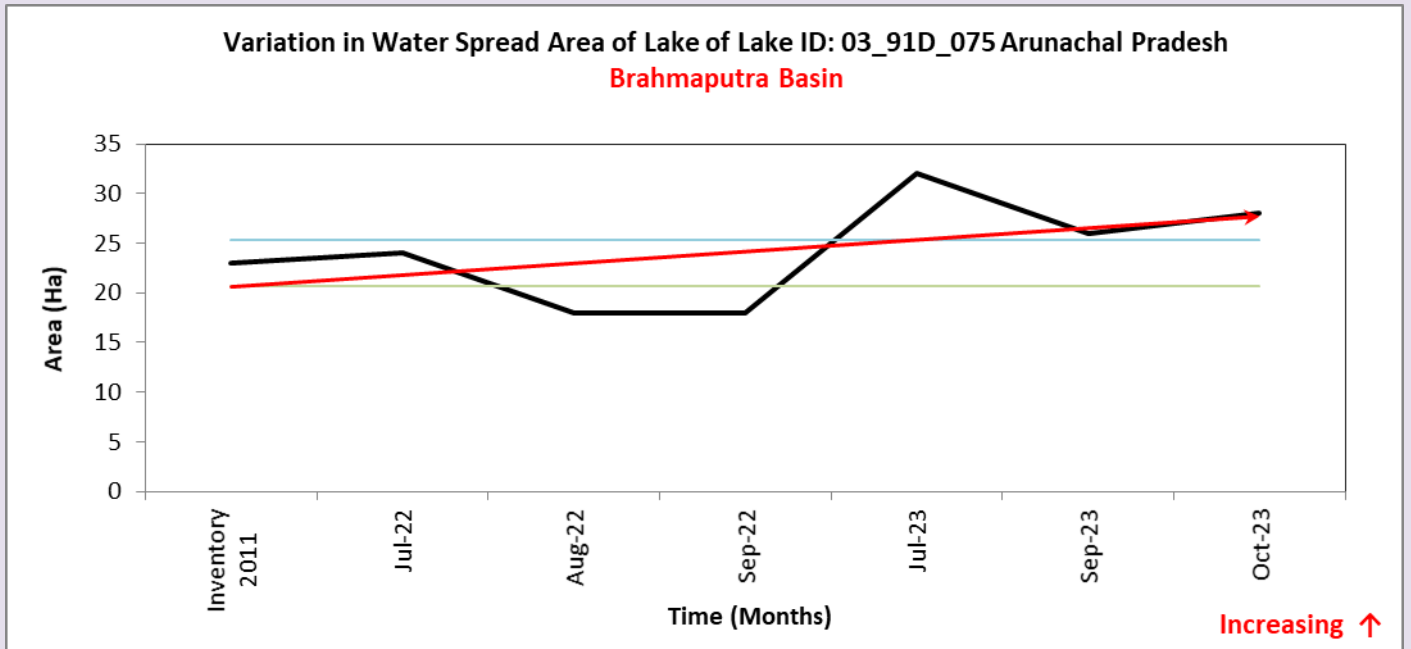


Figure 4.115(ii) Trend Analysis Plot  $\pm 20\%$

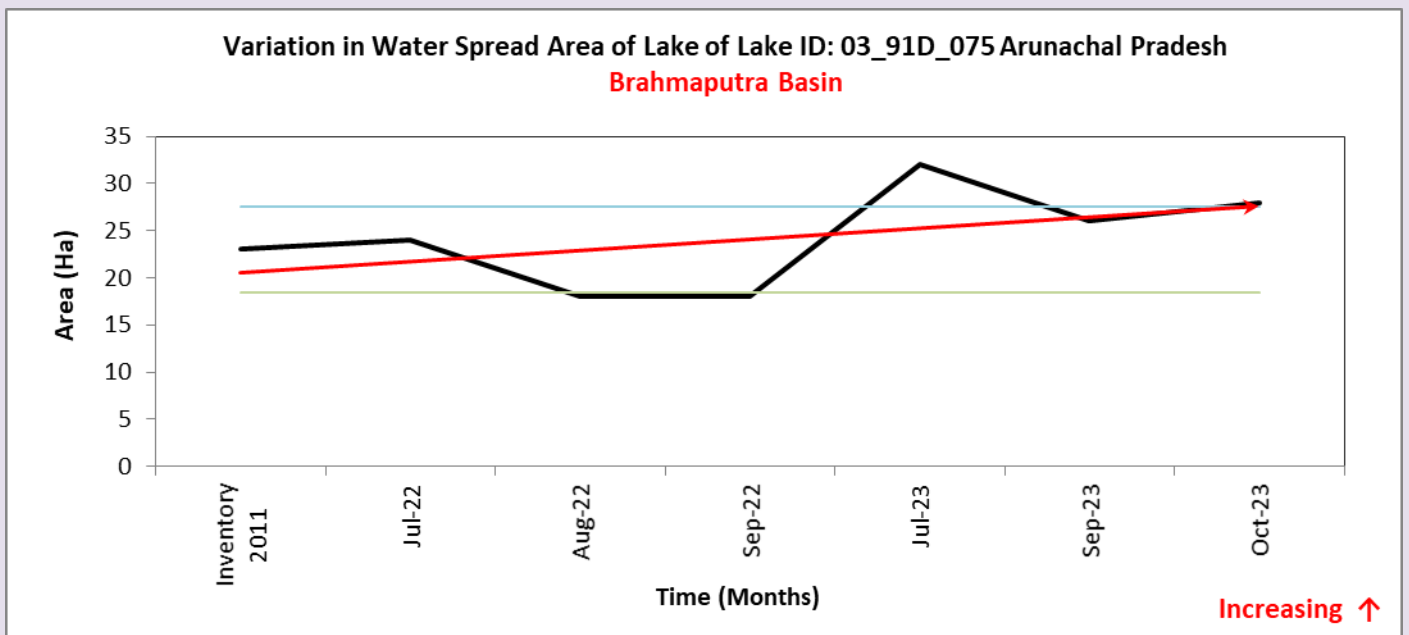


Figure 4.116(i) Trend Analysis Plot  $\pm 10\%$

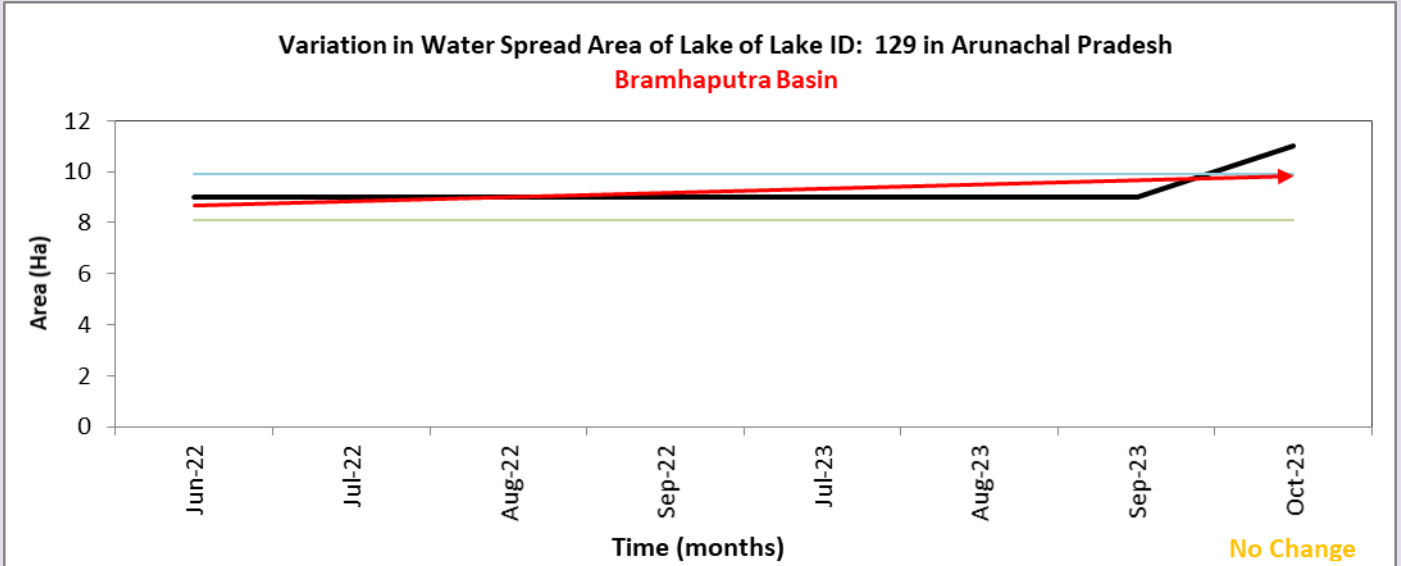


Figure 4.116(ii) Trend Analysis Plot  $\pm 20\%$

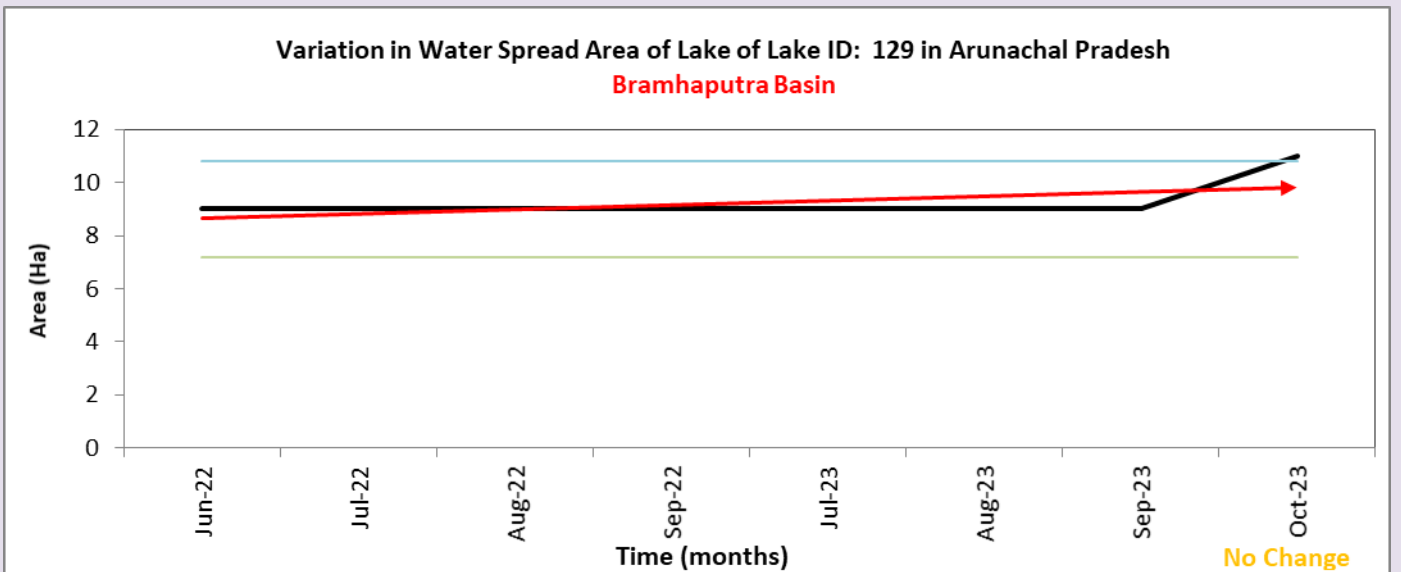


Figure 4.117(i) Trend Analysis Plot  $\pm 10\%$

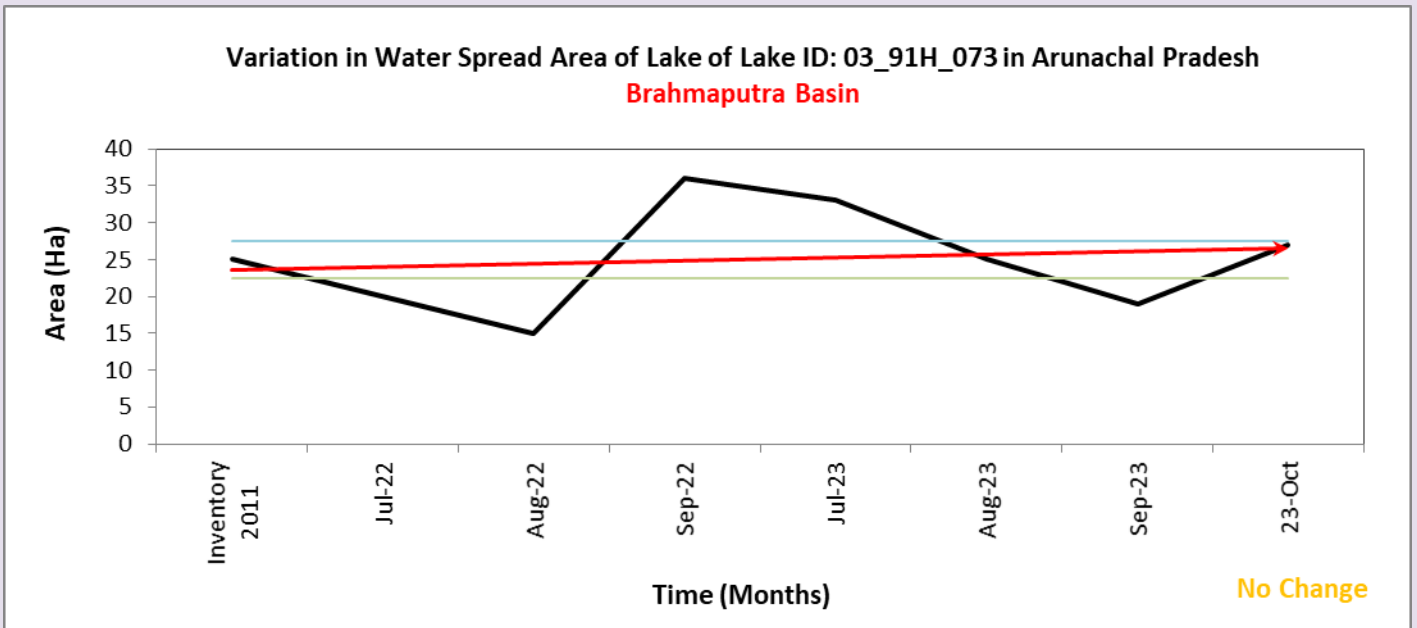


Figure 4.117(ii) Trend Analysis Plot  $\pm 20\%$

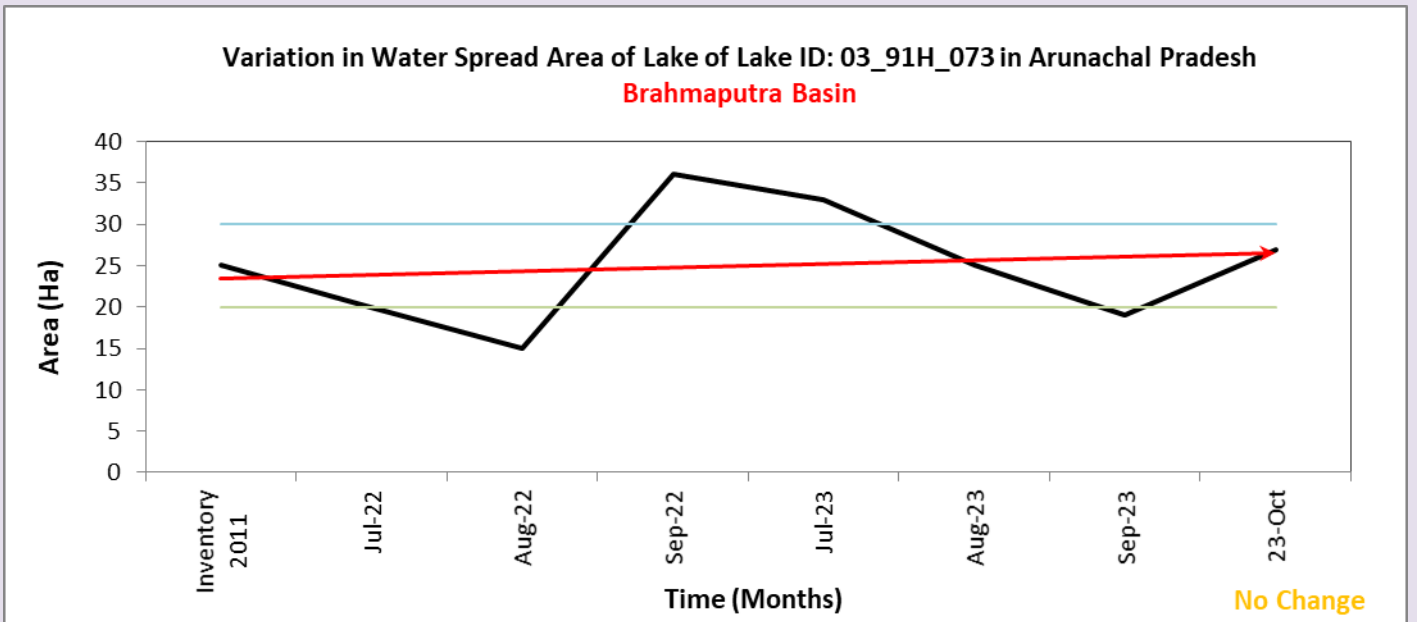


Figure 4.118(i) Trend Analysis Plot  $\pm 10\%$

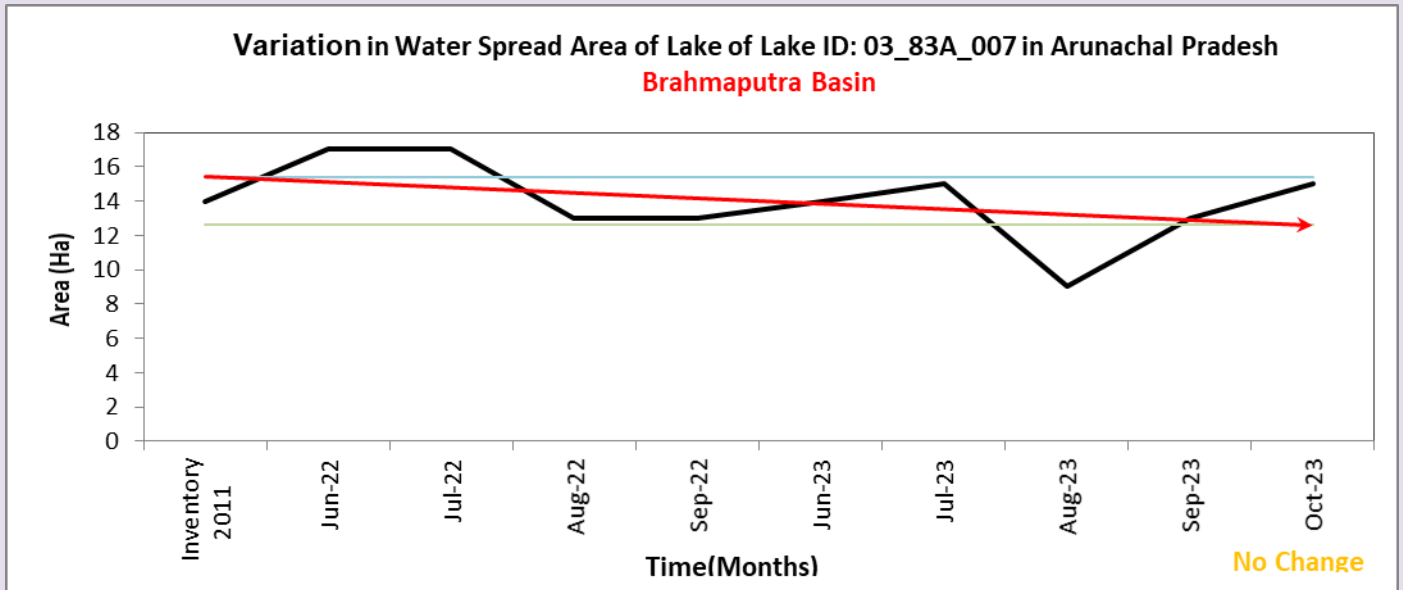


Figure 4.118(ii) Trend Analysis Plot  $\pm 20\%$

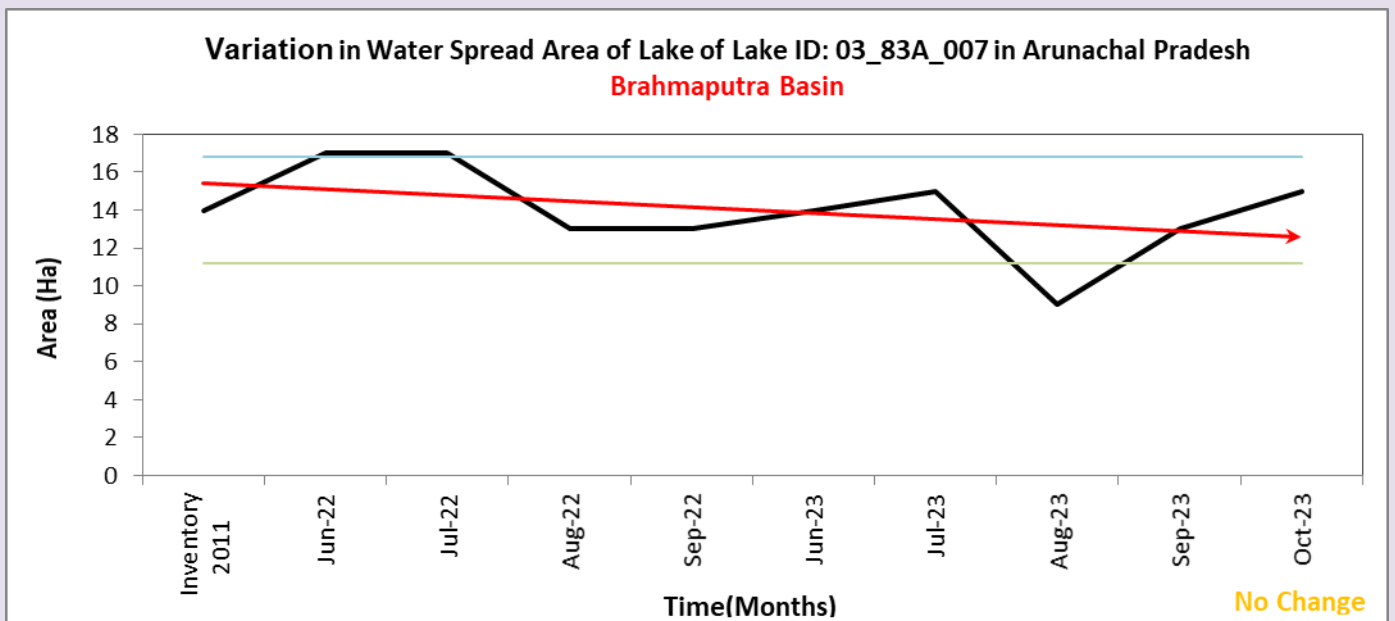


Figure 4.119(i) Trend Analysis Plot  $\pm 10\%$

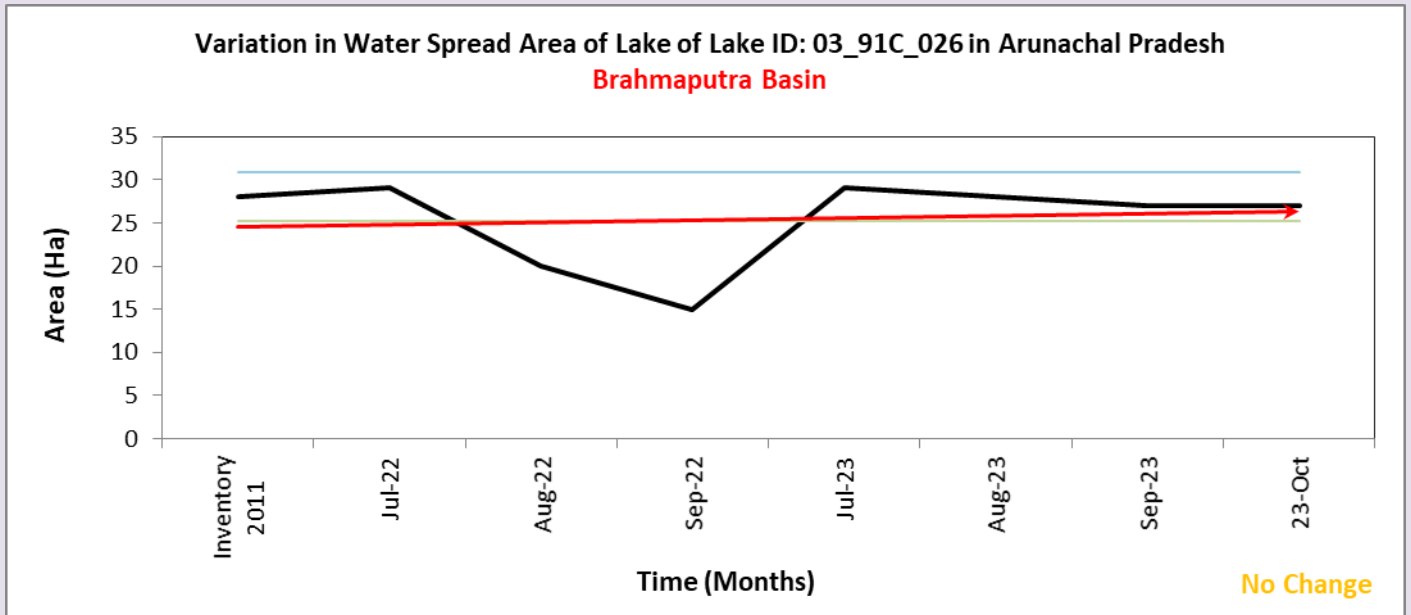


Figure 4.119(ii) Trend Analysis Plot  $\pm 20\%$

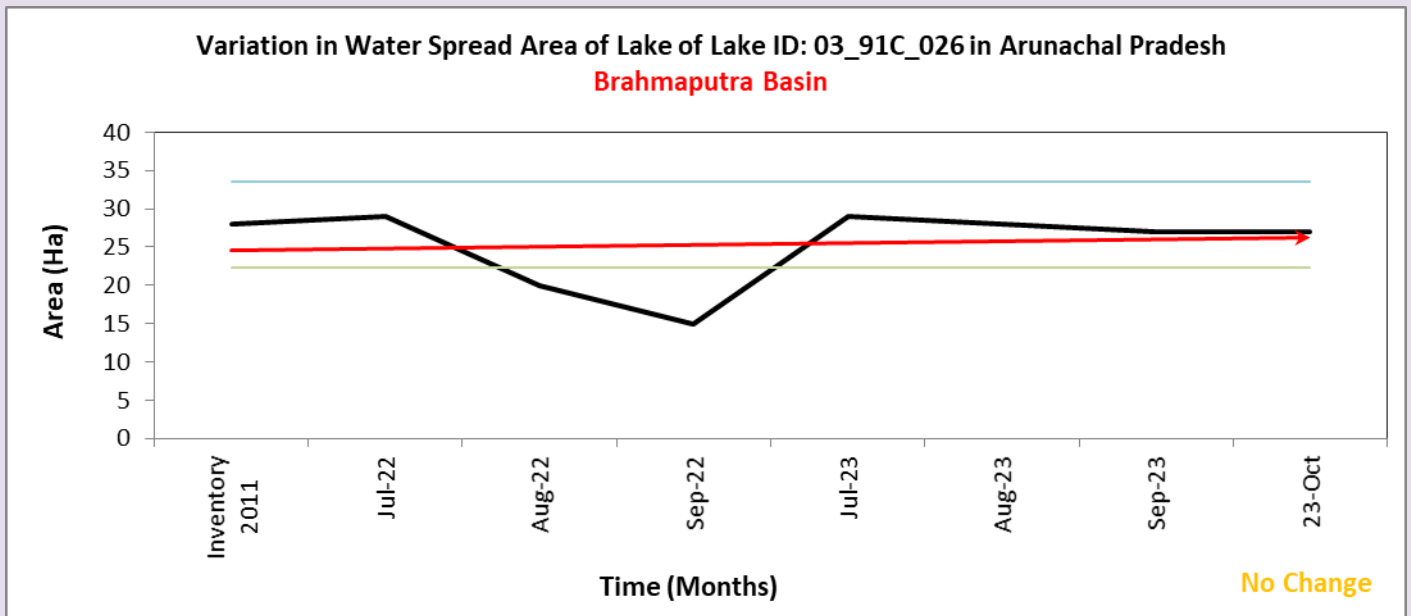


Figure 4.120(i) Trend Analysis Plot  $\pm 10\%$

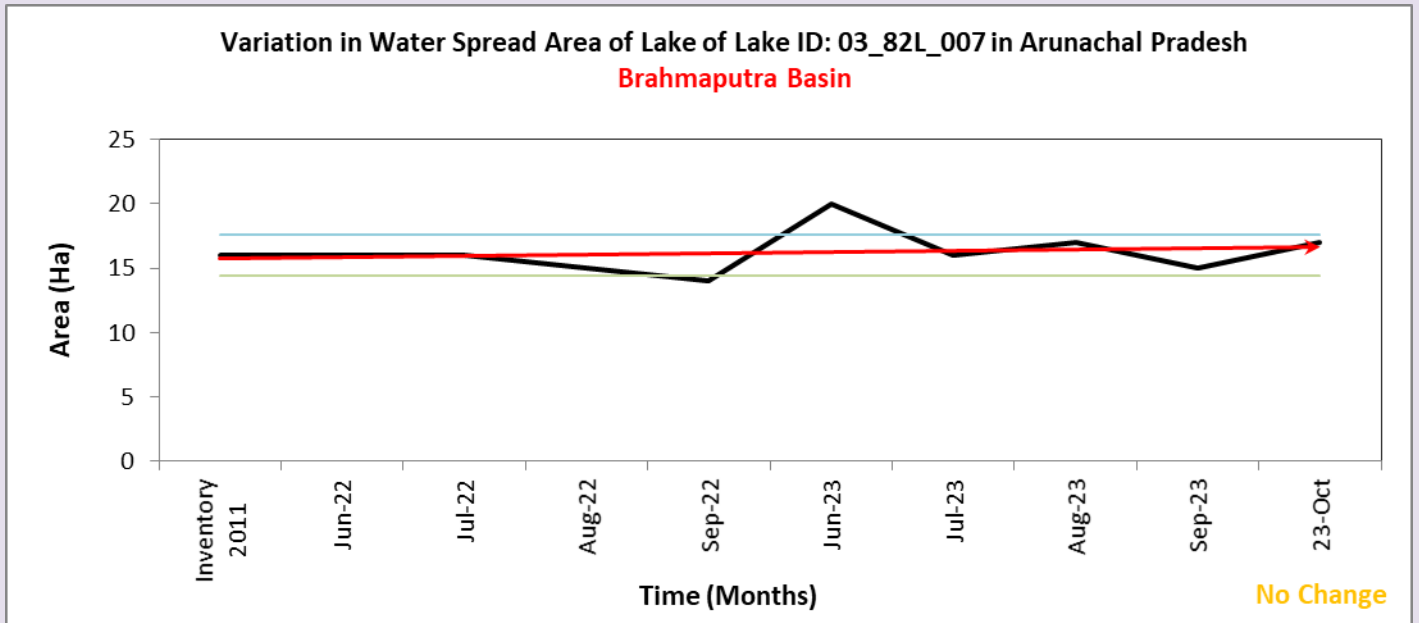


Figure 4.120(ii) Trend Analysis Plot  $\pm 20\%$

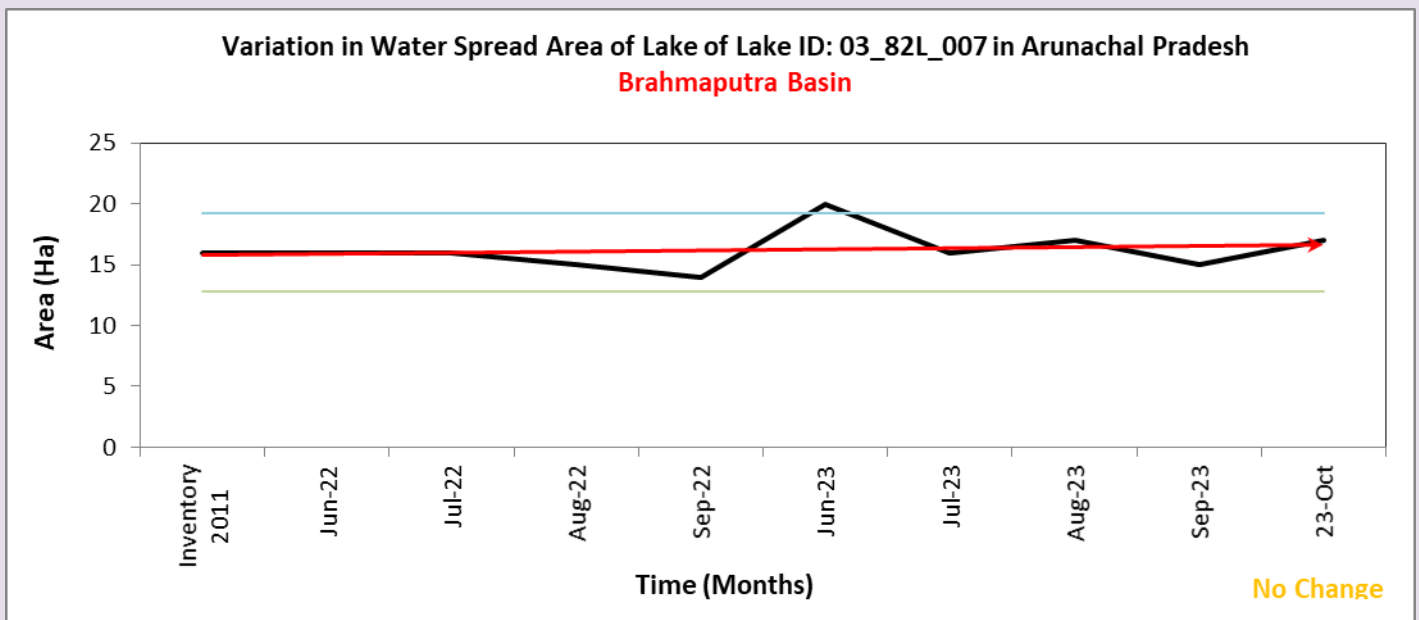


Figure 4.121(i) Trend Analysis Plot  $\pm 10\%$

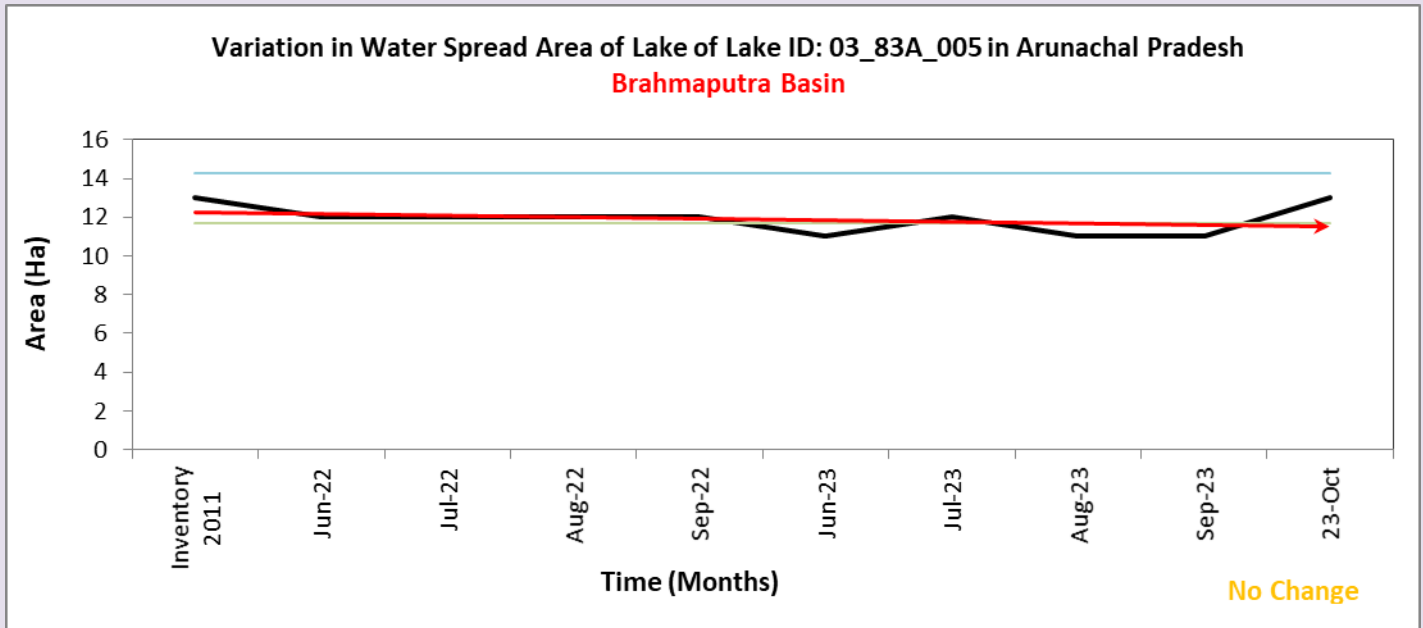
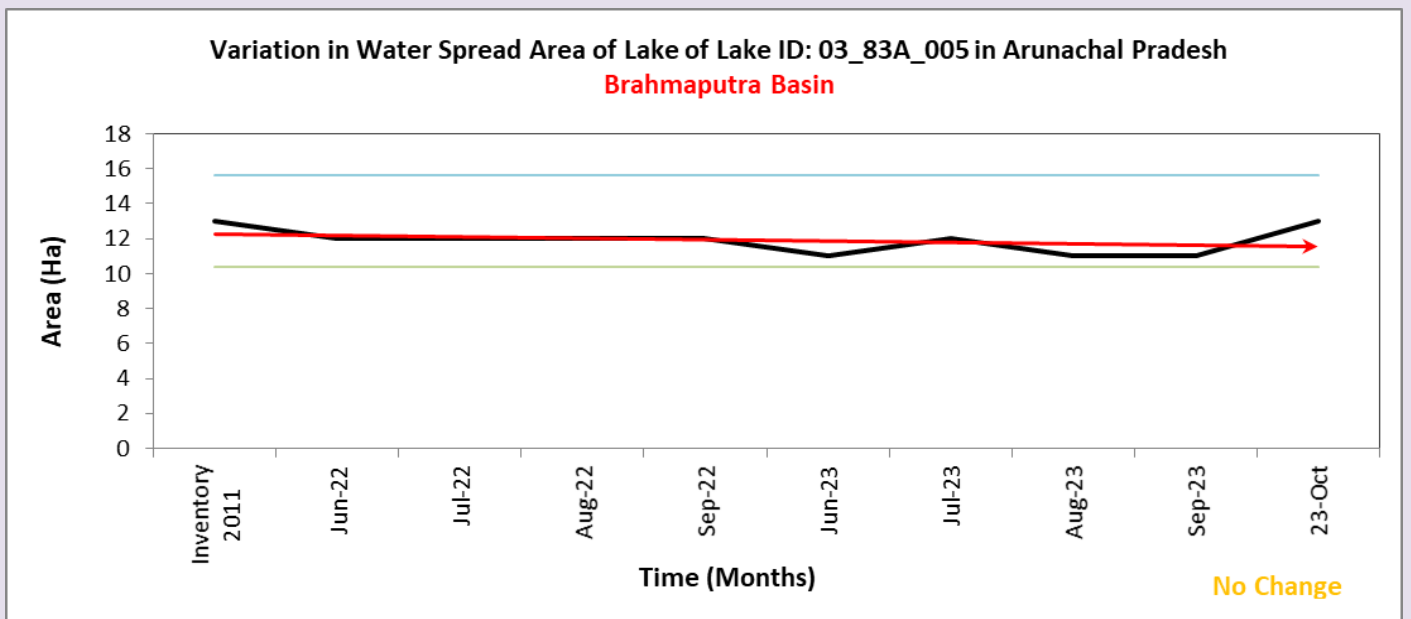


Figure 4.121(ii) Trend Analysis Plot  $\pm 20\%$



#### 4.6.7 Trend analysis of 85 Glacial Lakes of size between 10 Ha to 50 Ha (2022-2023) for $\pm 10\%$ variation Base Year data June 2022

Trend analysis was carried on the monitoring data of the year 2022 and 2023, for a  $\pm 10\%$  variation with respect to June 2022 data, so as to find out the **recent trend** in change in water spread area. Any sudden increase in water spread area lakes for the last two years alarms vigorous monitoring from disaster point of view.

**18 Glacial Lakes** have shown a consistent increase in water spread area when analysis was carried out for  $\pm 10\%$  variation with respect to 2022 data. Sikkim has the maximum number of lakes with increasing trend (6 Nos.), followed by Jammu & Kashmir and Arunachal Pradesh (4 Nos. each), Himachal Pradesh (2 Nos.) and Ladakh & Uttarakhand (1 No. each).

The state-wise distribution of lakes is given in table No. 4.18. The details are furnished in table No 4.19

**Table No.4.18: State wise details of trend analysis of Glacial Lakes of water spread area of 10 Ha to 50 Ha for a  $\pm 10\%$  variation in water spread area w.r.t June 2022 data**

S.No.	States	Increasing	No Change	Decreasing	No Analysis	Total
1	Ladakh	1	9	2	0	12
2	Jammu & Kashmir	4	8	3	0	15
3	Himachal Pradesh	2	5	1	0	8
4	Uttarakhand	1	5	1	2	9
5	Sikkim	6	14	12	0	32
6	Arunachal Pradesh	4	5	0	0	9
	<b>Total</b>	18	46	19	2	85

**Table 4.19: Trend Analysis of Glacial Lakes 10- 50 ha in size located in India analysed for 10% variation in water spread area based on 2 years data (2022-2023) w.r.t. June 2022 data**

Sl. No	Lake ID	Latitude(N)	Longitude (E)	Elevation (m)	River	Basin	Country	State	Inventory 2011(Area in Ha)	Trend ( $\pm 10\%$ )
1	01_42H_002	36° 38' 34.8"	73° 24' 26.64"	2763	Gilgit	Indus	India	Ladakh	13	No Change
2	01_52C_001	33° 56' 44.52"	76° 13' 53.76"	4394	Shingo (Indus)	Indus	India	Ladakh	36	No Change
3	1360	35° 1' 40.87"	75° 43' 36.84"	4667		Indus	India	Ladakh		Increasing
4	01_52L_006	32° 26' 27.24"	78° 55' 29.28"	5727	Indus	Indus	India	Ladakh	12	No Change
5	01_52B_012	34° 0' 19.8"	76° 47' 12.84"	5137	Indus	Indus	India	Ladakh	17	No Change
6	01_52L_007	32° 24' 36.36"	78° 53' 56.4"	5498	Indus	Indus	India	Ladakh	32	No Change
7	01_52B_010	34° 3' 6.48"	76° 43' 5.16"	5122	Indus	Indus	India	Ladakh	18	No Change
8	173	34° 46' 12.35"	76° 42' 31.20"	5150		Indus	India	Ladakh		No Change
9	180	34° 21' 13.694"	76° 4' 35.57"	4442		Indus	India	Ladakh		No Change
10	01_52A_002	35° 5' 48.12"	76° 14' 0.6"	4537	Shyok	Indus	India	Ladakh	23	Decreasing
11	01_52A_004	35° 4' 28.2"	76° 17' 33.72"	4619	Shyok	Indus	India	Ladakh	11	No Change
12	01_52A_003	35° 5' 33.36"	76° 15' 7.2"	4586	Shyok	Indus	India	Ladakh	24	Decreasing
13	01_52C_002	33° 52' 10.2"	76° 7' 9.48"	4092	Chenab	Indus	India	Jammu & Kashmir	26	No Change

14	27	34°22'40.837"	74°52'34.23"	3775		Indus	India	Jammu & Kashmir		Increasing
15	98	34°23'30.053"	75°5'6.93"	4103		Indus	India	Jammu & Kashmir		Increasing
16	958	34°8'15.508"	75°24'59.64"	4103		Indus	India	Jammu & Kashmir		Increasing
17	963	34°8'13.5"	75°22'33.06"	3725		Indus	India	Jammu & Kashmir		Increasing
18	182	34°14'1.589"	75°19'25.60"	4304		Indus	India	Jammu & Kashmir		No Change
19	931	33°55'55.346"	75°23'33.77"	4082		Indus	India	Jammu & Kashmir		No Change
20	951	34°3'58.769"	75°28'31.00"	3762		Indus	India	Jammu & Kashmir		No Change
21	976	34°11'2.939"	75°22'24.77"	4314		Indus	India	Jammu & Kashmir		No Change
22	1032	34°23'8.758"	75°3'55.60"	4007		Indus	India	Jammu & Kashmir		No Change
23	1037	34°25'28.86"	75°3'48.35"	3603		Indus	India	Jammu & Kashmir		No Change
24	01_43I_003	34° 55' 36.12"	74° 9' 19.44"	3954	Jhelum	Indus	India	Jammu & Kashmir	20	No Change
25	938	33°57'13.97"	75°22'40.33"	3683		Indus	India	Jammu & Kashmir		Decreasing
26	993	34°13'39.02"	75°13'19.29"	4148		Indus	India	Jammu & Kashmir		Decreasing
27	1014	34°17'51.96"	75°3'40.49"	3989		Indus	India	Jammu & Kashmir		Decreasing
28	01_53I_002	31° 39' 38.52"	78° 10' 1.92"	4273	Satluj	Indus	India	Himachal Pradesh	23	No Change
29	01_52H_003	32° 29' 54.6"	77° 32'37.32"	4165	Chenab	Indus	India	Himachal Pradesh	28	No Change
30	1805	32°45'44.51"	77°11'41.17"	4775		Indus	India	Himachal Pradesh		Increasing
31	1847	31°55'1.289"	77°32'17.84"	4570		Indus	India	Himachal Pradesh		Increasing
32	1774	32°13'19.45"	76°47'16.97"	4593		Indus	India	Himachal Pradesh		No Change
33	1936	32°15'17.28"	76°46'37.13"	4606		Indus	India	Himachal Pradesh		No Change
34	1998	32°19'12.49"	76°54'26.81"	3857		Indus	India	Himachal Pradesh		No Change
35	2031	31°20'14.094"	78°15'17.03"	4702		Indus	India	Himachal Pradesh		Decreasing
36	02_62B_005	30° 26' 44.52"	80°23'16.08"	4314	Sarda	Ganga	India	Uttarakhand	12	Increasing
37	01_62B_003	30° 28' 36.48"	80°35'35.16"	5288	Satluj	Indus	India	Uttarakhand	12	No Change
38	02_53N_001	30° 54' 7.92"	79° 45' 12.6"	4688	Ganga	Ganga	India	Uttarakhand	21	No Change
39	02_62B_004	30° 33' 52.2"	80° 10'41.16"	4918	Sarda	Ganga	India	Uttarakhand	19	No Change
40	2108	30°58'30.65"	79°27'32.41"	5587		Ganga	India	Uttarakhand		No Change
41	2207	30°54'40.89"	78°57'31.16"	4707		Ganga	India	Uttarakhand		No Change
42	2147	30°58'44.98"	79°29'8.99"	5688		Ganga	India	Uttarakhand		Decreasing
43	02_62B_007	30° 16' 42.96"	80° 7' 49.8"	4839	Sarda	Ganga	India	Uttarakhand	19	No Analysis
44	2299	30°10'59.57"	79°52'52.3"	4490		Ganga	India	Uttarakhand		No Analysis
45	03_78A_035	27° 57' 3.24"	88° 21'15.48"	4998	Teesta	Brahmaputra	India	Sikkim	N.A.	Increasing
46	03_78A_027	27° 32' 0.6"	88° 5' 8.52"	4888	Teesta	Brahmaputra	India	Sikkim	33	Increasing
47	03_77D_006	28° 0' 51.84"	88° 33'41.76"	5084	Teesta	Brahmaputra	India	Sikkim	22	Increasing
48	03_78A_005	27° 58' 31.44"	88° 25'20.64"	5201	Teesta	Brahmaputra	India	Sikkim	11	No Change
49	03_78A_002	27° 58' 56.28"	88° 30'28.08"	4952	Teesta	Brahmaputra	India	Sikkim	22	Decreasing
50	227	27°59'32.62"	88°32'49.54"	5176		Brahmaputra	India	Sikkim		Increasing
51	295	27°55'16.42"	88°40'21.86"	4850		Brahmaputra	India	Sikkim		Increasing
52	298	27°42'3.09"	88°30'55.99"	4508		Brahmaputra	India	Sikkim		Increasing
53	03_78A_007	27° 57' 38.88"	88° 38'57.48"	4977	Teesta	Brahmaputra	India	Sikkim	17	No Change
54	03_78A_023	27° 40' 17.04"	88° 30'46.44"	4547	Teesta	Brahmaputra	India	Sikkim	33	No Change
55	03_78A_031	27° 26' 15"	88° 5' 9.6"	4305	Teesta	Brahmaputra	India	Sikkim	14	No Change

56	03_78A_010	27° 57' 0.72"	88° 18'16.92"	5078	Teesta	Brahmaputra	India	Sikkim	36	No Change
57	03_78A_017	27° 53' 34.8"	88° 11'31.92"	5545	Teesta	Brahmaputra	India	Sikkim	19	Decreasing
58	03_78A_006	27° 58' 15.6"	88° 25'45.84"	5004	Teesta	Brahmaputra	India	Sikkim	11	Decreasing
59	03_77D_007	28° 0' 26.28"	88° 34'18.48"	5015	Teesta	Brahmaputra	India	Sikkim	24	Decreasing
60	03_78A_012	27° 54' 4.32"	88° 46'54.84"	5130	Teesta	Brahmaputra	India	Sikkim	26	Decreasing
61	03_78A_020	27° 52' 49.44"	88° 15' 4.68"	5219	Teesta	Brahmaputra	India	Sikkim	14	Decreasing
62	03_78A_026	27° 33' 44.28"	88° 7' 24.96"	4736	Teesta	Brahmaputra	India	Sikkim	11	No Change
63	237	27°59'39.437"	88°48'7.87"	5322		Brahmaputra	India	Sikkim		No Change
64	260	27°53'42.16"	88°45'40.71"	5253		Brahmaputra	India	Sikkim		No Change
65	312	27°52'27.53"	88°38'18.65"	5137		Brahmaputra	India	Sikkim		No Change
66	515	27°51'14.44"	88°48'31.30"	5063		Brahmaputra	India	Sikkim		No Change
67	569	28°0'9.23"	88°38'17.48"	5450		Brahmaputra	India	Sikkim		No Change
68	599	27°41'40.45"	88°42'56.53"	4251		Brahmaputra	India	Sikkim		No Change
69	03_78A_019	27° 51' 52.2"	88° 51'46.44"	4809	Teesta	Brahmaputra	India	Sikkim	15	No Change
70	03_78A_015	27° 52' 23.88"	88° 47' 22.2"	4970	Teesta	Brahmaputra	India	Sikkim	12	Decreasing
71	03_78A_016	27° 53' 33.72"	88° 12'47.16"	5451	Teesta	Brahmaputra	India	Sikkim	14	No Change
72	03_78A_008	27° 57' 3.24"	88° 21'15.48"	4998	Teesta	Brahmaputra	India	Sikkim	44	Decreasing
73	256	27°48'58.33"	88°39'19.44"	4615		Brahmaputra	India	Sikkim		Decreasing
74	292	28°0'20.43"	88°39'20.18"	5577		Brahmaputra	India	Sikkim		Decreasing
75	293	27°57'7.01"	88°42'18.24"	5048		Brahmaputra	India	Sikkim		Decreasing
76	345	27°51'49.12"	88°44'44.29"	5108		Brahmaputra	India	Sikkim		Decreasing
77	03_83A_004	27° 45' 47.16"	92°25'29.64"	5109	Dangme Chu	Brahmaputra	India	Arunachal Pradesh	17	Increasing
78	03_83A_003	27° 46' 12.72"	92° 25'56.64"	5188	Dangme Chu	Brahmaputra	India	Arunachal Pradesh	24	No Change
79	03_91D_075	28° 36' 28.8"	96° 19'14.16"	4274	Dibang	Brahmaputra	India	Arunachal Pradesh		Increasing
80	03_91H_073	28° 3' 15.48"	97° 19'47.64"	4481	Luhit	Brahmaputra	India	Arunachal Pradesh	25	Increasing
81	03_91C_026	29° 20' 18.24"	96° 4' 57.72"	4305	Dibang	Brahmaputra	India	Arunachal Pradesh	28	Increasing
82	03_82L_007	28° 50' 15"	94° 27' 5.04"	4163	Ding	Brahmaputra	India	Arunachal Pradesh	16	No Change
83	03_83A_005	27° 45' 20.52"	92° 24' 2.52"	4994	Dangme Chu	Brahmaputra	India	Arunachal Pradesh	13	No Change
84	03_83A_007	27° 43' 39.36"	92° 26'12.48"	5028	JiaBrali	Brahmaputra	India	Arunachal Pradesh	14	No Change
85	129	27°46'24.165"	92°19'1.10"	4895		Brahmaputra	India	Arunachal Pradesh		No Change

#### 4.6.8 Trend analysis of 85 Glacial Lakes of size between 10 Ha to 50 Ha (2022-2023) for $\pm 20\%$ variation Base Year data June 2022

Trend analysis was carried out for  $\pm 20\%$  variation with respect to June 2022 data, on the monitoring data of the year 2022 and 2023 to find out the recent trend in change in water spread area. Lakes showing increasing trend within  $\pm 20\%$  band are more potentially dangerous and may require risk and vulnerability assessment.

**17 Glacial Lakes** have shown a consistent increase in water spread area when analysis was carried out for  $\pm 20\%$  variation with respect to June 2022 data. Sikkim has the maximum number of lakes with increasing trend (5 Nos.), followed by Jammu & Kashmir and Arunachal Pradesh (4 Nos. each), Himachal Pradesh (2 Nos.) and Ladakh & Uttarakhand (1 No. each).

The state-wise distribution of lakes are given in table No.4.20. The details are furnished in table No.4.21.

**Table No.4.20: State wise details of trend analysis of Glacial Lakes of water spread area of 10 Ha to 50 Ha for a  $\pm 20\%$  variation in water spread area w.r.t June 2022 data**

S.No.	States	Increasing	No Change	Decreasing	No Analysis	Total
1	Ladakh	1	9	2	0	12
2	Jammu & Kashmir	4	8	3	0	15
3	Himachal Pradesh	2	5	1	0	8
4	Uttarakhand	1	5	1	2	9
5	Sikkim	5	15	12	0	32
6	Arunachal Pradesh	4	5	0	0	9
	<b>Total</b>	17	47	19	2	85

**Table No.4.21: Trend Analysis of Glacial Lakes 10- 50 ha in size located in India analysed for  $\pm 20\%$  variation in water spread area based on 2 years data (2022-2023)**

SL No	Lake ID	Latitude(N)	Longitude (E)	Elevation (m)	River	Basin	Country	State	Inventory 2011 (Area in Ha)	Trend ( $\pm 20\%$ )
1	01_42H_002	36° 38' 34.8"	73° 24' 26.64"	2763	Gilgit	Indus	India	Ladakh	13	No Change
2	01_52C_001	33° 56' 44.52"	76° 13' 53.76"	4394	Shingo (Indus)	Indus	India	Ladakh	36	No Change
3	1360	35° 1' 40.87"	75° 43' 36.84"	4667		Indus	India	Ladakh		Increasing
4	01_52L_006	32° 26' 27.24"	78° 55' 29.28"	5727	Indus	Indus	India	Ladakh	12	No Change
5	01_52B_012	34° 0' 19.8"	76° 47' 12.84"	5137	Indus	Indus	India	Ladakh	17	No Change
6	01_52L_007	32° 24' 36.36"	78° 53' 56.4"	5498	Indus	Indus	India	Ladakh	32	No Change
7	01_52B_010	34° 3' 6.48"	76° 43' 5.16"	5122	Indus	Indus	India	Ladakh	18	No Change
8	173	34° 46' 12.35"	76° 42' 31.20"	5150		Indus	India	Ladakh		No Change
9	180	34° 21' 13.694"	76° 4' 35.57"	4442		Indus	India	Ladakh		No Change
10	01_52A_002	35° 5' 48.12"	76° 14' 0.6"	4537	Shyok	Indus	India	Ladakh	23	Decreasing
11	01_52A_004	35° 4' 28.2"	76° 17' 33.72"	4619	Shyok	Indus	India	Ladakh	11	No Change

12	01_52A_003	35° 5' 33.36"	76° 15' 7.2"	4586	Shyok	Indus	India	Ladakh	24	Decreasing
13	01_52C_002	33° 52' 10.2"	76° 7' 9.48"	4092	Chenab	Indus	India	Jammu & Kashmir	26	No Change
14	27	34°22'40.837"	74°52'34.23"	3775		Indus	India	Jammu & Kashmir		Increasing
15	98	34°23'30.053"	75°5'6.93"	4103		Indus	India	Jammu & Kashmir		Increasing
16	958	34°8'15.508"	75°24'59.64"	4103		Indus	India	Jammu & Kashmir		Increasing
17	963	34°8'13.5"	75°22'33.06"	3725		Indus	India	Jammu & Kashmir		Increasing
18	182	34°14'1.589"	75°19'25.60"	4304		Indus	India	Jammu & Kashmir		No Change
19	931	33°55'55.346"	75°23'33.77"	4082		Indus	India	Jammu & Kashmir		No Change
20	951	34°3'58.769"	75°28'31.00"	3762		Indus	India	Jammu & Kashmir		No Change
21	976	34°11'2.939"	75°22'24.77"	4314		Indus	India	Jammu & Kashmir		No Change
22	1032	34°23'8.758"	75°3'55.60"	4007		Indus	India	Jammu & Kashmir		No Change
23	1037	34°25'28.86"	75°3'48.35"	3603		Indus	India	Jammu & Kashmir		No Change
24	01_43J_003	34° 55' 36.12"	74° 9' 19.44"	3954	Jhelum	Indus	India	Jammu & Kashmir	20	No Change
25	938	33°57'13.97"	75°22'40.33"	3683		Indus	India	Jammu & Kashmir		Decreasing
26	993	34°13'39.02"	75°13'19.29"	4148		Indus	India	Jammu & Kashmir		Decreasing
27	1014	34°17'51.96"	75°3'40.49"	3989		Indus	India	Jammu & Kashmir		Decreasing
28	01_53I_002	31° 39' 38.52"	78° 10' 1.92"	4273	Satluj	Indus	India	Himachal Pradesh	23	No Change
29	01_52H_003	32° 29' 54.6"	77° 32'37.32"	4165	Chenab	Indus	India	Himachal Pradesh	28	No Change
30	1805	32°45'44.51"	77°11'41.17"	4775		Indus	India	Himachal Pradesh		Increasing
31	1847	31°55'1.289"	77°32'17.84"	4570		Indus	India	Himachal Pradesh		Increasing
32	1774	32°13'19.45"	76°47'16.97"	4593		Indus	India	Himachal Pradesh		No Change
33	1936	32°15'17.28"	76°46'37.13"	4606		Indus	India	Himachal Pradesh		No Change
34	1998	32°19'12.49"	76°54'26.81"	3857		Indus	India	Himachal Pradesh		No Change
35	2031	31°20'14.094"	78°15'17.03"	4702		Indus	India	Himachal Pradesh		Decreasing
36	02_62B_005	30° 26' 44.52"	80°23'16.08"	4314	Sarda	Ganga	India	Uttarakhand	12	Increasing
37	01_62B_003	30° 28' 36.48"	80°35'35.16"	5288	Satluj	Indus	India	Uttarakhand	12	No Change
38	02_53N_001	30° 54' 7.92"	79° 45' 12.6"	4688	Ganga	Ganga	India	Uttarakhand	21	No Change
39	02_62B_004	30° 33' 52.2"	80° 10'41.16"	4918	Sarda	Ganga	India	Uttarakhand	19	No Change
40	2108	30°58'30.65"	79°27'32.41"	5587		Ganga	India	Uttarakhand		No Change
41	2207	30°54'40.89"	78°57'31.16"	4707		Ganga	India	Uttarakhand		No Change
42	2147	30°58'44.98"	79°29'8.99"	5688		Ganga	India	Uttarakhand		Decreasing
43	02_62B_007	30° 16' 42.96"	80° 7' 49.8"	4839	Sarda	Ganga	India	Uttarakhand	19	No Analysis
44	2299	30°10'59.57"	79°52'52.3"	4490		Ganga	India	Uttarakhand		No Analysis
45	03_78A_035	27° 57' 3.24"	88° 21'15.48"	4998	Teesta	Brahmaputra	India	Sikkim	N.A.	Increasing
46	03_78A_027	27° 32' 0.6"	88° 5' 8.52"	4888	Teesta	Brahmaputra	India	Sikkim	33	Increasing
47	03_77D_006	28° 0' 51.84"	88° 33'41.76"	5084	Teesta	Brahmaputra	India	Sikkim	22	No Change
48	03_78A_005	27° 58' 31.44"	88° 25'20.64"	5201	Teesta	Brahmaputra	India	Sikkim	11	No Change
49	03_78A_002	27° 58' 56.28"	88° 30'28.08"	4952	Teesta	Brahmaputra	India	Sikkim	22	Decreasing
50	227	27°59'32.62"	88°32'49.54"	5176		Brahmaputra	India	Sikkim		Increasing
51	295	27°55'16.42"	88°40'21.86"	4850		Brahmaputra	India	Sikkim		Increasing
52	298	27°42'3.09"	88°30'55.99"	4508		Brahmaputra	India	Sikkim		Increasing

53	03_78A_007	27° 57' 38.88"	88° 38'57.48"	4977	Teesta	Brahmaputra	India	Sikkim	17	No Change
54	03_78A_023	27° 40' 17.04"	88° 30'46.44"	4547	Teesta	Brahmaputra	India	Sikkim	33	No Change
55	03_78A_031	27° 26' 15"	88° 5' 9.6"	4305	Teesta	Brahmaputra	India	Sikkim	14	No Change
56	03_78A_010	27° 57' 0.72"	88° 18'16.92"	5078	Teesta	Brahmaputra	India	Sikkim	36	No Change
57	03_78A_017	27° 53' 34.8"	88° 11'31.92"	5545	Teesta	Brahmaputra	India	Sikkim	19	Decreasing
58	03_78A_006	27° 58' 15.6"	88° 25'45.84"	5004	Teesta	Brahmaputra	India	Sikkim	11	Decreasing
59	03_77D_007	28° 0' 26.28"	88° 34'18.48"	5015	Teesta	Brahmaputra	India	Sikkim	24	Decreasing
60	03_78A_012	27° 54' 4.32"	88° 46'54.84"	5130	Teesta	Brahmaputra	India	Sikkim	26	Decreasing
61	03_78A_020	27° 52' 49.44"	88° 15' 4.68"	5219	Teesta	Brahmaputra	India	Sikkim	14	Decreasing
62	03_78A_026	27° 33' 44.28"	88° 7' 24.96"	4736	Teesta	Brahmaputra	India	Sikkim	11	No Change
63	237	27°59'39.437"	88°48'7.87"	5322		Brahmaputra	India	Sikkim		No Change
64	260	27°53'42.16"	88°45'40.71"	5253		Brahmaputra	India	Sikkim		No Change
65	312	27°52'27.53"	88°38'18.65"	5137		Brahmaputra	India	Sikkim		No Change
66	515	27°51'14.44"	88°48'31.30"	5063		Brahmaputra	India	Sikkim		No Change
67	569	28°0'9.23"	88°38'17.48"	5450		Brahmaputra	India	Sikkim		No Change
68	599	27°41'40.45"	88°42'56.53"	4251		Brahmaputra	India	Sikkim		No Change
69	03_78A_019	27° 51' 52.2"	88° 51'46.44"	4809	Teesta	Brahmaputra	India	Sikkim	15	No Change
70	03_78A_015	27° 52' 23.88"	88° 47' 22.2"	4970	Teesta	Brahmaputra	India	Sikkim	12	Decreasing
71	03_78A_016	27° 53' 33.72"	88° 12'47.16"	5451	Teesta	Brahmaputra	India	Sikkim	14	No Change
72	03_78A_008	27° 57' 3.24"	88° 21'15.48"	4998	Teesta	Brahmaputra	India	Sikkim	44	Decreasing
73	256	27°48'58.33"	88°39'19.44"	4615		Brahmaputra	India	Sikkim		Decreasing
74	292	28°0'20.43"	88°39'20.18"	5577		Brahmaputra	India	Sikkim		Decreasing
75	293	27°57'7.01"	88°42'18.24"	5048		Brahmaputra	India	Sikkim		Decreasing
76	345	27°51'49.12"	88°44'44.29"	5108		Brahmaputra	India	Sikkim		Decreasing
77	03_83A_004	27° 45' 47.16"	92°25'29.64"	5109	Dangme Chu	Brahmaputra	India	Arunachal Pradesh	17	Increasing
78	03_83A_003	27° 46' 12.72"	92° 25'56.64"	5188	Dangme Chu	Brahmaputra	India	Arunachal Pradesh	24	No Change
79	03_91D_075	28° 36' 28.8"	96° 19'14.16"	4274	Dibang	Brahmaputra	India	Arunachal Pradesh		Increasing
80	03_91H_073	28° 3' 15.48"	97° 19'47.64"	4481	Luhit	Brahmaputra	India	Arunachal Pradesh	25	Increasing
81	03_91C_026	29° 20' 18.24"	96° 4' 57.72"	4305	Dibang	Brahmaputra	India	Arunachal Pradesh	28	Increasing
82	03_82L_007	28° 50' 15"	94° 27' 5.04"	4163	Ding	Brahmaputra	India	Arunachal Pradesh	16	No Change
83	03_83A_005	27° 45' 20.52"	92° 24' 2.52"	4994	Dangme Chu	Brahmaputra	India	Arunachal Pradesh	13	No Change
84	03_83A_007	27° 43' 39.36"	92° 26'12.48"	5028	JiaBrali	Brahmaputra	India	Arunachal Pradesh	14	No Change
85	129	27°46'24.165"	92°19'1.10"	4895		Brahmaputra	India	Arunachal Pradesh		No Change

Lake-wise plot are appended as given below.

<i>Trend analysis for Change in Water spread area of Glacial Lakes (10-50 Ha) for <math>\pm 10\%</math> &amp; <math>\pm 20\%</math> w.r.t base year data of June 2022</i>		
S.No.	States	Figure No.
1	Ladakh	Figure 4.122(i)-Figure 4.133(ii)
2	Jammu & Kashmir	Figure 4.134(i)-Figure 4.148(ii)
3	Himachal Pradesh	Figure 4.149(i)-Figure 4.156(ii)
4	Uttarakhand	Figure 4.157(i)-Figure 4.163(ii)
5	Sikkim	Figure 4.164(i)-Figure 4.195(ii)
6	Arunachal Pradesh	Figure 4.196(i)-Figure 4.204(ii)

**Trend analysis of “Change in water spread area of Glacial Lakes between 10 Ha to 50 Ha of Ladakh (2022-2023)”**

Figure 4.122(i) Trend Analysis Plot  $\pm 10\%$

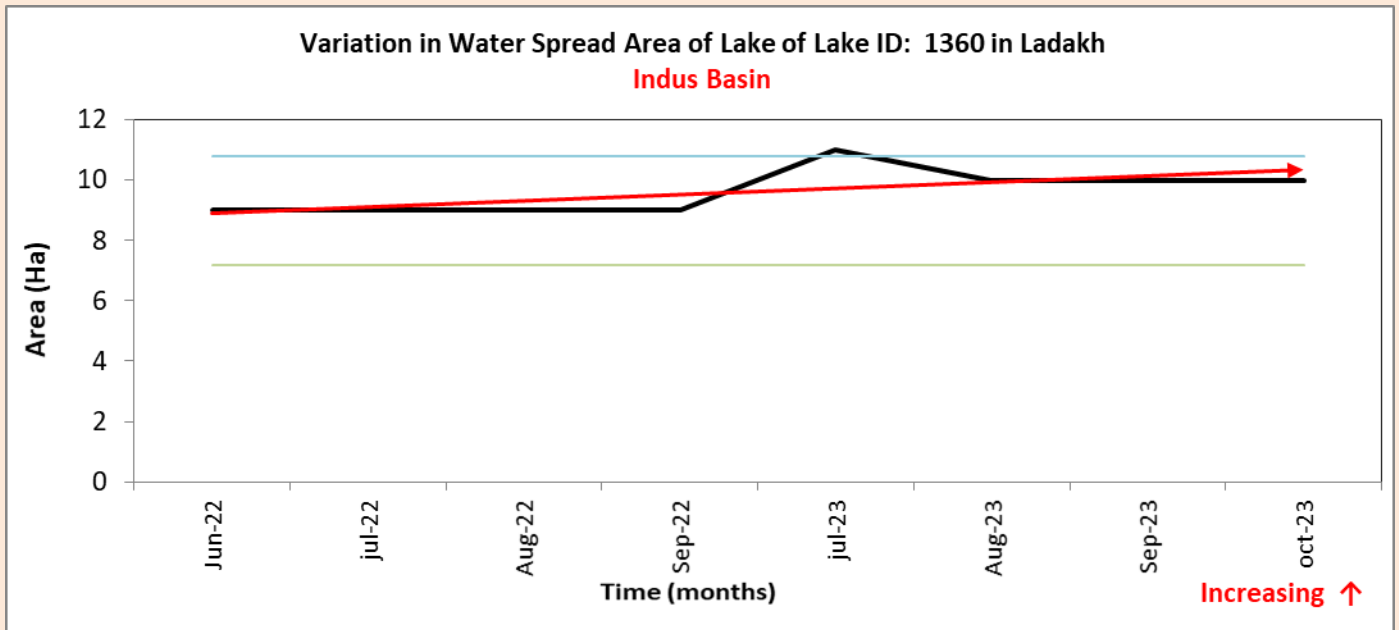


Figure 4.122(ii) Trend Analysis Plot  $\pm 20\%$

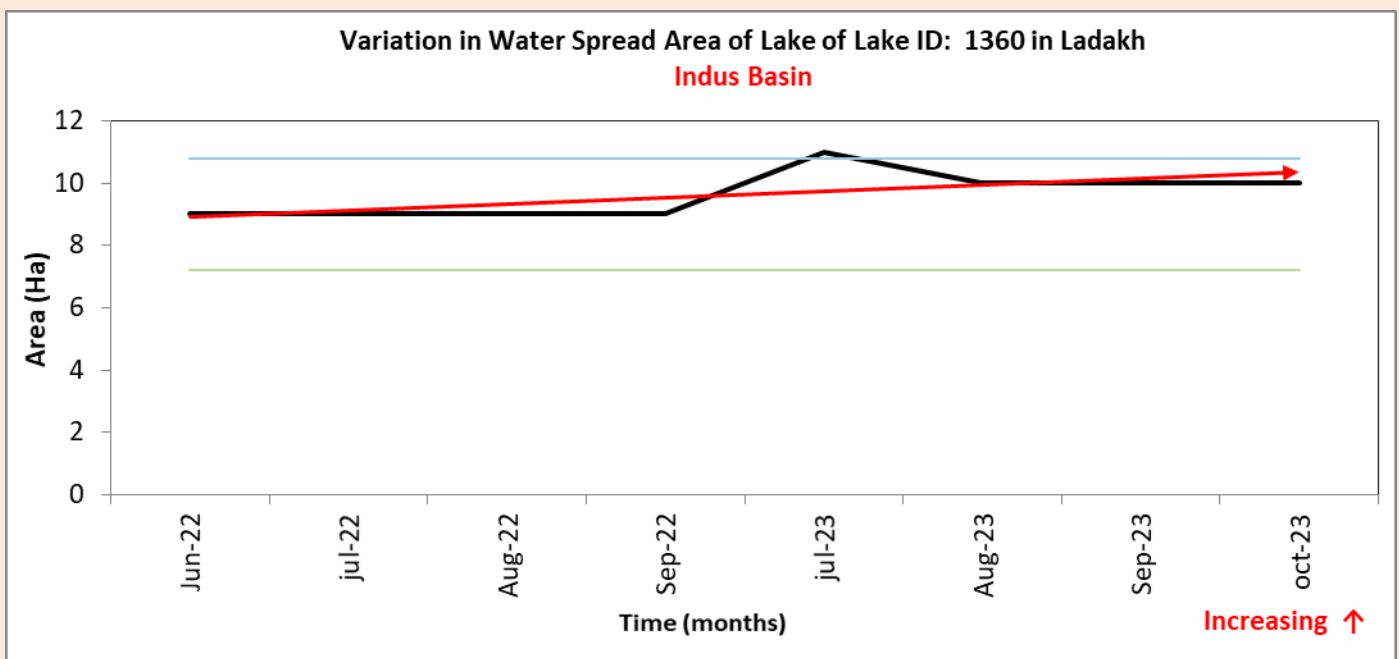


Figure 4.123(i) Trend Analysis Plot  $\pm 10\%$

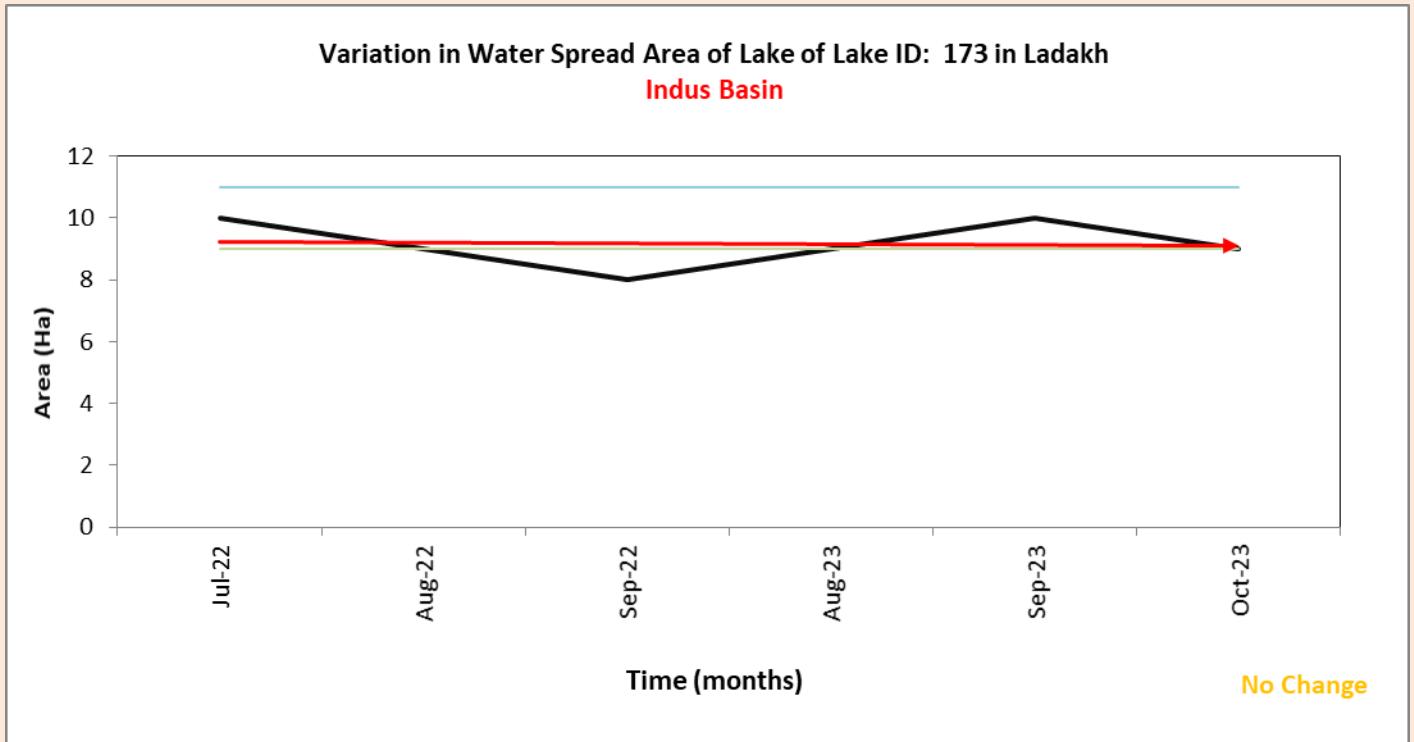


Figure 4.123(ii) Trend Analysis Plot  $\pm 20\%$

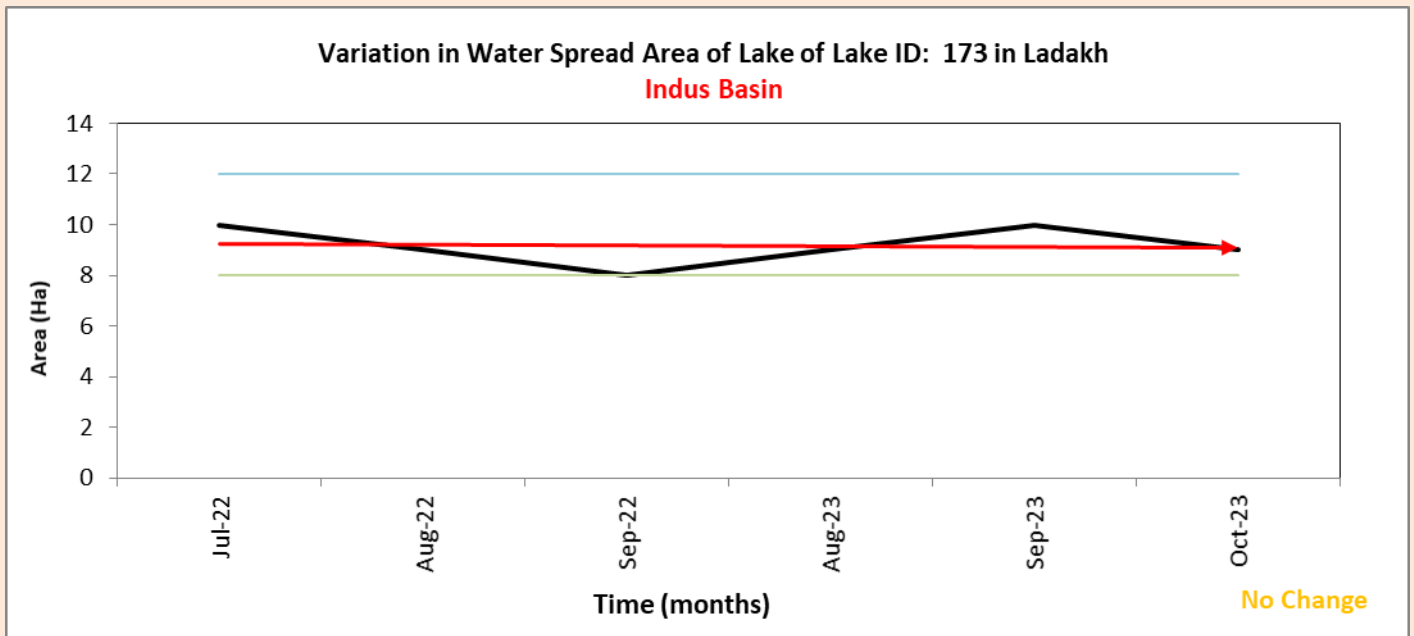


Figure 4.124(i) Trend Analysis Plot  $\pm 10\%$

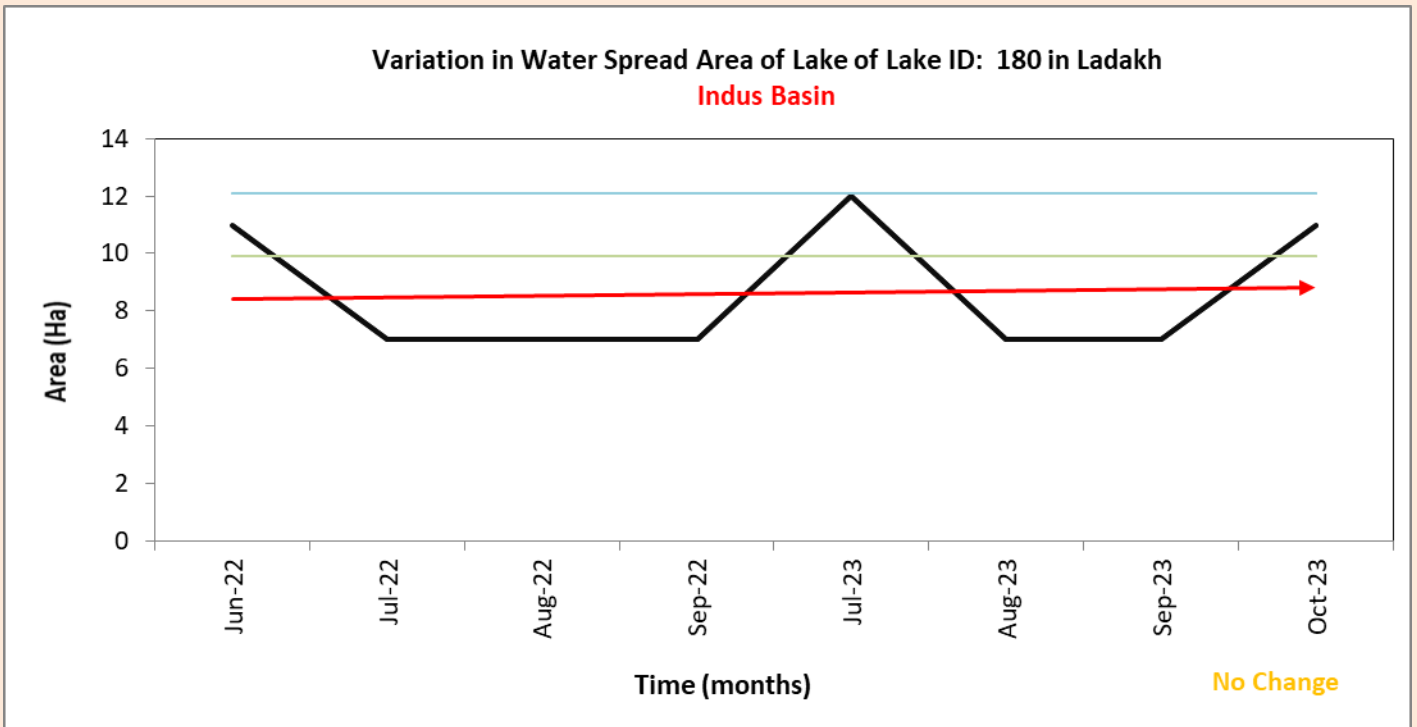


Figure 4.124(ii) Trend Analysis Plot  $\pm 20\%$

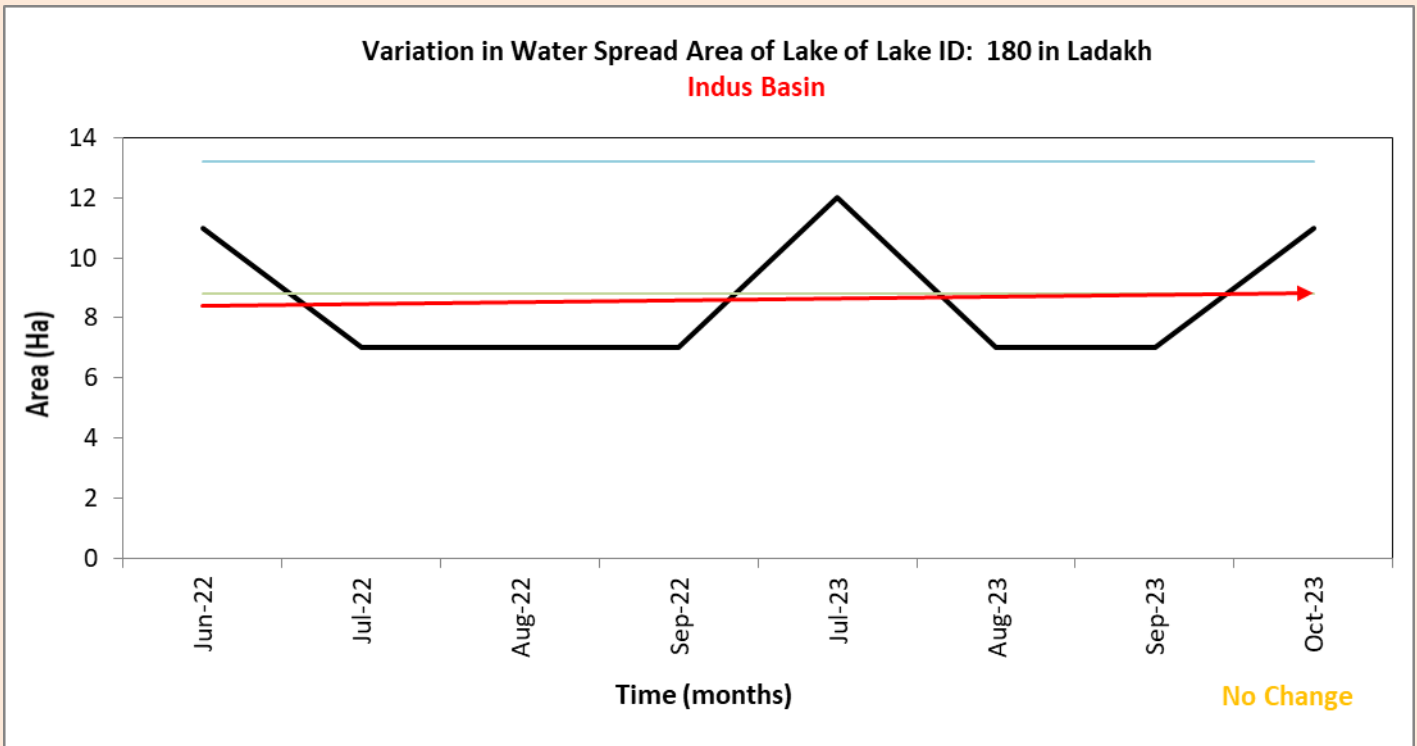


Figure 4.125(i) Trend Analysis Plot  $\pm 10\%$

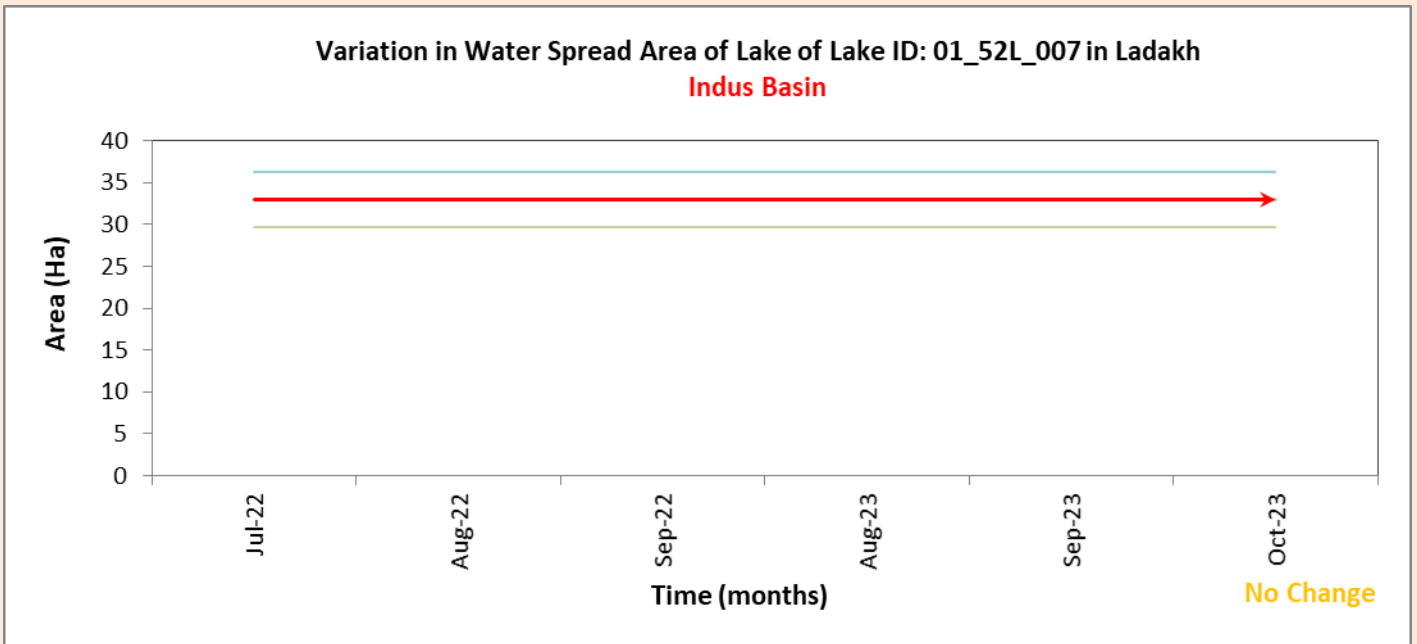


Figure 4.125(ii) Trend Analysis Plot  $\pm 20\%$

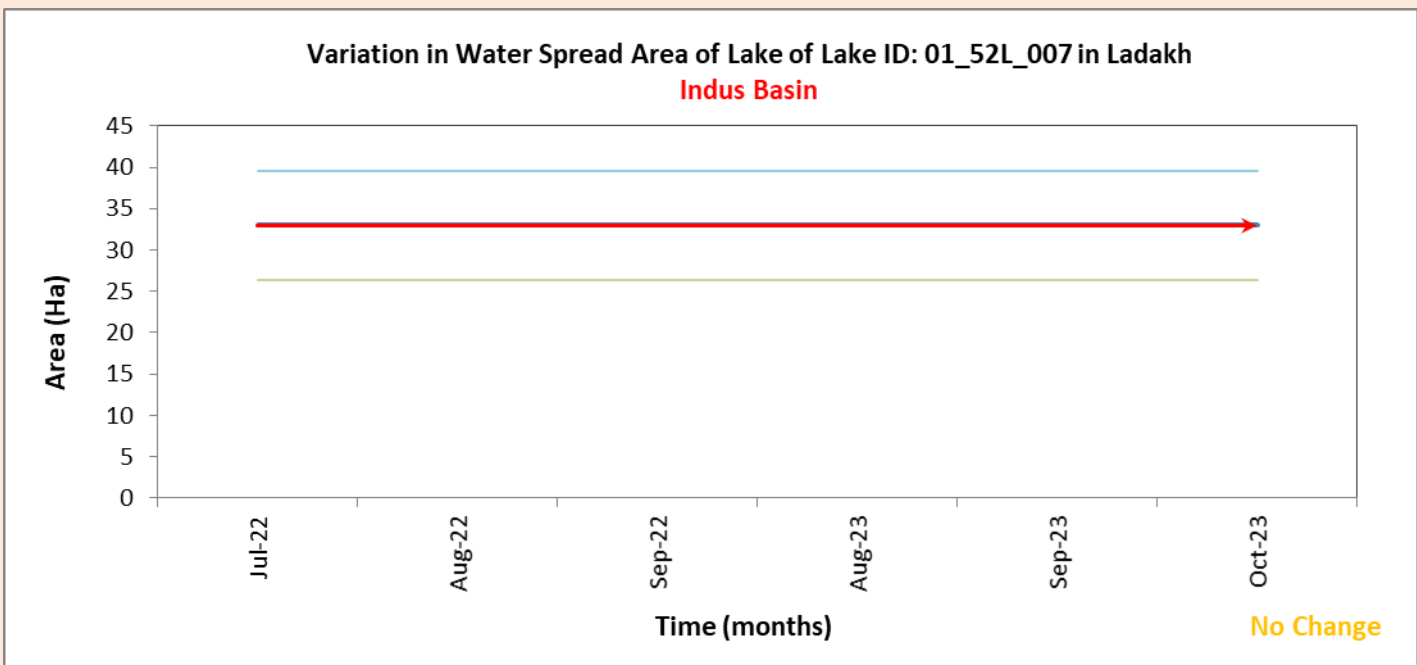


Figure 4.126(i) Trend Analysis Plot  $\pm 10\%$

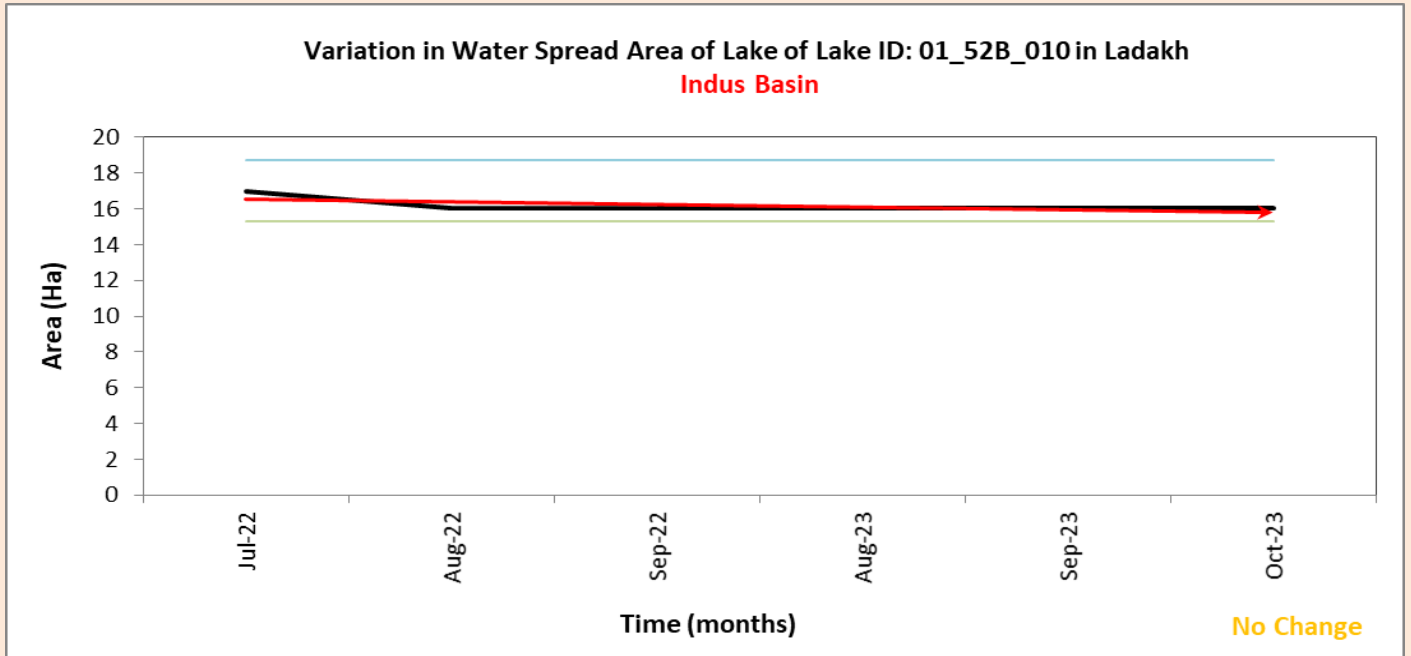


Figure 4.126(ii) Trend Analysis Plot  $\pm 20\%$

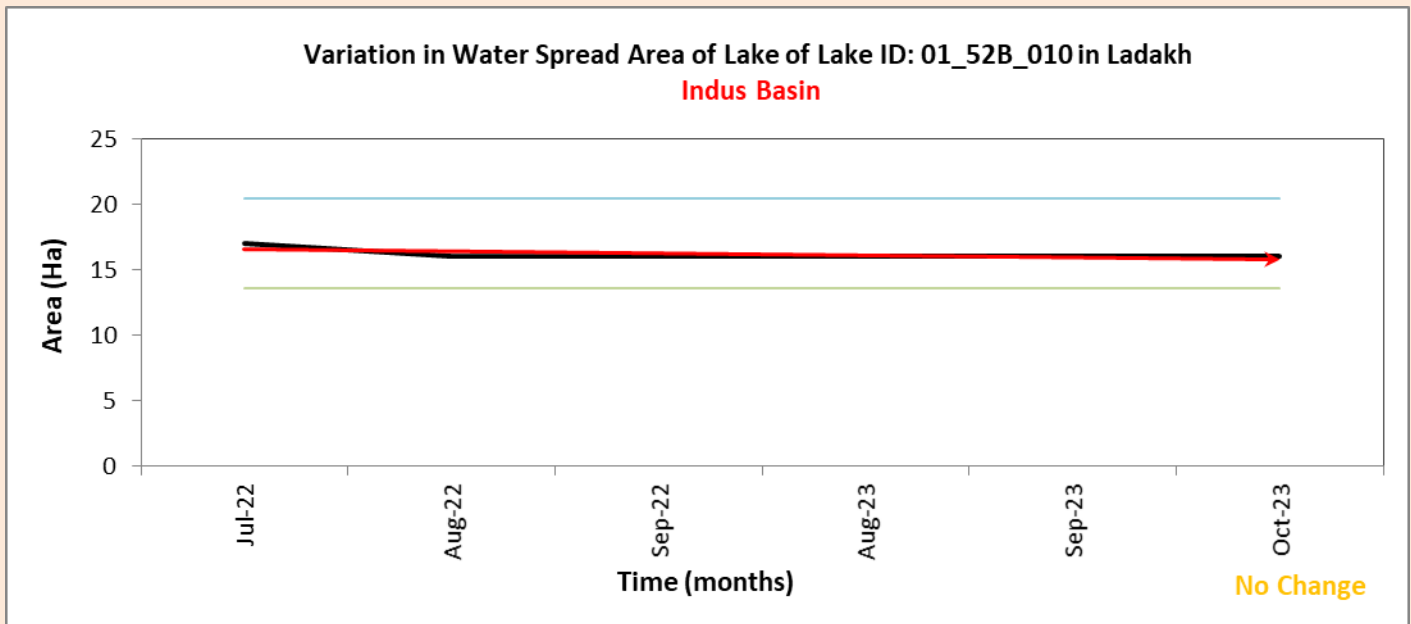


Figure 4.127(i) Trend Analysis Plot  $\pm 10\%$

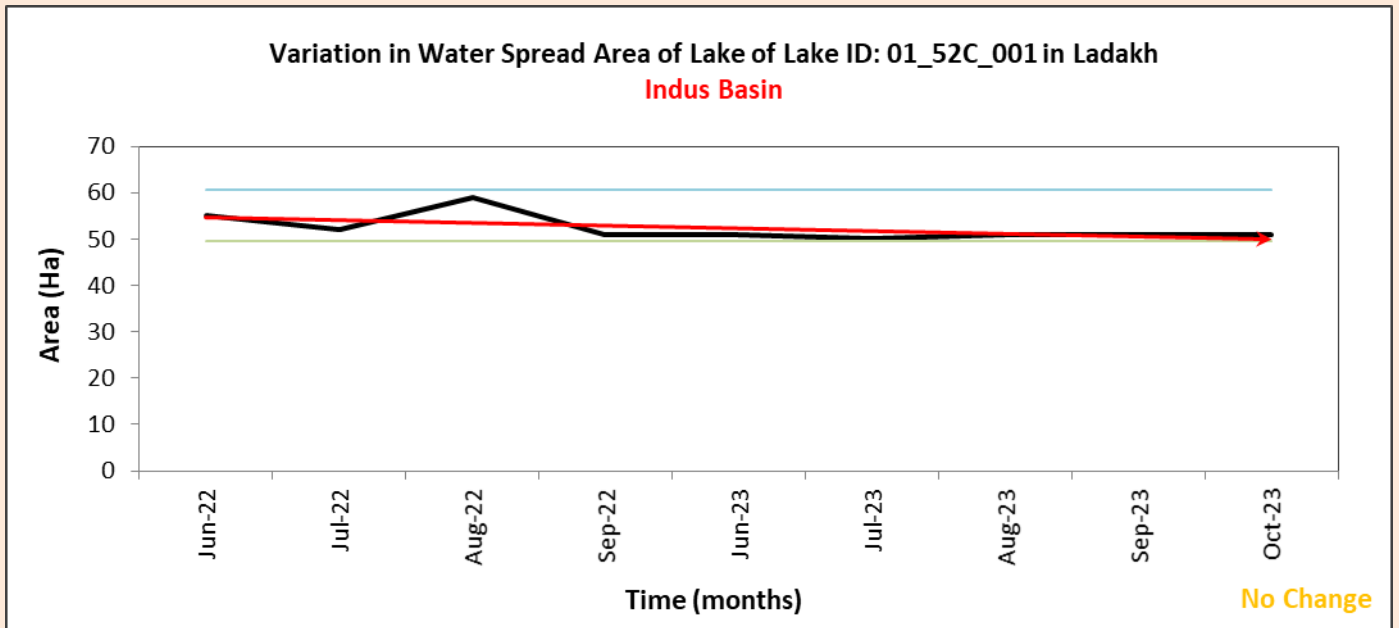


Figure 4.127(ii) Trend Analysis Plot  $\pm 20\%$

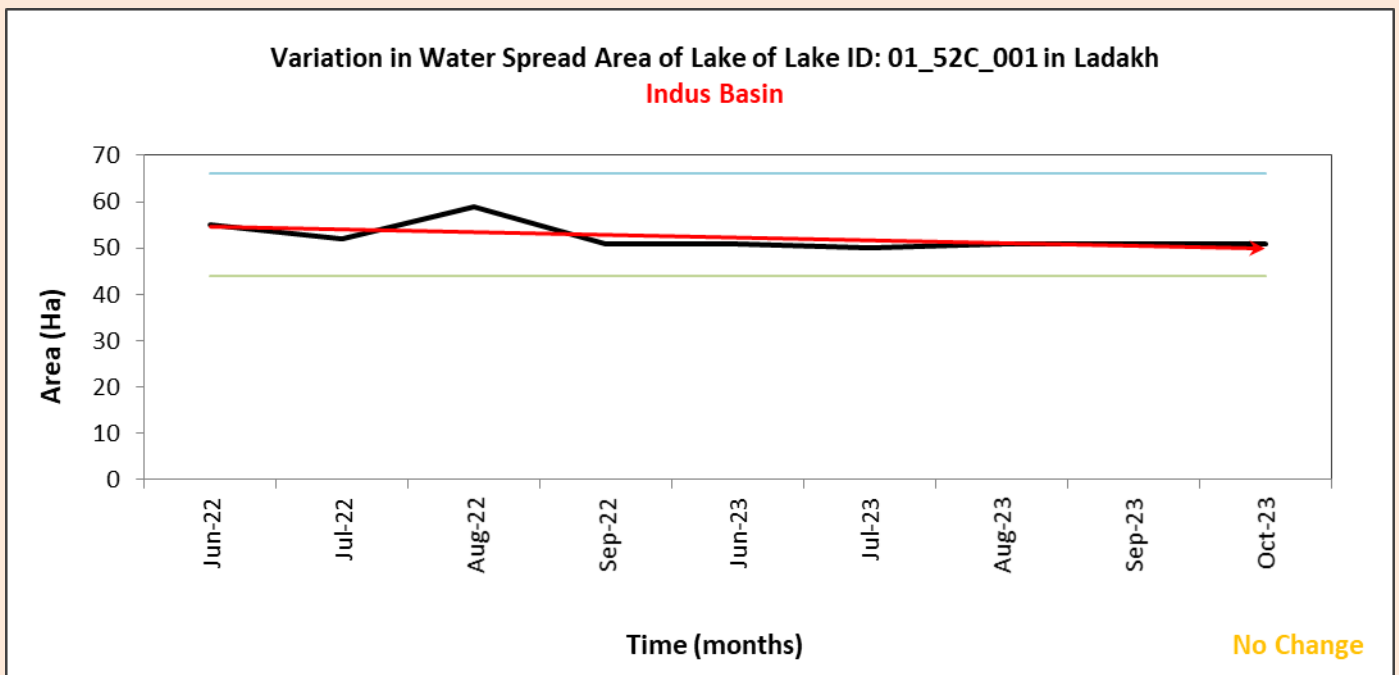


Figure 4.128(i) Trend Analysis Plot  $\pm 10\%$

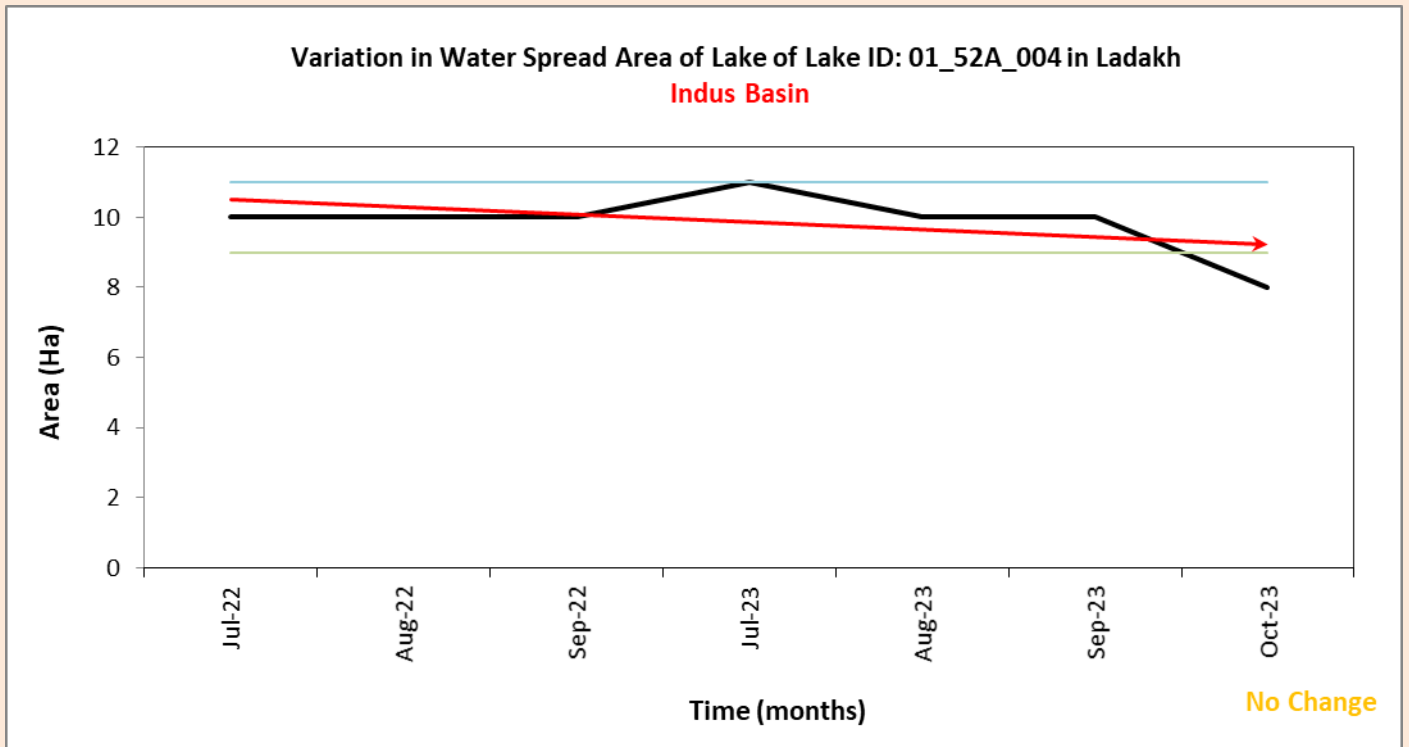


Figure 4.128(ii) Trend Analysis Plot  $\pm 20\%$

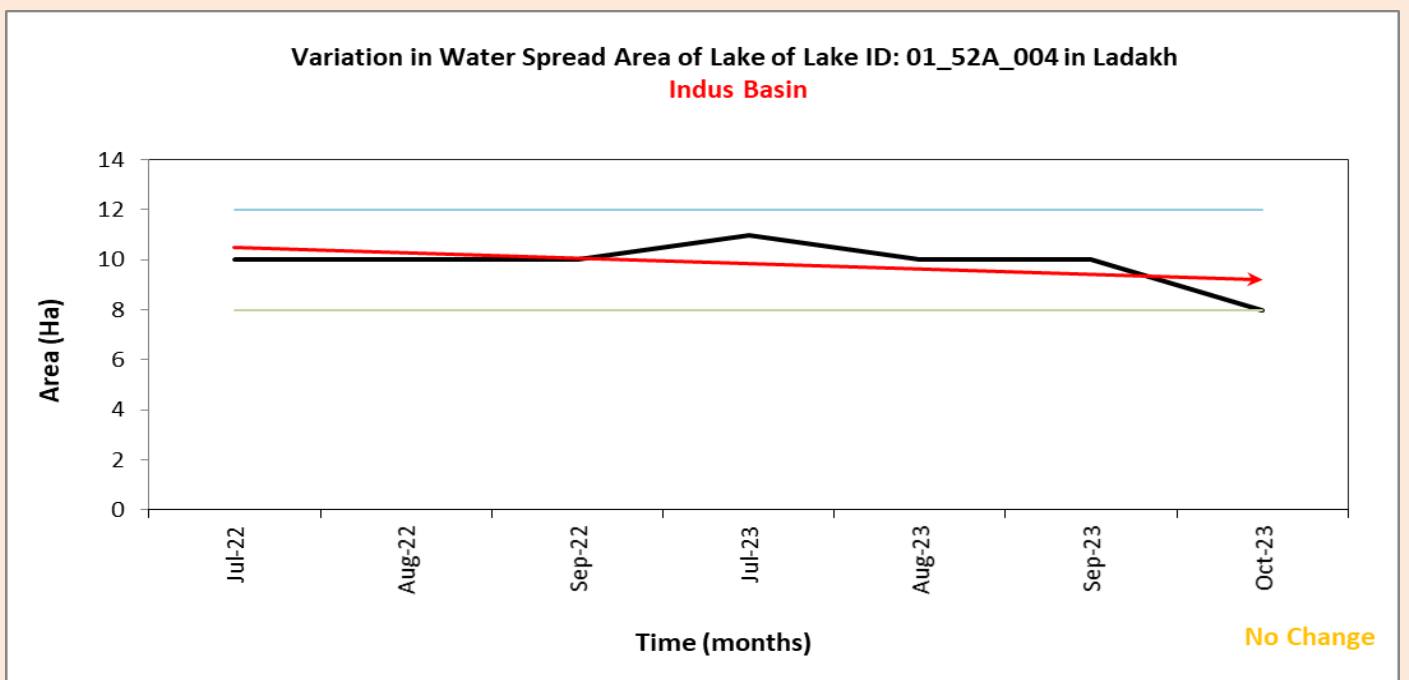


Figure 4.129(i) Trend Analysis Plot  $\pm 10\%$

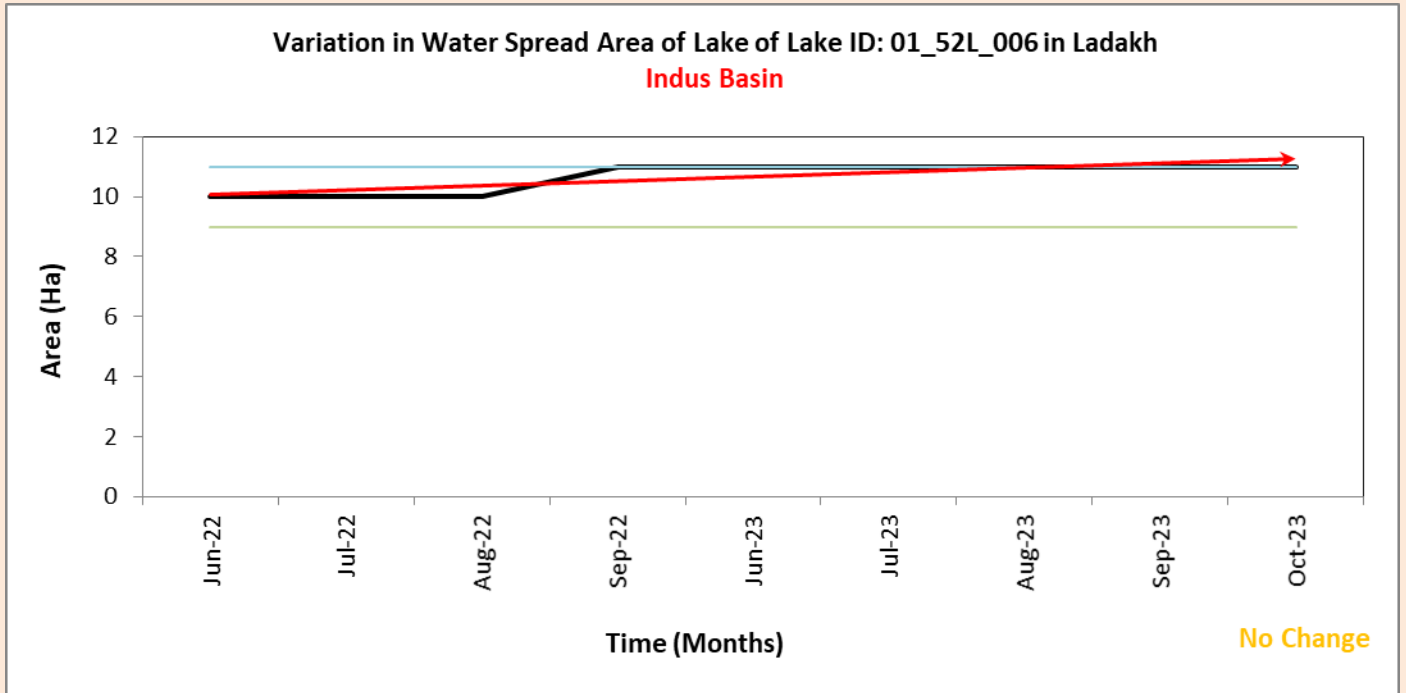


Figure 4.129(ii) Trend Analysis Plot  $\pm 20\%$

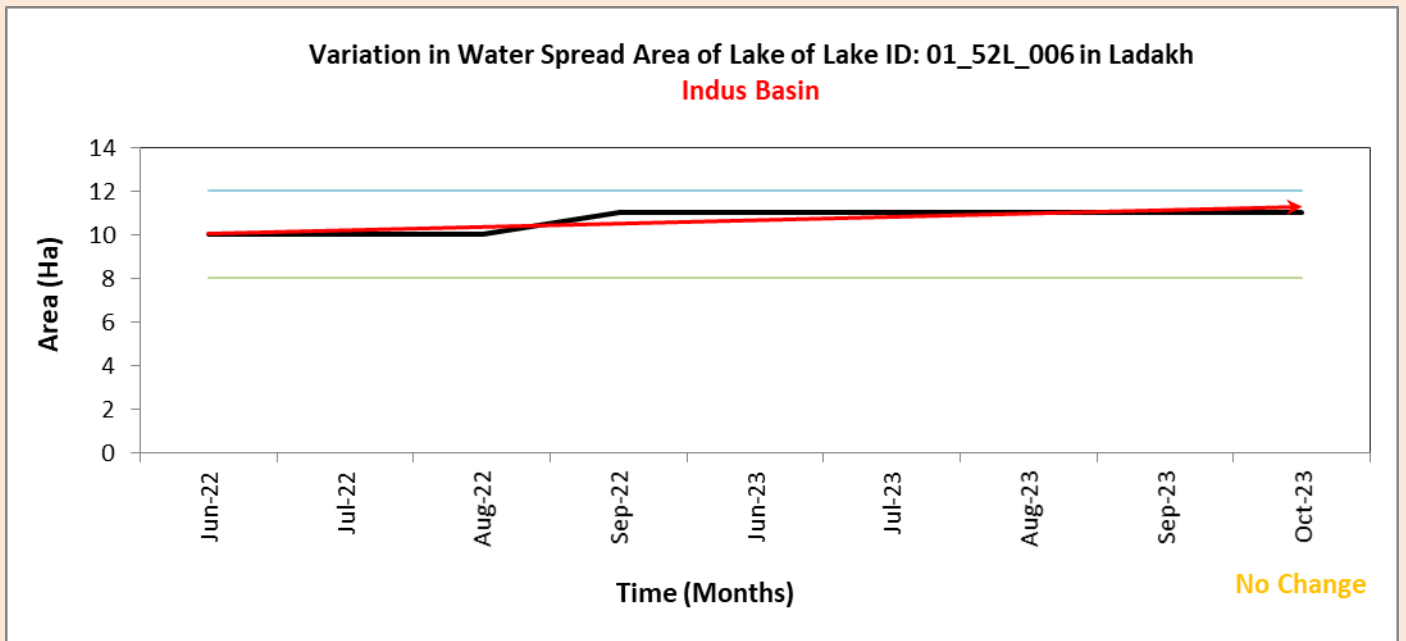


Figure 4.130(i) Trend Analysis Plot  $\pm 10\%$

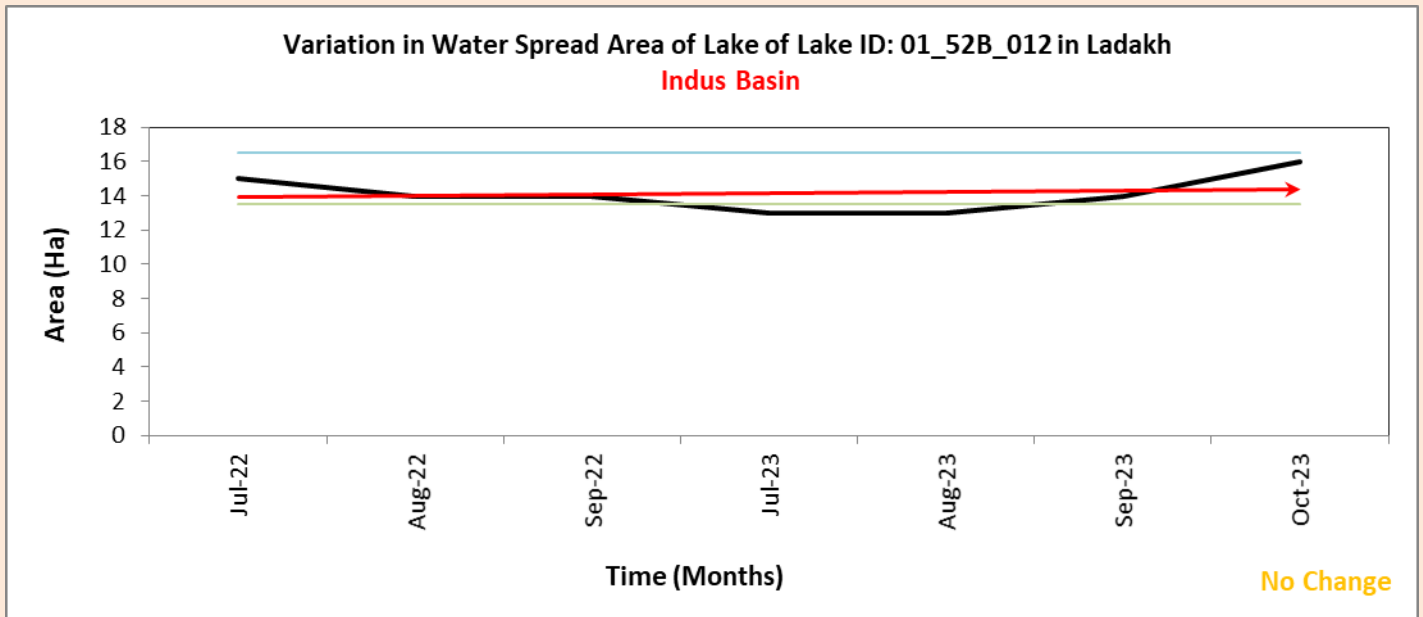


Figure 4.130(ii) Trend Analysis Plot  $\pm 20\%$

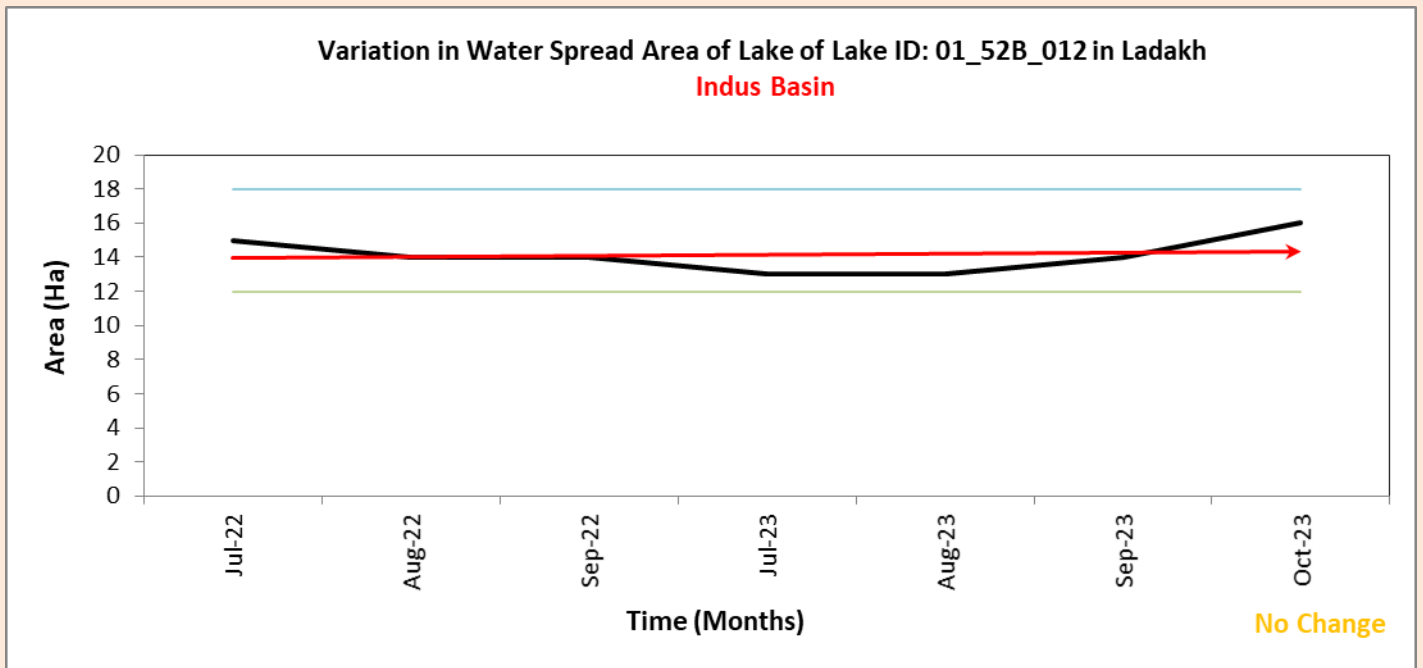


Figure 4.131(i) Trend Analysis Plot  $\pm 10\%$

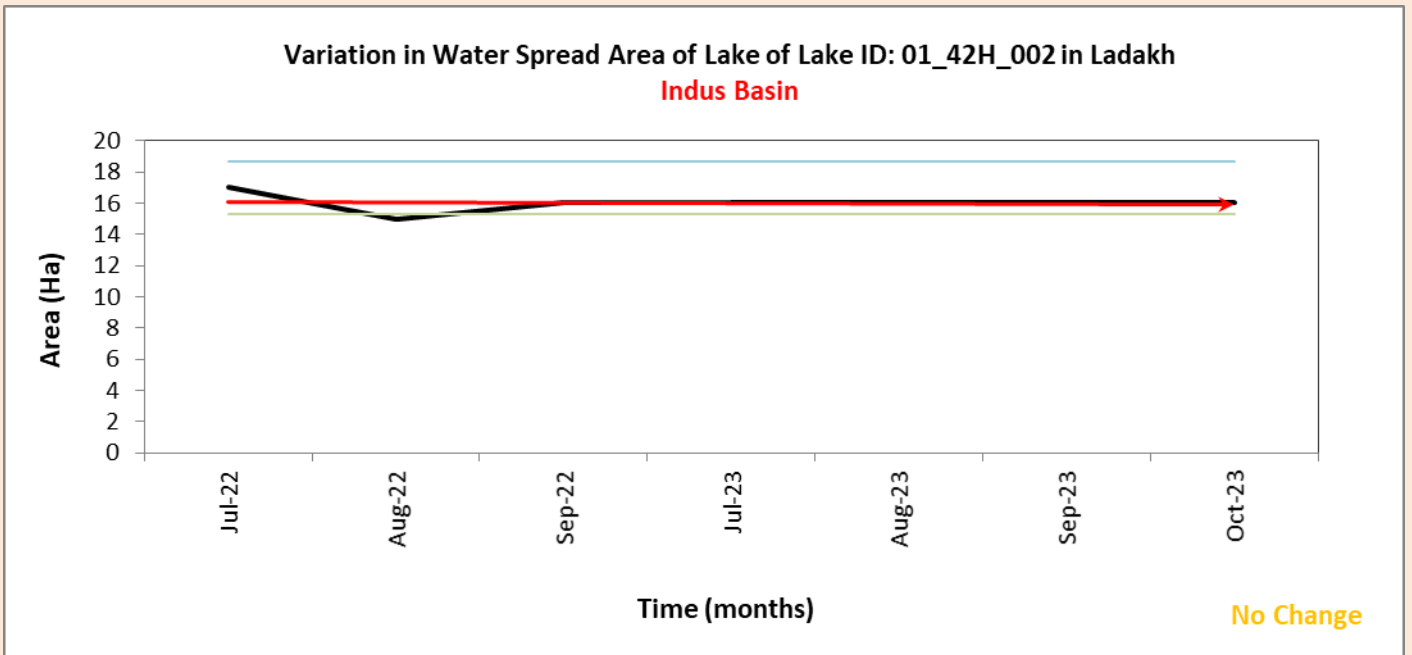


Figure 4.131(ii) Trend Analysis Plot  $\pm 20\%$

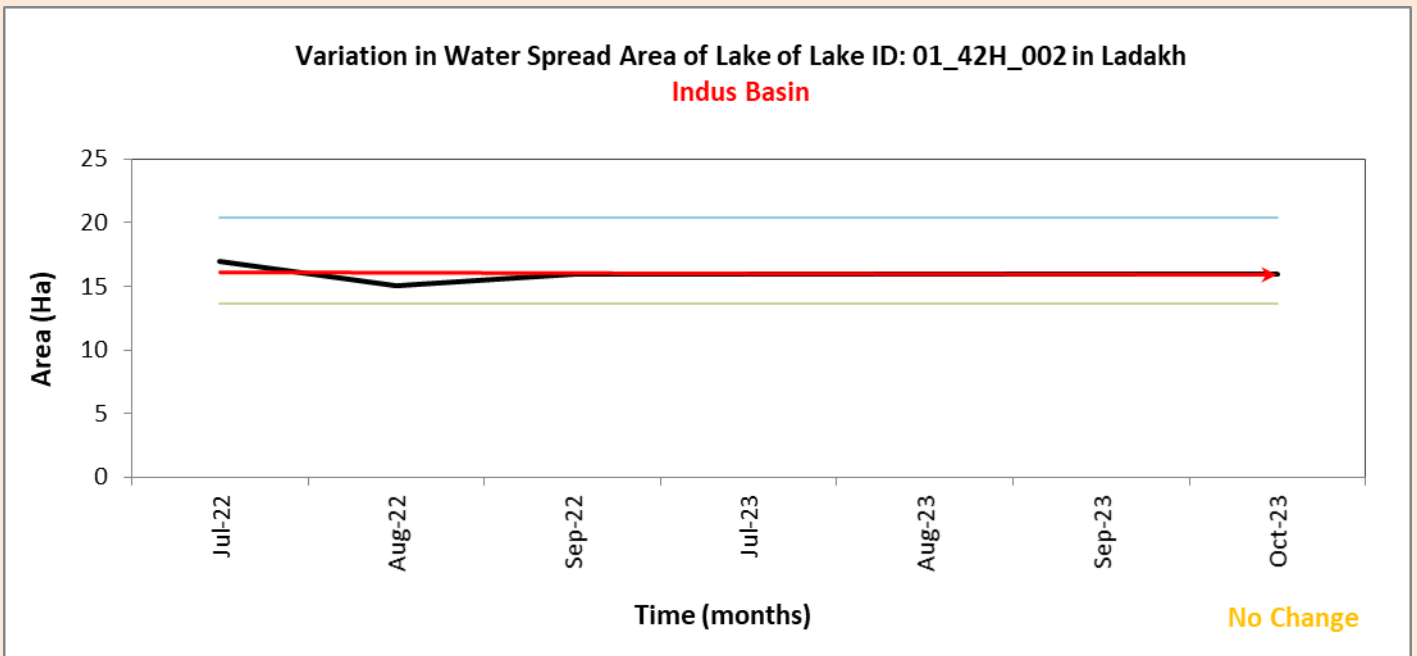


Figure 4.132(i) Trend Analysis Plot  $\pm 10\%$

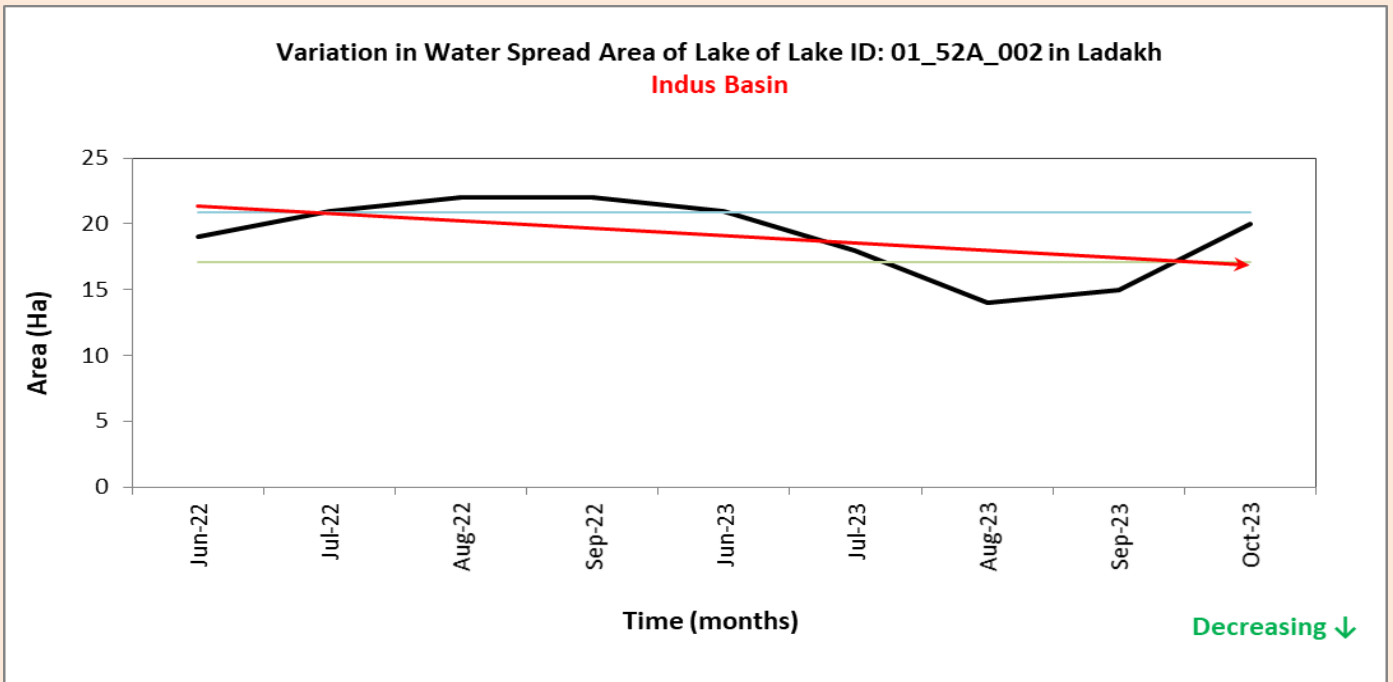


Figure 4.132(ii) Trend Analysis Plot  $\pm 20\%$

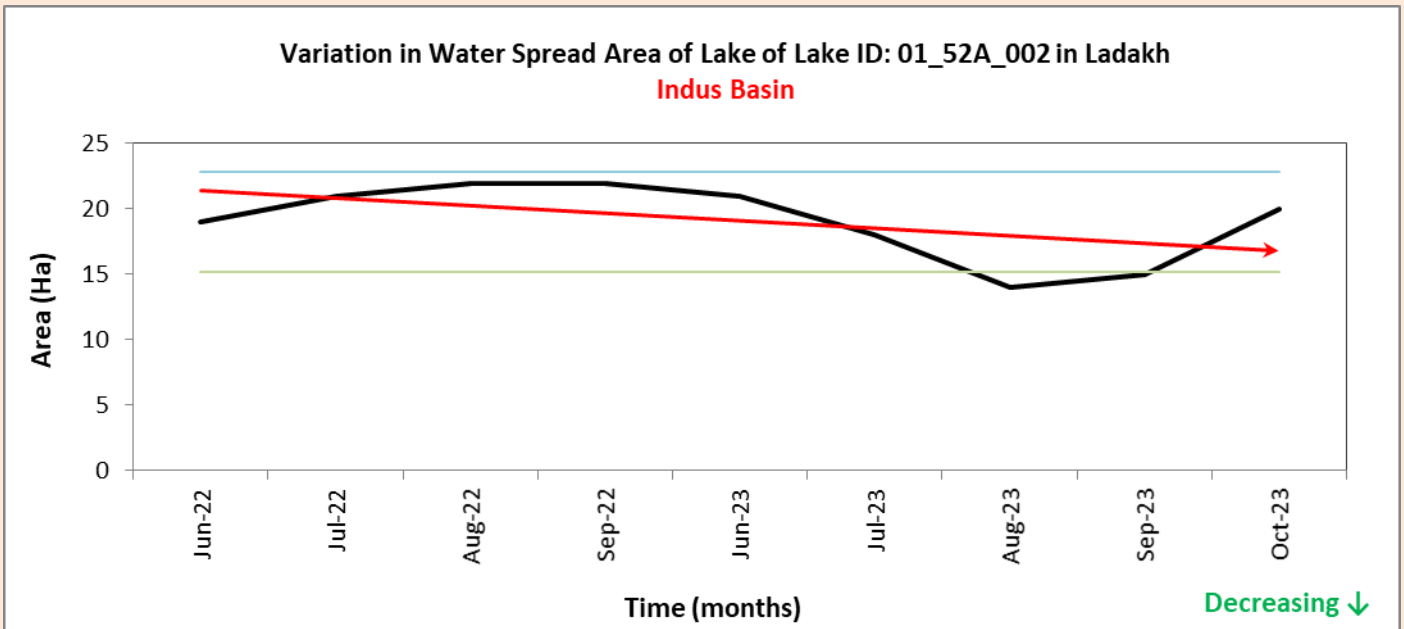


Figure 4.133(i) Trend Analysis Plot  $\pm 10\%$

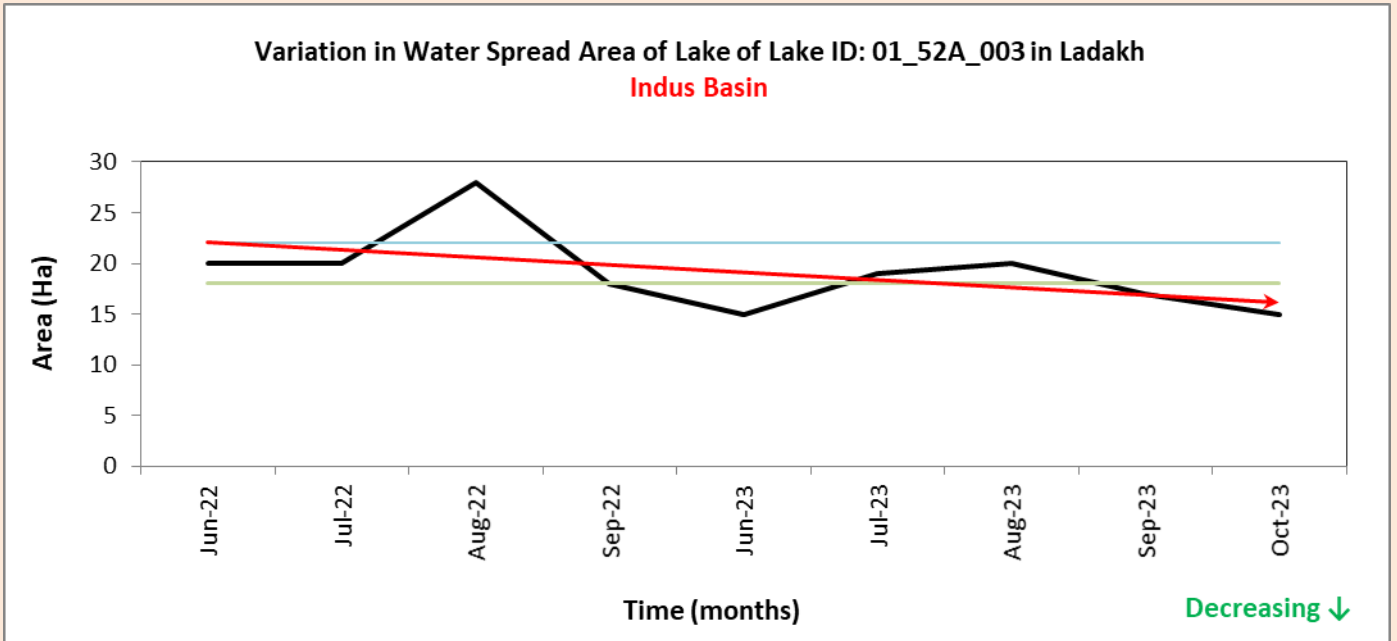
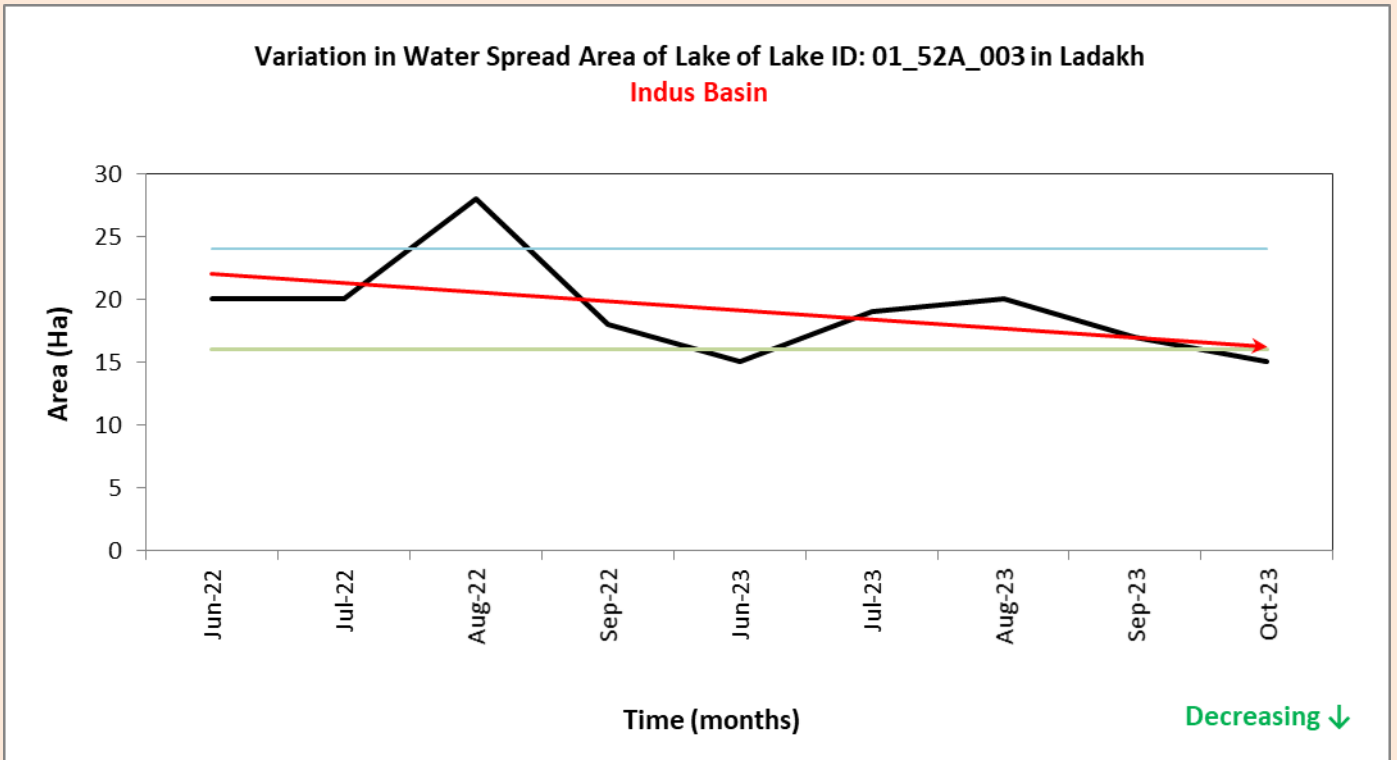


Figure 4.133(ii) Trend Analysis Plot  $\pm 20\%$



**Trend analysis of “Change in water spread area of Glacial Lakes between 10 Ha to 50  
Ha of  
Jammu & Kashmir (2022-2023)”**

Figure 4.134(i) Trend Analysis Plot  $\pm 10\%$

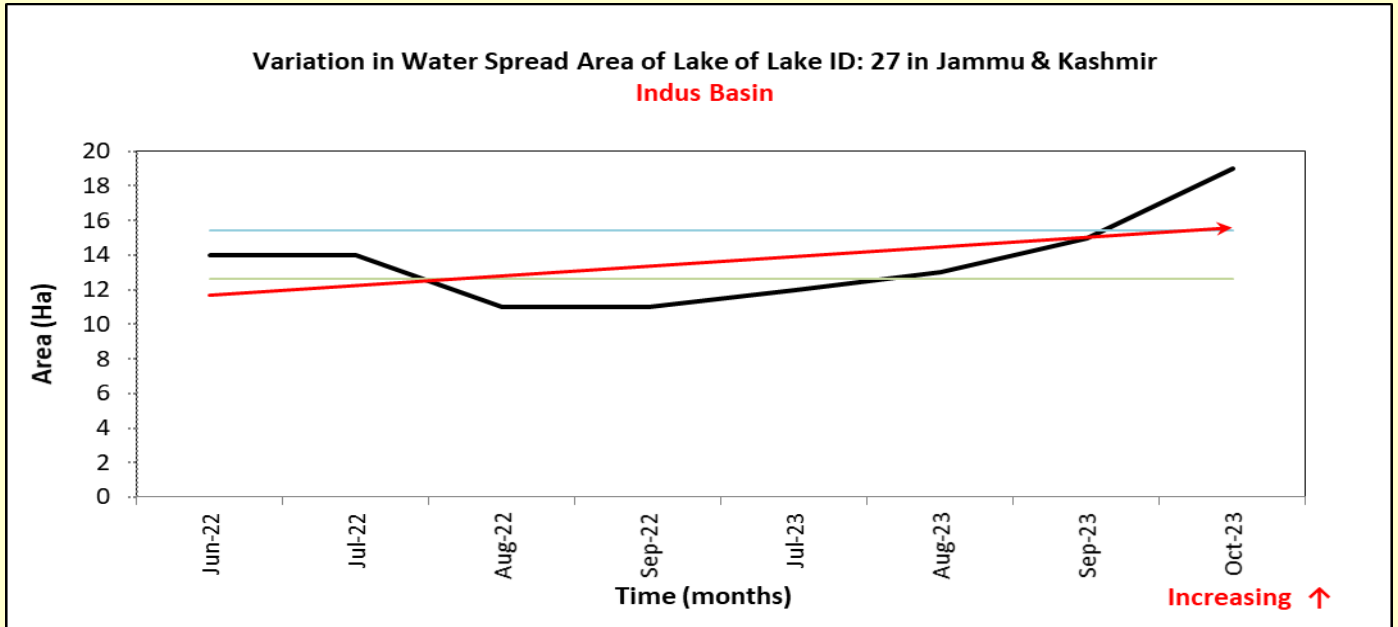


Figure 4.134(ii) Trend Analysis Plot  $\pm 20\%$

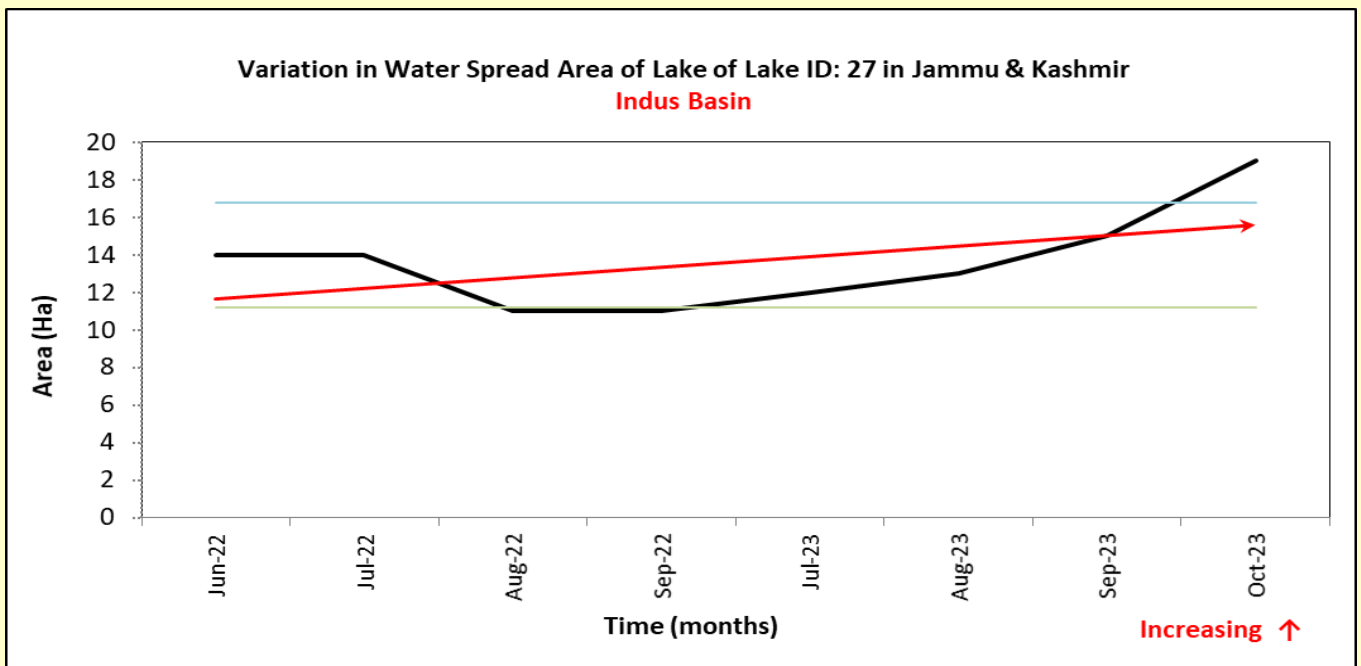


Figure 4.135(i) Trend Analysis Plot  $\pm 10\%$

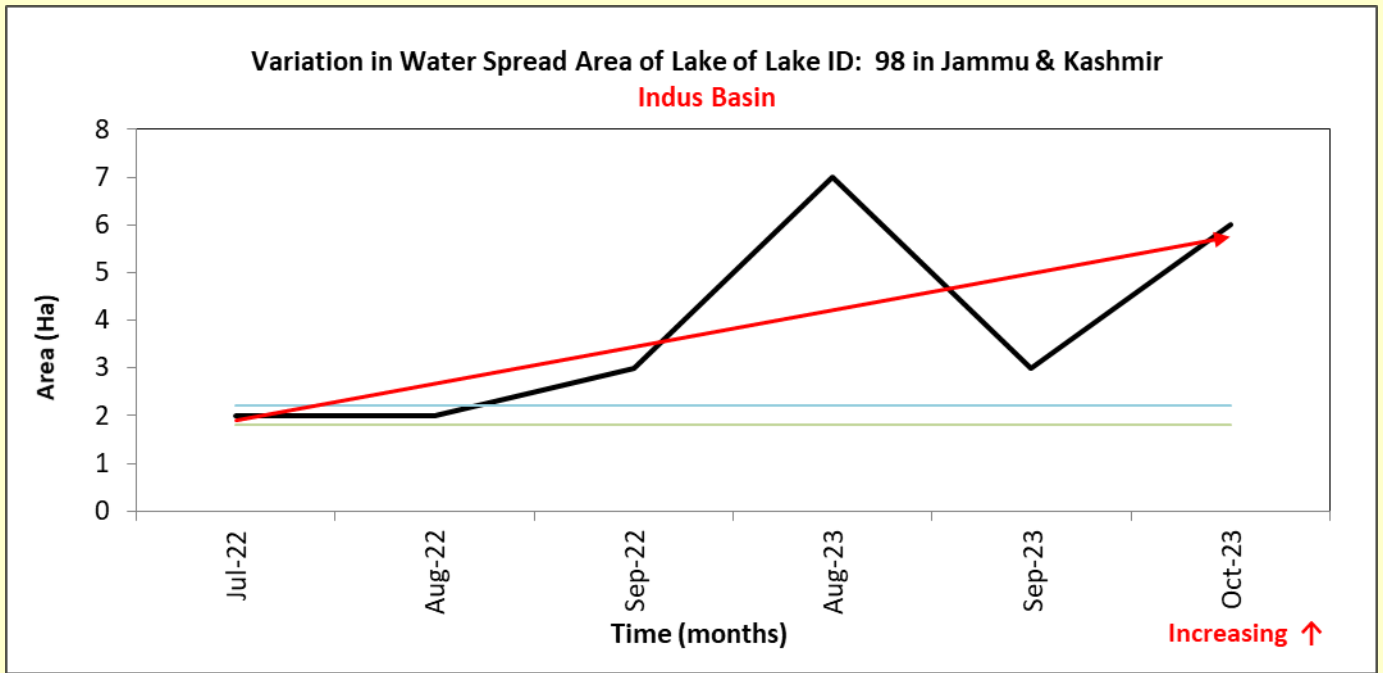


Figure 4.135(ii) Trend Analysis Plot  $\pm 20\%$

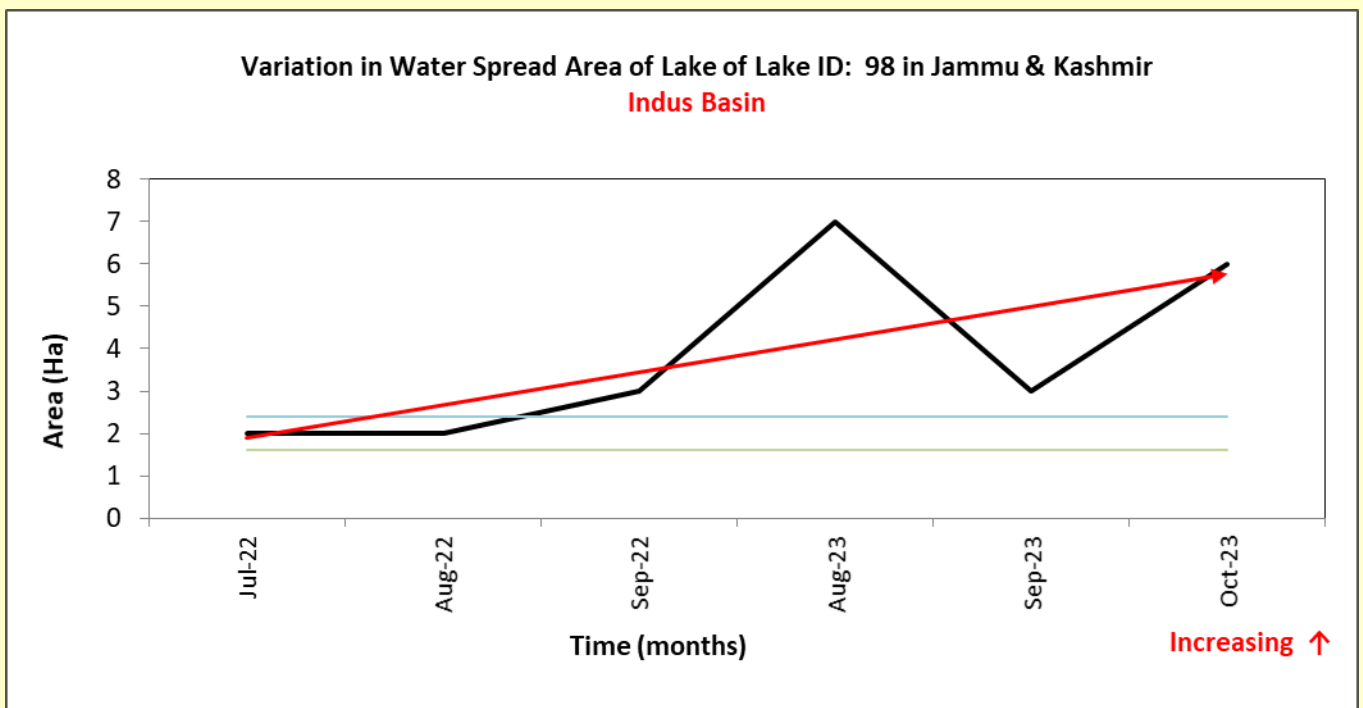


Figure 4.136(i) Trend Analysis Plot  $\pm 10\%$

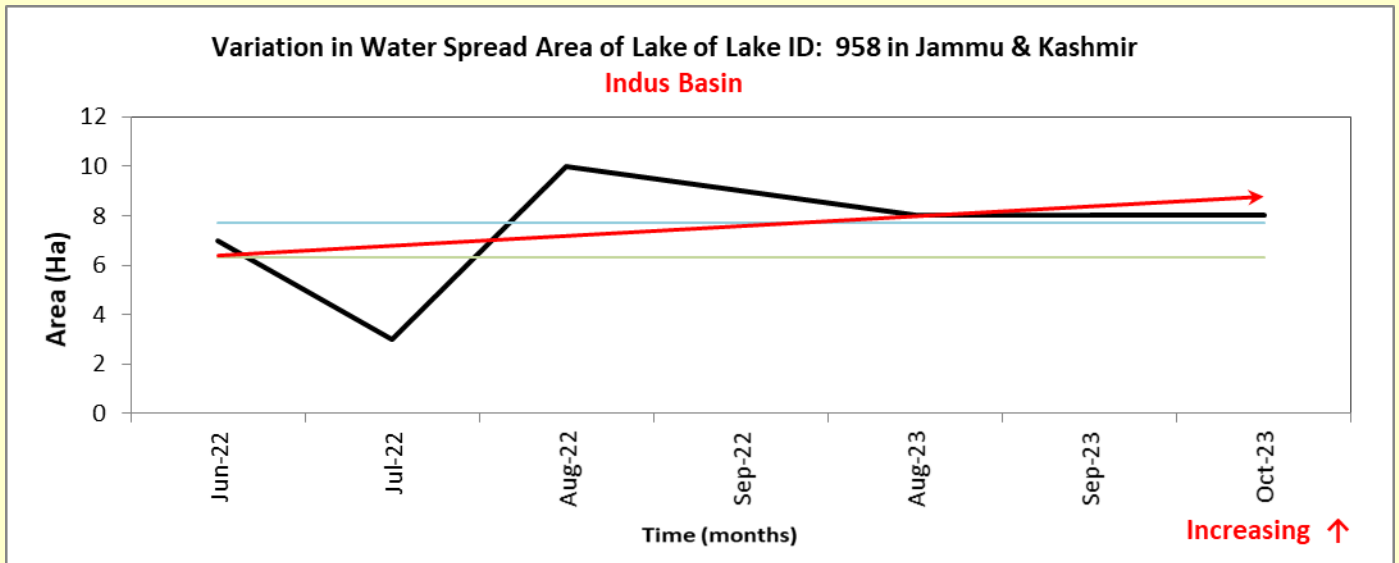


Figure 4.136(ii) Trend Analysis Plot  $\pm 20\%$

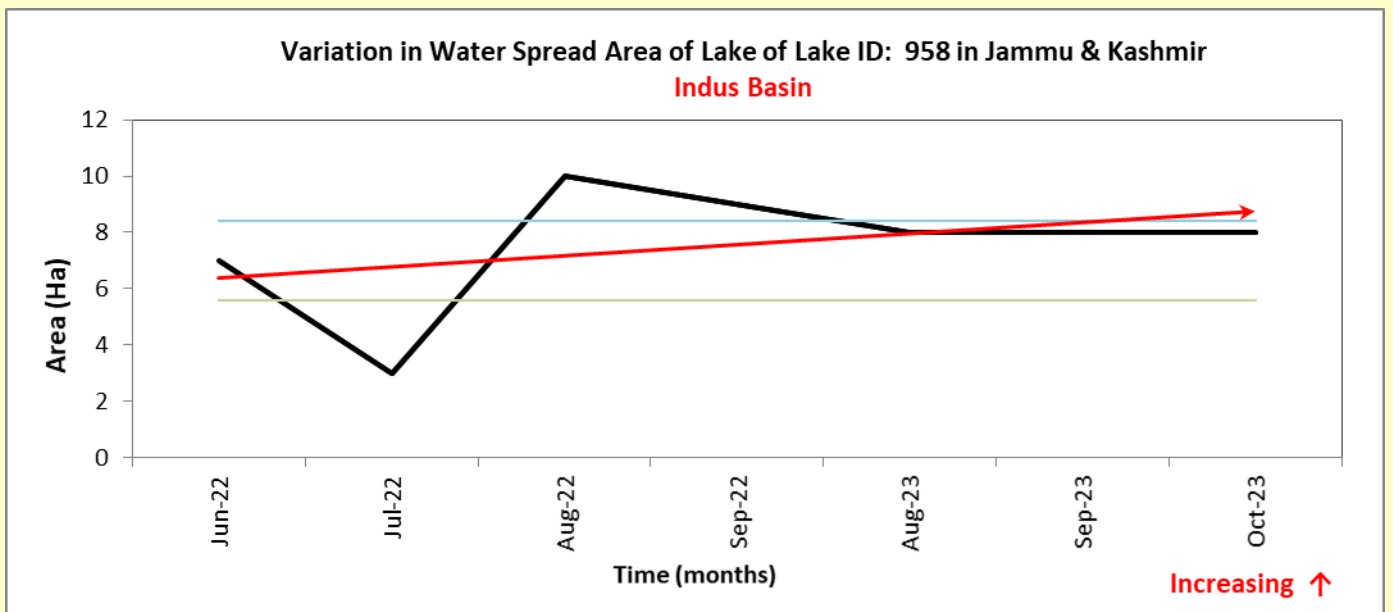


Figure 4.137(i) Trend Analysis Plot  $\pm 10\%$

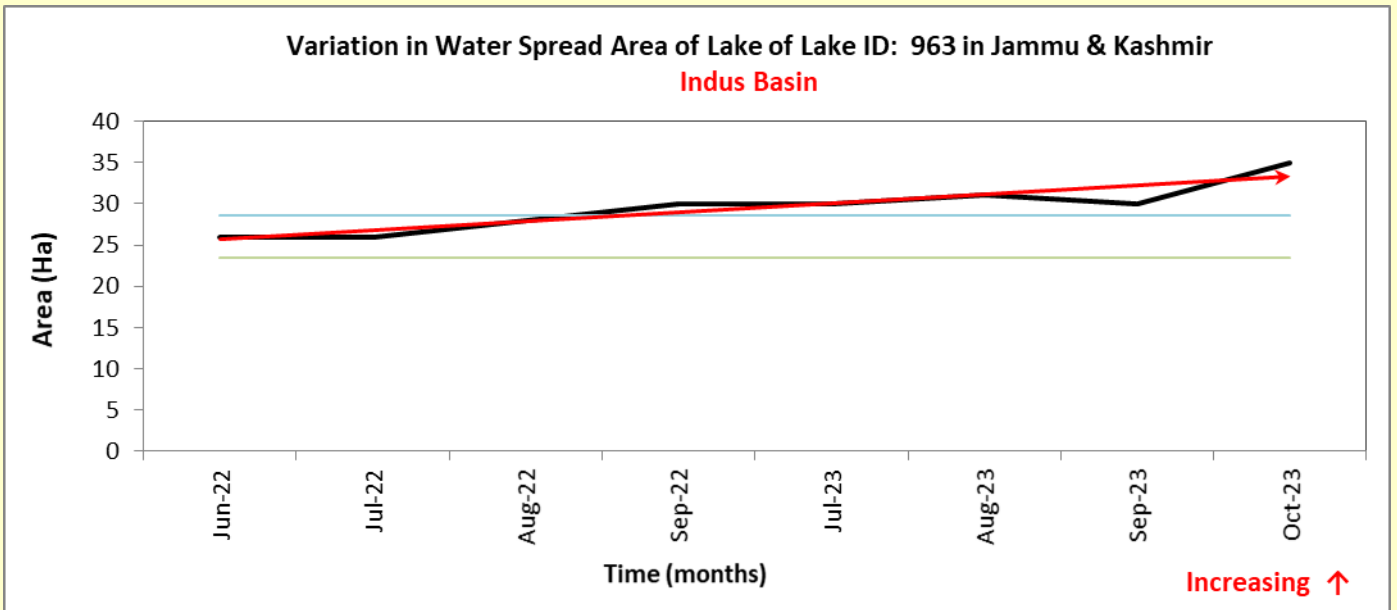


Figure 4.137(ii) Trend Analysis Plot  $\pm 20\%$

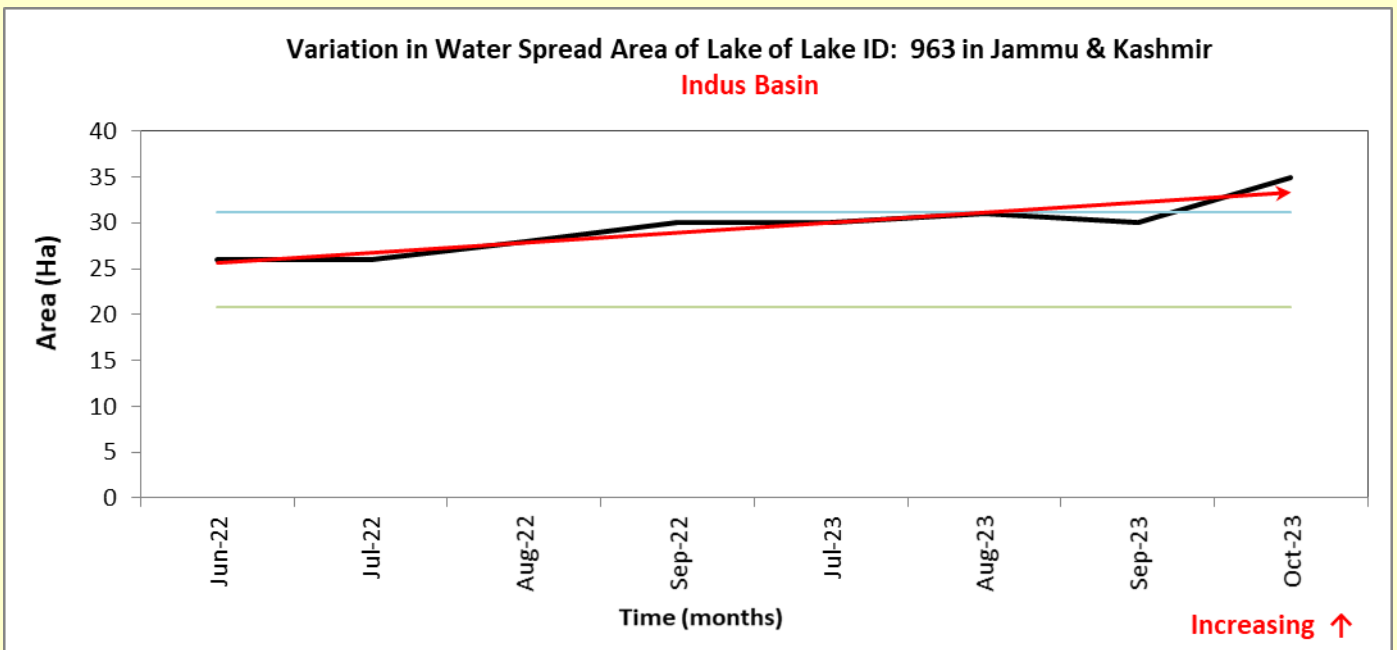


Figure 4.138(i) Trend Analysis Plot  $\pm 10\%$

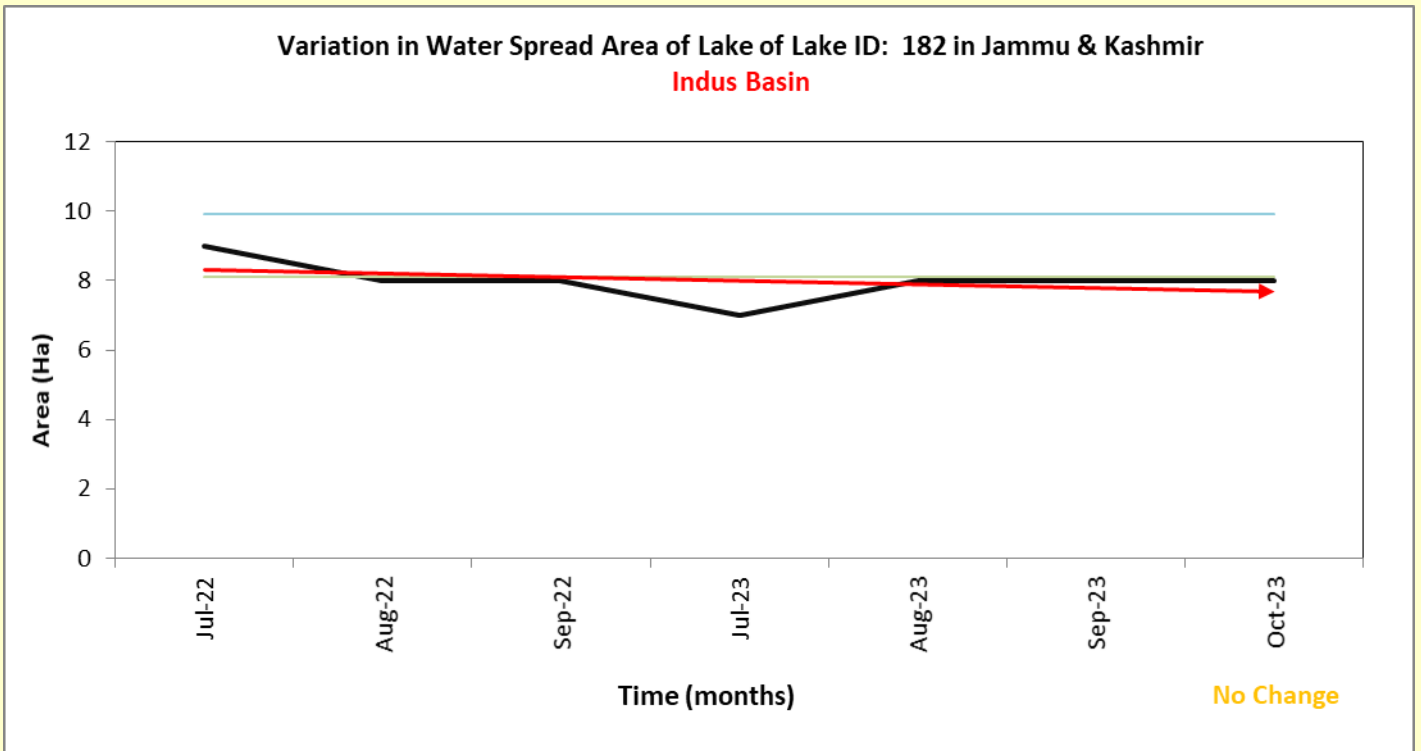


Figure 4.138(ii) Trend Analysis Plot  $\pm 20\%$

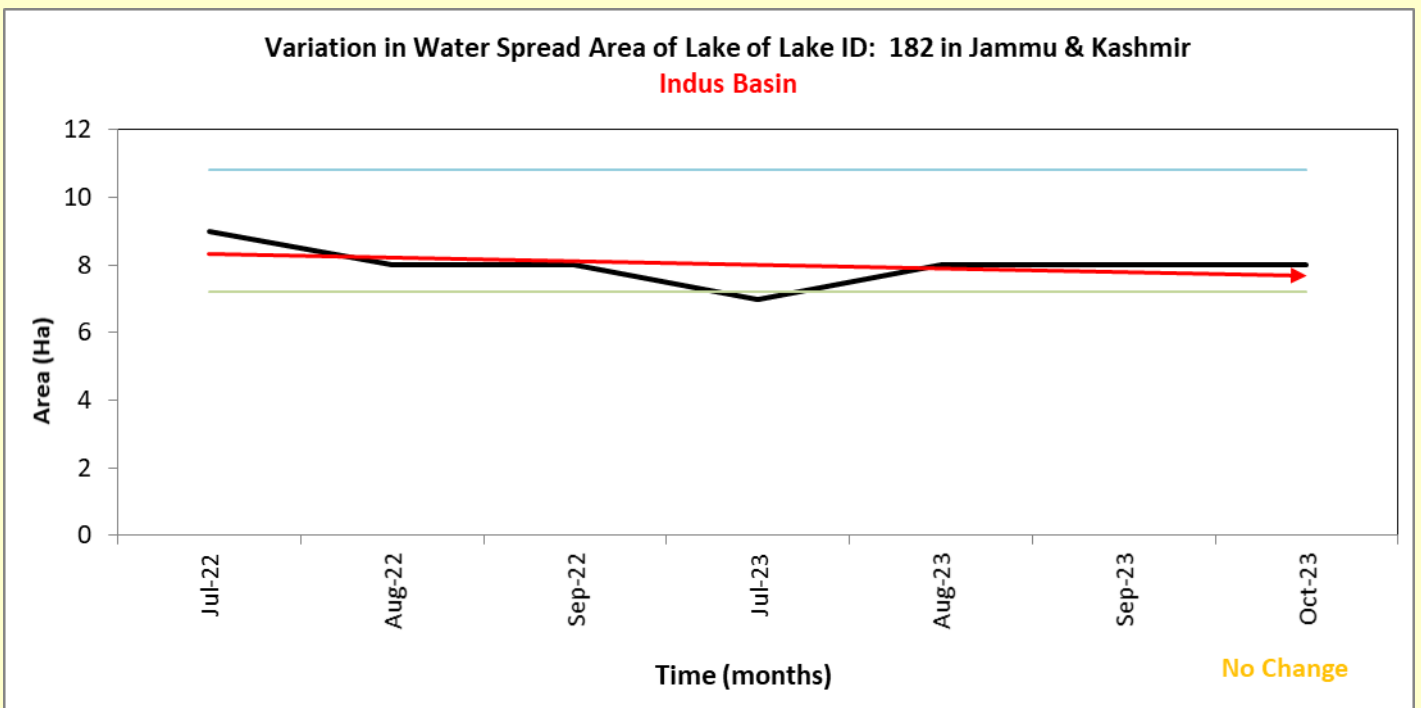


Figure 4.139(i) Trend Analysis Plot  $\pm 10\%$

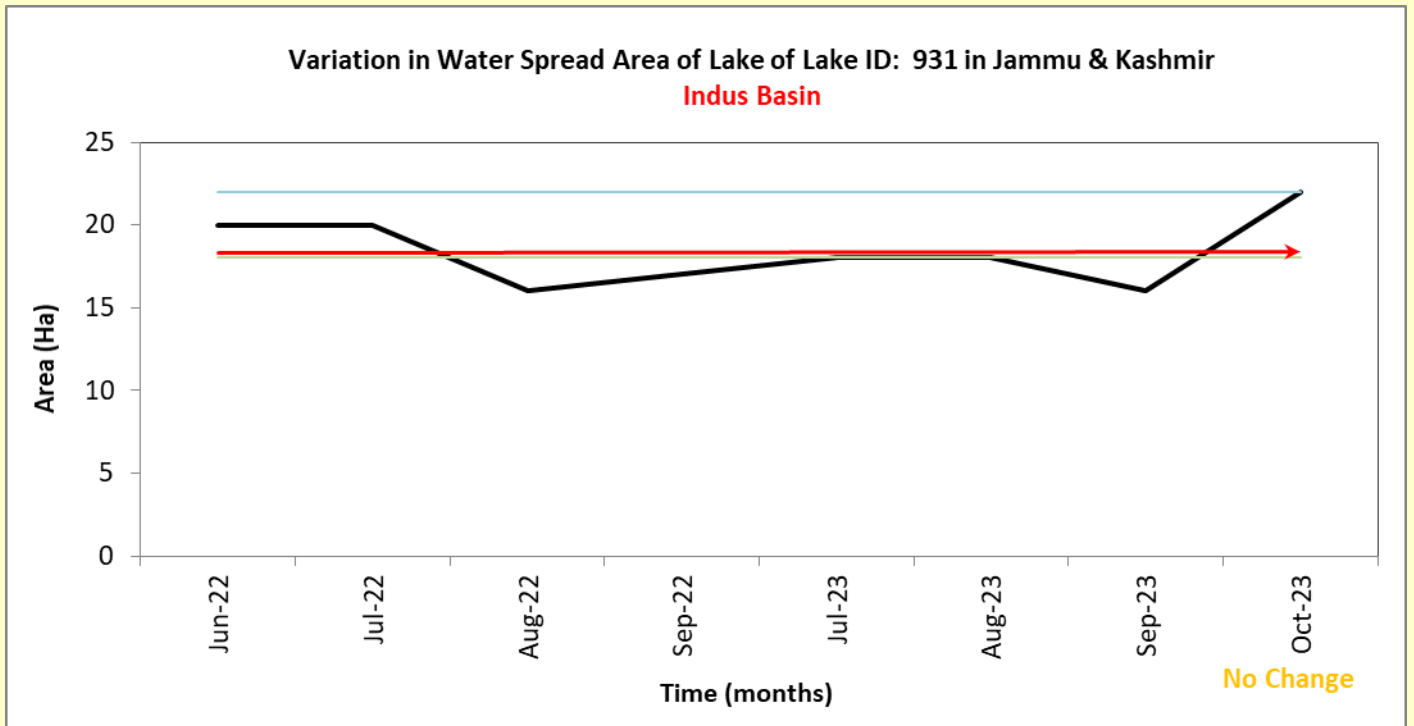


Figure 4.139(ii) Trend Analysis Plot  $\pm 20\%$

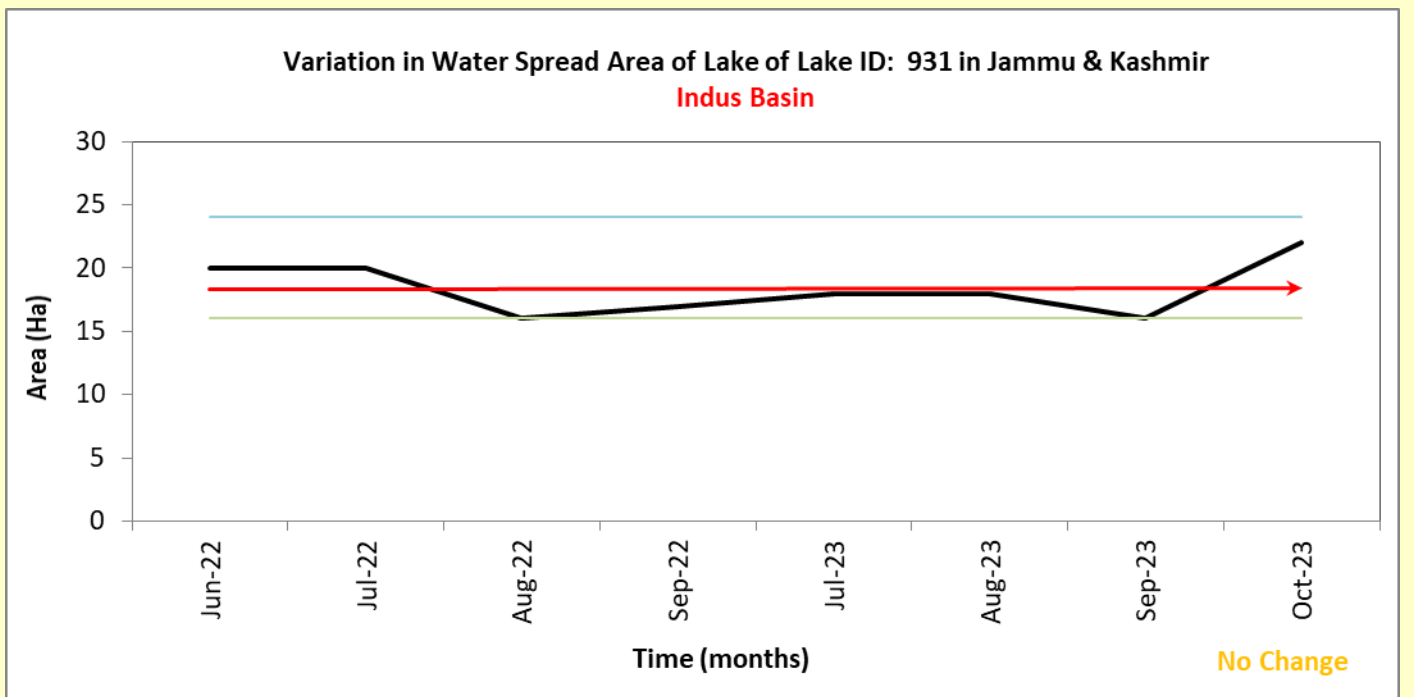


Figure 4.140(i) Trend Analysis Plot  $\pm 10\%$

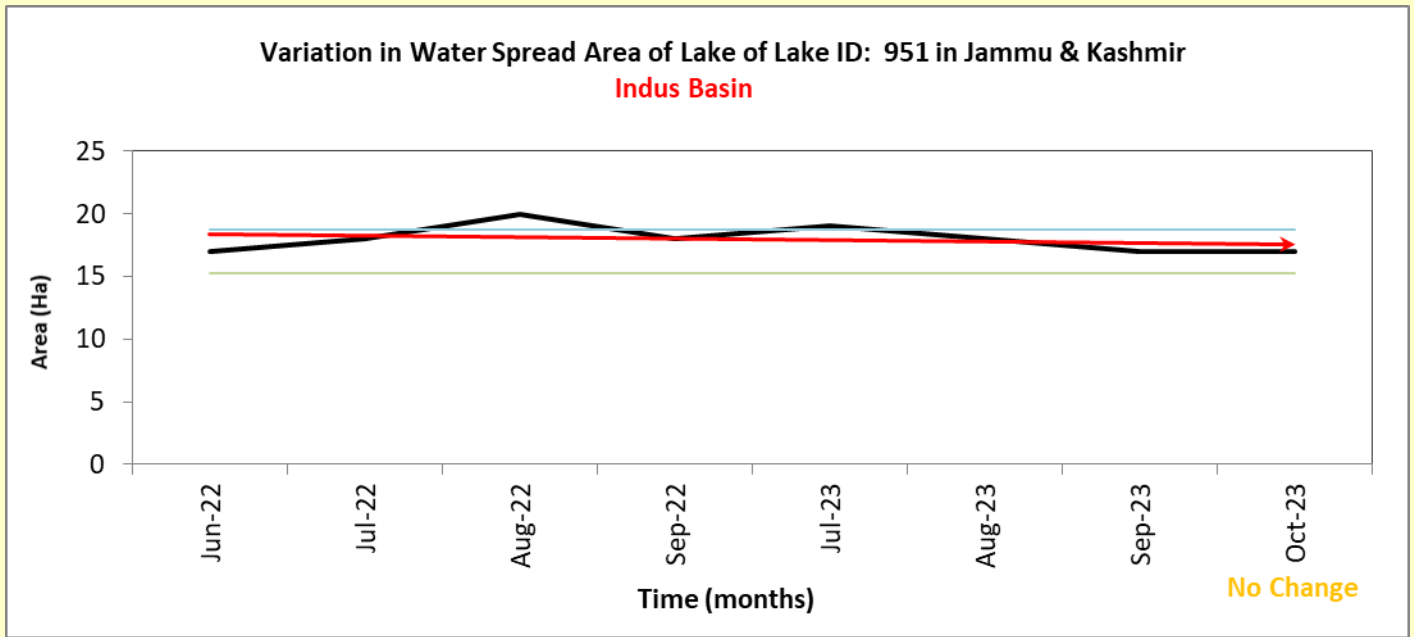


Figure 4.140(ii) Trend Analysis Plot  $\pm 20\%$

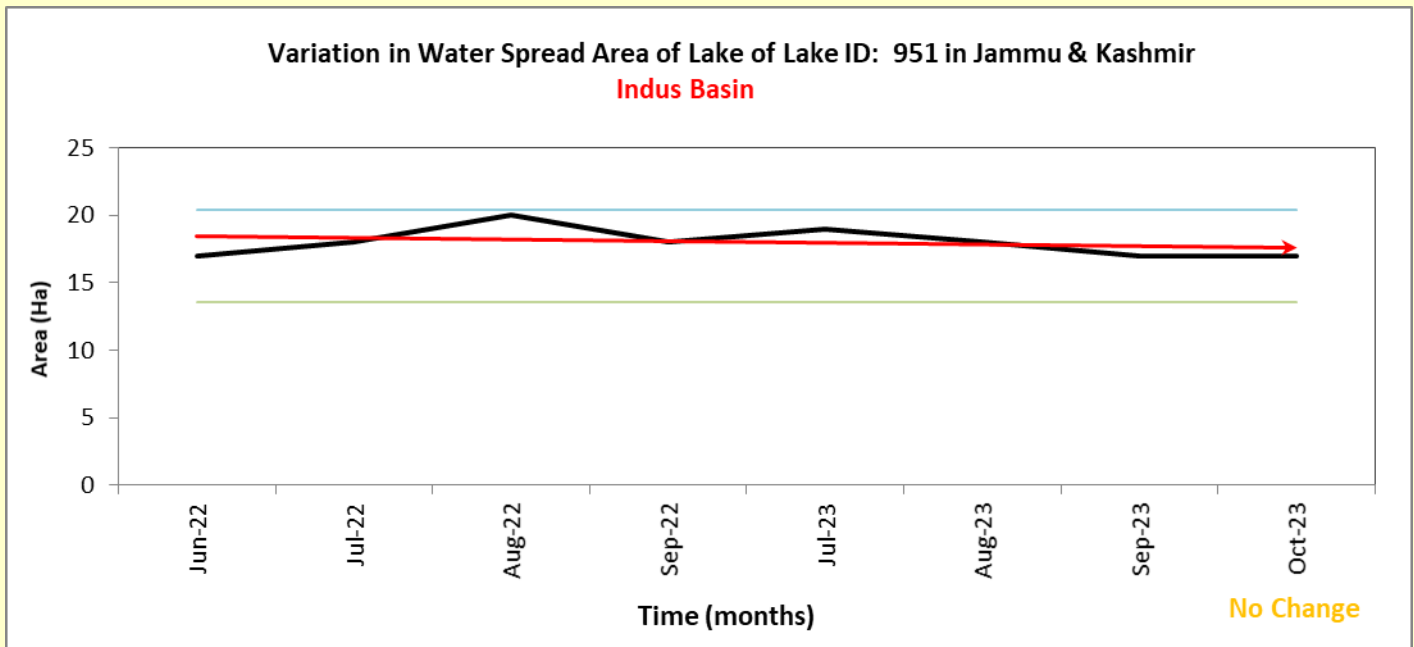


Figure 4.141(i) Trend Analysis Plot  $\pm 10\%$

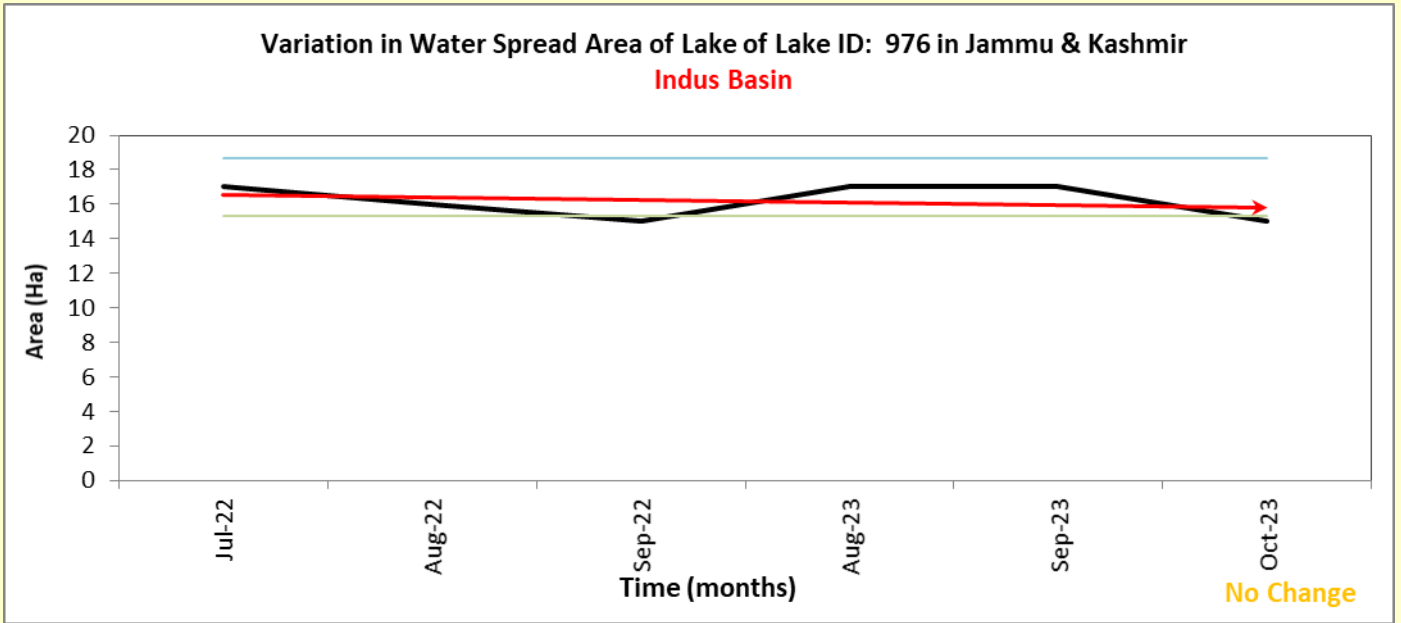


Figure 4.141(ii) Trend Analysis Plot  $\pm 20\%$

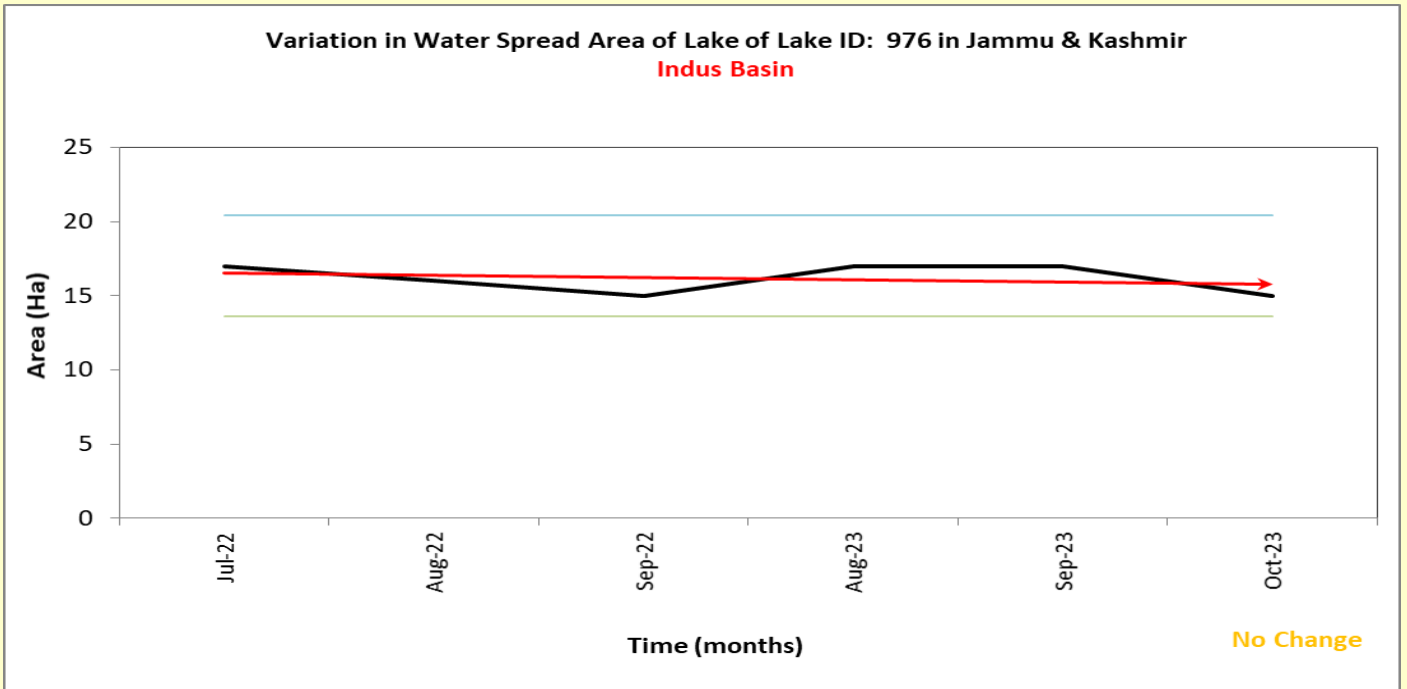


Figure 4.142(i) Trend Analysis Plot  $\pm 10\%$

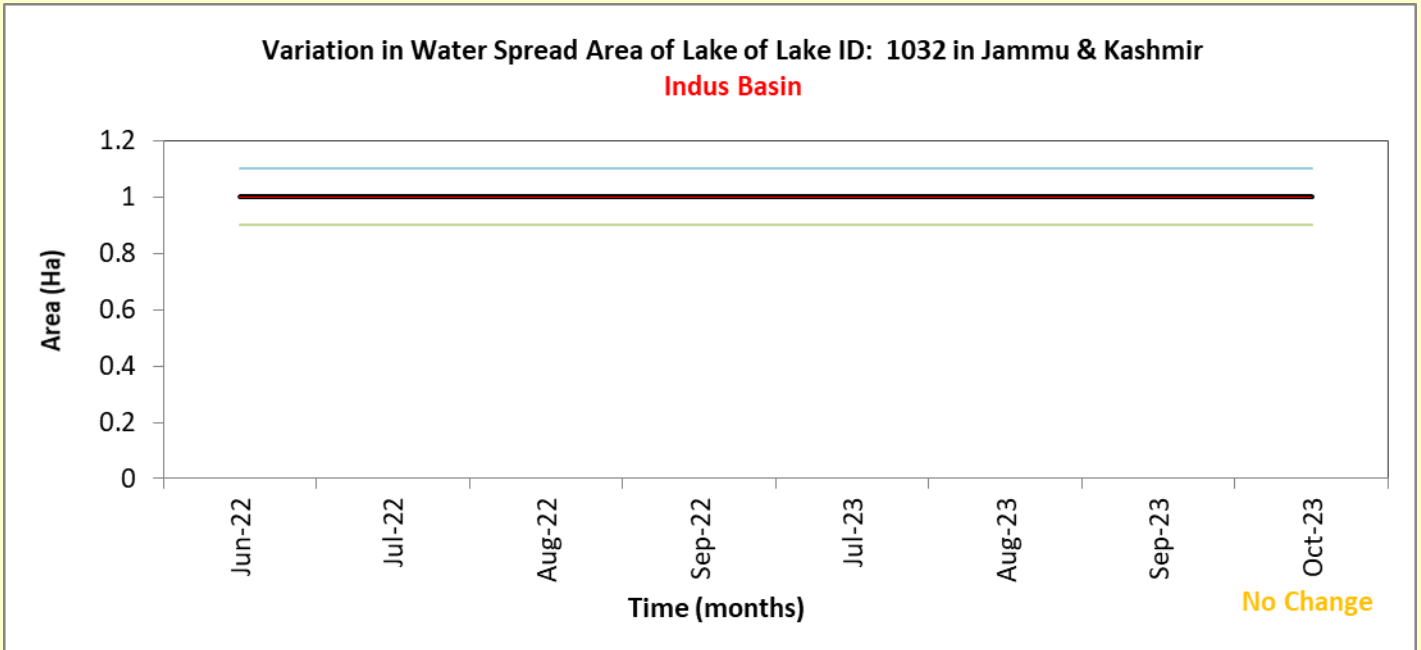


Figure 4.142(ii) Trend Analysis Plot  $\pm 20\%$

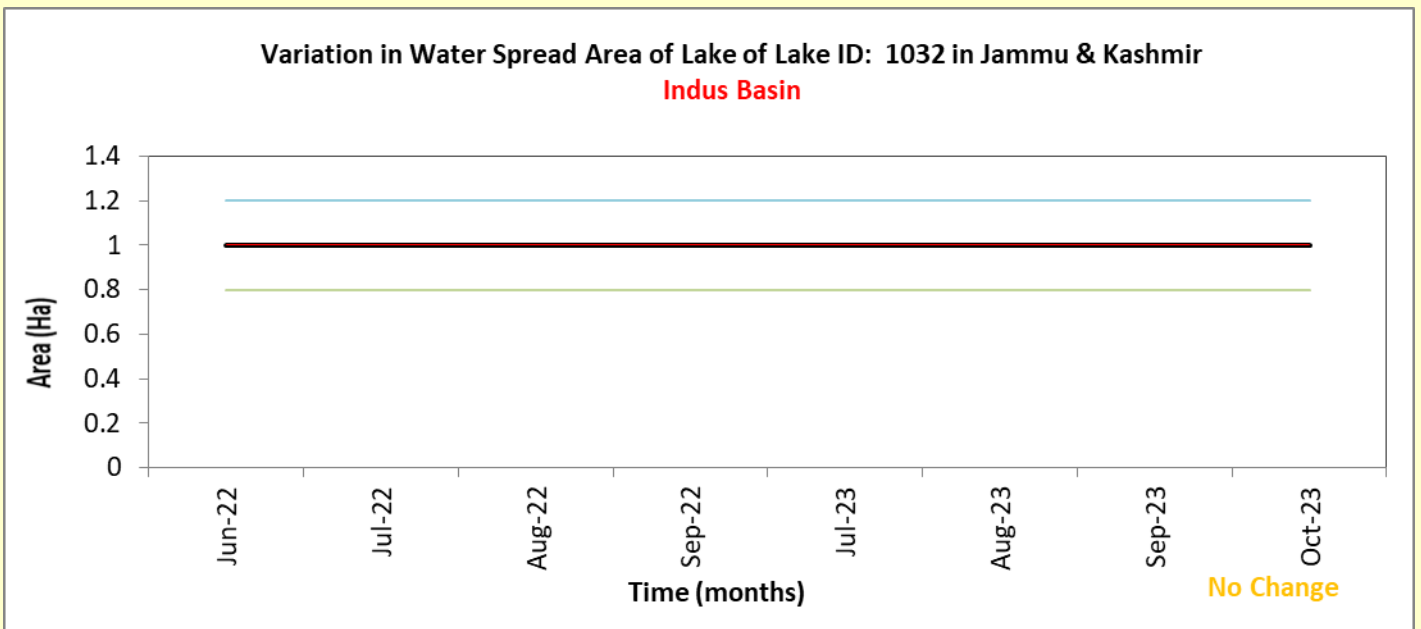


Figure 4.143(i) Trend Analysis Plot  $\pm 10\%$

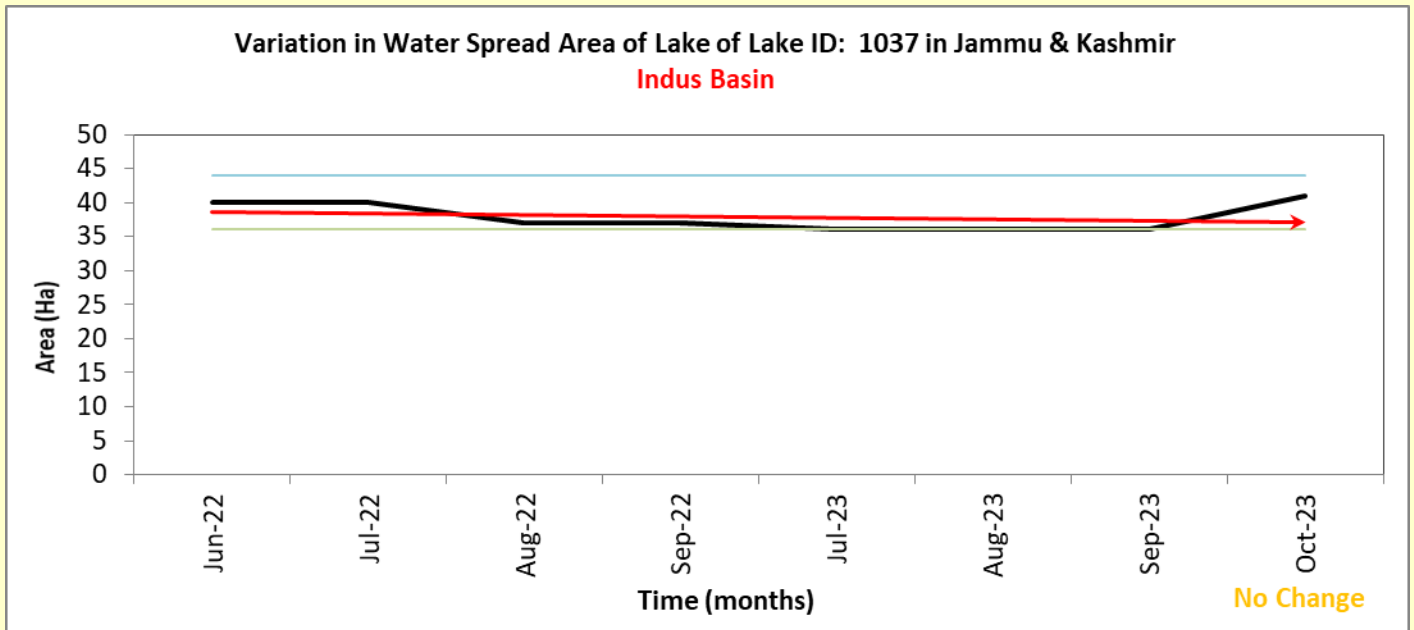


Figure 4.143(ii) Trend Analysis Plot  $\pm 20\%$

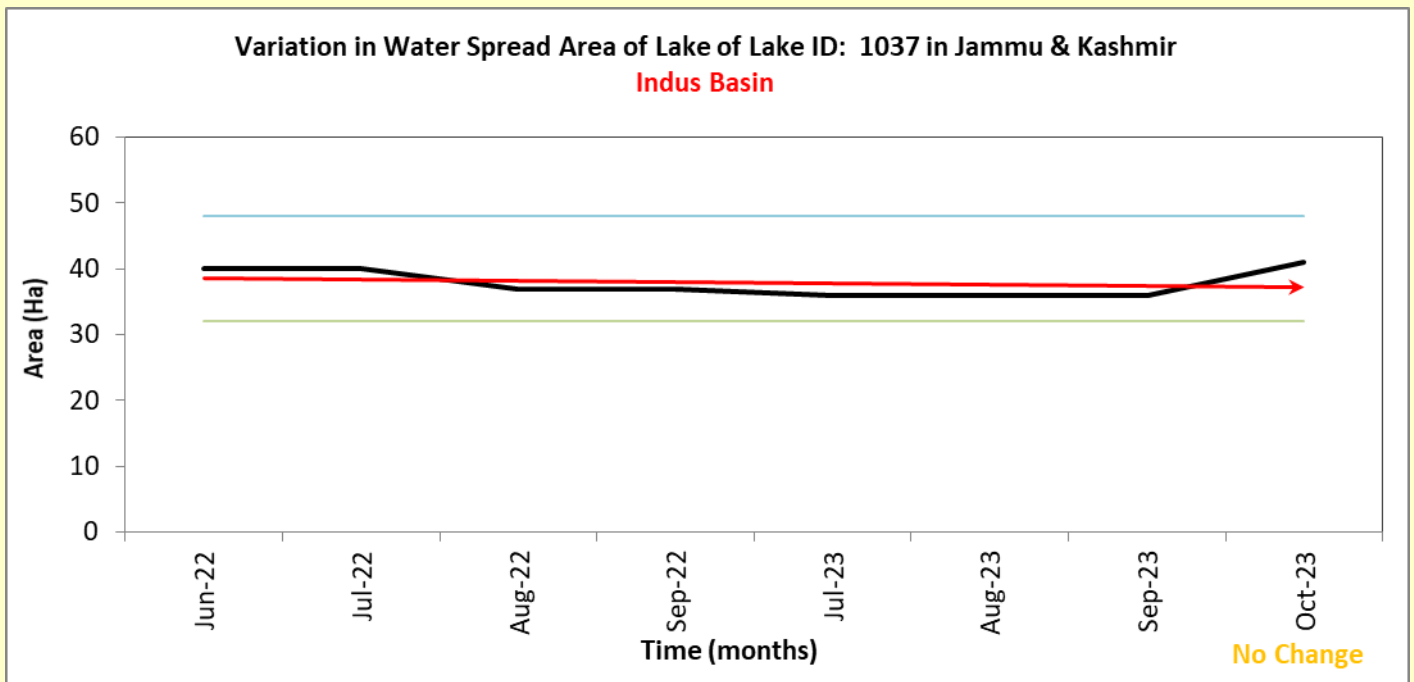


Figure 4.144(i) Trend Analysis Plot  $\pm 10\%$

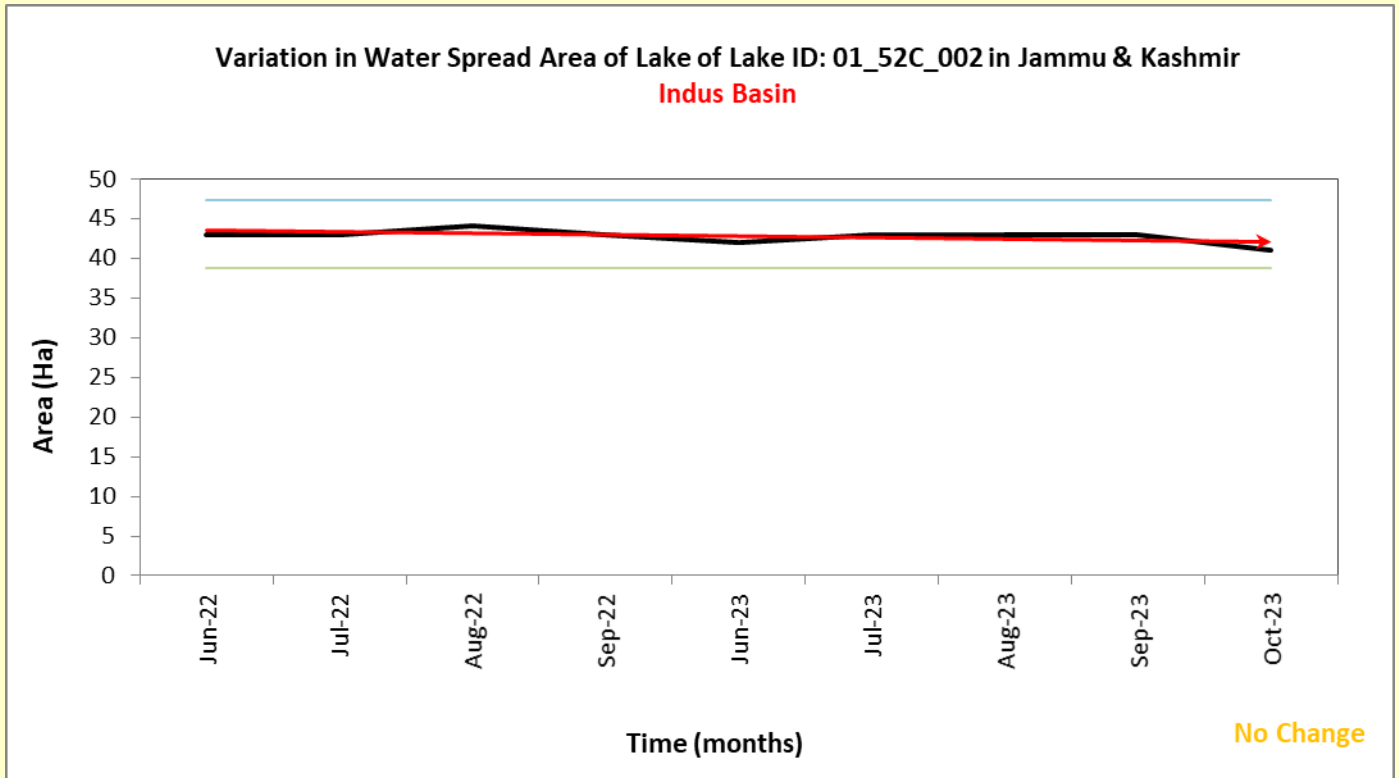


Figure 4.144(ii) Trend Analysis Plot  $\pm 20\%$

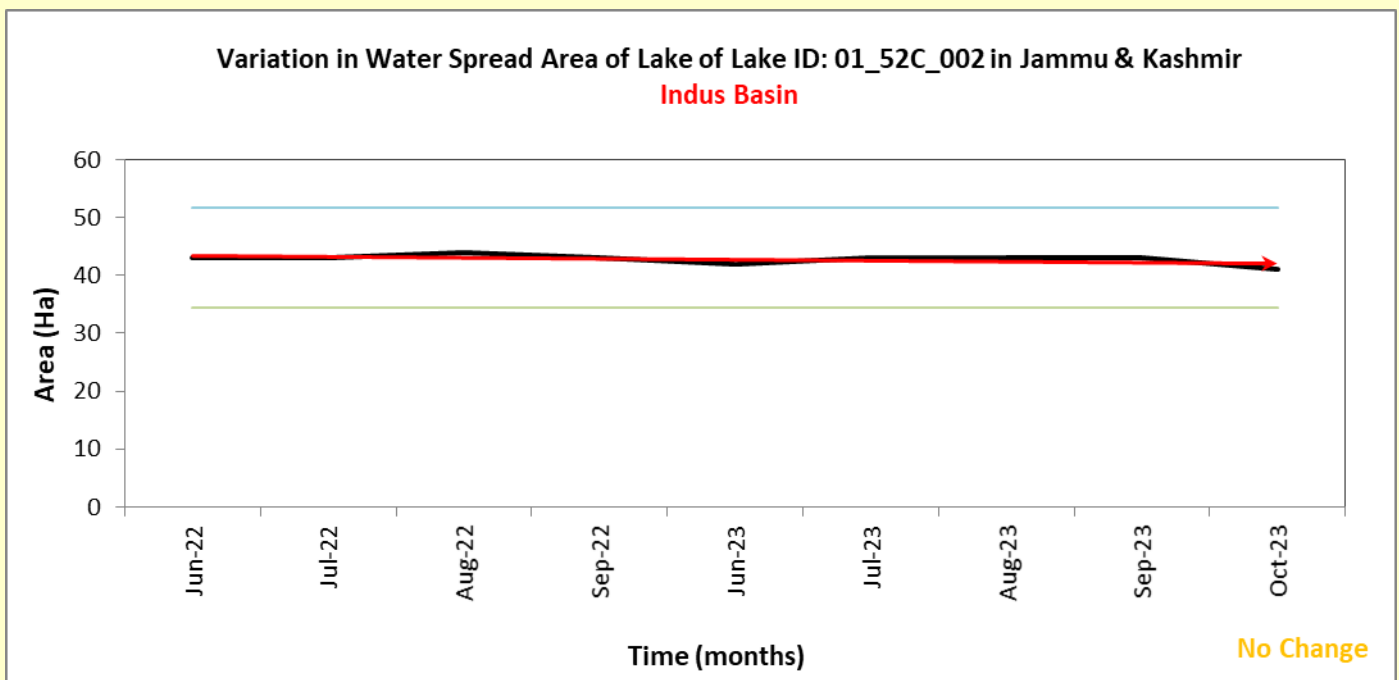


Figure 4.145(i) Trend Analysis Plot  $\pm 10\%$

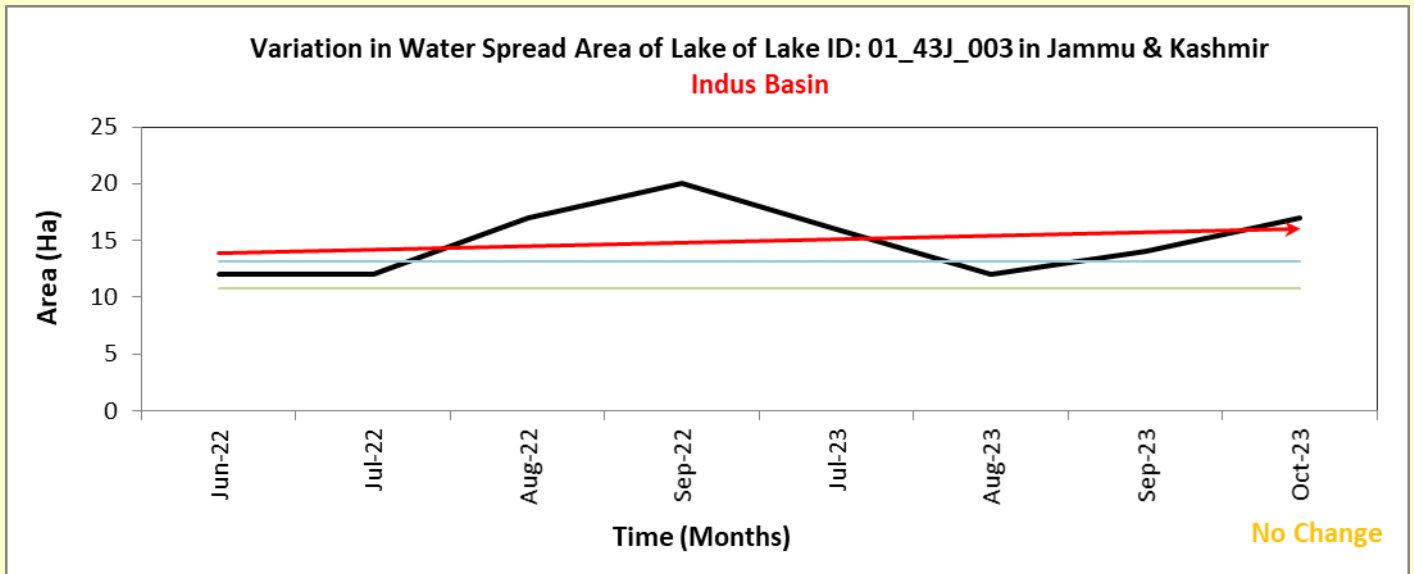


Figure 4.145(ii) Trend Analysis Plot  $\pm 20\%$

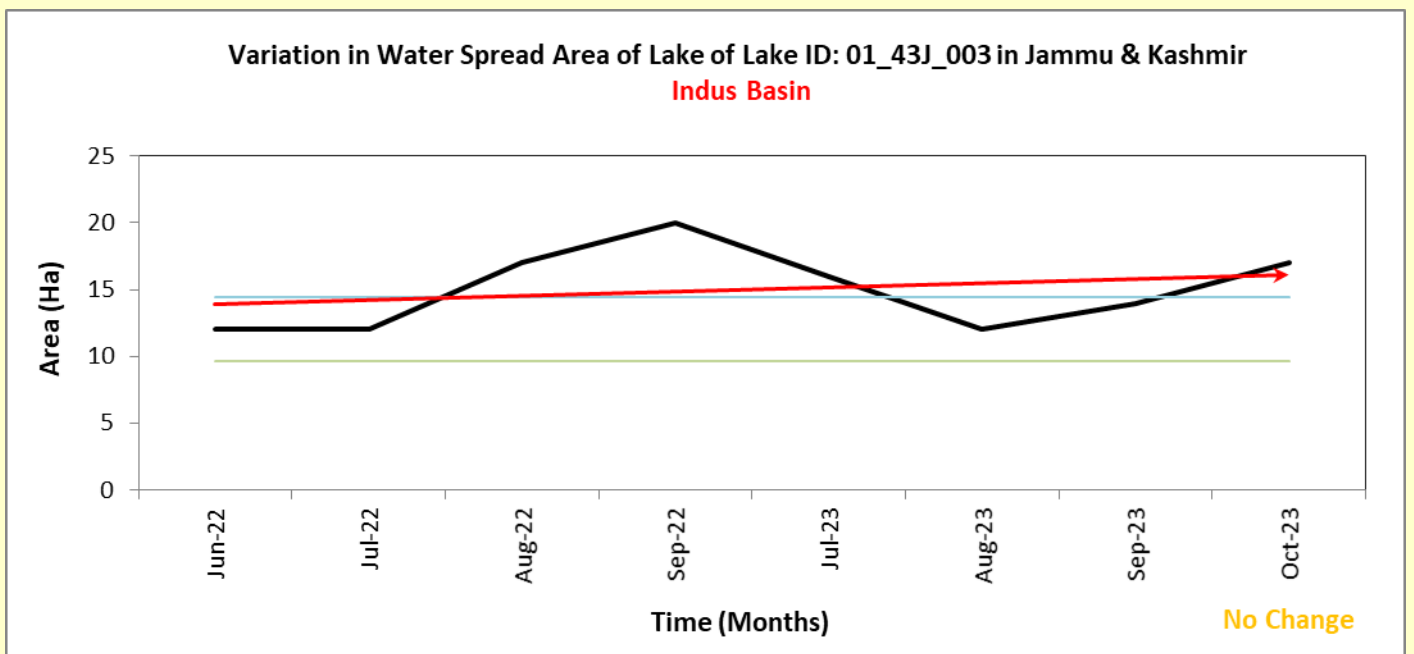


Figure 4.146(i) Trend Analysis Plot  $\pm 10\%$

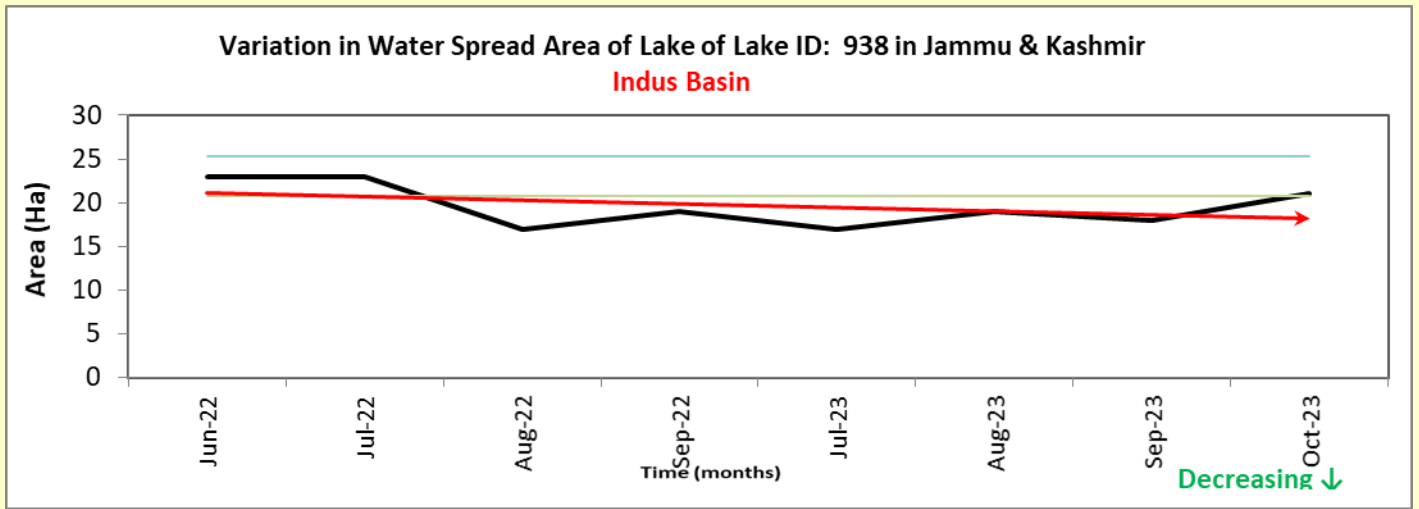


Figure 4.146(ii) Trend Analysis Plot  $\pm 20\%$

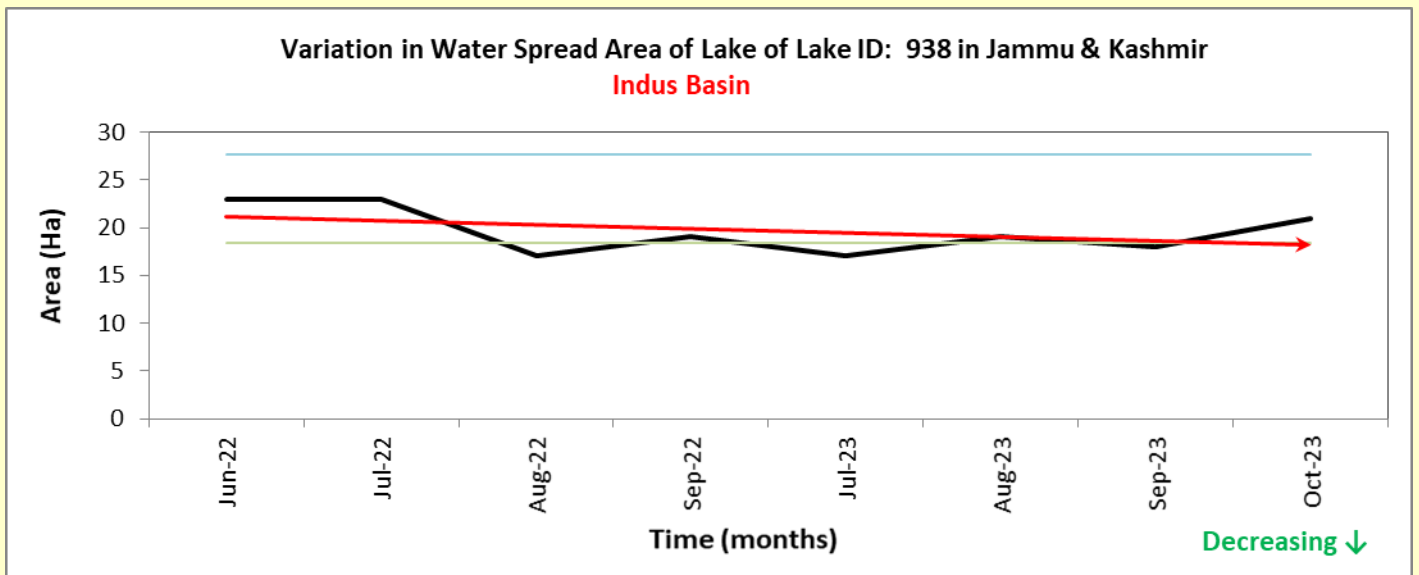


Figure 4.147(i) Trend Analysis Plot  $\pm 10\%$

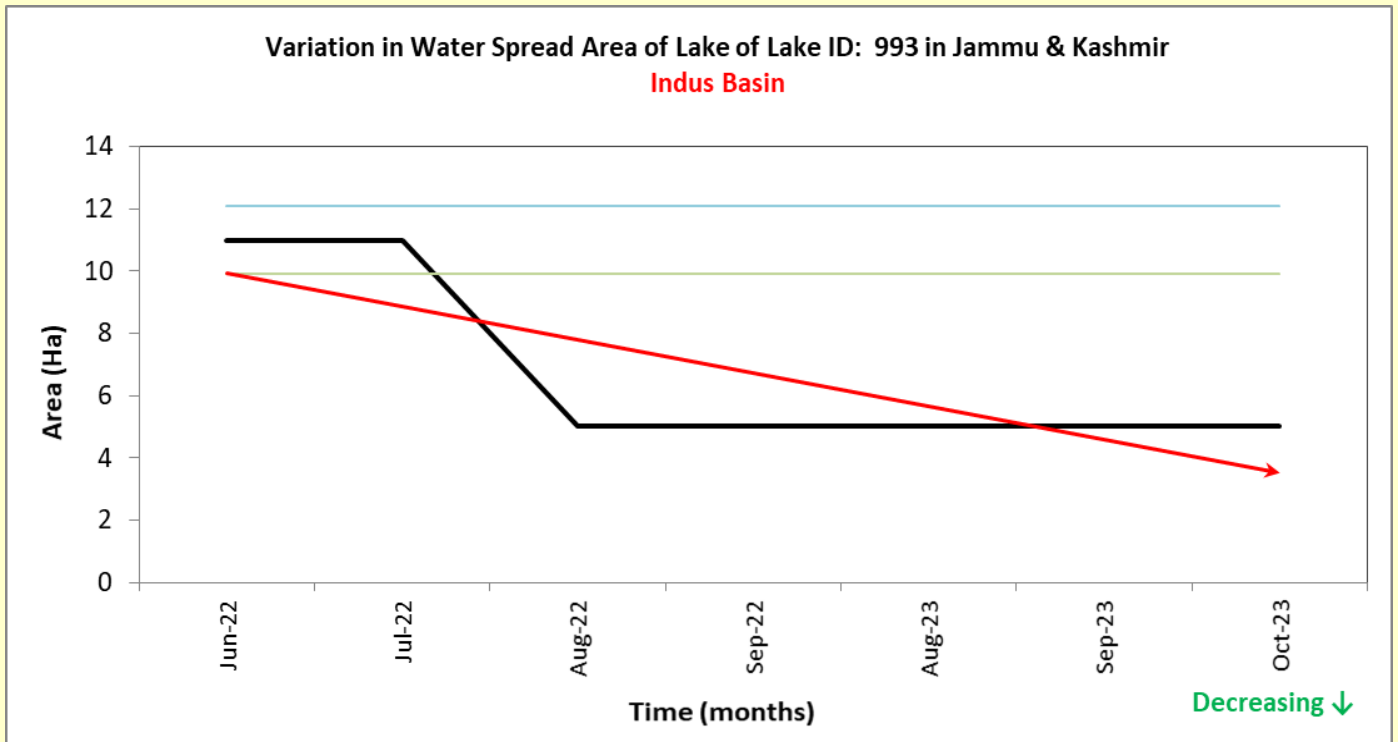


Figure 4.147(ii) Trend Analysis Plot  $\pm 20\%$

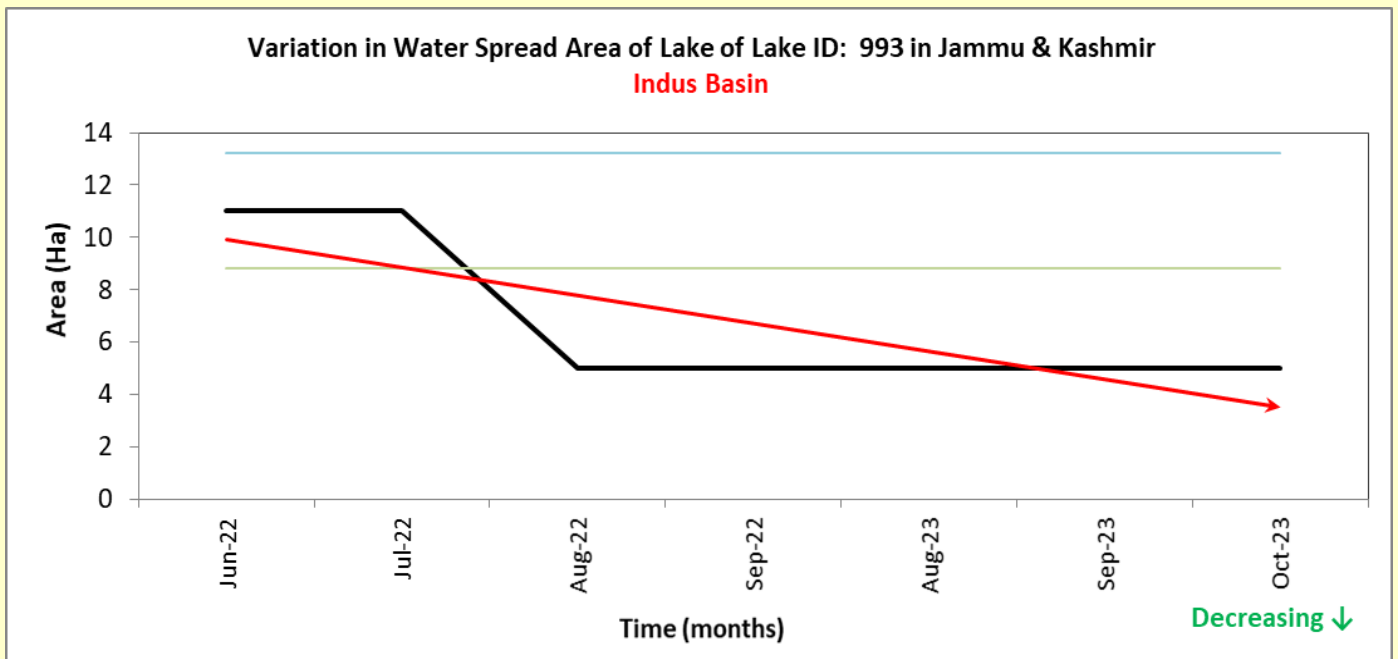


Figure 4.148(i) Trend Analysis Plot  $\pm 10\%$

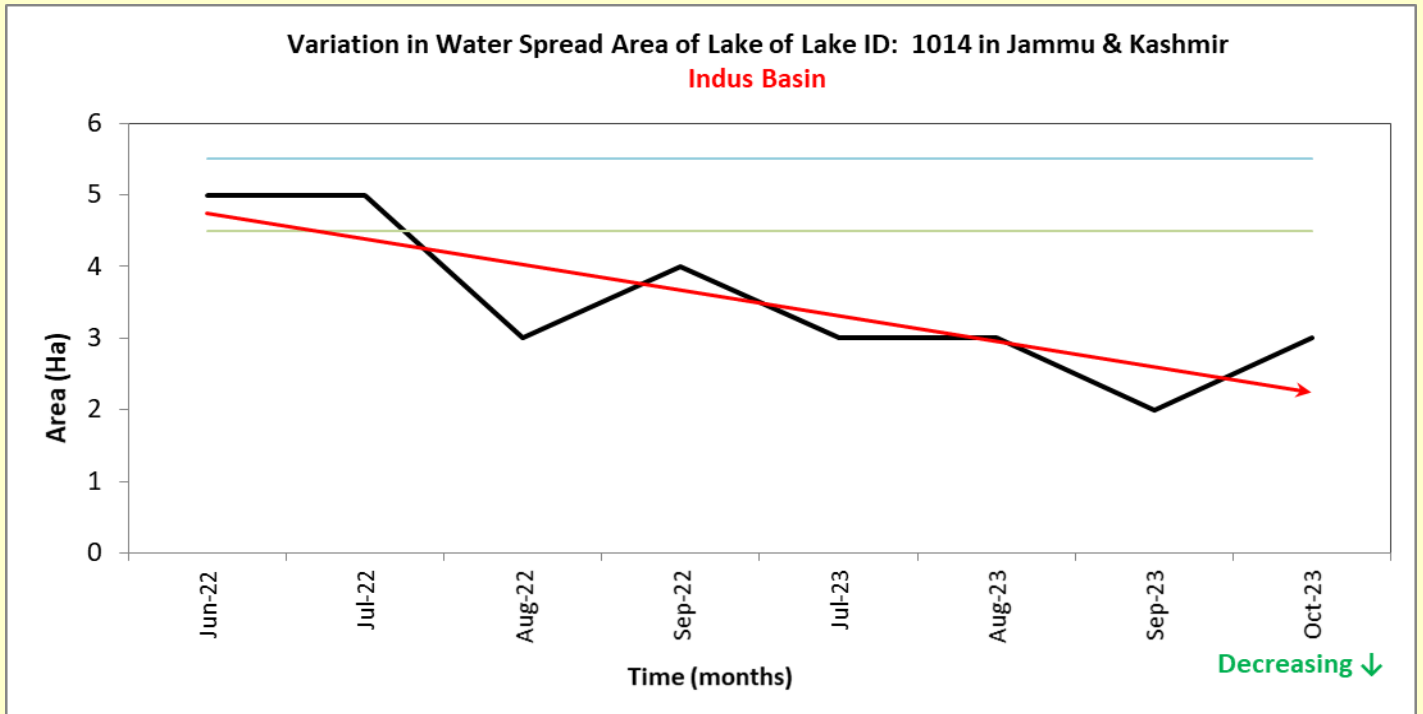
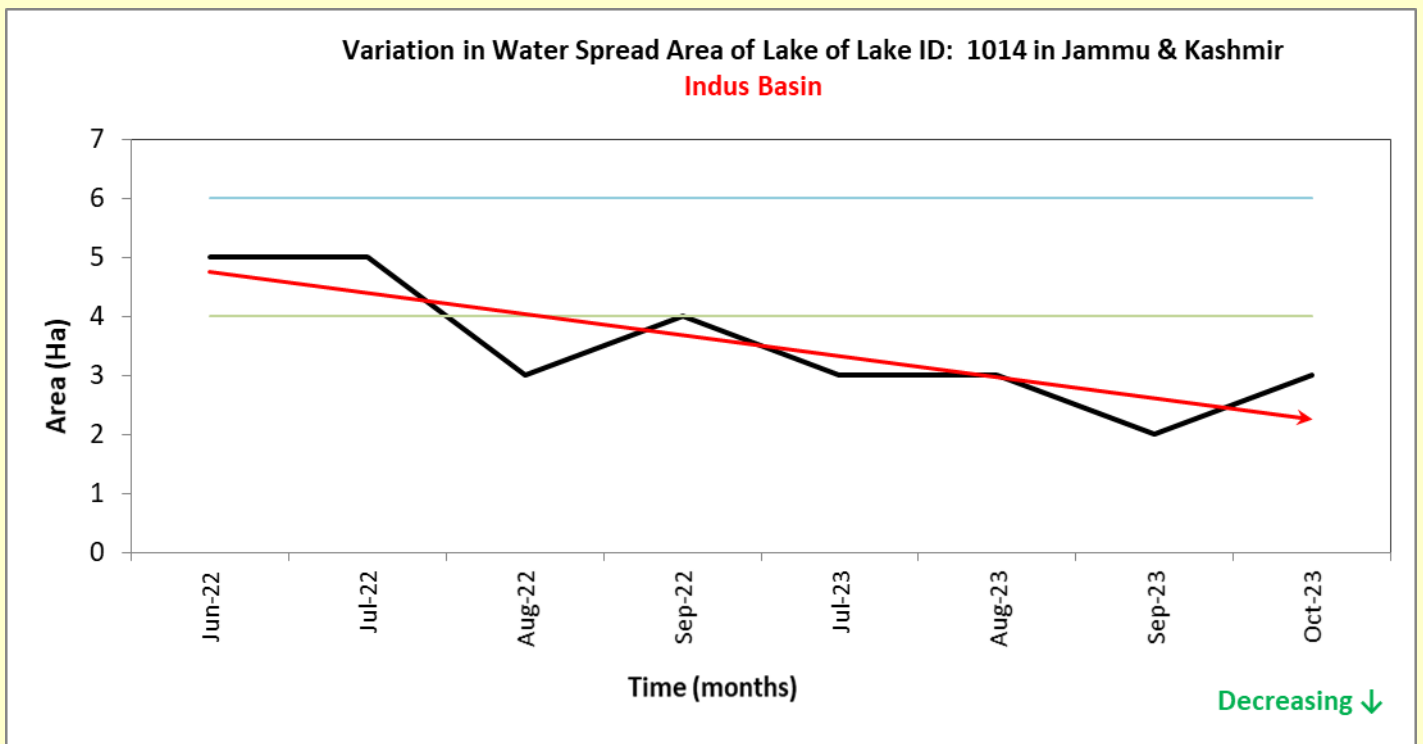


Figure 4.148(ii) Trend Analysis Plot  $\pm 10\%$



**Trend analysis of “Change in water spread area of Glacial Lakes between 10 Ha to 50 Ha of Himachal Pradesh (2022-2023)”**

Figure 4.149(i) Trend Analysis Plot  $\pm 10\%$

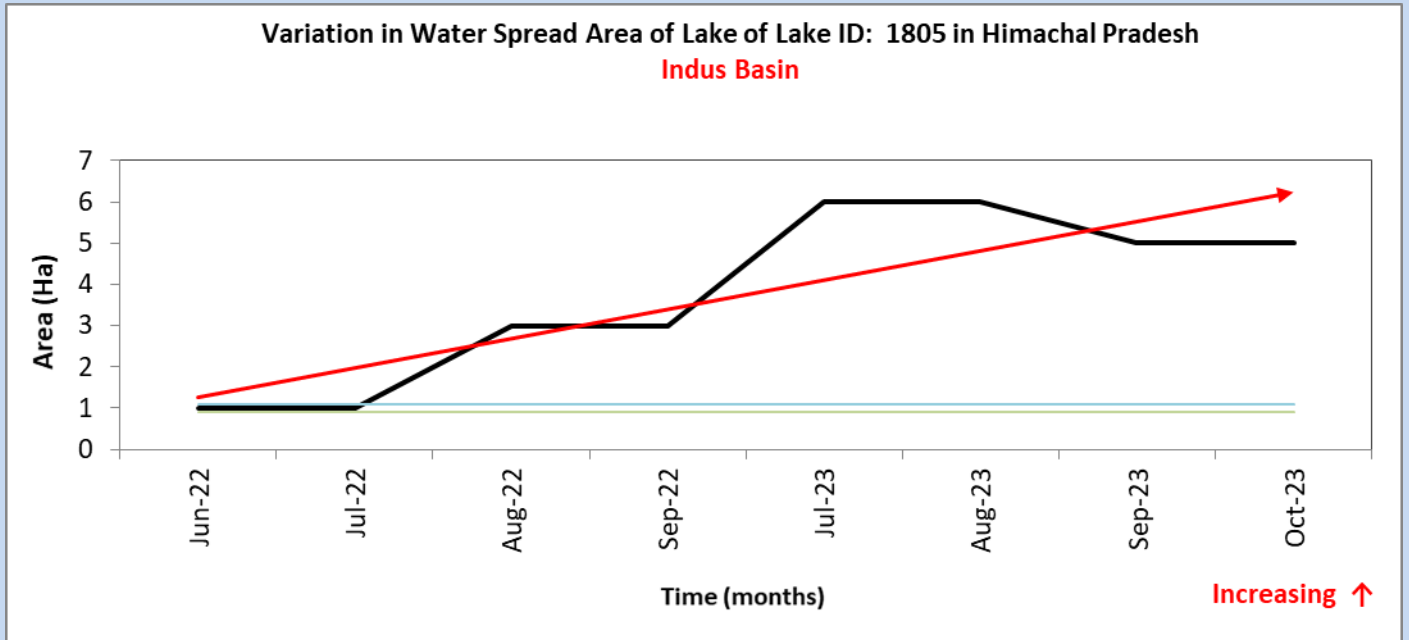


Figure 4.149(ii) Trend Analysis Plot  $\pm 20\%$

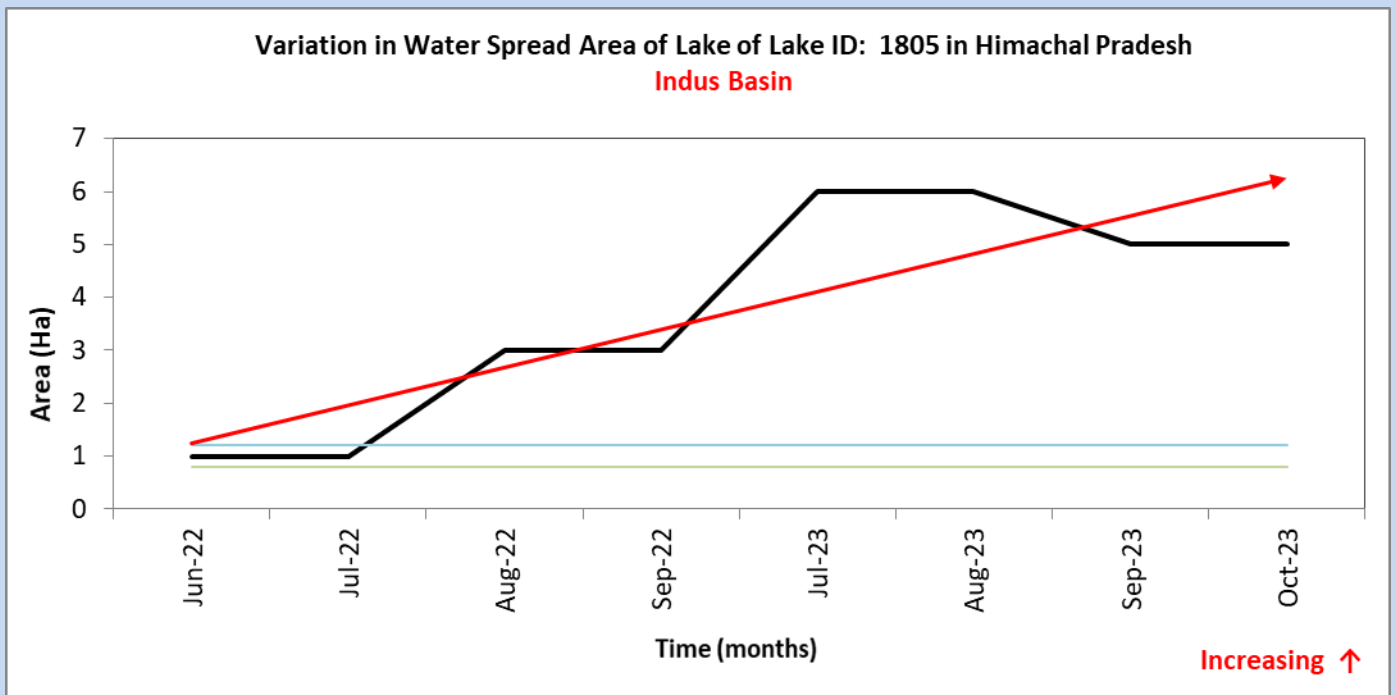


Figure 4.150(i) Trend Analysis Plot  $\pm 10\%$

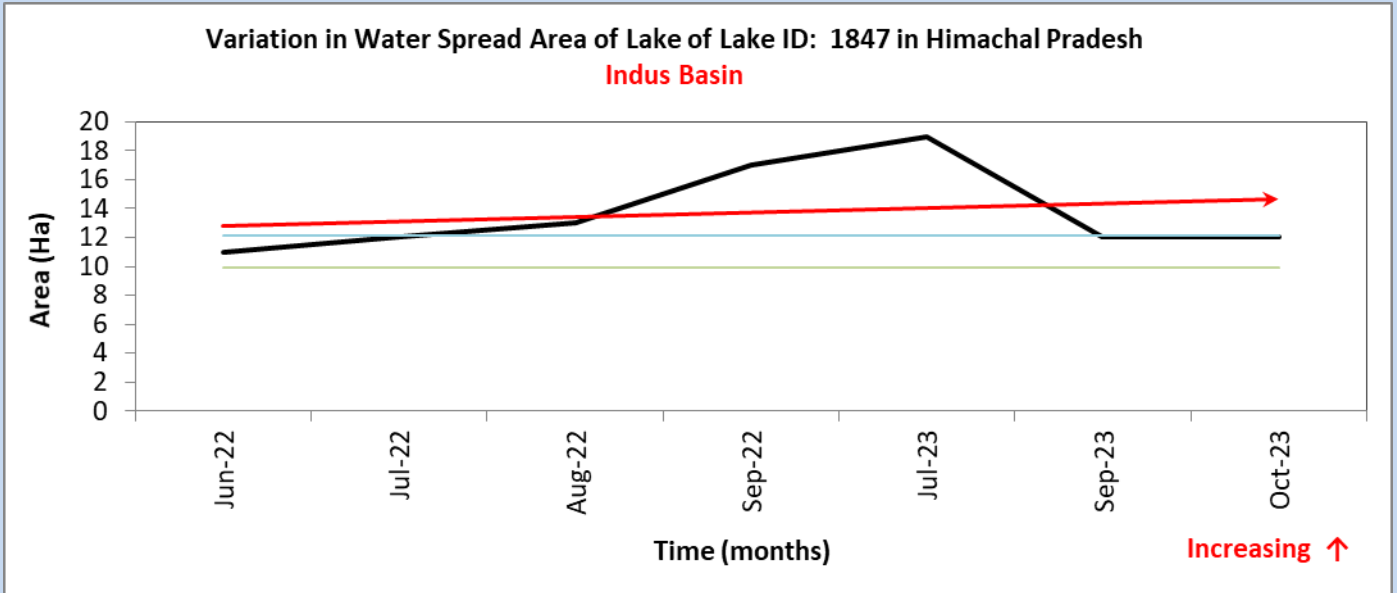


Figure 4.150(ii) Trend Analysis Plot  $\pm 20\%$

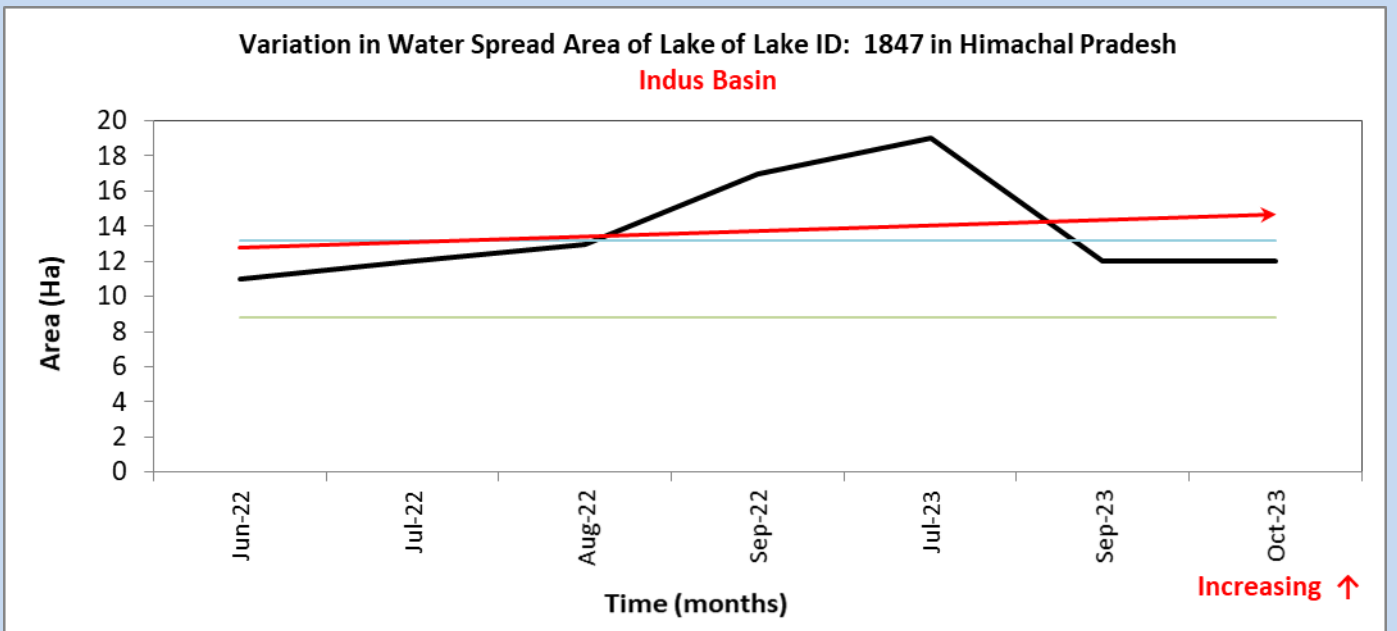


Figure 4.151(i) Trend Analysis Plot  $\pm 10\%$

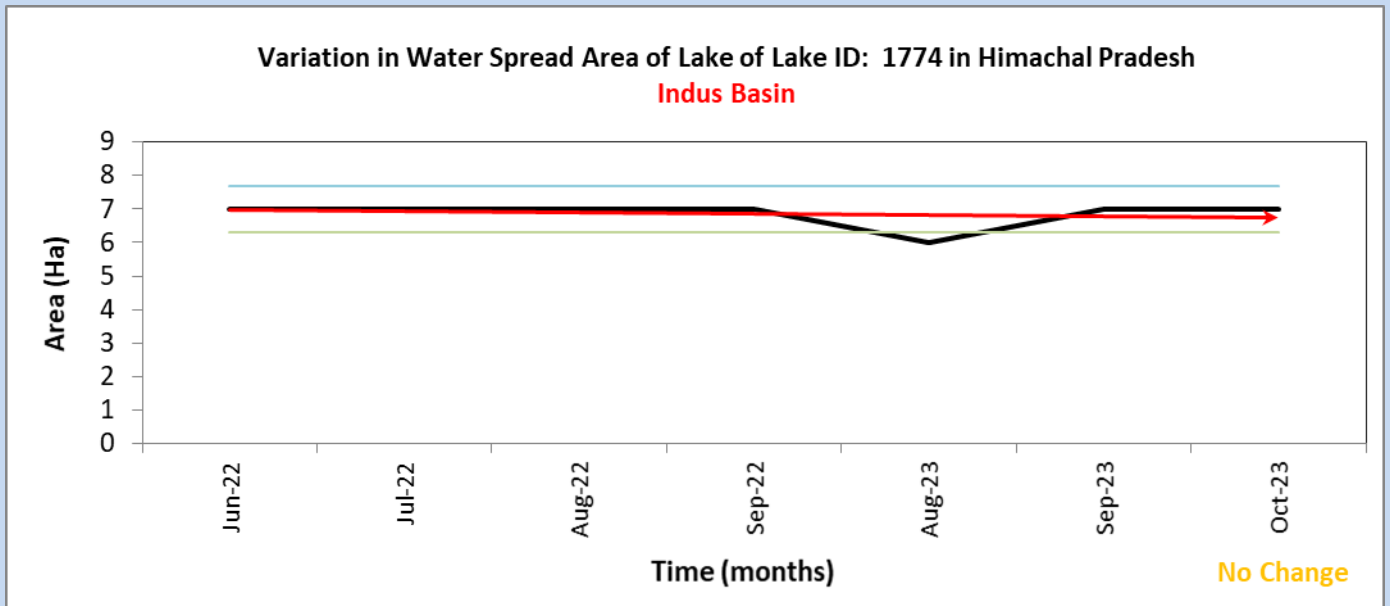


Figure 4.151(ii) Trend Analysis Plot  $\pm 20\%$

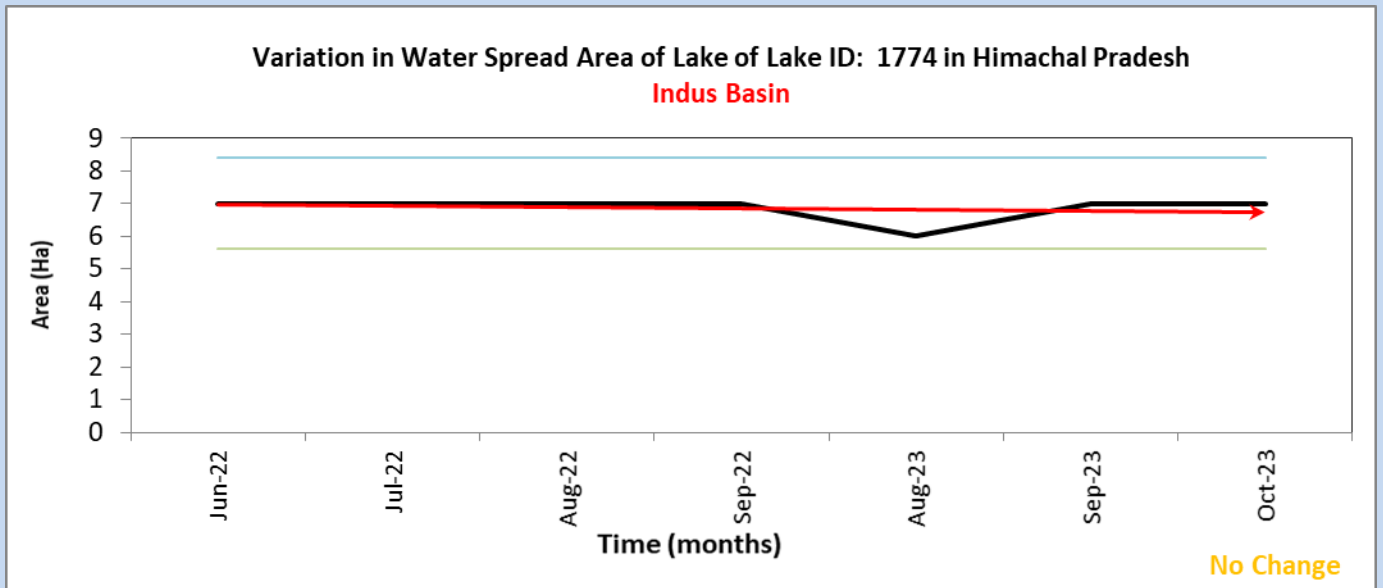


Figure 4.152(i) Trend Analysis Plot  $\pm 10\%$

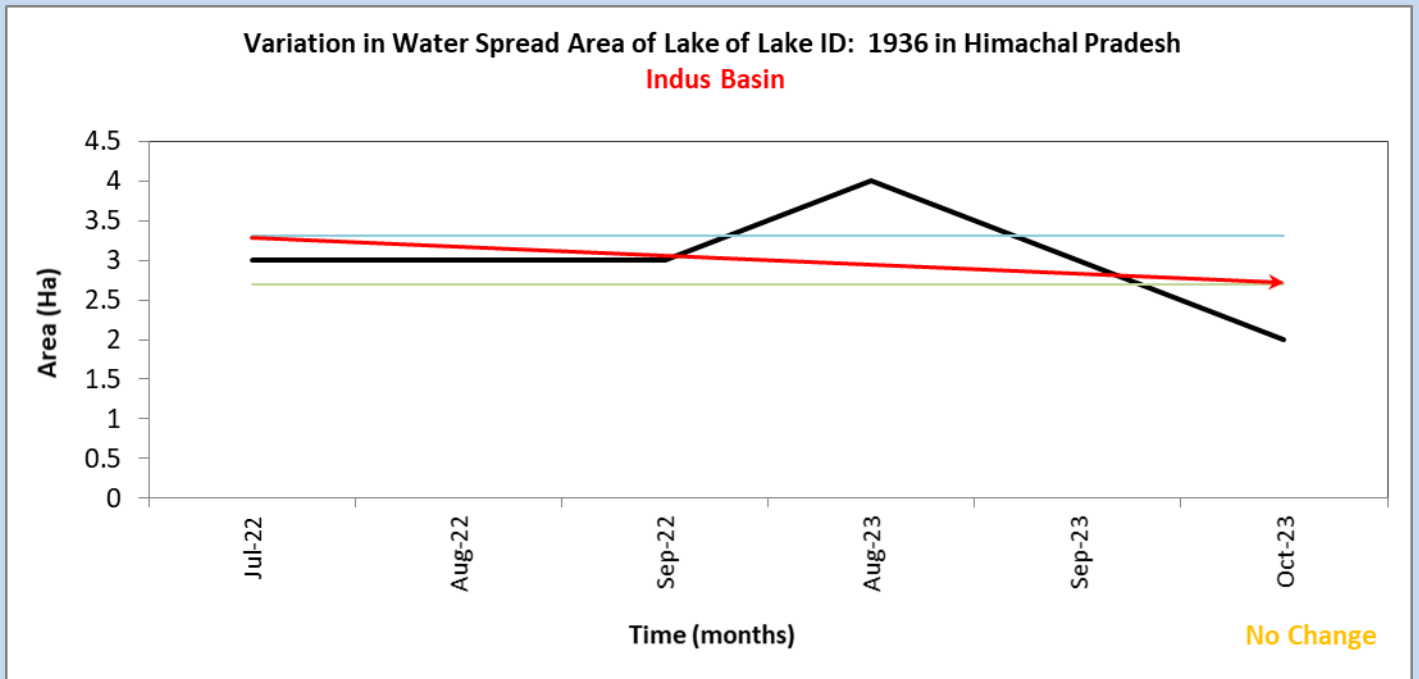


Figure 4.152(ii) Trend Analysis Plot  $\pm 20\%$

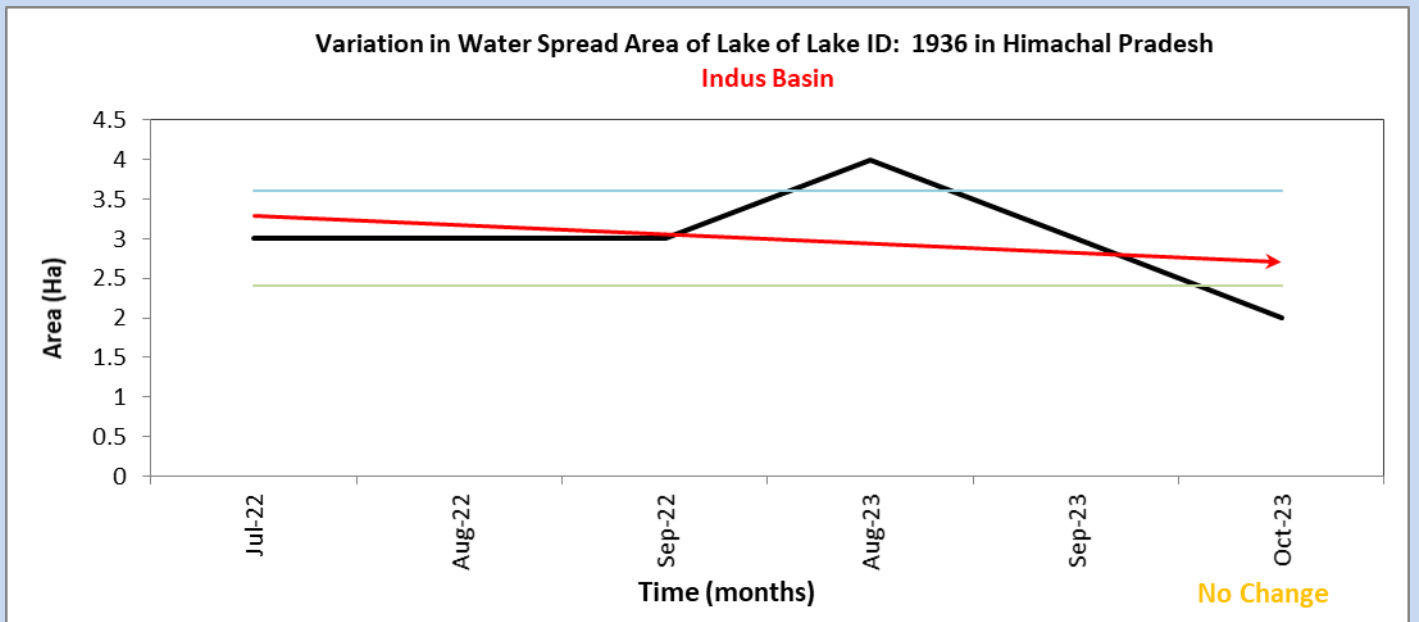


Figure 4.153(i) Trend Analysis Plot  $\pm 10\%$

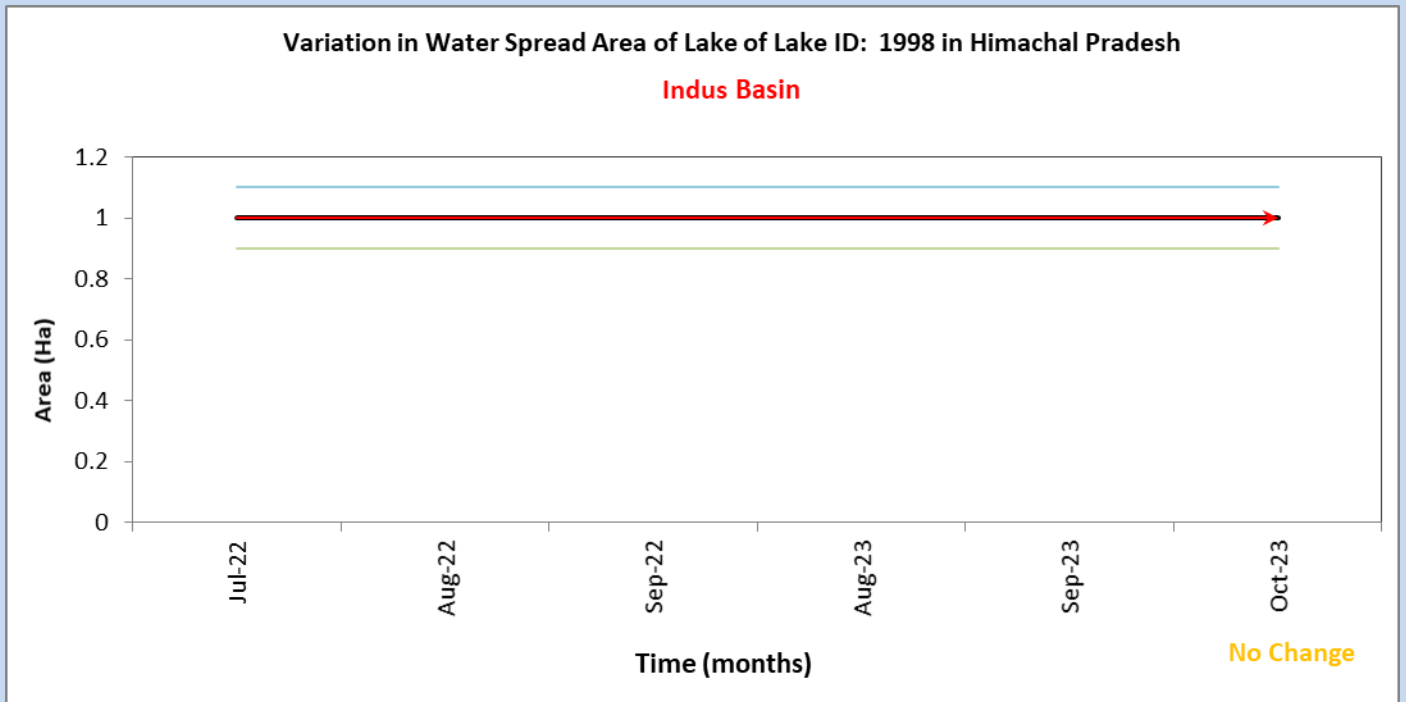


Figure 4.153(ii) Trend Analysis Plot  $\pm 20\%$

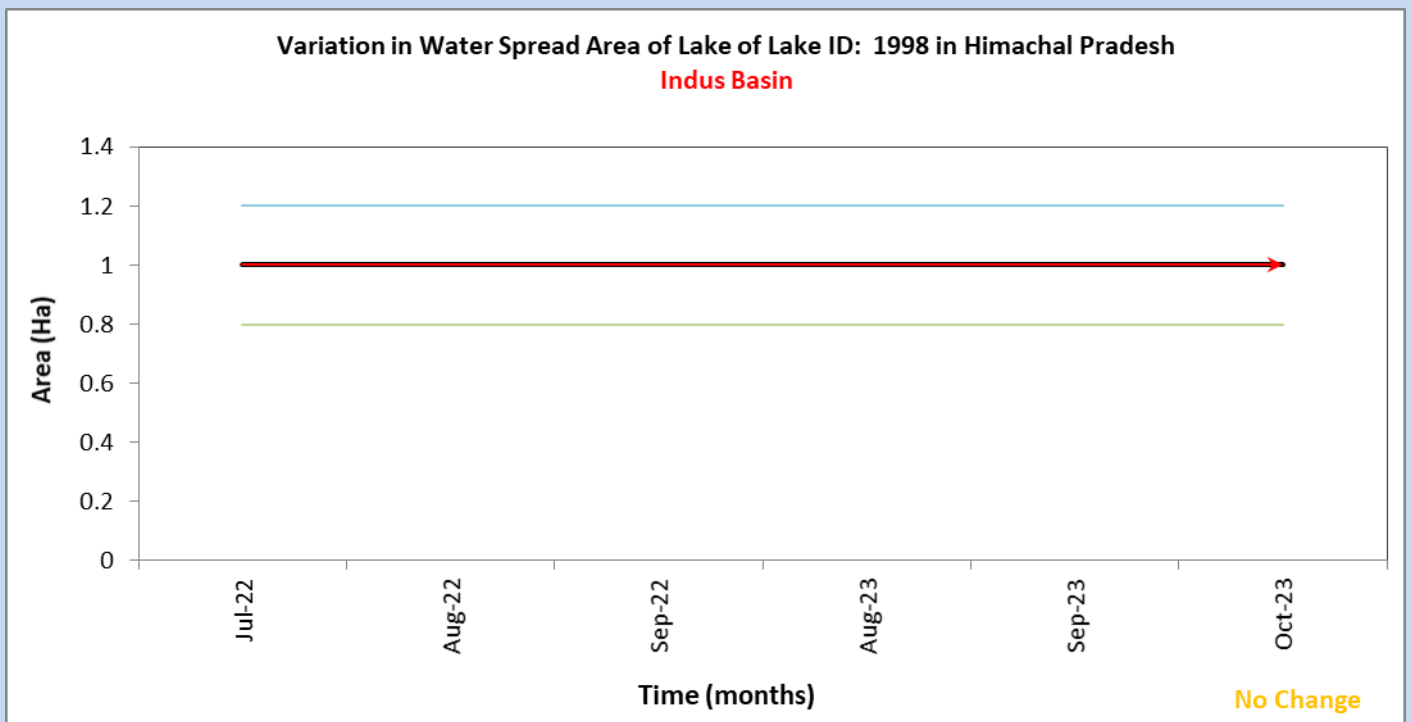


Figure 4.154(i) Trend Analysis Plot  $\pm 10\%$

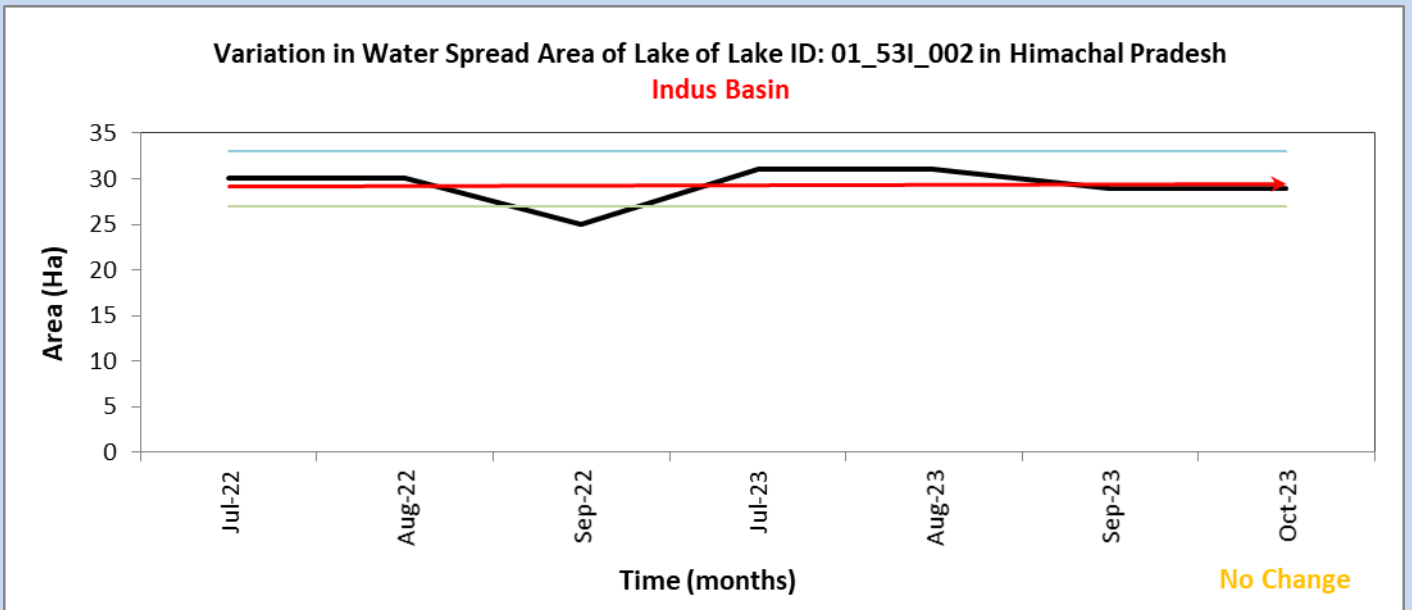


Figure 4.154(ii) Trend Analysis Plot  $\pm 20\%$

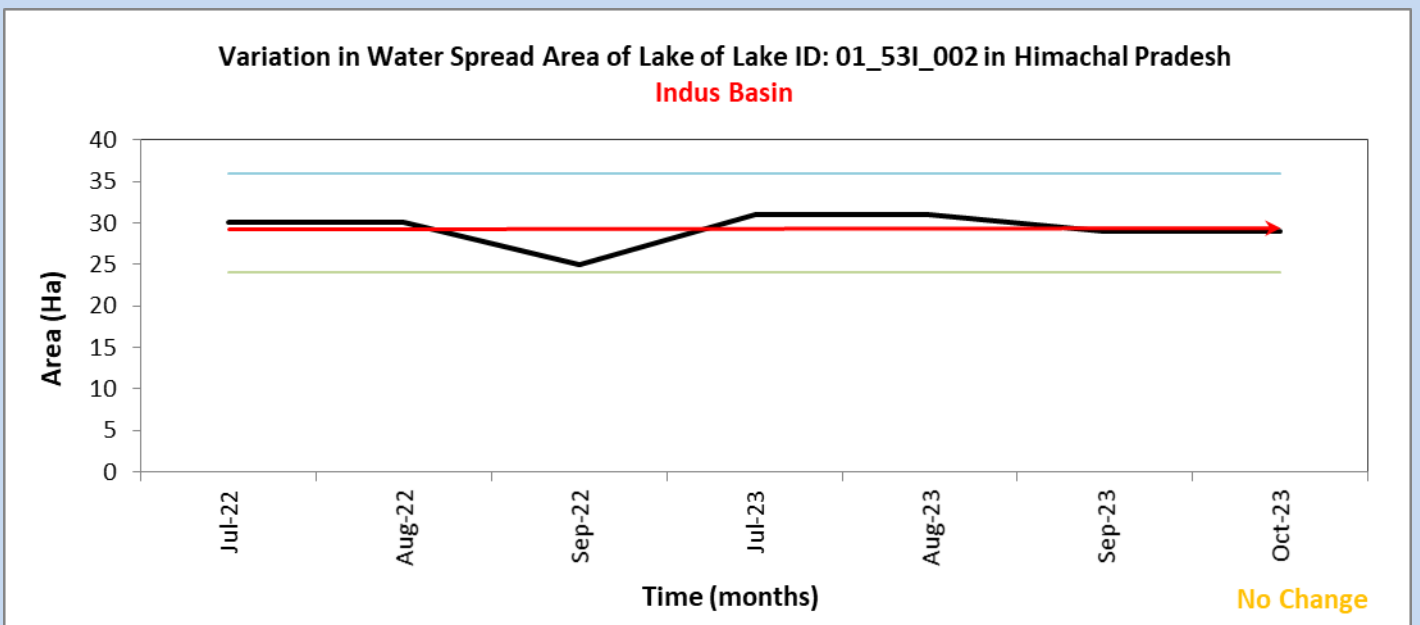


Figure 4.155(i) Trend Analysis Plot  $\pm 10\%$

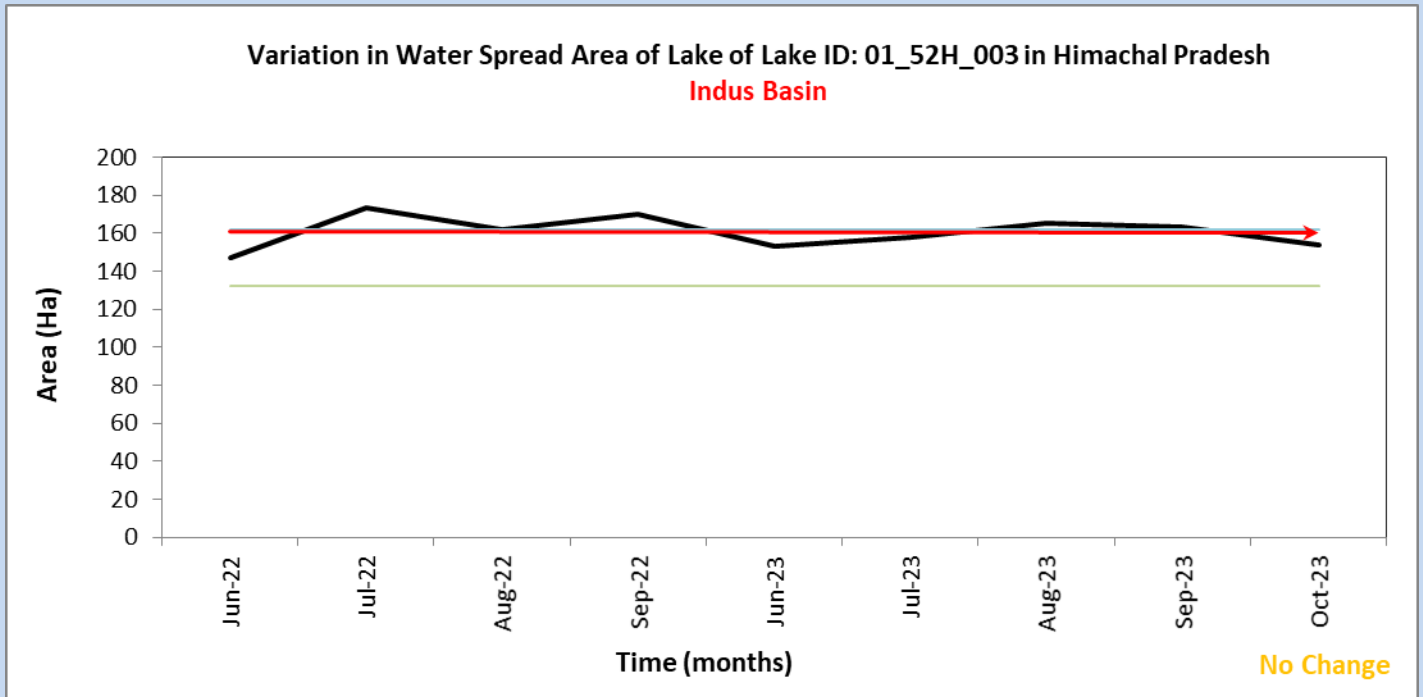


Figure 4.155(ii) Trend Analysis Plot  $\pm 20\%$

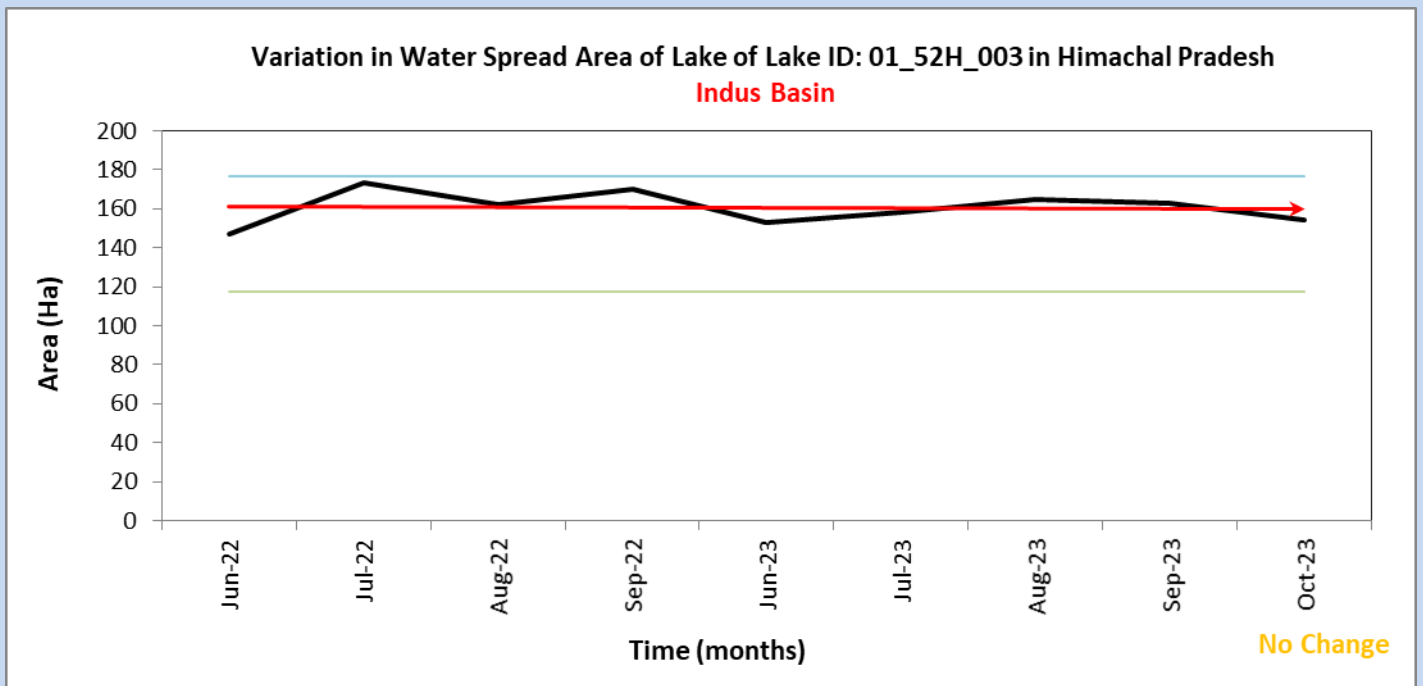


Figure 4.156(i) Trend Analysis Plot  $\pm 10\%$

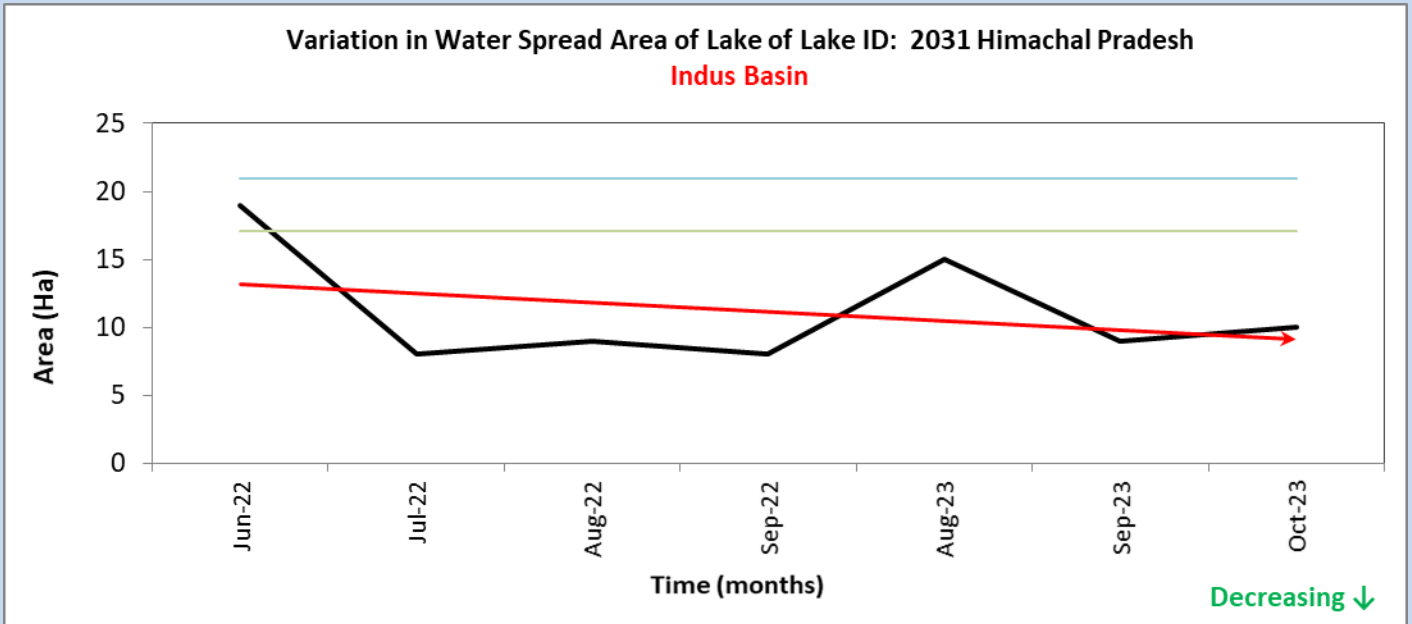
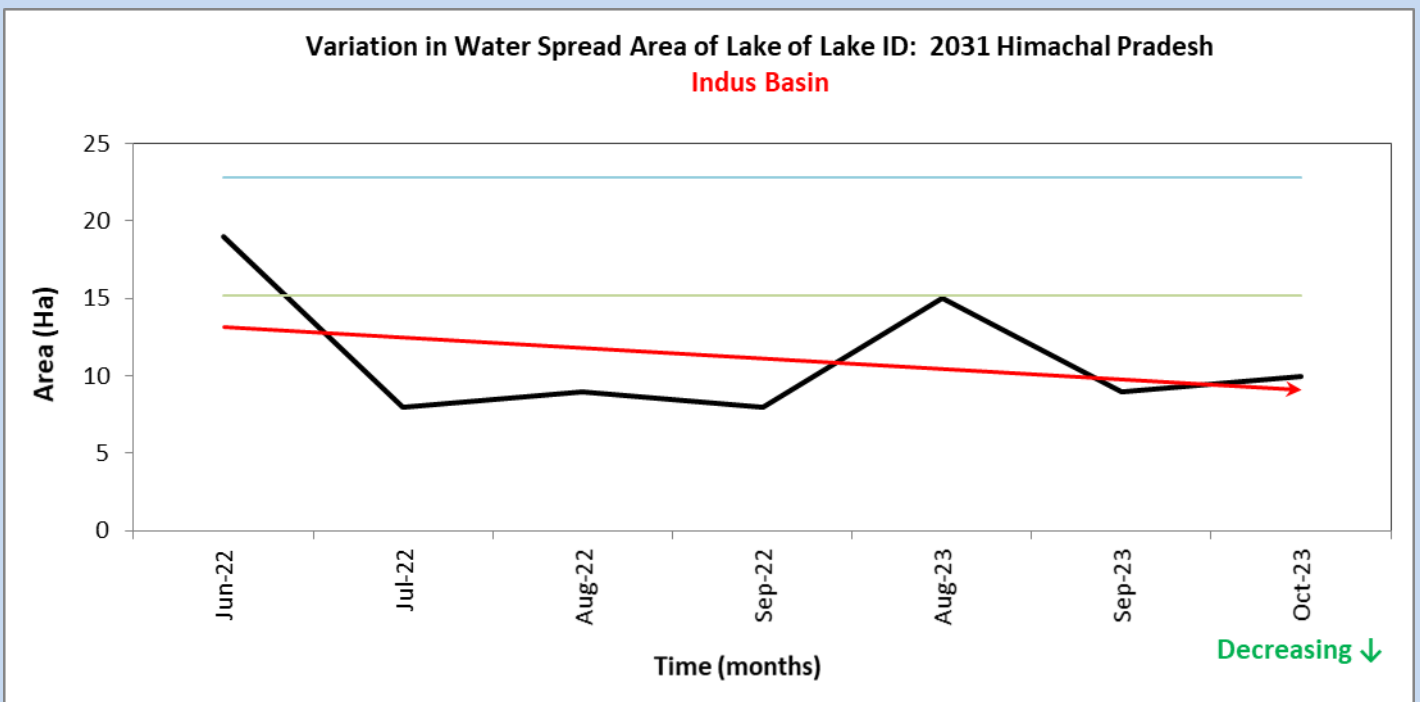


Figure 4.156(ii) Trend Analysis Plot  $\pm 20\%$



**Trend analysis of “Change in water spread area of Glacial Lakes between 10 Ha to 50 Ha of Uttarakhand (2022-2023)”**

Figure 4.157(i) Trend Analysis Plot  $\pm 10\%$

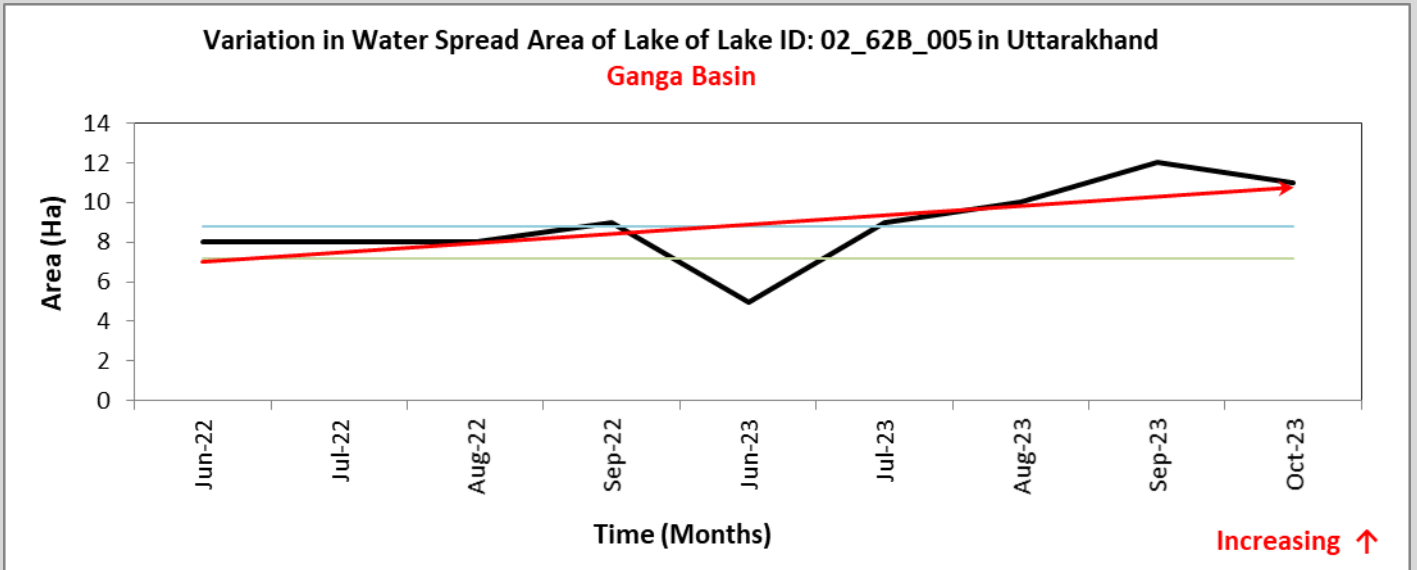


Figure 4.157(ii) Trend Analysis Plot  $\pm 20\%$

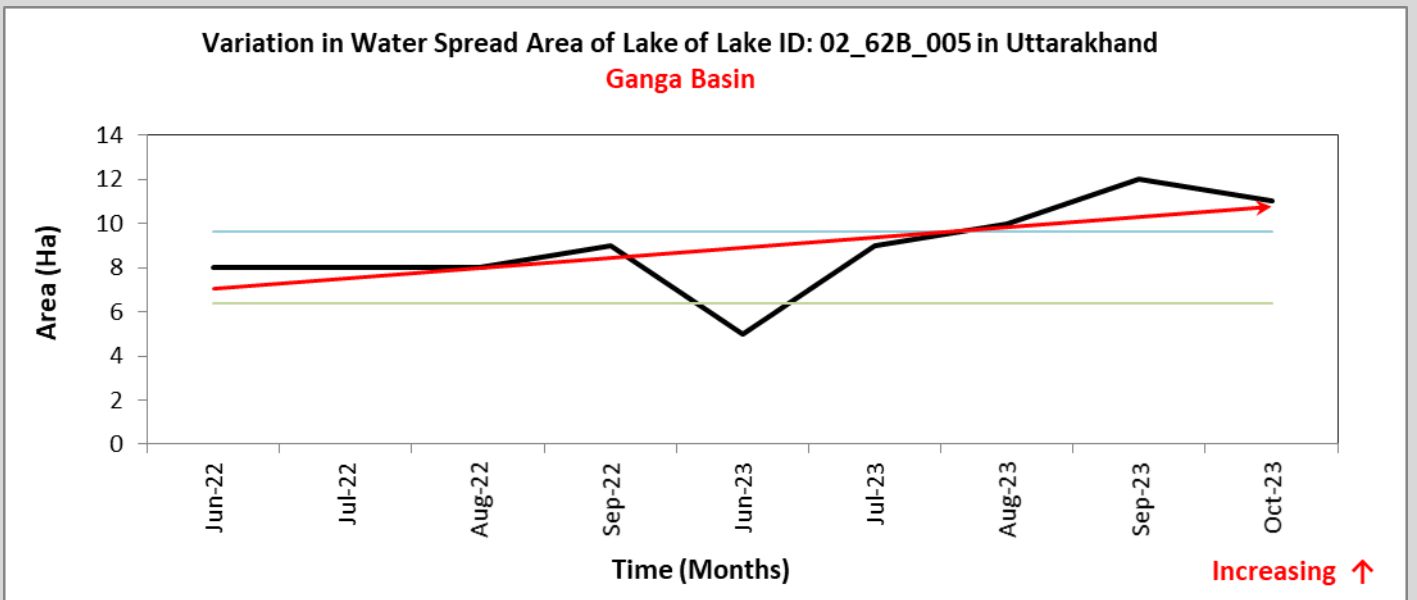


Figure 4.158(i) Trend Analysis Plot  $\pm 10\%$

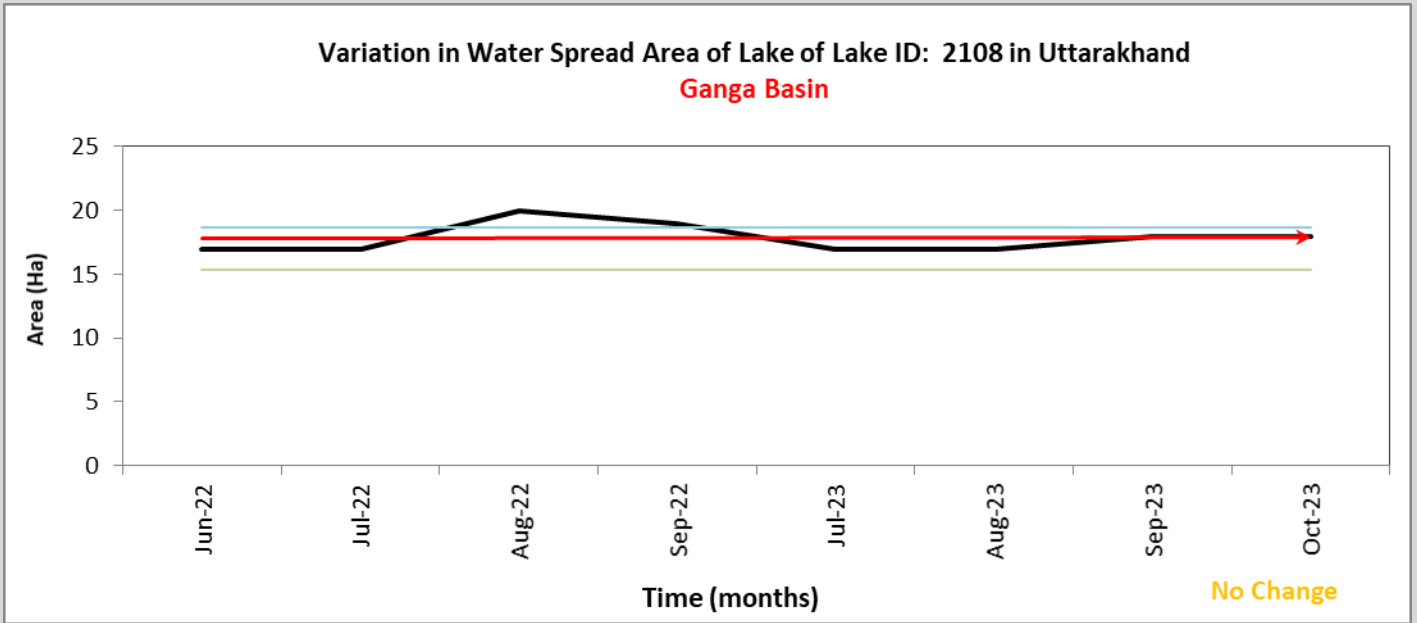


Figure 4.158(ii) Trend Analysis Plot  $\pm 20\%$

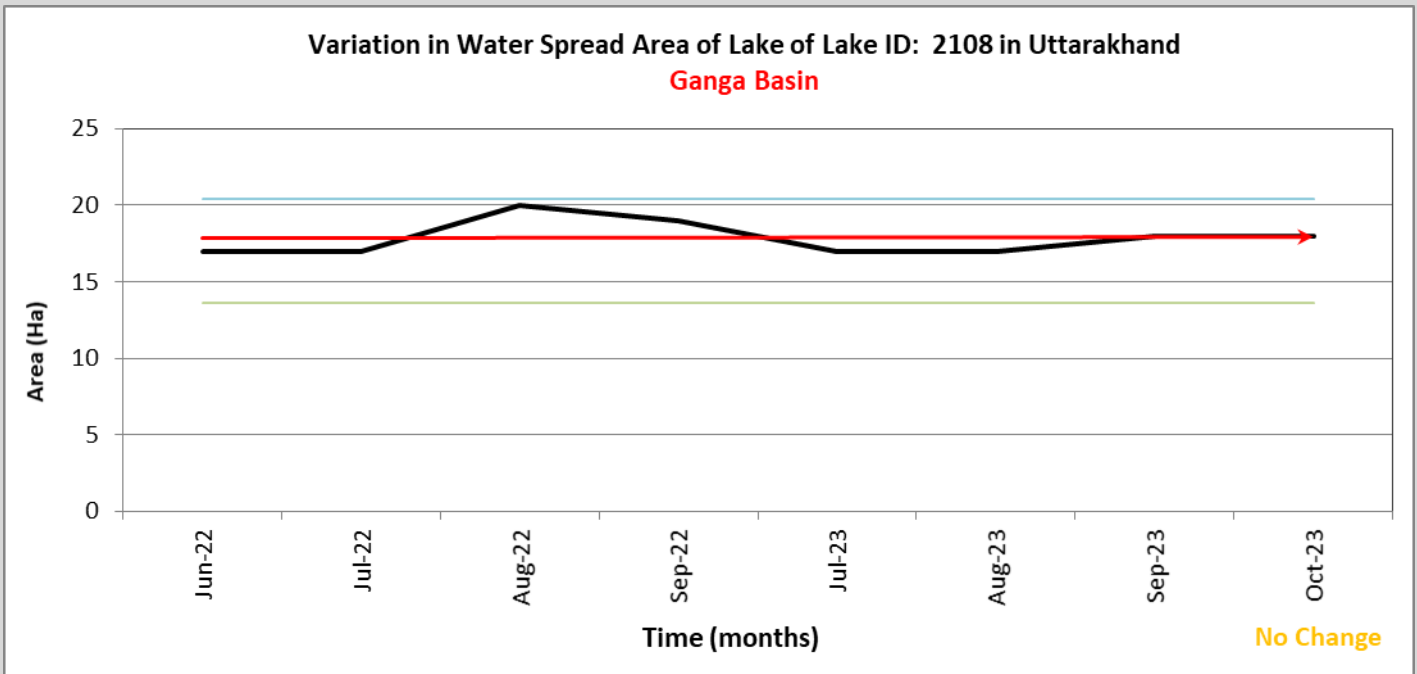


Figure 4.159(i) Trend Analysis Plot  $\pm 10\%$

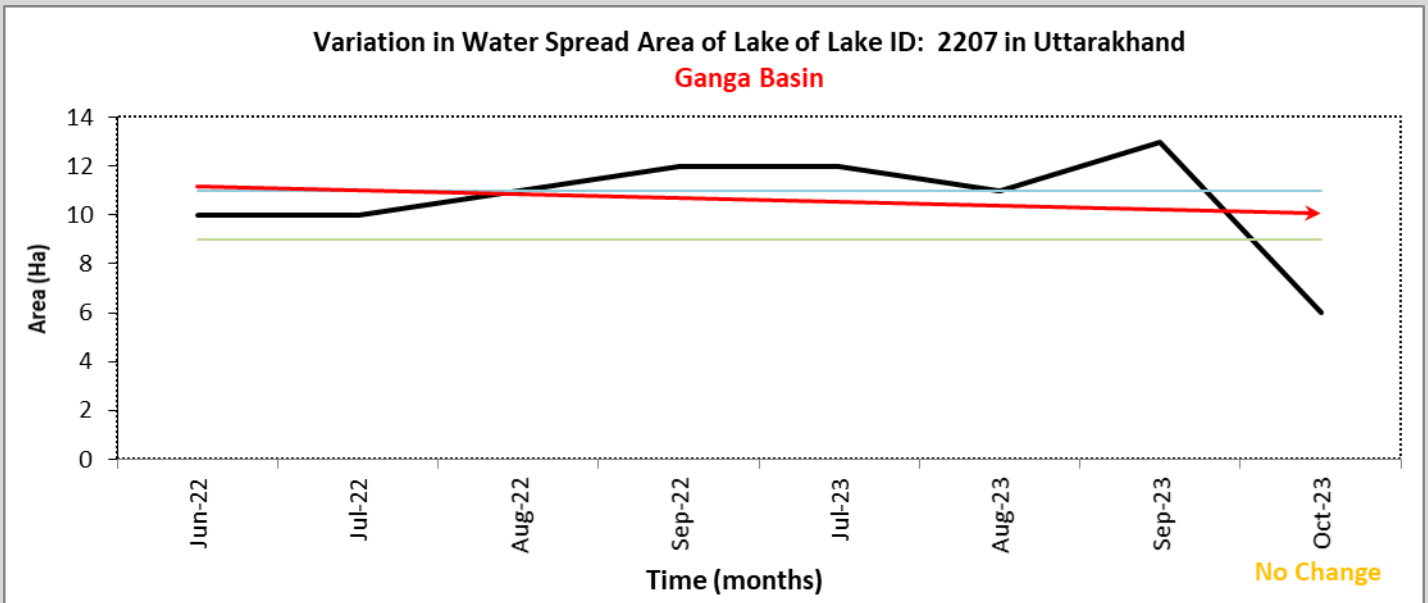


Figure 4.159(ii) Trend Analysis Plot  $\pm 20\%$

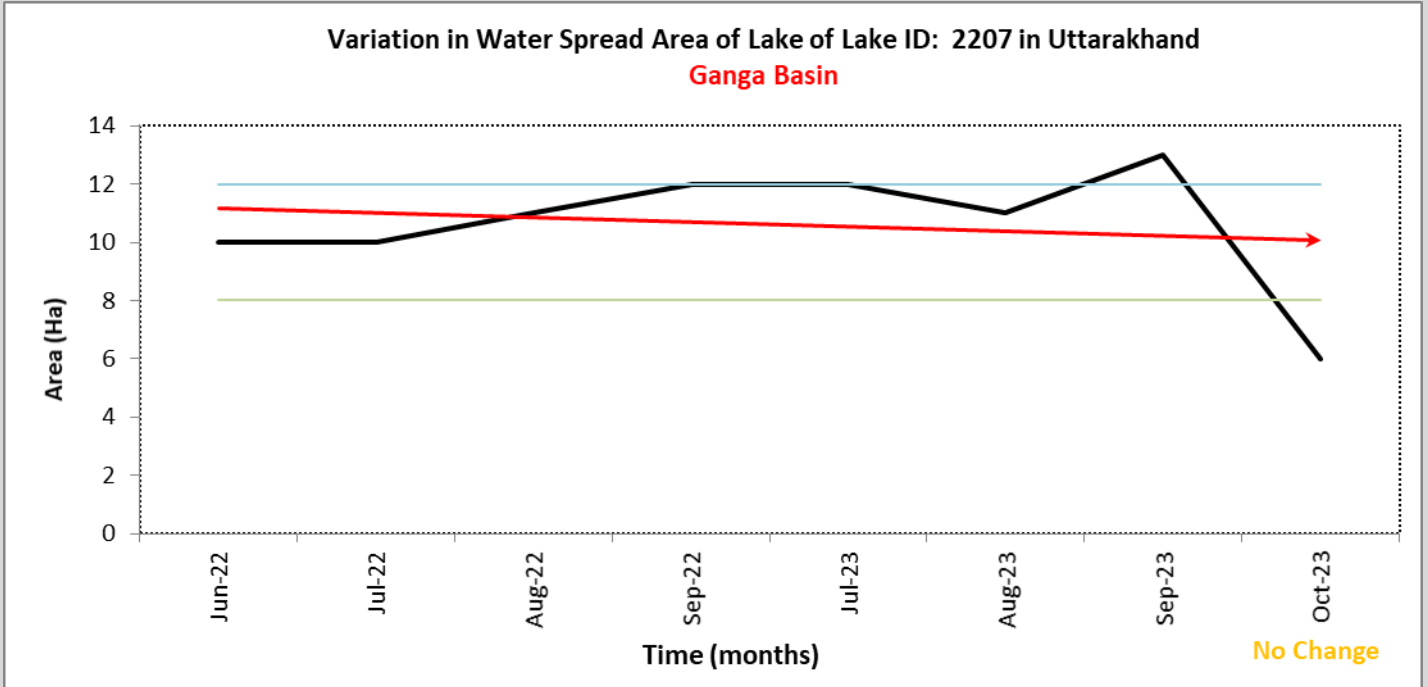


Figure 4.160(i) Trend Analysis Plot  $\pm 10\%$

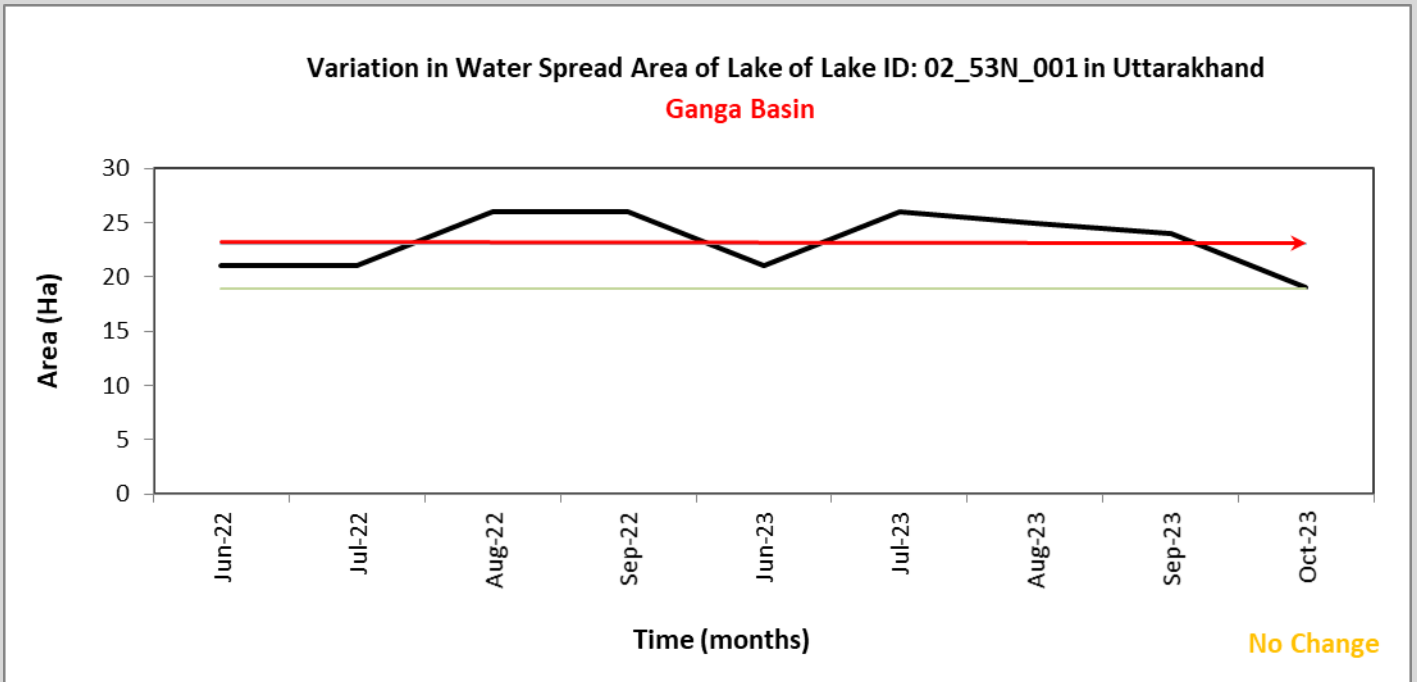
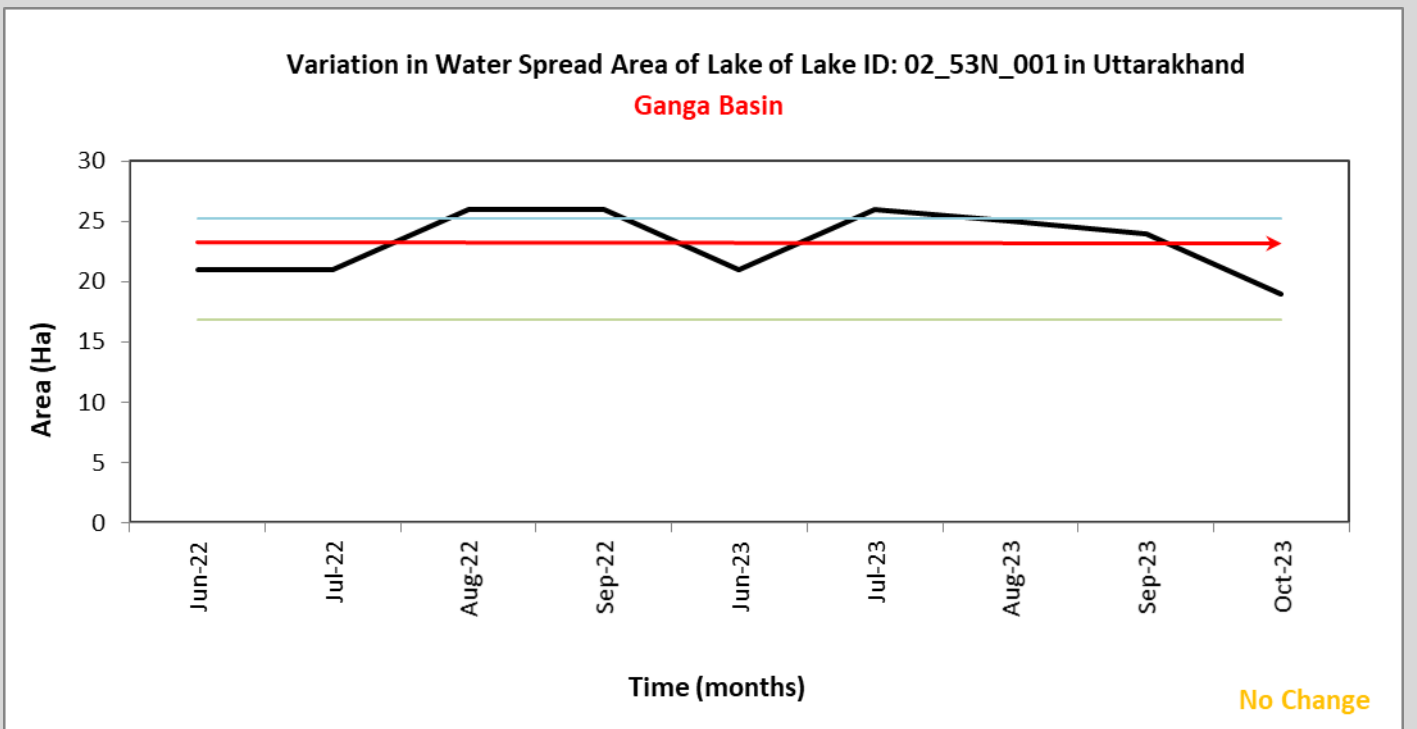
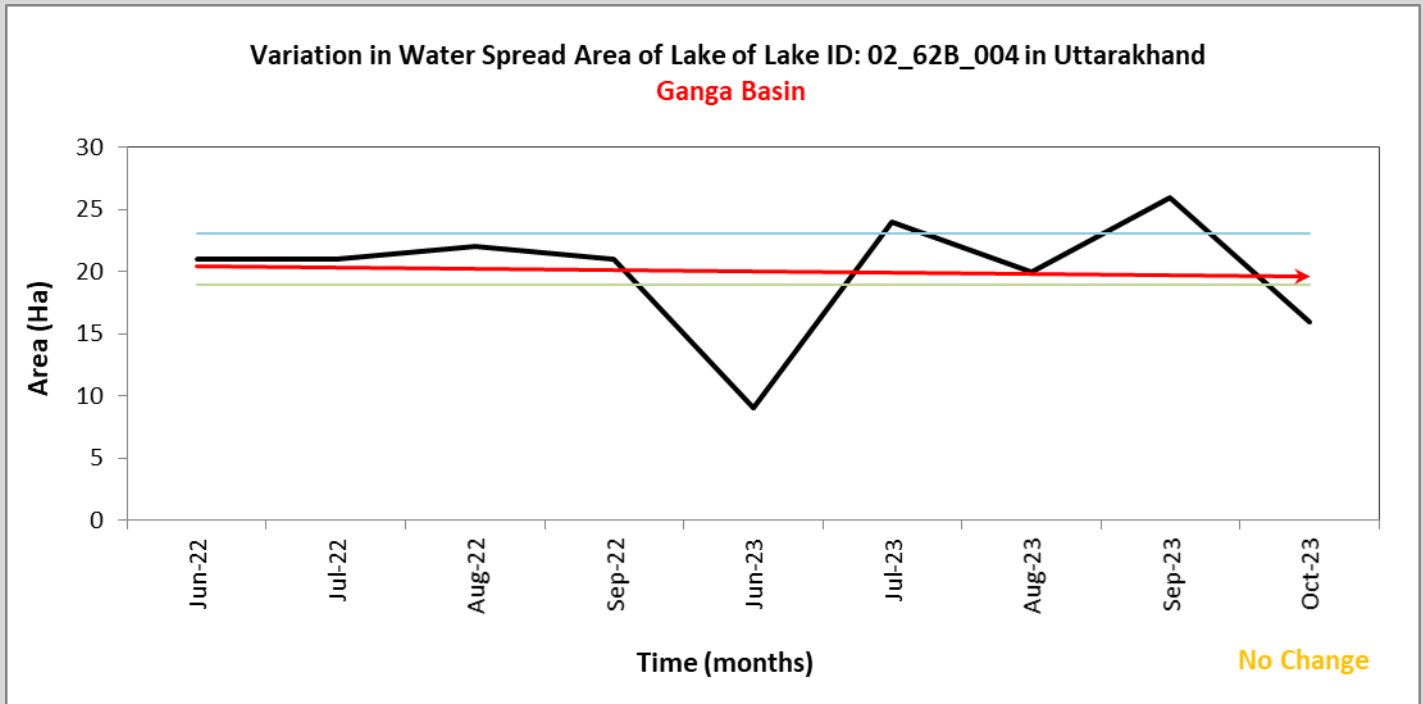


Figure 4.160(ii) Trend Analysis Plot  $\pm 20\%$



**Figure 4.161(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.161(ii)** Trend Analysis Plot  $\pm 20\%$

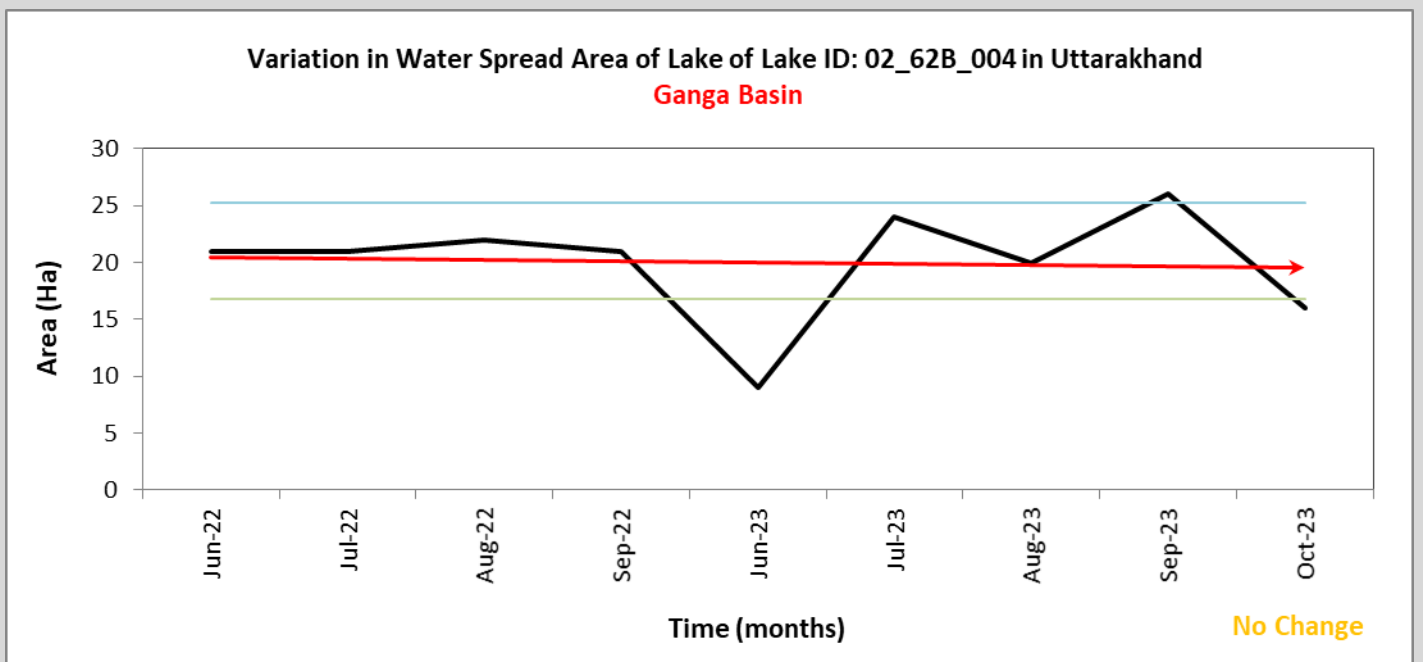


Figure 4.162(i) Trend Analysis Plot  $\pm 10\%$

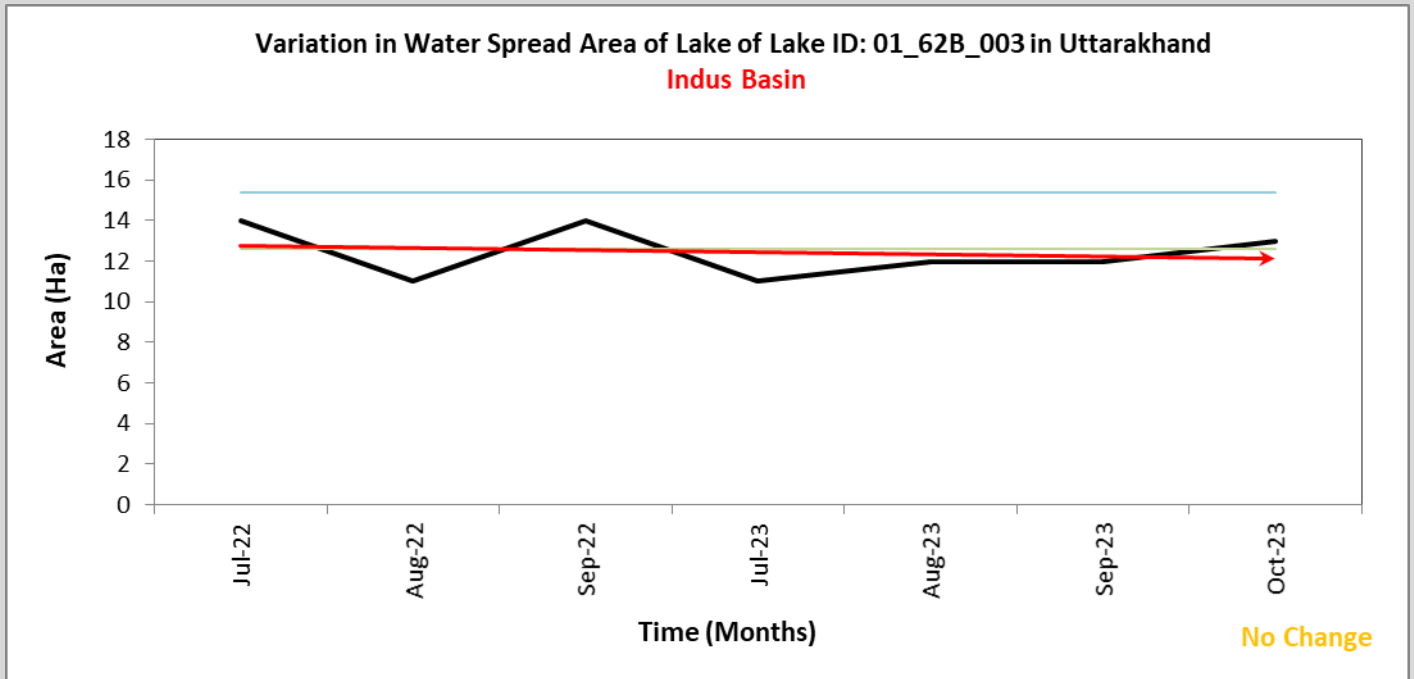


Figure 4.162(ii) Trend Analysis Plot  $\pm 20\%$

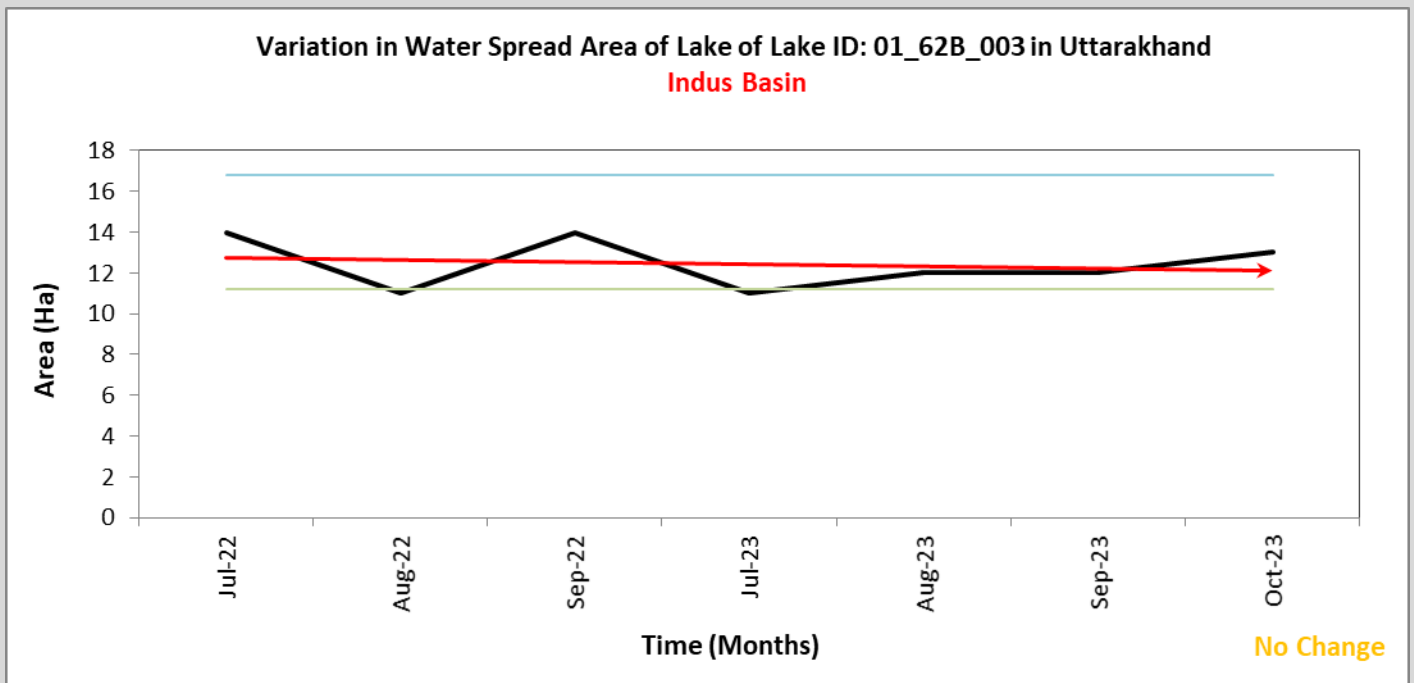


Figure 4.163(i) Trend Analysis Plot  $\pm 10\%$

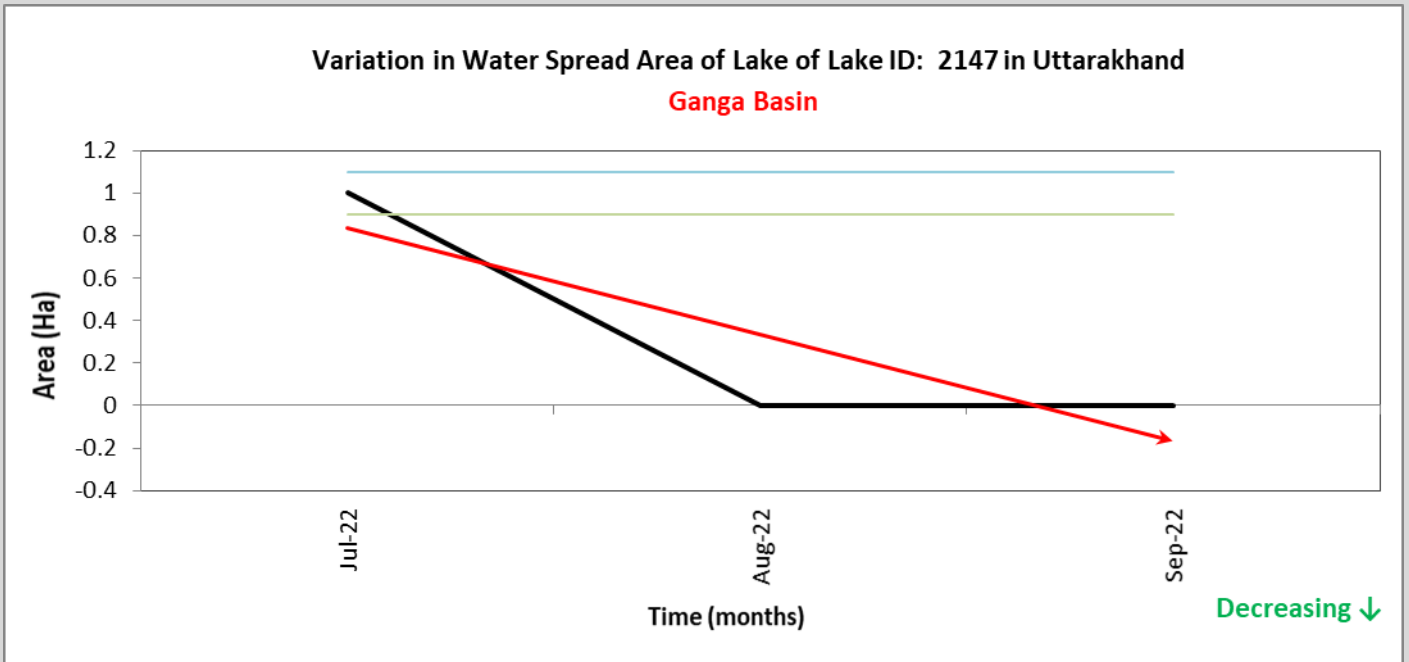
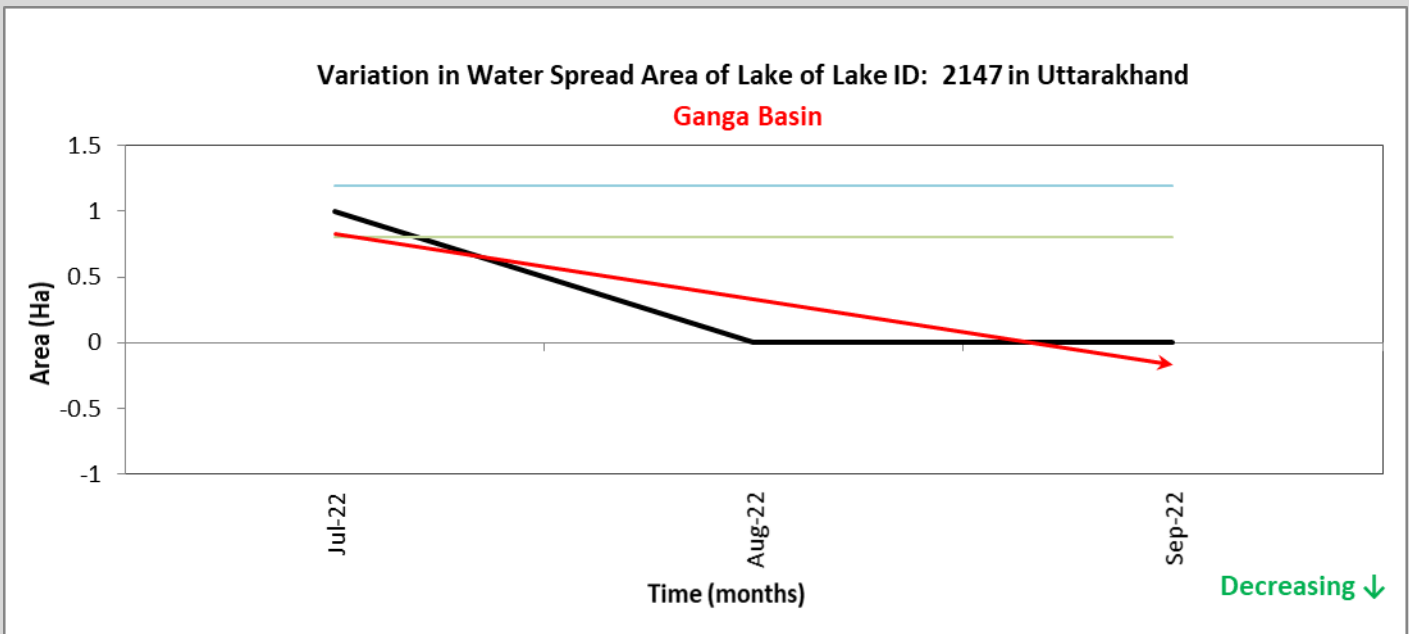
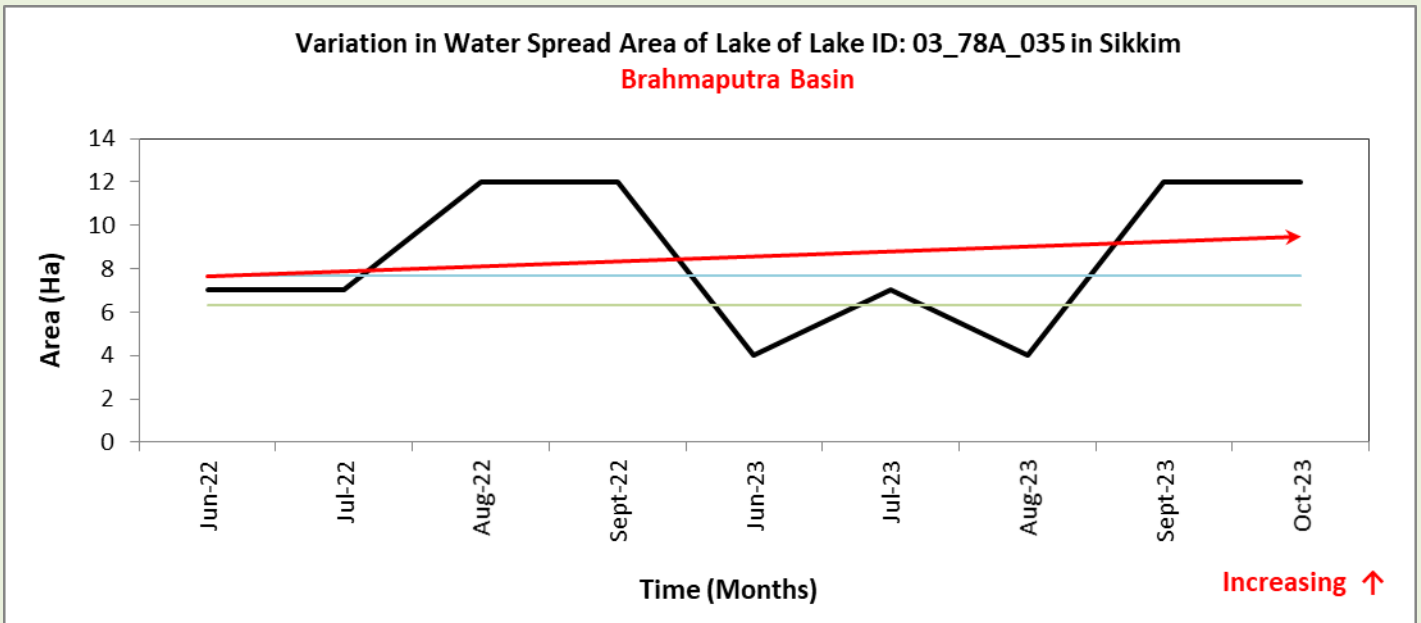


Figure 4.163(ii) Trend Analysis Plot  $\pm 20\%$



Trend analysis of “Change in water spread area of Glacial Lakes between 10 Ha to 50 Ha of Sikkim (2022-2023)”

**Figure 4.164(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.164(ii)** Trend Analysis Plot  $\pm 20\%$

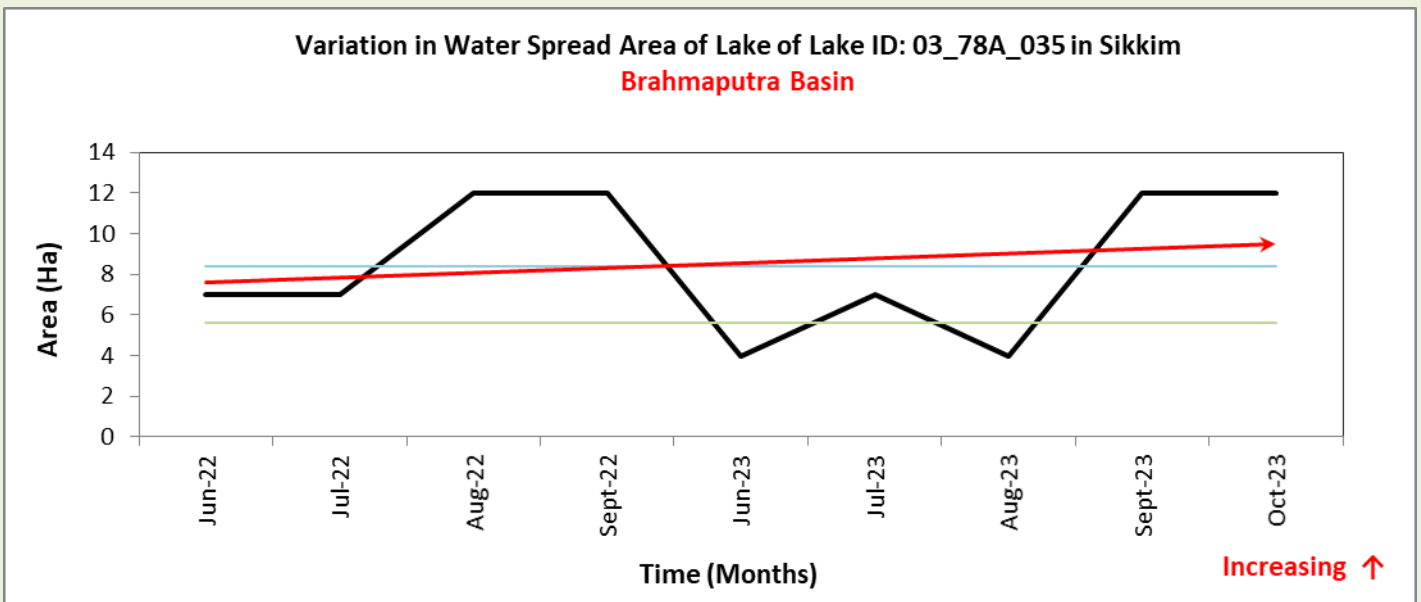


Figure 4.165(i) Trend Analysis Plot  $\pm 10\%$

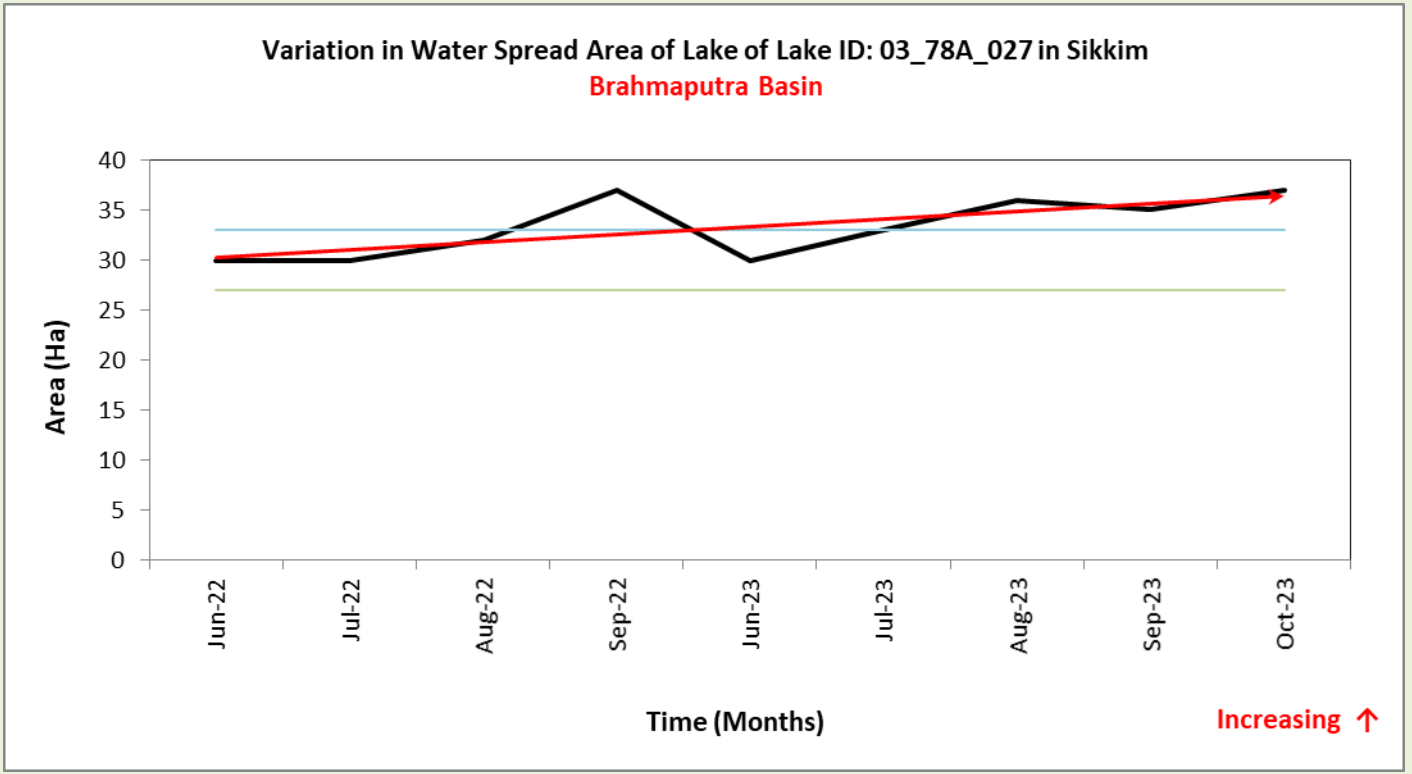
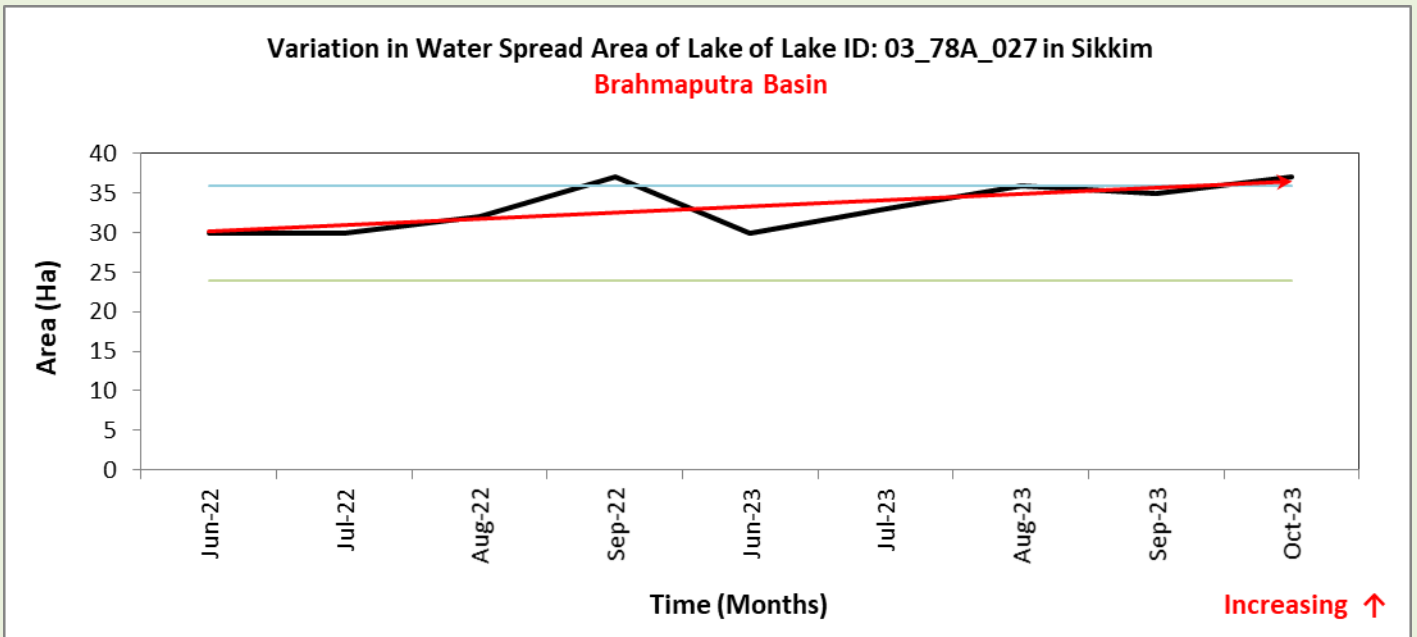
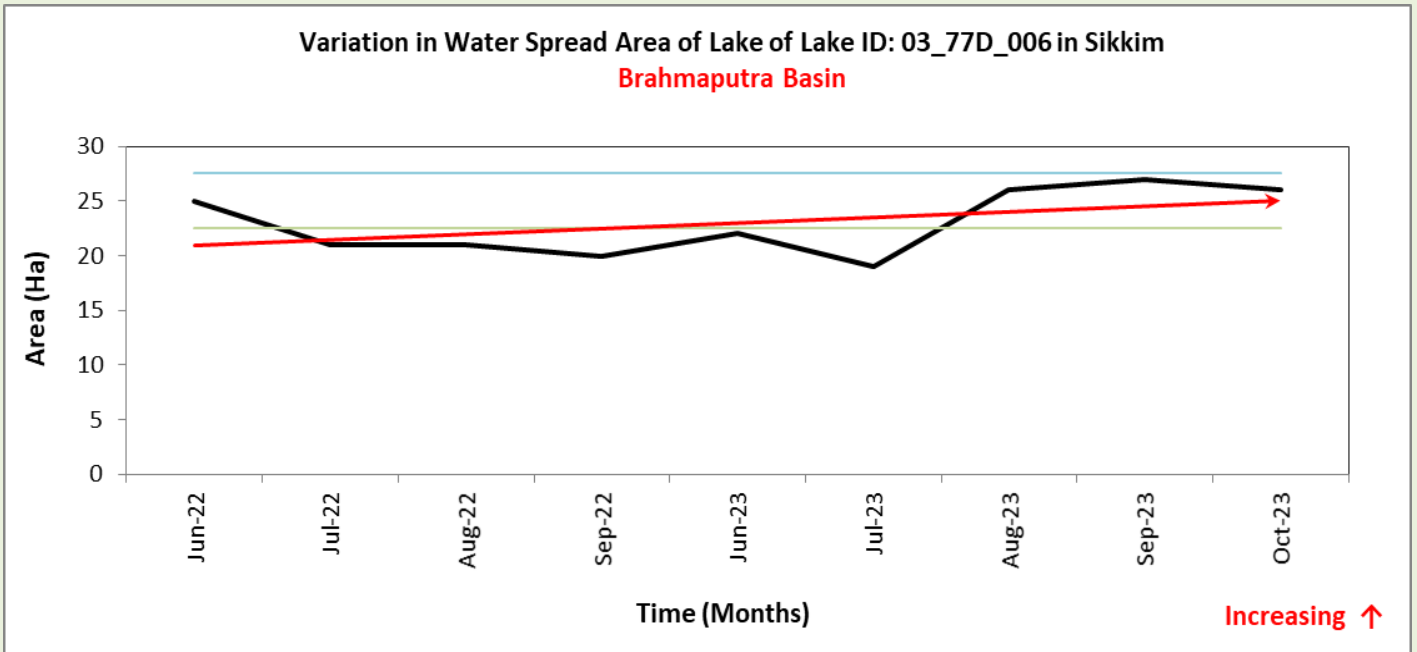


Figure 4.165(ii) Trend Analysis Plot  $\pm 20\%$



**Figure 4.166(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.166(ii)** Trend Analysis Plot  $\pm 20\%$

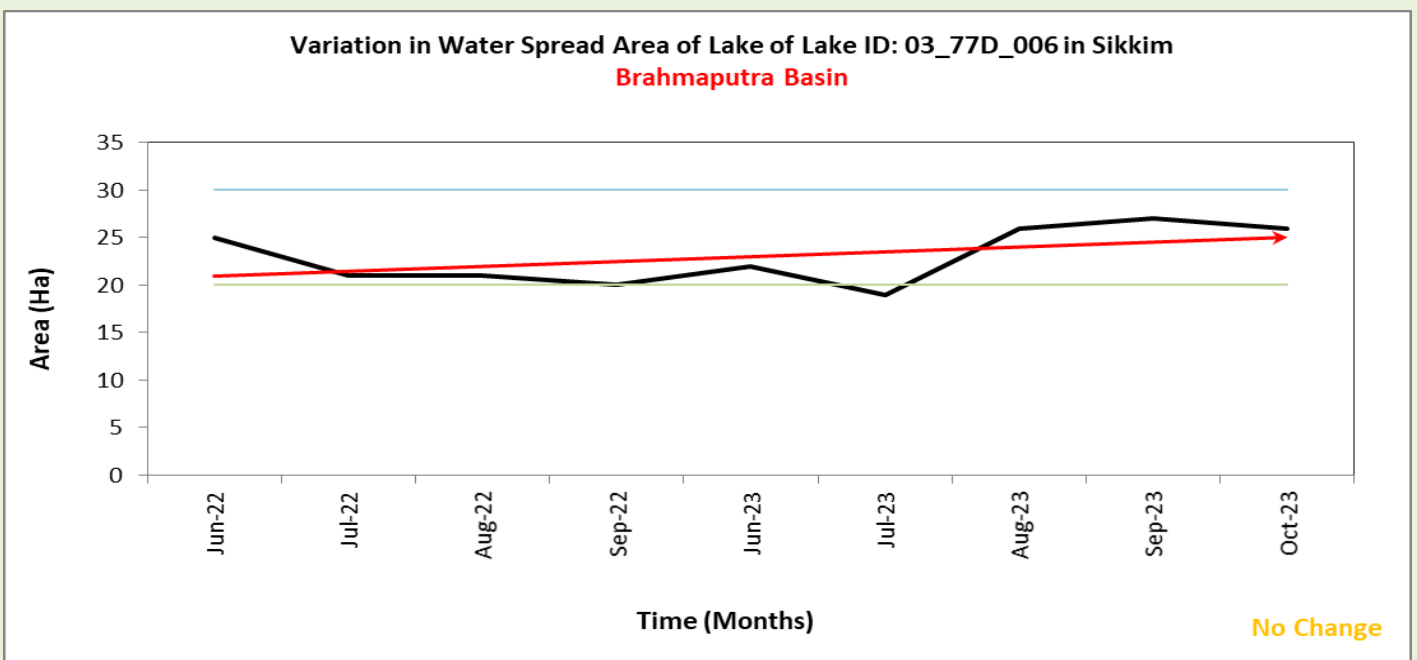


Figure 4.167(i) Trend Analysis Plot  $\pm 10\%$

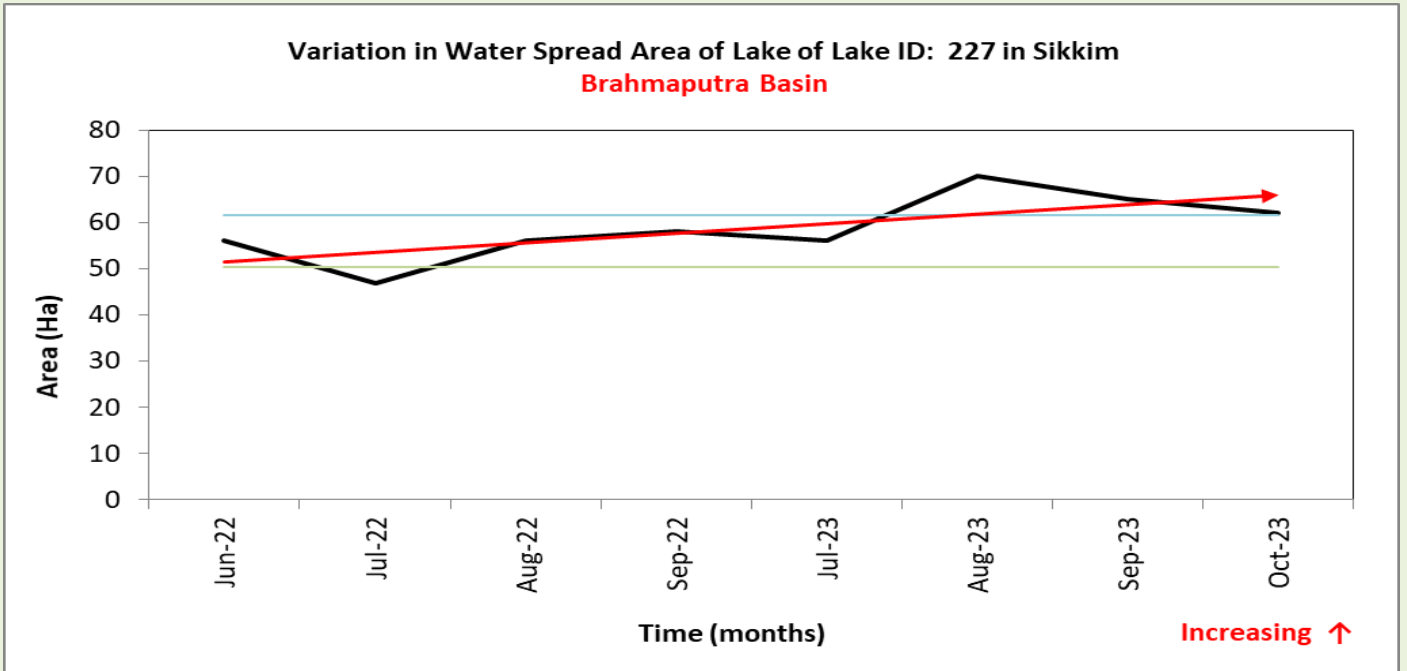


Figure 4.167(ii) Trend Analysis Plot  $\pm 20\%$

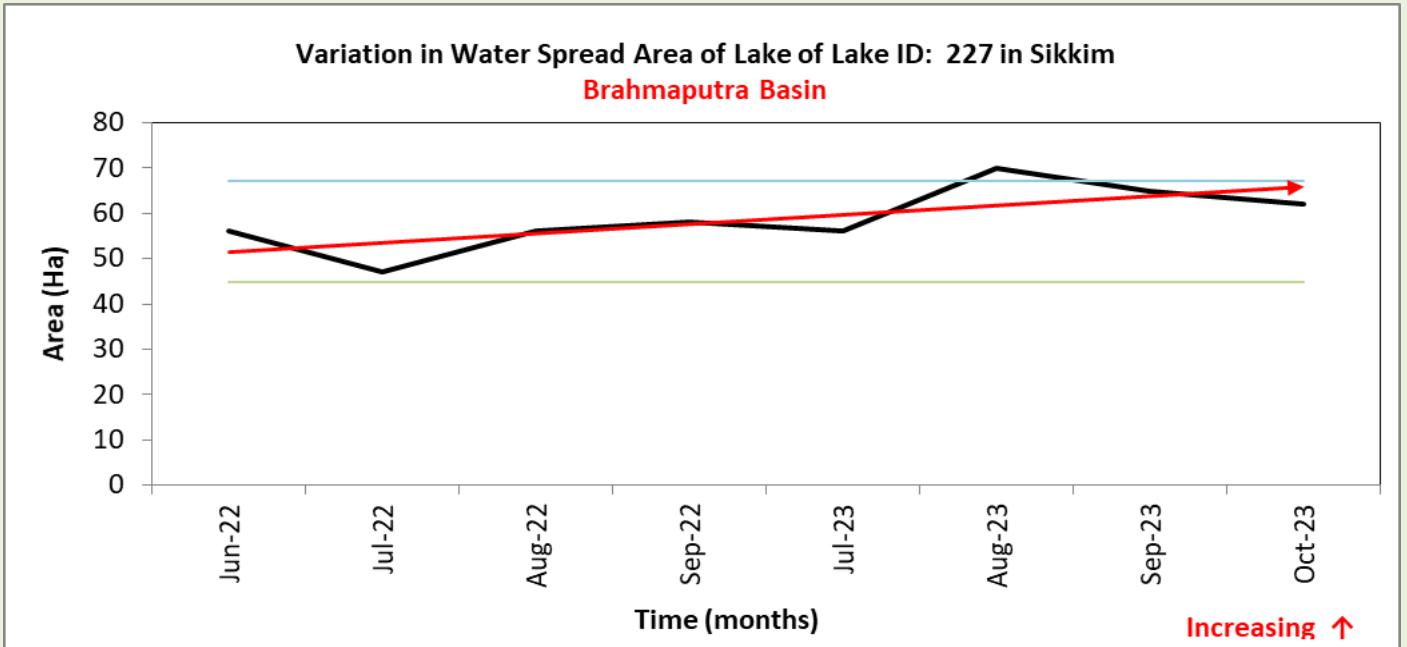


Figure 4.168(i) Trend Analysis Plot  $\pm 10\%$

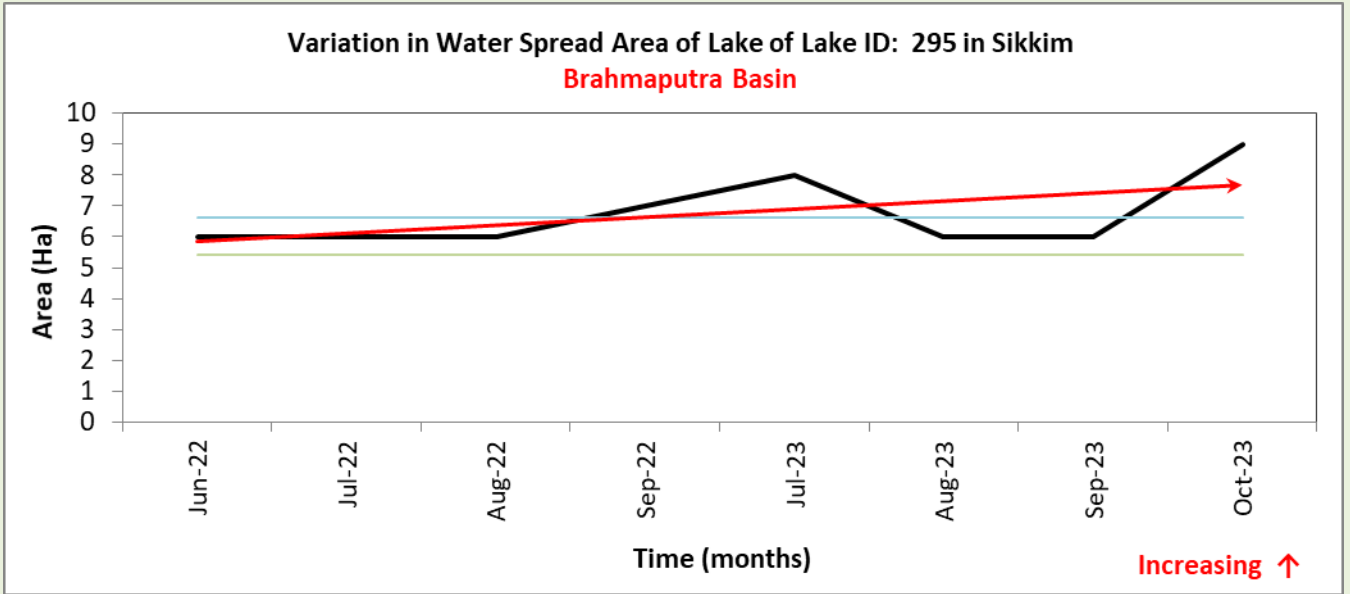


Figure 4.168(ii) Trend Analysis Plot  $\pm 20\%$

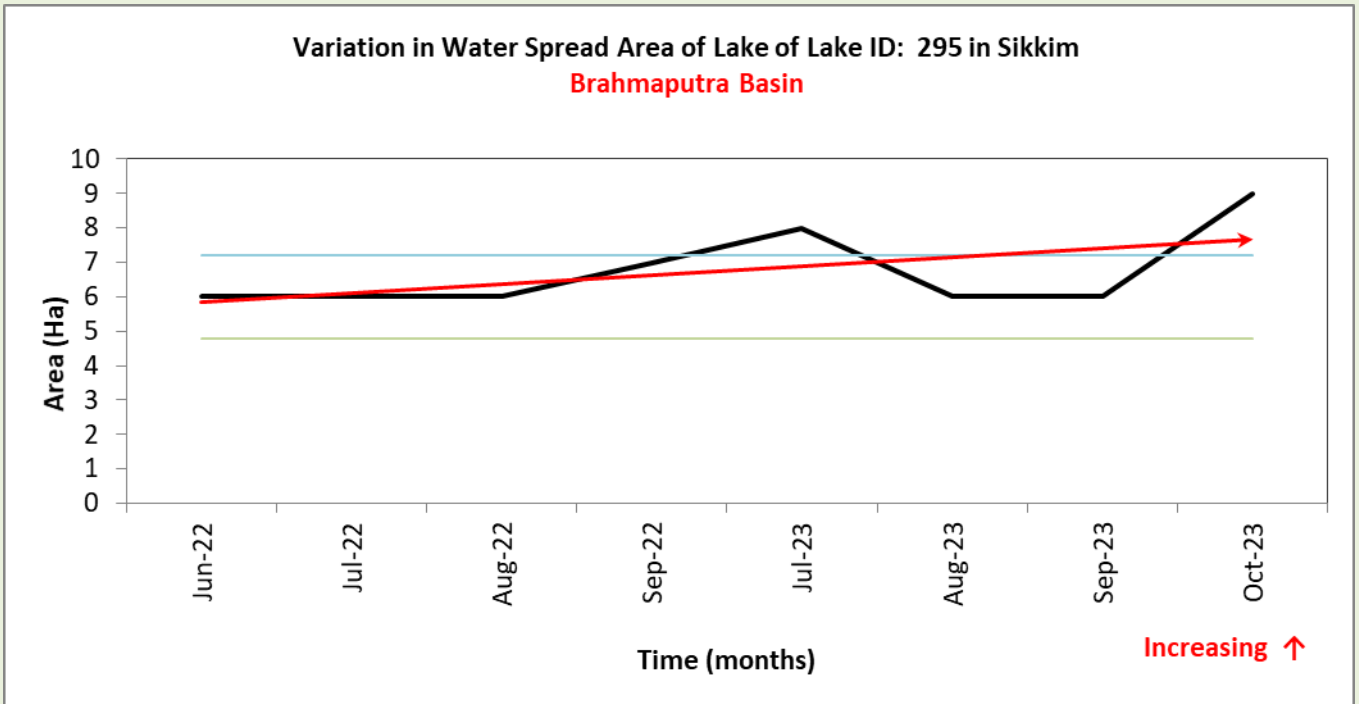


Figure 4.169(i) Trend Analysis Plot  $\pm 10\%$

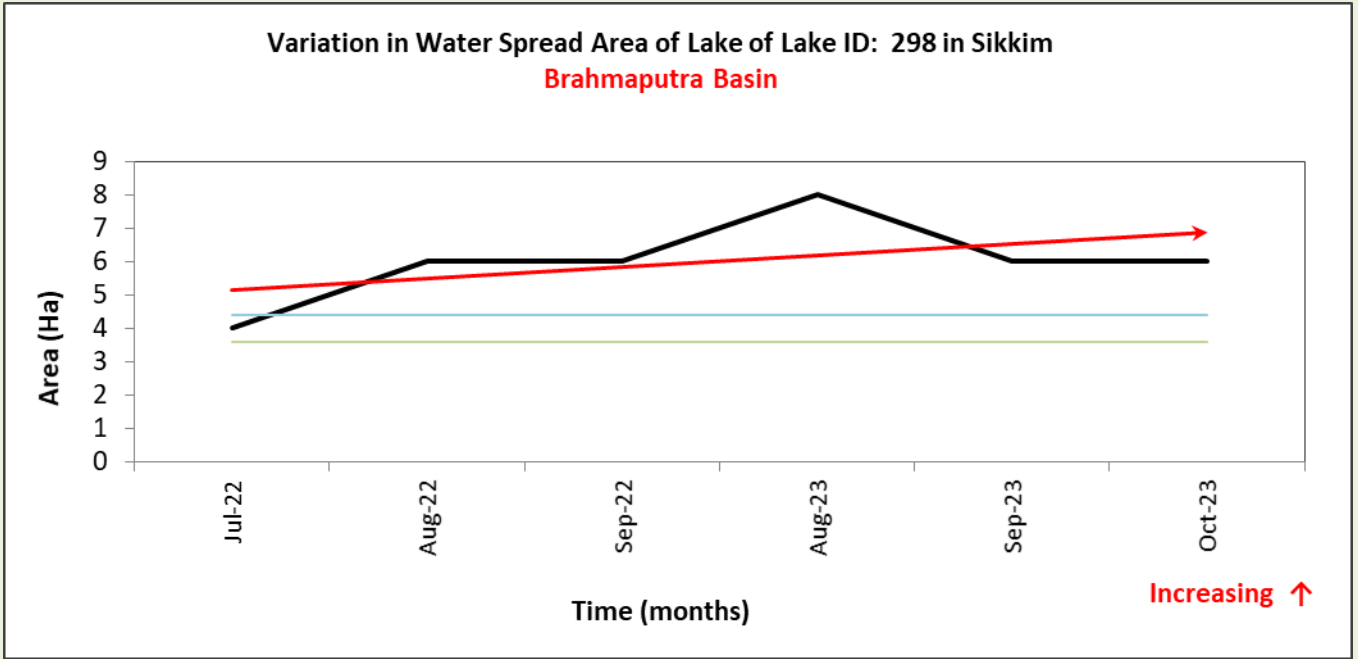


Figure 4.169(ii) Trend Analysis Plot  $\pm 20\%$

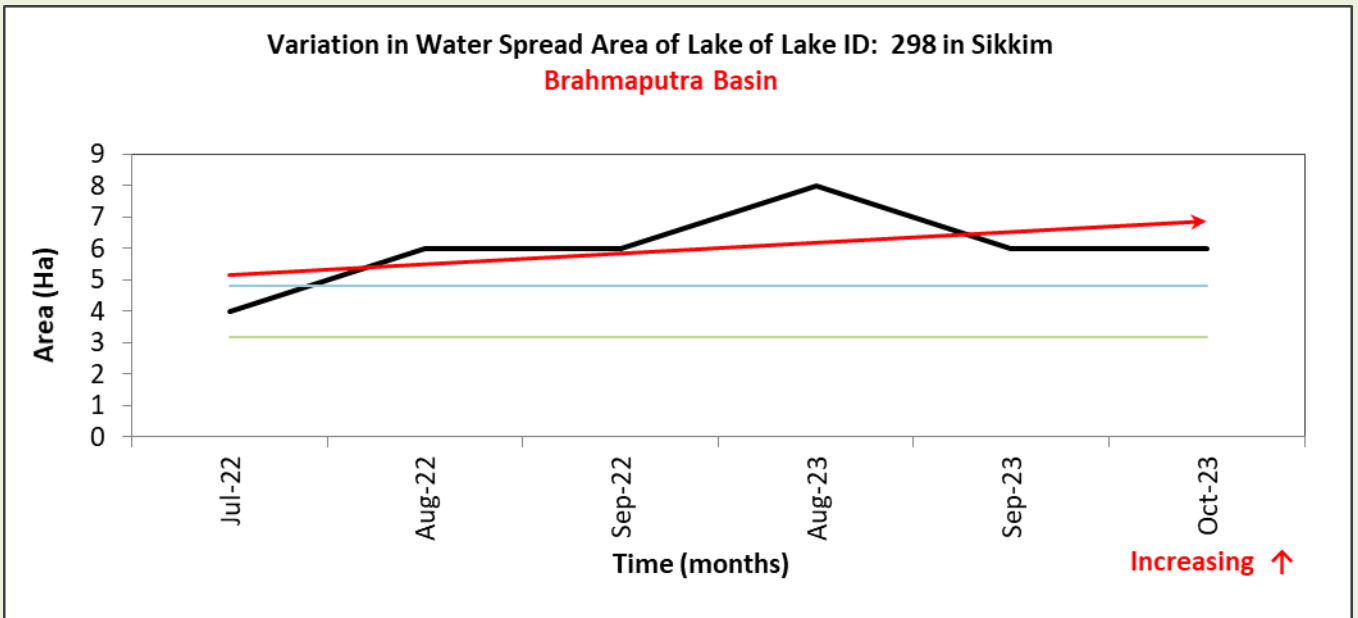


Figure 4.170(i) Trend Analysis Plot  $\pm 10\%$

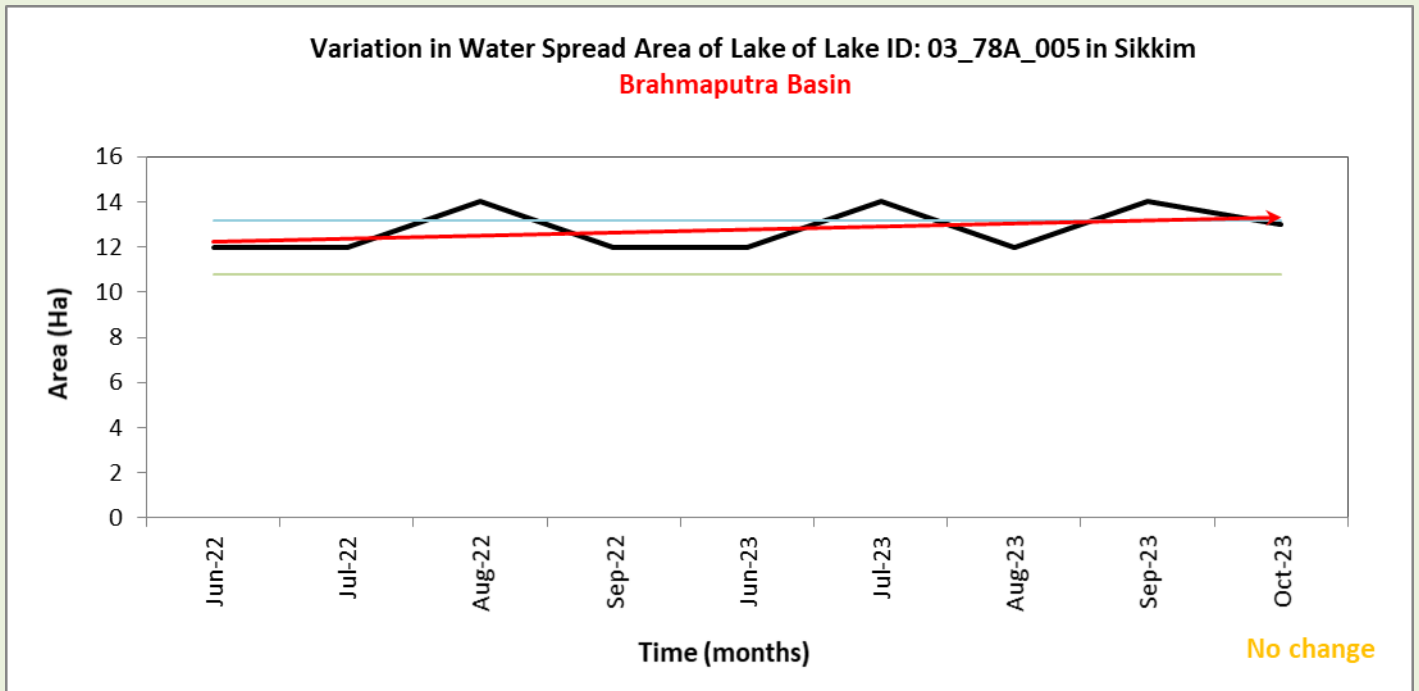


Figure 4.170(ii) Trend Analysis Plot  $\pm 20\%$

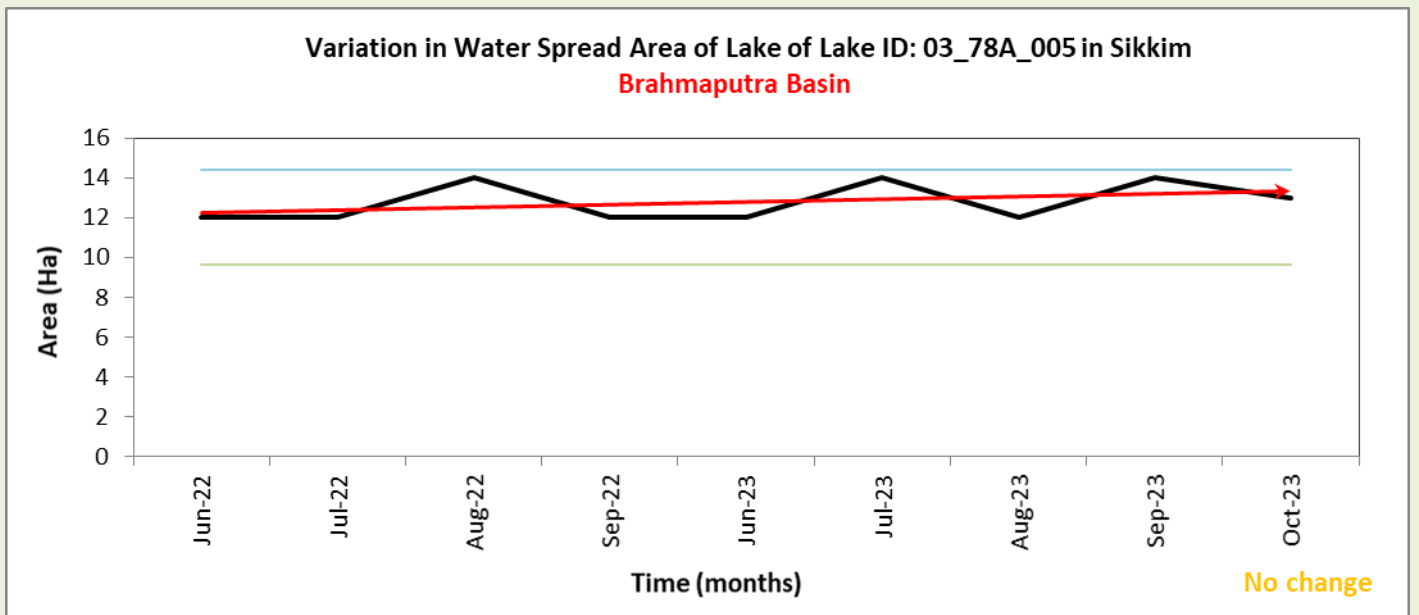


Figure 4.171(i) Trend Analysis Plot  $\pm 10\%$

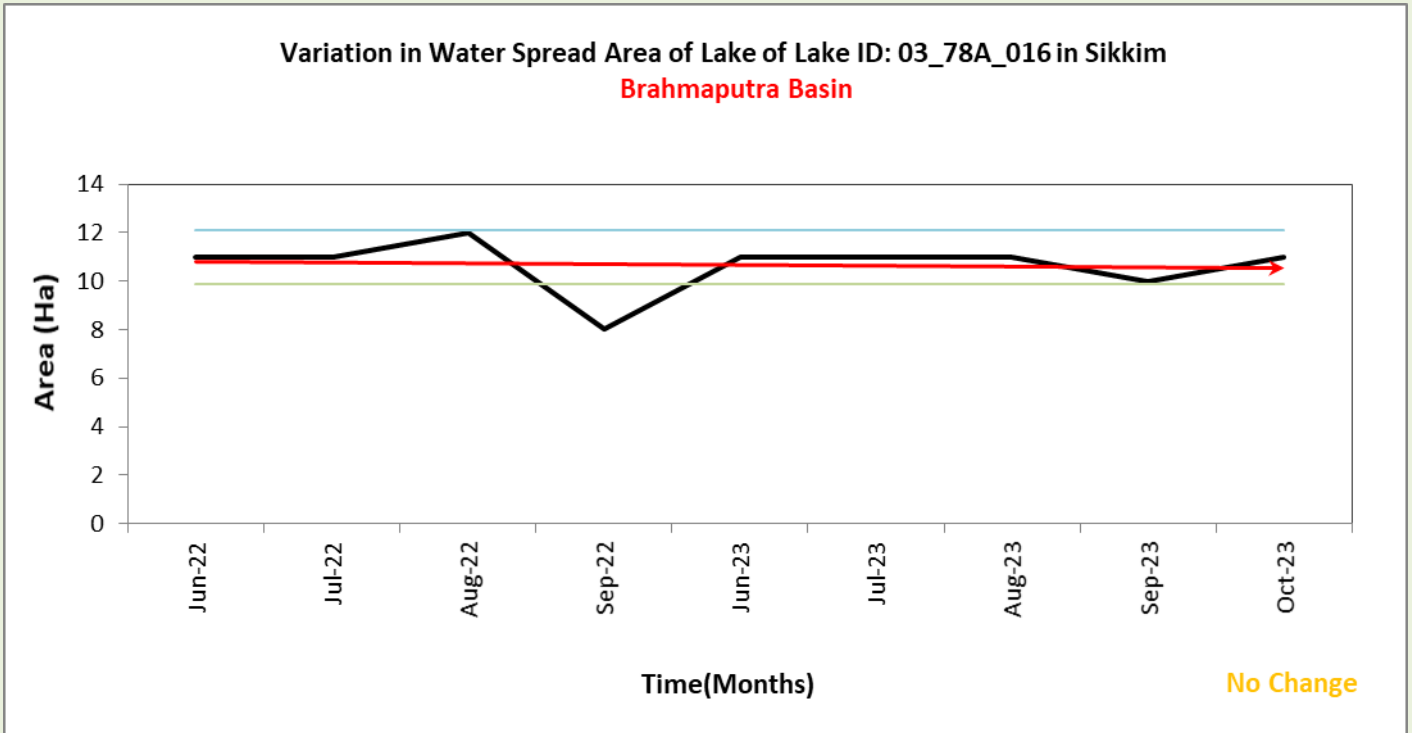


Figure 4.171(ii) Trend Analysis Plot  $\pm 20\%$

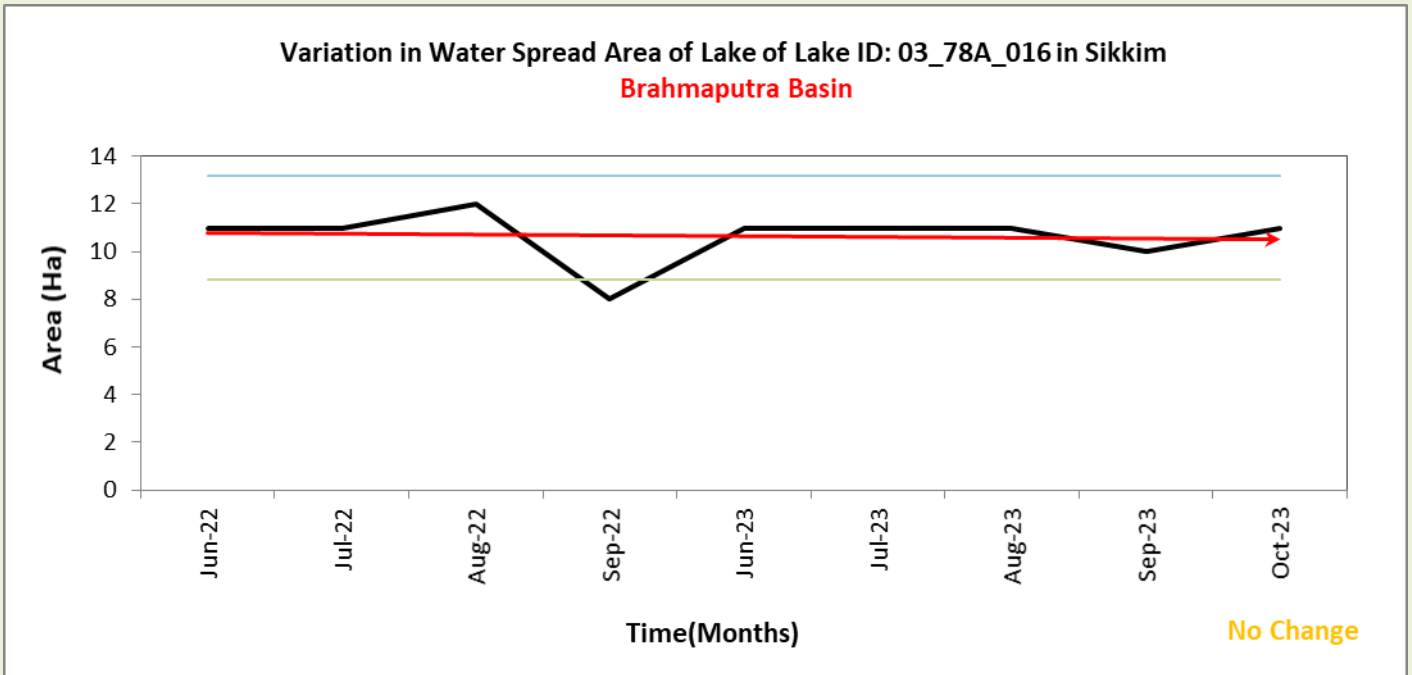


Figure 4.172(i) Trend Analysis Plot  $\pm 10\%$

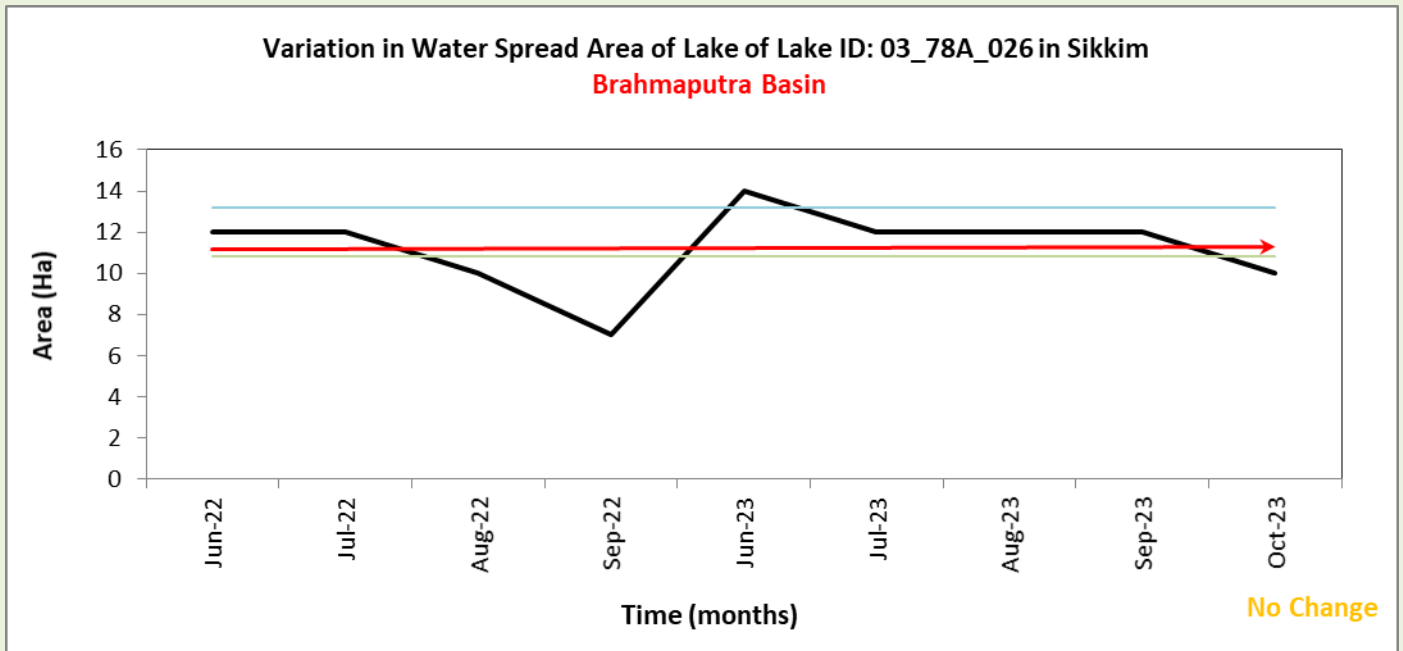


Figure 4.172(ii) Trend Analysis Plot  $\pm 20\%$

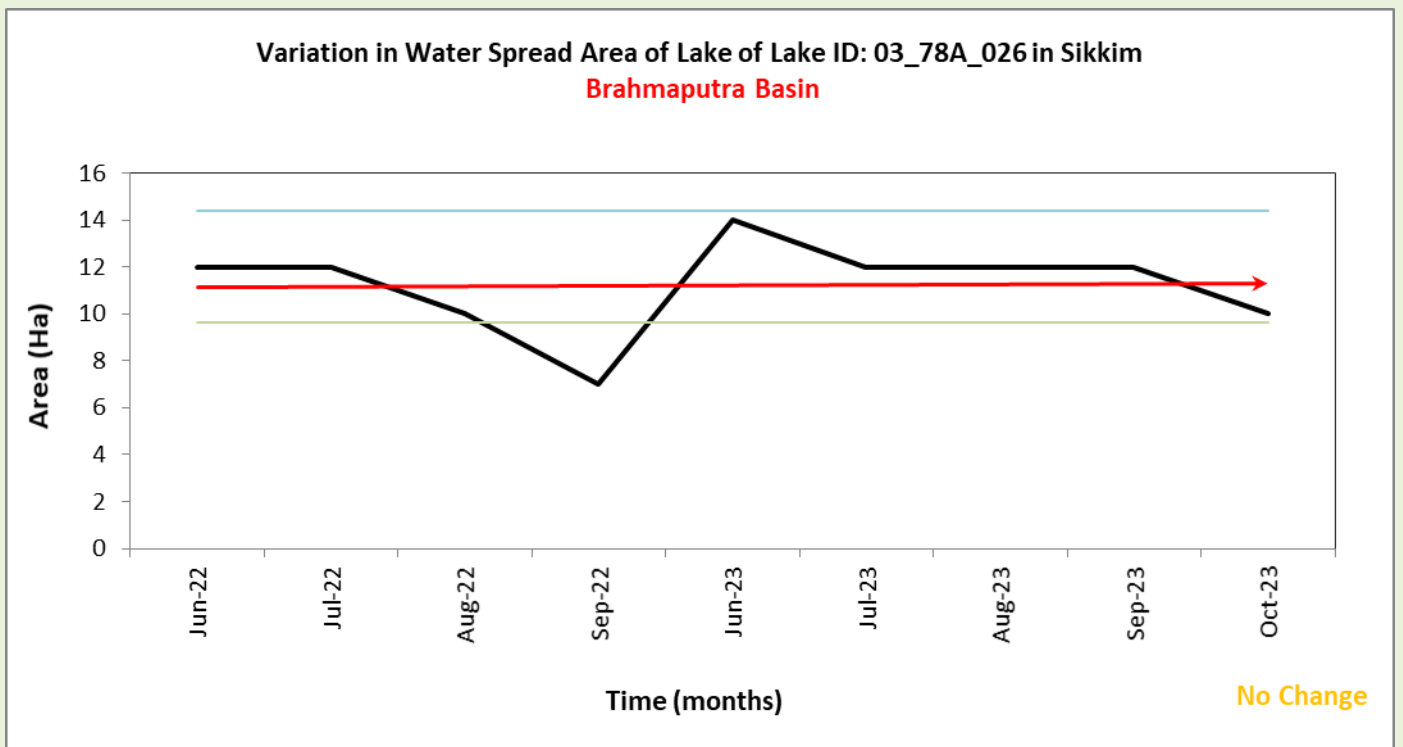


Figure 4.173(i) Trend Analysis Plot  $\pm 10\%$

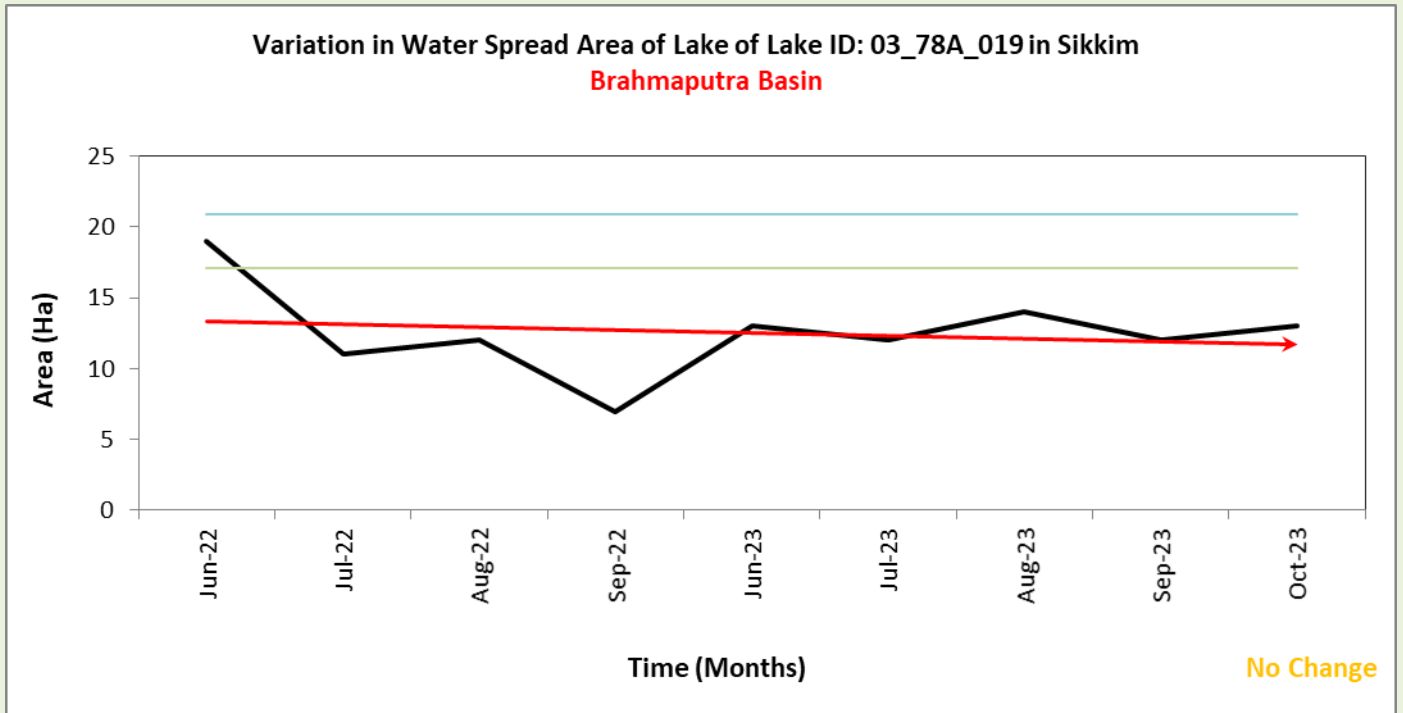


Figure 4.173(ii) Trend Analysis Plot  $\pm 20\%$

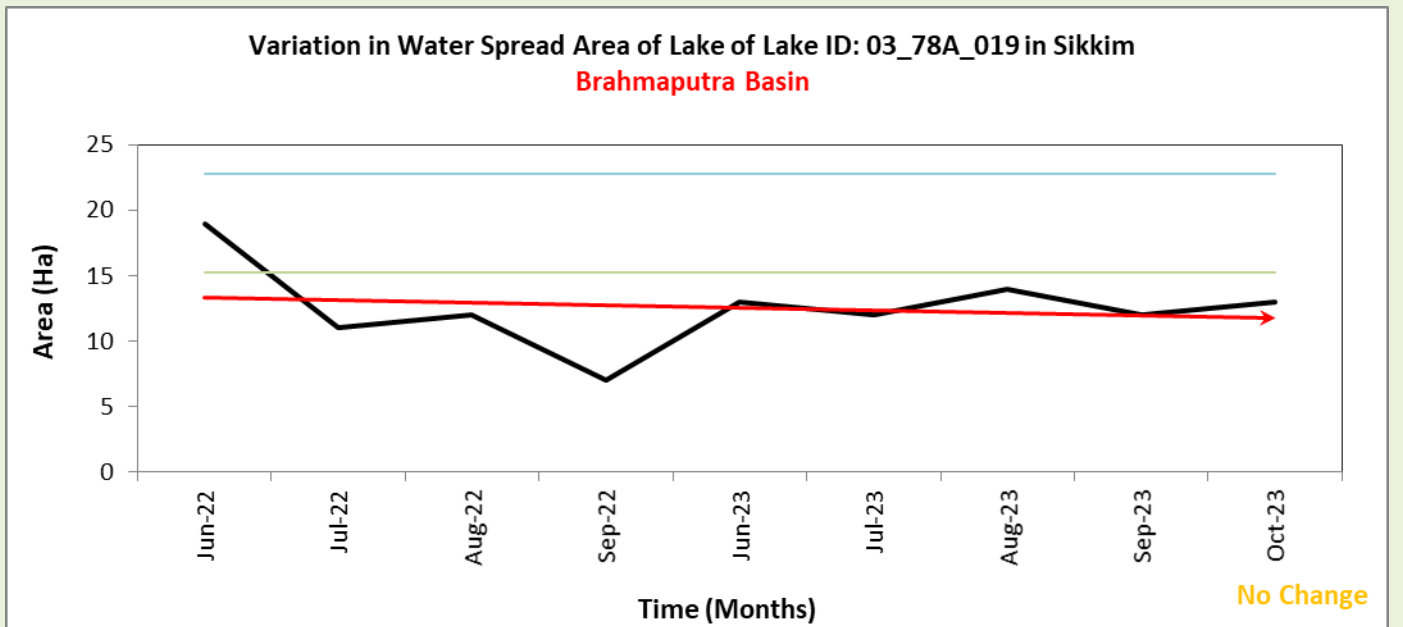


Figure 4.174(i) Trend Analysis Plot  $\pm 10\%$

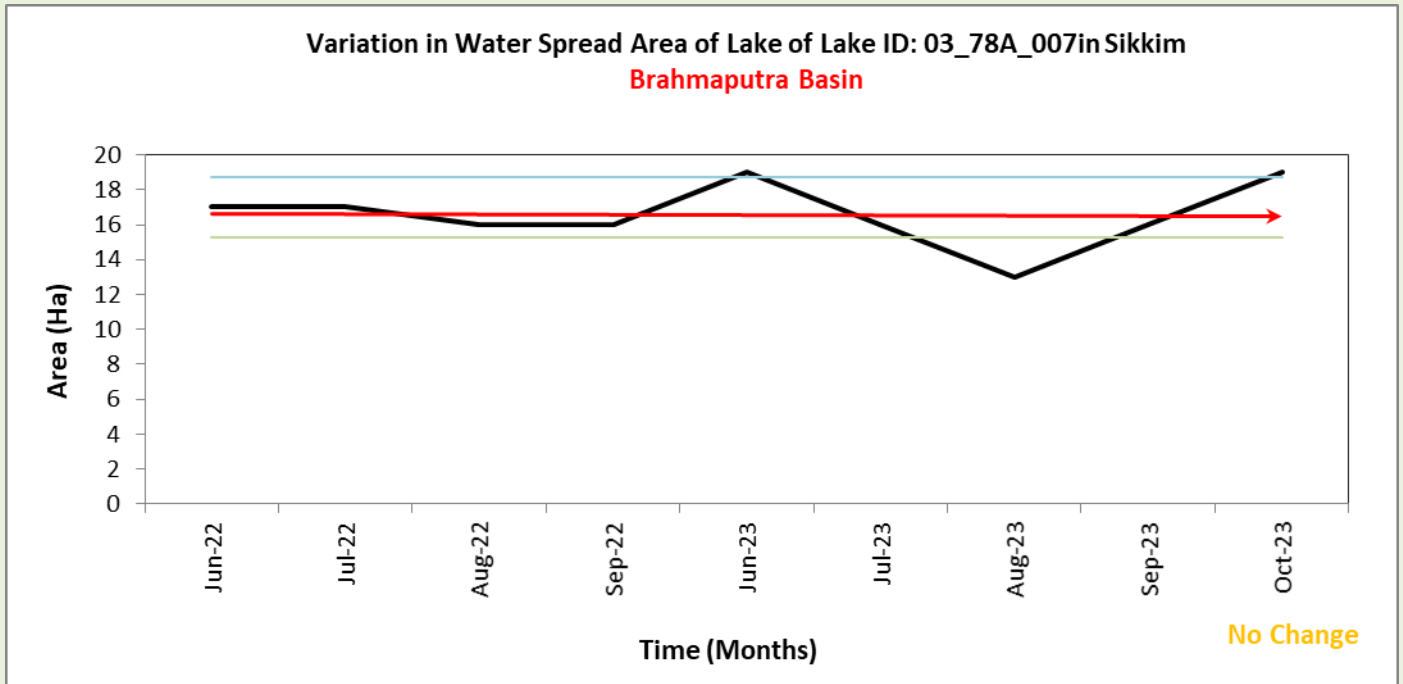


Figure 4.174(ii) Trend Analysis Plot  $\pm 20\%$

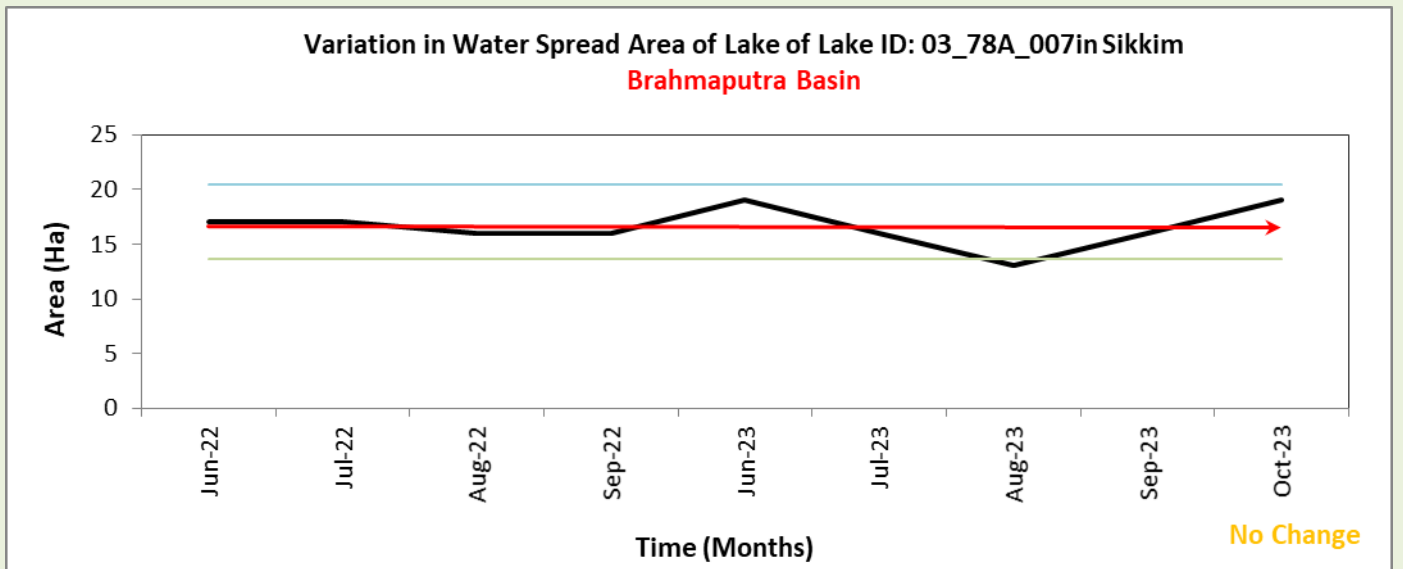


Figure 4.175(i) Trend Analysis Plot  $\pm 10\%$

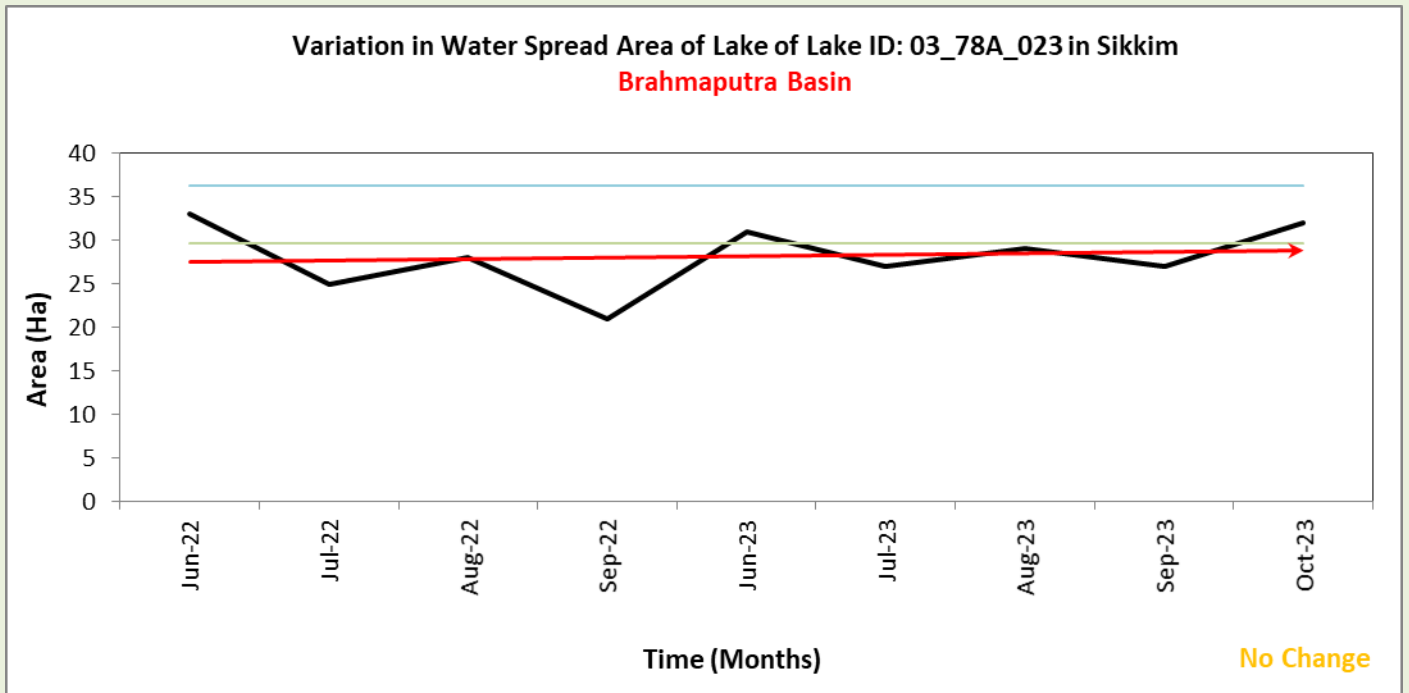


Figure 4.175(ii) Trend Analysis Plot  $\pm 20\%$

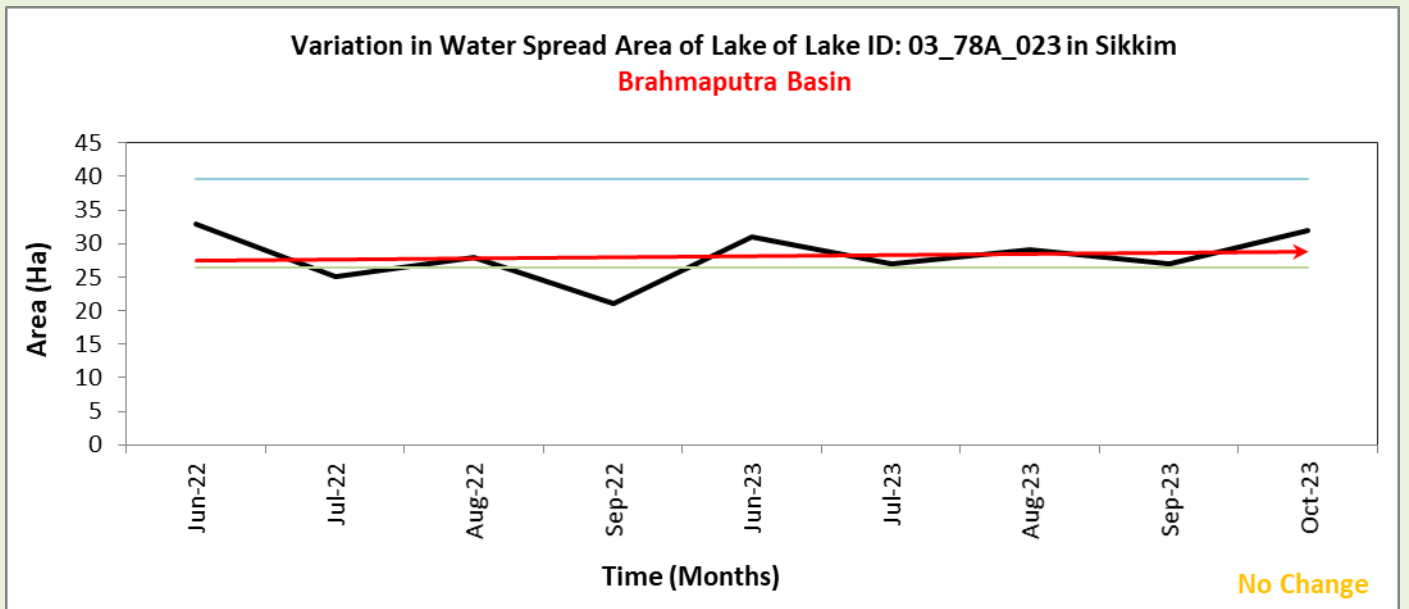


Figure 4.176(i) Trend Analysis Plot  $\pm 10\%$

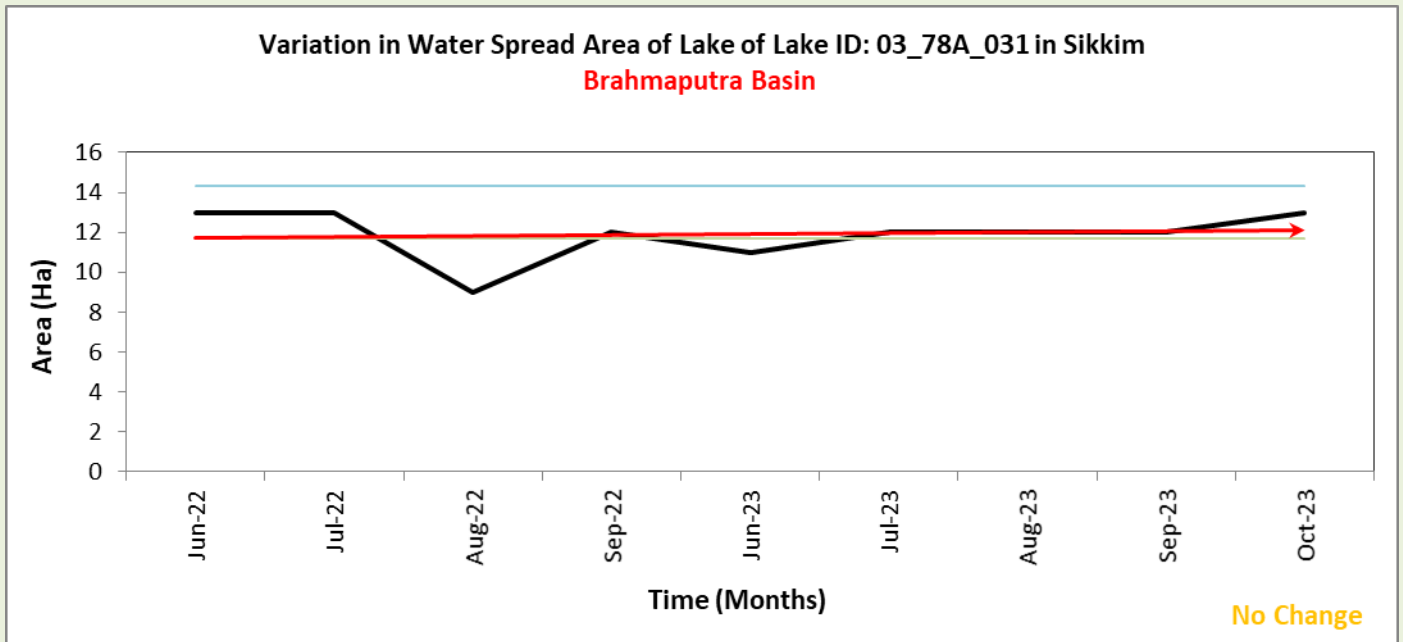


Figure 4.176(ii) Trend Analysis Plot  $\pm 20\%$

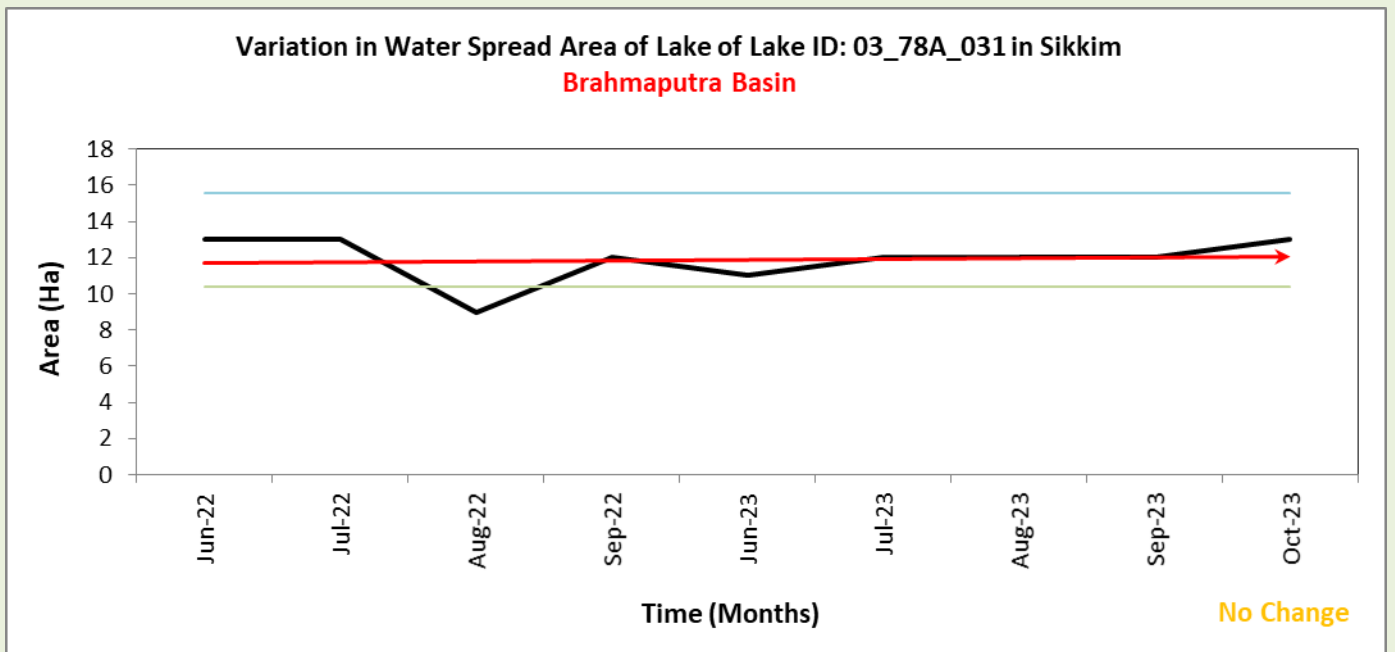


Figure 4.177(i) Trend Analysis Plot  $\pm 10\%$

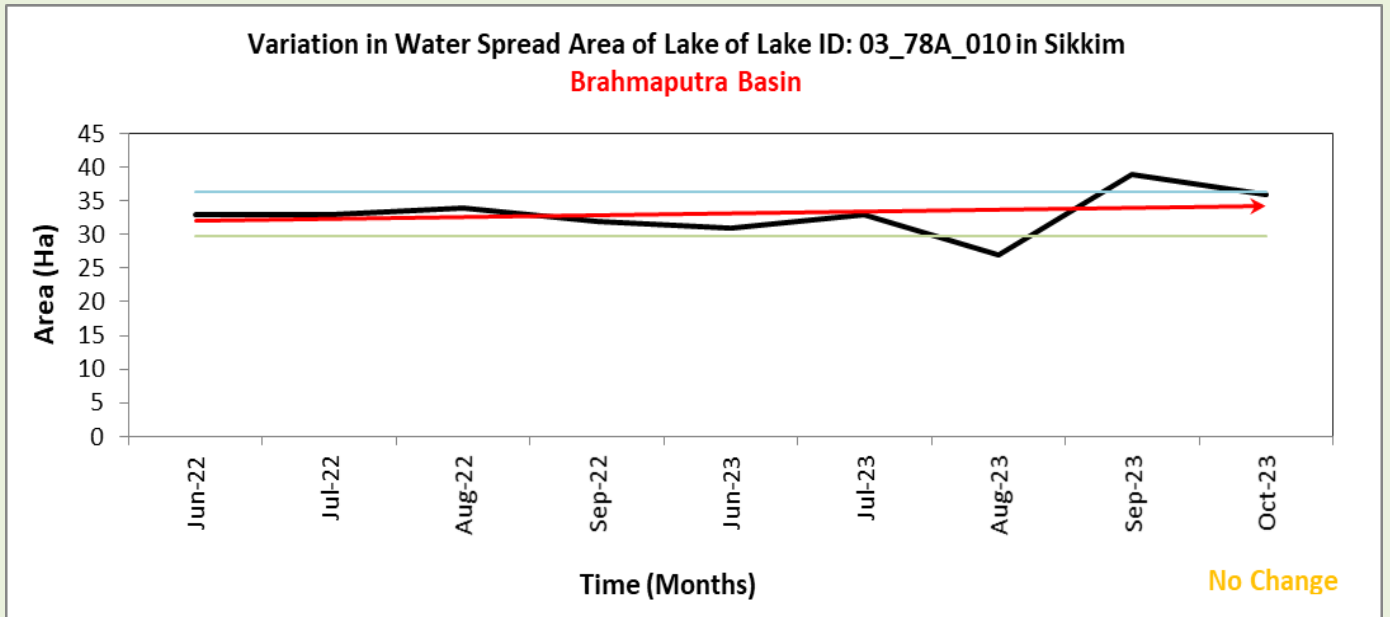


Figure 4.177(ii) Trend Analysis Plot  $\pm 20\%$

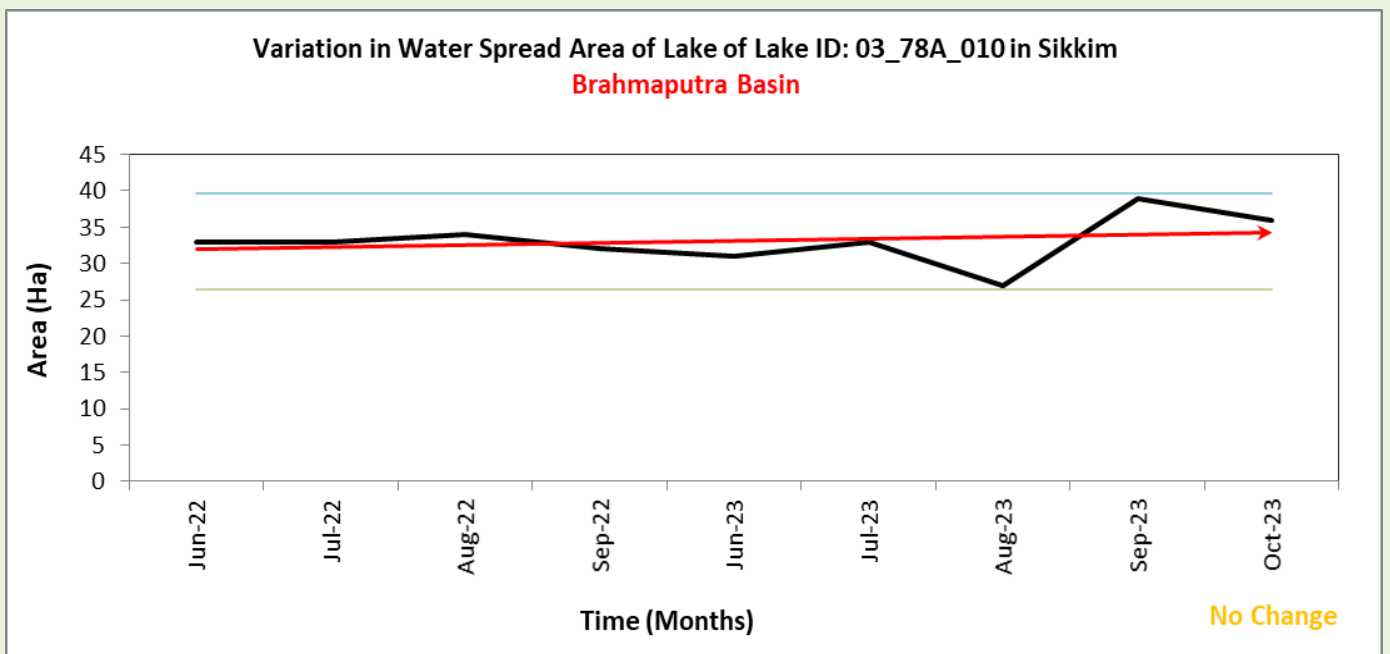


Figure 4.178(i) Trend Analysis Plot  $\pm 10\%$

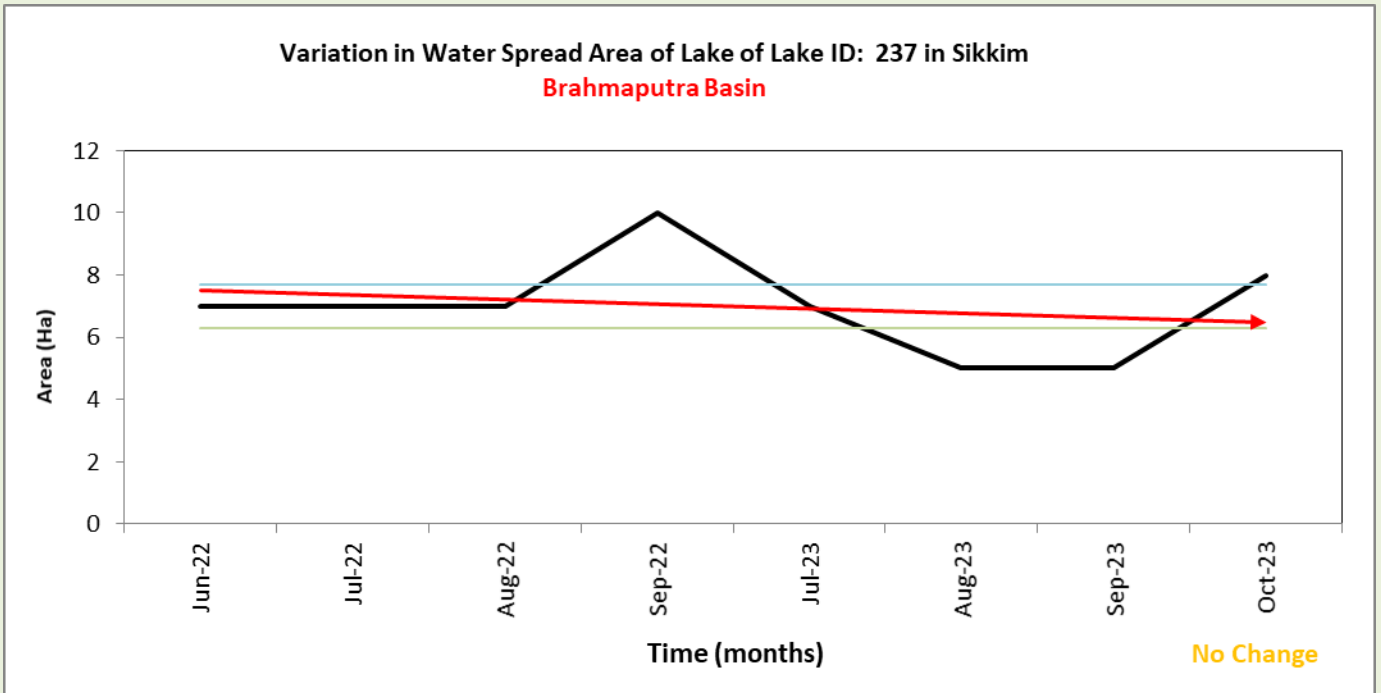


Figure 4.178(ii) Trend Analysis Plot  $\pm 20\%$

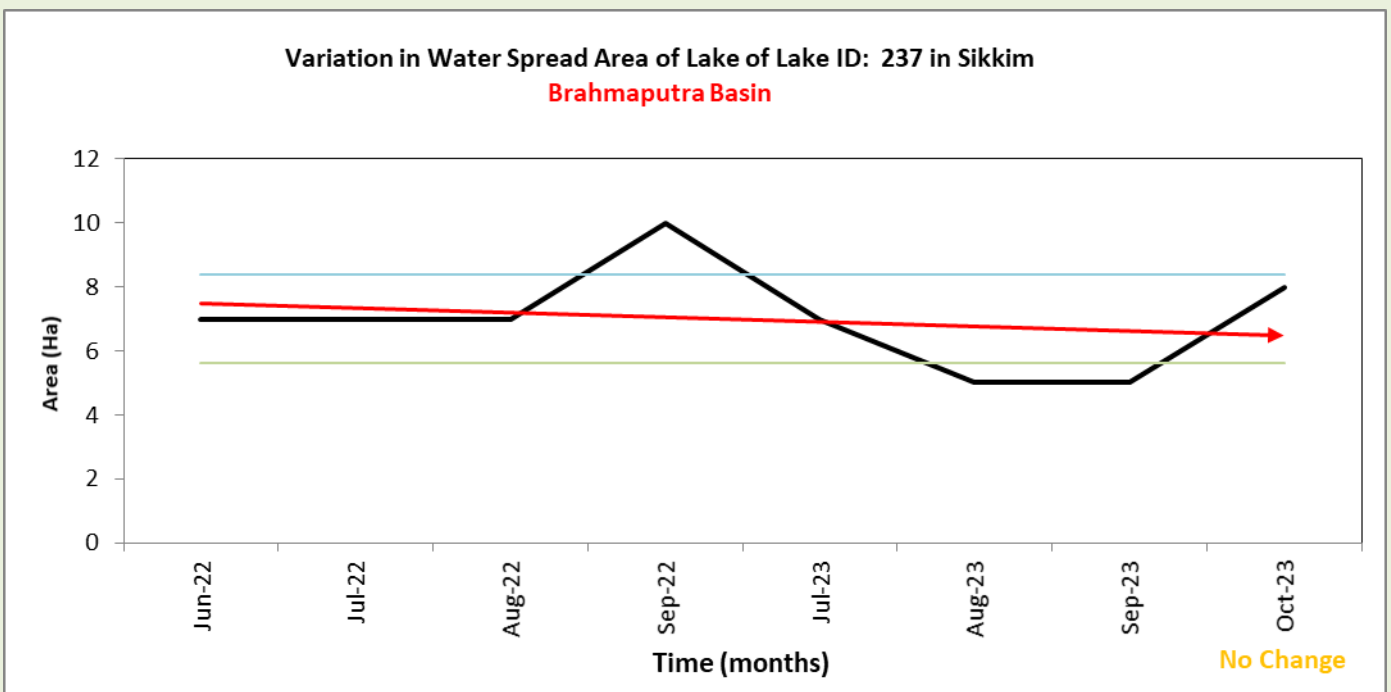


Figure 4.179(i) Trend Analysis Plot  $\pm 10\%$

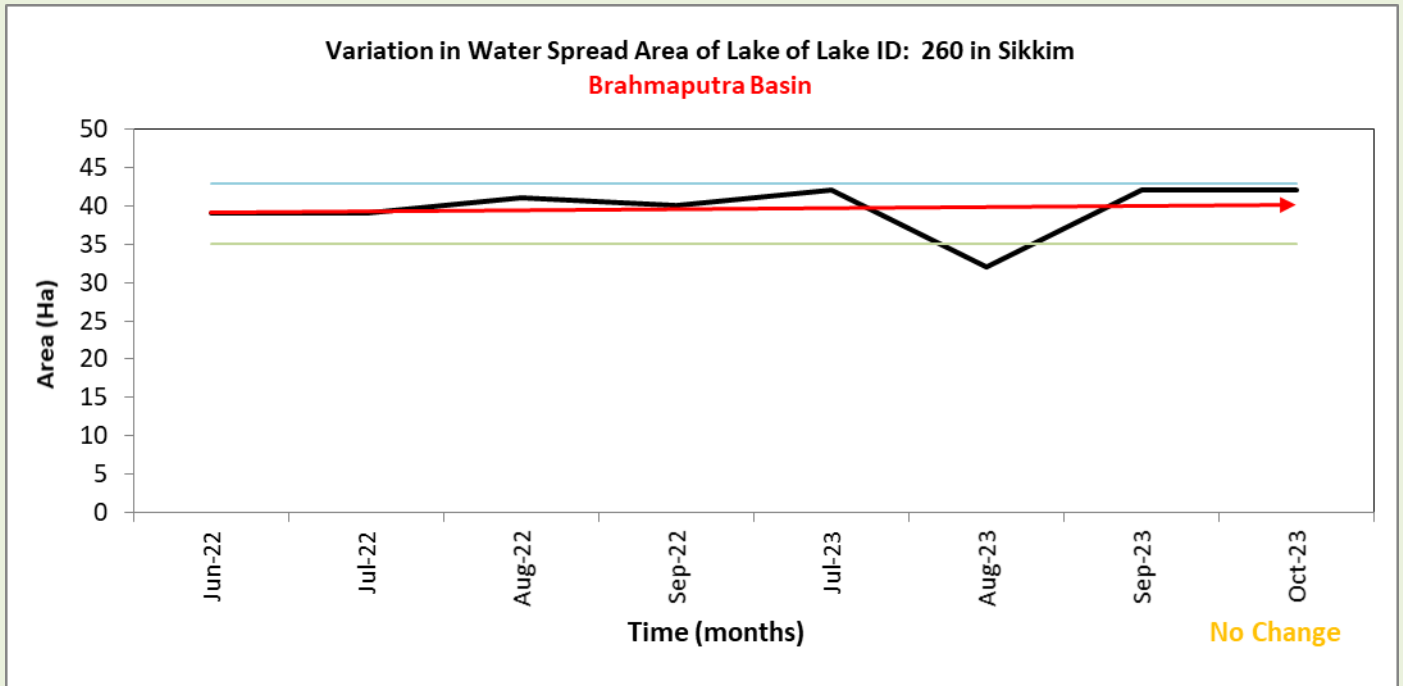
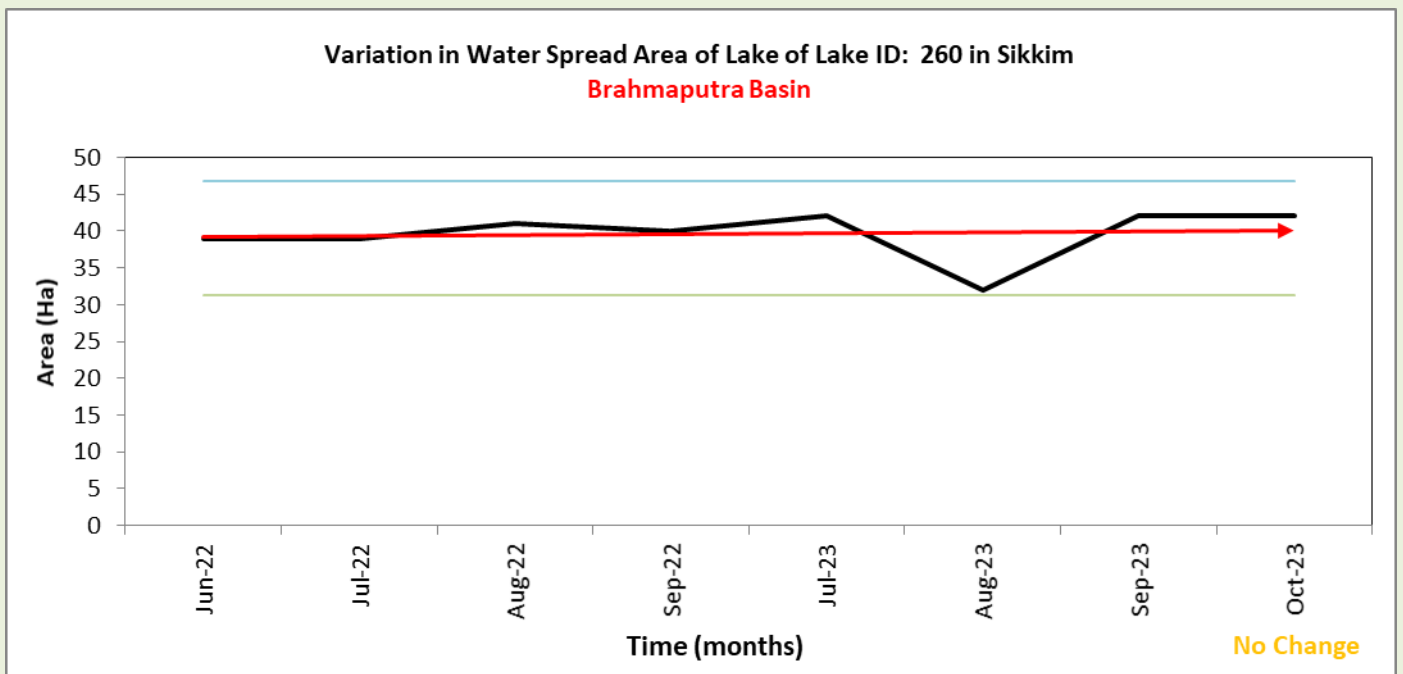
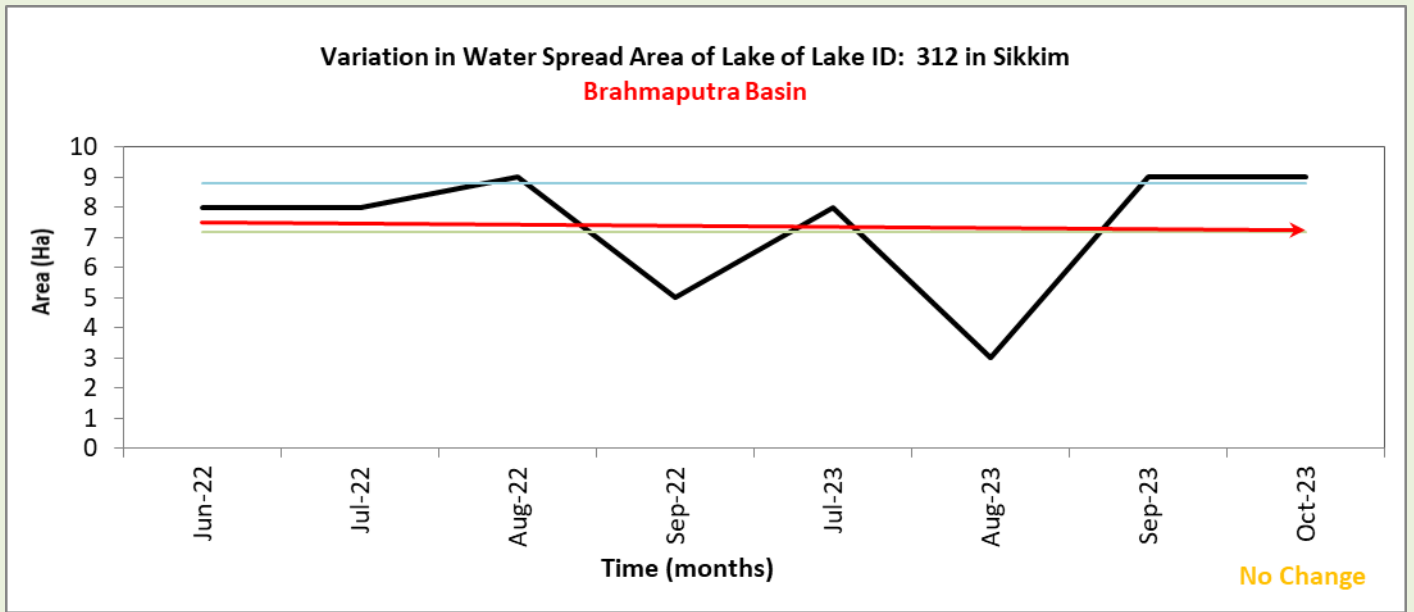


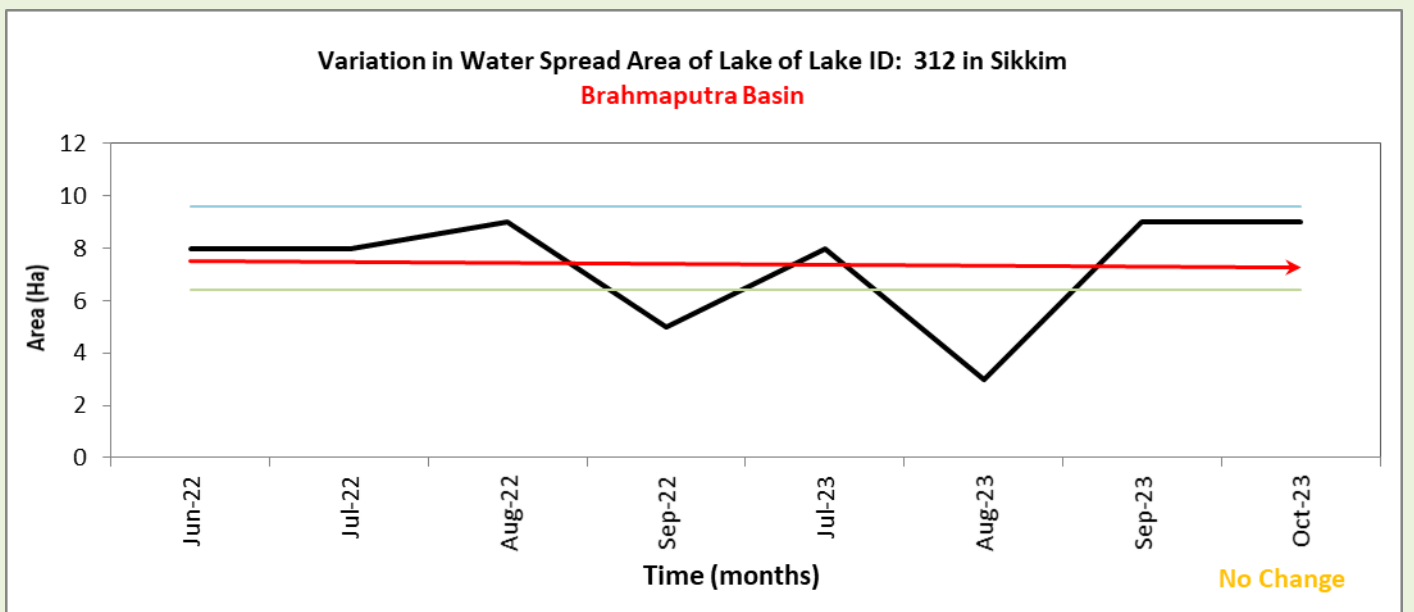
Figure 4.179(ii) Trend Analysis Plot  $\pm 20\%$



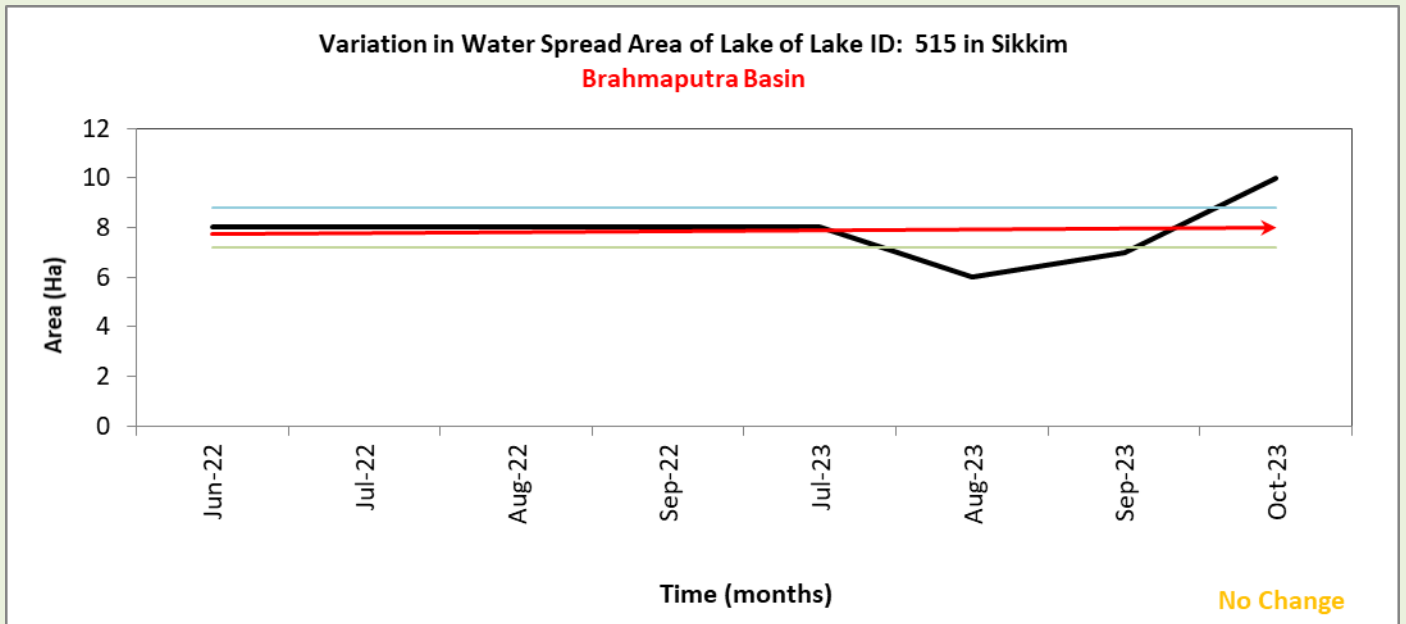
**Figure 4.180(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.180(ii)** Trend Analysis Plot  $\pm 20\%$



**Figure 4.181(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.181(ii)** Trend Analysis Plot  $\pm 20\%$

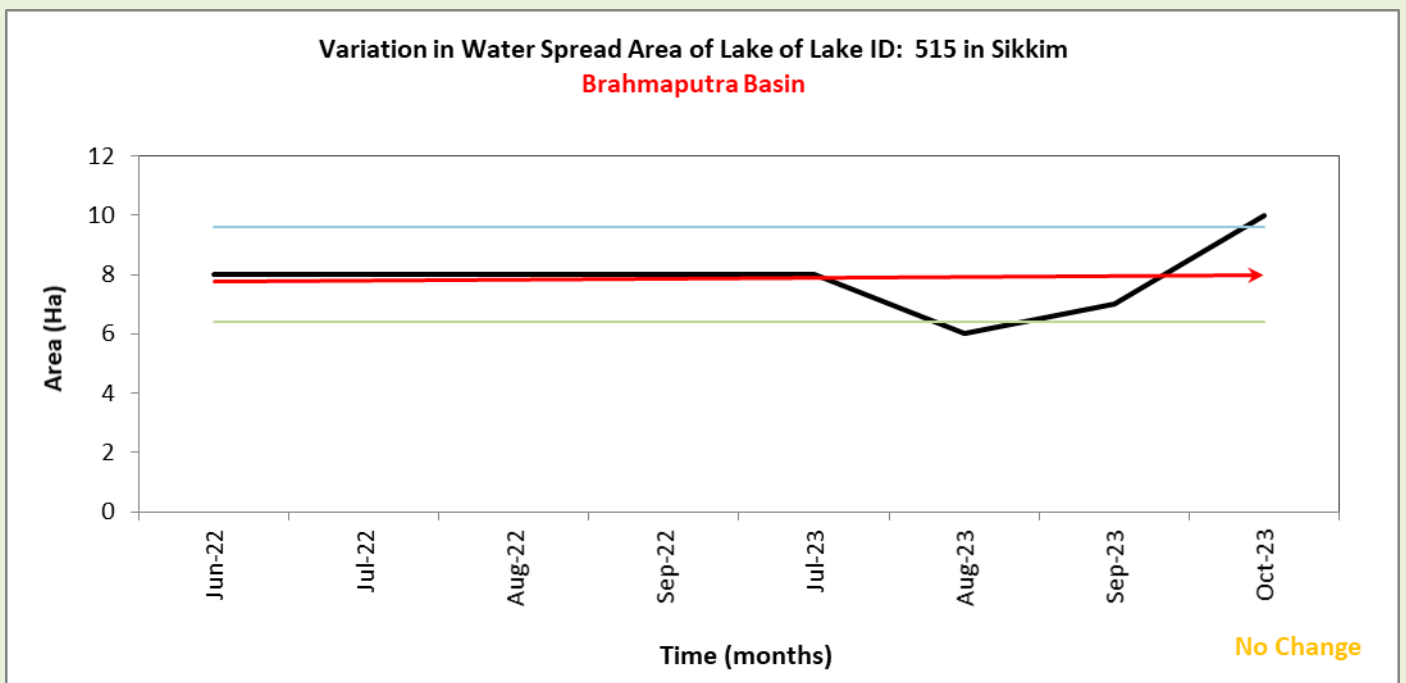


Figure 4.182(i) Trend Analysis Plot  $\pm 10\%$

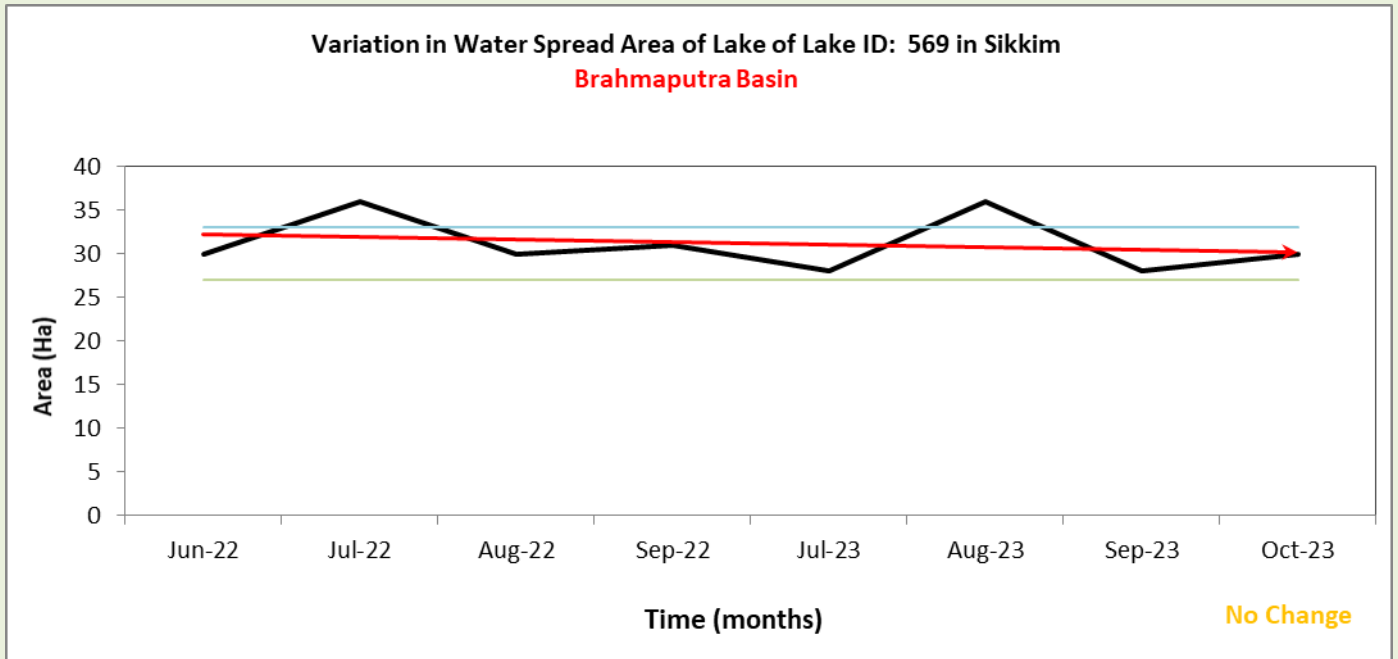


Figure 4.182(ii) Trend Analysis Plot  $\pm 20\%$

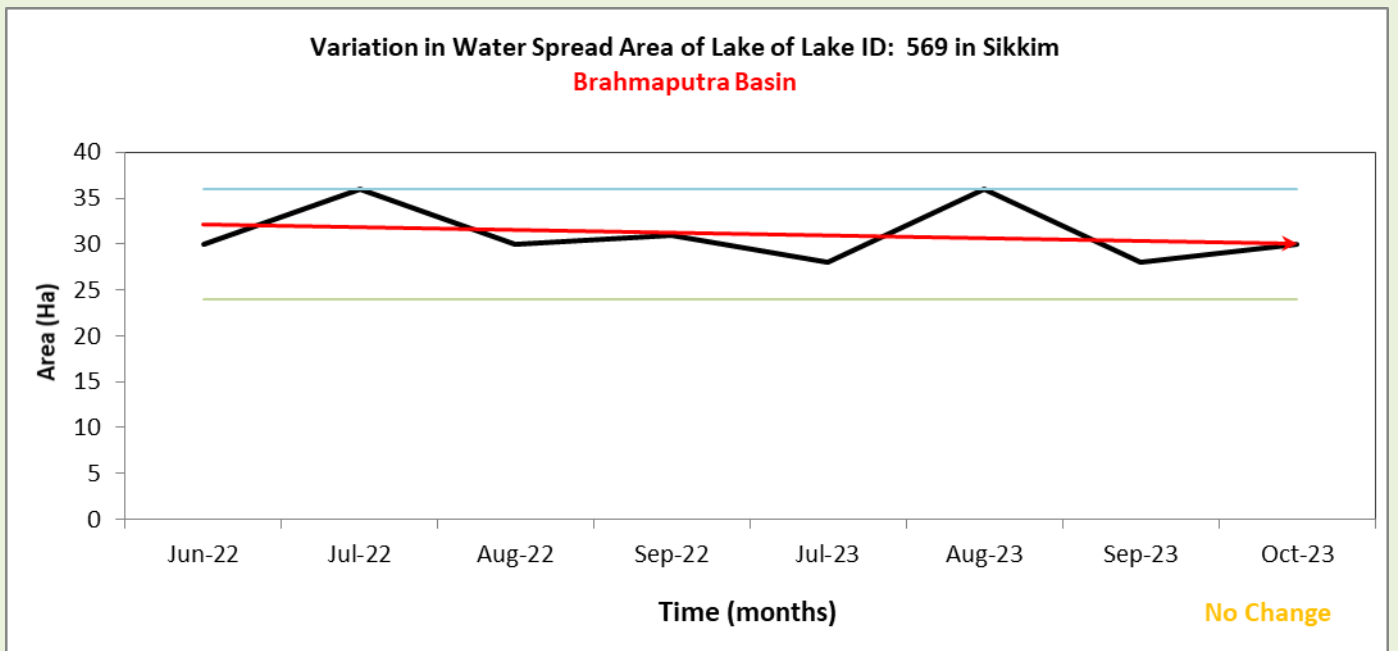


Figure 4.183(i) Trend Analysis Plot  $\pm 10\%$

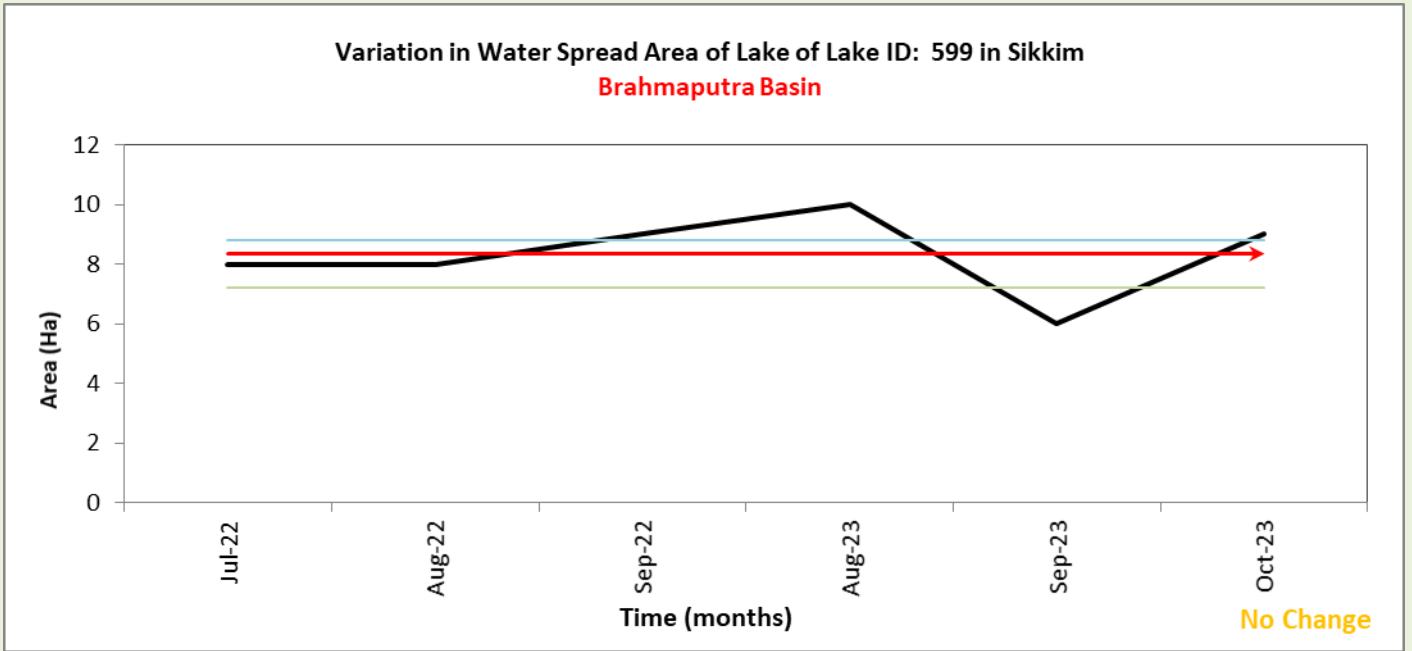
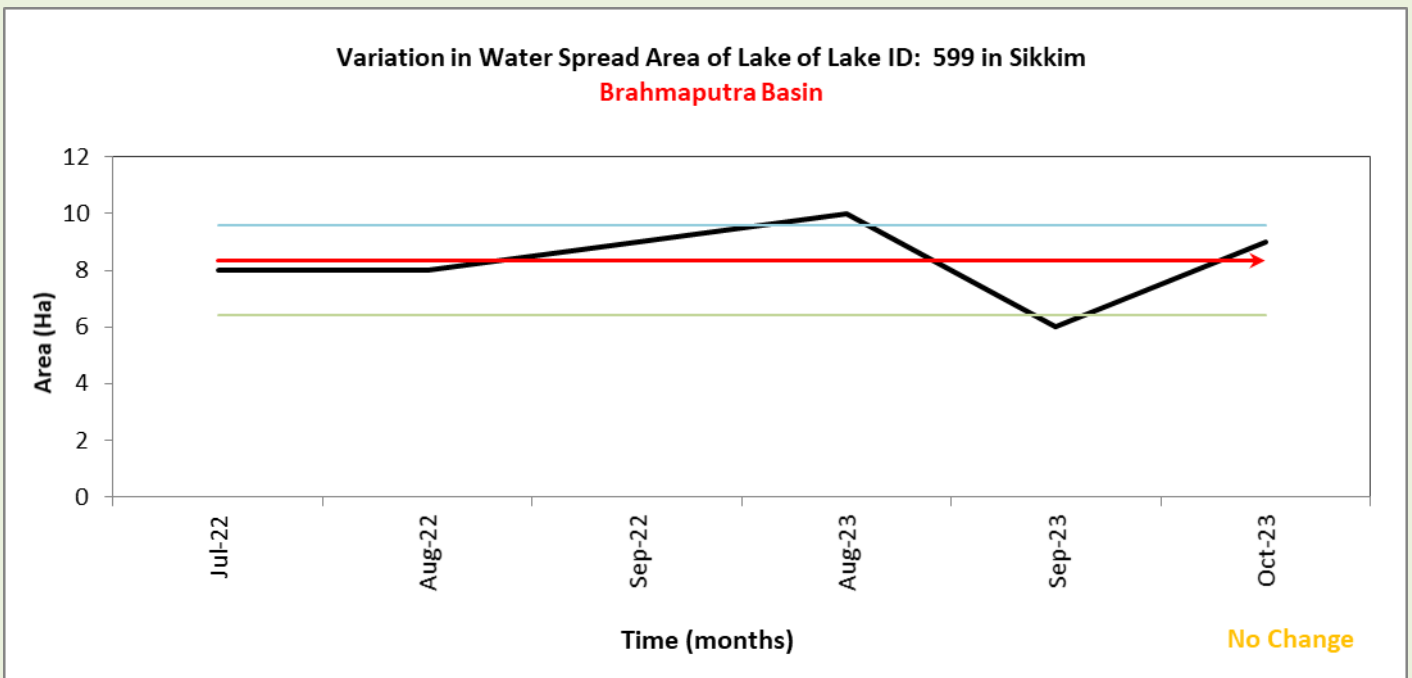
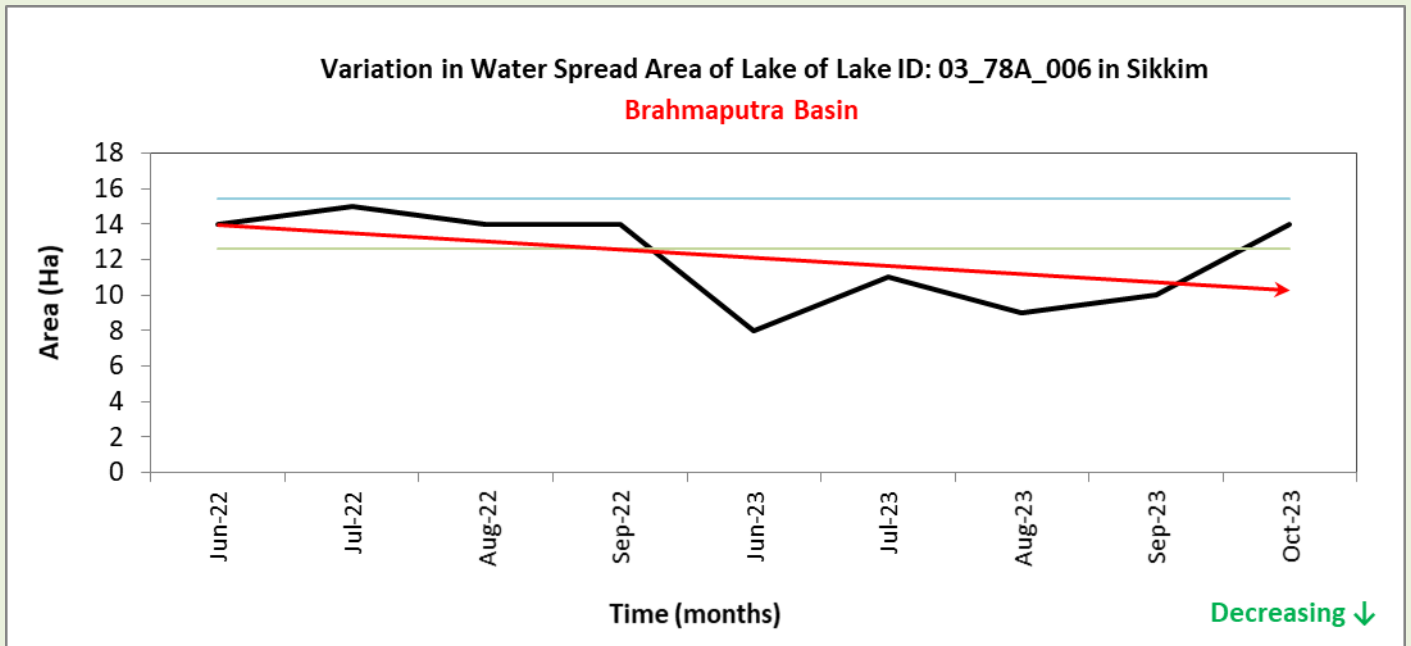


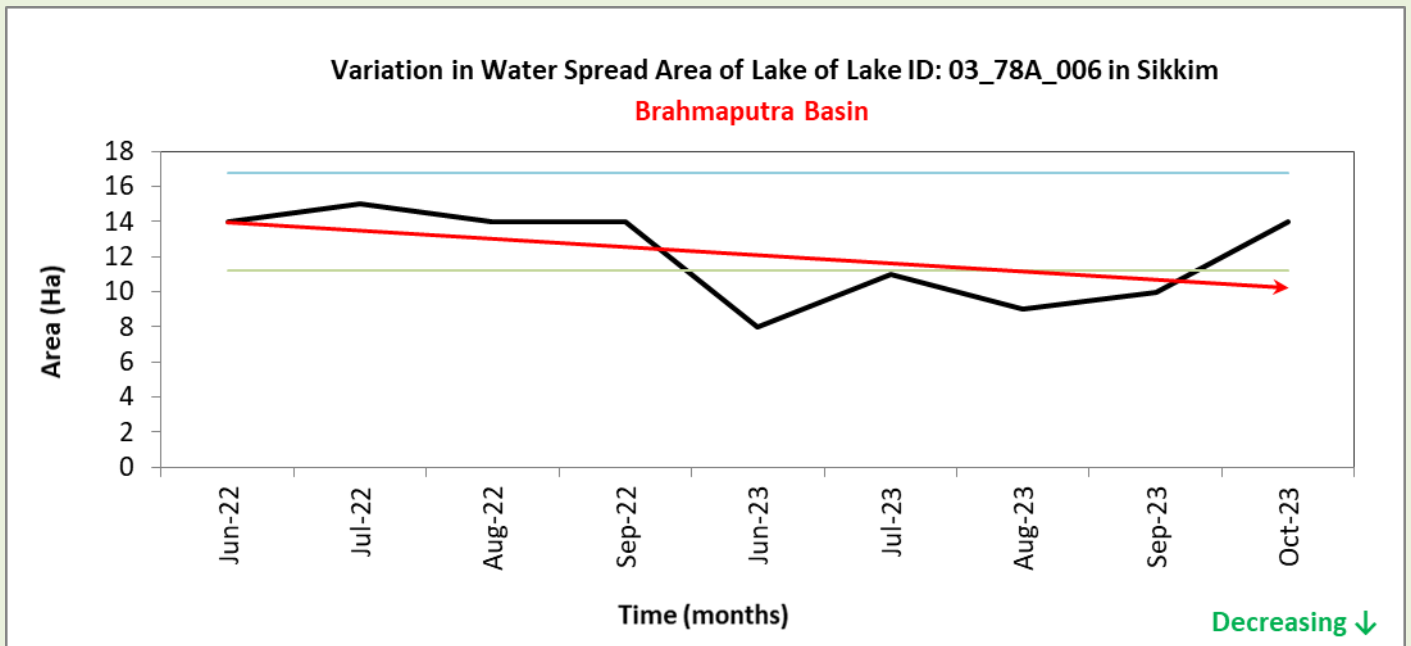
Figure 4.183(ii) Trend Analysis Plot  $\pm 20\%$



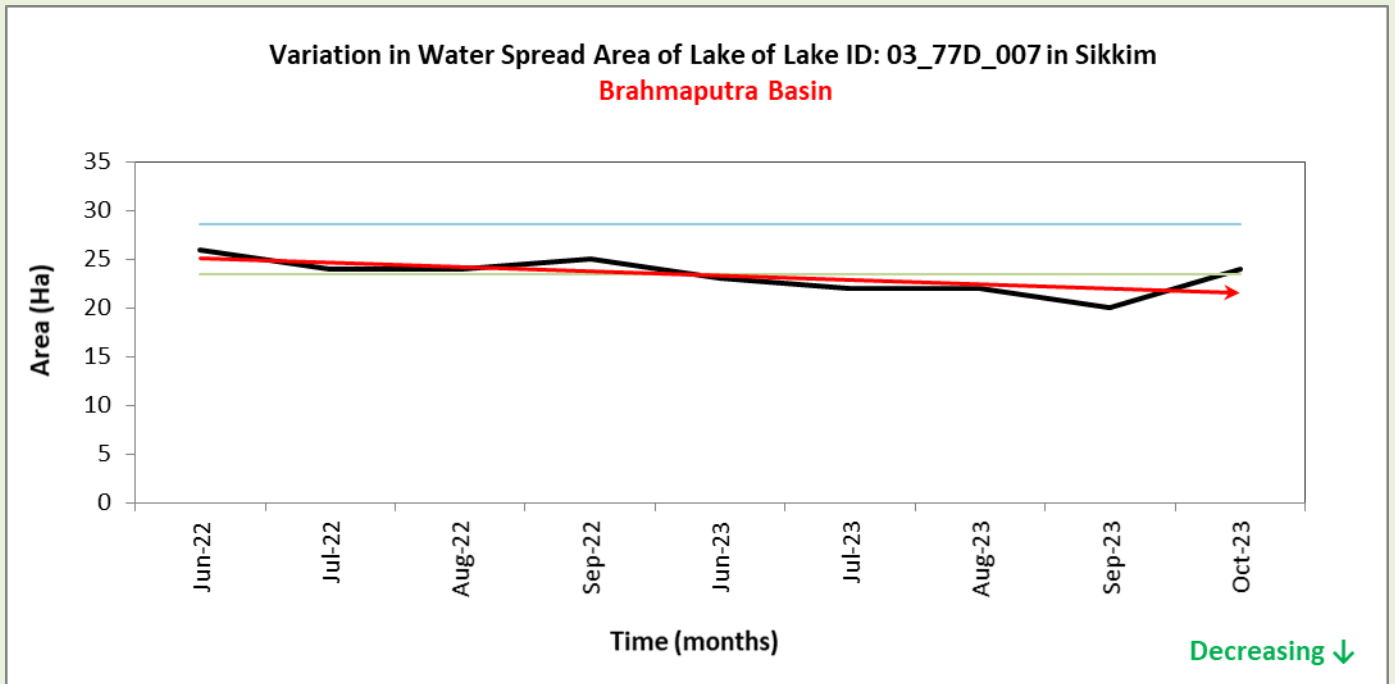
**Figure 4.184(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.184(ii)** Trend Analysis Plot  $\pm 20\%$



**Figure 4.185(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.185(ii)** Trend Analysis Plot  $\pm 20\%$

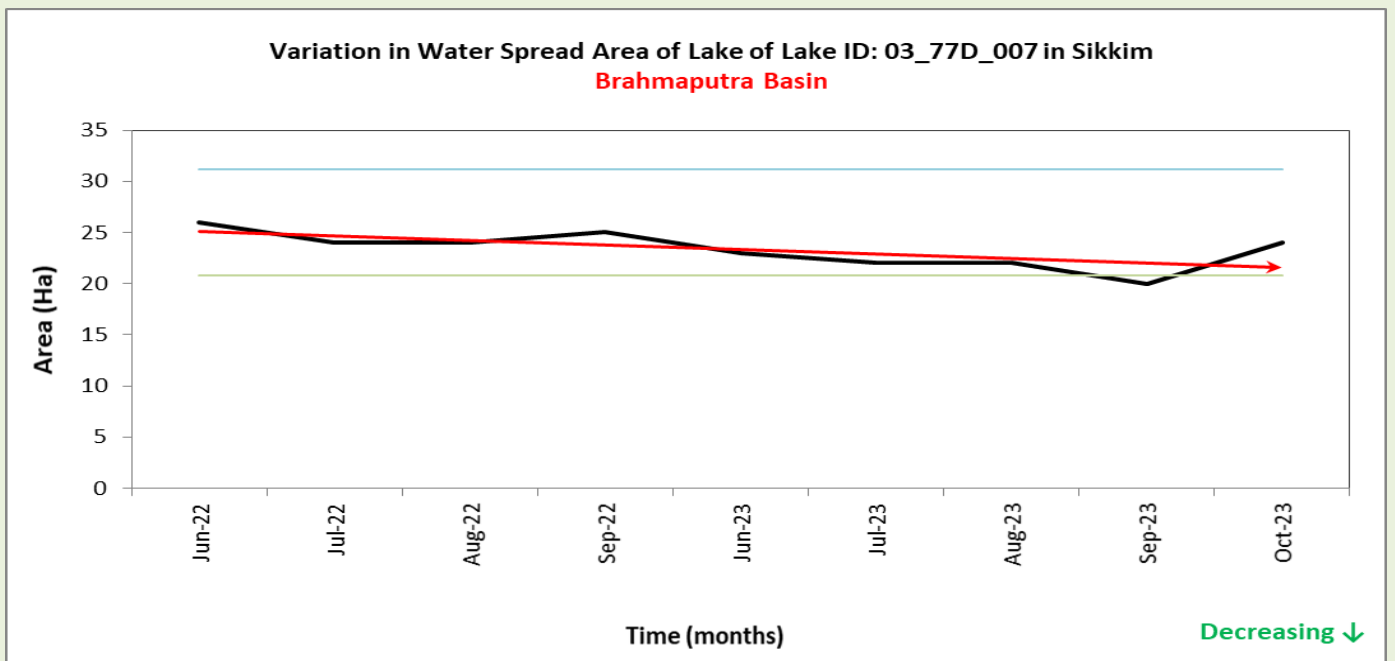


Figure 4.186(i) Trend Analysis Plot  $\pm 10\%$

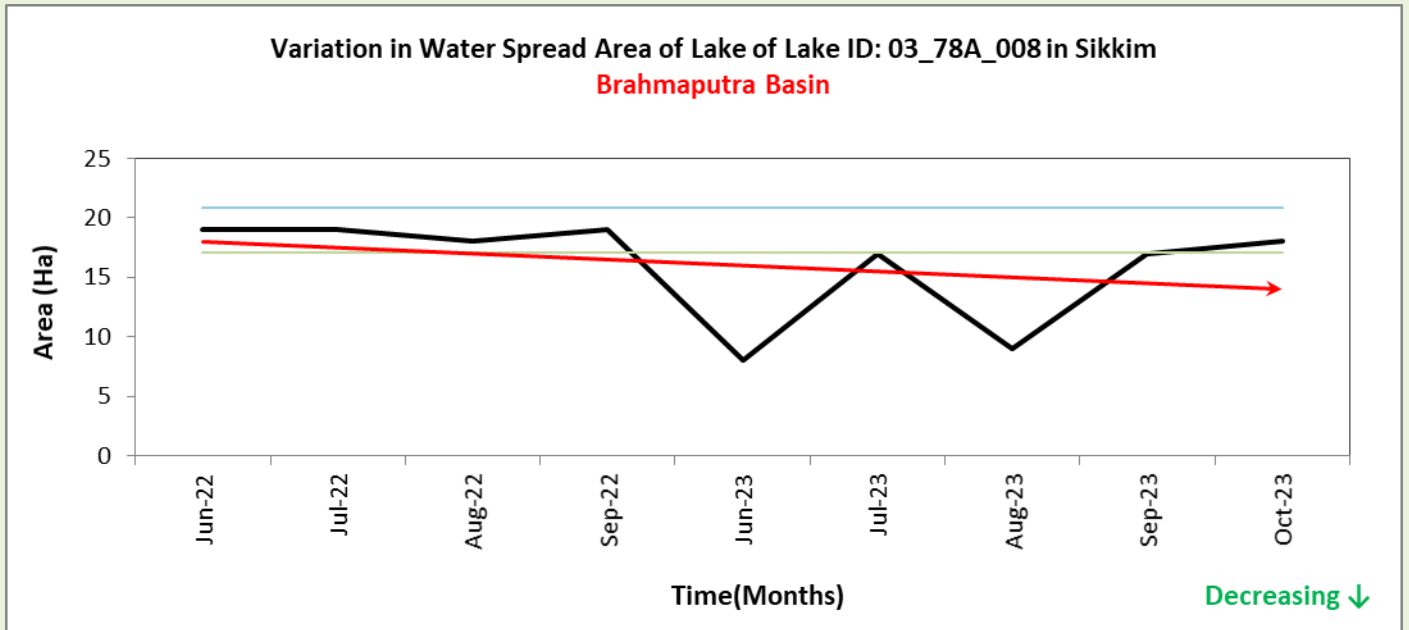
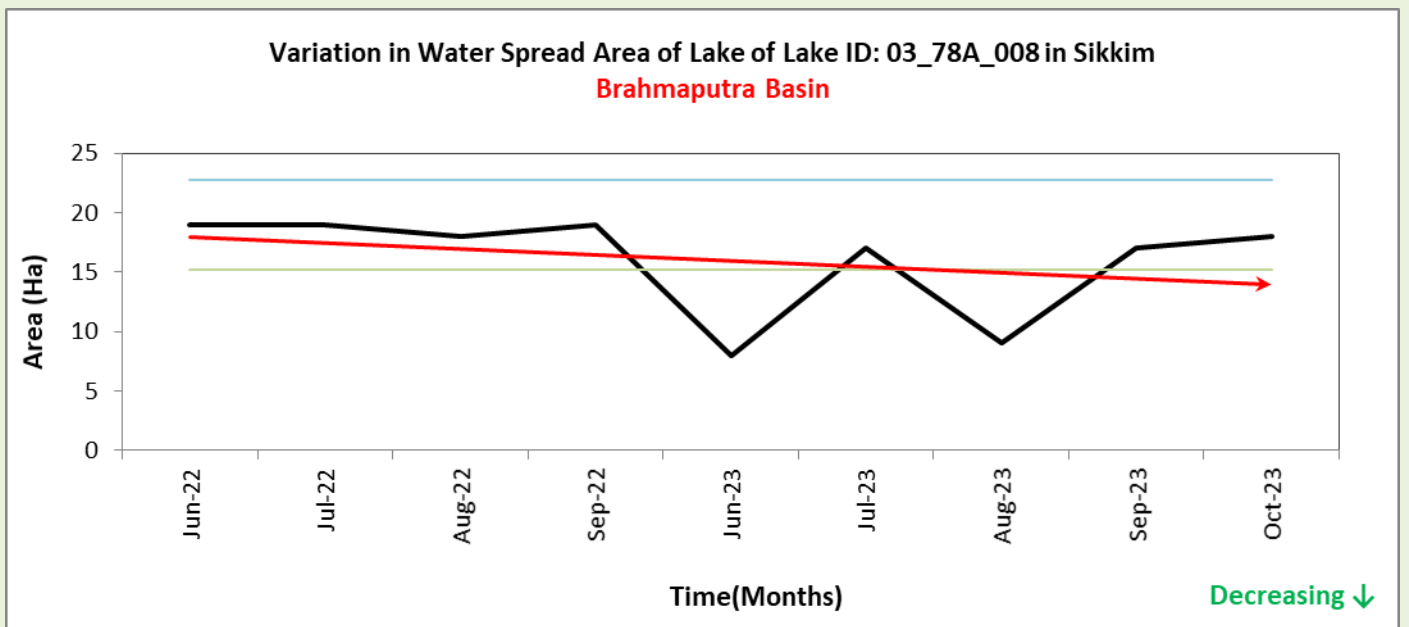
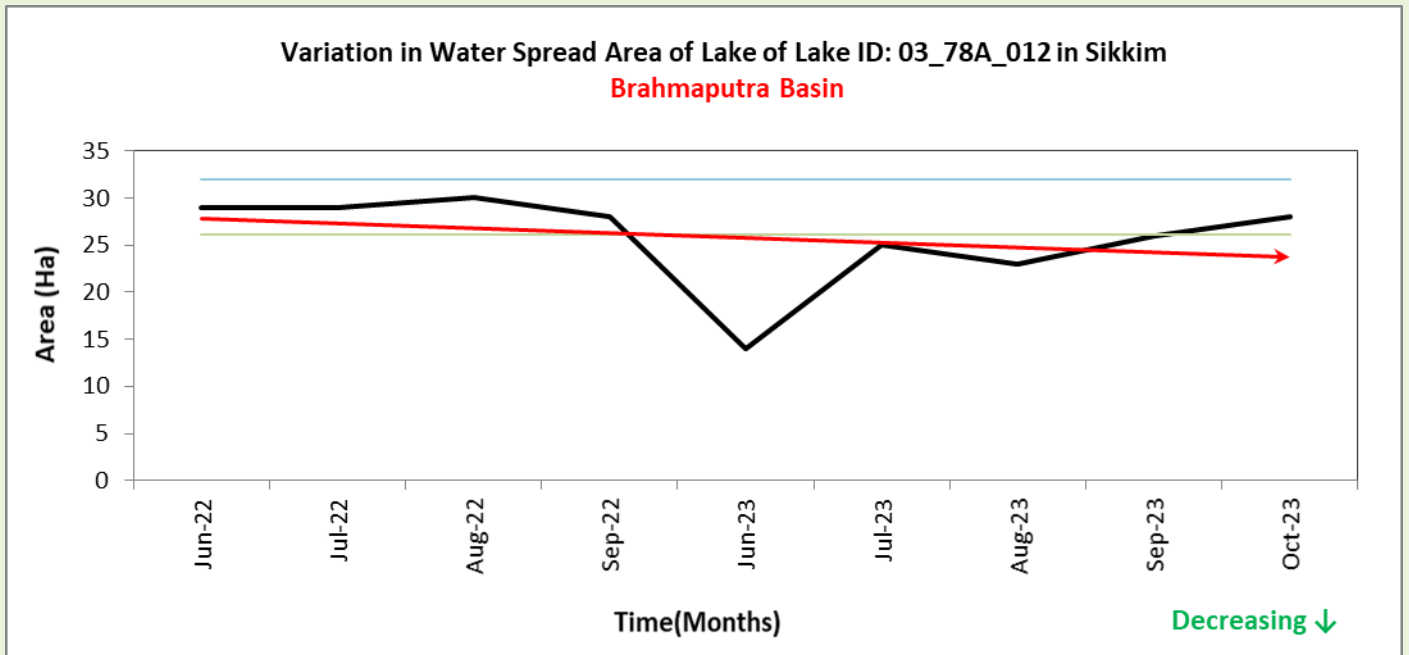


Figure 4.186(ii) Trend Analysis Plot  $\pm 20\%$



**Figure 4.187(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.187(ii)** Trend Analysis Plot  $\pm 20\%$

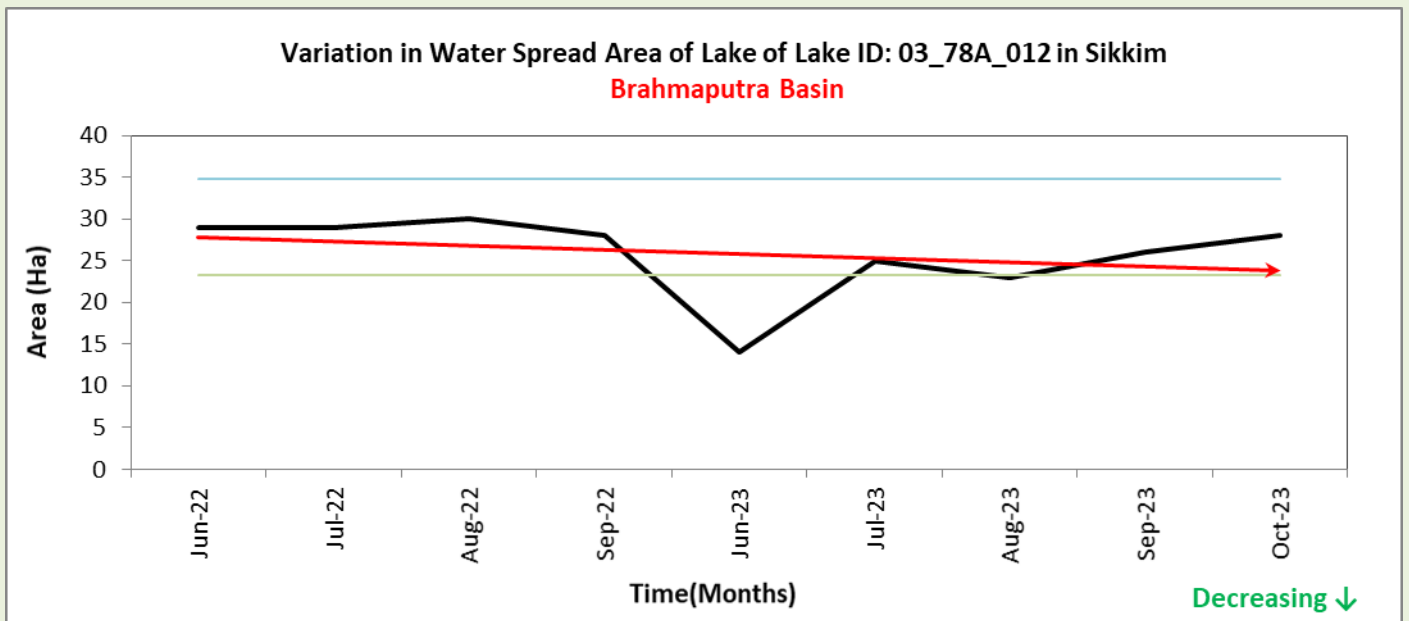


Figure 4.188(i) Trend Analysis Plot  $\pm 10\%$

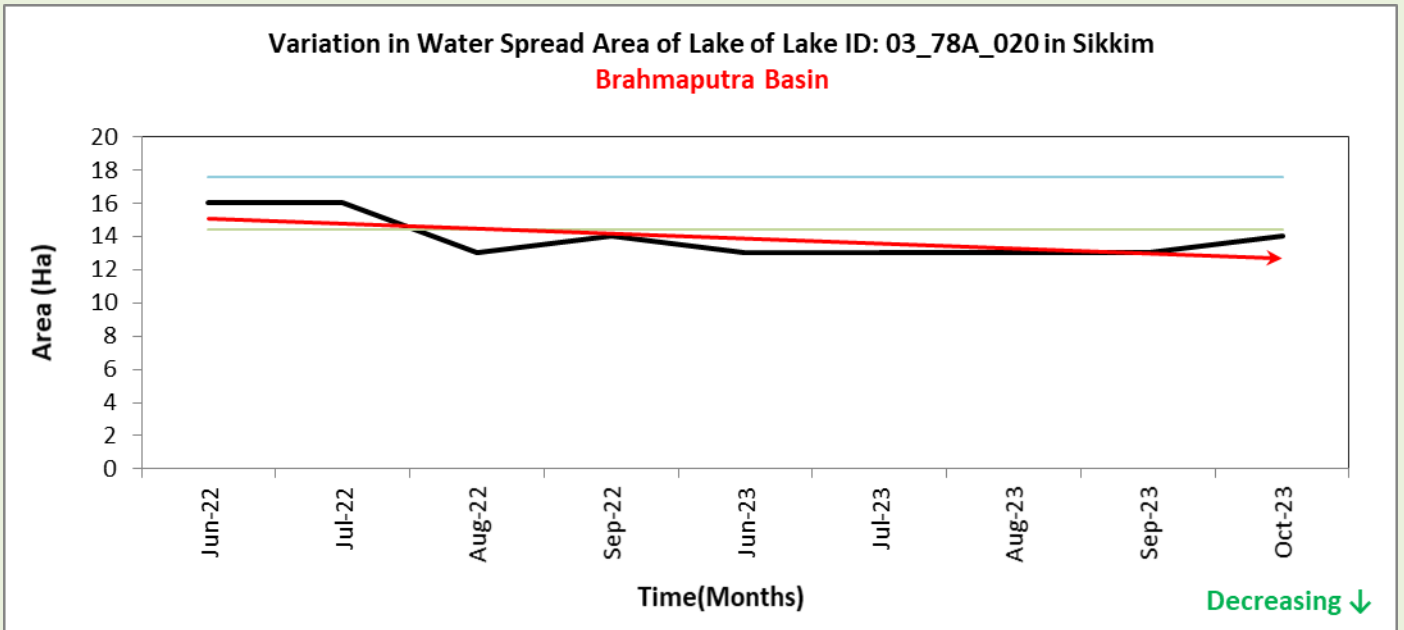


Figure 4.188(ii) Trend Analysis Plot  $\pm 20\%$

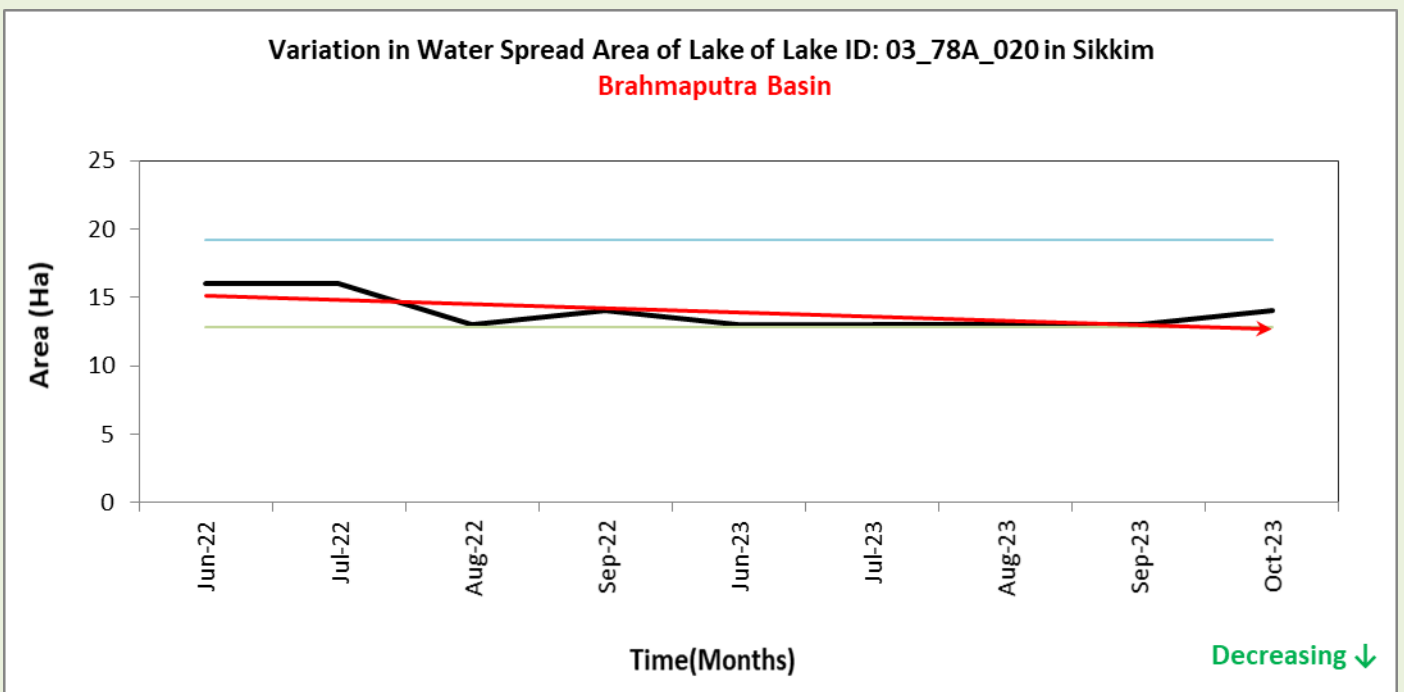


Figure 4.189(i) Trend Analysis Plot  $\pm 10\%$

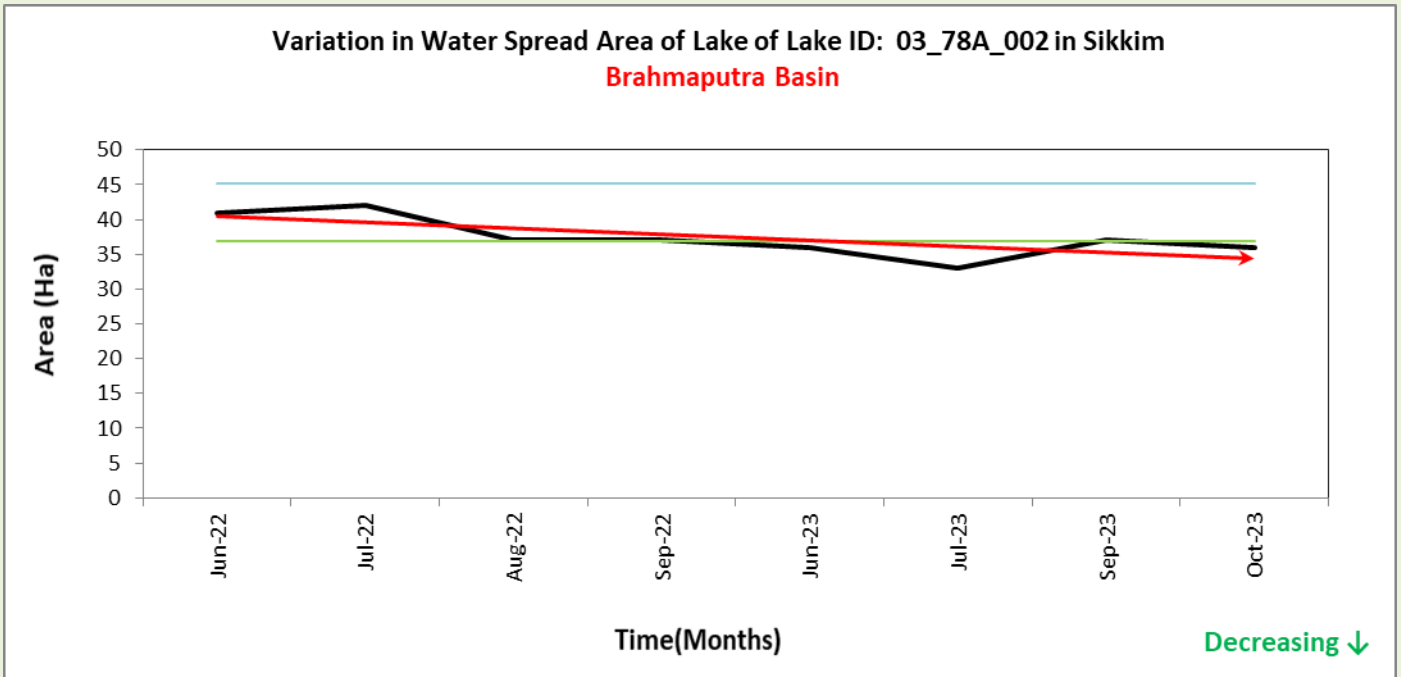


Figure 4.189(ii) Trend Analysis Plot  $\pm 20\%$

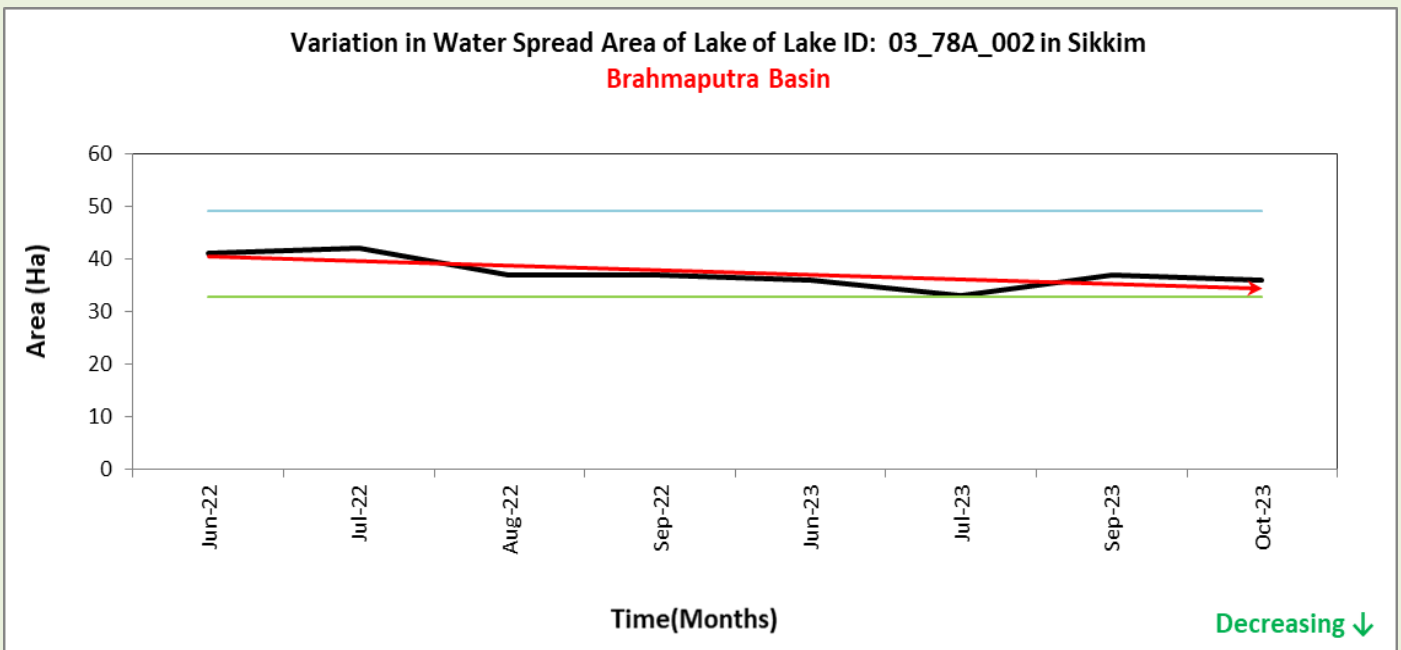


Figure 4.190(i) Trend Analysis Plot  $\pm 10\%$

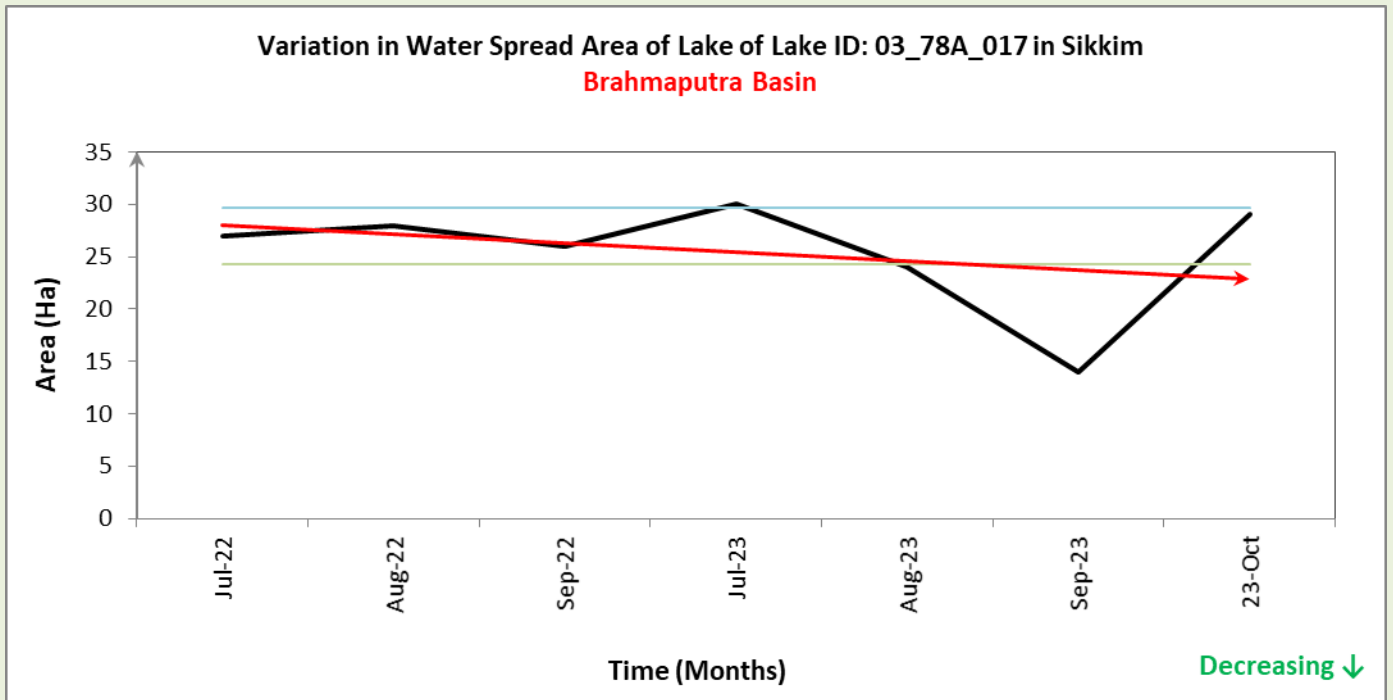


Figure 4.190(ii) Trend Analysis Plot  $\pm 20\%$

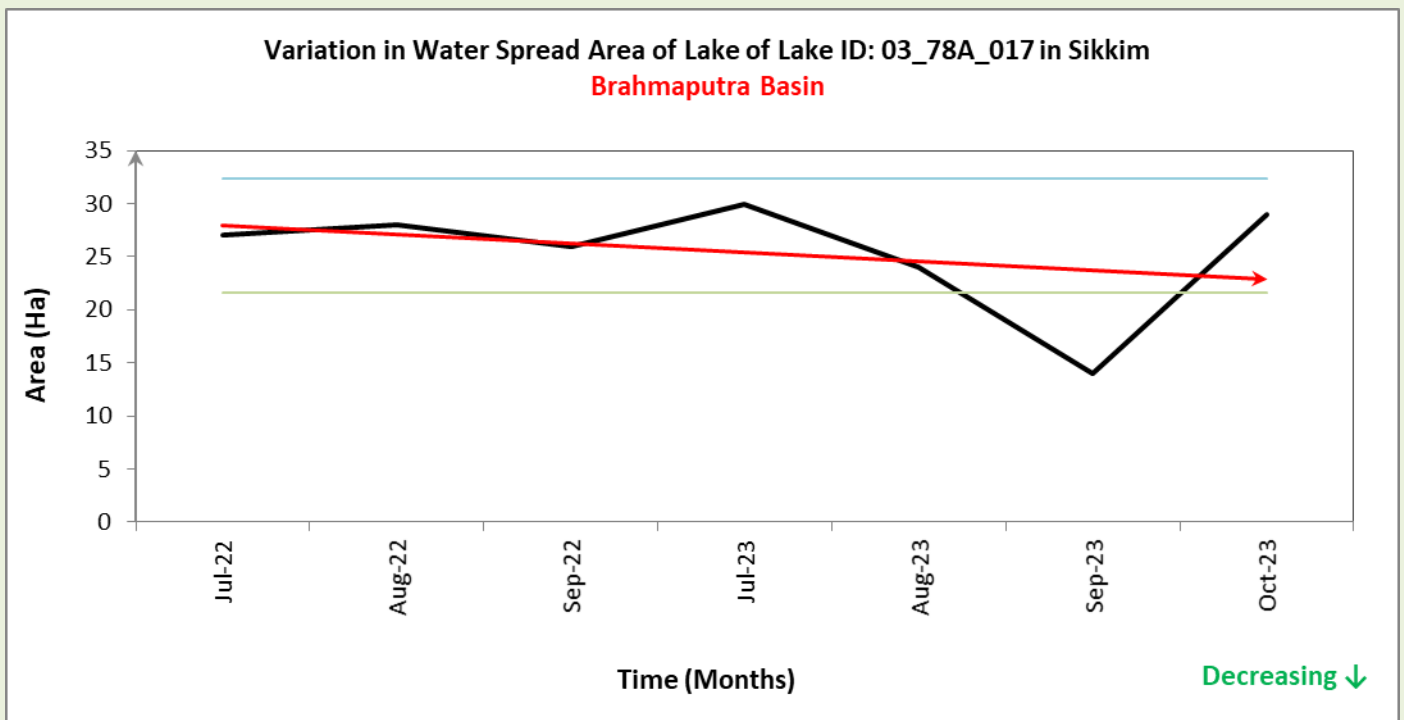


Figure 4.191(i) Trend Analysis Plot  $\pm 10\%$

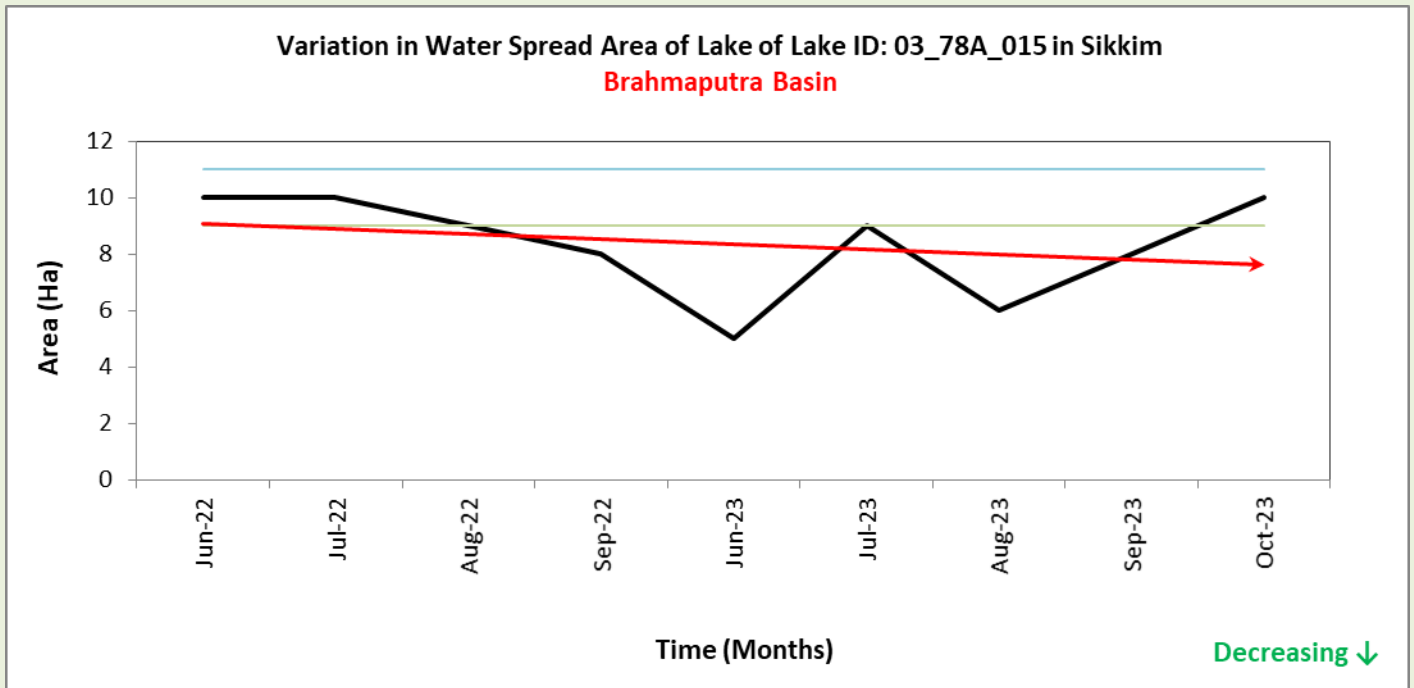


Figure 4.191(ii) Trend Analysis Plot  $\pm 20\%$

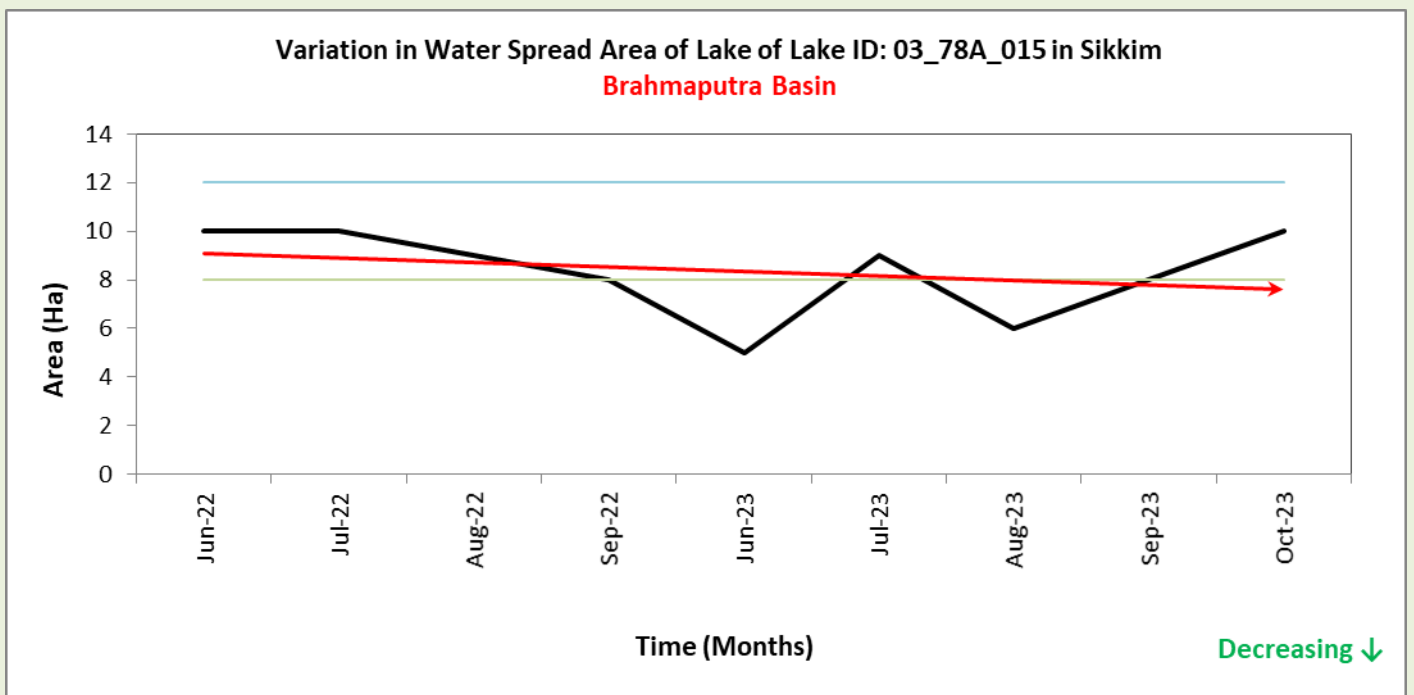


Figure 4.192(i) Trend Analysis Plot  $\pm 10\%$

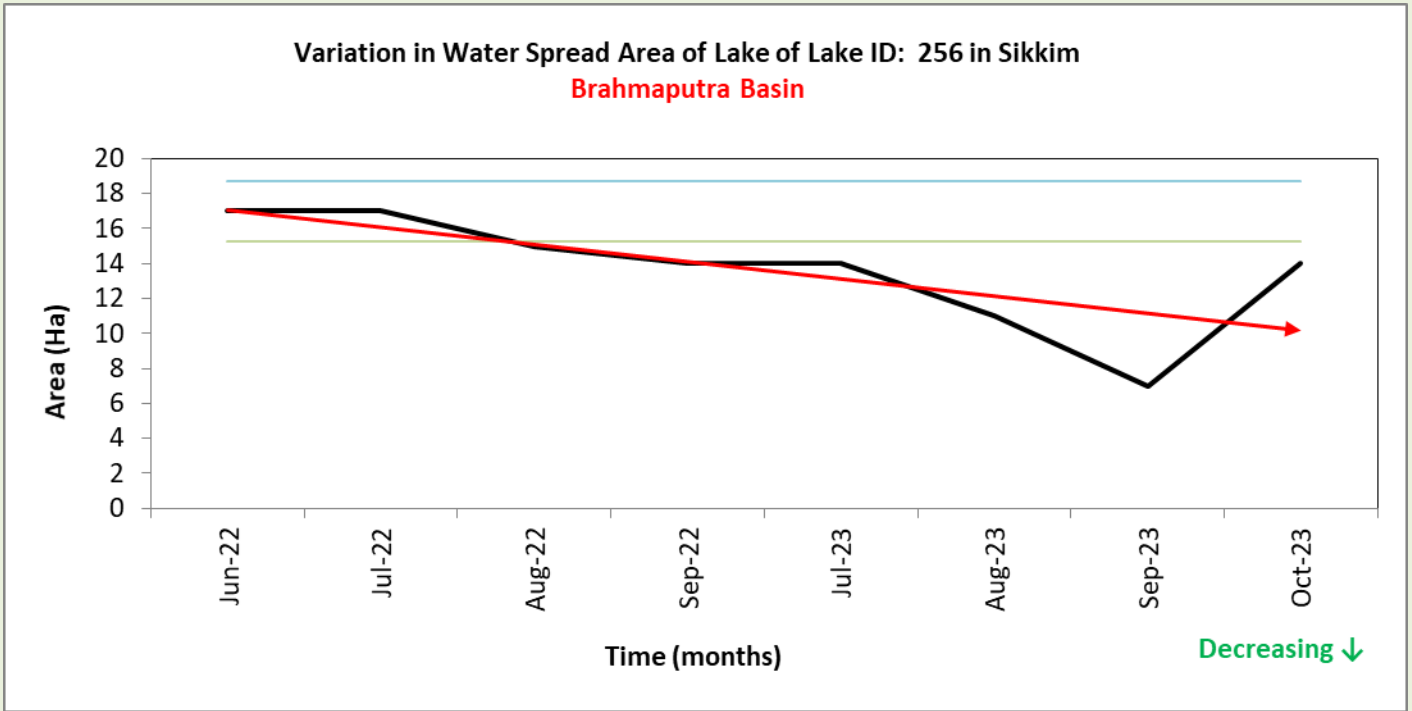


Figure 4.192(ii) Trend Analysis Plot  $\pm 20\%$

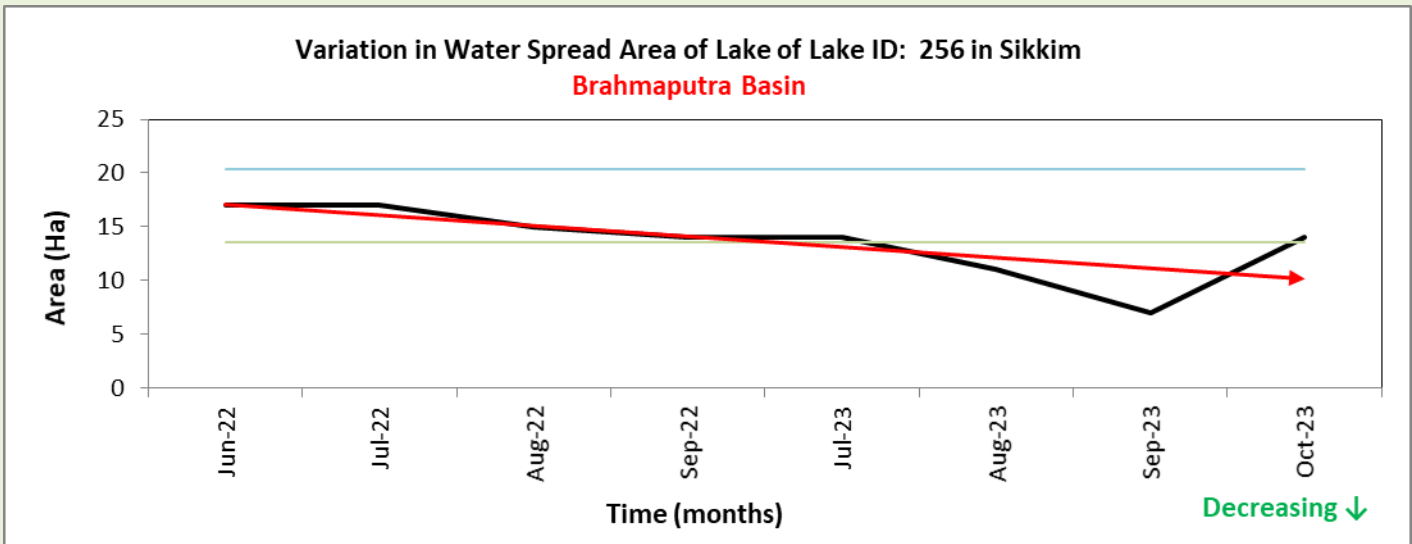


Figure 4.193(i) Trend Analysis Plot  $\pm 10\%$

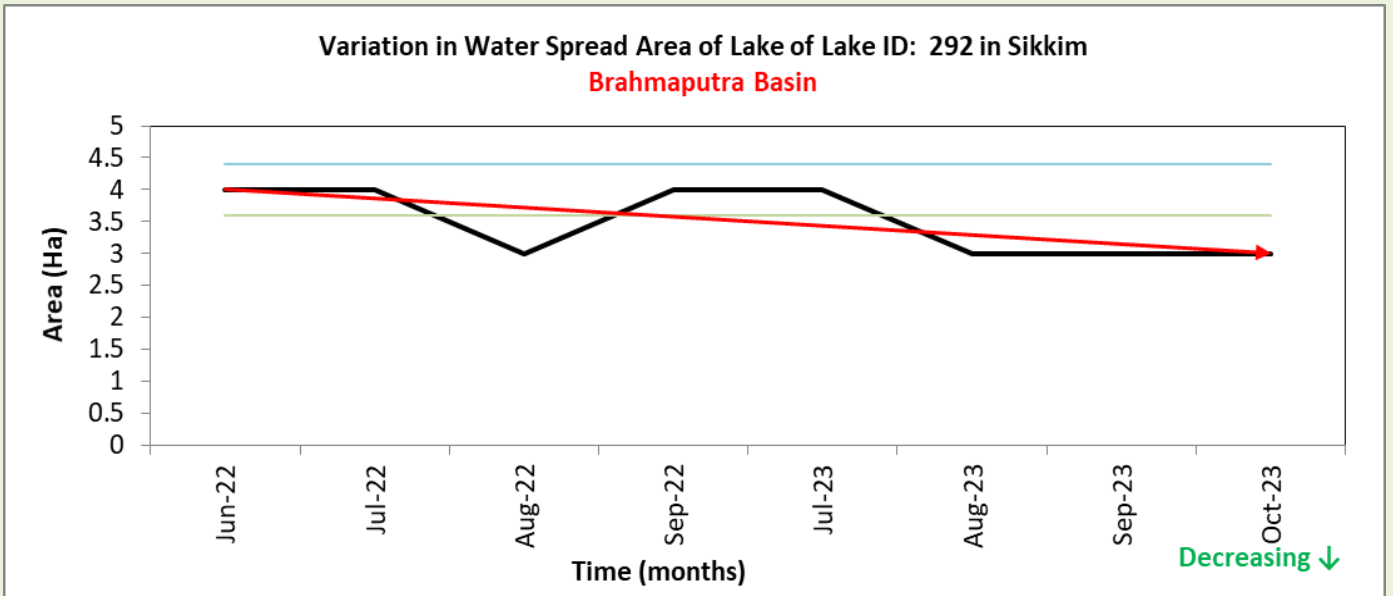


Figure 4.193(ii) Trend Analysis Plot  $\pm 20\%$

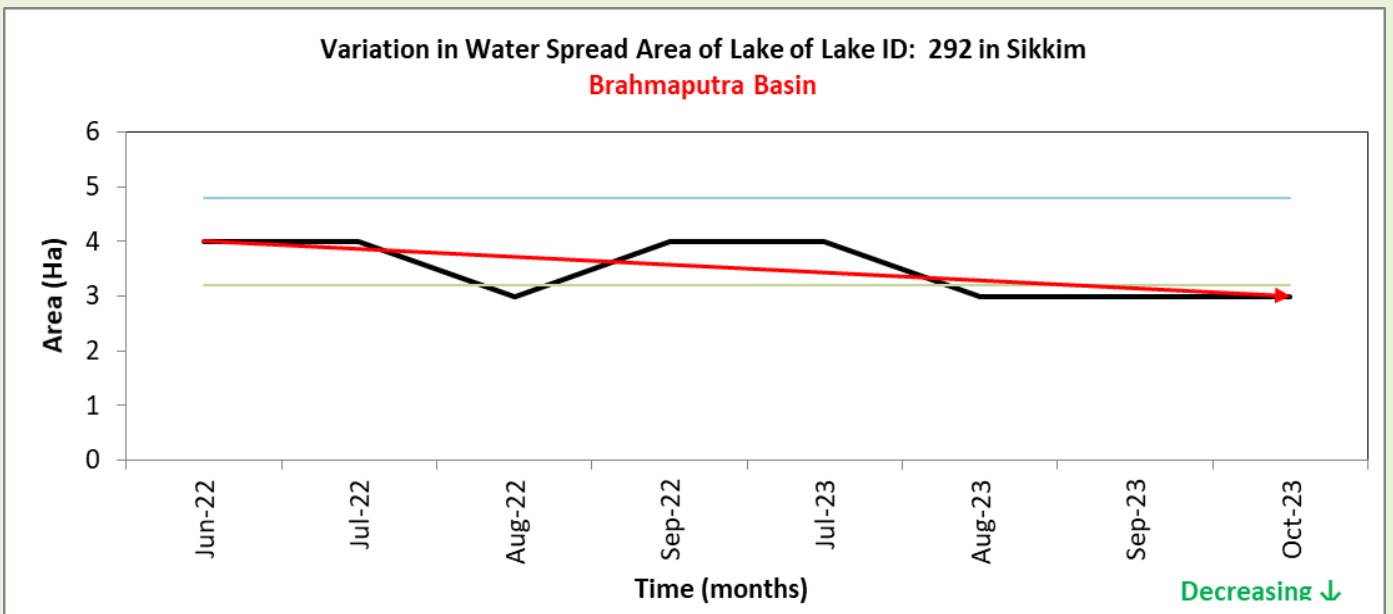


Figure 4.194(i) Trend Analysis Plot  $\pm 10\%$

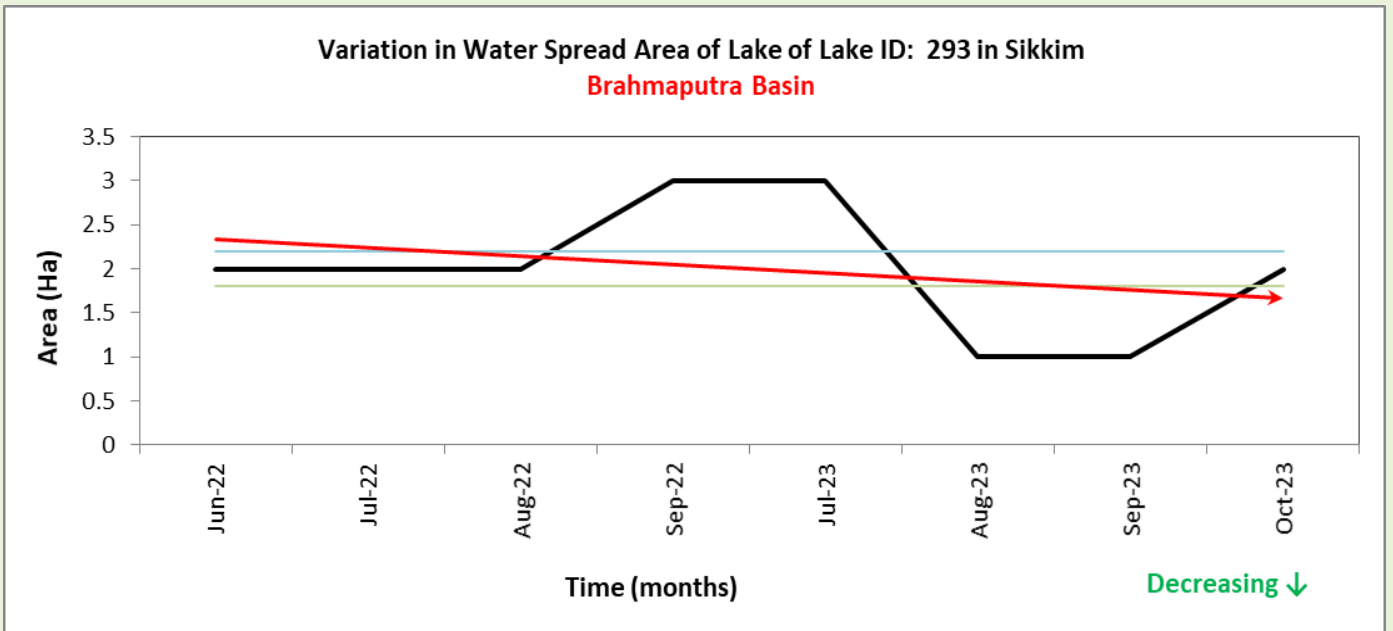


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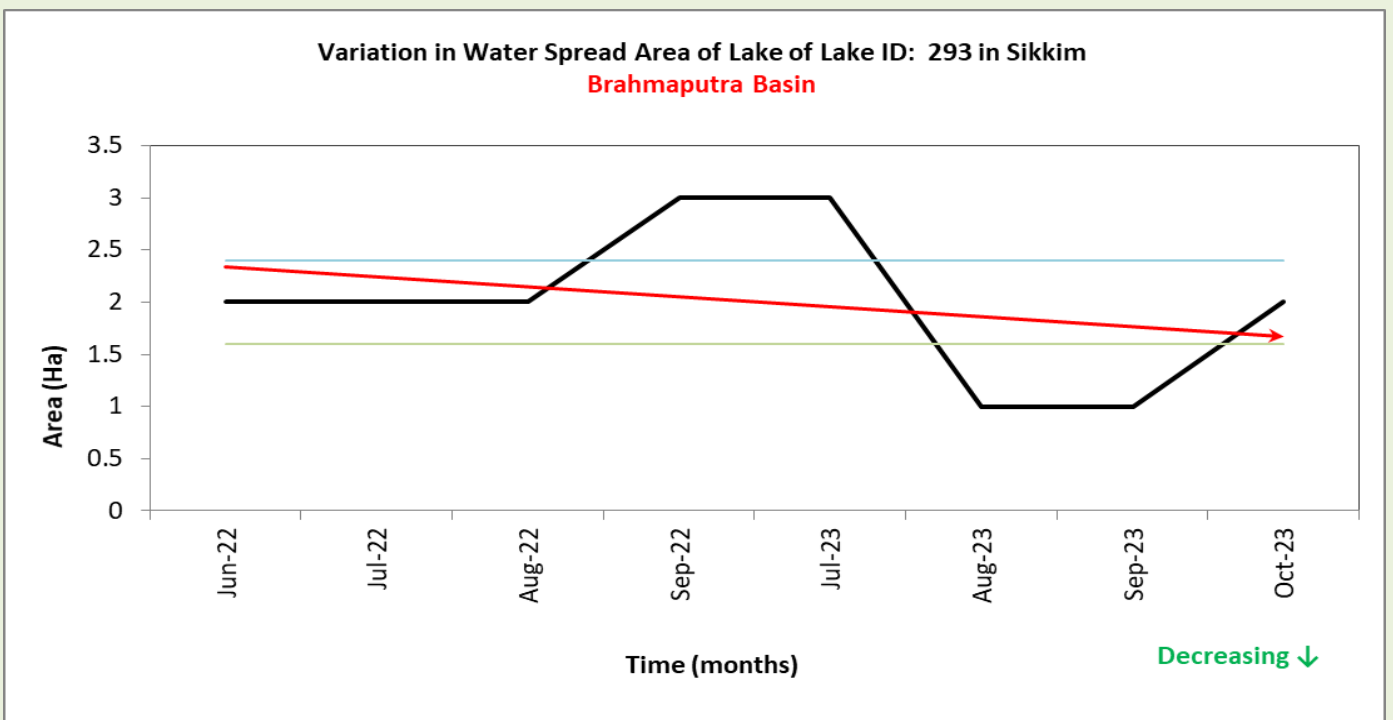


Figure 4.195(i) Trend Analysis Plot  $\pm 10\%$

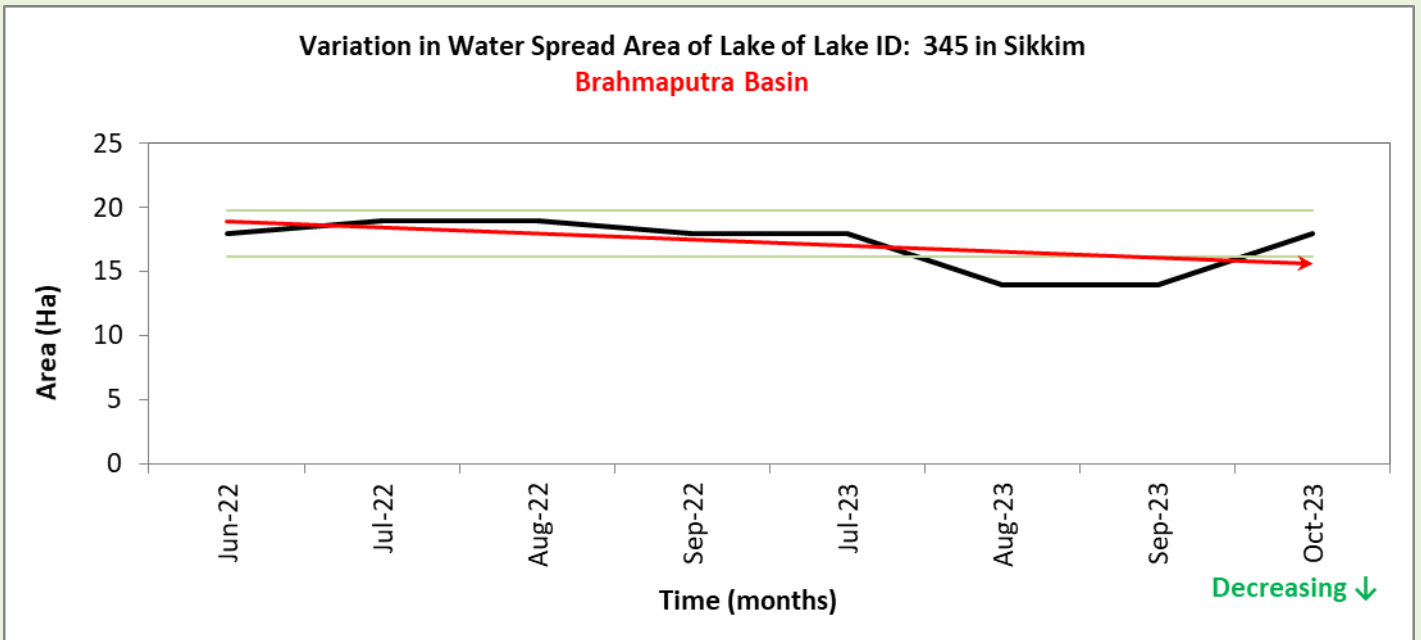
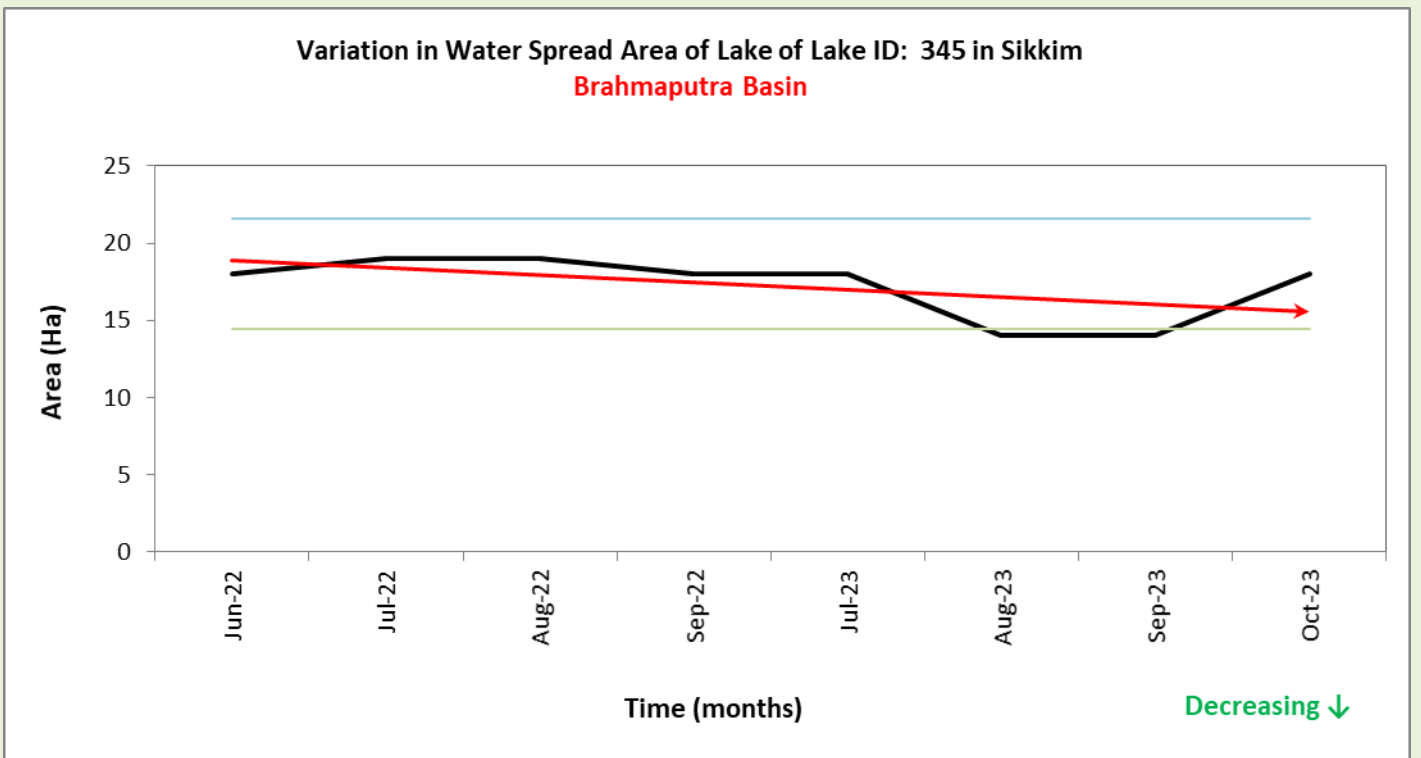


Figure 4.195(ii) Trend Analysis Plot  $\pm 20\%$



**Trend analysis of “Change in water spread area of Glacial Lakes between 10 Ha to 50 Ha of Arunachal Pradesh (2022-2023)”**

Figure 4.196(i) Trend Analysis Plot  $\pm 10\%$

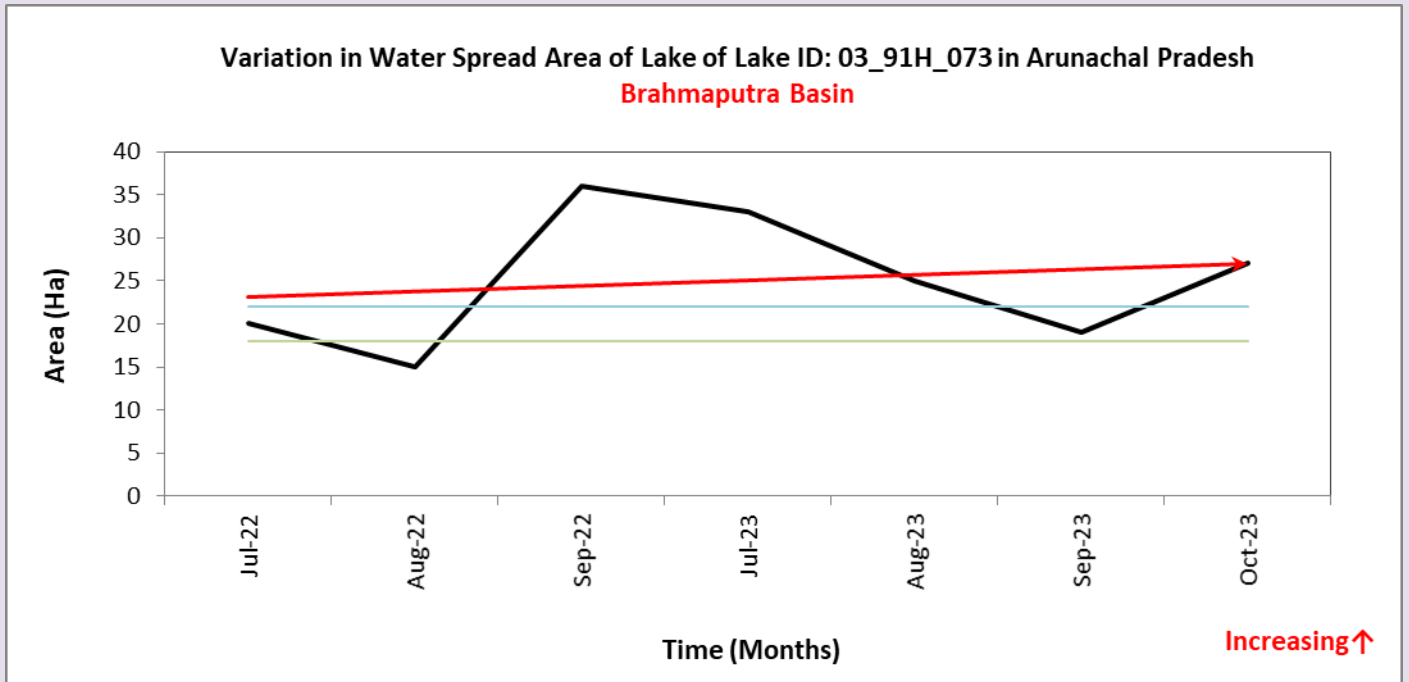


Figure 4.196(ii) Trend Analysis Plot  $\pm 20\%$

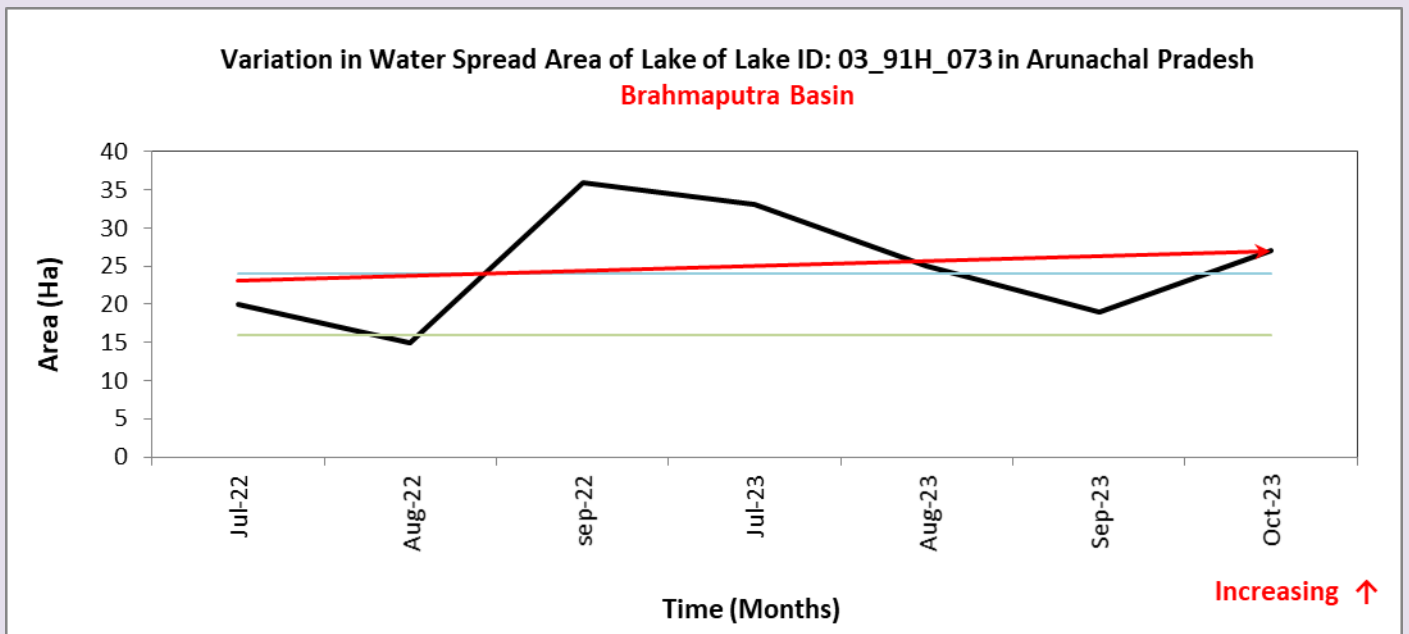


Figure 4.197(i) Trend Analysis Plot  $\pm 10\%$

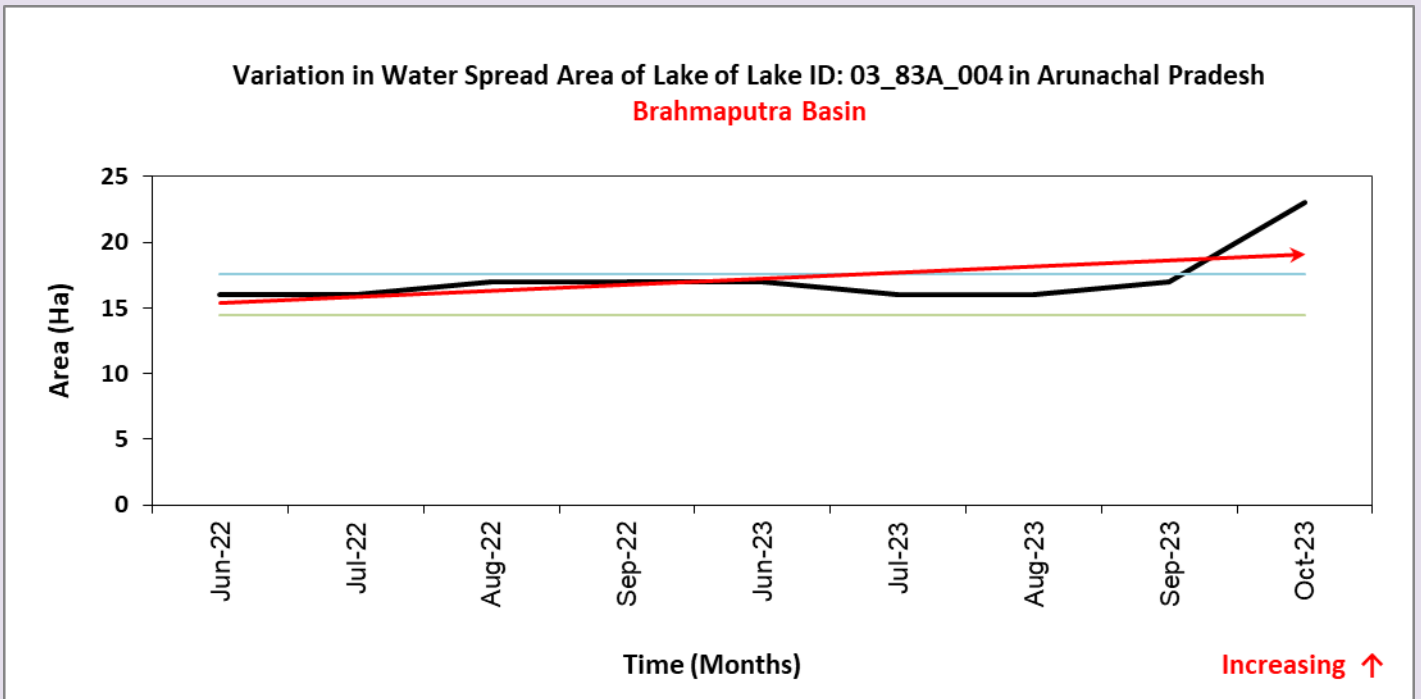


Figure 4.197(ii) Trend Analysis Plot  $\pm 20\%$

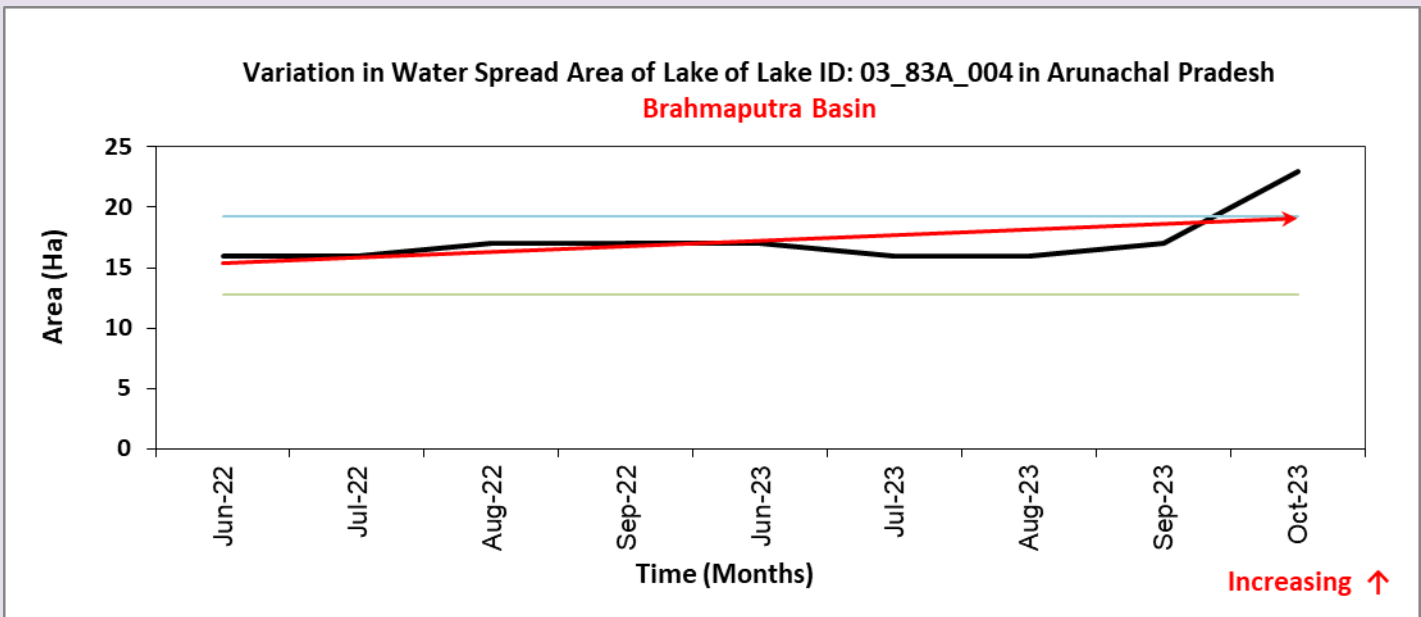


Figure 4.198(i) Trend Analysis Plot  $\pm 10\%$

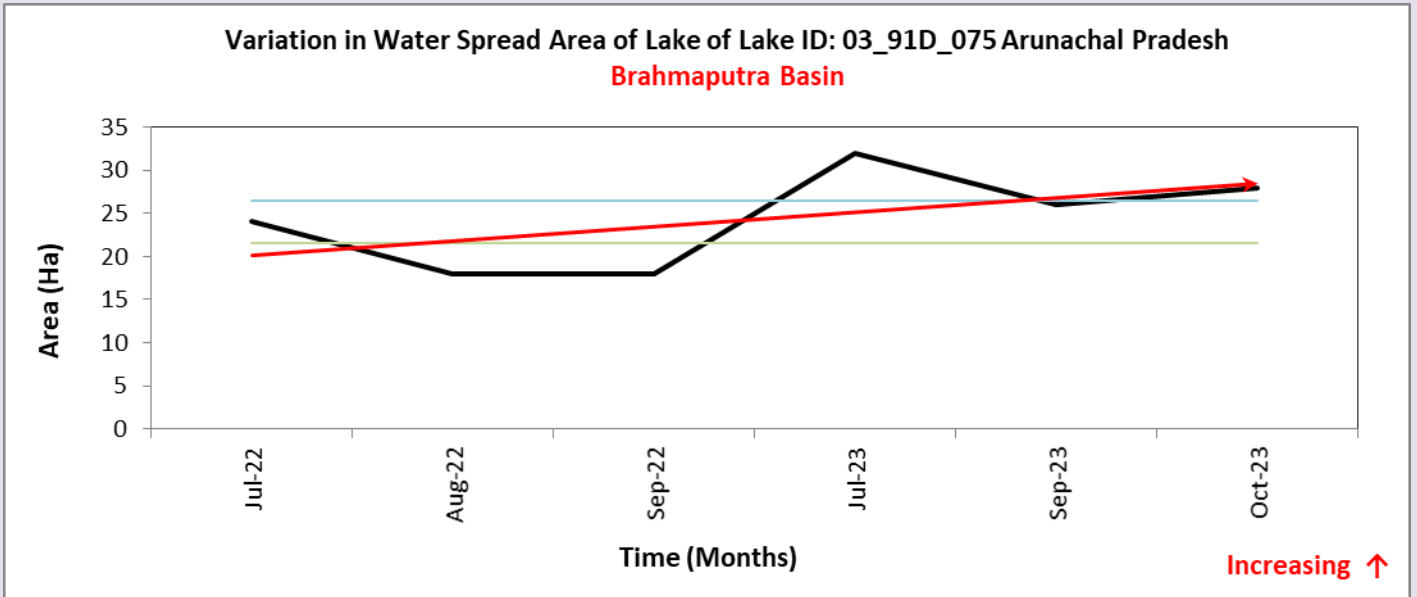


Figure 4.198(ii) Trend Analysis Plot  $\pm 20\%$

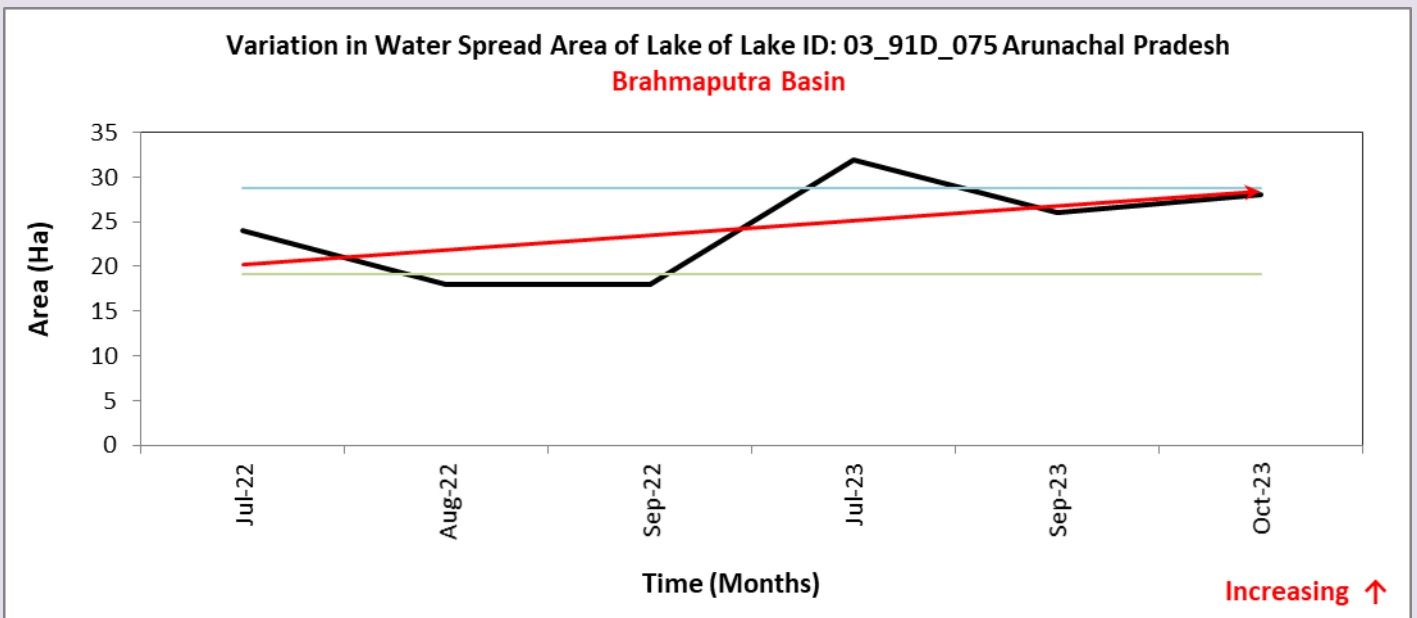


Figure 4.199(i) Trend Analysis Plot  $\pm 10\%$

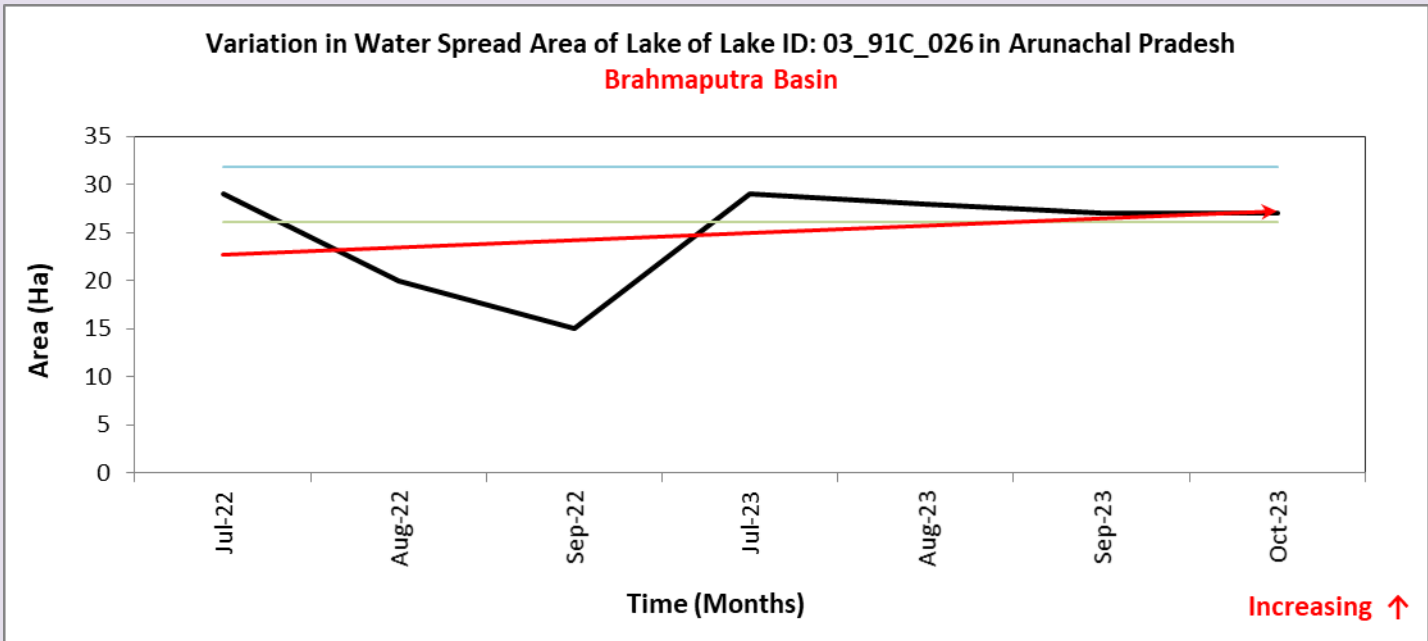


Figure 4.199(ii) Trend Analysis Plot  $\pm 20\%$

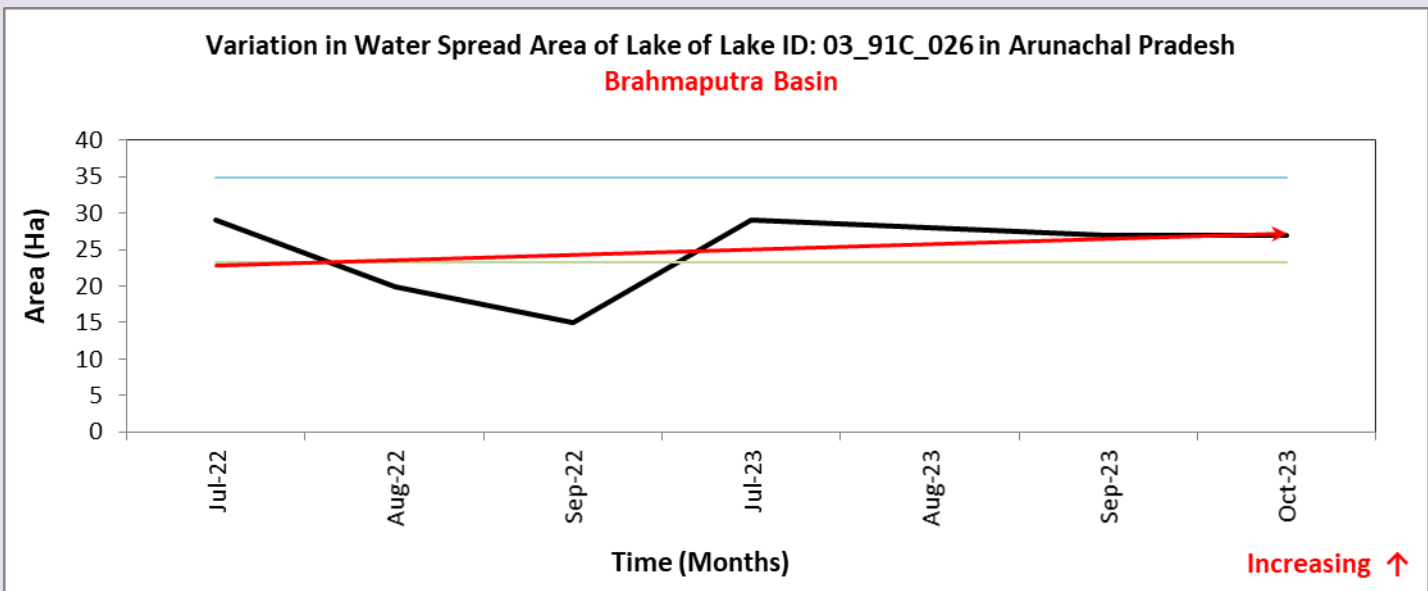


Figure 4.200(i) Trend Analysis Plot  $\pm 10\%$

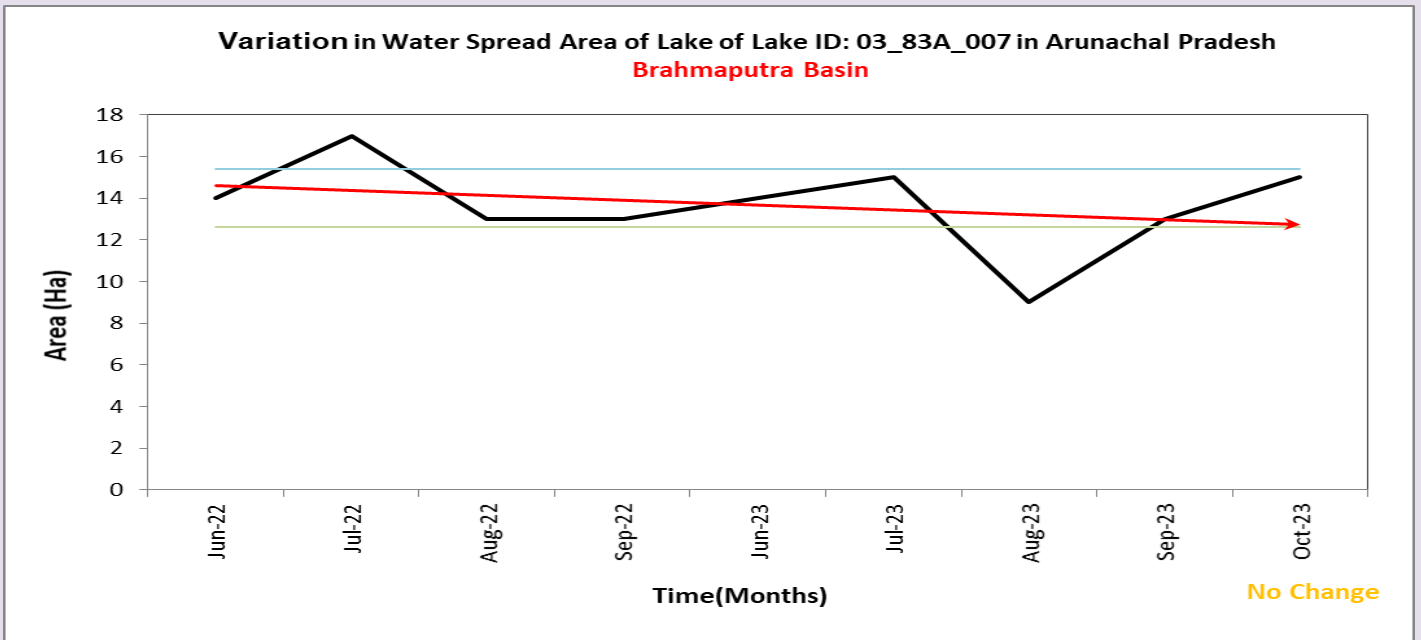


Figure 4.200(ii) Trend Analysis Plot  $\pm 20\%$

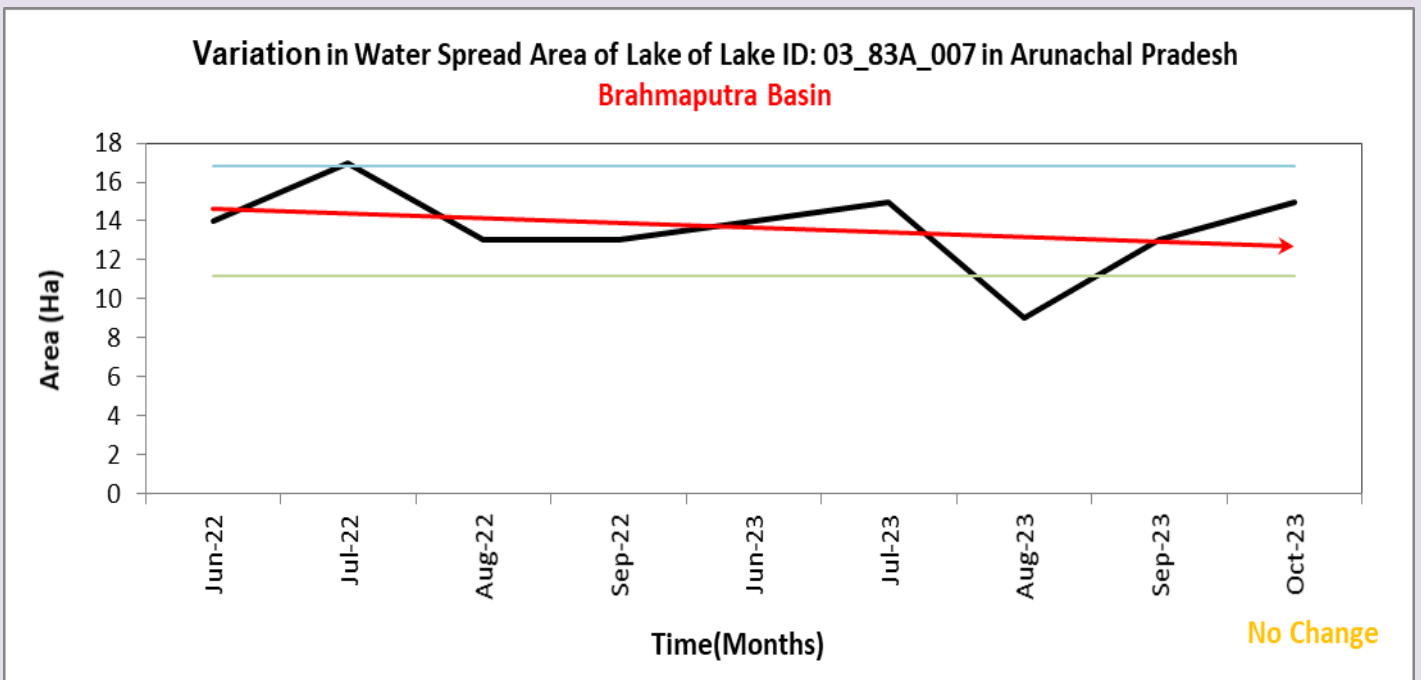


Figure 4.201(i) Trend Analysis Plot  $\pm 10\%$

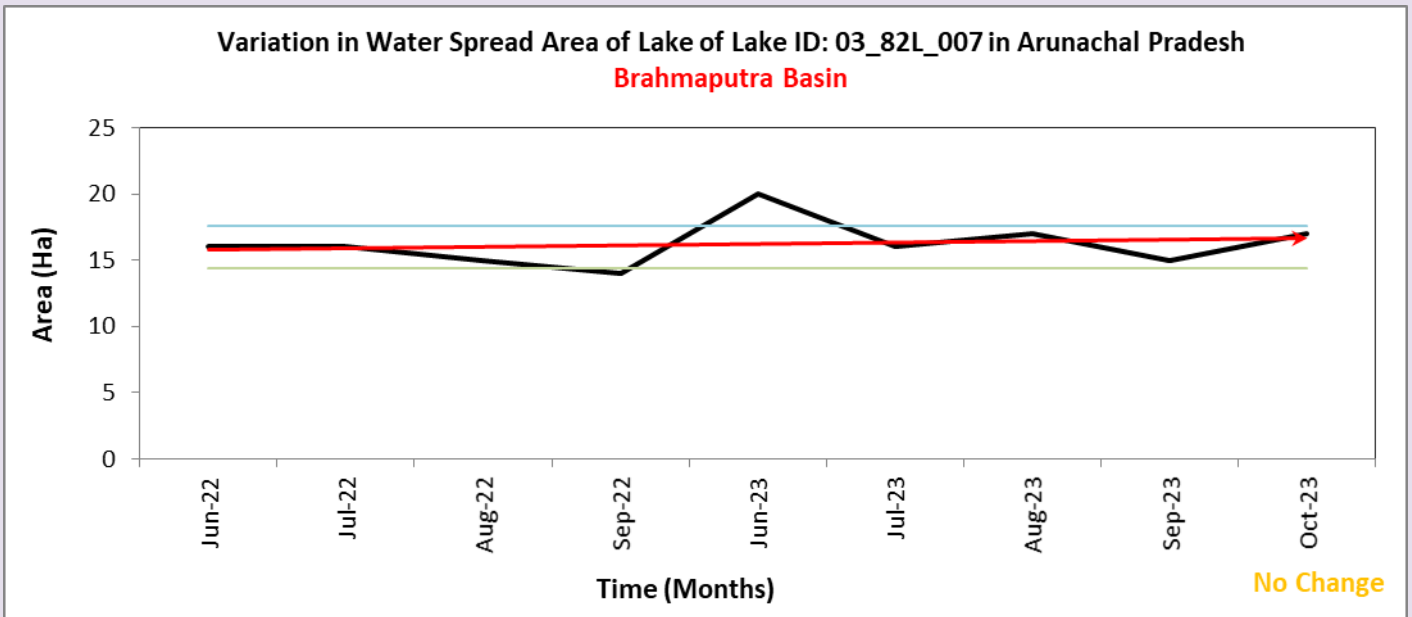
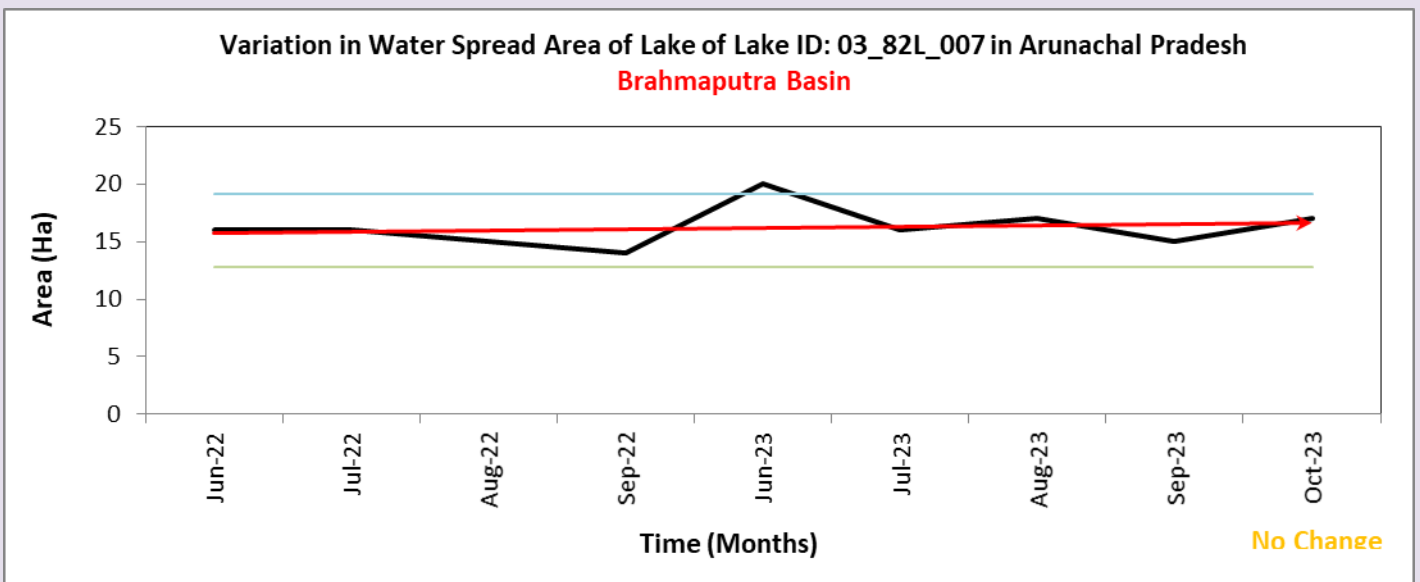
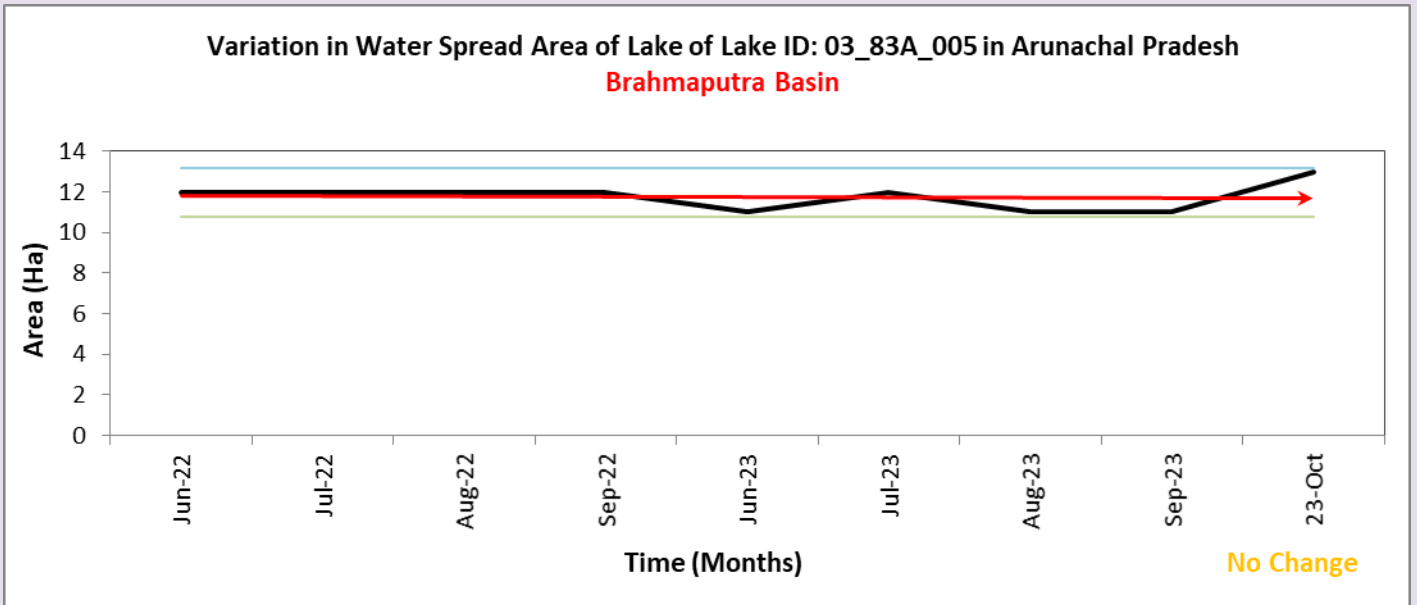


Figure 4.201(ii) Trend Analysis Plot  $\pm 20\%$



**Figure 4.202(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.202(ii)** Trend Analysis Plot  $\pm 20\%$

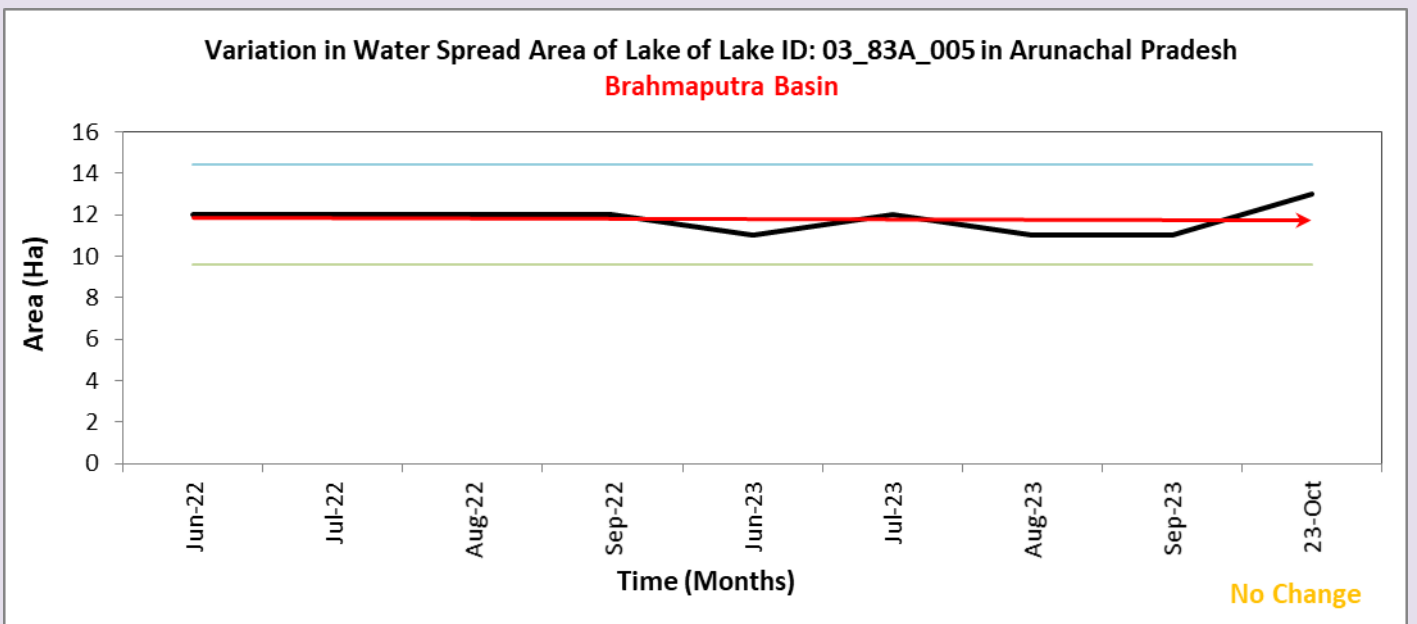


Figure 4.203(i) Trend Analysis Plot  $\pm 10\%$

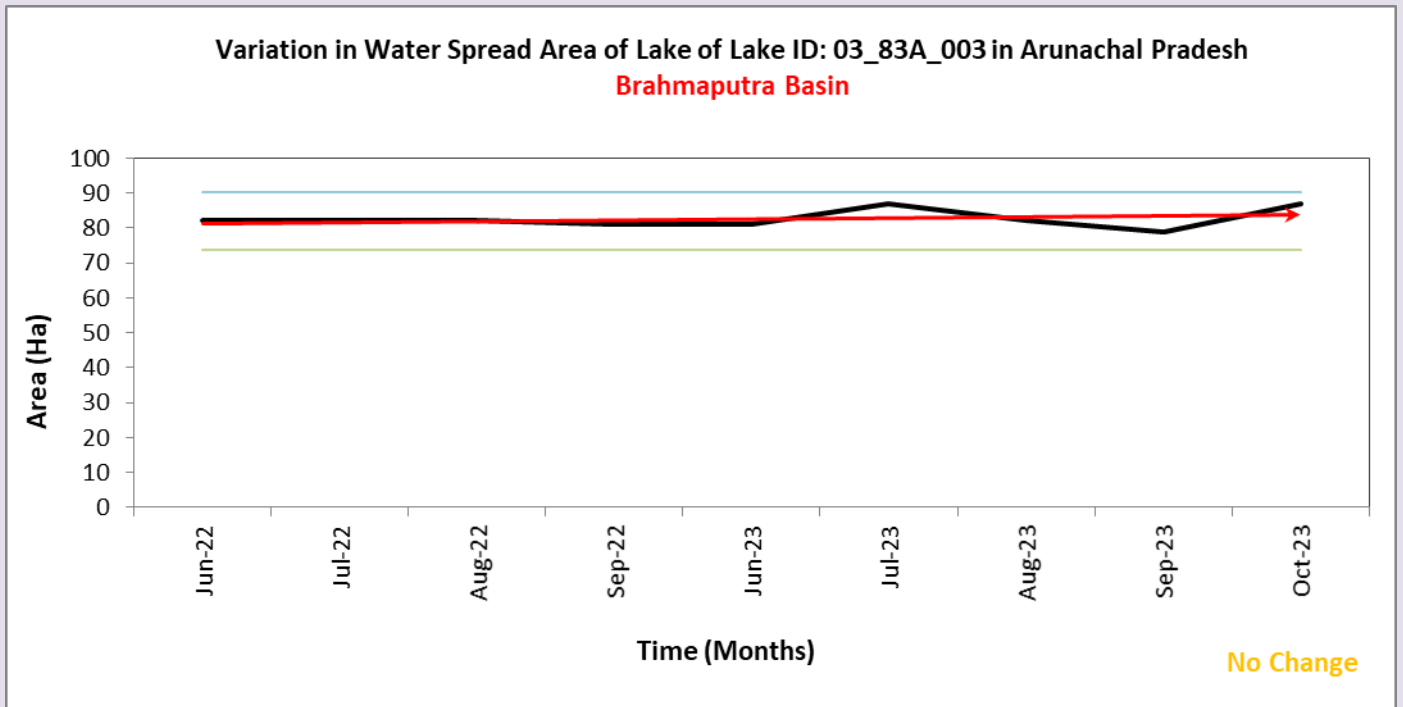
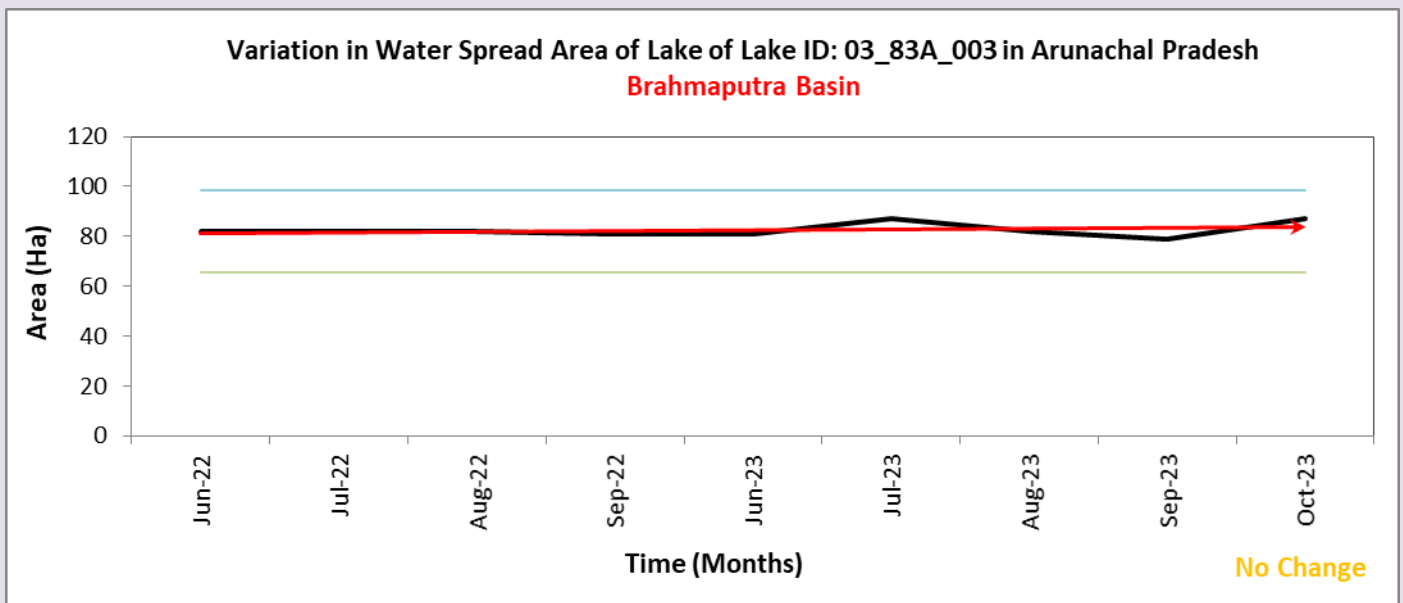
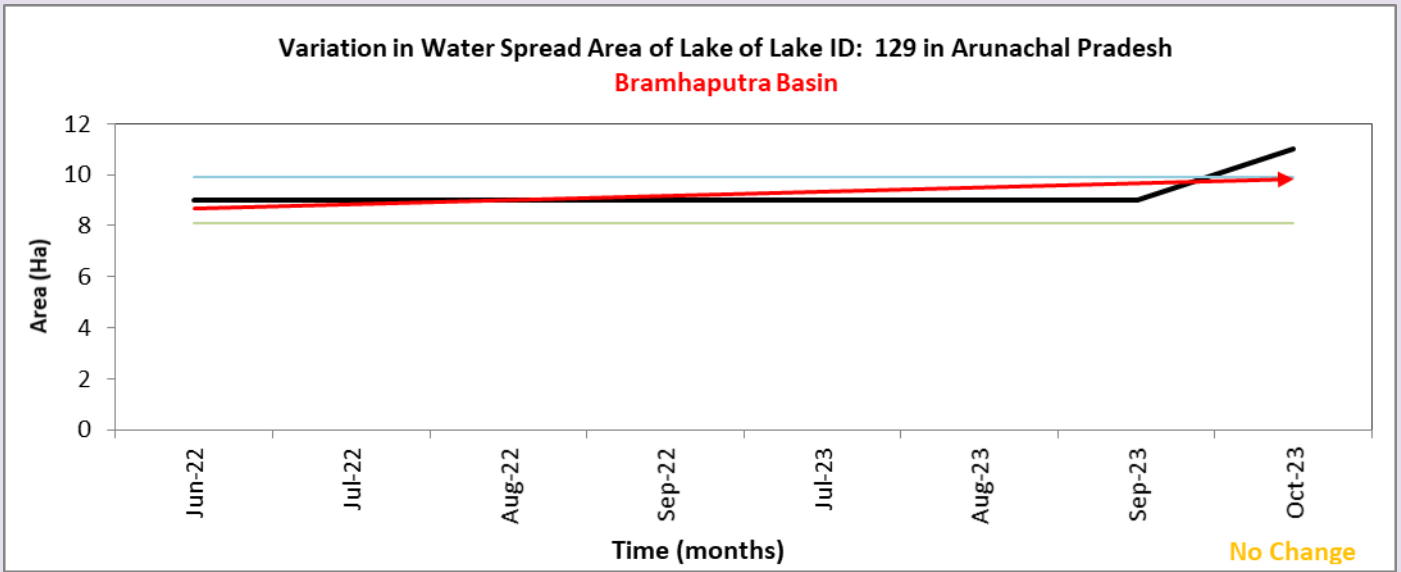


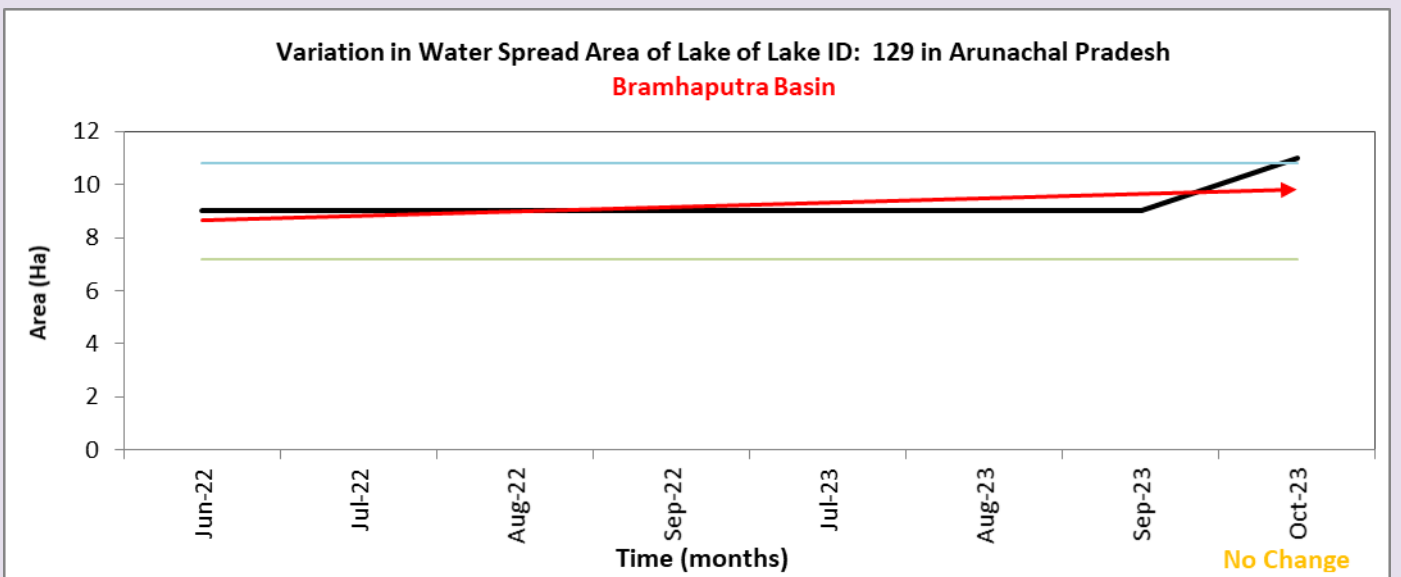
Figure 4.203(ii) Trend Analysis Plot  $\pm 20\%$



**Figure 4.204(i)** Trend Analysis Plot  $\pm 10\%$



**Figure 4.204(ii)** Trend Analysis Plot  $\pm 20\%$



4.7 Abstract of Trend Analysis

Trend Analysis carried out for Change in Waterspread area of 15 GL (>50 Ha) w.r.t. Base year Data 2009

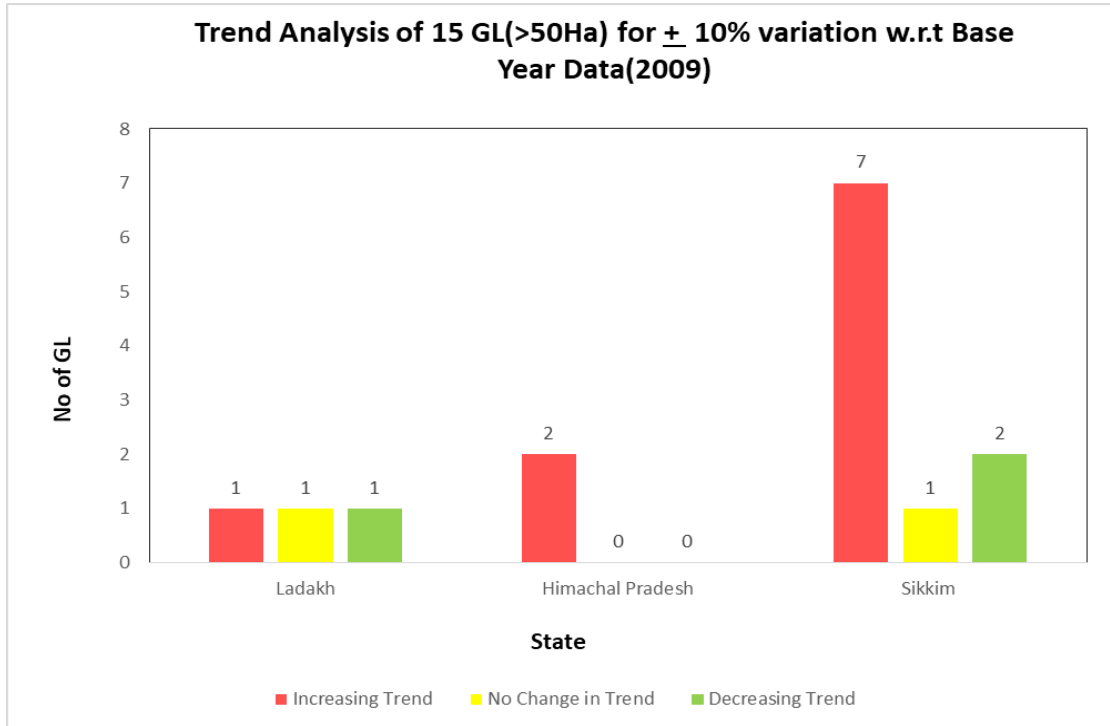


Figure 4.205(i): Trend Analysis carried out for Change in Waterspread area of 15 GL (>50 Ha) w.r.t. Base year Data 2009 for ±10% variation

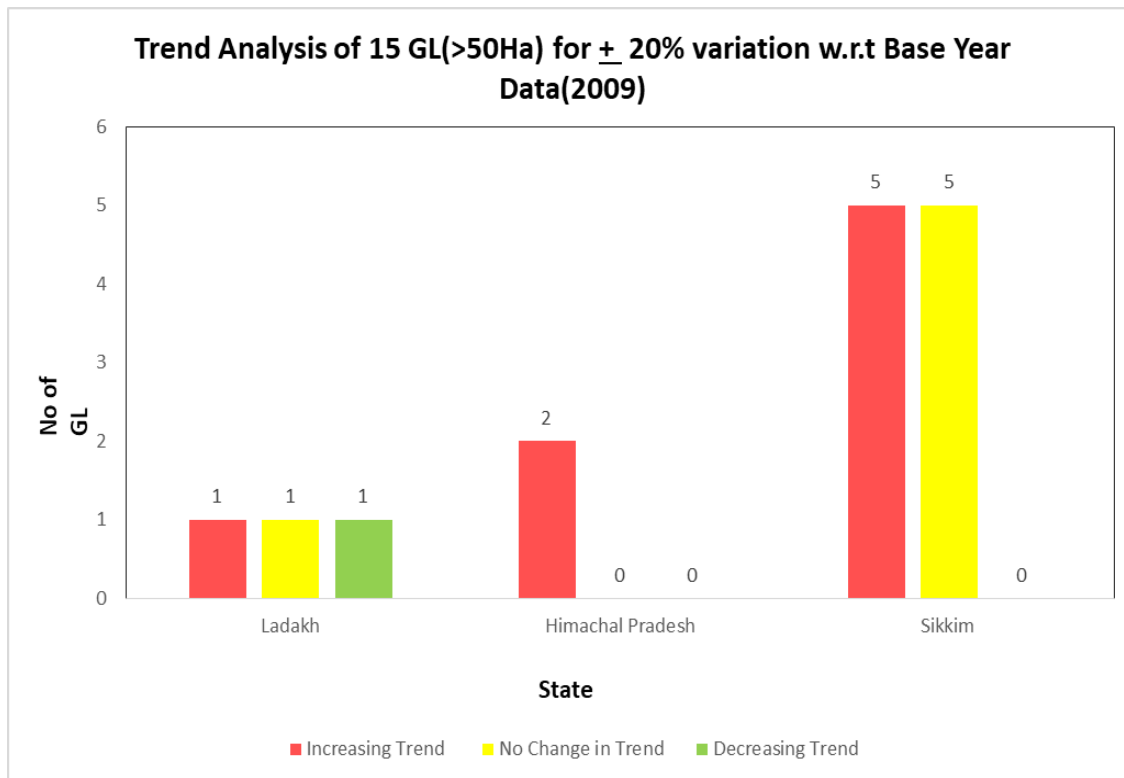


Figure 4.205(ii) Trend Analysis carried out for Change in Waterspread area of 15 GL (>50 Ha) w.r.t. Base year Data 2009 for ±20% variation

Trend Analysis carried out for Change in Waterspread area of 15 GL (>50 Ha) w.r.t. Base year Data 2022

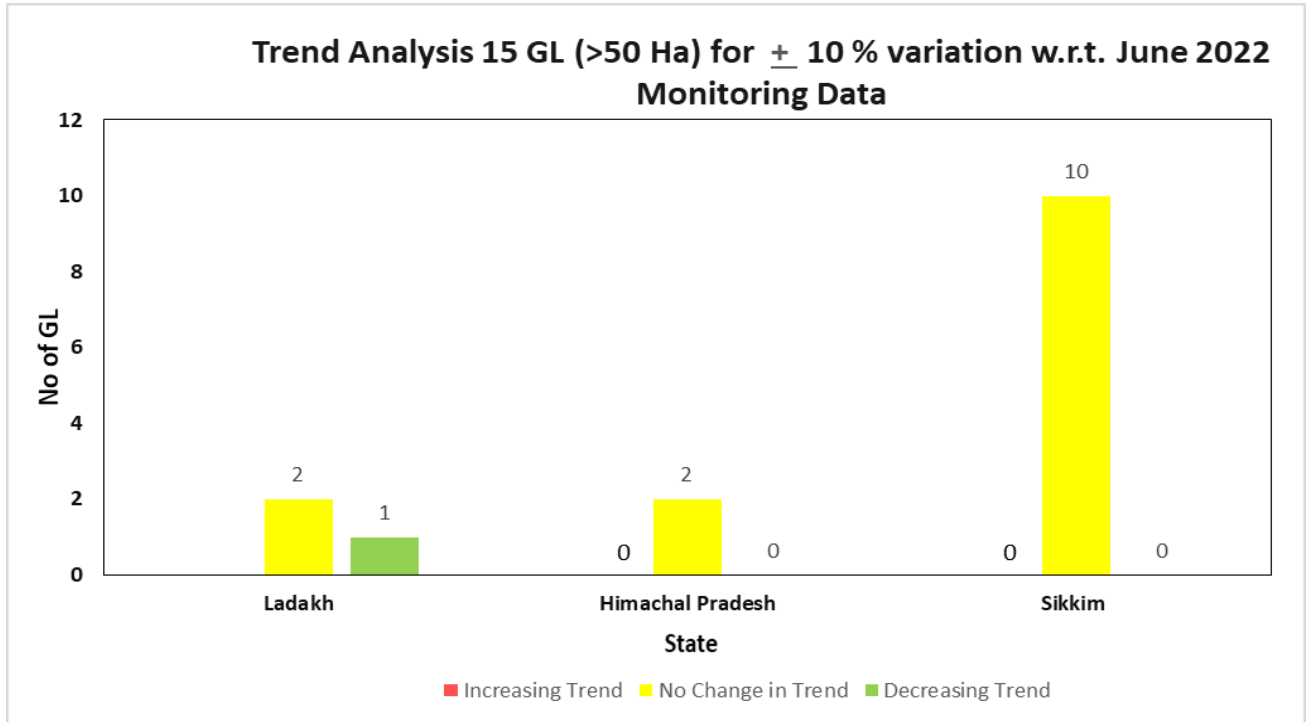


Figure 4.206(i): Trend Analysis carried out for Change in Waterspread area of 15 GL (>50 Ha) w.r.t. Base year Data 2022 for ±10%variation

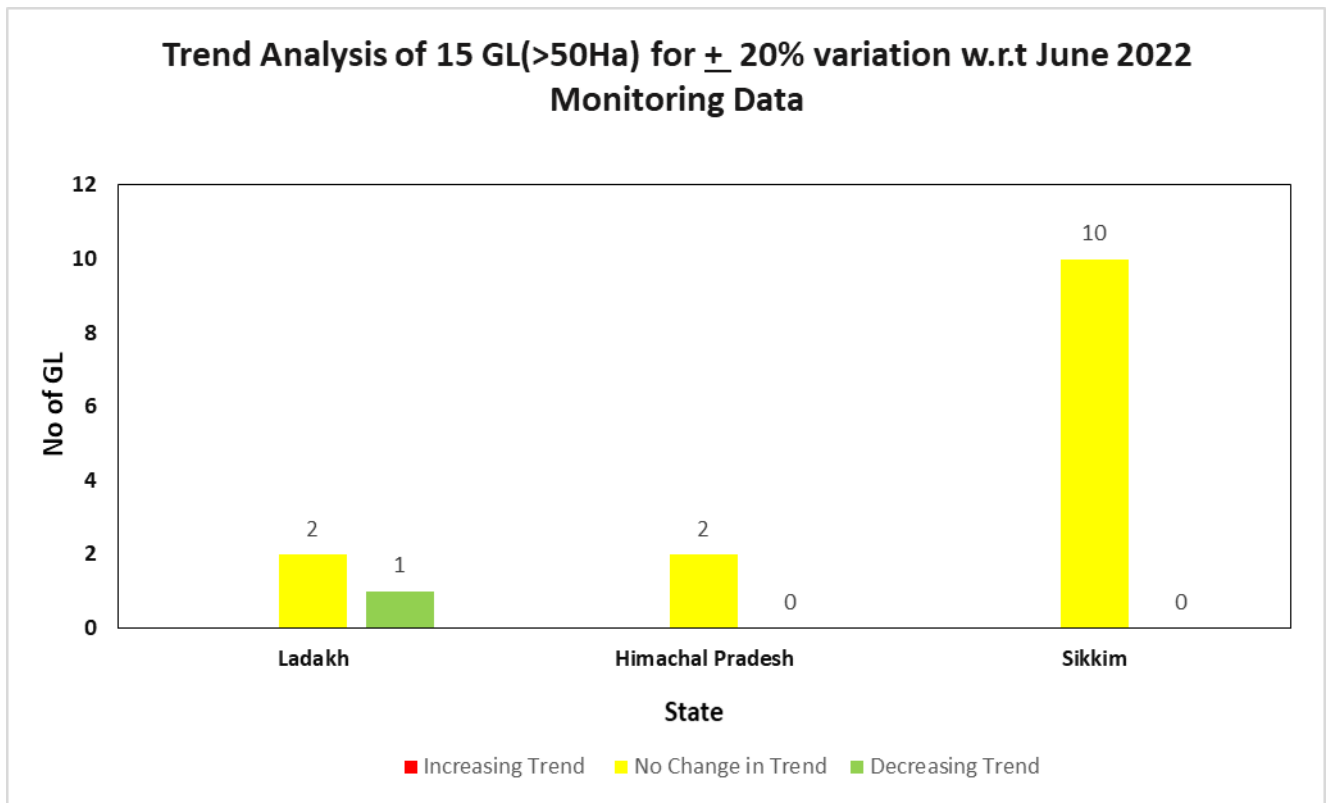


Figure 7.206(ii): Trend Analysis carried out for Change in Waterspread area of 15 GL (>50 Ha) w.r.t. Base year Data 2022 for ±20%variation

Trend Analysis carried out for Change in Waterspread area of 85 GL (10 Ha - 50 Ha) w.r.t. Base Year Data 2011

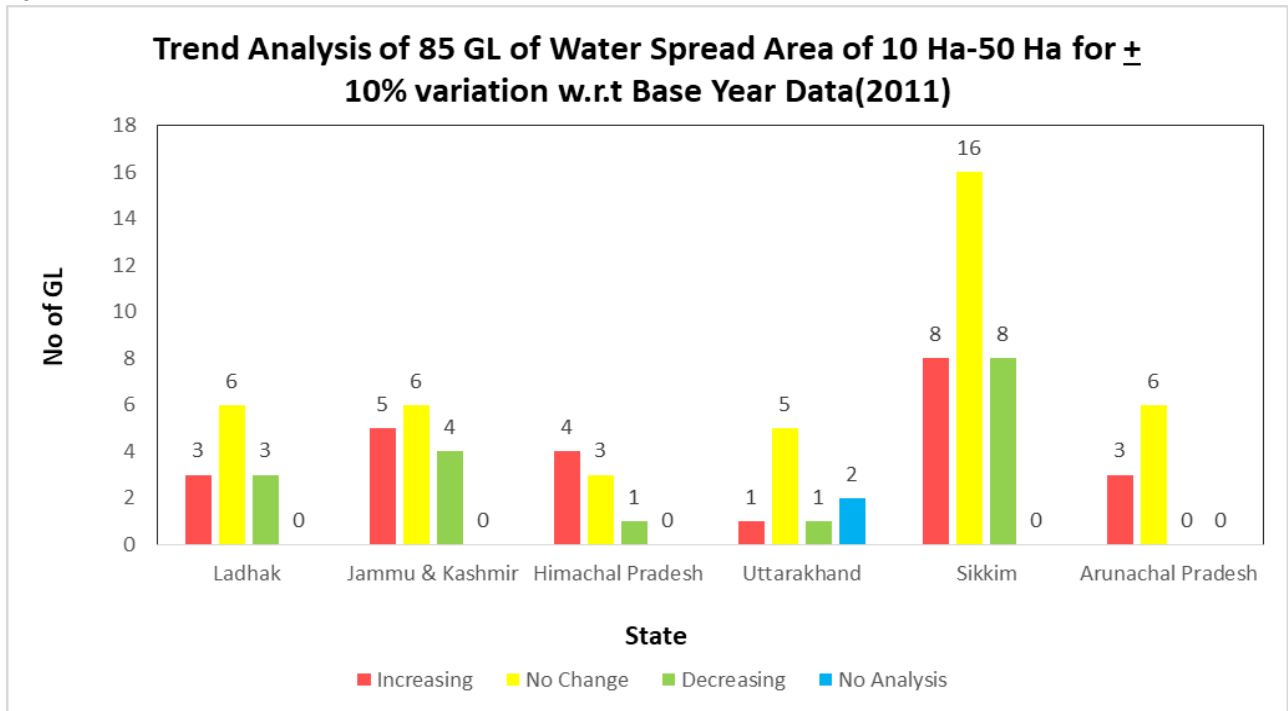


Figure 4.207(i): Trend Analysis carried out for Change in Waterspread area of 85 GL (10-50 Ha) w.r.t. Base year Data 2011 for ±10% variation

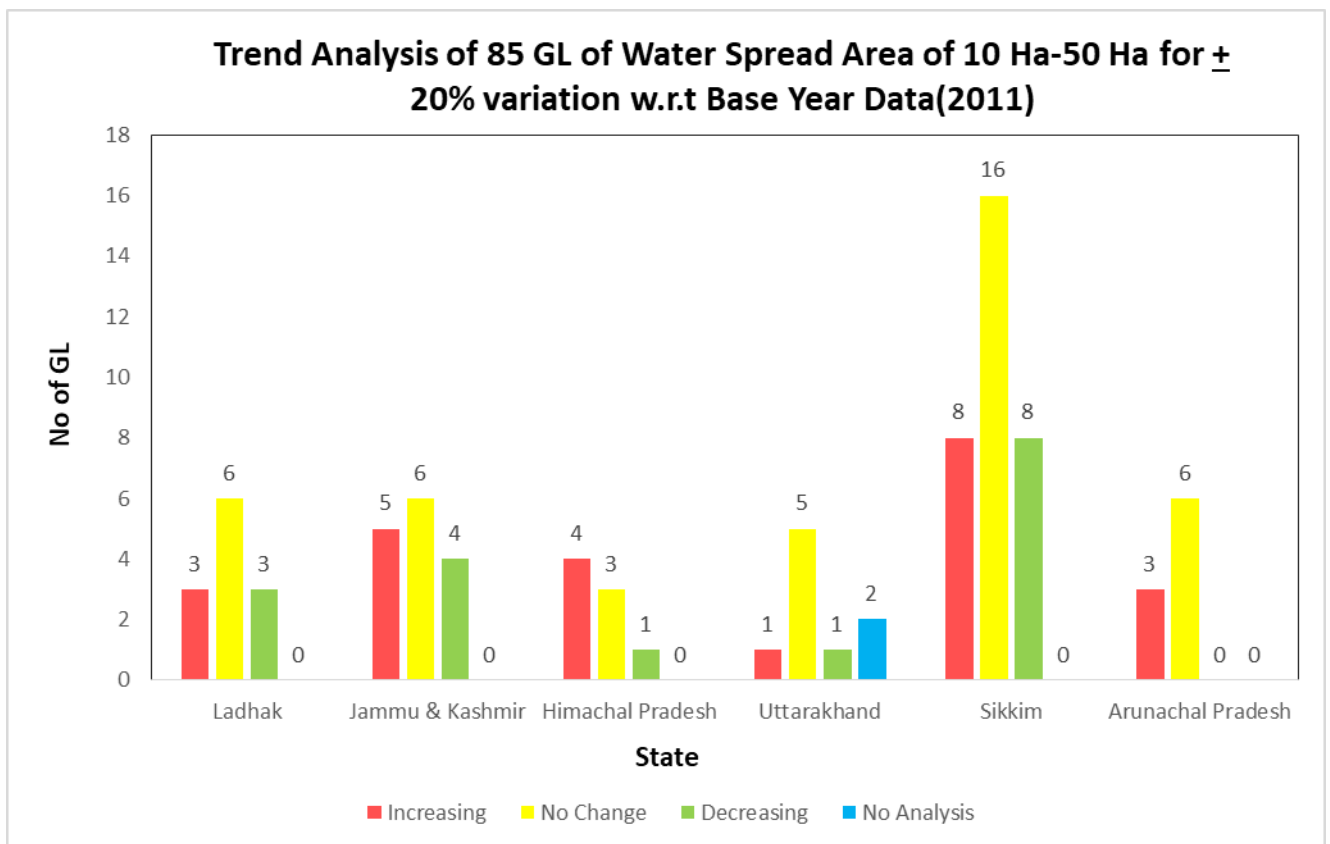


Figure 4.207(ii):: Trend Analysis carried out for Change in Waterspread area of 85 GL (10-50 Ha) w.r.t. Base year Data 2011 for ±20% variation

**Trend Analysis carried out for Change in Waterspread 85 GL (10 Ha - 50 Ha) w.r.t. June 2022 Monitoring Data**

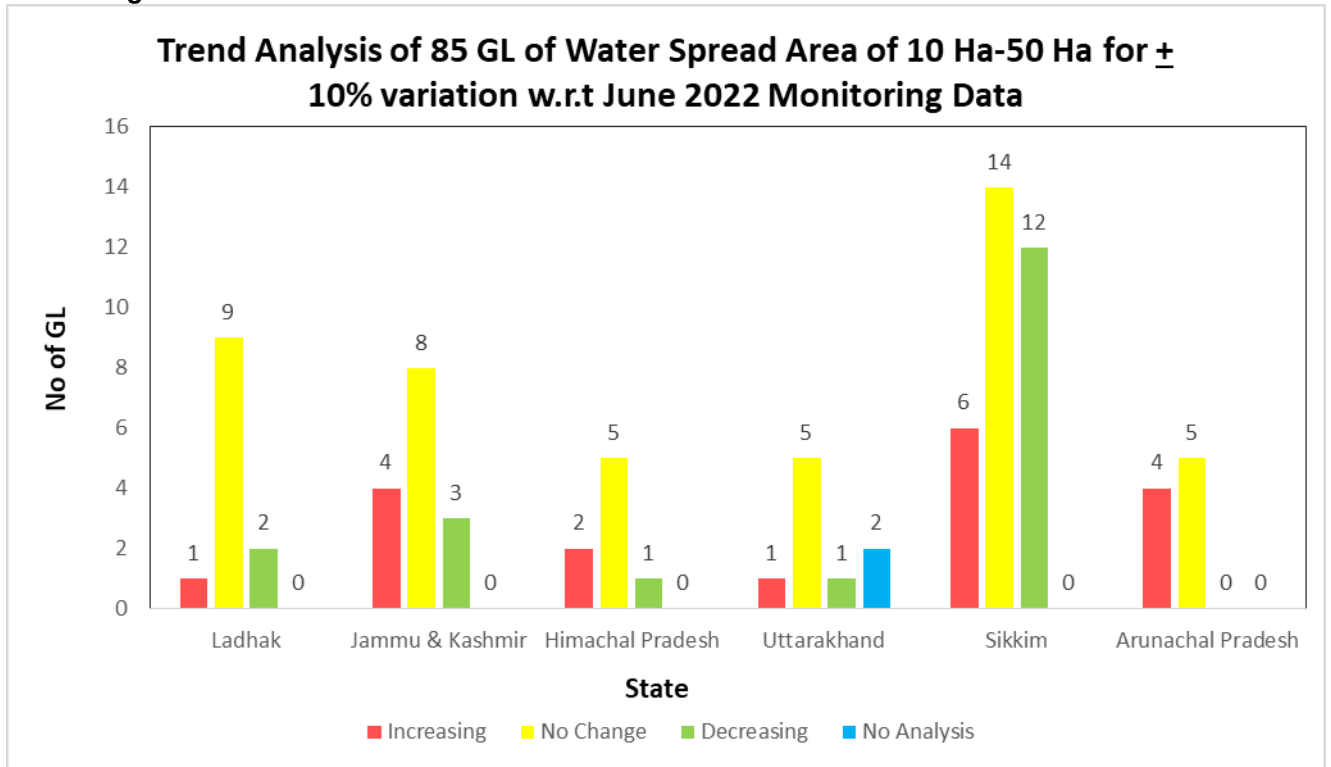


Figure 4.208(i): Trend Analysis carried out for Change in Waterspread area of 85 GL (10-50 Ha) w.r.t. Base year Data 2022 for  $\pm$ 10%variation

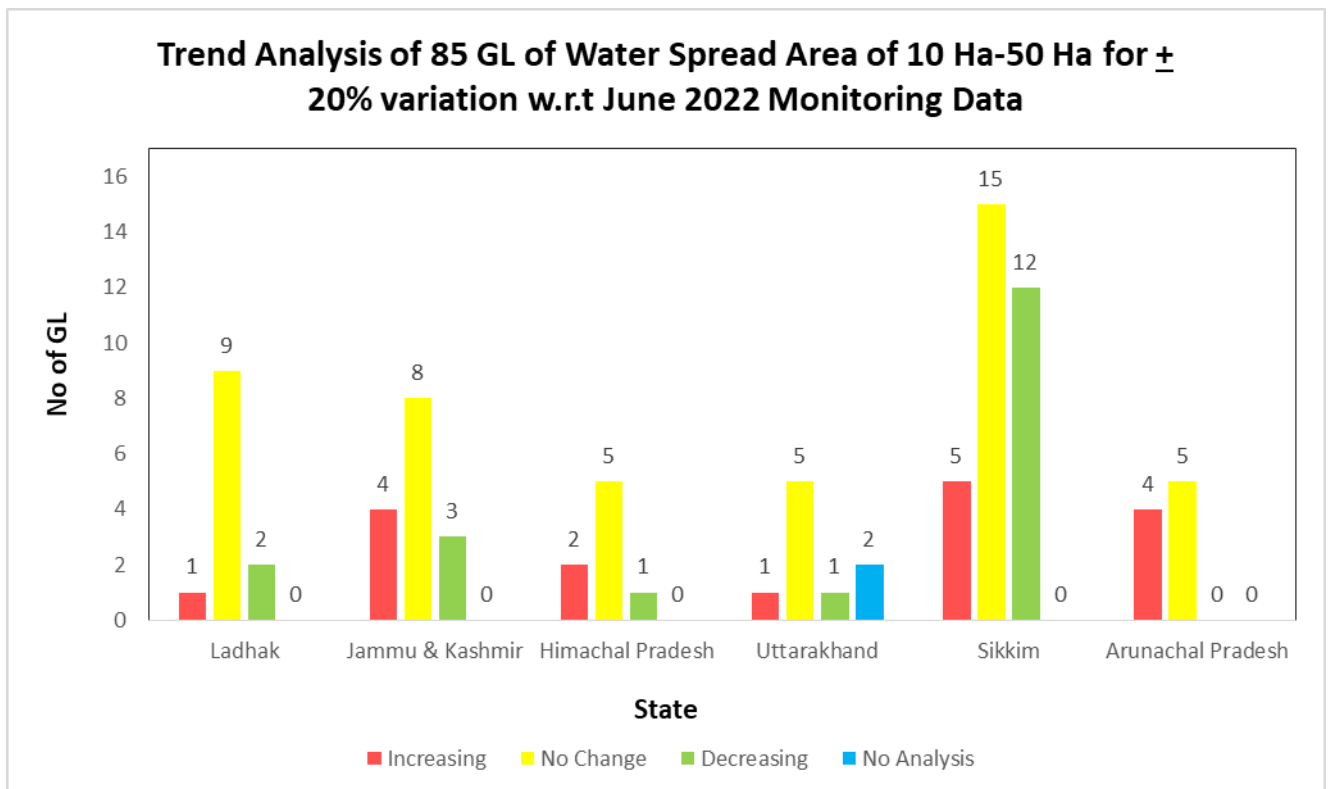


Figure 4.208(ii): Trend Analysis carried out for Change in Waterspread area of 85 GL (10-50 Ha) w.r.t. Base year Data 2022 for  $\pm$ 10%variation

#### 4.8 Conclusion of Trend Analysis

- A total of **10 Glacial lakes** show an increasing trend on carrying out trend analysis on “Change of Water spread area for the period from 2011 to 2023” on Glacial Lakes of size *greater than 50 Ha*, for **±10% variation** w.r.t. base year 2009.
- Only **8 GLs** show increasing trend when the analysis was carried out for **±20% variation**.

State	No of Lakes showing Increasing Trend	
	± 10% Variation	± 20% Variation
Ladakh	1	1
Himachal Pradesh	2	2
Sikkim	7	5
<b>Total</b>	<b>10</b>	<b>8</b>

- No lakes show increasing trend when recent trend analysis was carried out for ±10% and ±20% variation for 2 year period (2022 & 2023).

State	No of Lakes showing Increasing Trend	
	± 10% Variation	± 20% Variation
Ladakh	0	0
Himachal Pradesh	0	0
Sikkim	0	0
<b>Total</b>	<b>0</b>	<b>0</b>

- The lakes showing increasing trend remains the **same (24Nos.)** for **±10% and ±20% variation** for the 85 Glacial Lakes of size *between 10 Ha to 50 Ha* on trend analysis on “Change of Water spread area for the period from 2011 to 2023”.

State	No of Lakes showing Increasing Trend	
	± 10% Variation	± 20% Variation
Ladakh	3	3
Jammu & Kashmir	5	5
Himachal Pradesh	4	4
Uttarakhand	1	1
Sikkim	8	8
Arunachal Pradesh	3	3
<b>Total</b>	<b>24</b>	<b>24</b>

- The lakes showing increasing trend for  $\pm 10\%$  is **18 Nos.** and  $\pm 20\%$  variation is **17 Nos.**, on carrying out trend analysis for the 85 Glacial Lakes of size between 10 Ha to 50 Ha for 2 year period (2022 & 2023).

State	No of Lakes showing Increasing Trend	
	$\pm 10\%$ Variation	$\pm 20\%$ Variation
Ladakh	1	1
Jammu & Kashmir	4	4
Himachal Pradesh	2	2
Uttarakhand	1	1
Sikkim	6	5
Arunachal Pradesh	4	4
<b>Total</b>	<b>18</b>	<b>17</b>

- The trend analysis has been done for the period of “2011-2023” and “2022-2023” to depict the long term and recent trend of the lakes respectively.

Sl. No.	Trend Analysis carried out for Change in Water spread area of	Lakes showing Increasing Trend		Lakes showing No Change Trend		Lakes showing Decreasing Trend		Lakes with No Analysis	Total no. of Lakes
		$\pm 10\%$ Variation	$\pm 20\%$ Variation	$\pm 10\%$ Variation	$\pm 20\%$ Variation	$\pm 10\%$ Variation	$\pm 20\%$ Variation		
1	15 GL (>50 Ha) w.r.t. Base year Data 2009 (Long Term)	10	8	2	6	3	1	0	15
2	15 GL (>50 Ha) w.r.t. June 2022 Monitoring Data (Recent)	0	0	14	14	1	1	0	15
3	85 GL (10 Ha - 50 Ha) w.r.t. Base year Data 2011 (Long Term)	24	24	42	42	17	17	2	85
4	85 GL (10 Ha - 50 Ha) w.r.t. June 2022 Monitoring Data (Recent)	18	17	46	47	19	19	2	85

- From the above table, it is observed that the number of increasing lakes under  $\pm 10\%$  and  $\pm 20\%$  are more or less the same, which indicates that the Glacial Lakes showing increasing trend has increased more than 20% with reference to baseline data.
- Almost 50% of larger lakes (size >50 Ha) has increase more than 20% whereas 28% of the medium sized lakes (size 10-50 Ha) have increase more than 20%. The interpretation of trend line of individual lakes shows that the medium sized lakes are increasing at a faster pace than larger lakes.
- If we observe the larger lakes, it is seen that none of the larger lakes have shown increase more than 20% in the recent term, whereas about 20% of the medium sized lakes shown increase more than 20% in recent years.

## Section-II

Mapping of Projects & CWC HO stations  
enroute flow path of 100 GLs within India

## **5. Mapping of anticipated GLOF (Glacial Lake Outburst Flood) Damage centres of Glacial Lakes located in India**

### **5.1 Introduction**

A glacial lake outburst flood (GLOF) is a type of catastrophic flood that occurs when the dam containing a glacial lake fails, releasing a large volume of water. These floods can be triggered by a number of factors, including changes in the volume of the parent glacier, changes in the water level of the lake due to heavy precipitation or the inflow of meltwater, and earthquakes, landslides, avalanches, earthquakes etc.

### **5.2 Impacts of GLOF**

GLOF can have devastating impacts on population and livestock, infrastructure, agriculture, environment etc. GLOF are deadly events which cause loss of life for those living in the affected area as there is not enough time to evacuate or prepare for the flood. The high volume and force of water released during a GLOF causes significant damage to infrastructure such as roads, bridges, buildings, and power plants. This leads to severe economic losses and long term disruption of essential services. GLOF also cause damage to agricultural land, crops and livestock leading to food shortages and loss of income for farmers. These also have long-term effects on the local economy and pose challenges to food security. GLOF causes heavy destruction of biodiversity in the areas of its occurrence with large scale loss of flora and fauna.

### **5.3 Delineation of Flow Path of Glacial Lake**

Flowpath is the path followed by the spill of a Glacial Lake in the event of GLOF. In normal scenario, the outflow of the glacial lake having an outlet also follows the flowpath.

Flowpath can be delineated either manually from toposheets, or automatically from a digital elevation model (DEM) data in softwares like ArcGIS etc. Both the methods have their own advantages and disadvantages. Manual delineation is a tedious process requiring lot of time and effort. It is also difficult to completely rely on the automatic delineation without identifying the drainage areas of the watershed manually. The understanding of the geomorphology of the study area, the examination of the pit-filling data and the use of available stream network data are essential to accurately delineate any watershed using automatic delineation procedure.

### **5.4 Methodology for Delineation of Flow Path of Glacial Lake**

The delineation of flow path was carried out partially by manual digitization in Google Earth and then connected to an available river network layer.

The river network of India prepared by National Water Information Centre (NWIC), New Delhi, was adopted as the base layer. But in most of the cases it was not connected upto the glacial lakes under consideration. Hence, it was required to manually digitize the 1<sup>st</sup> and 2<sup>nd</sup> order streams and connect them with the base layer. This was done in Google Earth.

The Glacial Lakes were identified in Google Earth. The outlet of each Glacial Lake was identified manually by comparing the elevation of the pixels surrounding the lake boundary. Then, first order streams originating from the outlet of each lake was digitized. This required images of multiple years for different seasons as the water and land area remains snow covered in many images.

### 5.5 Mapping of Damage Center

Glacial lake outburst flood pose high risk to downstream communities, infrastructure Projects, etc. Hence it is required to identify damage centers. Damage center include habitation, roads, highways, bridges, tunnels, dams and power plants etc. along/enroute of flowpath of glacial lakes. Mapping of damage center seek importance as it forms one of the basic information for installation of early warning systems, evacuation of communities in the event of GLOF, preparation of flood inundation maps, etc.

State-wise mapped features are listed below

(i) After trend analysis on water spread area of Glacial Lakes (100 Nos.) for  $\pm 10\%$  variation w.r.t base year 2009/2011, they have been classified into four categories

- Glacial Lakes exhibiting increasing trend
- Glacial Lakes exhibiting no change trend
- Glacial Lakes exhibiting decreasing trend
- Glacial Lakes not analyzed

These lakes have been mapped using different colours for better interpretation.

(ii) The flowpath of Glacial Lakes from the outlet to the main rivers were mapped.

(iii) The primary damage center, dams, have been mapped along each flowpath.

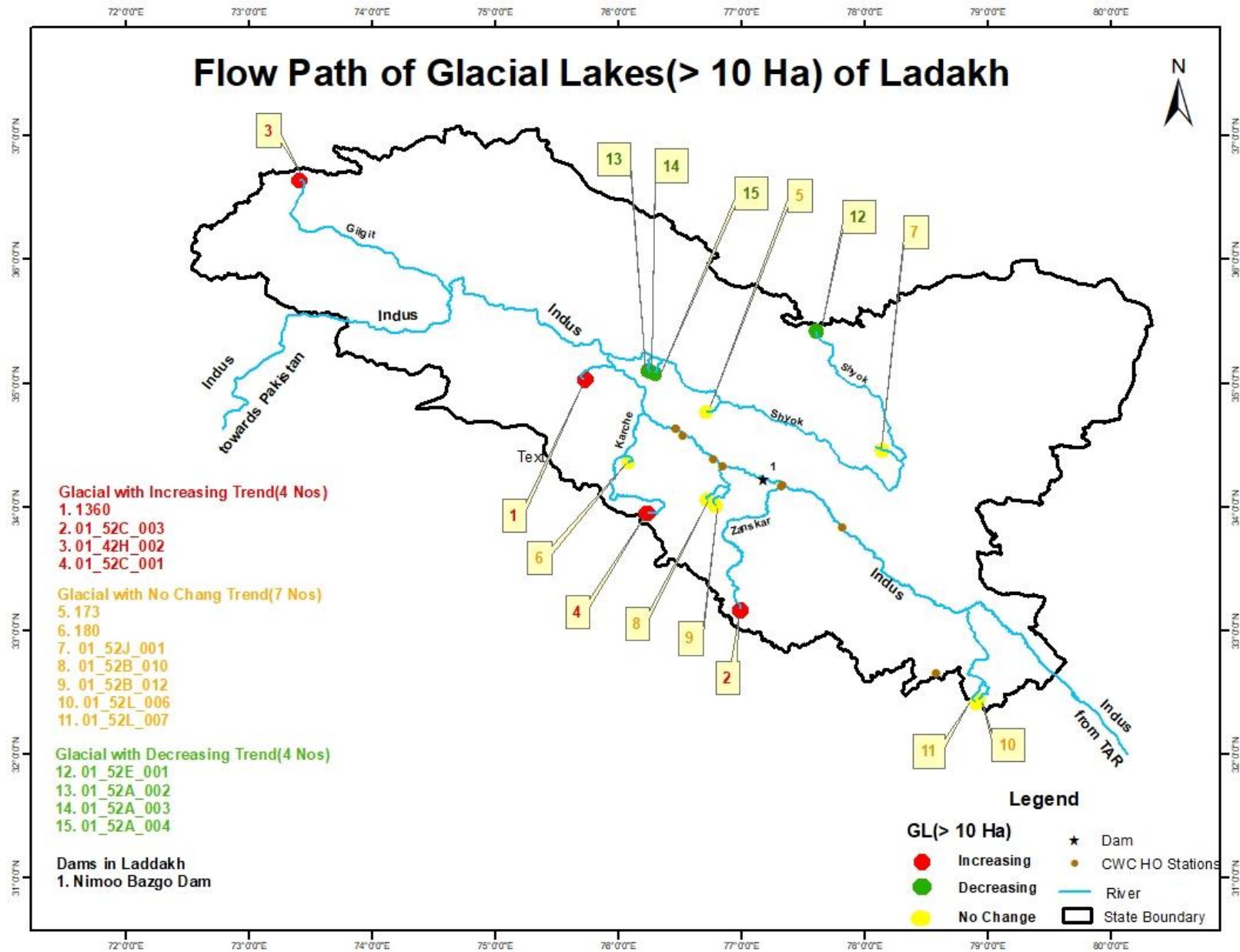
(iv) Finally, the CWC Hydrological Observation Stations have also been mapped.

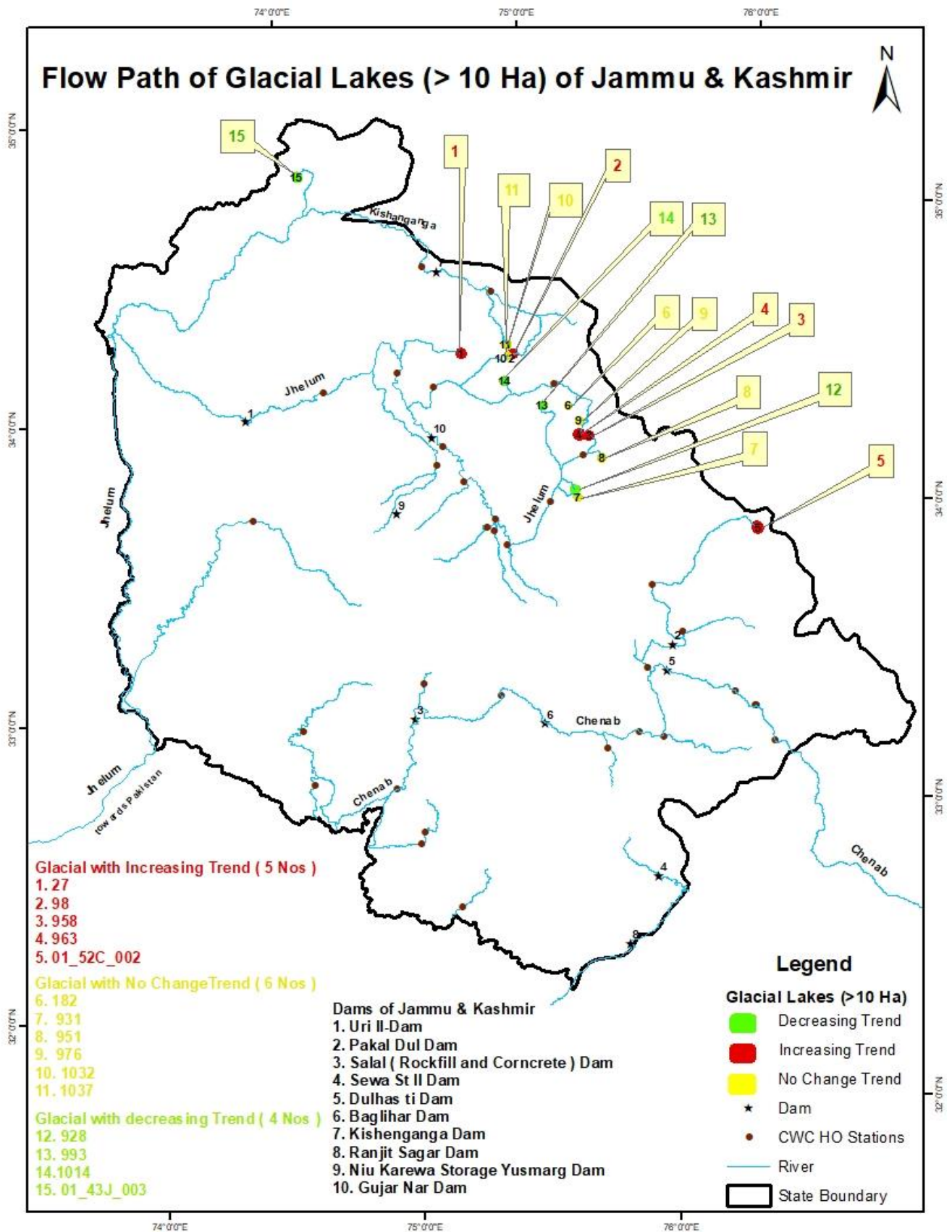
### 5.6 Usefulness of Mapping of Damage Center

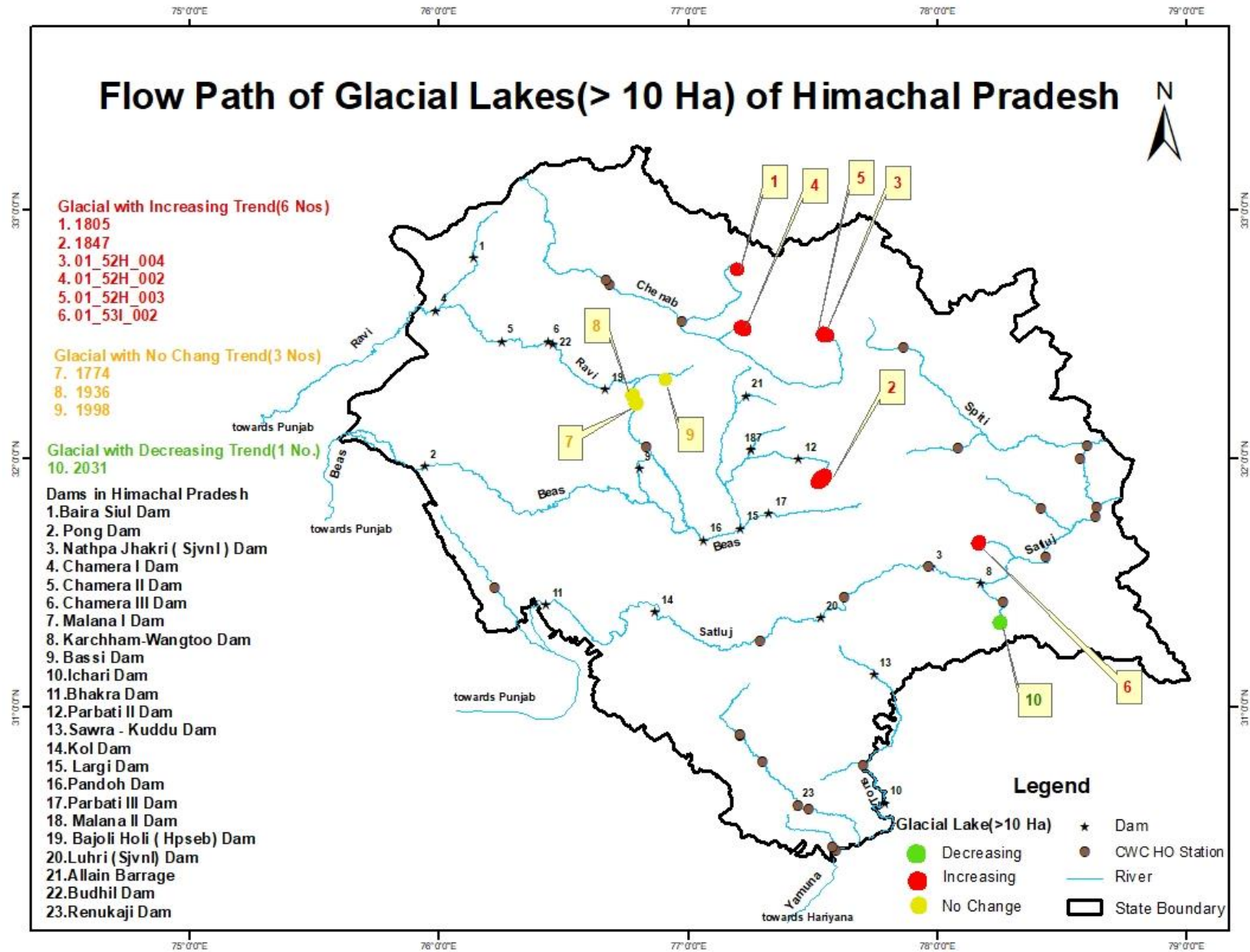
These maps will be quiet handy for

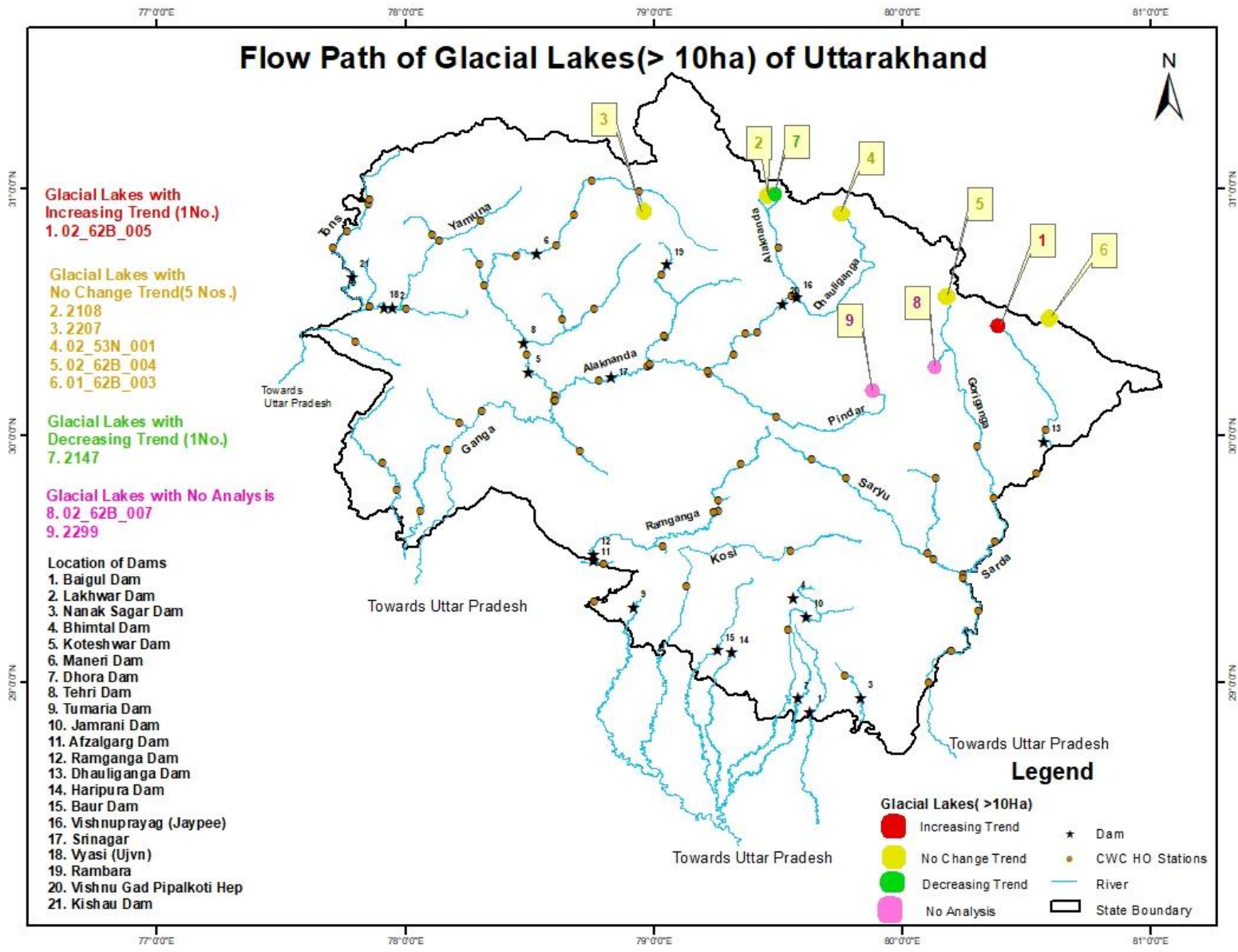
- (i) GLOF Preparedness
- (ii) GLOF Dam Break Analysis
- (iii) Risk assessment in the event of GLOF
- (iv) Installation of Early Warning System
- (v) Planning of Mitigation Measures

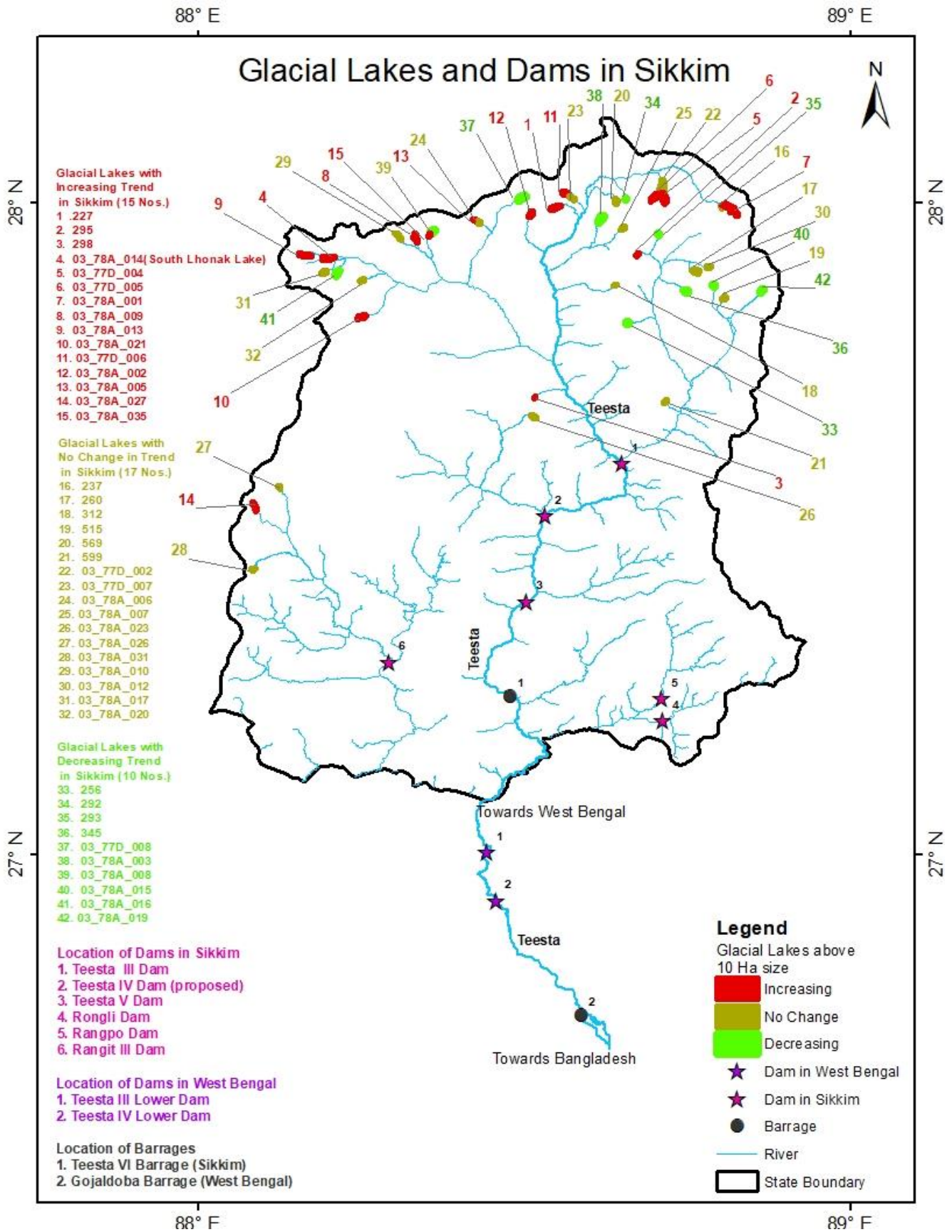
Further mapping of settlements, various infrastructures are in progress.

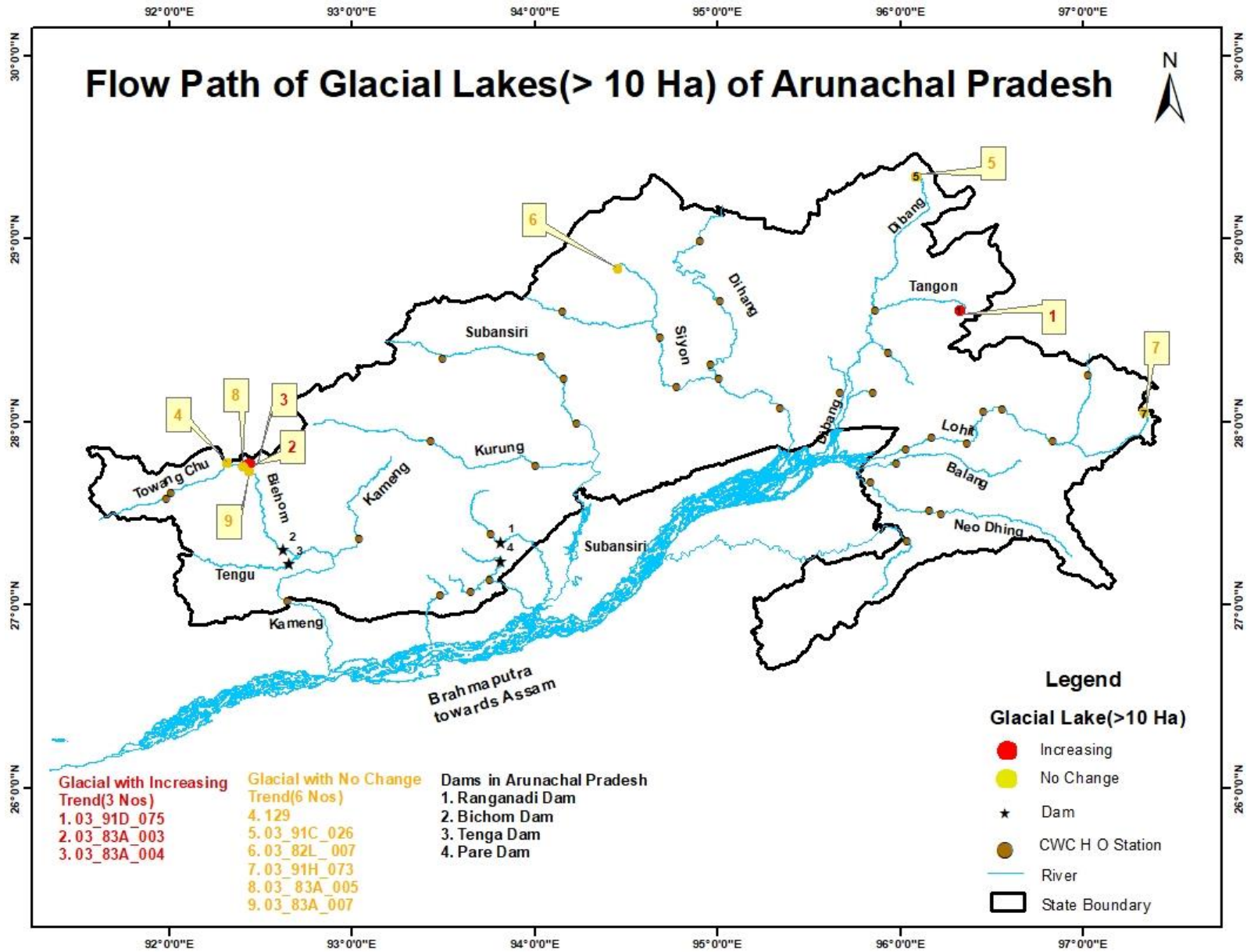












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# Central Water Commission



## Criteria for Risk Indexing of Glacial Lakes in Indian Himalayan Region



September-2024

अध्यक्ष, केंद्रीय जल आयोग एवं  
पदेन सचिव, भारत सरकार



Chairman, Central Water  
Commission & Ex-officio Secretary  
to Government of India

सेवा भवन, नई दिल्ली-110066

Sewa Bhawan, New Delhi-110066

## Foreword

As glaciers retreat, the lakes they leave behind grow larger, while the unstable moraine dams that hold them in place remain vulnerable to collapse. This poses a significant threat for downstream communities and ecosystems, where a sudden breach could result in catastrophic flooding. The Indian Himalayan region, with its densely populated valleys and crucial infrastructure, faces unique risks from these outbursts, making it vital to prioritize mitigation efforts and disaster preparedness. The need for "Criteria for Risk Indexing of Glacial Lakes in Indian Himalayan Region" arises from the increasing threat posed by Glacial Lake Outburst Floods (GLOFs), a consequence of climate change accelerating the melting of glaciers and expanding Glacial Lakes.



Different agencies have adopted various approaches to identify critical Glacial Lakes. There is a need to establish a common set of criteria for identifying these critical Glacial Lakes. In response, CWC has taken the initiative to bring together agencies such as National Remote Sensing Center (NRSC), Centre for Development of Advanced Computing (C-DAC), Defence Geoinformatics Research Establishment (DGRE), India Meteorological Department (IMD), Central Water and Power Research Station (CWPRS), Central Soil and Materials Research Station (CSMRS), Geological Survey of India (GSI), National Dam Safety Authority (NDSA), Wadia Institute of Himalayan Geology (WIHG), Central Electricity Authority of India (CEA), National Institute of Hydrology (NIH), National Disaster Management Authority (NDMA) and State Disaster Management Authority (SDMA) to collaborate on developing a unified framework for rapid risk assessment in the Indian Himalayan region.

The criteria for Risk Indexing of Glacial Lakes offer a structured approach to identifying and ranking Glacial Lakes based on their likelihood of failure and the potential damage they could cause. By evaluating key factors such as the Glacial Lake's Size, Change in Size of GL, Stability of Side Slope, Proximity to other Glacial Lakes as well as considering Downstream vulnerabilities like Habitation, Infrastructures like Dams, Bridges etc, Authorities can allocate resources efficiently for Monitoring, Early Warning Systems (EWS), and Mitigation measures. This method enhances decision-making and provide a guideline to allocate resources where they are most needed, reducing the overall risk of GLOF-related disasters in the region. I hope that use of this unified risk index by all agencies shall help in GLOF mitigation efforts in a long way.

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## Preface

The Himalayan Mountain region, often referred to as the "third pole," is home to a vast number of glaciers and Glacial Lakes. One significant concern in this region is the rapid accumulation of water in Glacial Lakes, particularly in those situated near retreating glaciers. When this happens, there is a higher risk of the unstable moraine dams that contain these lakes suddenly breaching. Such breaches can result in extremely high flood known as Glacial Lake Outburst Flood (GLOF), which can have devastating consequences for the areas downstream. Understanding these Glacial Lakes is therefore crucial for effective disaster risk management, as well as for assessing the impacts of climate change.



This criteria for Risk indexing is designed to provide a comprehensive methodology for identifying and categorizing Glacial Lakes based on factors such as Glacial Lake size, Glacial Lake type, Side slope, Snout distance from GL etc and the potential socio-economic impacts of an outburst. By developing this method, we aim to support policymakers, disaster management agencies, and scientists in their efforts to safeguard both lives and livelihoods. The purpose of this document is to facilitate informed decision-making and strategic planning in the face of a growing environmental challenge, ensuring that mitigation efforts are directed toward the most risky lakes within the Indian Himalayas regions.

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## Acknowledgement

Advent of an appropriate Criteria for Risk Indexing of Glacial Lakes has been an issue requiring not only broad basing the diverse and interdisciplinary input but also on boarding practical consideration in respect of monitorable destabilising factors. Accordingly efforts in this direction were initiated to assimilate views of various stockholders while also not losing the sight of present day limitation posed due to reasons of such Glacial Lakes being placed in inhospitable, high altitude remote location.



The Criteria for Risk Indexing of Glacial Lakes in Indian Himalayan Region has been arrived through the collaborative efforts of multiple agencies. Valuable Suggestions from organizations such as the National Remote Sensing Centre, Centre for Development of Advanced Computing Defence Geoinformatics Research Establishment, India Meteorological Department, Central Water and Power Research Station, Central Soil and Materials Research Station, Geological Survey of India, National Dam Safety Authority, Wadia Institute of Himalayan Geology, Central Electricity Authority of India, National Institute of Hydrology, National Disaster Management Authority and State Disaster Management Authority of Arunachal Pradesh, Himachal Pradesh, Jammu and Kashmir, Ladakh, Sikkim, Uttarakhand were helpful in formulation of criteria of Risk Indexing. A common set of criteria has now been formulated with the support of all the involved agencies, and their active participation is highly acknowledged and greatly appreciated.

The project team gratefully acknowledges the profuse guidance and continuous encouragement provided by Shri Kushvinder Vohra, Chairman, Central Water Commission & Ex-officio Secretary to the Government of India and Shri Ashok S. Goel, Member (River Management), Central Water Commission & Ex-officio Additional Secretary to Government of India. Shri Vishnu Deo Roy, in his earlier capacity as Director, Morphology & Climate Change Dte, CWC has been a key contributor of various ideas and concepts which crystalized in shape of these criteria. Furthermore, the valuable suggestions from Shri Sameer Kumar Shukla, Director, CWC, greatly enhanced the document. These contributions are sincerely appreciated.

We also extend our sincere thanks to our project team Shri Piyush Kumar, Director, Shri Piyush Kumar, Deputy Director; and Shri Rohit Kumar Yadav, Assistant Director, CWC, for their creative thinking with continuous effort. The team also expresses heartfelt gratitude to the colleagues of the Morphology & Climate Change Directorate for their cooperation and assistance.

**(D.P. Mathuria)**

## Table of Contents

Executive Summary .....	7
1.0 Introduction:.....	8
1.1 Glacial Lake Outburst Floods (GLOFs): .....	8
1.2 Importance of Risk Indexing: .....	9
1.3 Factors for Risk Assessment of Glacial Lake:.....	9
2.0 Criteria for Risk assessment through indexing.....	12
2.1 Background:.....	12
2.2. Measurable factors and their priority:.....	14
2.2.1 Size of Glacial Lake: .....	14
2.2.2 Type of Glacial Lake: .....	15
2.2.3 Change in Size of Glacial Lake: .....	15
2.2.4 Stability of Glacial Lake side slope (surrounding topography): .....	15
2.2.5 Glacial Lake inlet to snout distance: .....	16
2.2.6 Glacial Lake inlet to snout slope: .....	16
2.2.7 Glacial Lake in the vicinity and connected (>1 ha) within 1 Km: .....	16
2.2.8 Nearest downstream Habitation Distance (likely to be affected):.....	16
2.2.9 Distance to nearest downstream Dam: .....	16
2.2.10 Distance to nearest downstream Bridge: .....	17
2.2.11 Historical GLOF events:.....	17
2.2.12 Seismic Zones:.....	17
3.0 Criteria classification: .....	18
4.0 Result of application of criteria on 100 Glacial Lakes in India.....	19
4.1 Statewise Distribution of 100 Glacial Lakes: .....	19
4.2 Elevationwise Distribution of 100 Glacial Lakes:.....	20
4.3 Water Spread area (Size) wise Distribution of 100 Glacial Lakes: .....	21
4.4 Typeswise Distribution of 100 Glacial Lakes:.....	22
4.5 Result of Criteria application for 100 Glacial Lakes:.....	23
5.0 Limitations and Assumptions: .....	24
6.0 Conclusion: .....	25

## List of Graphs

Graph 1: Location-wise past GLOF events .....	12
Graph 2: Lake Type GLOF events .....	13
Graph 3: GLOF events of Moraine Dammed Lakes (Sizewise) .....	13
Graph 4: GLOF events of Ice Dammed Lakes (Sizewise) .....	14
Graph 5: Statewise Distribution of Glacial Lakes .....	19
Graph 6: Elevationwise Distribution of Glacial Lakes .....	20
Graph 7: Sizewise Distribution of Glacial Lakes .....	21
Graph 8: Typewise Distribution of Glacial Lakes .....	22
Graph 9: Result of criteria on 100 GLs in India .....	23

## List of Tables

Table 1: Risk Score Classification .....	18
Table 2: Statewise Distribution of Glacial Lakes .....	19
Table 3: Elevationwise Distribution of Glacial Lakes .....	20
Table 4: Sizewise Distribution of Glacial Lakes .....	21
Table 5: Typewise Distribution of Glacial Lakes .....	22
Table 6: Result of criteria on 100 GLs in India .....	23

## List of Annexures

Annexure I .....	26
Annexure II .....	27

## Executive Summary

Central Water Commission (CWC) acts as the nodal agency for Glacial Studies in India, playing a pivotal role in guiding states on critical aspects related to glacial hazards. As a leading organization, CWC provides expertise in monitoring Glacial Lakes, conceptualizing and installing Early Warning Systems and conducting hazard risk mapping.

In order to conduct a rapid risk assessment of Glacial Lakes, CWC has initiated collaboration among concerned stakeholders to develop a unified framework for risk assessment in the Indian Himalayan region. Through multiple meetings and discussions with stakeholders, it has been identified that criteria for Glacial Lake assessments should prioritize those that can be monitored through remote sensing due to the inaccessibility of many lakes and the substantial resources required for conducting physical studies on each one.

There are 12 criteria identified for the risk assessment of which 4 are for Glacial Lake itself, 3 for upstream of Glacial Lake, 3 for downstream of Glacial Lake and 2 for others. Out of total 100 marks, 45 is allocated to the Glacial Lake itself, upstream 15, downstream 30 and other 10. The weightage for these criteria ranges between 5 and 15 marks. Among the criteria, Glacial Lake size, Changes in Glacial Lake size, and Proximity to the nearest dam are particularly emphasized due to their potential severity, each receiving a maximum of 15 marks.

This methodology has been applied to assess 100 Glacial Lakes spread across four States (Arunachal Pradesh, Himachal Pradesh, Sikkim and Uttarakhand) and two Union Territories (Jammu & Kashmir and Ladakh) in the Indian Himalayan Region, at elevations ranging from 3,000 to 6,000 meters. These lakes include moraine-dammed lakes, ice dammed lake and Glacial erosion lakes, with moraine-dammed lakes considered most vulnerable in Indian Himalayan Region.

The assessment categorizes Glacial Lakes into four risk categories, with Category 1 (Score above 70) indicating the highest risk, and Category 4 (Score below 50) representing the lowest risk. Generally, Glacial Lakes classified under Category 1 are deemed the most risky, while those in Category 4 pose the least risk. However, it is possible that a single parameter with a lower weightage could still significantly influence the overall risk of a Glacial Lake, potentially outweighing other factors in the assessment.

The physical monitoring of each glacial lake in the Indian Himalayan Region (IHR) demands considerable financial and logistical resources, making it impractical to assess all glacial lakes comprehensively. Criteria for Risk Indexing of Glacial Lakes in Indian Himalayan Region will act as a crucial guide for stakeholders and the academic community, helping to prioritize monitoring efforts and interventions where they are most needed. By streamlining the assessment process, it supports more effective resource allocation and disaster preparedness.

## 1.0 Introduction:

The Indian Himalayan region, an integral part of the world's highest mountain range, is home to thousands of Glaciers that play a vital role in the hydrological cycle and serve as a crucial water source for the region. Glaciers in this region, particularly those located in the upper reaches of river basins such as the Ganges, Brahmaputra, and Indus, store large volumes of freshwater, gradually releasing it to feed rivers and streams. However, in recent decades, glaciers have been rapidly retreating due to global warming, leading to the formation and expansion of Glacial Lakes. These lakes, formed by melt water accumulating behind natural moraine or ice dams, are highly sensitive to climatic changes and pose a growing threat to downstream communities.

A significant concern associated with Glacial Lakes is the potential for sudden and catastrophic events known as Glacial Lake Outburst Floods (GLOFs). These occur when the natural dam holding the lake fails, either due to increased water pressure, seismic activity, landslides, or avalanche into the lake. The resulting floodwaters can cause massive destruction, with devastating impacts on life, property, and infrastructure downstream.

It is crucial to establish a framework for the rapid risk assessment of Glacial Lakes that provides a structured and systematic method for identifying and ranking these lakes. This approach enables authorities to prioritize resources for monitoring, mitigation and reducing the risk of catastrophic Glacial Lake Outburst Floods (GLOFs).

This framework assesses critical factors such as the Glacial Lake size, Changes in Glacial Lake size over time, Stability of side slopes, Proximity to other Glacial Lakes etc. It also considers downstream vulnerabilities, including nearby Habitations and key infrastructures like dams, bridges, roads etc. By evaluating these parameters, authorities can prioritize which lakes pose the greatest threat, ensuring that limited resources are used efficiently for monitoring, Early Warning Systems (EWS), and preventive measures.

### 1.1 Glacial Lake Outburst Floods (GLOFs):

Glacial Lake Outburst Floods (GLOFs) have occurred in various parts of the world. Indian Himalayan region is also vulnerable due to the presence of a large number of Glacial Lakes and the growing influence of Climate Change. These floods can have significant socio-economic consequences, as many communities in the region depend on the rivers fed by glacial melt water for agriculture, drinking water, and energy generation. Additionally, critical infrastructure, including dams, roads, bridges, and hydropower plants, is often located in the river valleys, putting them at risk from GLOFs.

Several GLOF events in the past have underscored the dangers posed by these floods. Notable GLOF occurrences in the Indian Himalayan region include the 1929 GLOF in the Shyok River basin and the 1985 Dig Tsho outburst in Nepal, which resulted in significant loss of life and property. Recently, the breach of the moraine dam embankment at Chorabari Lake in 2013 triggered by heavy rainfall and South Lhonak Lake in 2023, triggered by a landslide, exemplifies the complex interplay between climate change, glacial dynamics, and extreme weather events. These events have highlighted the urgency of monitoring and managing Glacial Lakes to mitigate the risks associated with GLOFs.

## 1.2 Importance of Risk Indexing:

The importance of risk indexing for Glacial Lakes lies in its ability to systematically assess and manage the hazards associated with Glacial Lake outburst floods (GLOFs), particularly in regions like the Himalayas where these lakes are becoming increasingly unstable. As glaciers retreat and melt water accumulates in Glacial Lakes held back by fragile moraine or ice dams, the risk of sudden and catastrophic floods grows. Risk indexing provides a method for identifying which Glacial Lakes are most likely to experience such outbursts and prioritizing them for monitoring and intervention.

By evaluating key factors such as the Glacial Lake size, type, Stability of the side slope etc. and its potential impact on downstream habitations and infrastructure, risk indexing assists authorities focus resources on most risky Glacial Lake. This proactive approach is critical for minimizing the loss of life, reducing economic damage, and enhancing preparedness efforts. It also assists the development of Early Warning Systems (EWS) and long-term climate adaptation strategies, making it a crucial tool in mitigating the impacts of Glacial Lake hazards in vulnerable regions.

## 1.3 Factors for Risk Assessment of Glacial Lake:

Glacial Lakes are situated in high-altitude regions with harsh climatic conditions and challenging terrain, making them generally inaccessible. This inaccessibility is a key factor contributing to the lack of monitoring capabilities for these lakes. Therefore, when considering the wide range of factors influencing Glacial Lakes, it is essential to account for practical constraints. These constraints must be weighed carefully when selecting the factors to be included in any risk assessment framework.

Among the factors influencing the risk associated with Glacial Lakes, some can be measured or monitored, while others cannot. Additionally, some factors are predictable, while others are sudden. This document focuses on factors that are measurable uniformly for remotely located Glacial Lakes and are known in advance. Certain factors that apply equally to all lakes, and thus do not differentiate risk levels, have been excluded from the criteria. For a more detailed risk analysis, additional lake-specific information may be considered for priority lakes. Instantaneous factors can be incorporated into an Early Warning System through systematic and continuous monitoring of high-risk lakes.

The NRSC's Glacial Lake ranking procedure involves a two-step methodology. First, a preliminary screening is conducted using four criteria. Then, six parameters are assigned to the Glacial Lakes, normalized, and weighted. The normalized scores are multiplied by the weights and summed for each Glacial Lake, with the highest total score indicating the most vulnerable Glacial Lake. C-DAC has separately identified 35 criteria with varying weights to assess the risk of glacial lakes in Sikkim. The overall score is determined by adding the points assigned

in each category, resulting in a total score where the highest value indicates the most vulnerable lake.

Risk associated with Glacial Lakes is determined by evaluating several key factors that influence the likelihood of a Glacial Lake Outburst Flood (GLOF) and the potential impact on downstream areas. The Glacial Lake size, type, Change in Size, Stability of side slope, Snout to Glacial Lake distance, Snout to Glacial Lake Slope, Glacial Lake in vicinity and connected are some of the important remotely measurable parameters on upstream of Glacial Lake and Glacial Lake itself.

Downstream parameters, including proximity to human settlements and infrastructures like dams, roads and bridges, are crucial for assessing the potential damage if a GLOF occurs. Glacial Lakes closer to infrastructure and populated areas poses a higher risk of catastrophic impacts. Additionally, historical GLOF events and the location of Glacial Lakes in seismic zones further elevate the risk, as past events and seismic activity may destabilize the Glacial Lakes triggering outbursts.

Factors for Risk Assessment of Glacial is divided into four categories which are as follows:

(i) **Glacial Lake:** This category examines factors that directly impact the stability and integrity of the Glacial Lake. Several key factors are considered to assess the potential hazard:

1. **Size of Glacial Lake** – Larger Glacial Lake tend to hold more water, increasing the potential for catastrophic flooding if they burst.
2. **Type of Glacial Lake** – The Glacial Lake's formation (moraine-dammed, ice-dammed, etc.) influences its structural stability.
3. **Change in Size of Glacial Lake over Time** – Rapid expansion of the Glacial Lake indicates growing instability and increased risk of an outburst.
4. **Stability of Lake Side Slope** – The condition of the surrounding slopes is crucial, as unstable slopes can lead to landslides that may trigger a dam breach.

(ii) **Upstream of Glacial Lake:** This section assesses conditions and parameters upstream (u/s) of the lake that could influence its stability and risk level.

1. **Snout to Glacial Lake Distance** – The distance between the glacier's snout and the Glacial Lake helps determine how glacial meltwater might affect the lake.
2. **Snout to Glacial Lake Slope** – The gradient between the glacier and the Glacial Lake can affect water flow dynamics and stability.
3. **Glacial Lakes in the Vicinity and Connected (>1 ha) within 1 Km in same Valley** – The presence of nearby connected Glacial Lake(s) increases the overall water volume and complexity, which can heighten the risk of chain-reaction events.

(iii) **Downstream of Glacial Lake:** This focuses on the parameters downstream (d/s) of the Glacial Lake to assess the potential impact on human life and infrastructure.

1. **Distance from Nearest Habitation likely to be affected** – The Glacial Lake located closer to populated areas poses higher risk to human casualties in the event of an outburst.
2. **Distance from Nearest Dam** – The proximity to critical infrastructure like dams is important, as a GLOF could lead to secondary disasters if the dam fails or opens gates suddenly.
3. **Distance from Nearest Bridge** – Assessing the risk to transportation infrastructure such as bridges helps gauge the potential for widespread disruption.

(iv) **Other Parameters:** Additional factors that can affect the overall risk are considered in this section.

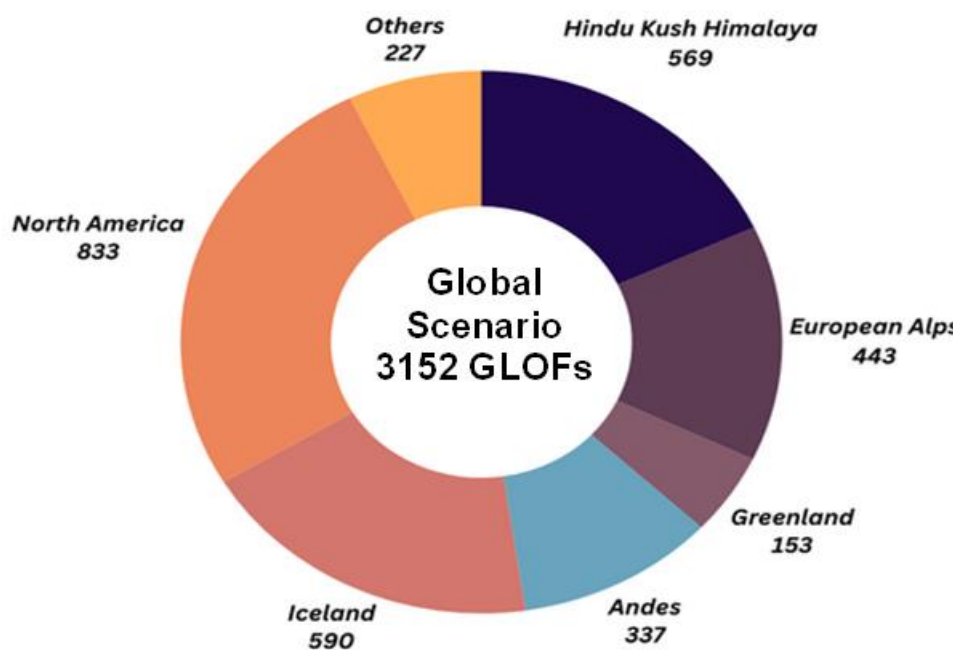
1. **Historical GLOF Events** – Previous GLOFs in the area offer insights into patterns of Glacial Lake instability and potential recurrence.
2. **Seismic Zones** – Glacial Lakes situated in active seismic zones are at higher risk of dam failure due to earthquake-induced destabilization.

## 2.0 Criteria for Risk assessment through indexing

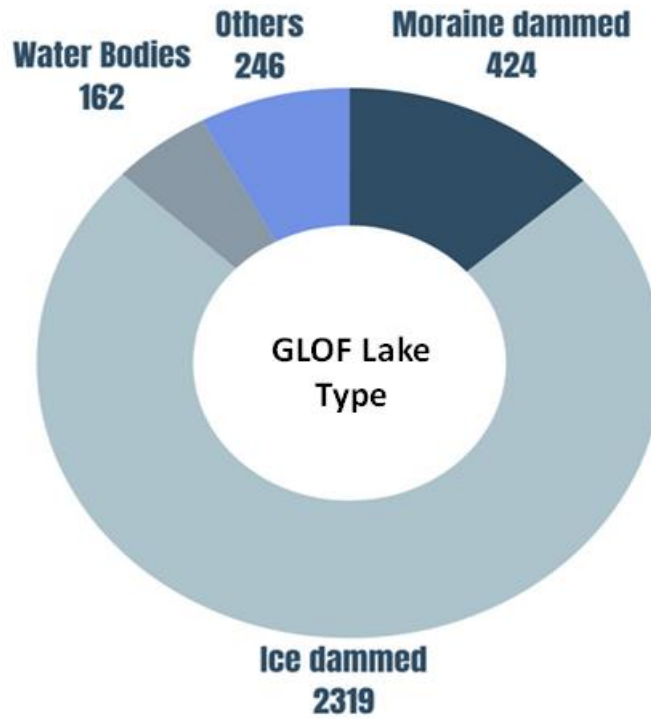
*The basic concept behind shortlisting of Index for Risk associated with Glacial Lakes is to prescribe common criteria for studies being/proposed to be taken in this area of concern as mentioned above.*

### 2.1 Background:

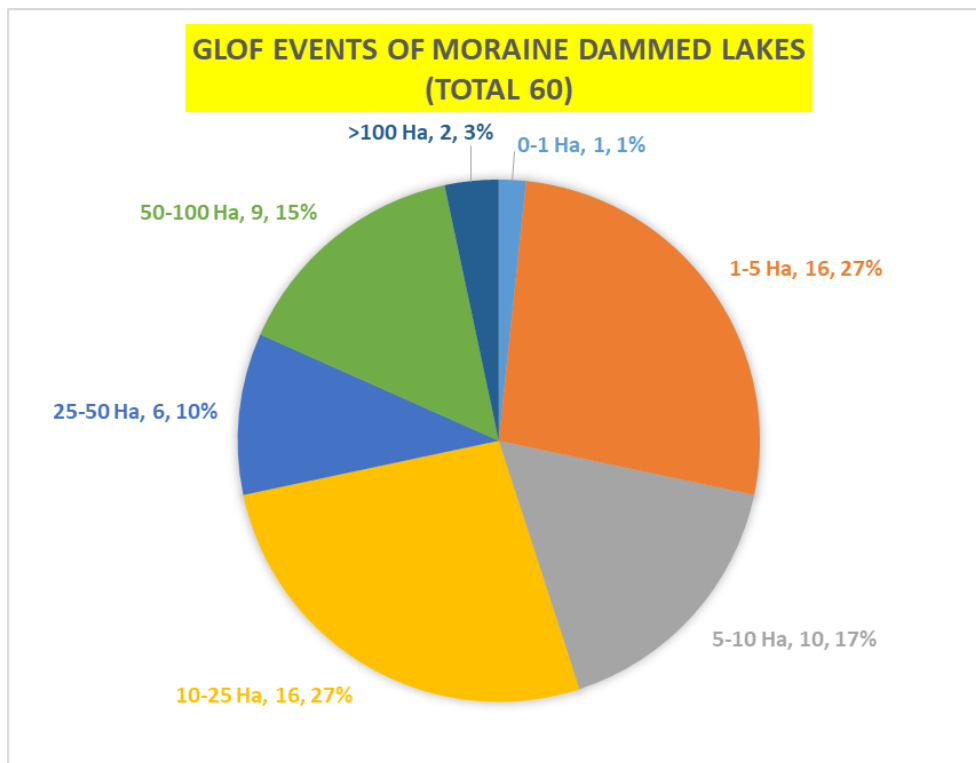
To develop the criteria for risk indexing, it was deemed essential to study the global scenario of Glacial Lake Outburst Floods (GLOFs). A search revealed a historical GLOF events database from a study titled “A Global Database of Historic Glacier Lake Outburst Floods,” published on July 12, 2023. This database identified 3,152 GLOF events that occurred across 27 countries from 850 to 2022 CE, with 569 of these events reported in the Hindu Kush Himalaya region. The database includes 2,319 ice-dammed lakes and 424 moraine-dammed lakes. According to the findings, there have been 60 reported failures of moraine-dammed lakes and 394 failures of ice-dammed lakes in the Hindu Kush Himalaya. The size-related details for failures of moraine and ice-dammed lakes are as follows:



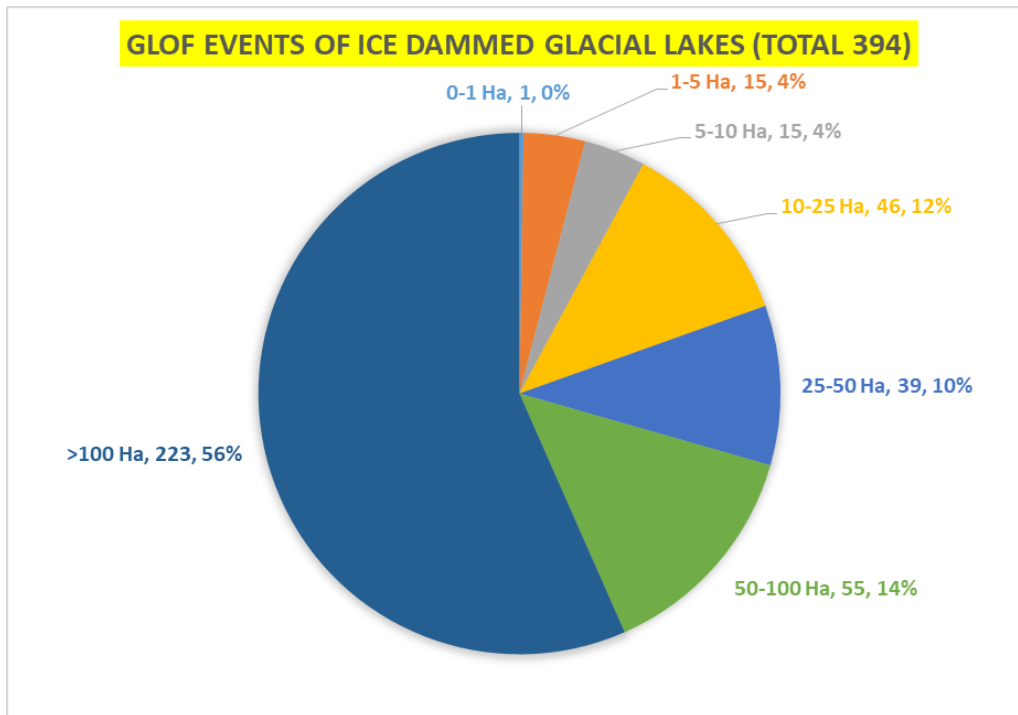
**Graph 1: Location-wise past GLOF events**



Graph 2: Lake Type GLOF events



Graph 3: GLOF events of Moraine Dammed Lakes (Sizewise)



**Graph 4: GLOF events of Ice Dammed Lakes (Sizewise)**

Therefore, susceptibility for failure of ice dammed lakes are higher than the moraine dammed lake. Similarly, larger Glacial Lakes are more prone to outburst than small lakes. Glacial Erosion lakes are mostly stable in nature.

However, as per article namely “*Increasing risk of Glacial Lake Outburst Floods from future Third Pole deglaciation*” published in nature climate change by Guoxiong Zheng, most past GLOF sources were related to moraine dammed Glacial Lakes.

## 2.2. Measurable factors and their priority:

GLOF is the primary hazard associated with the Glacial Lake. It's the potential for a sudden and catastrophic release of water from a Glacial Lake, causing widespread destruction downstream. The following criteria proposed/identified for Glacial Lakes:

**2.2.1 Size of Glacial Lake:** The size of a Glacial Lake provide fundamental insights into its water storage capacity. In the event of a GLOF, this characteristic becomes a critical factor. Normally, larger Glacial Lakes have a greater potential for catastrophic outbursts compared to smaller ones due to the volume of water they contain. However, the smaller Glacial Lakes can also pose risks. Lakes with larger sizes should be given higher priority.

**2.2.2 Type of Glacial Lake:** The diversity of Glacial Lakes necessitates a differentiated approach to risk assessment. Different types of Glacial Lakes exhibit distinct characteristics, formation processes, and potential hazards. Broadly Glacial Lakes are divided into four major types as per NRSC inventory:

- i. **Moraine-dammed lake:** When glaciers melt, the water in these Glacial Lakes accumulates behind loose naturally formed glacial/moraine dams made of ice, sand, pebbles and ice residue. This is the another most common type of outburst due to failure of unstructured end moraine material on account of spillage due to flood surge or heavy inflow into the lake /seepage due to high hydraulic head or disappearance of permafrost condition with rise in temperature.
- ii. **Ice-dammed lake:** An Ice-dammed Lake is created when a glacier blocks the flow of a river or stream, forming a lake behind the ice. Outburst of such glaciers are the most common due to melting of ice with rise in temperature in addition to other factors like sudden fall of ice/rock/moraine material in the lake.
- iii. **Glacier Erosion lake:** These are the water bodies formed in a depression after the glacier has retreated in a form of cirque or trough valley, might be isolated and far away from the present glaciated area, and mostly stable in nature.
- iv. **Other Glacial Lake**

**2.2.3 Change in Size of Glacial Lake:** The change in size of a Glacial Lake refers to increase or decrease in the lake's surface area and volume over time. A lake that rapidly increases in size is often a sign of accelerated glacier melting or instability in the surrounding terrain. This rapid growth can exert immense pressure on the natural or artificial dams containing the lake, increasing the risk of breach. Changes in lake size will be determined by analysing data from the preceding five years/ available data from monitoring reports or base year data from inventory reports. Lakes size increasing at higher rates needs more attention and therefore higher weightage.

**2.2.4 Stability of Glacial Lake side slope (surrounding topography):** The Glacial Lake side slopes influences erosion, landslides, avalanche and other forms of mass movement. Steeper slopes are more prone to failure and vice versa. Factors such as slope angle, material composition, vegetation cover and water content are important for assessment of surrounding topography of Glacial Lakes. Landslide susceptibility maps of lake's surroundings as available or to be prepared by GSI may be of use for scoring. Avalanche prone maps or similar database, as available with DGRE for the lakes area may also be of use in this context. Pending availability of desired information from GSI & DGRE, average slope of the surrounding area of the lake derived from publicly available DEM generated from remote sensing data may be used for analysis.

**2.2.5 Glacial Lake inlet to snout distance:** The snout of a glacier refers to its lower, terminal end where the glacier meets its surrounding environment. A shorter distance between the Glacial Lake inlet and the glacier snout implies a shorter pathway for melt water to reach the lake. This can lead to rapid lake level rise and increased pressure on the lake's dam, enhancing the risk of a GLOF whereas a longer distance can provide a buffer zone, allowing for some attenuation of the water flow before it reaches the lake. Therefore, longer distances between the lake inlet and glacier snout may indicate a lower risks and vice versa. Such data can be derived from publicly available DEM generated from remote sensing data.

**2.2.6 Glacial Lake inlet to snout slope:** The "Glacier Lake Inlet to Snout slope" refers to the gradient or incline from where a glacier feeds into a lake (the inlet) down to the glacier's terminus (snout). For risk assessment of Glacier Lake Outburst Floods (GLOFs), analysing this slope is crucial. A steep glacier slope accelerates the flow of melt water towards the lake, increasing the rate of lake level rise and pressure on the dam. A gentler slope reduces the velocity of melt water, allowing for more gradual lake level rise and potentially reducing the risk of a sudden outburst. Therefore, gentle slopes may indicate a lower risk and vice versa. Such data can be derived from publicly available DEM generated from remote sensing data.

**2.2.7 Glacial Lake in the vicinity and connected (>1 ha) within 1 Km:** The Indian Himalayan region is characterized by a high density of Glacial Lakes, many of which are in close proximity to each other. This clustering increases the risk of cascading failures. Global warming has accelerated the formation of new Glacial Lakes in recent years, exacerbating the situation. Interconnected lakes within this region pose a significant threat as the breach of one can trigger a chain reaction, leading to catastrophic GLOFs. Such information can be derived from analysing the inventory of Glacial Lakes in any GIS platform along with DEM and drainage network of the area.

**2.2.8 Nearest downstream Habitation Distance (likely to be affected):** The assessment of proximity of human settlements to the Glacial Lakes means distance of population and their livelihood in the path of the floodwaters from the lake. The floodwaters from a GLOF can carry debris, boulders, and ice, further increasing the destructive power of the flood. Settlements that are closer to the Glacial Lake are more likely to experience severe and immediate consequences, while those farther away may be less affected or have more time to respond. As first estimate, such data can be generated from Google Earth along with draining network of the area covering lakes. Subsequently, such data can be refined in consultation with local authority or any other source.

**2.2.9 Distance to nearest downstream Dam:** Downstream dams are particularly vulnerable to the destructive force of a GLOF. These massive surges of water, often carrying significant sediment loads, can overwhelm dam structures, leading to catastrophic consequences. Closer distances between the Glacial Lake and Dam indicates floodwaters will reach the dam more quickly, reducing the time available for early warning & response and vice

versa. Such data can be generated from Google Earth or GIS along with drainage network covering the lake in GIS environment.

**2.2.10 Distance to nearest downstream Bridge:** Bridges are crucial components of transportation infrastructure, acting as vital lifelines connecting communities and facilitating the movement of people, goods, and emergency services. It plays a significant role in emergency response in the event of GLOF. Bridges located close to Glacial Lakes are at a higher risk of damage or destruction from GLOFs and vice versa. As first estimate, such data can be generated from Google Earth along with draining network of the area covering lakes. Subsequently, such data can be refined in consultation with local authority or any other source.

**2.2.11 Historical GLOF events:** Historical GLOF events are crucial for understanding the potential magnitude, frequency, and impacts of the hazards. Past occurrences where Glacial Lakes have burst, leading to sudden and catastrophic flooding. Evaluating the frequency of past GLOF events in the region helps identify trends and recurring risks. *Initially, such information may be taken from the historical database from a study titled “A global database of historic glacier lake outburst floods” published on 12th July 2023 identified 3151 GLOF events occurred in 27 countries between 850 and 2022 CE. Subsequently, the same can be refined in consultation with local authority of literatures.*

**2.2.12 Seismic Zones:** Seismic zones are categorized based on the likelihood and intensity of earthquakes occurring in a specific area. These classifications are crucial for understanding the seismic hazards in regions prone to earthquakes. Identifying and mapping these zones allows for the assessment of risks associated with natural disasters, such as GLOFs. Higher magnitude earthquake in the vicinity of the lakes may cause outburst of frontal dams releasing water from lakes or landslide of surrounding slopes resulting fall of mass into the lake leading to spilling of water or avalanche leading to fall of ice mass into the lake. It is to be noted that Indian Himalayan Region (IHR) includes four states—Himachal Pradesh, Uttarakhand, Sikkim, and Arunachal Pradesh and two Union Territories, Jammu & Kashmir and Ladakh, which fall under Seismic Zones IV and V.

Based on the above identified criteria, a matrix for risk identification has been prepared and placed at **Annexure-I**.

**3.0 Criteria classification:** The score for classification of the risky Glacial Lakes is as under (Table 1):

**Table 1: Risk Score Classification**

Risk Score Classification			Remarks
SI No	Score (S)	Category	In general, Category 1 lakes are considered to be the most risky and category 4 is the least risky
1	$S > 70$	Category-1	
2	$60 < S \leq 70$	Category-2	
3	$50 < S \leq 60$	Category-3	
4	$S \leq 50$	Category-4	

However, the identification of different categories is not intended to suggest that Category-1 lakes, being the most at risk, will necessarily fail, while Category-4 lakes will not. Categorization is meant as a tool for assessment of risk associated with a Glacial Lake only. The failure of a Glacial Lake depends on the interaction of various factors, which can trigger such events depending on the intensity of destabilizing forces.

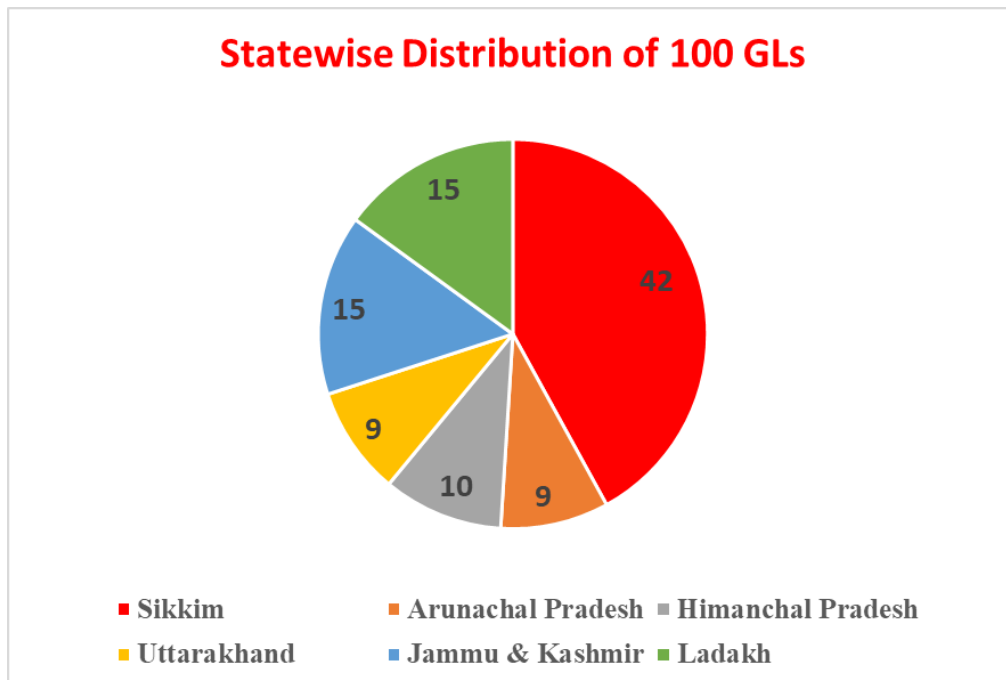
## 4.0 Result of application of criteria on 100 Glacial Lakes in India

### 4.1 Statewise Distribution of 100 Glacial Lakes:

The above criteria has been applied on 100 GLs in 4 States and 2 UTs of India in the Indian Himalayan Region. List of these 100 lakes is attached at **Annexure-II**. The details may be seen as per the following **Table 2**.

**Table 2: Statewise Distribution of Glacial Lakes**

State	No of GLs
Sikkim	42
Arunachal Pradesh	9
Himanchal Pradesh	10
Uttarakhand	9
Jammu & Kashmir	15
Ladakh	15
<b>Total</b>	<b>100</b>

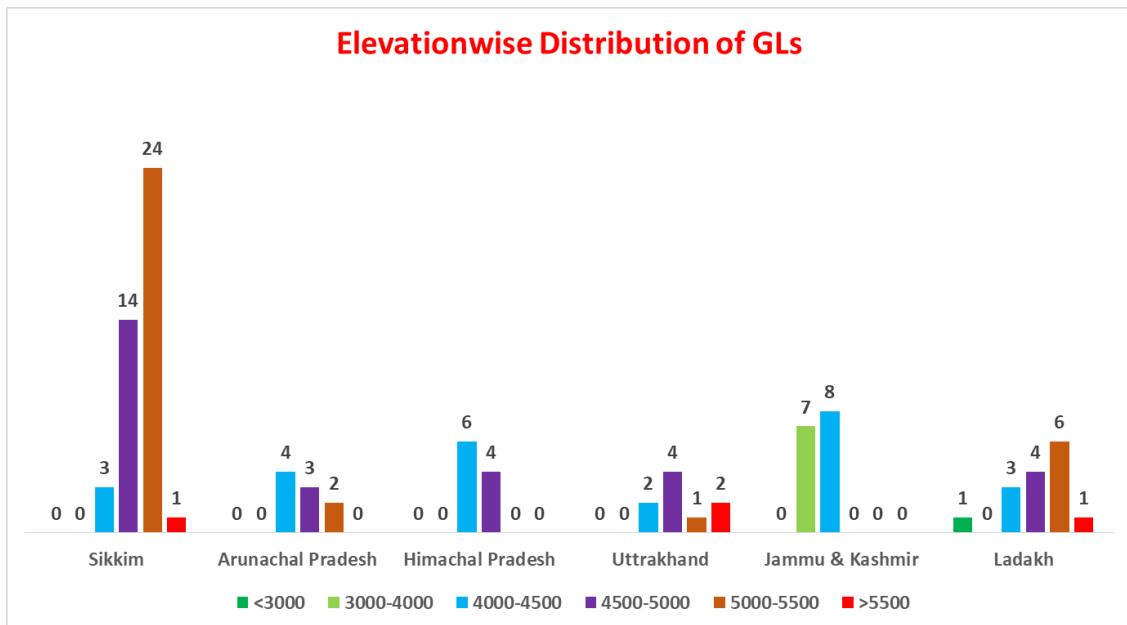


**Graph 5: Statewise Distribution of Glacial Lakes**

## 4.2 Elevationwise Distribution of 100 Glacial Lakes:

**Table 3: Elevationwise Distribution of Glacial Lakes**

Elevation (m)	Sikkim	Arunachal Pradesh	Himachal Pradesh	Uttrakhand	Jammu & Kashmir	Ladakh	Total
<3000	0	0	0	0	0	1	1
3000-4000	0	0	0	0	7	0	7
4000-4500	3	4	6	2	8	3	26
4500-5000	14	3	4	4	0	4	29
5000-5500	24	2	0	1	0	6	33
>5500	1	0	0	2	0	1	4
<b>Total</b>	<b>42</b>	<b>9</b>	<b>10</b>	<b>9</b>	<b>15</b>	<b>15</b>	<b>100</b>

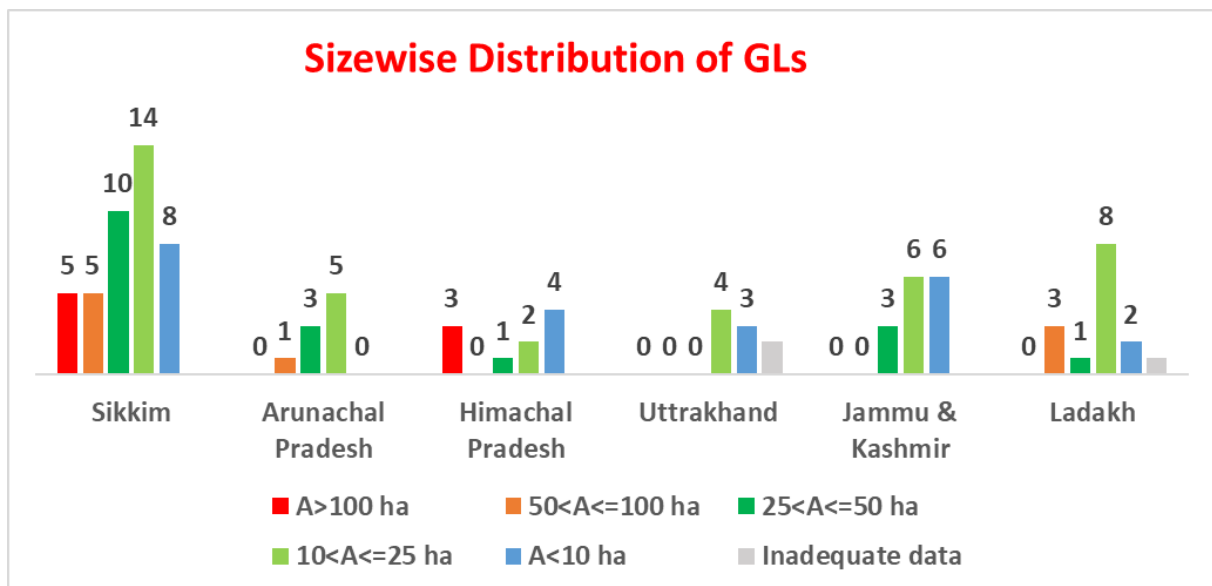


**Graph 6: Elevationwise Distribution of Glacial Lakes**

### 4.3 Water Spread area (Size) wise Distribution of 100 Glacial Lakes:

**Table 4: Sizewise Distribution of Glacial Lakes**

Glacial Lakes Size Distribution							
Area (Ha)	Sikkim	Arunachal Pradesh	Himachal Pradesh	Uttrakhand	Jammu & Kashmir	Ladakh	Total
A>100 ha	5	0	3	0	0	0	8
50<A<=100 ha	5	1	0	0	0	3	9
25<A<=50 ha	10	3	1	0	3	1	18
10<A<=25 ha	14	5	2	4	6	8	39
A<10 ha	8	0	4	3	6	2	23
Inadequate data	0	0	0	2	0	1	3
<b>Total</b>	<b>42</b>	<b>9</b>	<b>10</b>	<b>9</b>	<b>15</b>	<b>15</b>	<b>100</b>

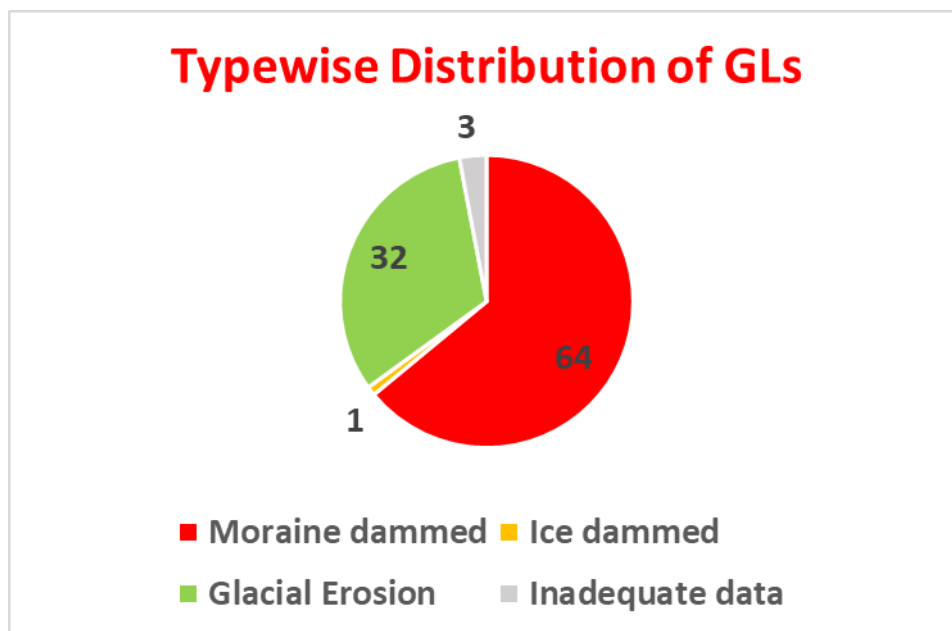


**Graph 7: Sizewise Distribution of Glacial Lakes**

#### 4.4 Typeswise Distribution of 100 Glacial Lakes:

**Table 5: Typewise Distribution of Glacial Lakes**

Type of GL	No of GLs
Moraine dammed	64
Ice dammed	1
Glacial Erosion	32
Inadequate data	3
<b>Total</b>	<b>100</b>

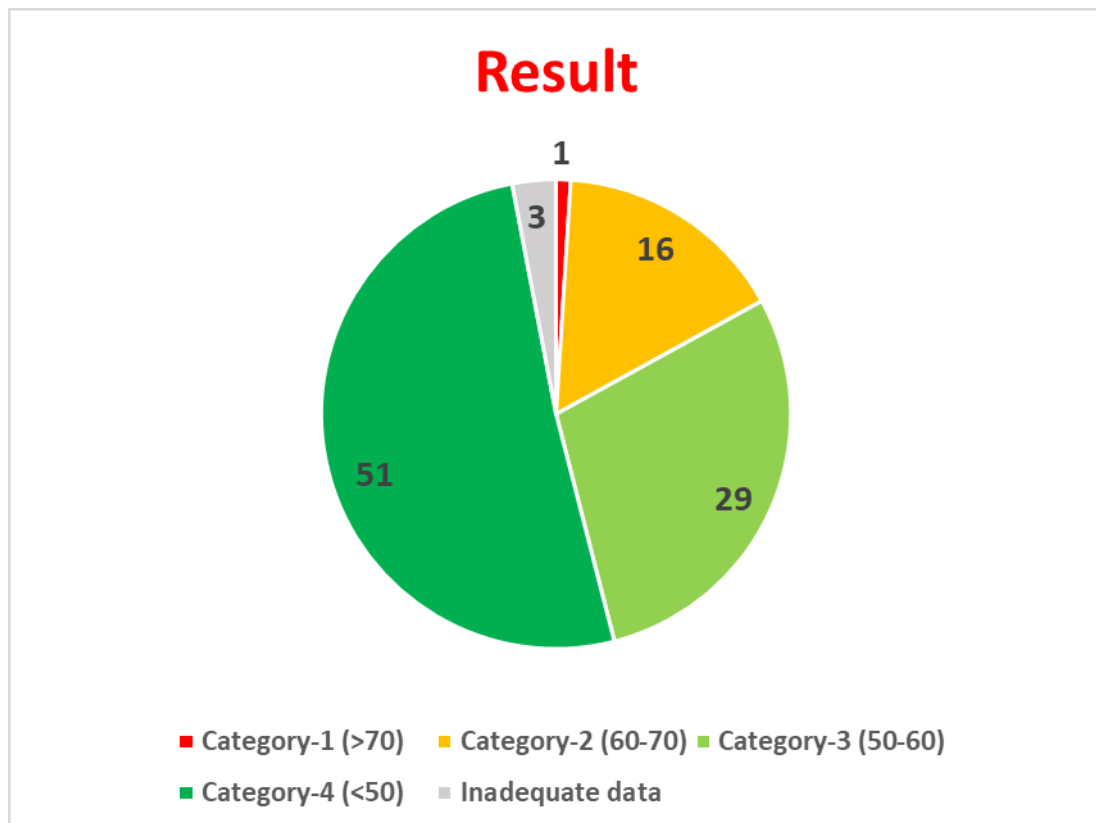


**Graph 8: Typewise Distribution of Glacial Lakes**

#### 4.5 Result of Criteria application for 100 Glacial Lakes:

**Table 6: Result of criteria on 100 GLs in India**

Result of criteria on 100 GLs in India			
Category	Score (S)	No of GLs	State-wise break up
Category-1	$S > 70$	1	SK-1
Category-2	$60 < S \leq 70$	16	SK-12, HP-4
Category-3	$50 < S \leq 60$	29	SK-11, AP-1, HP-4, UK-3, J&K-8, Ladakh-2
Category-4	$S \leq 50$	51	SK-18, AP-8, HP-2, UK-4, J&K-7, Ladakh-12
Inadequate Data	-	3	UK-2, Ladakh-1



**Graph 9: Result of criteria on 100 GLs in India**

## 5.0 Limitations and Assumptions:

1. **Data Dependency:** Glacial Lakes are situated in remote, high-altitude regions with challenging terrain and harsh climatic conditions which makes physical monitoring infrequent. Therefore, the risk assessment criteria rely heavily on remote sensing data, which may not capture all relevant parameters with the required precision.
2. **Field Verification Requirement:** Some parameters cannot be measured remotely and require on-the-ground verification, which may be time-consuming and resource-intensive.
3. **Interdependence of Criteria:** Some of the factors are independent and other are dependent. Attempts has been made to consider measurable independent factors only to keep minimum no of factors.
4. **Potential for Criteria Overpowering:** The proposed criteria is for rapid risk assessment assigning certain score to each factor. However, on ground, factors with low score may play more important role in certain condition. This needs to be considered whenever felt necessary as special cases.
5. **Evolving Criteria:** The criteria are indicative and may need revision as new technologies or environmental conditions emerge, potentially altering risk assessments.
6. **Uniform Impact of Criteria:** It is assumed that all criteria have been appropriately weighted, and their impact on the overall risk score is proportionate and balanced.
7. **Stable Environmental Conditions:** The criteria assume relatively stable environmental conditions, though future changes may require reassessmen

## 6.0 Conclusion:

The finalization of the criteria for assessing Glacial Lakes involved extensive input from various stakeholders, ensuring that the criteria are both comprehensive and effective in addressing the relevant challenges. The risk assessment criteria were systematically applied to evaluate 100 Glacial Lakes across the Indian Himalayan region, which encompasses four states and two Union Territories, each exhibiting diverse elevations and topographical features. This comprehensive assessment leveraged remote sensing technology to gather vital data, given the challenging accessibility of many of these lakes.

The finalized criteria for Glacial Lake risk assessment are based on easily measurable, independent parameters, and are intended to be updated as new technologies or conditions emerge. While the criteria prioritize risk across multiple factors, certain parameters may disproportionately influence the overall score, requiring adjustments. These criteria enable rapid risk assessments to identify high-risk lakes, helping agencies allocate resources efficiently and initiate appropriate monitoring. This process is crucial for planning and implementing Early Warning Systems and mitigation measures for Glacial Lakes identified as having higher risk.

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Annexure I

Risk Index Criteria for Glacial Lakes																								
	Glacial lake (45)								U/s of GL (15)					D/s of GL (30)						Other (10)				
1	2		3		4		5		6		7		8	9		10		11		12		13		
Parameters	Size (ha) of GL		Type of GL		Change in size (in last 5 years/available data)		Stability of lake side Slope (Degree)		Snout to GL distance (Km)		Snout to GL slope (Degree)		Glacial Lake in the vicinity and connected (>1 ha) within 1 Km in same valley	Distance from nearest Habitation likely to be affected (Km)		Distance from nearest Dam (Km)		Distance from nearest Bridge(RCC/Bailey/Rope) (Km)		Historical GLOF events		Seismic Zones		
Total Score	15		5		15		10		5		5		5	10		15		5		5		5		
Score break-up	Size (ha)	Score	Type	Score	Status	Score	Side Slope	Score	Distance	Score	Slope	Score	Draining	Score	Distance	Score	Distance	Score	Distance	Score	Yes/No	Score	Zone	Score
	A>100	15	Moraine dammed	5	Increasing (>25%)	15	S>30	10	D<=0.5	5	S>30	5	Yes	5	D<=25	10	D<=25	15	D<=10	5	Yes	5	V	5
	50<A<=100	12	Ice dammed	3	Increasing (20-25%)	12	20<S<=30	7	0.5<D<=1	3	20<S<=30	3	No	0	25<D<=50	8	25<D<=50	12	10<D<=25	4	No	0	IV	3
	25<A<=50	8	Glacial Erosion	2	Increasing (15-20%)	9	10<S<=20	5	1<D<=2	2	10<S<=20	2			D>50	5	50<D<=100	8	25<D<=50	3				
	10<A<=25	5	Other	1	Increasing (10-15%)	7	S<=10	2	D>2	1	S<= 10	1					D>100	5	D>50	0				
	A<=10	3			Change(within +/- 10% )	3											No Dam	0						
				Decrease (>10%)	0																			

Risk Score Classification		
SI No	Score (S)	Classification
1	S>70	Category-1
2	60<S<=70	Category-2
3	50<S<=60	Category-3
4	S<=50	Category-4

## Annexure II

State	District	Old Lake ID	New Lake ID	Name	Lat	Long	Type	River	Basin	Elevation (m)	Category
Sikkim	North Sikkim	03_78A_009	07478A050213	Khola Chhobuh	27.9466	88.3316	M(o): Other Moraine Dammed Lake	Khara Chu	Teesta	5034	Category-4
	North Sikkim	03_78A_014	07478A010059	South Lhonak Lake	27.9126	88.1955	M(e): End-moraine Dammed Lake	Gama Chu	Teesta	5194	Category-2
	North Sikkim	03_78A_021	07478A050272	NA	27.8245	88.2492	M(e): End-moraine Dammed Lake	Rhuling Chu	Teesta	5414	Category-3
	North Sikkim	03_77D_005	07477D120030	Lakes of Kangchengyao	28.0075	88.6981	M(e): End-moraine Dammed Lake	Teesta	Teesta	5209	Category-2
	North Sikkim	03_78A_001	07478A130523	Khangchung Tso	27.9902	88.8158	M(e): End-moraine Dammed Lake	Teesta	Teesta	5303	Category-2
	North Sikkim	03_78A_020	07478A050249	NA	27.881	88.2504	M(e): End-moraine Dammed Lake	Gama Chu	Teesta	5198	Category-4

State	District	Old Lake ID	New Lake ID	Name	Lat	Long	Type	River	Basin	Elevation (m)	Category
Sikkim	North Sikkim	03_78A_010	07478A050211	NA	27.9489	88.3052	M(e): End-moraine Dammed Lake	Khara Chu	Teesta	5049	Category-3
	North Sikkim	03_78A_035	07478A050208	Khola Chhamna	27.9513	88.3549	M(o): Other Moraine Dammed Lake	Khara Chu	Teesta	4989	Category-4
	North Sikkim	03_78A_008							Teesta	4989	Category-4
	North Sikkim	03_78A_005	07478A050186	NA	27.9736	88.4224	M(o): Other Moraine Dammed Lake	Nakul Chu	Teesta	5185	Category-4
	North Sikkim	03_78A_006	07478A050193	NA	27.969	88.4296	M(o): Other Moraine Dammed Lake	Nakul Chu	Teesta	4974	Category-3
	North Sikkim	03_78A_002	07478A090358	NA	27.982	88.5084	M(e): End-moraine Dammed Lake	Teesta	Teesta	4917	Category-3
	North Sikkim	227	07478A090355	NA	27.9924	88.5453	M(e): End-moraine Dammed Lake	Teesta	Teesta	5161	Category-2
	North Sikkim	03_77D_006	07477D120025	Lu tso	28.0143	88.5612	E(c): Cirque Erosion Lake	Teesta	Teesta	5073	Category-2
	North Sikkim	03_77D_004	07477D120034	Lakes of Kangchengyao	28.0056	88.7129	M(e): End-moraine Dammed Lake	Teesta	Teesta	5238	Category-3
	North Sikkim	295	07478A090403	Subu Chho	27.9203	88.6723	M(e): End-moraine Dammed Lake	Laehung Chu	Teesta	4827	Category-2

State	District	Old Lake ID	New Lake ID	Name	Lat	Long	Type	River	Basin	Elevation (m)	Category
Sikkim	North Sikkim	237	07478A130519	NA	27.9934	88.8014	M(o): Other Moraine Dammed Lake	Laehung Chu	Teesta	5299	Category-4
	North Sikkim	260	07478A130553	NA	27.8947	88.7614	M(e): End-moraine Dammed Lake	Laehung Chu	Teesta	5232	Category-3
	North Sikkim	03_78A_012	07478A130550	Penbawa Khangse	27.901	88.7819	M(o): Other Moraine Dammed Lake	Penbawa Chu	Teesta	5118	Category-3
	North Sikkim	03_78A_015	07478A130563	NA	27.8731	88.7893	M(e): End-moraine Dammed Lake	Sebozung Chu	Teesta	4962	Category-4
	North Sikkim	515	07478A130576	NA	27.8539	88.8059	E(o): Other Glacial Erosion Lake	Sebozung Chu	Teesta	5051	Category-4
	North Sikkim	312	07478A100485	NA	27.7003	88.5138	E(o): Other Glacial Erosion Lake	Teesta	Teesta	4491	Category-2
	North Sikkim	03_78A_023	07478A100495	Shingo Chho	27.6712	88.5125	E(c): Cirque Erosion Lake	Nathang Chu	Teesta	4525	Category-1
	West Sikkim	03_78A_027	07478A020131	Tikip Chu Lake	27.5331	88.0856	M(e): End-moraine Dammed Lake	Tikip Chu	Teesta	4860	Category-3
	West Sikkim	03_78A_031	07478A030158	Lachmi Pokhari	27.4373	88.0831	E(c): Cirque Erosion Lake	NA	Teesta	4280	Category-3
	West Sikkim	03_78A_026	07478A020123	Bhale Pokhari	27.563	88.1233	M(o): Other Moraine Dammed Lake	Choktsering Chu	Teesta	4710	Category-2

State	District	Old Lake ID	New Lake ID	Name	Lat	Long	Type	River	Basin	Elevation (m)	Category
Sikkim	North Sikkim	599	07478A100486	Chhumzomo Chhokha	27.6951	88.7165	E(o): Other Glacial Erosion Lake	Teesta	Teesta	4207	Category-2
	North Sikkim	03_78A_016	07478A010062	NA	27.8933	88.2123	I(s): Supra-Glacial Lake	Gama Chu	Teesta	5433	Category-4
	North Sikkim	03_78A_003	07478A090361	Gyapu Chho	27.9751	88.6161	M(e): End-moraine Dammed Lake	Lasha Chu	Teesta	4960	Category-3
	North Sikkim	03_78A_017	07478A010063	Green Lake	27.893	88.1909	M(o): Other Moraine Dammed Lake	Gama Chu	Teesta	5496	Category-4
	North Sikkim	03_78A_013	07478A010058	NA	27.9195	88.159	M(e): End-moraine Dammed Lake	Gama Chu	Teesta	5441	Category-4
	North Sikkim	03_77D_008	07477D080005	NA	28.0062	88.4935	M(e): End-moraine Dammed Lake	Nakul Chu	Teesta	5023	Category-4
	North Sikkim	03_77D_007	07477D120032	NA	28.0073	88.5714	M(o): Other Moraine Dammed Lake	Teesta	Teesta	4998	Category-4
	North Sikkim	03_77D_002	07477D120019	Gurudongmar Lake	28.0258	88.7104	M(e): End-moraine Dammed Lake	Teesta	Teesta	5148	Category-3
	North Sikkim	293	07478A090383	NA	27.9509	88.7043	M(o): Other Moraine Dammed Lake	Laehung Chu	Teesta	5030	Category-4
	North Sikkim	298	07478A090425	NA	27.8729	88.6379	M(e): End-moraine Dammed Lake	Kalep Chu	Teesta	5118	Category-2

State	District	Old Lake ID	New Lake ID	Name	Lat	Long	Type	River	Basin	Elevation (m)	Category
Sikkim	North Sikkim	256	07478A090447	NA	27.8156	88.6565	E(o): Other Glacial Erosion Lake	Lako Chu	Teesta	4603	Category-4
	North Sikkim	345	07478A090432	Khangpup Khangse	27.8636	88.7468	M(e): End-moraine Dammed Lake	Khangpup Chu	Teesta	5084	Category-4
	North Sikkim	03_78A_019	07478A130571	NA	27.8645	88.8629	M(e): End-moraine Dammed Lake	Sebozung Chu	Teesta	4781	Category-2
	North Sikkim	292	07477D120035	NA	28.0055	88.6546	M(o): Other Moraine Dammed Lake	Teesta	Teesta	5550	Category-4
	North Sikkim	569	07477D120039	NA	28.0019	88.6391	M(e): End-moraine Dammed Lake	Teesta	Teesta	5424	Category-2
	North Sikkim	03_78A_007	07478A090375	Yulhe khang	27.9609	88.65	M(e): End-moraine Dammed Lake	Lasha Chu	Teesta	4964	Category-4
Arunachal Pradesh	West Kameng	03_83A_004	08683A050830	NA	27.7633	92.4248	M(o): Other Moraine Dammed Lake	Dungma Chu	Manas	5094	Category-4
	Tawang	03_83A_003	08683A050827	NA	27.7706	92.435	M(o): Other Moraine Dammed Lake	Dungma Chu	Dangme Chu	5179	Category-4
	Tawang	03_83A_005	08683A050836	NA	27.7558	92.4011	E(o): Other Glacial Erosion Lake	Dungma Chu	Dangme Chu	4967	Category-4
	Dibang Valley	03_91D_075	10391D060672	NA	28.6078	96.3205	E(c): Cirque Erosion Lake	Thangkung Chu	Dibang	4239	Category-3
	Tawang	129	08683A050825	NA	27.7742	92.3147	E(o): Other Glacial Erosion Lake	Dungma Chu	Dangme Chu	4870	Category-4

State	District	Old Lake ID	New Lake ID	Name	Lat	Long	Type	River	Basin	Elevation (m)	Category
Arunachal Pradesh	West Kameng	03_83A_007	09383A060091	NA	27.7276	92.4362	M(l): Lateral Moraine Dammed Lake	Bichom	Jia Bharali	4995	Category-4
	Siang	03_82L_007	09682L050102	NA	28.8374	94.4514	E(o): Other Glacial Erosion Lake	Slke	Siyom	4136	Category-4
	Dibang Valley	03_91C_026	10391C030254	NA	29.3381	96.0821	M(o): Other Moraine Dammed Lake	Jairu Chu	Dibang	4290	Category-4
	Anjaw	03_91H_073	10591H081931	NA	28.0541	97.3296	E(o): Other Glacial Erosion Lake	NA	Lohit	4424	Category-4
Himachal Pradesh	Lahul & Spiti	01_52H_002	0152H0203651	NA	32.5255	77.2197	M(e): End-moraine Dammed Lake	Gepang Gath (Sissu)	Chenab	4069	Category-3
	Lahul & Spiti	01_52H_004	0152H1103771	NA	32.4987	77.5467	M(e): End-moraine Dammed Lake	Chandra	Chenab	4150	Category-4
	Lahul & Spiti	01_52H_003	0152H1103771	NA	32.4987	77.5467	M(e): End-moraine Dammed Lake	Chandra	Chenab	4150	Category-3
	Kangra	1774	0152D1603265	NA	32.2219	76.789	E(o): Other Glacial Erosion Lake	Uhl	Beas	4577	Category-4
	Lahul & Spiti	1805	0152H0103646	NA	32.7623	77.1955	M(e): End-moraine Dammed Lake	Dudha Khol	Chenab	4766	Category-3
	Kangra	1998	0152D1503248	NA	32.32	76.908	M(e): End-moraine Dammed Lake	Ravi	Ravi	4401	Category-2

State	District	Old Lake ID	New Lake ID	Name	Lat	Long	Type	River	Basin	Elevation (m)	Category
Himachal Pradesh	Kangra	1936	0152D1503254	NA	32.2561	76.7778	M(o): Other Moraine Dammed Lake	Thamsar Nala	Ravi	4563	Category-2
	Kullu	1847	0153E0904453	NA	31.9147	77.5258	M(e): End-moraine Dammed Lake	NA	Beas	4462	Category-2
	Kinnaur	01_53I_002	0153I0204530	NA	31.661	78.1677	M(e): End-moraine Dammed Lake	NA	Satluj	4255	Category-3
	Kinnaur	2031	0153I0704552	NA	31.3394	78.2535	M(o): Other Moraine Dammed Lake	Hurba Khad	Satluj	4676	Category-2
Uttarakhand	Pithoragarh	02_62B_005	0262B0700349	NA	30.4458	80.3875	M(e): End-moraine Dammed Lake	NA	Sarda	4306	Category-3
	Chamoli	2108	0253N0500173	NA	30.976	79.4597	M(e): End-moraine Dammed Lake	NA	Alaknanda	5537	Category-4
	Pithoragarh	02_62B_004	0262B0200331	NA	30.5645	80.1785	M(e): End-moraine Dammed Lake	NA	Sarda	4872	Category-4
	Pithoragarh	01_62B_003	0162B1104954	NA	30.4766	80.5923	M(e): End-moraine Dammed Lake	Darma Yankti	Satluj	5263	Inadequate Data
	Uttarkashi	2207	0253J1300055	NA	30.9122	78.9581	M(l): Lateral Moraine Dammed Lake	NA	Bhagirathi	4707	Category-3
	Chamoli	2147	0253N0500169	NA	30.9807	79.4881	M(o): Other Moraine Dammed Lake	NA	Alaknanda	5656	Category-4

State	District	Old Lake ID	New Lake ID	Name	Lat	Long	Type	River	Basin	Elevation (m)	Category
Uttarakhand	Chamoli	02_53N_001	0253N1300271	Basudhara Tal	30.9009	79.7543	M(e): End-moraine Dammed Lake	Dhauli Ganga	Alaknanda	4677	Category-3
	Bageshwar	2299	0253N1600329	Nag Kund	30.1835	79.8757	E(c): Cirque Erosion Lake	NA	Alaknanda	4462	Category-4
	NA	02_62B_007	NA	NA	30.2786	80.1305	NA	NA	NA	4830	Inadequate Data
Jammu & Kashmir	Anantnag	958	0143N0802057	NA	34.1377	75.4167	E(o): Other Glacial Erosion Lake	NA	Jhelum	4083	Category-3
	Muzaffarabad	01_43J_003	0143J0101344	NA	34.9262	74.1555	E(c): Cirque Erosion Lake	NA	Jhelum	3926	Category-4
	Bandipore	27	0143J1501501	NA	34.3796	74.8762	E(o): Other Glacial Erosion Lake	NA	Jhelum	3738	Category-3
	Bandipore	1037	0143N0301929	Gadsar lake	34.4217	75.0578	E(c): Cirque Erosion Lake	Gadsar Nala	Jhelum	3570	Category-3
	Ganderbal	182	0143N0802046	NA	34.2338	75.3248	E(o): Other Glacial Erosion Lake	Durin Nar	Jhelum	4279	Category-4
	Anantnag	963	0143N0802055	NA	34.1389	75.377	E(o): Other Glacial Erosion Lake	Daphhinpar Nar	Jhelum	3709	Category-3
	Anantnag	938	0143O0502269	Sorus Nag	33.9534	75.378	E(o): Other Glacial Erosion Lake	Sorus Nag	Jhelum	3644	Category-3
	Anantnag	931	0143O0502273	NA	33.9287	75.3891	E(c): Cirque Erosion Lake	Lanaihal Nala	Jhelum	4048	Category-4
	Ganderbal	1032	0143N0301938	NA	34.3864	75.0642	E(o): Other Glacial Erosion Lake	NA	Jhelum	4006	Category-4

State	District	Old Lake ID	New Lake ID	Name	Lat	Long	Type	River	Basin	Elevation (m)	Category
Jammu & Kashmir	Bandipore	98	0143N0301935	NA	34.3918	75.0848	E(o): Other Glacial Erosion Lake	Raman Nala	Kishan ganga	4072	Category-3
	Ganderbal	1014	0143N0301959	NA	34.2986	75.0607	E(o): Other Glacial Erosion Lake	NA	Jhelum	3975	Category-4
	Anantnag	993	0143N0401963	Doda Sar	34.2272	75.2223	E(o): Other Glacial Erosion Lake	NA	Jhelum	4137	Category-4
	Anantnag	976	0143N0802050	NA	34.1844	75.3728	E(c): Cirque Erosion Lake	Daphhinpar Nar	Jhelum	4276	Category-4
	Anantnag	951	0143N0802066	NA	34.0668	75.4754	E(o): Other Glacial Erosion Lake	Sonasar Nala	Jhelum	3724	Category-3
	Kishtwar	01_52C_002	0152C0102950	NA	33.8683	76.1208	M(e): End-moraine Dammed Lake	Tanak Nala	Chenab	4071	Category-3
Ladakh	Kargil	01_52C_003	0152C1603156	NA	33.1586	76.9839	M(e): End-moraine Dammed Lake	Katkar Nala	Indus Upper	4479	Category-4
	Kargil	01_52C_001	0152C0102941	NA	33.9453	76.2302	M(e): End-moraine Dammed Lake	Ringdom Sankpo	Indus	4357	Category-4
	Leh	01_52B_012	0152B1602938	NA	34.0056	76.7876	M(e): End-moraine Dammed Lake	Photang	Indus	5126	Category-4
	Leh	01_42H_002	0142H0600150	Ghamu Bar Lake	36.6421	73.4068	M(e): End-moraine Dammed Lake	Darkot Bar	Gilgit	2748	Category-4
	Kargil	180	0152B0302731	NA	34.3513	76.0753	M(e): End-moraine Dammed Lake	Katpachan Lungpa	Indus	4435	Category-3

State	District	Old Lake ID	New Lake ID	Name	Lat	Long	Type	River	Basin	Elevation (m)	Category
Ladakh	Leh	1360	0143M1201790	NA	35.0273	75.7255	E(o): Other Glacial Erosion Lake	Indus	Indus	4647	Category-4
	Leh	01_52A_002	0152A0402408	NA	35.0965	76.2337	E(o): Other Glacial Erosion Lake	Shyok	Indus	4512	Category-4
	Leh	01_52A_003	0152A0802503	NA	35.092	76.2523	M(e): End-moraine Dammed Lake	Shyok	Indus	4533	Category-3
	Leh	01_52A_004	0152A0802509	NA	35.0743	76.2928	E(c): Cirque Erosion Lake	Shyok	Indus	4599	Category-4
	Leh	173	0152B0902855	NA	34.7649	76.7109	E(o): Other Glacial Erosion Lake	Shyok	Indus	5123	Category-4
	Leh	01_52E_001	NA	NA	35.418	77.6046	NA	Shyok	Indus	5122	Inadequate Data
	Leh	01_52J_001	0152J0303811	NA	34.4565	78.1364	M(o): Other Moraine Dammed Lake	Kunzang Lungpa	Shyok	5295	Category-4
	Leh	01_52B_010	0152B1202878	NA	34.0512	76.7178	M(e): End-moraine Dammed Lake	Spang	Indus	5093	Category-4
	Leh	01_52L_006	0152L1504080	NA	32.4406	78.9249	M(e): End-moraine Dammed Lake	Miksadiu	Indus	5680	Category-4
	Leh	01_52L_007	0152L1504092	NA	32.4093	78.8997	M(e): End-moraine Dammed Lake	Nalung	Indus	5468	Category-4

