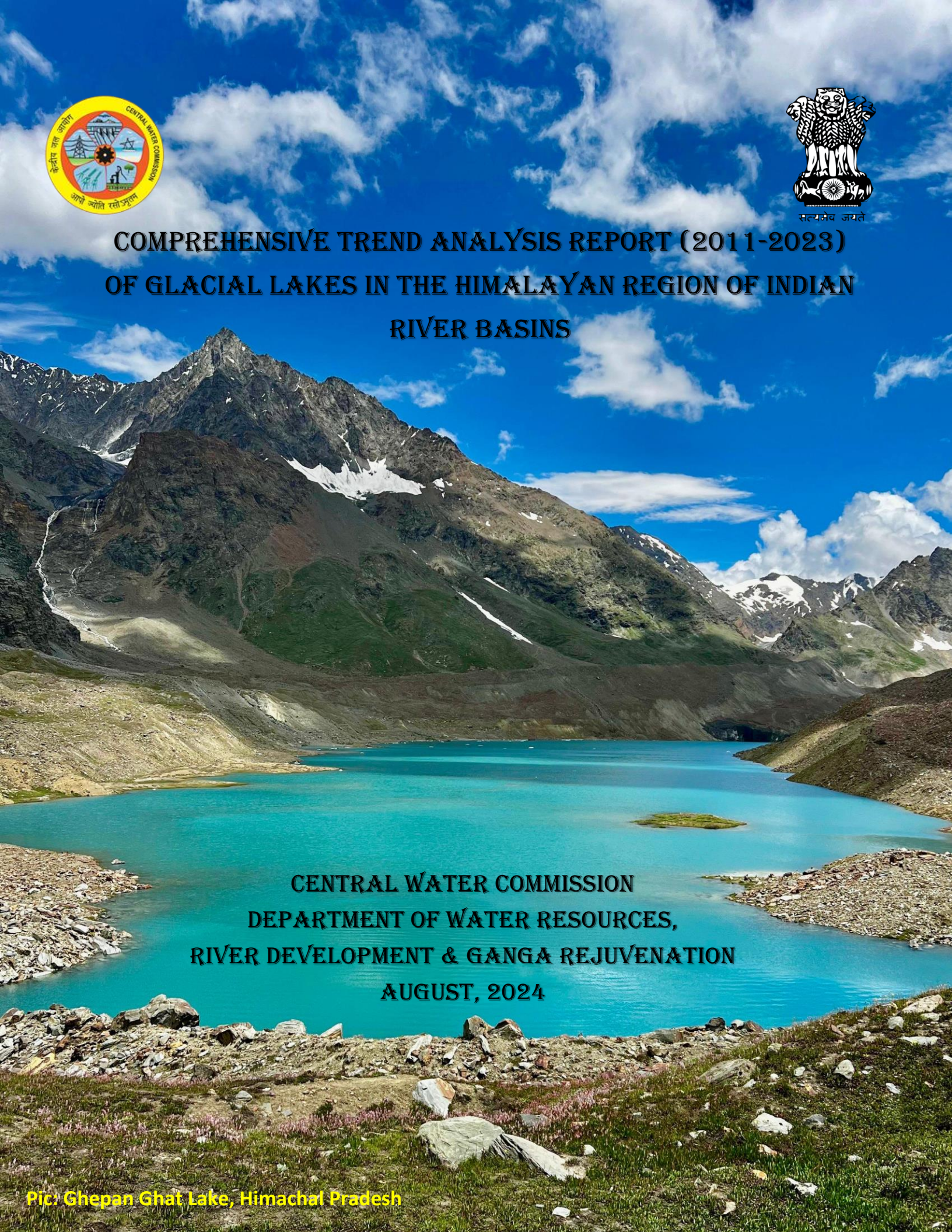
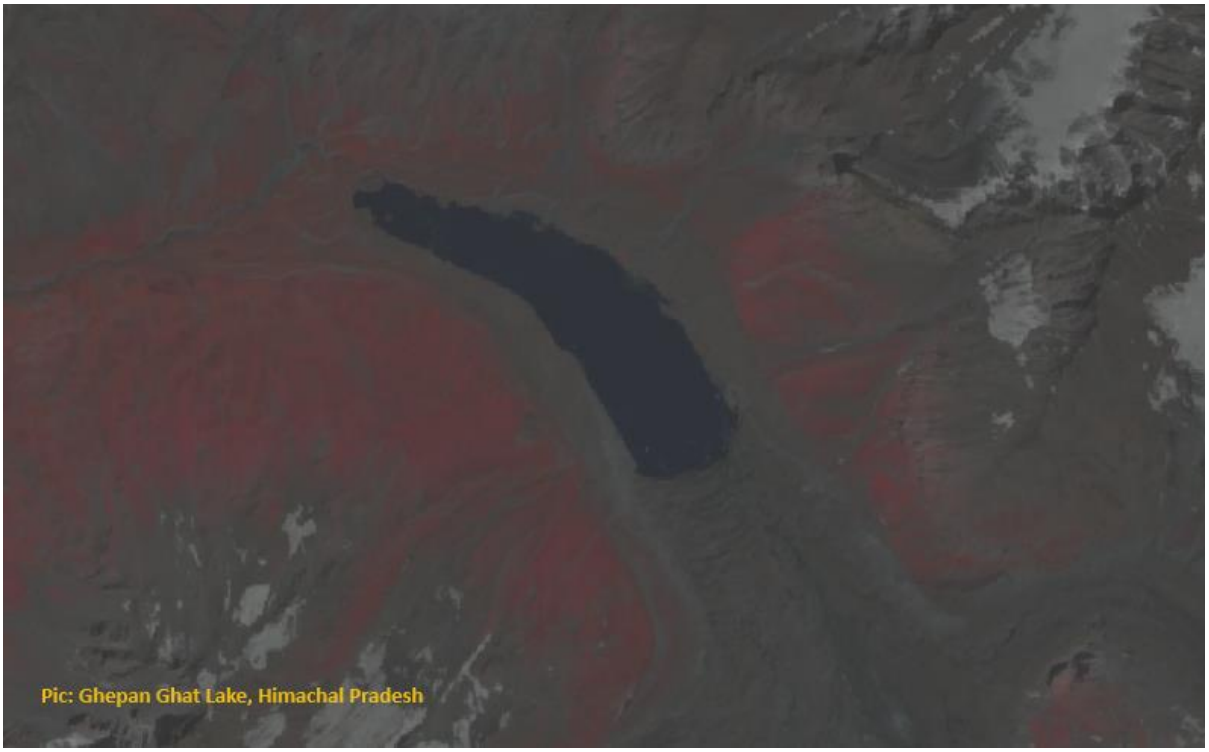
COMPREHENSIVE TREND ANALYSIS REPORT (2011-2023) OF GLACIAL LAKES IN THE HIMALAYAN REGION OF INDIAN RIVER BASINS



CENTRAL WATER COMMISSION
DEPARTMENT OF WATER RESOURCES,
RIVER DEVELOPMENT & GANGA REJUVENATION
AUGUST, 2024

Pic: Ghepan Ghat Lake, Himachal Pradesh

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	**Comprehensive Trend Analysis Report (2011-2023) of Glacial Lakes in the Himalayan Region of Indian River Basins**			
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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.	Abstract (with Keywords): CWC monitors 902 Glacial Lakes & 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 & 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 $\pm$10 and $\pm$20% margin has been covered under **Section-I**. **Section-II** 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. Keywords: Glacial Lake, Water Bodies, Indian Himalayan Region, Satellite Images, Remote Sensing, Google Earth Engine, Trend Analysis, Flow Path, GLOF				

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ABBREVIATIONS	
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		**Total**	**503**	**1525**	**2028**
Myanmar	-	4	4					
Total	**503**	**1525**	**2028**					

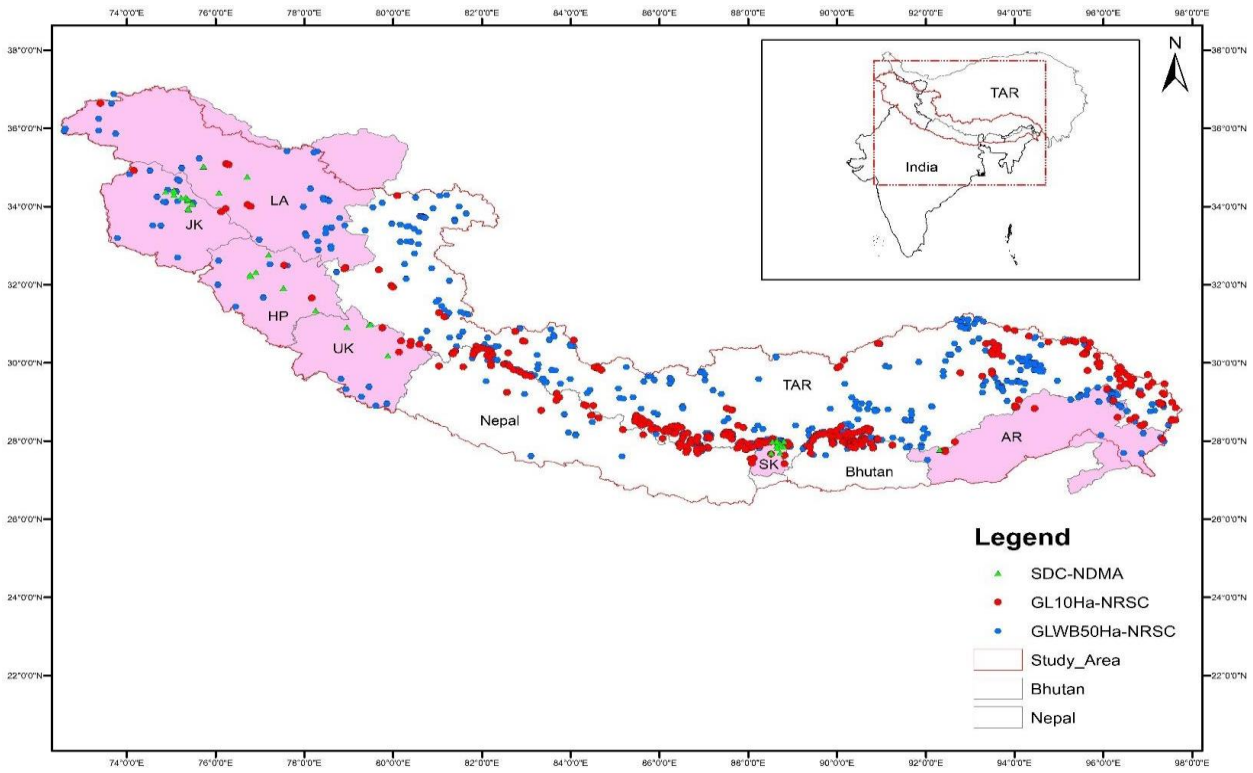
Monitoring of 477 GLs/WBs with size more than 50 ha, sourced from Glacial Lake Inventory 2011, for change in water spread area, was carried out during monsoon season (June to October) every year since 2011. The monitoring activity initiated in NRSC was continued till 2015. CWC has taken up monitoring 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
	Total	40	9	51	100		47	6	26	79	179
	India Total	100					79				179
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
	Total	12	174	258	444		49	28	202	279	723
	Transboundary Total	444					279				723
Grand Total		544					358				902

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 ±10% & ±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
Total	**10**	**8**	**0**	**0**

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
Total	**24**	**24**	**18**	**17**

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 ±10% and ±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.

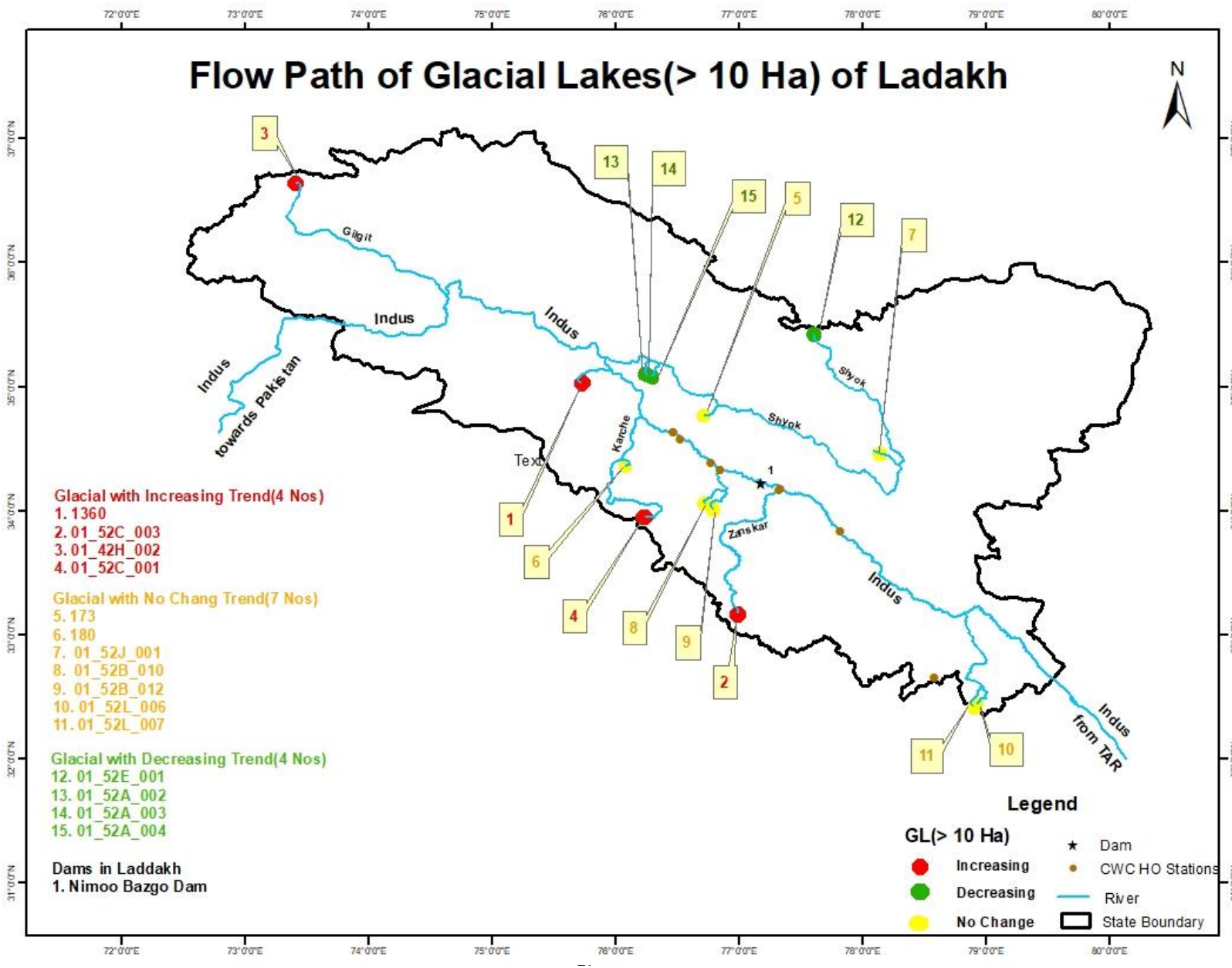
- Almost *50% of larger lakes(size >50 Ha)* has increase more than 20% whereas *28% of the medium sized lakes (size 10-50 Ha)* have increase more than 20%. The interpretation of trend line of individual lakes shows that the medium sized lakes are increasing at a faster pace than larger lakes.

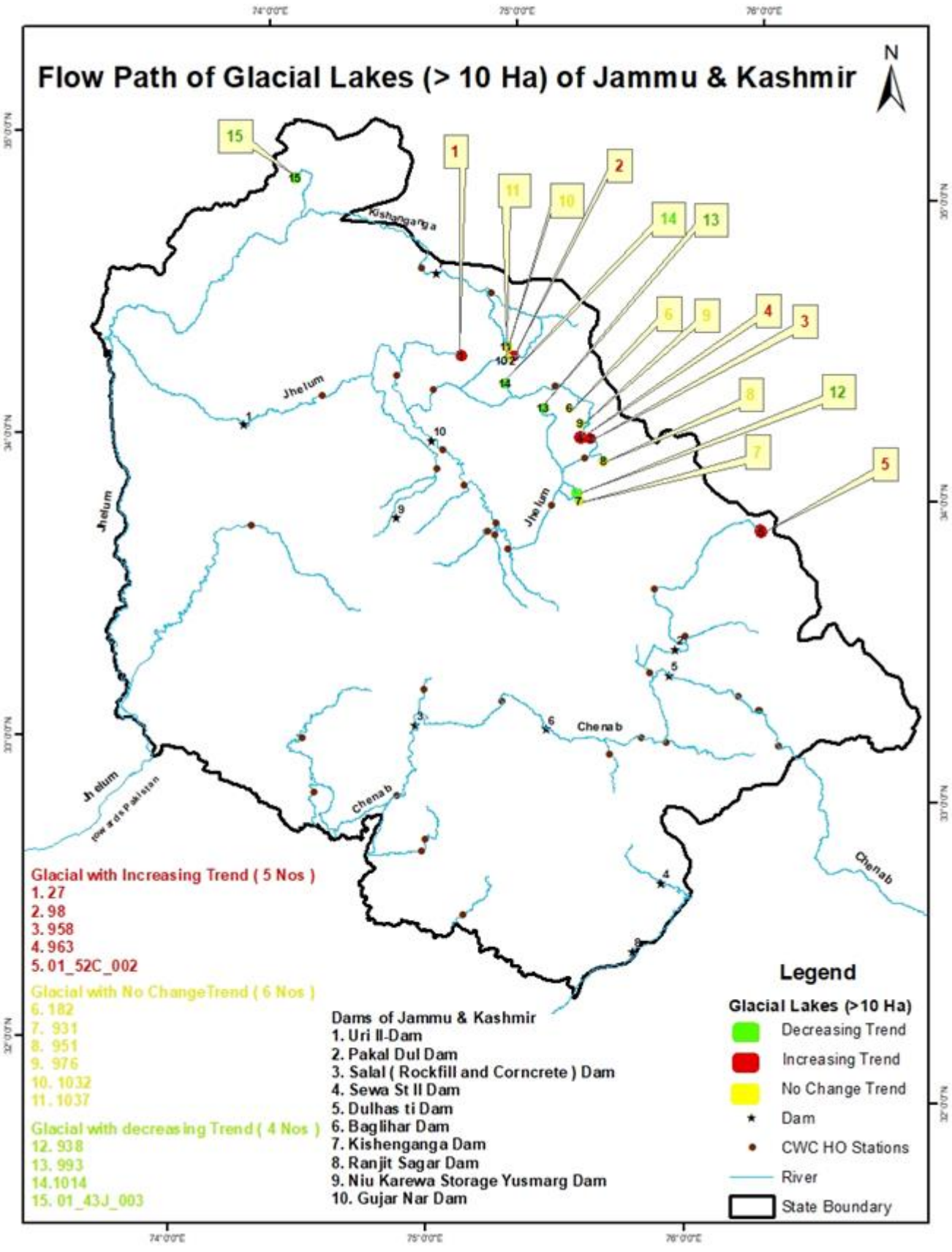
- It is seen that none of the larger lakes have shown increase more than 20% in the recent term, whereas about 20% of the medium sized lakes shown increase more than 20% in recent years.

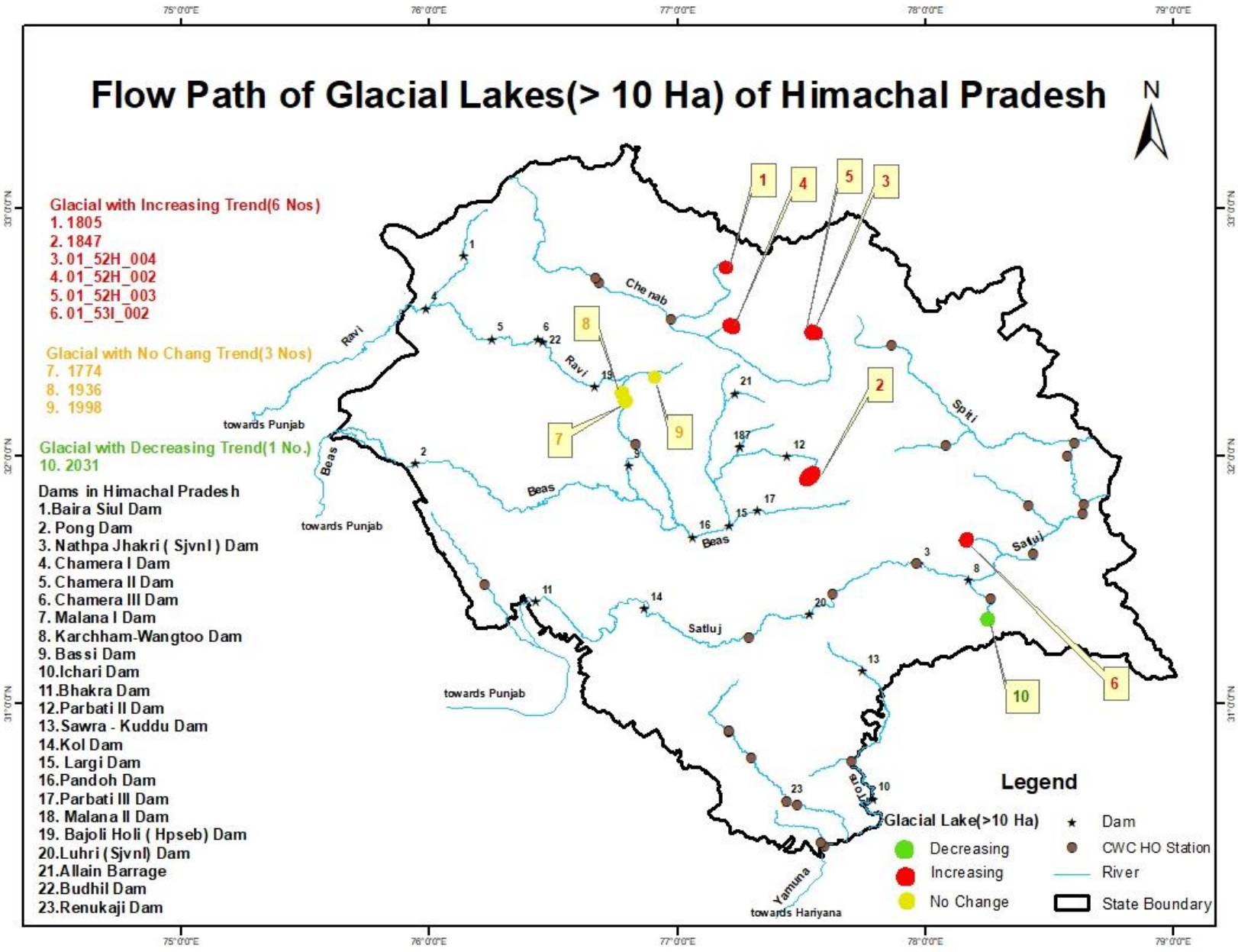
Section-II:

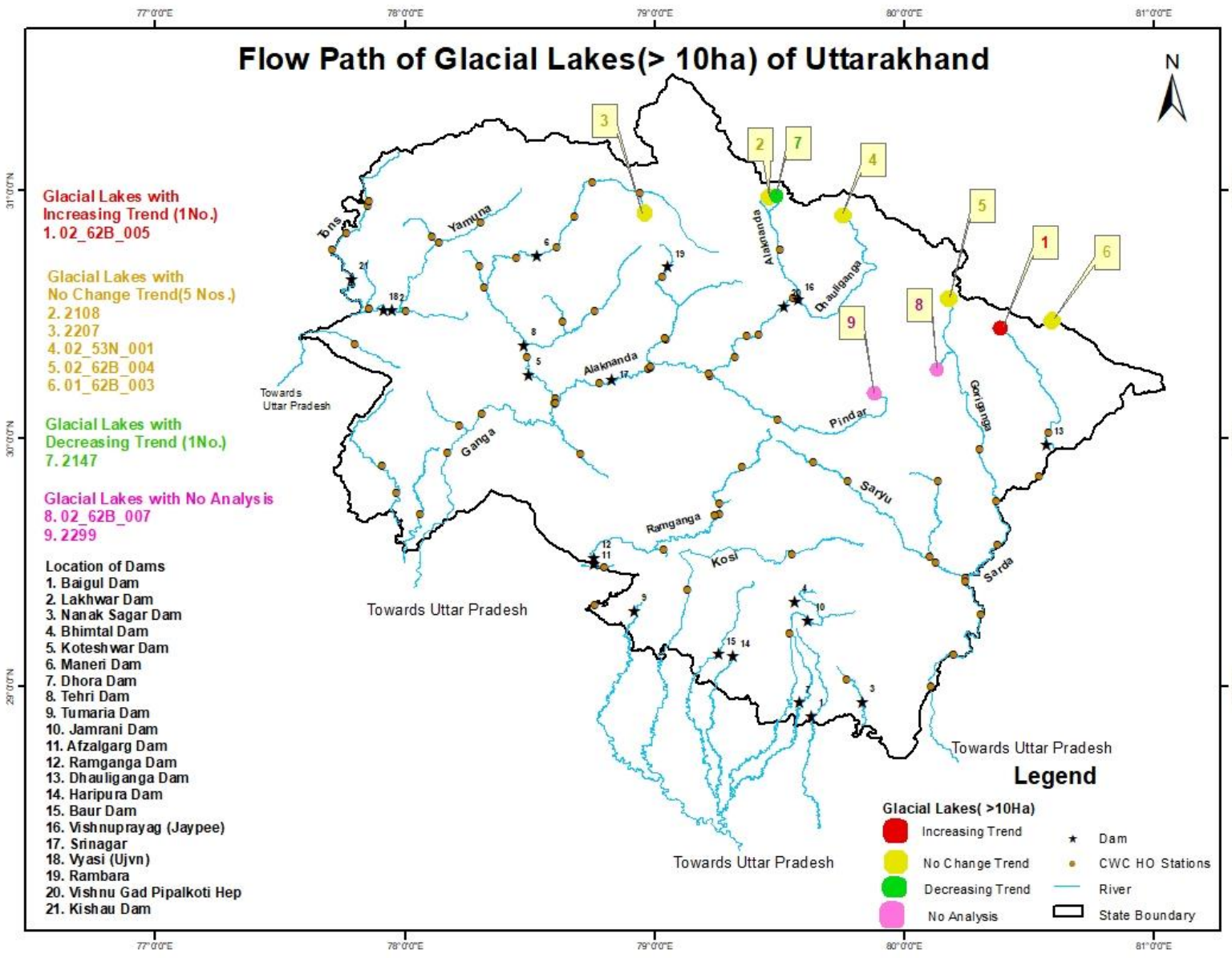
Finally to have knowledge in advance about the impact of damage on settlements, infrastructures, Projects, etc due to breach of Glacial Lake resulting in GLOF, the **flow path for all the 100 Glacial Lakes** have been mapped along with projects and CWC HO stations enroute. This is presented in **Section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

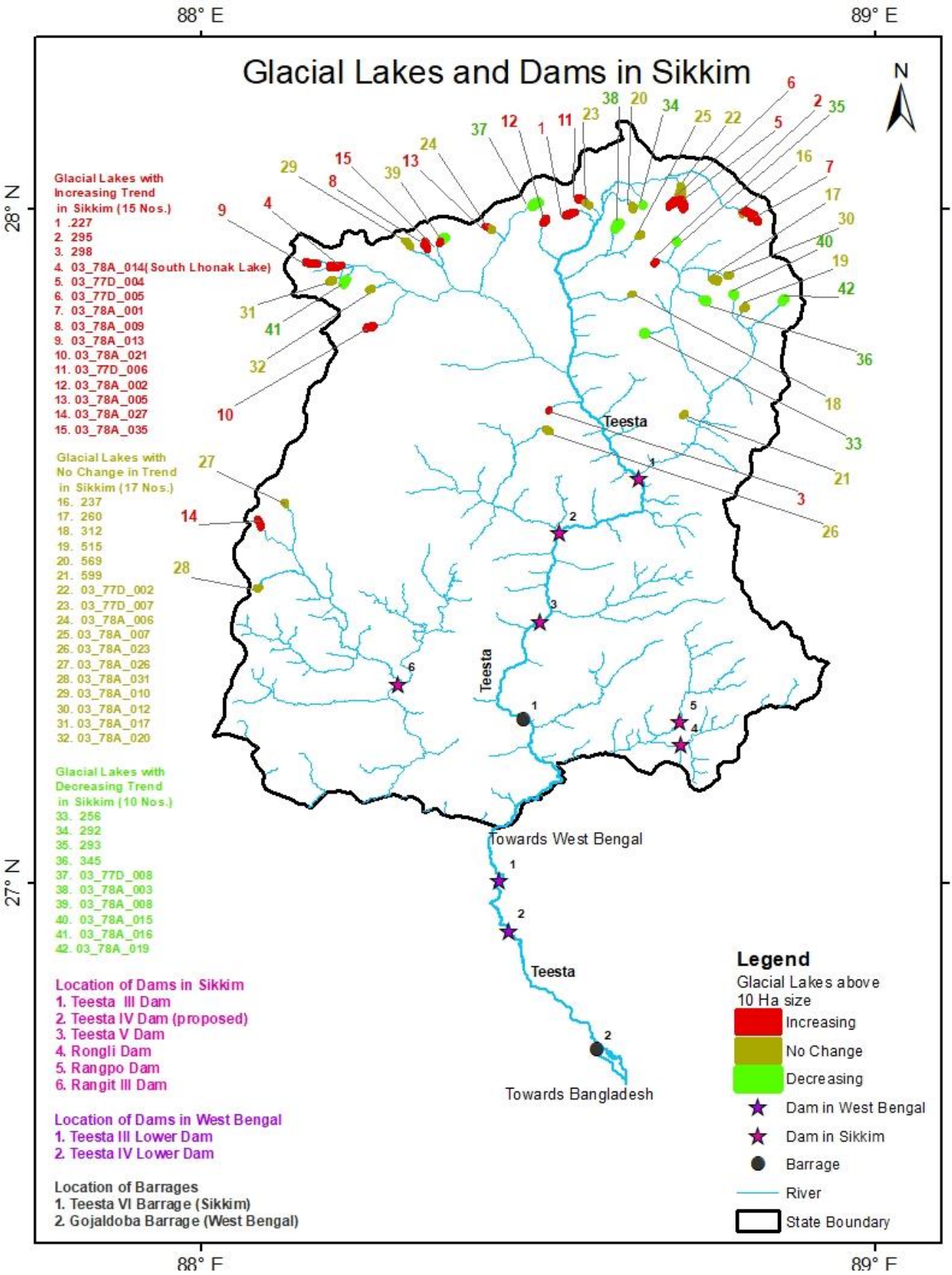
Further mapping of settlements, various infrastructures are in progress. State wise maps are given below.

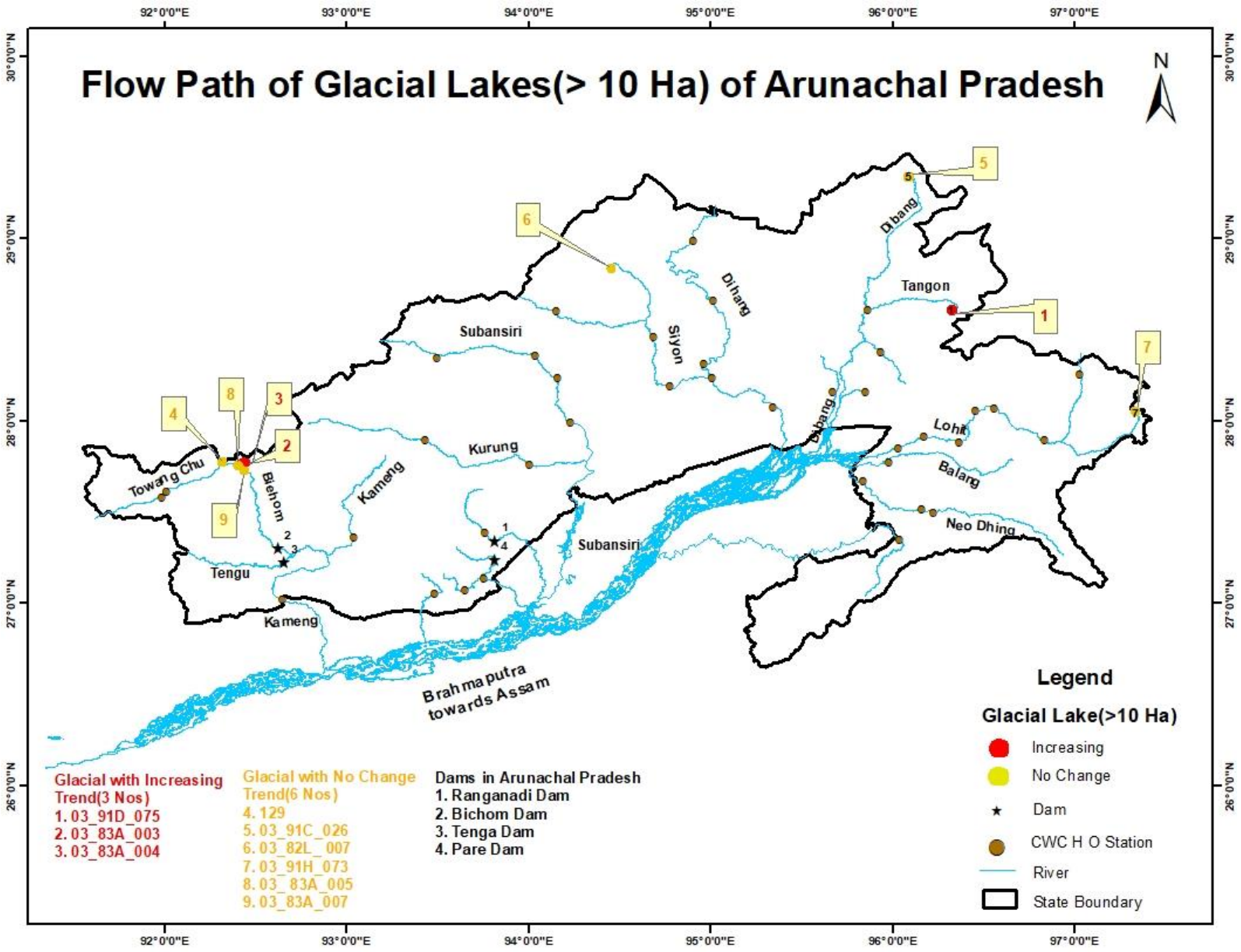

Flow Path of Glacial Lakes(> 10 Ha) of Ladakh
N
72°0'0"E
73°0'0"E
74°0'0"E
75°0'0"E
76°0'0"E
77°0'0"E
78°0'0"E
79°0'0"E
80°0'0"E
37°0'0"N
36°0'0"N
35°0'0"N
34°0'0"N
33°0'0"N
32°0'0"N
31°0'0"N
Gilgit
Indus
Indus towards Pakistan
Indus
Shyok
Shyok
Karche
Zanskar
Indus
Indus from TAR
Text
Glacial with Increasing Trend(4 Nos)
1. 1360
2. 01_52C_003
3. 01_42H_002
4. 01_52C_001
Glacial with No Chang Trend(7 Nos)
5. 173
6. 180
7. 01_52J_001
8. 01_52B_010
9. 01_52B_012
10. 01_52L_006
11. 01_52L_007
Glacial with Decreasing Trend(4 Nos)
12. 01_52E_001
13. 01_52A_002
14. 01_52A_003
15. 01_52A_004
Dams in Laddakh
1. Nimoo Bazgo Dam
Legend
GL(> 10 Ha)
Increasing
Decreasing
No Change
Dam
CWC HO Stations
River
State Boundary


Flow Path of Glacial Lakes (> 10 Ha) of Jammu & Kashmir
N
Kishanganga
Jhelum
Chenab
Glacial with Increasing Trend (5 Nos)
1. 27
2. 98
3. 958
4. 963
5. 01_52C_002
Glacial with No ChangeTrend (6 Nos)
6. 182
7. 931
8. 951
9. 976
10. 1032
11. 1037
Glacial with decreasing Trend (4 Nos)
12. 938
13. 993
14.1014
15. 01_43J_003
Dams of Jammu & Kashmir
1. Uri II-Dam
2. Pakal Dul Dam
3. Salal (Rockfill and Corncrete) Dam
4. Sewa St II Dam
5. Dulhas ti Dam
6. Baglihar Dam
7. Kishenganga Dam
8. Ranjit Sagar Dam
9. Niu Karewa Storage Yusmarg Dam
10. Gujar Nar Dam
Legend
Glacial Lakes (>10 Ha)
Decreasing Trend
Increasing Trend
No Change Trend
Dam
CWC HO Stations
River
State Boundary


Flow Path of Glacial Lakes(> 10 Ha) of Himachal Pradesh
N
75°0'0"E
76°0'0"E
77°0'0"E
78°0'0"E
79°0'0"E
33°0'0"N
32°0'0"N
31°0'0"N
Glacial with Increasing Trend(6 Nos)
1. 1805
2. 1847
3. 01_52H_004
4. 01_52H_002
5. 01_52H_003
6. 01_53I_002
Glacial with No Chang Trend(3 Nos)
7. 1774
8. 1936
9. 1998
Glacial with Decreasing Trend(1 No.)
10. 2031
Dams in Himachal Pradesh
1.Baira Siul Dam
2. Pong Dam
3. Nathpa Jhakri (Sjvnl) Dam
4. Chamera I Dam
5. Chamera II Dam
6. Chamera III Dam
7. Malana I Dam
8. Karchham-Wangtoo Dam
9. Bassi Dam
10.Ichari Dam
11.Bhakra Dam
12.Parbati II Dam
13.Sawra - Kuddu Dam
14.Kol Dam
15. Largi Dam
16.Pandoh Dam
17.Parbati III Dam
18. Malana II Dam
19. Bajoli Holi (Hpseb) Dam
20.Luhri (Sjvnl) Dam
21.Allain Barrage
22.Budhil Dam
23.Renukaji Dam
Chenab
Ravi
Beas
Satluj
Spiti
Yamuna
towards Punjab
towards Hariyana
Legend
Glacial Lake(>10 Ha)
Decreasing
Increasing
No Change
Dam
CWC HO Station
River
State Boundary


Flow Path of Glacial Lakes(> 10ha) of Uttarakhand
N
77°0'0"E
78°0'0"E
79°0'0"E
80°0'0"E
81°0'0"E
31°0'0"N
30°0'0"N
29°0'0"N
Glacial Lakes with Increasing Trend (1No.)
1. 02_62B_005
Glacial Lakes with No Change Trend(5 Nos.)
2. 2108
3. 2207
4. 02_53N_001
5. 02_62B_004
6. 01_62B_003
Glacial Lakes with Decreasing Trend (1No.)
7. 2147
Glacial Lakes with No Analysis
8. 02_62B_007
9. 2299
Location of Dams
1. Baigul Dam
2. Lakhwar Dam
3. Nanak Sagar Dam
4. Bhimtal Dam
5. Koteshwar Dam
6. Maneri Dam
7. Dhora Dam
8. Tehri Dam
9. Tumaria Dam
10. Jamrani Dam
11. Afzalgarg Dam
12. Ramganga Dam
13. Dhauliganga Dam
14. Haripura Dam
15. Baur Dam
16. Vishnuprayag (Jaypee)
17. Srinagar
18. Vyasi (Ujvn)
19. Rambara
20. Vishnu Gad Pipalkoti Hep
21. Kishau Dam
Towards Uttar Pradesh
Towards Uttar Pradesh
Towards Uttar Pradesh
Towards Uttar Pradesh
Yamuna
Alaknanda
Dhauliganga
Alaknanda
Pindar
Ganga
Ramganga
Kosi
Saryu
Gori Ganga
Sarda
Legend
Glacial Lakes(>10Ha)
Increasing Trend
No Change Trend
Decreasing Trend
No Analysis
Dam
CWC HO Stations
River
State Boundary


Glacial Lakes and Dams in Sikkim
88° E
89° E
28° N
27° N
N
Glacial Lakes with Increasing Trend in Sikkim (15 Nos.)
1 .227
2. 295
3. 298
4. 03_78A_014(South Lhonak Lake)
5. 03_77D_004
6. 03_77D_005
7. 03_78A_001
8. 03_78A_009
9. 03_78A_013
10. 03_78A_021
11. 03_77D_006
12. 03_78A_002
13. 03_78A_005
14. 03_78A_027
15. 03_78A_035
Glacial Lakes with No Change in Trend in Sikkim (17 Nos.)
16. 237
17. 260
18. 312
19. 515
20. 569
21. 599
22. 03_77D_002
23. 03_77D_007
24. 03_78A_006
25. 03_78A_007
26. 03_78A_023
27. 03_78A_026
28. 03_78A_031
29. 03_78A_010
30. 03_78A_012
31. 03_78A_017
32. 03_78A_020
Glacial Lakes with Decreasing Trend in Sikkim (10 Nos.)
33. 256
34. 292
35. 293
36. 345
37. 03_77D_008
38. 03_78A_003
39. 03_78A_008
40. 03_78A_015
41. 03_78A_016
42. 03_78A_019
Location of Dams in Sikkim
1. Teesta III Dam
2. Teesta IV Dam (proposed)
3. Teesta V Dam
4. Rongli Dam
5. Rangpo Dam
6. Rangit III Dam
Location of Dams in West Bengal
1. Teesta III Lower Dam
2. Teesta IV Lower Dam
Location of Barrages
1. Teesta VI Barrage (Sikkim)
2. Gojaldoba Barrage (West Bengal)
Teesta
Towards West Bengal
Towards Bangladesh
Legend
Glacial Lakes above 10 Ha size
Increasing
No Change
Decreasing
Dam in West Bengal
Dam in Sikkim
Barrage
River
State Boundary


Flow Path of Glacial Lakes(> 10 Ha) of Arunachal Pradesh
N
92°0'0"E
93°0'0"E
94°0'0"E
95°0'0"E
96°0'0"E
97°0'0"E
30°0'0"N
29°0'0"N
28°0'0"N
27°0'0"N
26°0'0"N
Subansiri
Kurung
Kameng
Tengu
Siyon
Dihang
Dibang
Tangon
Lohit
Balang
Neo Dhing
Towang Chu
Bichom
Brahmaputra towards Assam
Glacial with Increasing Trend(3 Nos)
1. 03_91D_075
2. 03_83A_003
3. 03_83A_004
Glacial with No Change Trend(6 Nos)
4. 129
5. 03_91C_026
6. 03_82L_007
7. 03_91H_073
8. 03_83A_005
9. 03_83A_007
Dams in Arunachal Pradesh
1. Ranganadi Dam
2. Bichom Dam
3. Tenga Dam
4. Pare Dam
Legend
Glacial Lake(>10 Ha)
Increasing
No Change
Dam
CWC H O Station
River
State Boundary

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
Total	**503**	**1525**	**2028**

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**

Table 1.3: Abstract of Glacial Lakes as per Glacial Lake Atlas of IHR of NRSC 2023

Size(Ha)	No of Glacial Lakes		Total
	India	Transboundary	
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
Total	7570	20473	28043

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
	Total	5	0	10	15	47	6	26	79	94
	India Total	15				79				94
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
	Total	1	48	55	104	49	28	202	279	383
	Total Transboundary	104				279				383
Grand Total		**Total Glacial Lakes = 119**				**Total Water Bodies = 358**				477

(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
	Total	35	9	41	85
	India Total	85			
Transboundary	China	**11**	**74**	**147**	232
	Bhutan	0	0	**56**	56
	Nepal	0	**52**	0	52
	Total	11	126	203	340
	Total Transboundary	340			
Grand Total		425			

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.**

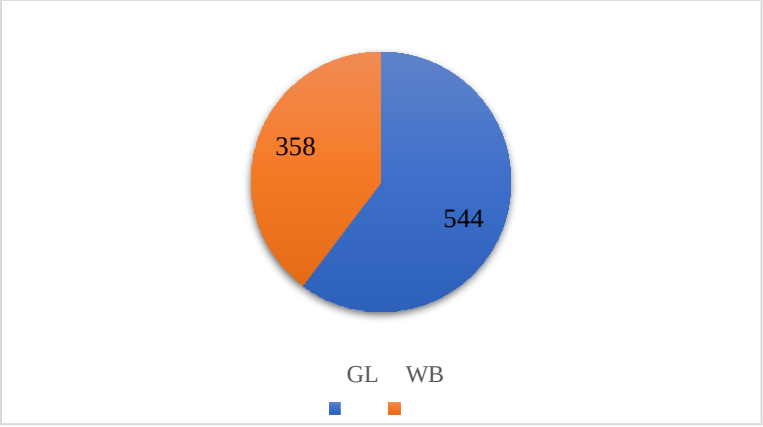


Figure 2.1: Lake Type Distribution

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
	Total	40	9	51	100		47	6	26	79	179
	India Total	100					79				179
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
	Total	12	174	258	444		49	28	202	279	723
	Transboundary Total	444					279				723
Grand Total		544					358				902

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**.

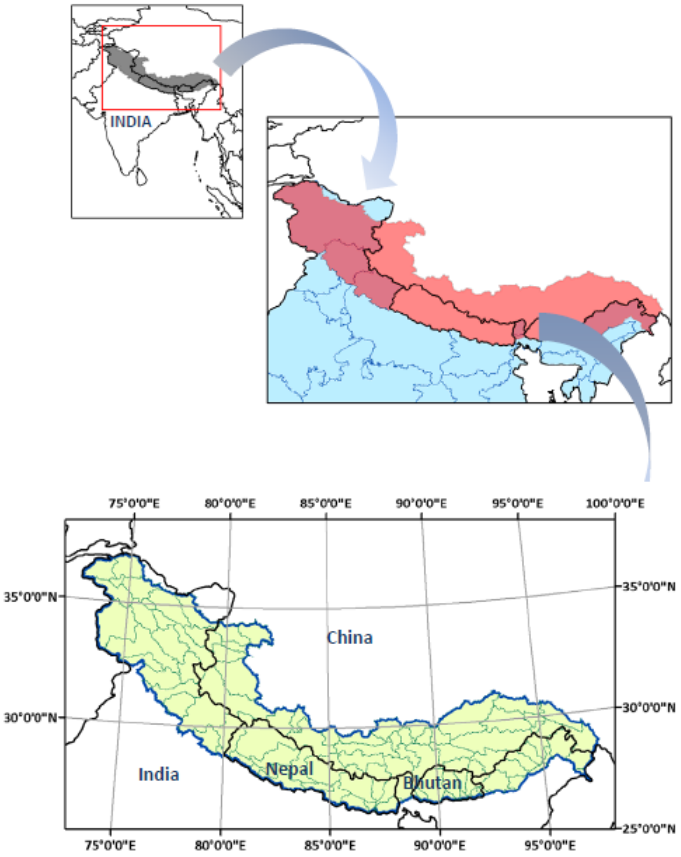


Figure 2.2: Index Map of Study Area

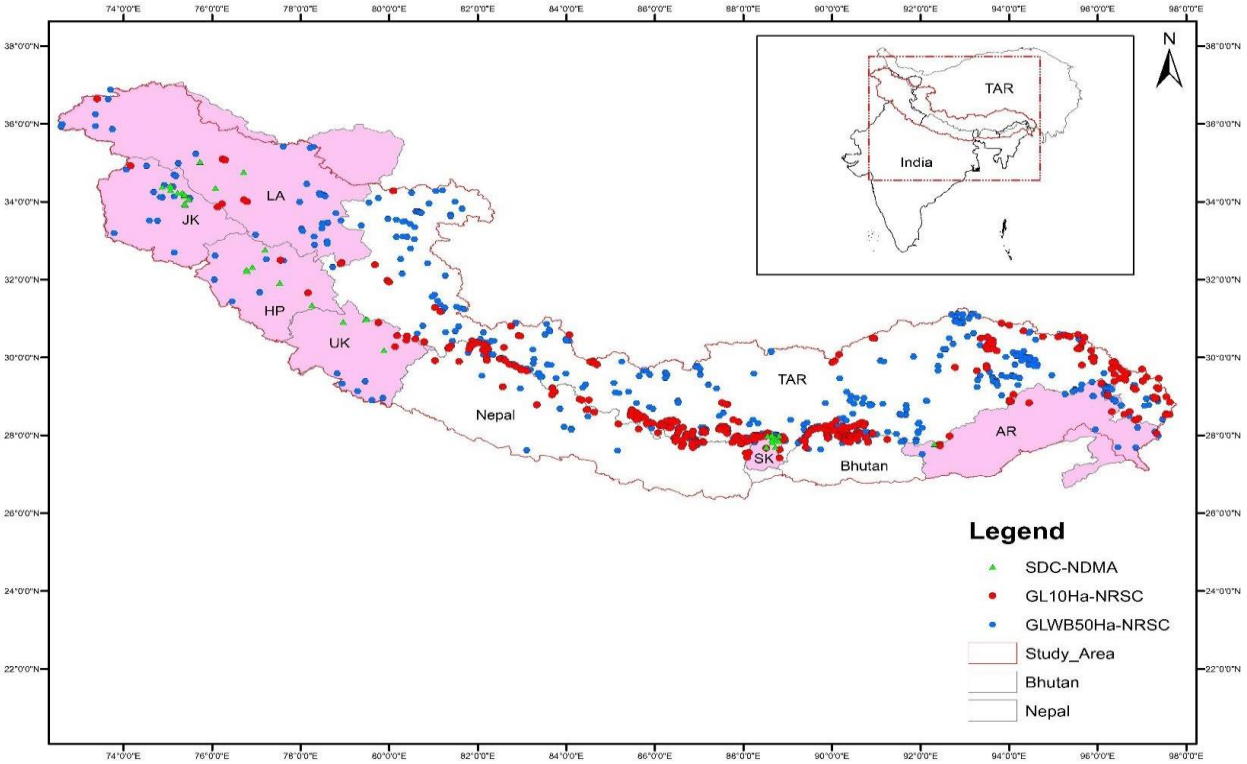


Figure 2.3: **Map of Study Area showing Glacial Lakes and Water Bodies being monitored by CWC**

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**

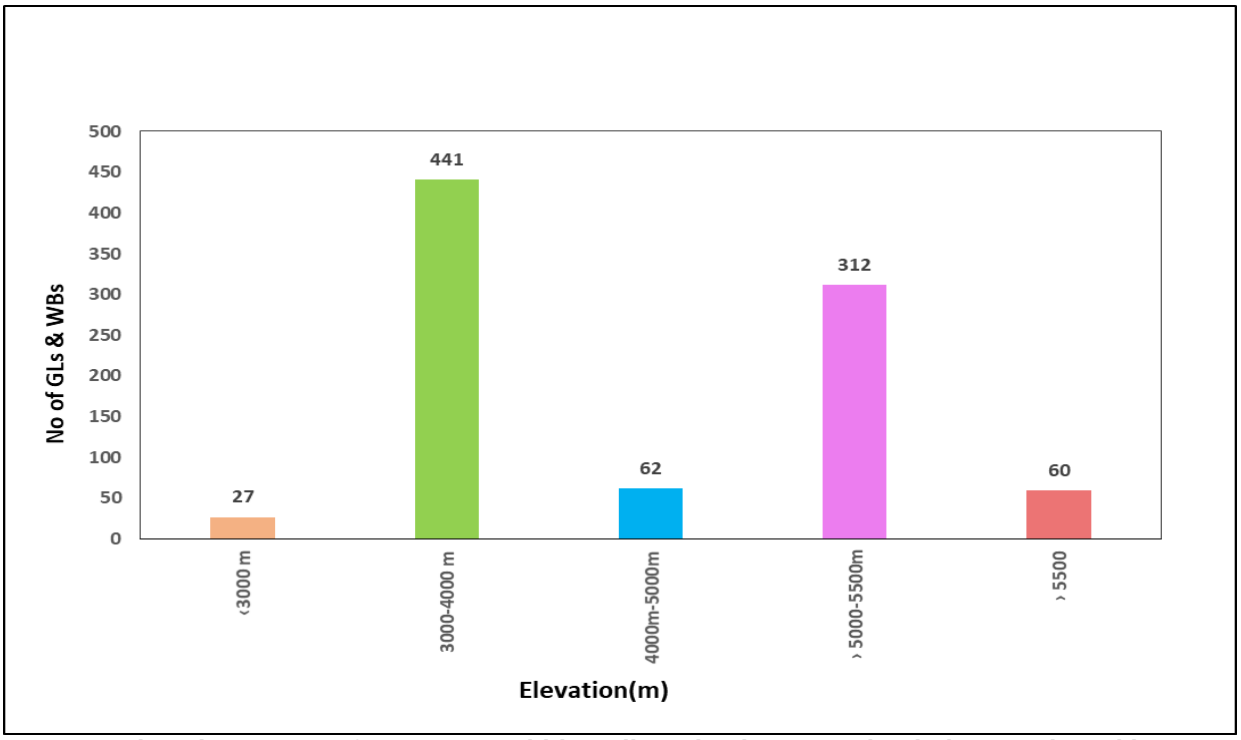


Figure 2.5: Elevation Range of GLs&WBs within Indian Himalayan Region being monitored by CWC

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

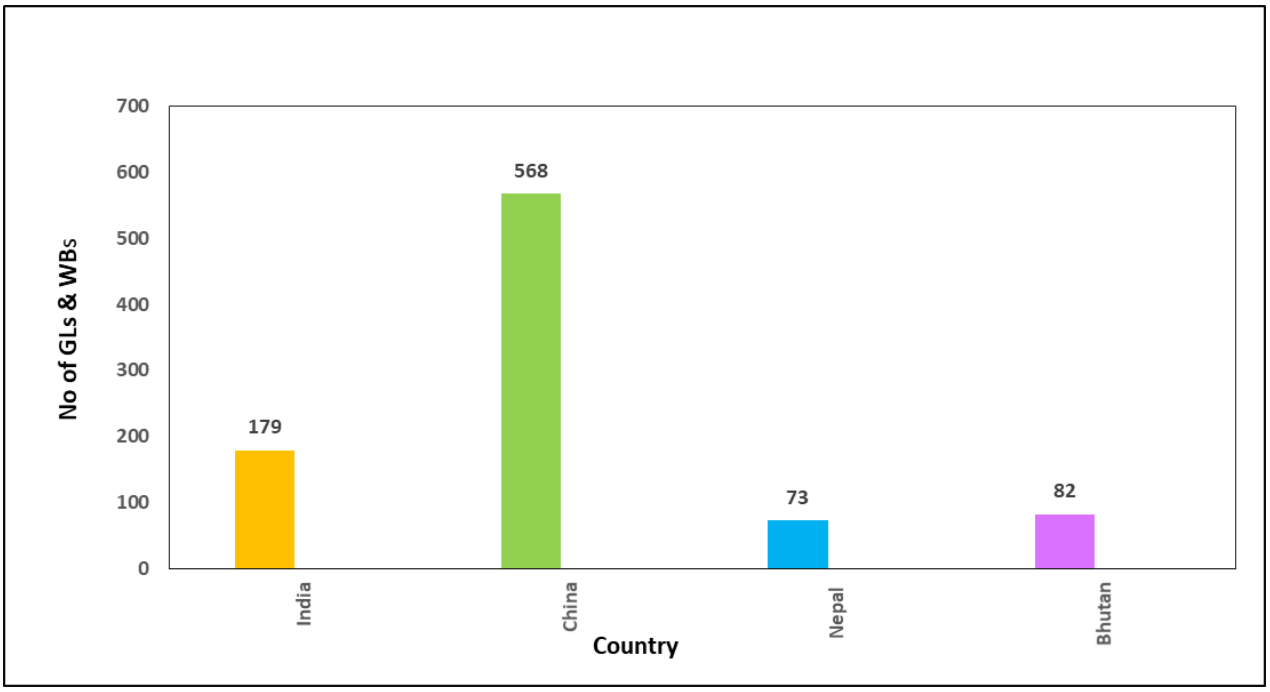


Figure 2.6:**Country-wise distribution of GLs & WBs in Indian Himalayan Region being monitored by CWC**

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

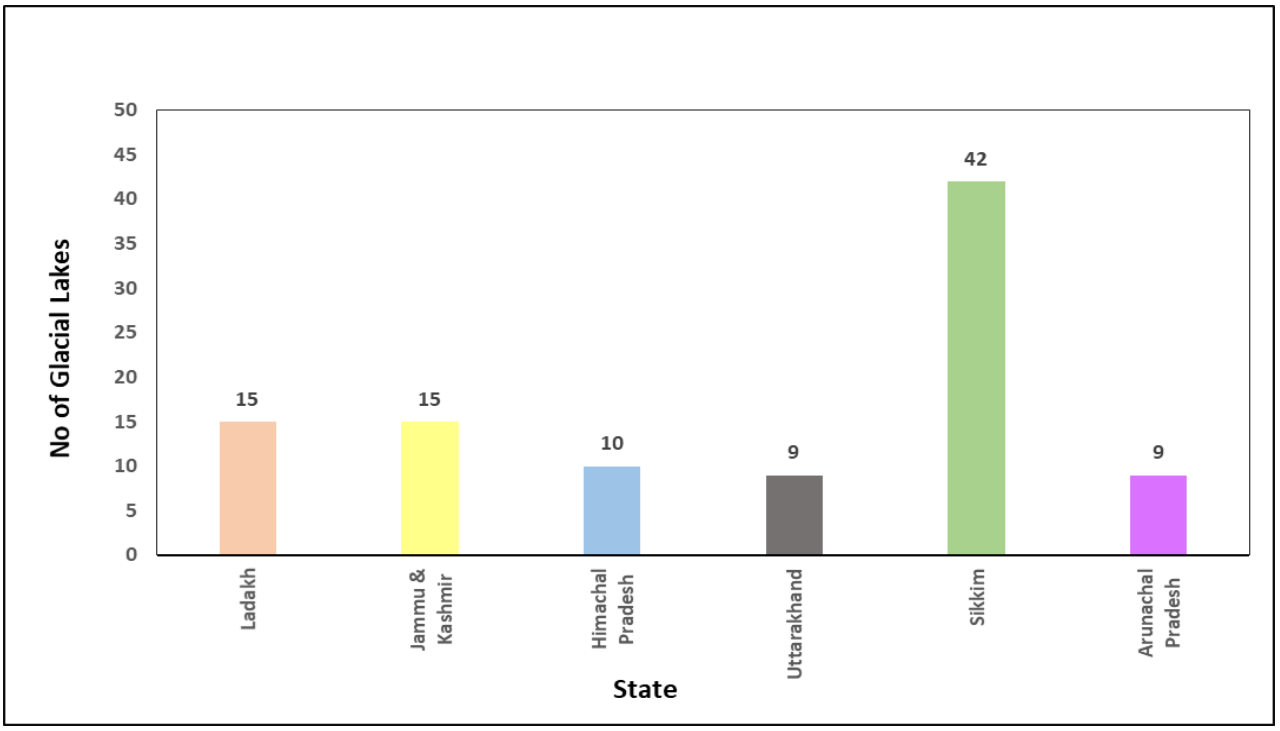


Figure: 2.7: State-wise Distribution of Glacial Lakes within India being monitored by CWC

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

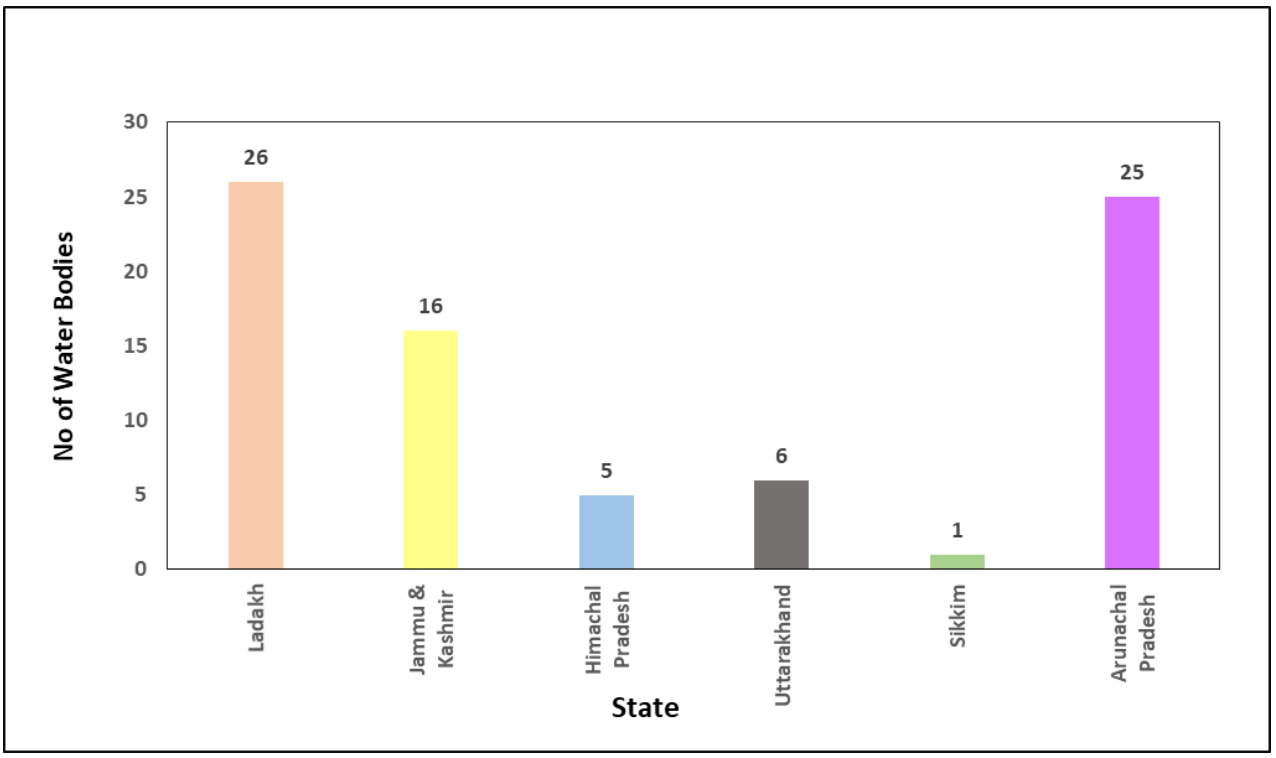


Figure: 2.8 State-wise Distribution of Water Bodies being monitored by CWC

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 plays 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 imageries 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 Sentinal-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 Clour 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**

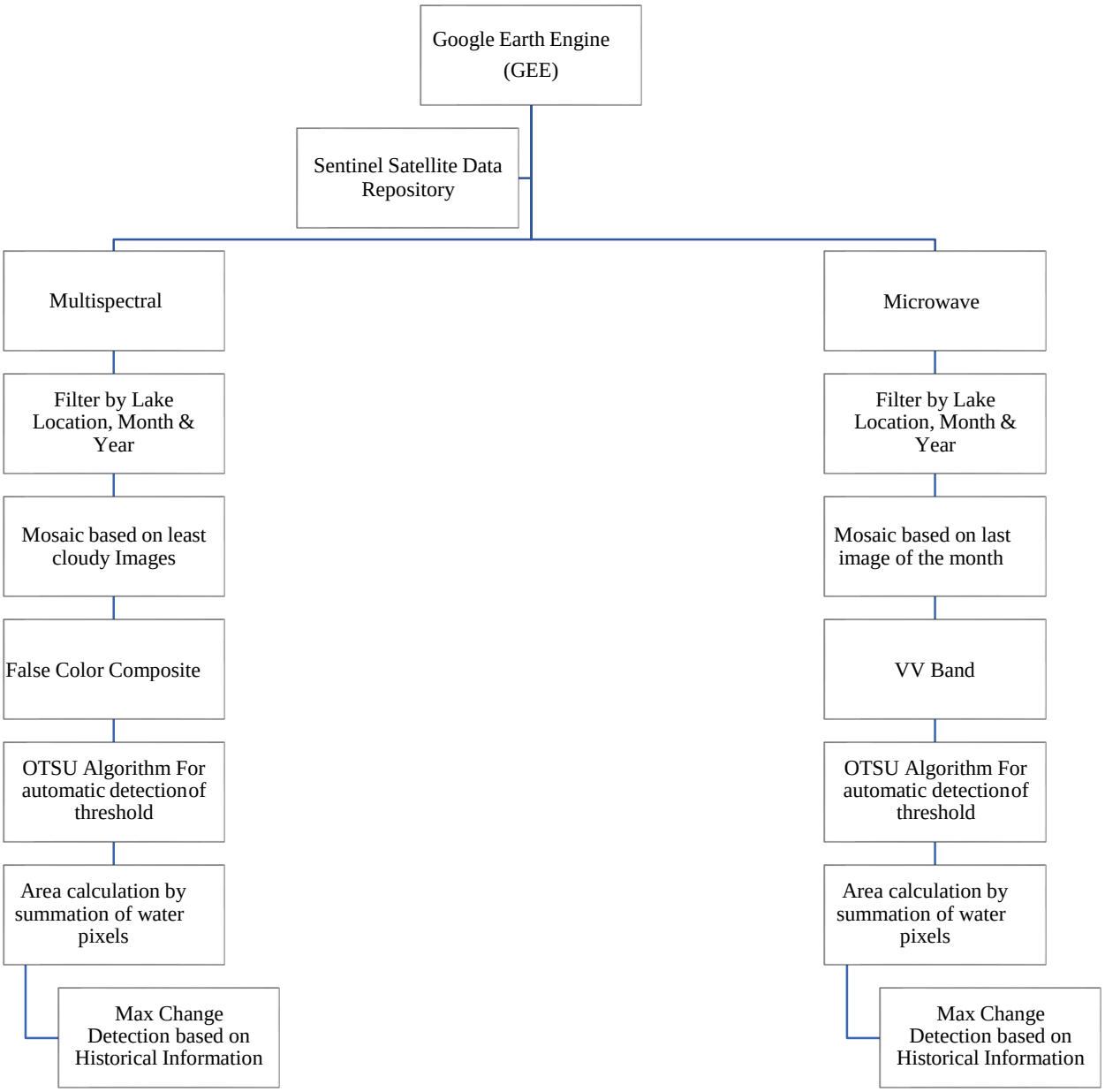


Figure 3.1*:* Methodology of automatic monitoring of Glacial Lakes & Water Bodies using Satellite Image

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.)*

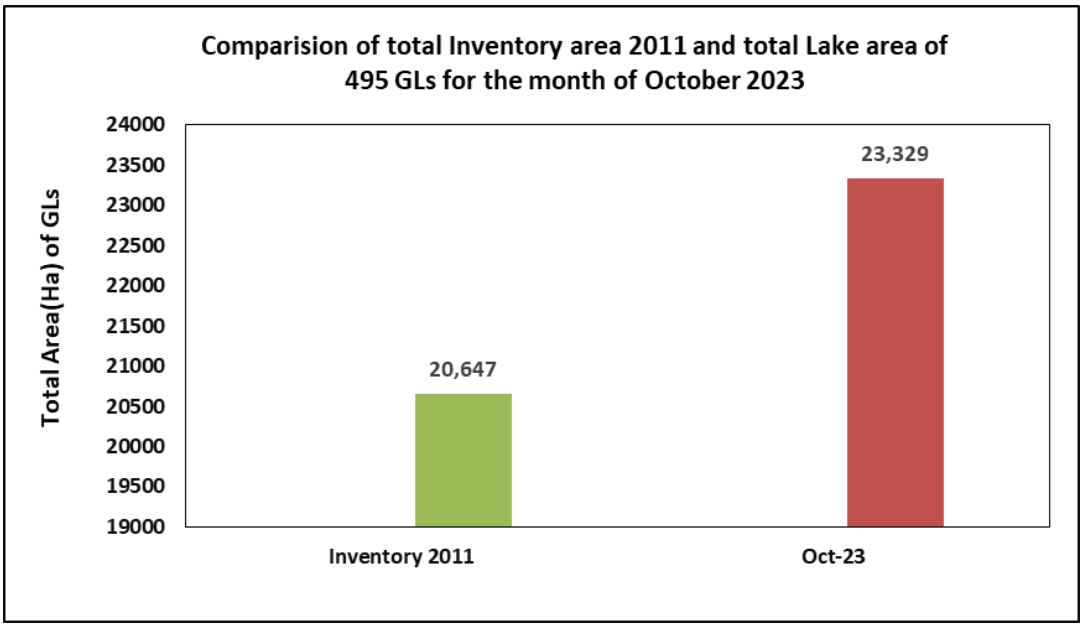


Figure 4.1: Comparison of total Inventory area (2011) and total area of October 2023 of 495 GLs

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.)*

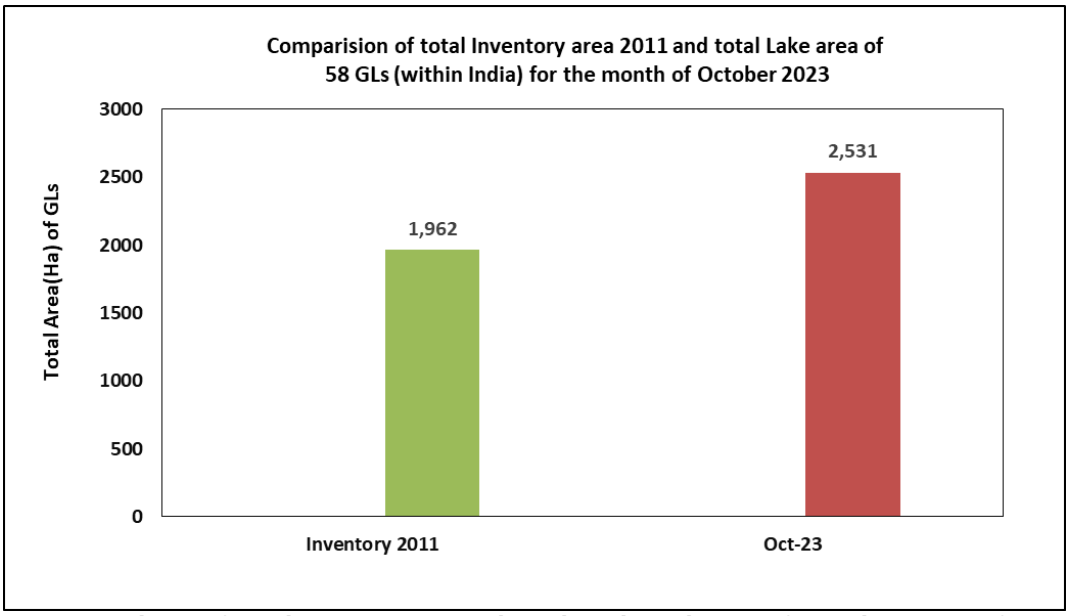


Figure 4.2: Comparison of total Inventory area (2011) and total area of October 2023 of 58 GLs located in India

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)*

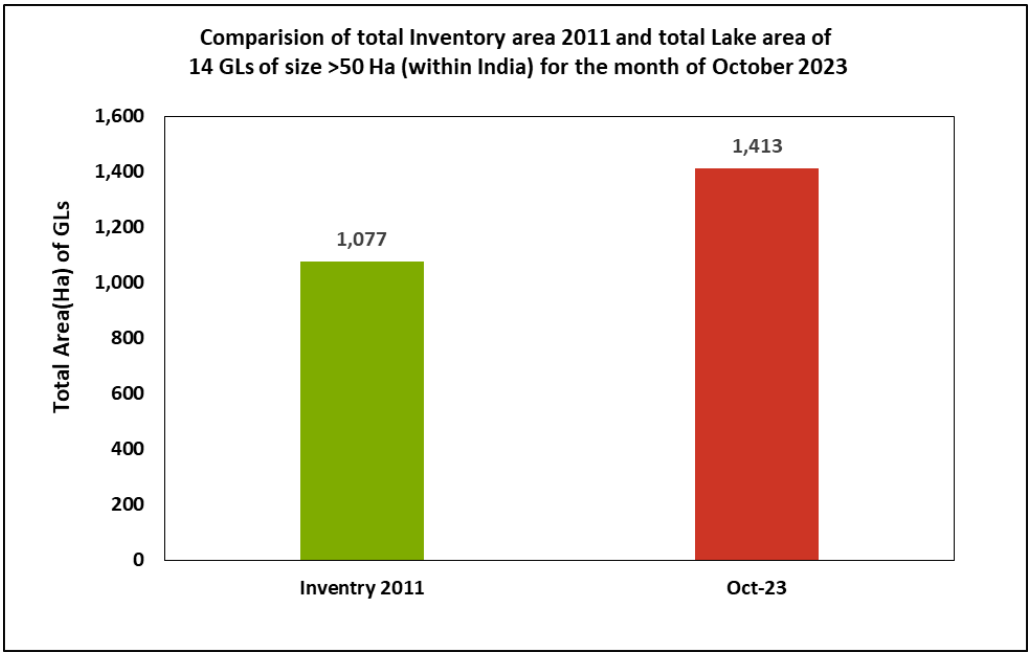


Figure 4.3: Comparison of total Inventory area (2011) and total area of October 2023 of 14 GLs (size > 50Ha) located in India

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)*

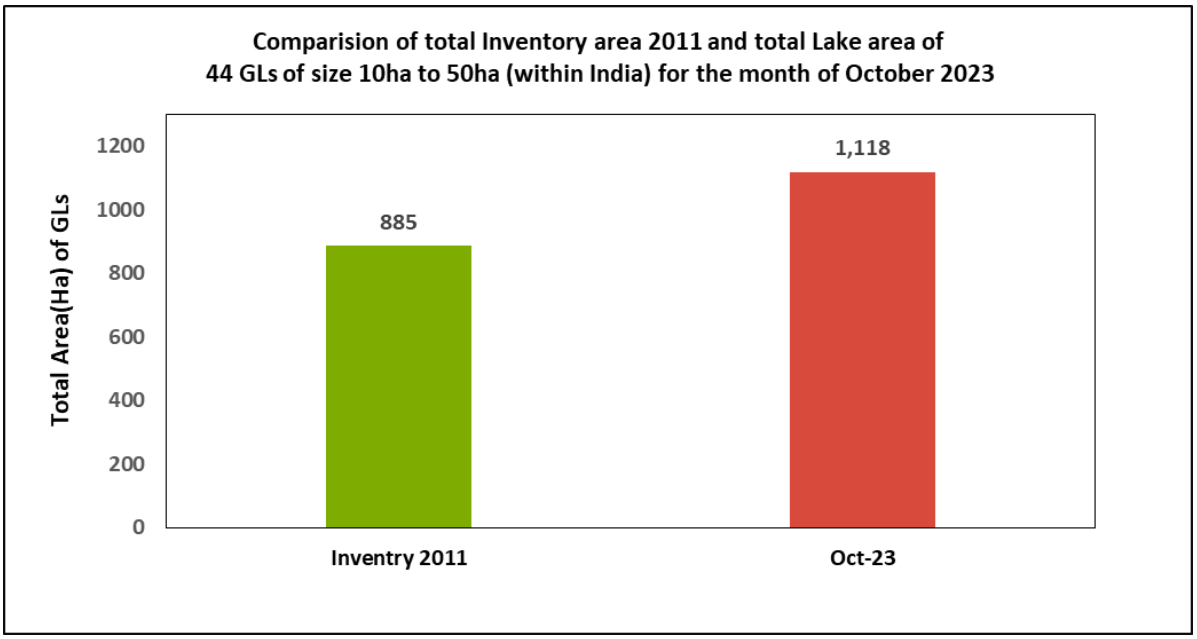


Figure 4.4: Comparison of total Inventory area (2011) and total area of October 2023 of 44 GLs (size 10 Ha to 50Ha) located in India

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 ±10% & ±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) ± 10%/± 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 tread, 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 ± 10% & ± 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 ± 10% & ± 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 ± 10% & ± 20% variation w.r.t. Base Year data of 2009**

(i) ± *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) ± *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 04th October 2023, leading to a decrease in water level on 05th October 2023.

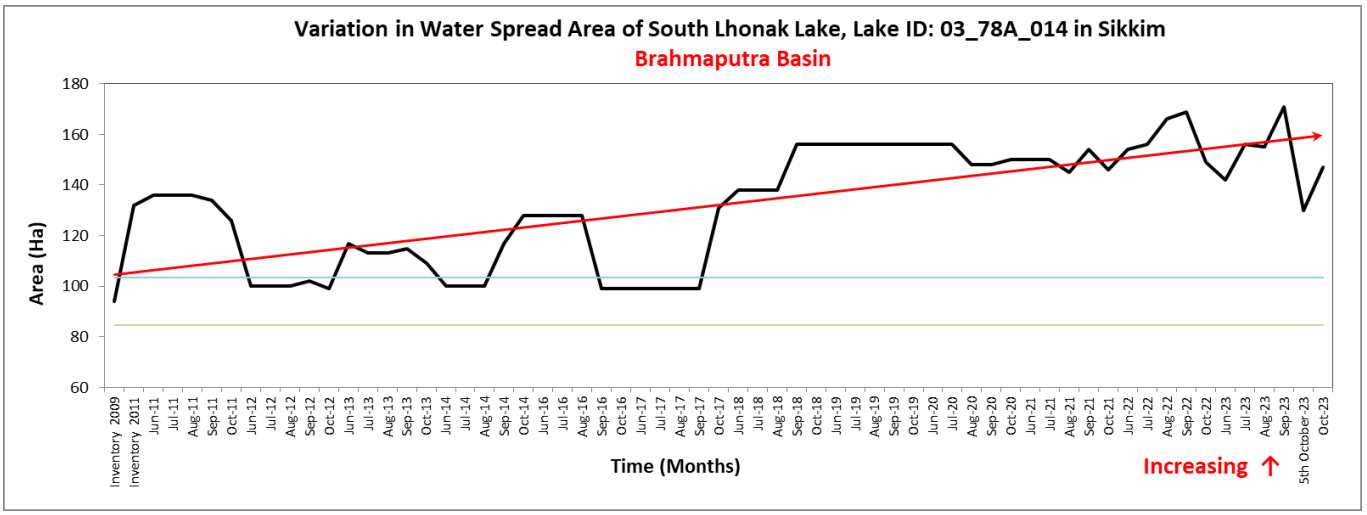


Figure 4.5(i): Trend Analysis plot of South Lhonak Lake (Lake ID: 03_78A_014), Sikkim, for ± 10% variation w.r.t. Base Year data of 2009

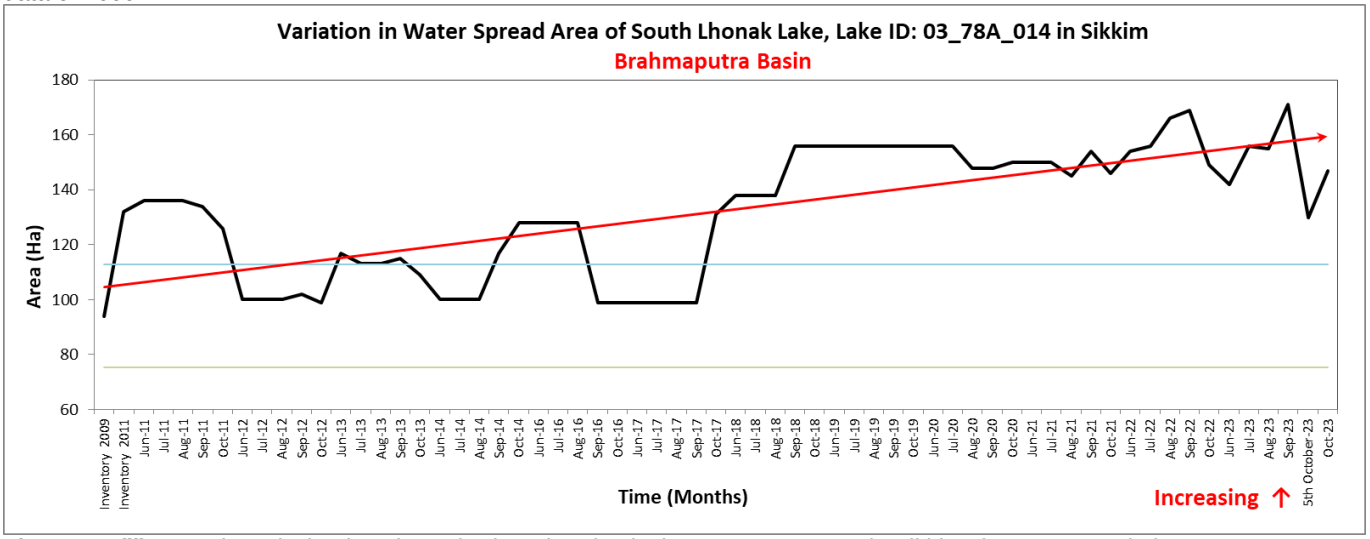


Figure 4.5(ii): Trend Analysis plot of South Lhonak Lake (Lake ID: 03_78A_014), Sikkim, for ± 20% variation w.r.t. Base Year data of 2009

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

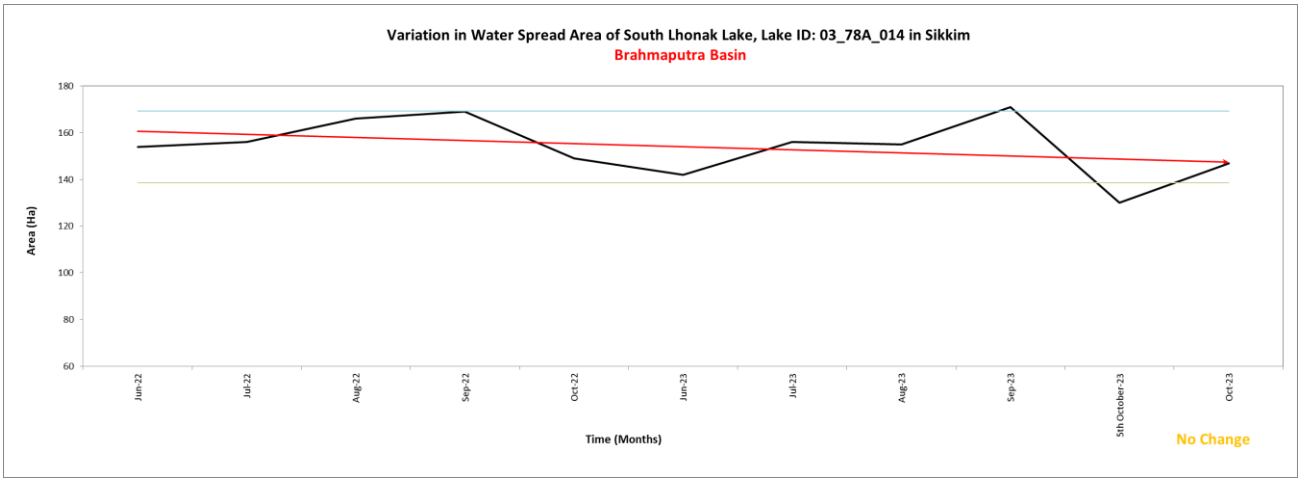


Figure 4.6(i): Trend Analysis plot of South Lhonak Lake (Lake ID: 03_78A_014), Sikkim, for ± 10% variation w.r.t. Base data of June 2022

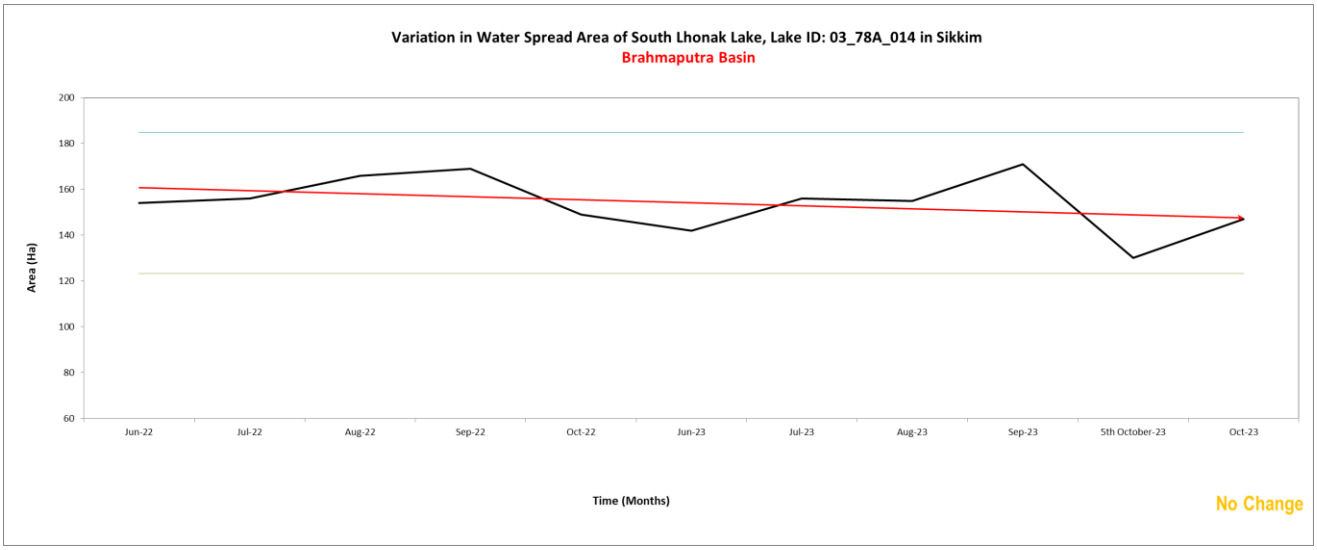


Figure 4.6(ii): Trend Analysis plot of South Lhonak Lake (Lake ID: 03_78A_014), Sikkim, for ± 20% variation w.r.t. Base data of June 2022

Table 4.4: Data set of Glacial Lake of Lake ID: 03_83A_003, Arunachal Pradesh, for ± 10% & ± 20% variation w.r.t. Base Year data of 2009

(i) ± *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) ± *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

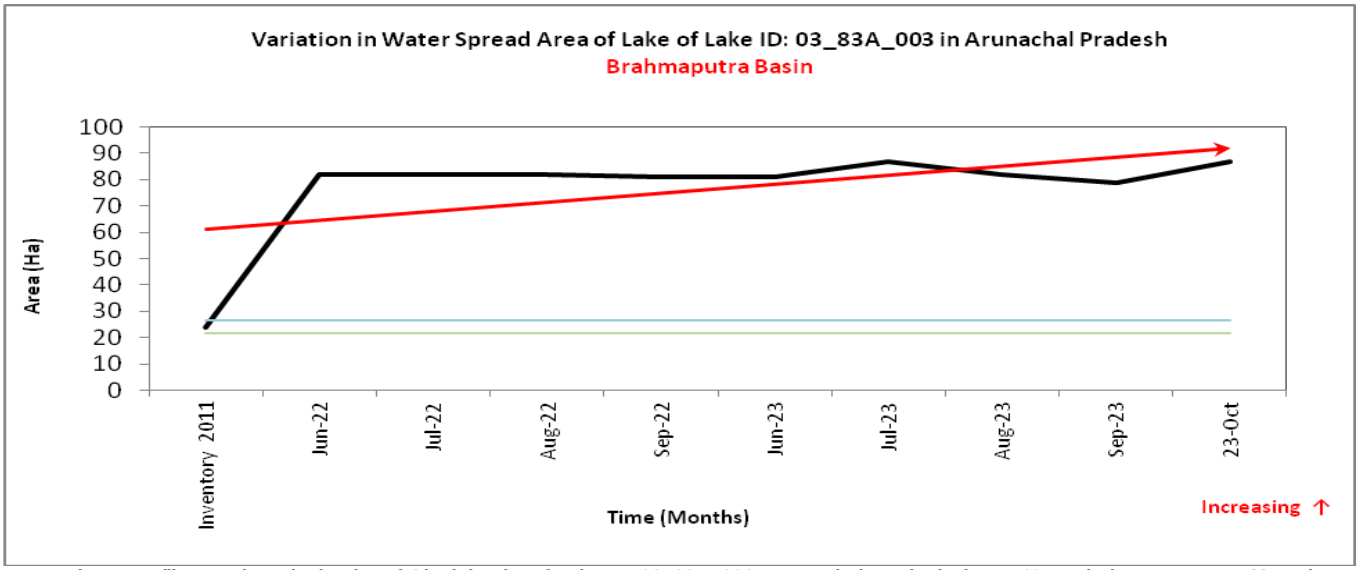


Figure 4.7(i): Trend Analysis plot of Glacial Lake of Lake ID: 03_83A_003, Arunachal Pradesh, for ± 10% variation w.r.t. Base Year data of 2009

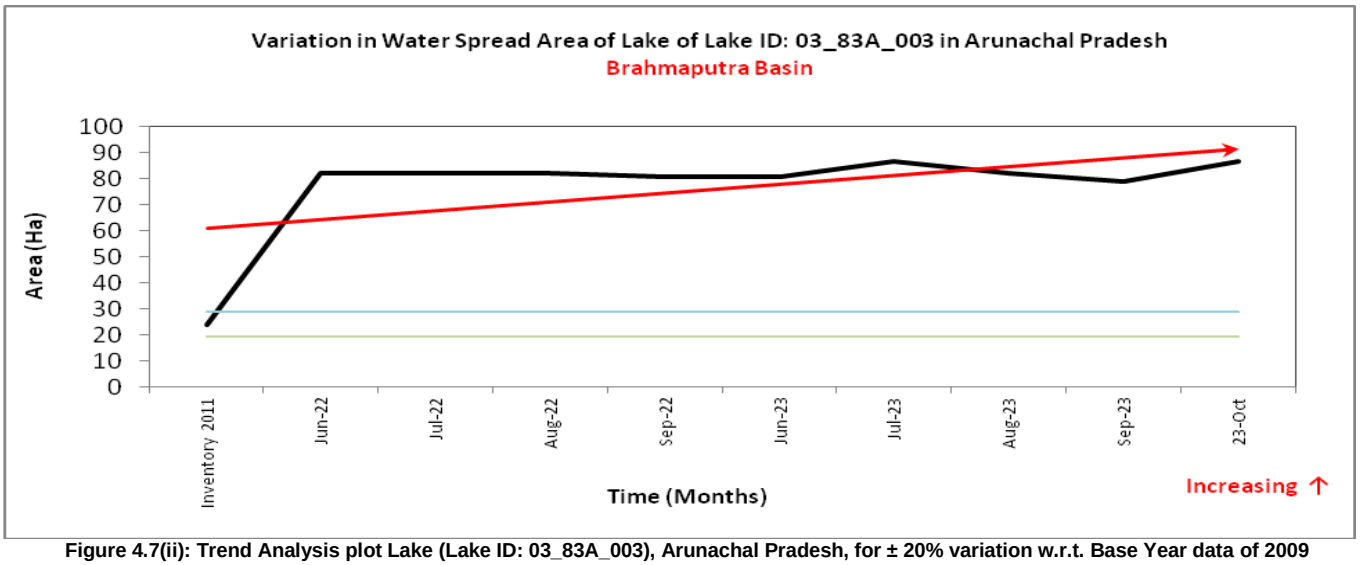


Figure 4.7(ii): Trend Analysis plot Lake (Lake ID: 03_83A_003), Arunachal Pradesh, for ± 20% variation w.r.t. Base Year data of 2009

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

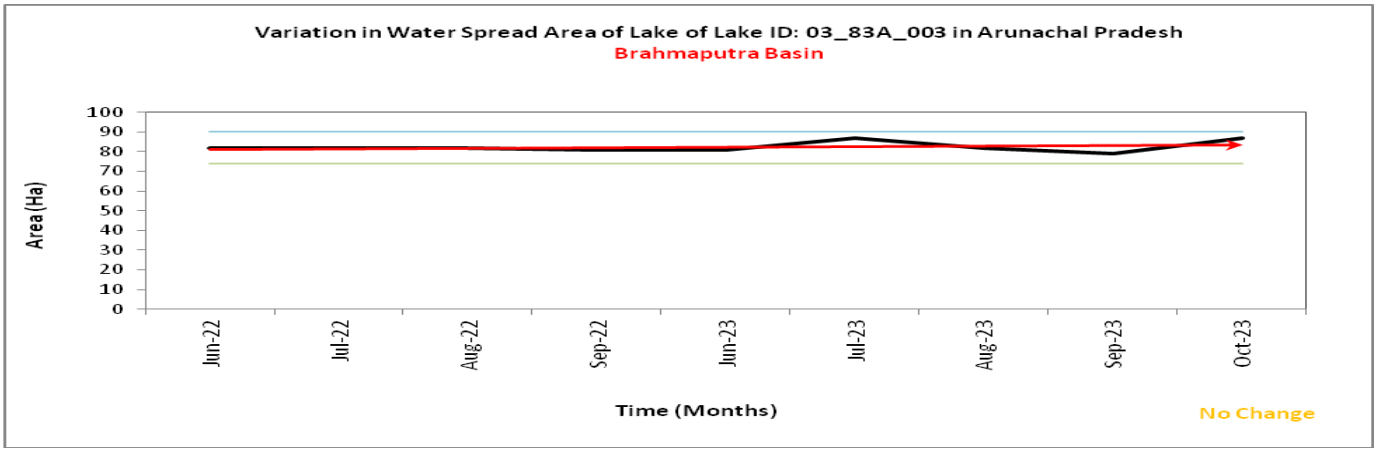


Figure 4.8(i): Trend Analysis plot of Lake (Lake ID: 03_83A_003), Arunachal Pradesh, for ± 10% variation w.r.t. Base data of June 2022

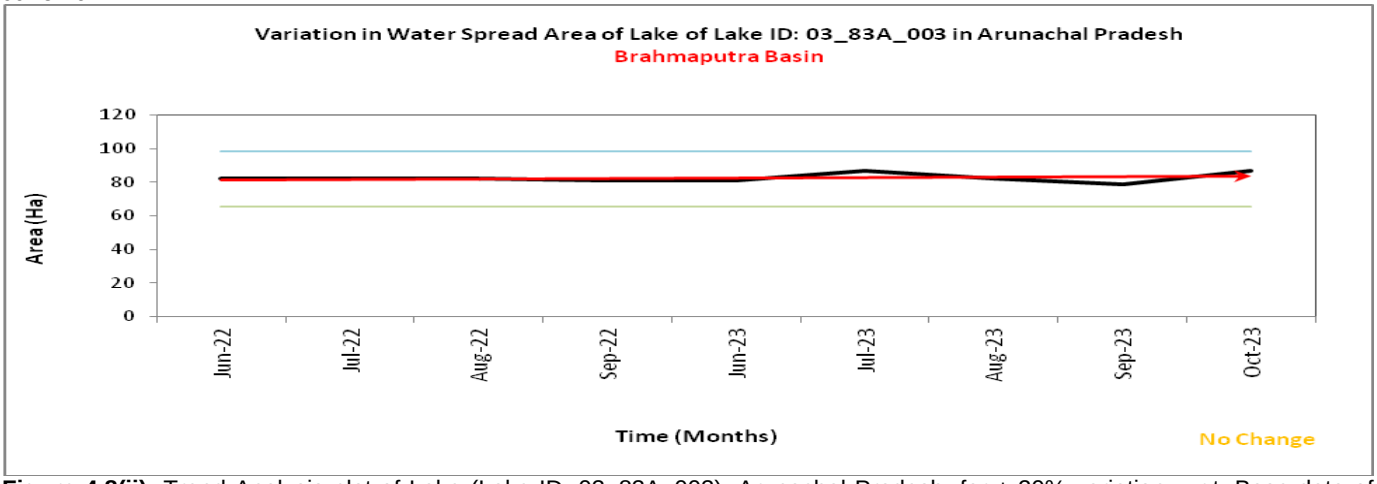


Figure 4.8(ii): Trend Analysis plot of Lake (Lake ID: 03_83A_003), Arunachal Pradesh, for ± 20% variation w.r.t. Base data of June 2022

4.6 Result of Trend Analysis

4.6.1 Trend analysis of 15 GL of size greater than 50 Ha (2011 to 2023) for ± 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 ±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**
	Total	**10**	**2**	**3**	**15**

Table No. 4.7: Trend Analysis of Glacial Lakes of size greater than 50 Ha in size located in India analysed for ±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 ± 20% variation w.r.t. Base Year data of 2009

As the analysis was carried out for ± 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 ±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**
	Total	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 ±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.

Trend analysis for Change in Water spread area of Glacial Lakes (>50 Ha) for ±10% & ±20% w.r.t base year data 2009		
S.No.	**States**	**Figure No.**
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 ±10%

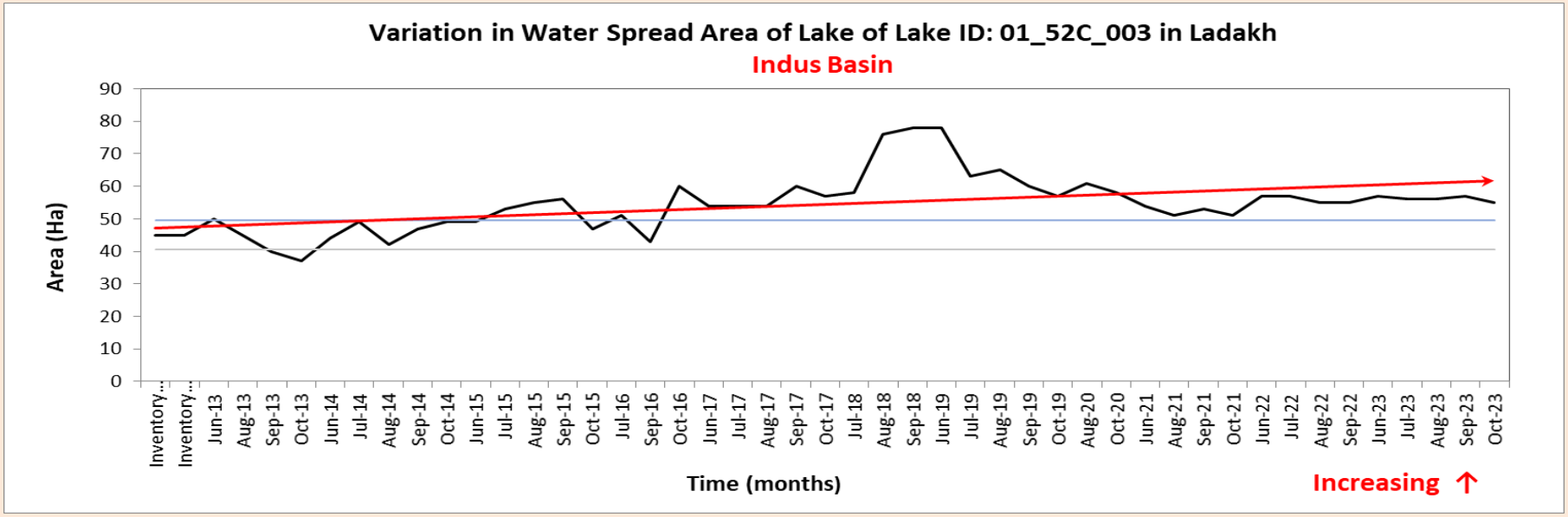


Figure 4.9(ii) Trend Analysis Plot ±20%

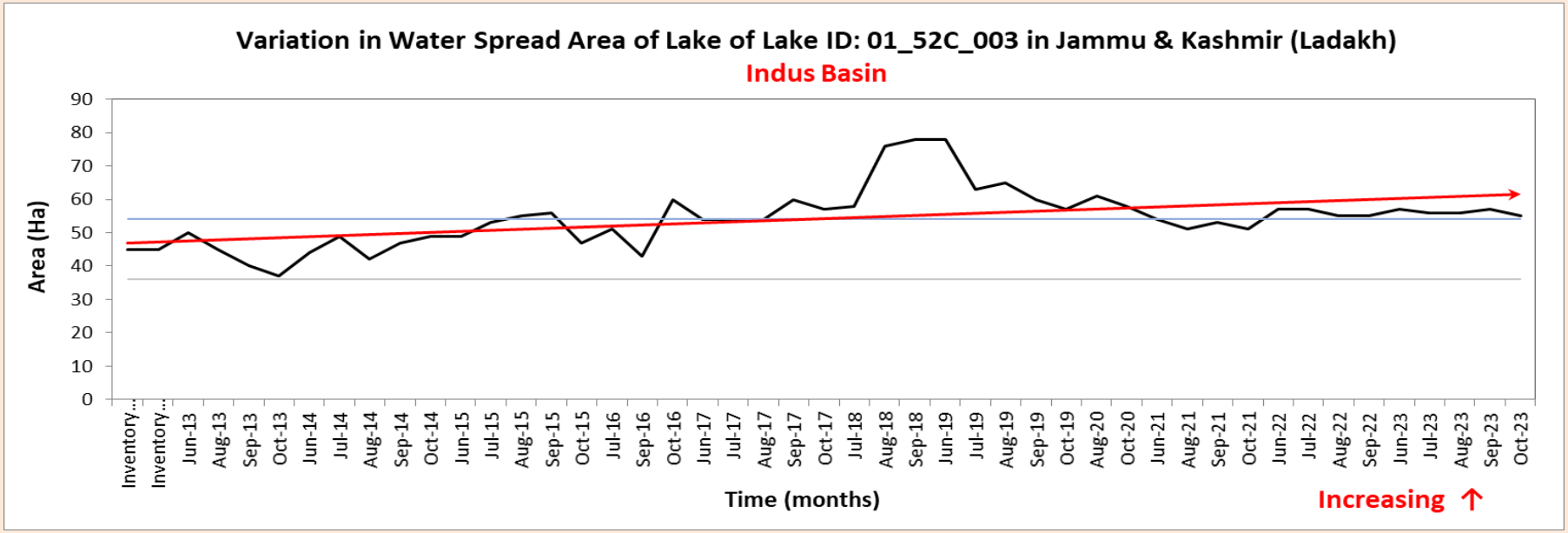


Figure 4.10(i) Trend Analysis Plot ±10%

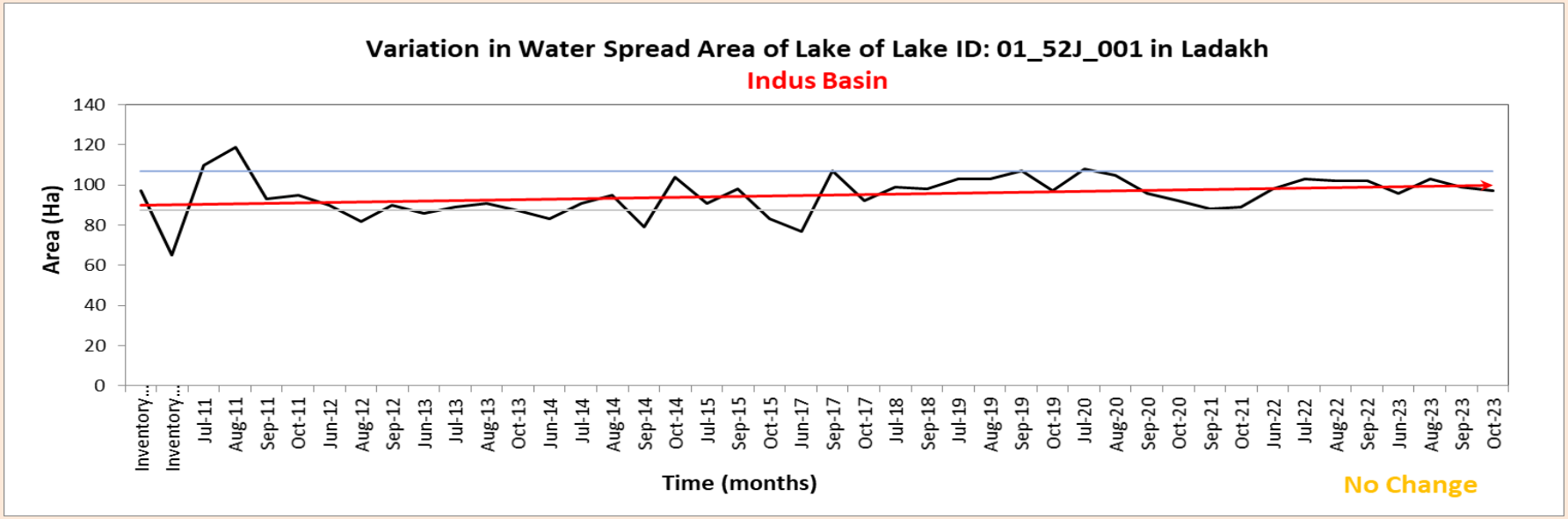


Figure 4.10(ii) Trend Analysis Plot ±20%

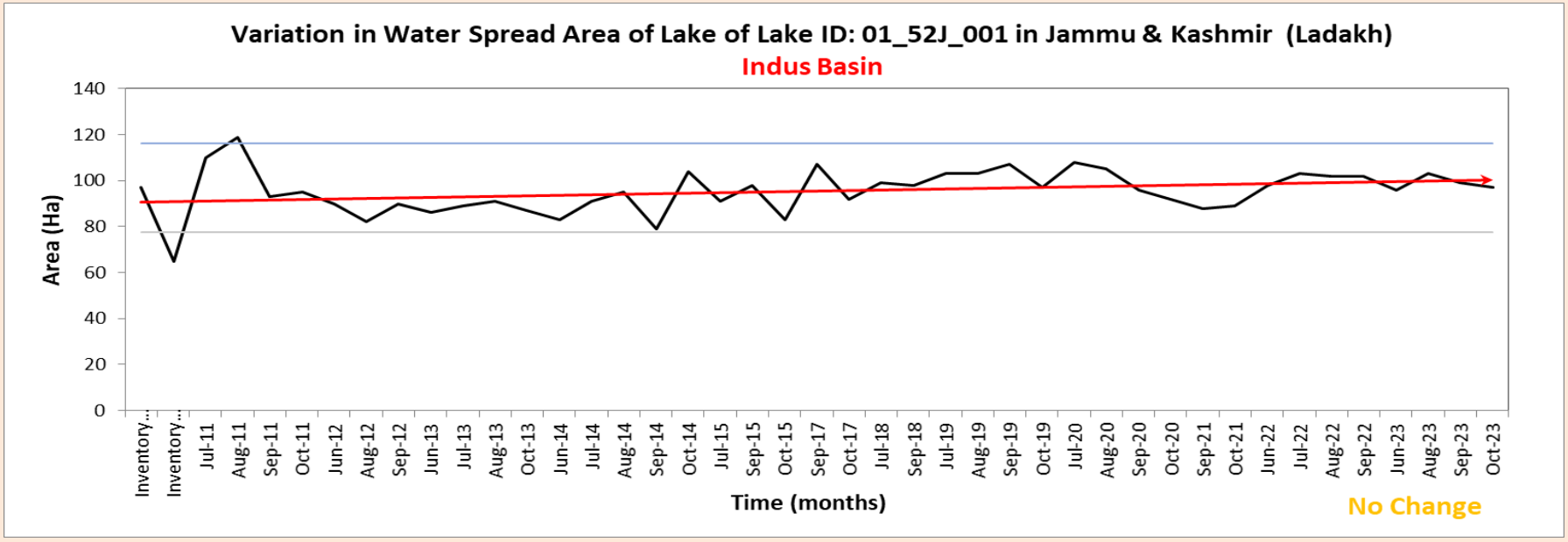


Figure 4.11(i) Trend Analysis Plot ±10%

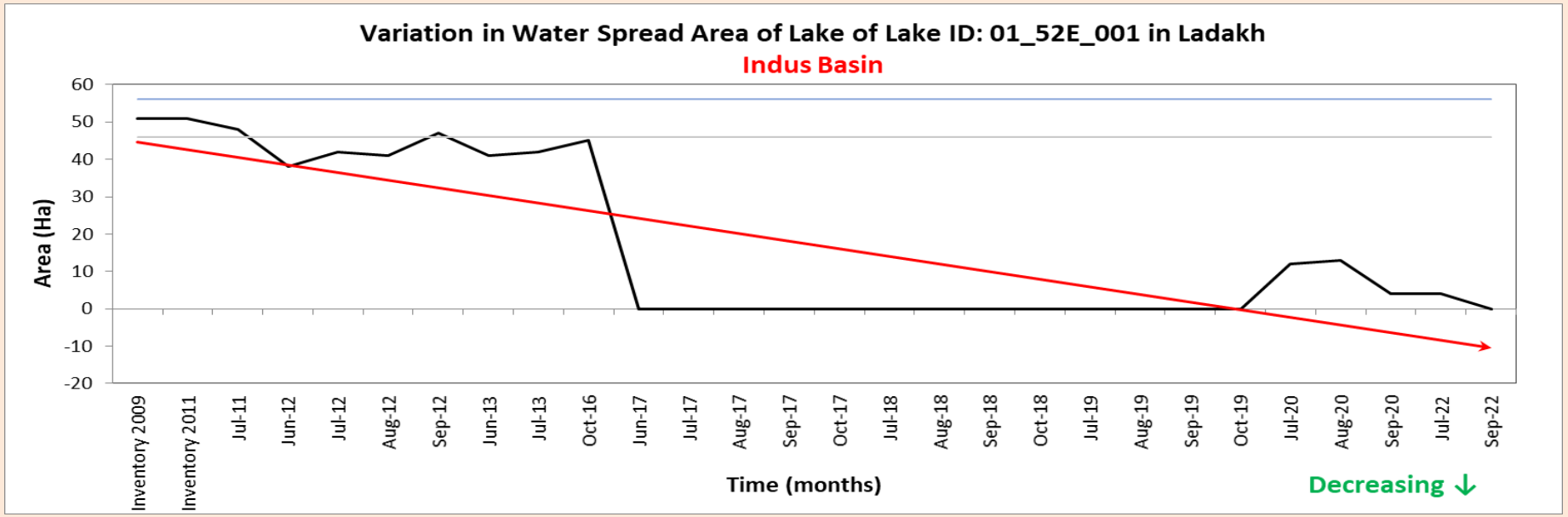
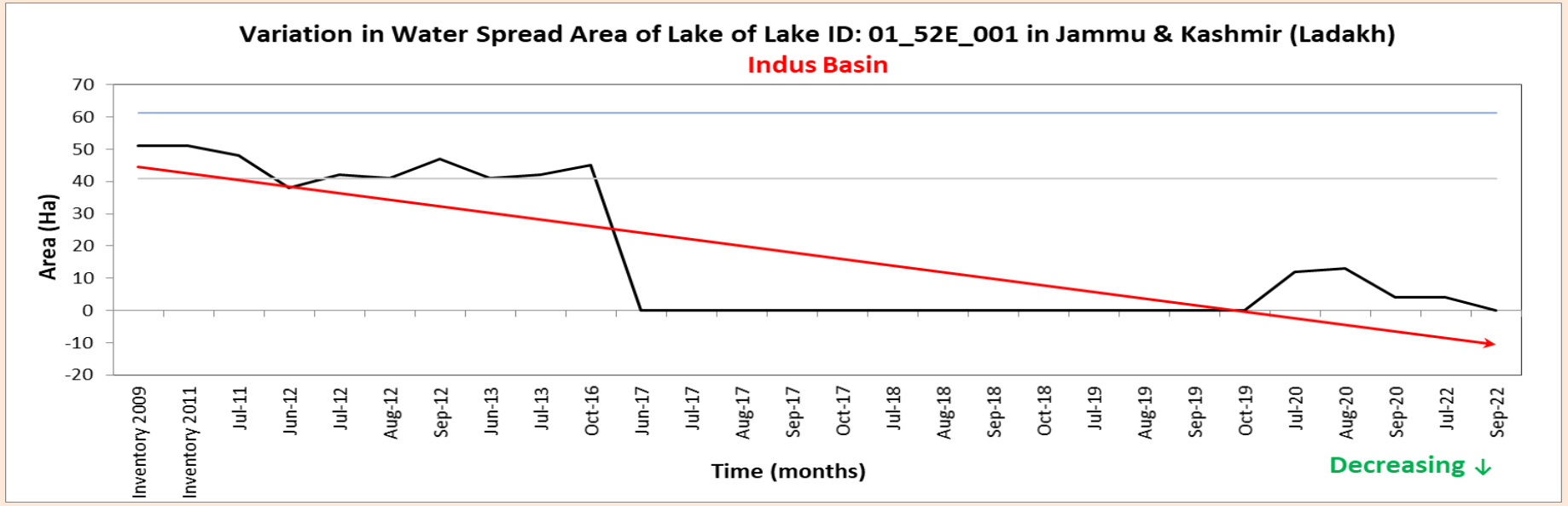


Figure 4.11(ii) Trend Analysis Plot ±20%



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

Figure 4.12(i) Trend Analysis Plot ±10%

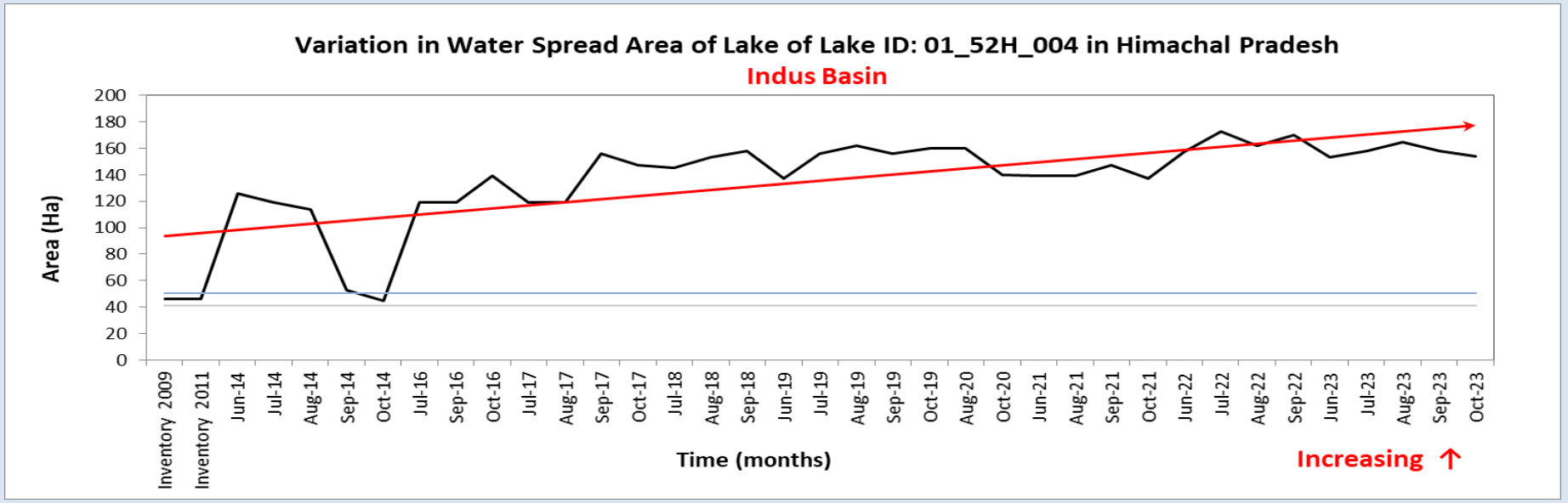


Figure 4.12(ii) Trend Analysis Plot ±20%

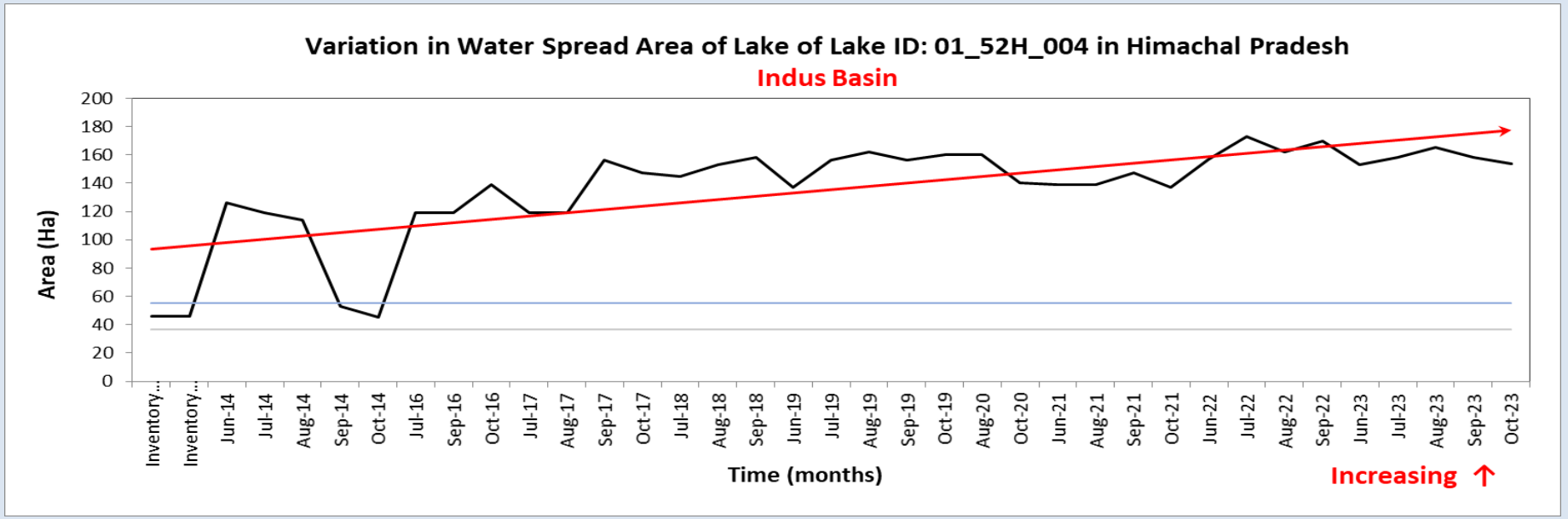


Figure 4.13(i) Trend Analysis Plot ±10%

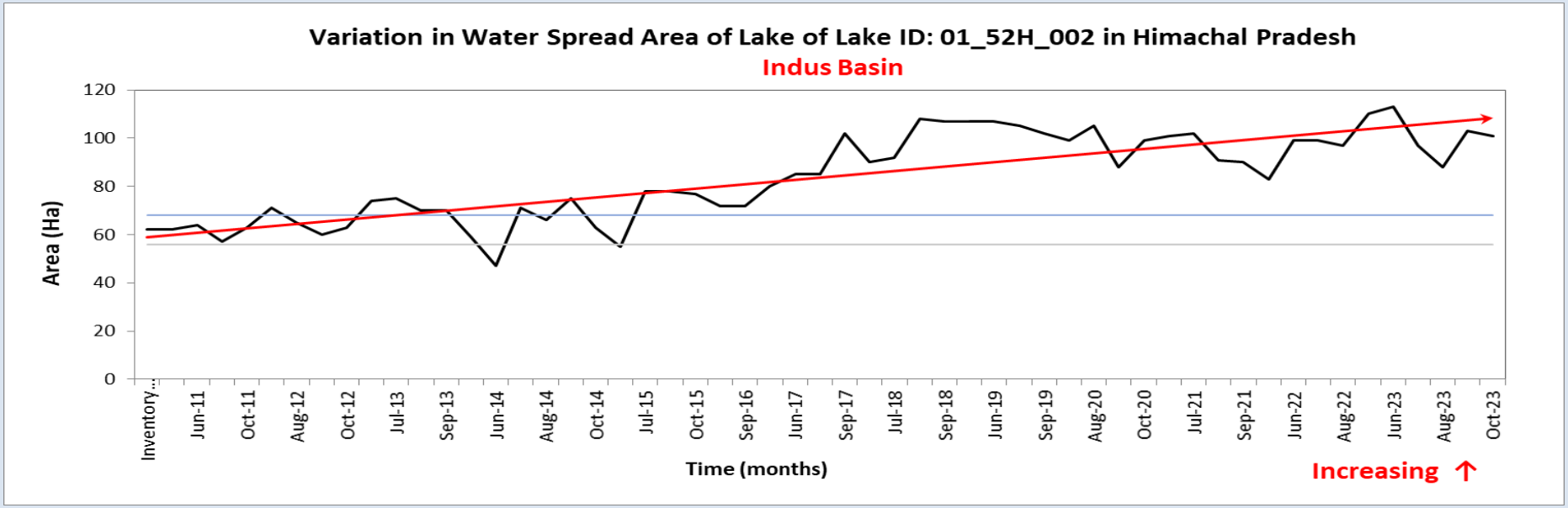
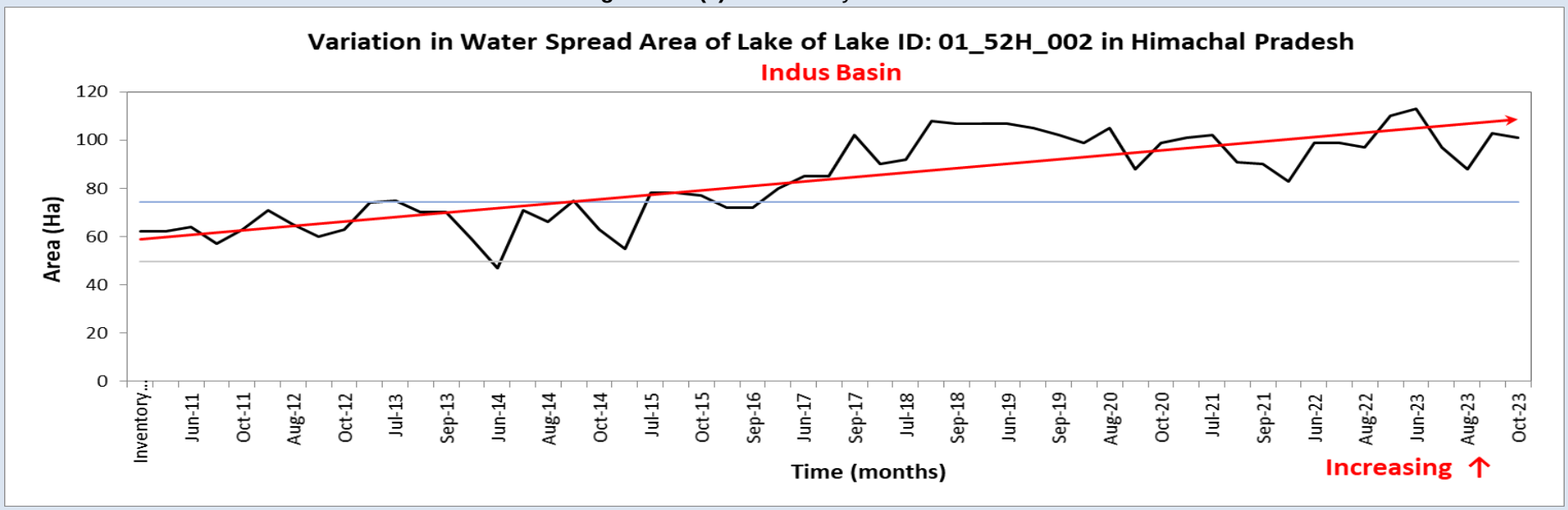


Figure 4.13(ii) Trend Analysis Plot ±20%



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

Figure 4.14(i) Trend Analysis Plot ±10%

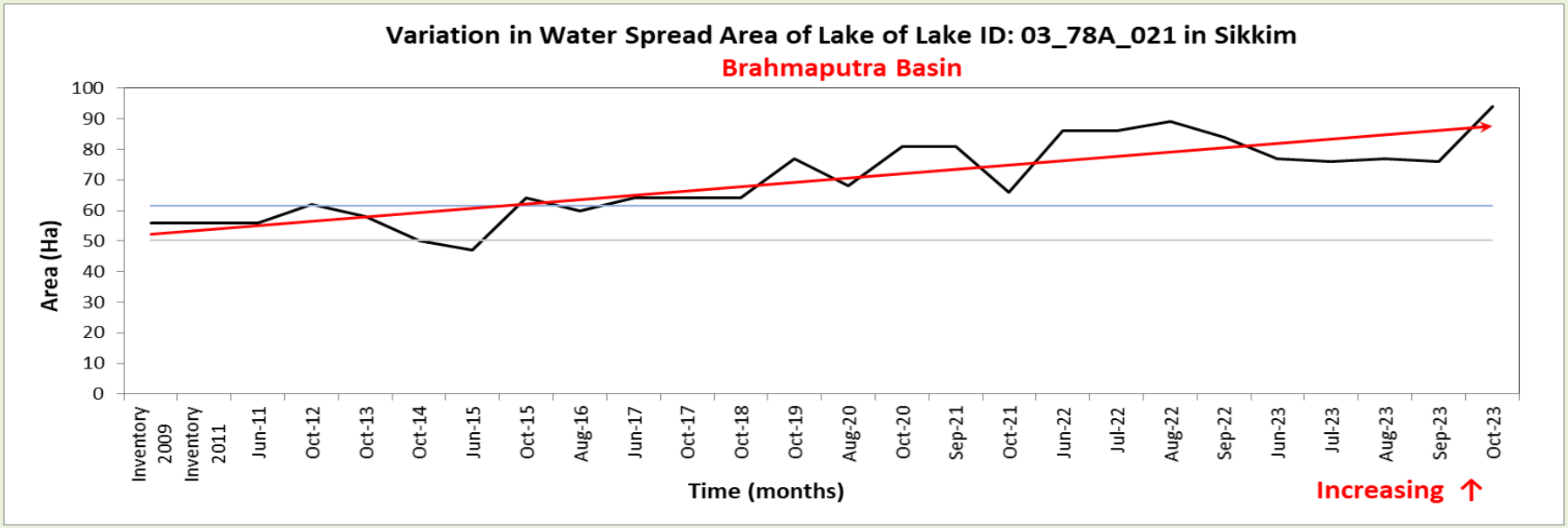


Figure 4.14(ii) Trend Analysis Plot ±20%

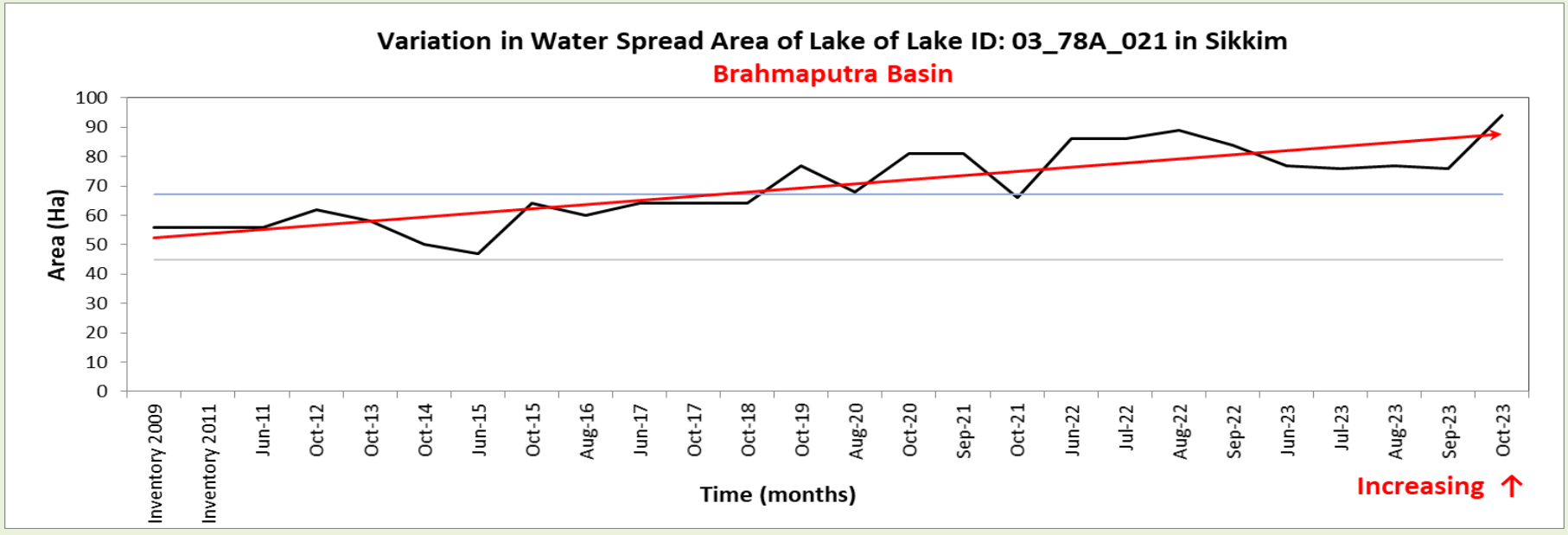


Figure 4.15(i) Trend Analysis Plot ±10%

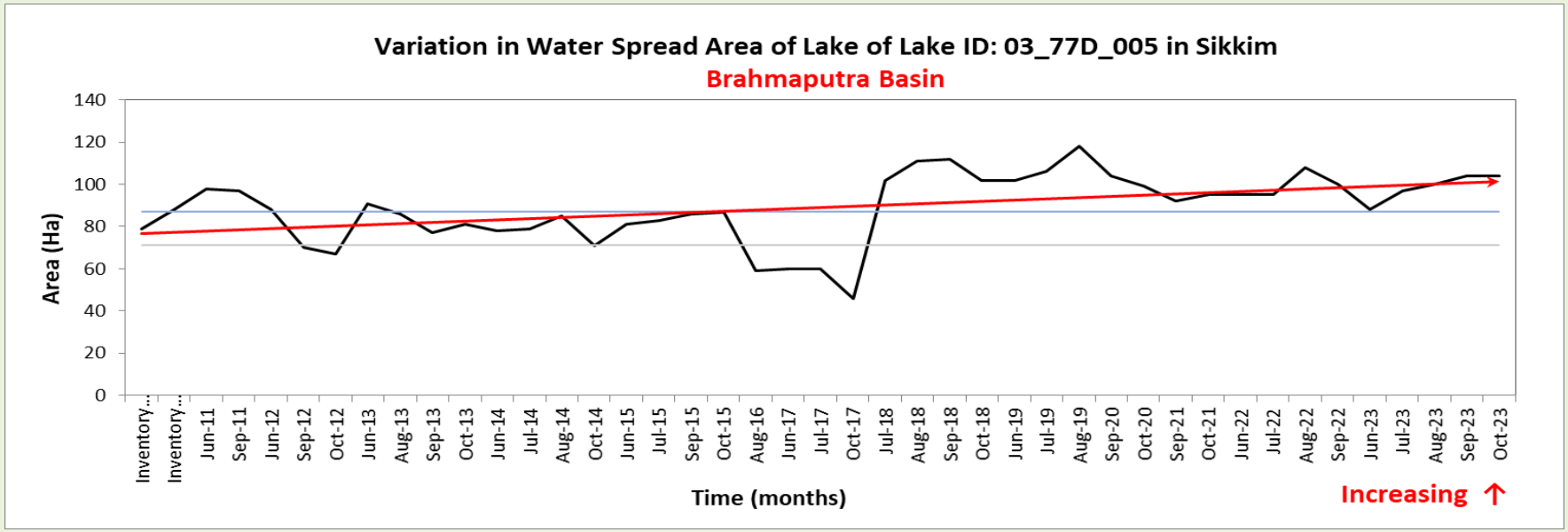


Figure 4.15(ii) Trend Analysis Plot ±20%

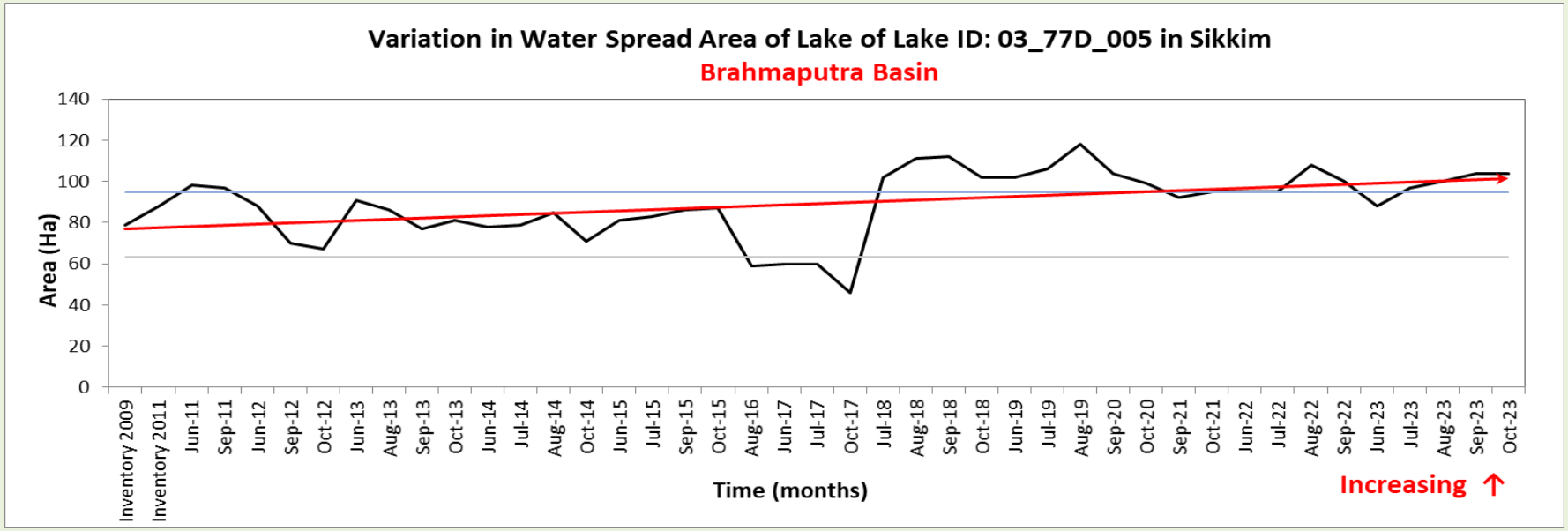


Figure 4.16(i) Trend Analysis Plot ±10%

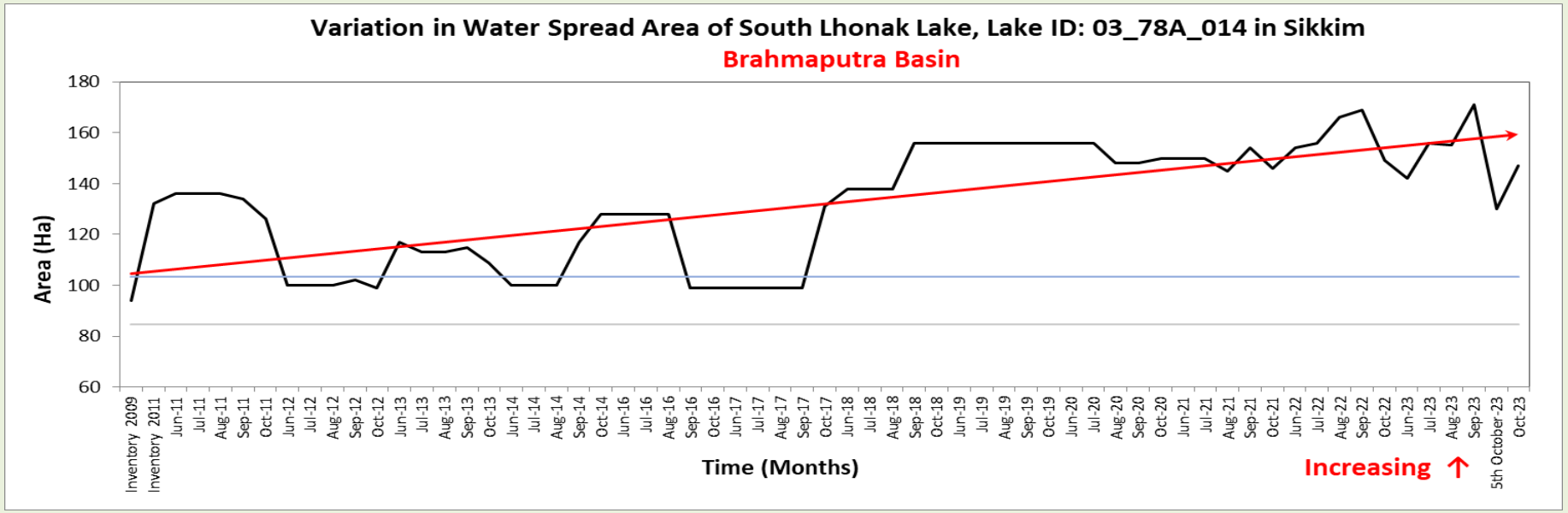


Figure 4.16(ii) Trend Analysis Plot ±20%

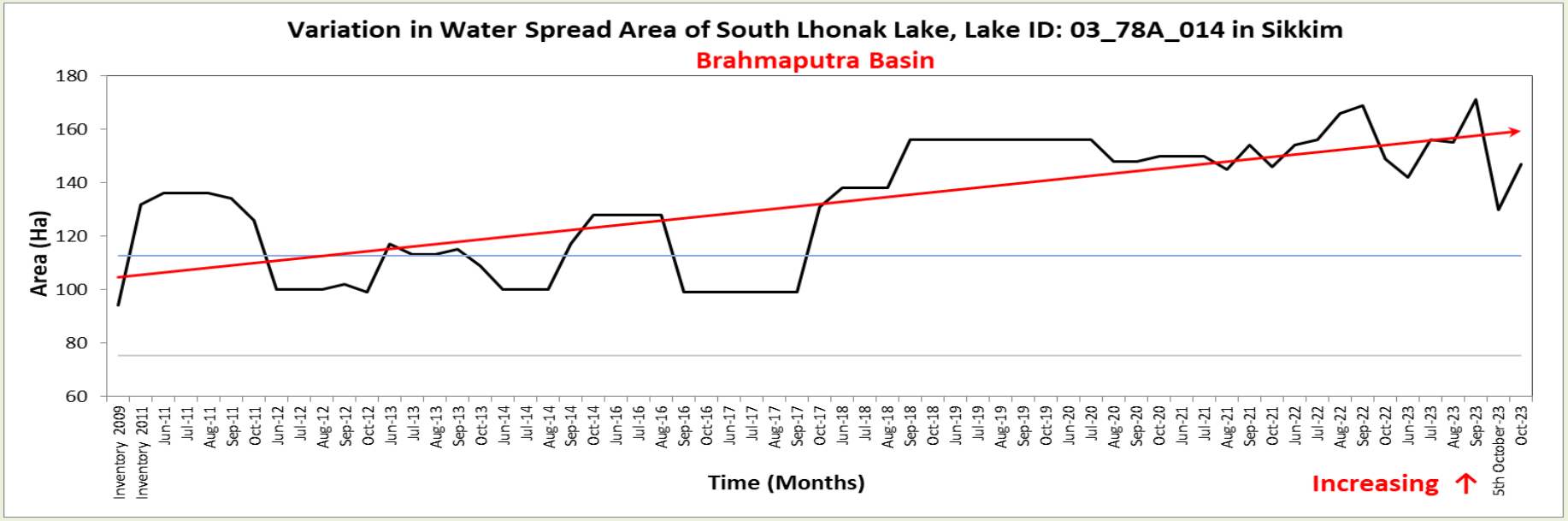


Figure 4.17(i) Trend Analysis Plot ±10%

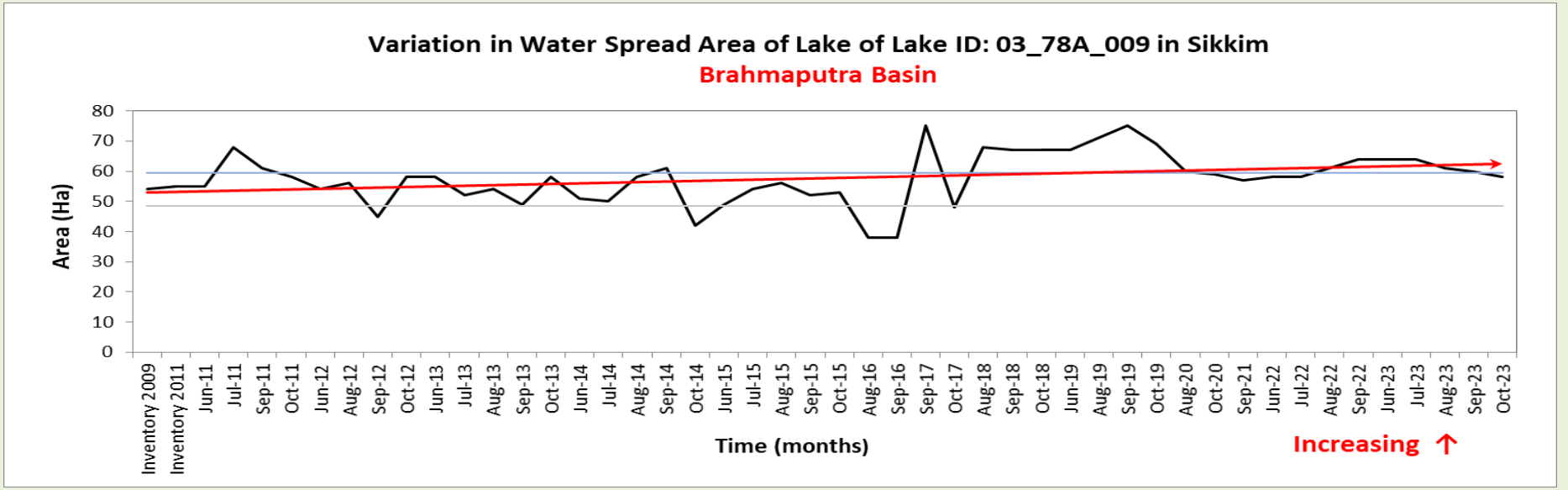


Figure 4.17(i) Trend Analysis Plot ±20%

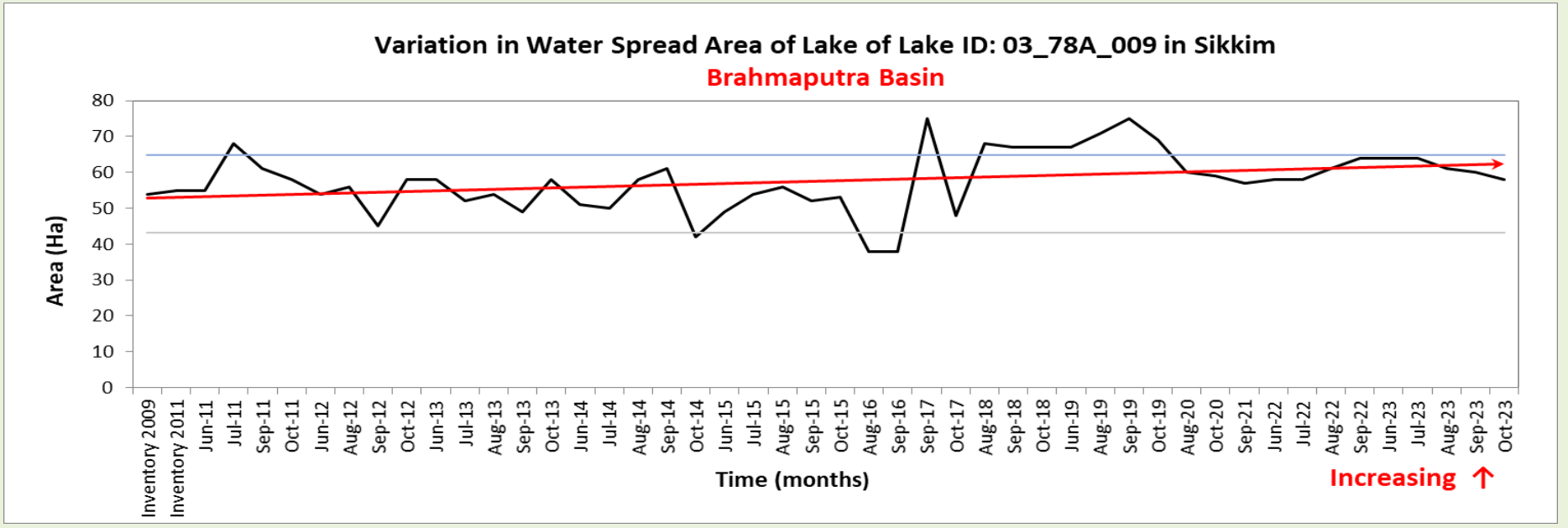


Figure 4.18(i) Trend Analysis Plot ±10%

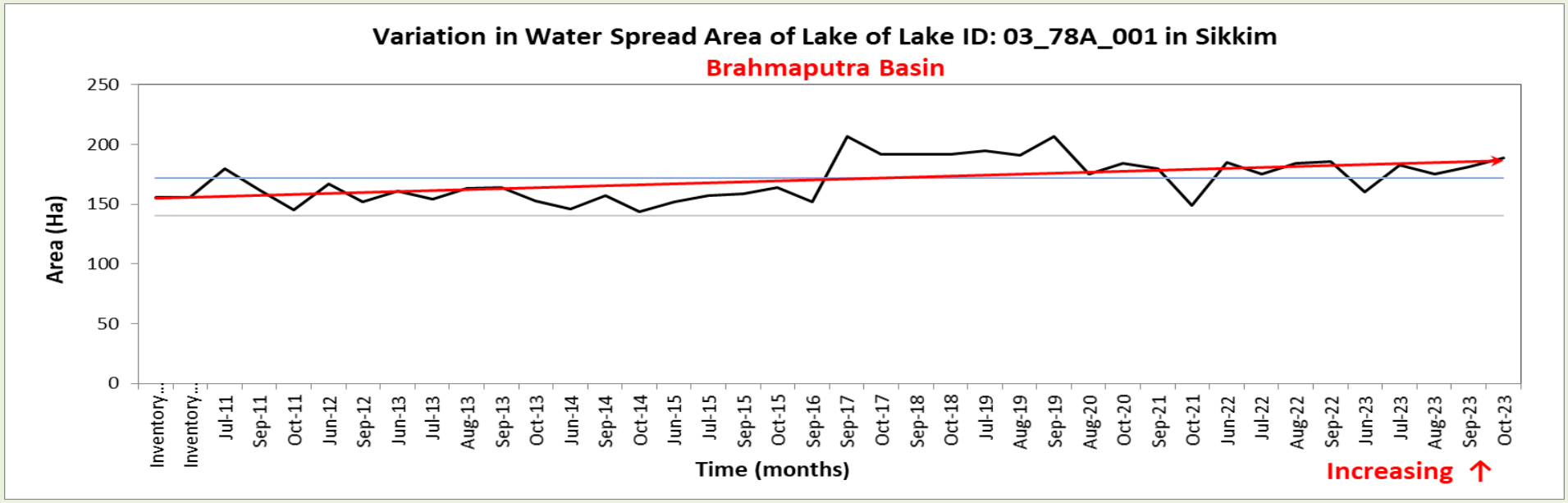


Figure 4.18(ii) Trend Analysis Plot ±20%

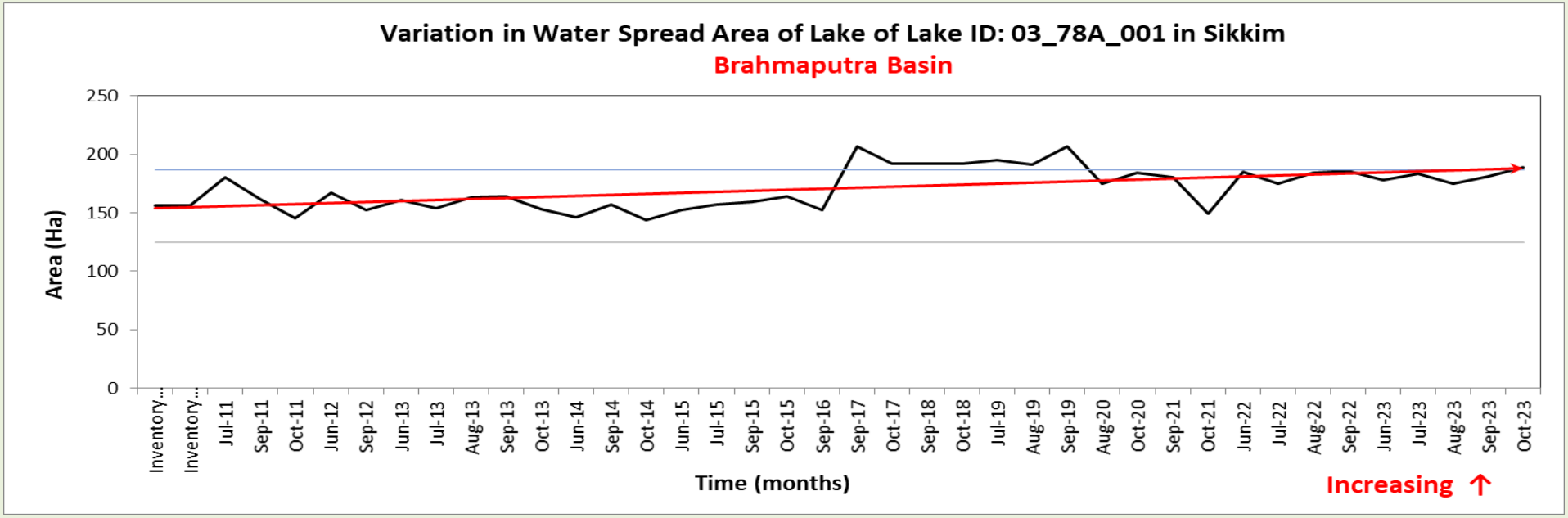


Figure 4.19(i) Trend Analysis Plot ±10%

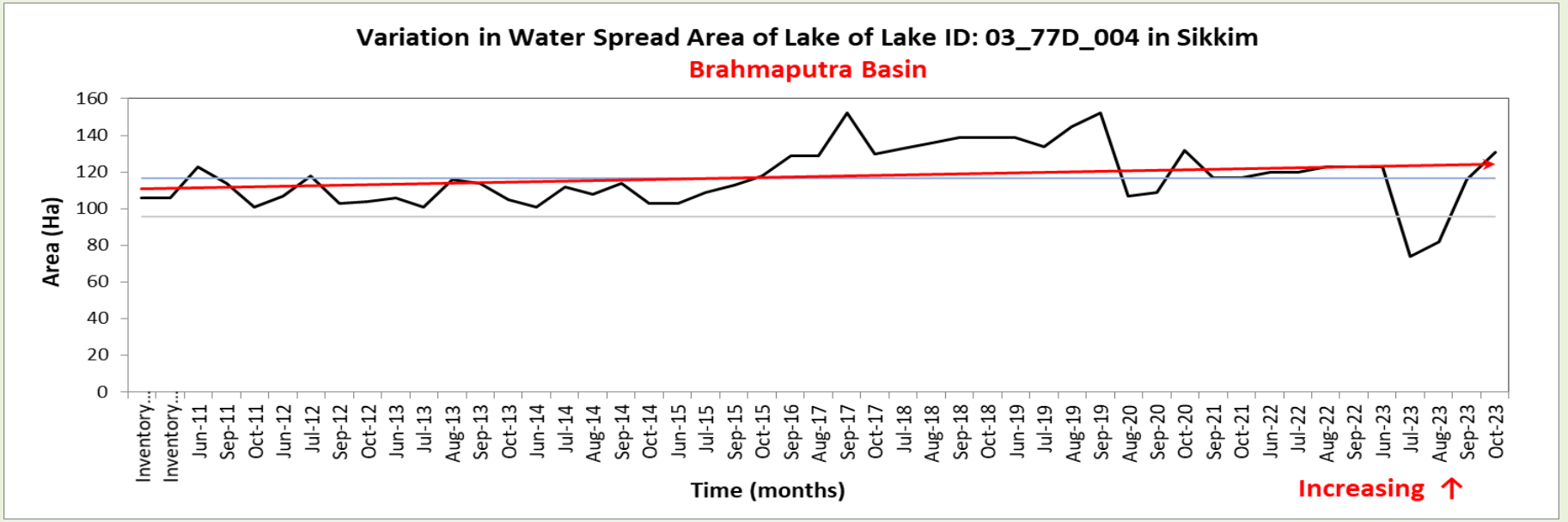


Figure 4.19(ii) Trend Analysis Plot ±20%

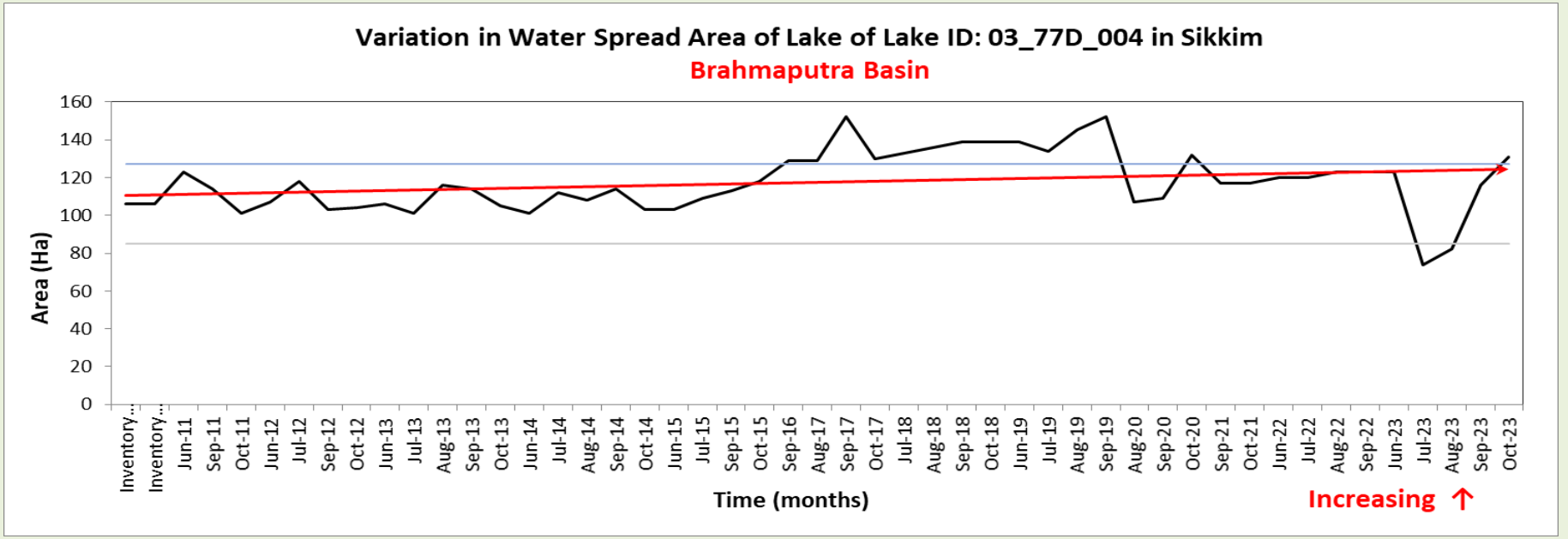


Figure 4.20(i) Trend Analysis Plot ±10%

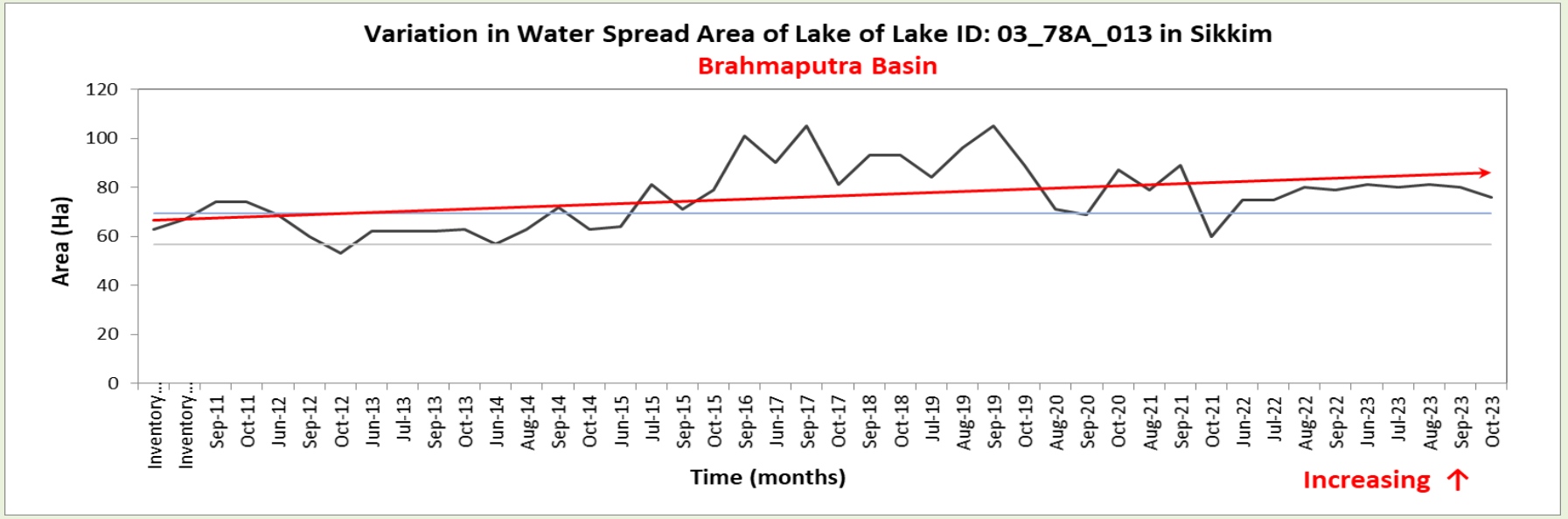


Figure 4.20(ii) Trend Analysis Plot ±20%

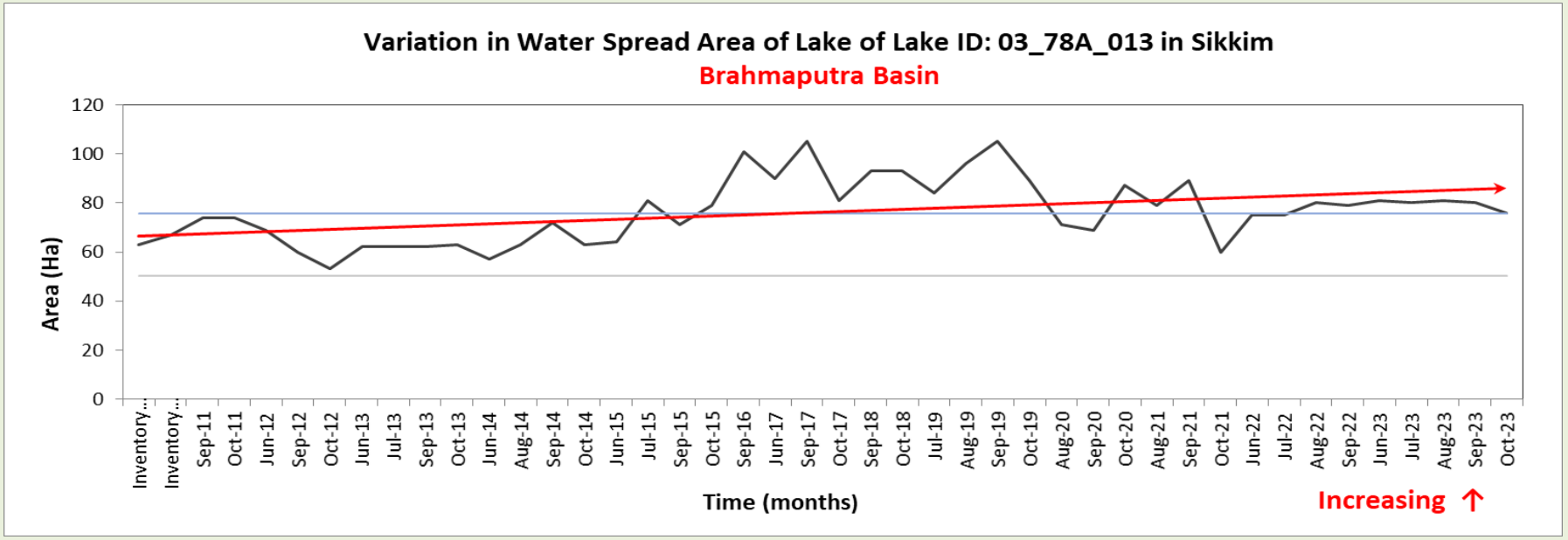


Figure 4.21(i) Trend Analysis Plot ±10%

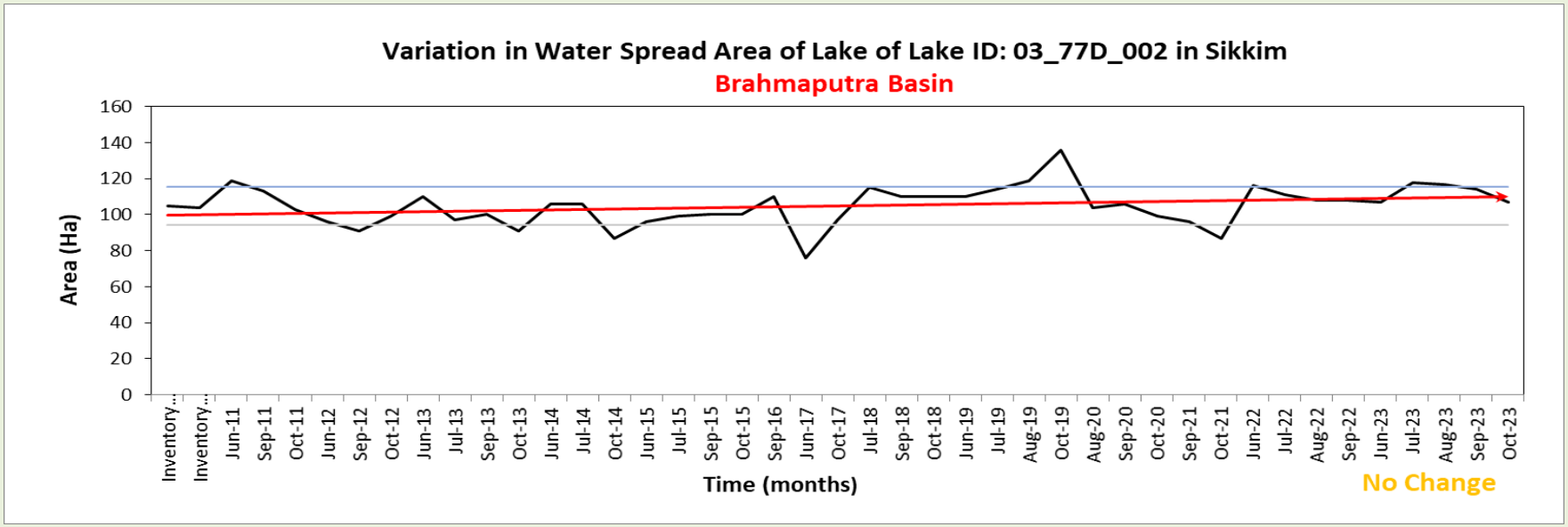


Figure 4.21(ii) Trend Analysis Plot ±20%

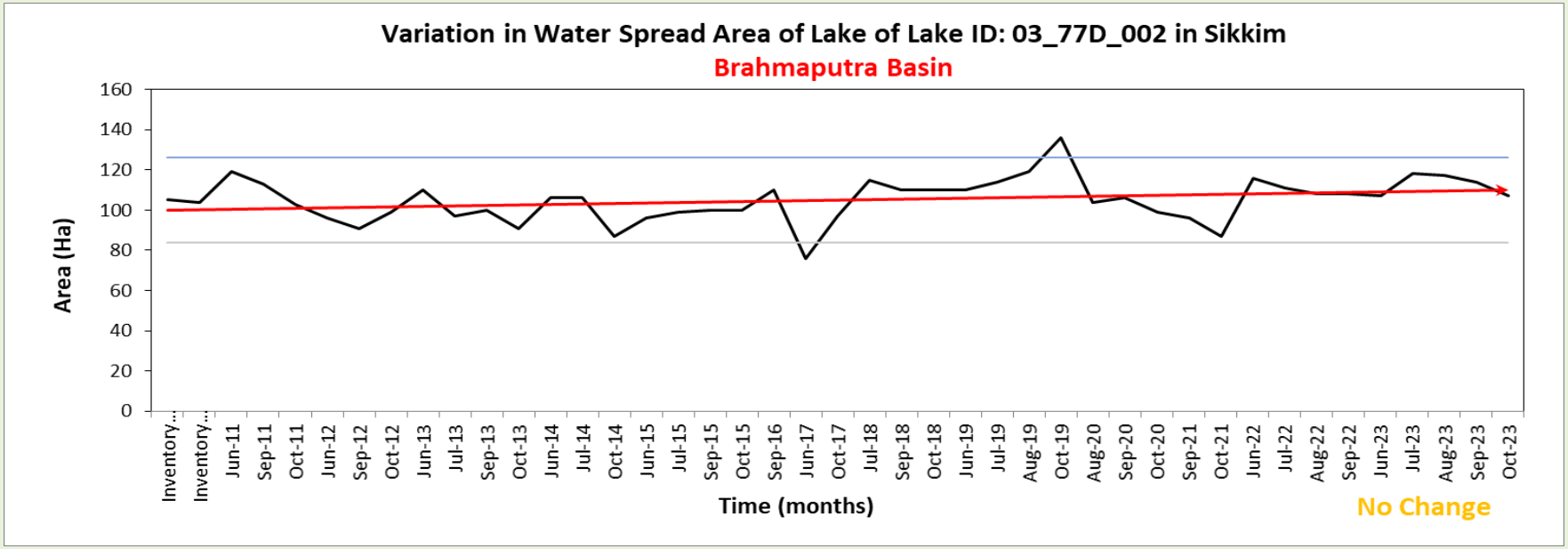


Figure 4.22(i) Trend Analysis Plot ±10%

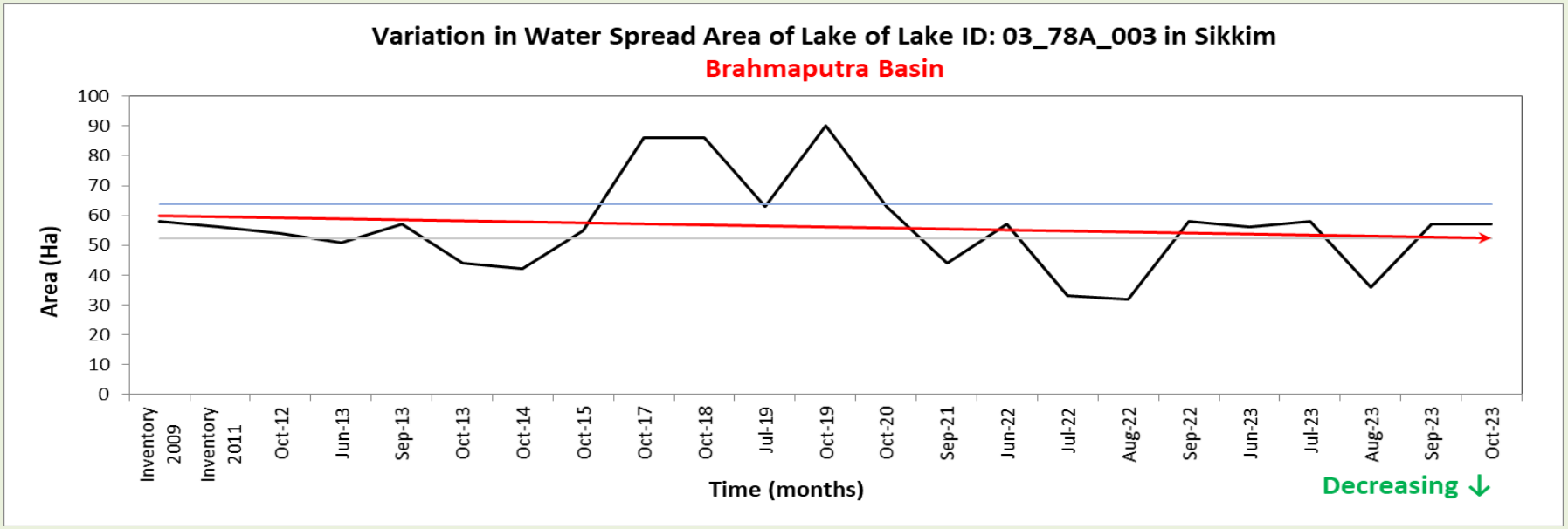


Figure 4.22(ii) Trend Analysis Plot ±20%

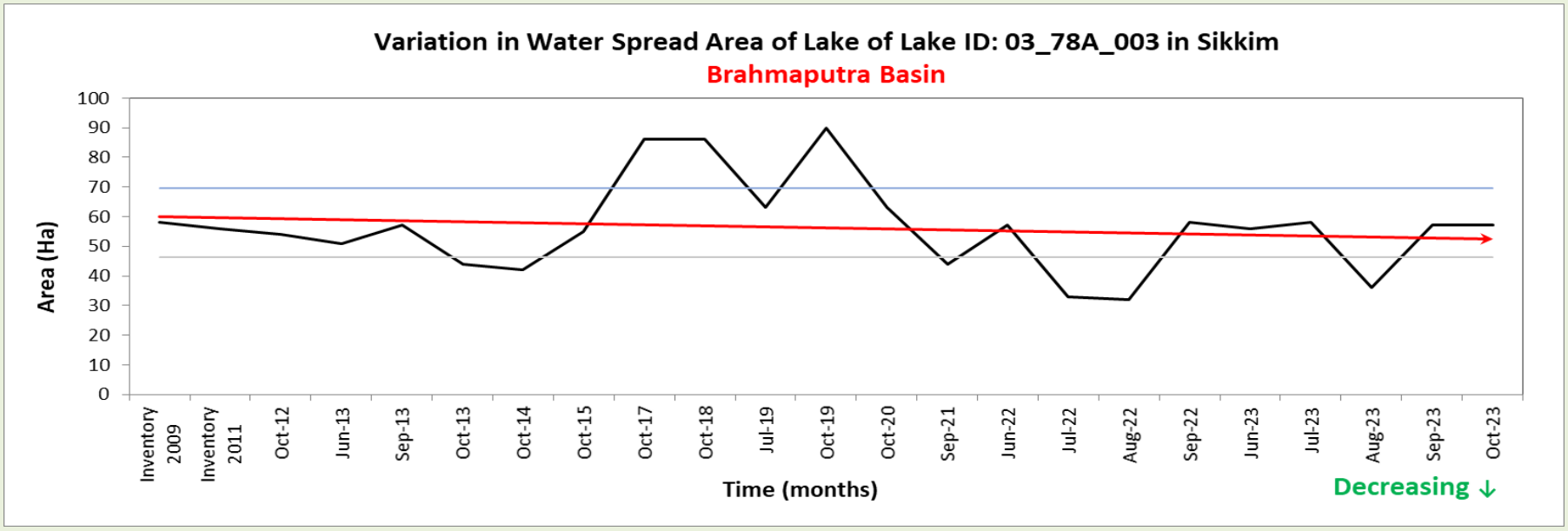


Figure 4.23(i) Trend Analysis Plot ±10%

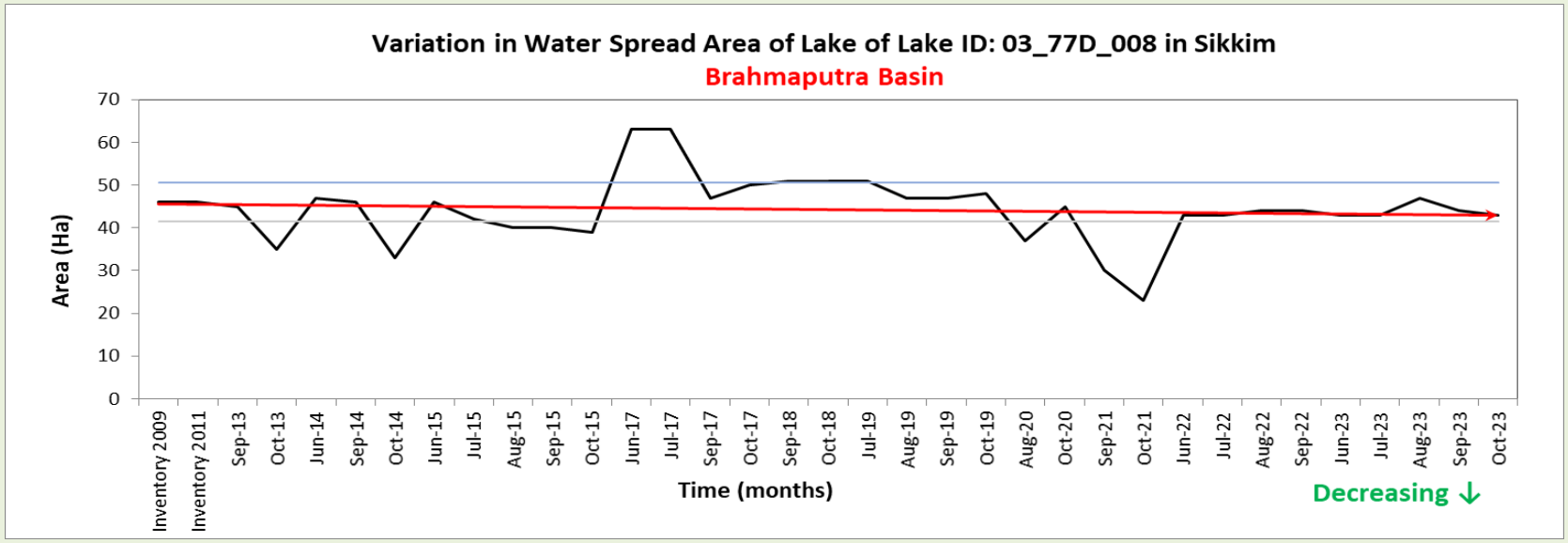
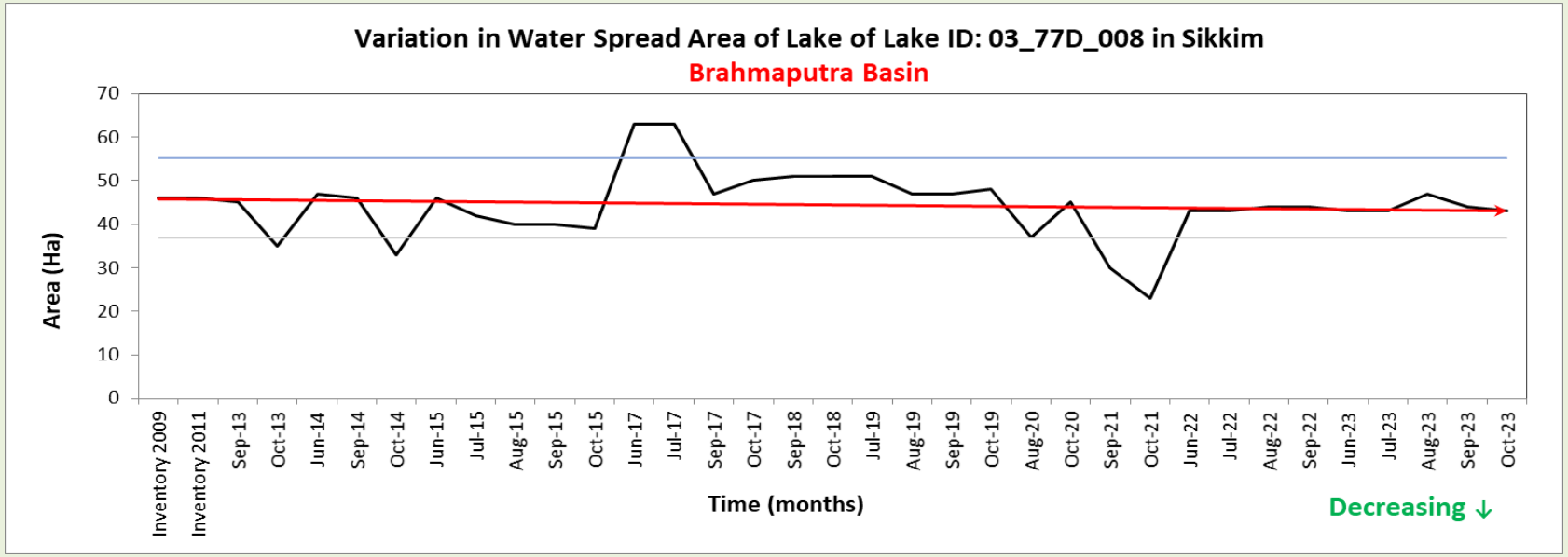


Figure 4.23(ii) Trend Analysis Plot ±20%



4.6.3 Trend analysis of 15 GL of size greater than 50 Ha (2022 - 2023) for ± 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 ±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**
	Total	**0**	**14**	**1**	**15**

Table No.4.11: Trend Analysis of Glacial Lakes of size greater than 50 Ha in size located in India analysed for ±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 ± 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 ±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**
	Total	**0**	**14**	**1**	**15**

Table No. 4.13: Trend Analysis of Glacial Lakes of size greater than 50 Ha in size located in India analysed for ±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.

Trend analysis for Change in Water spread area of Glacial Lakes (>50 Ha) for ±10% & ±20% w.r.t base year data of June 2022		
S.No.	**States**	**Figure No.**
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 ± 10%

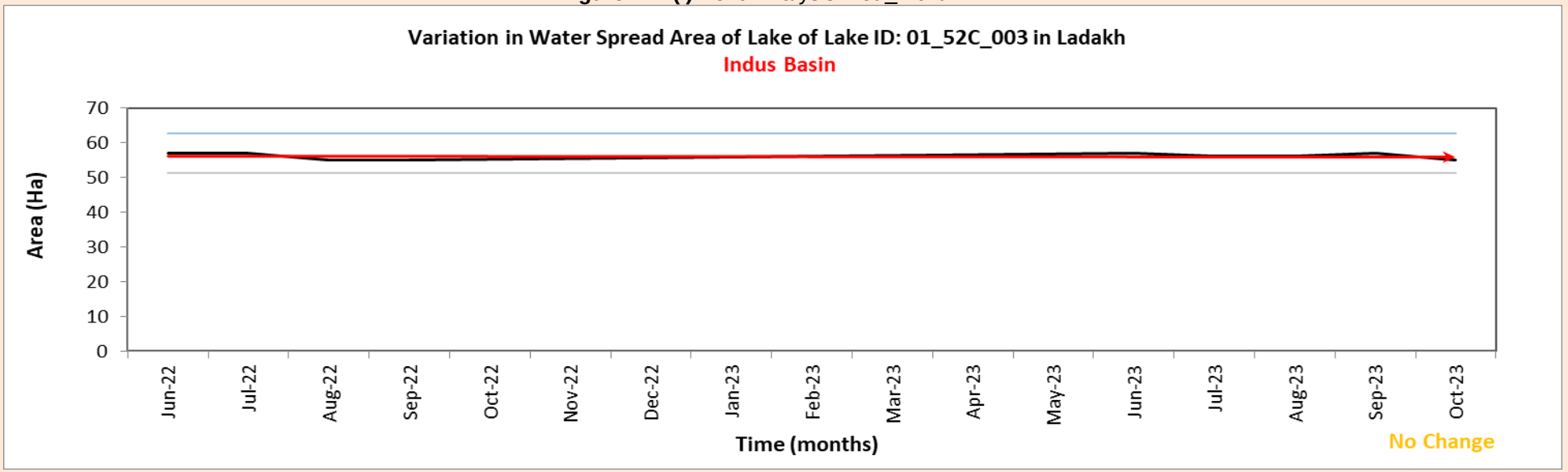


Figure 4.24(ii) Trend Analysis Plot ± 20%

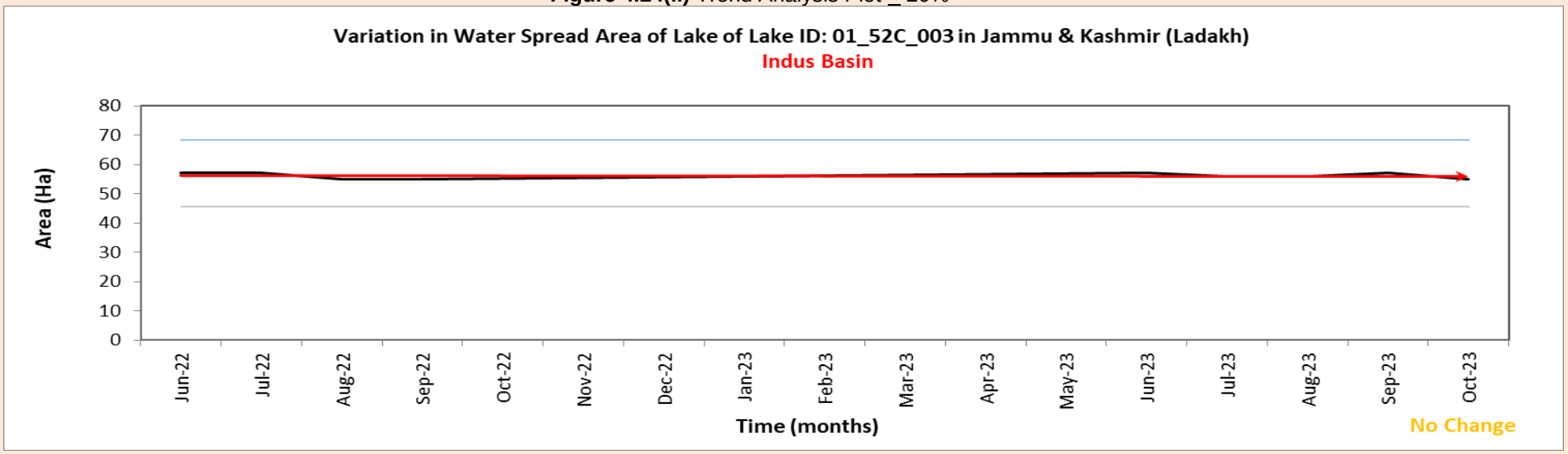


Figure 4.25(i) Trend Analysis Plot ± 10%

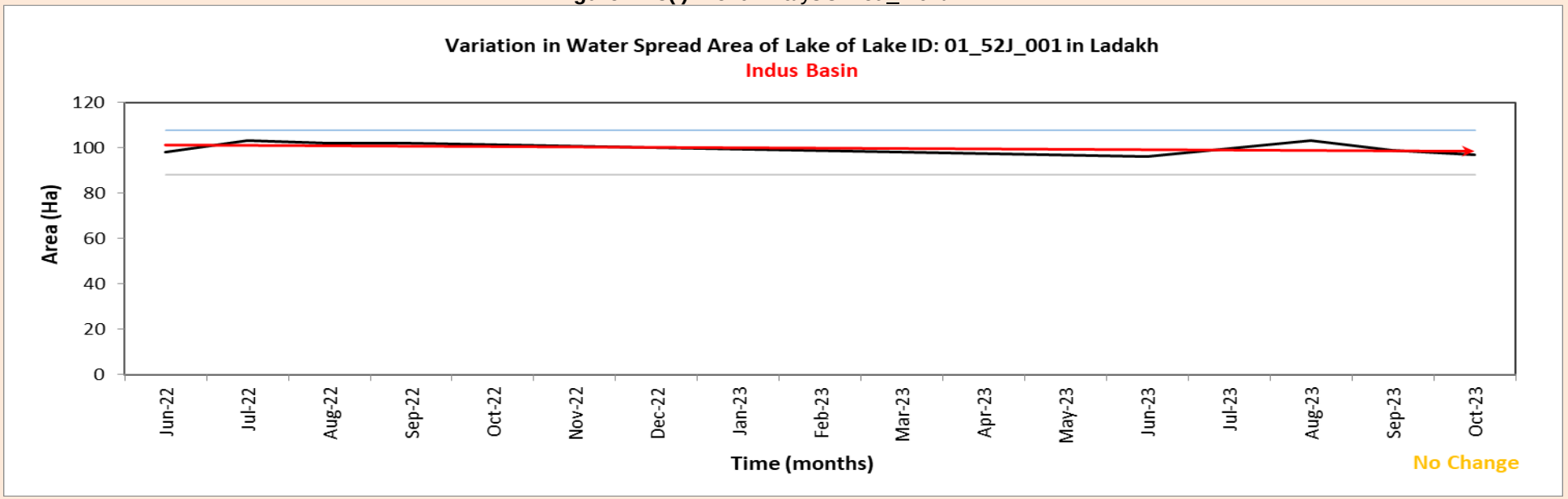


Figure 4.25(ii) Trend Analysis Plot ± 20%

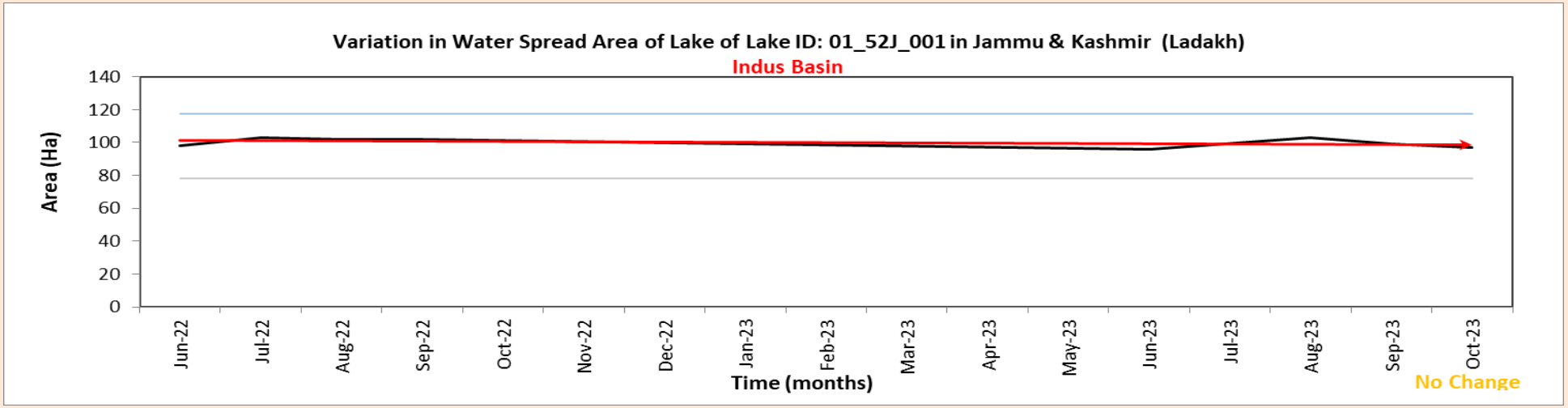


Figure 4.26(i) Trend Analysis Plot ± 10%

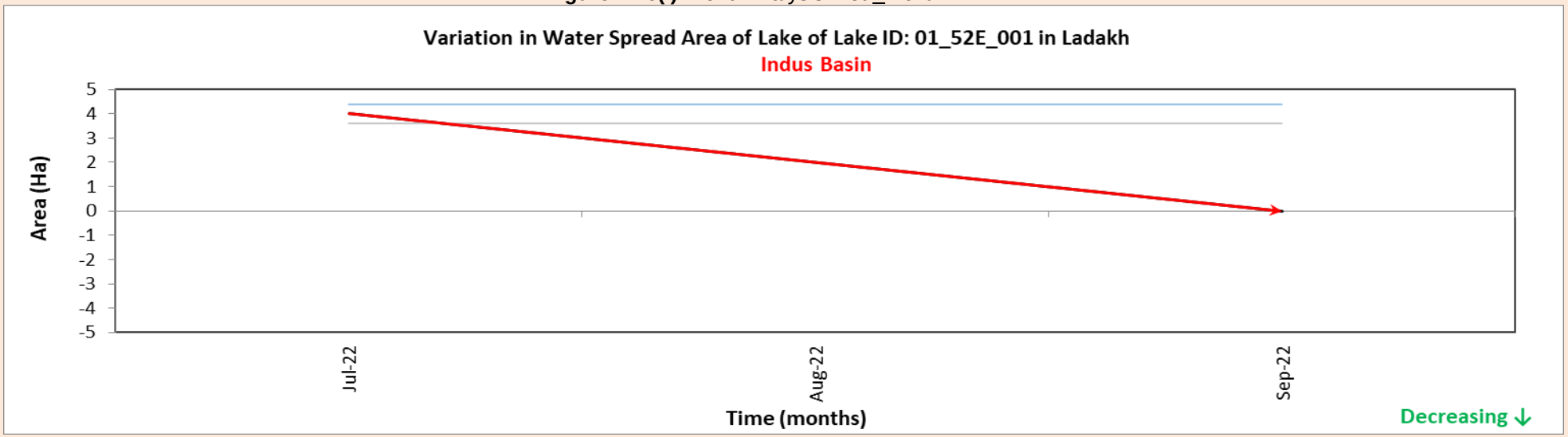
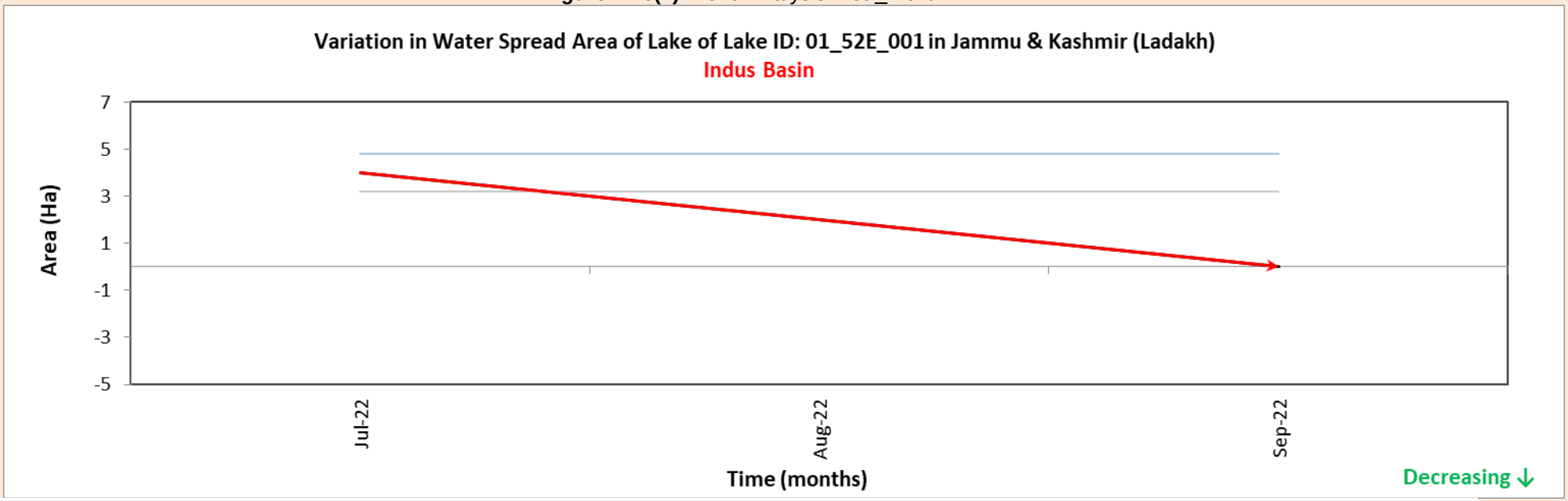


Figure 4.26(ii) Trend Analysis Plot ± 20%



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

Figure 4.27(i) Trend Analysis Plot ± 10%

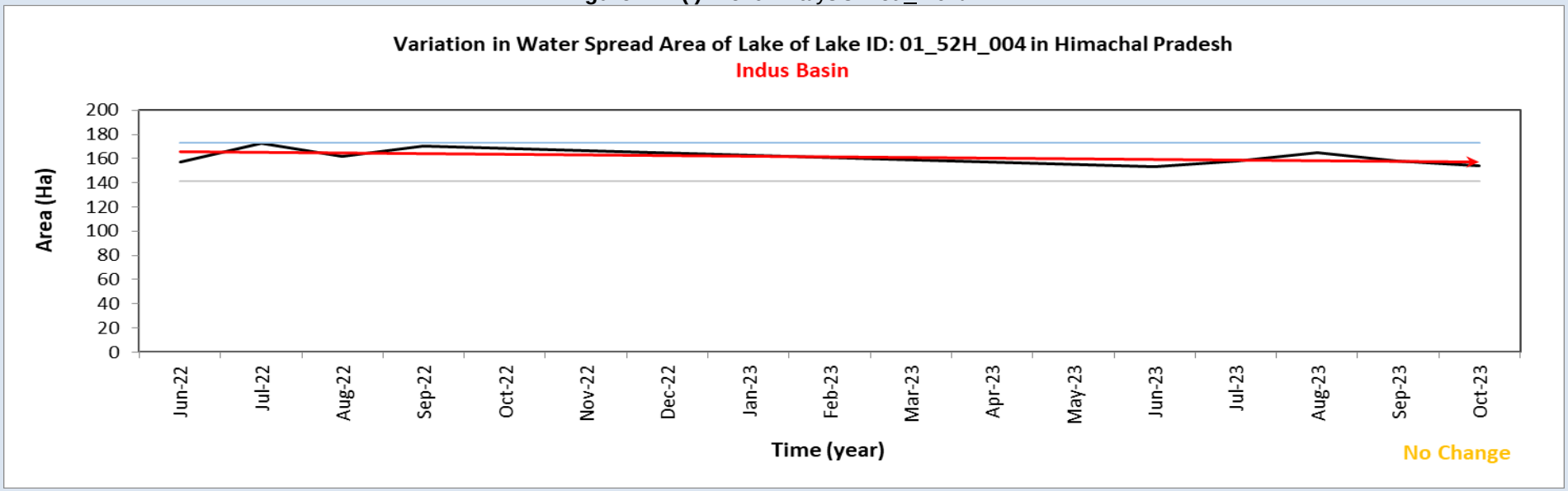


Figure 4.27(ii) Trend Analysis Plot ± 20%

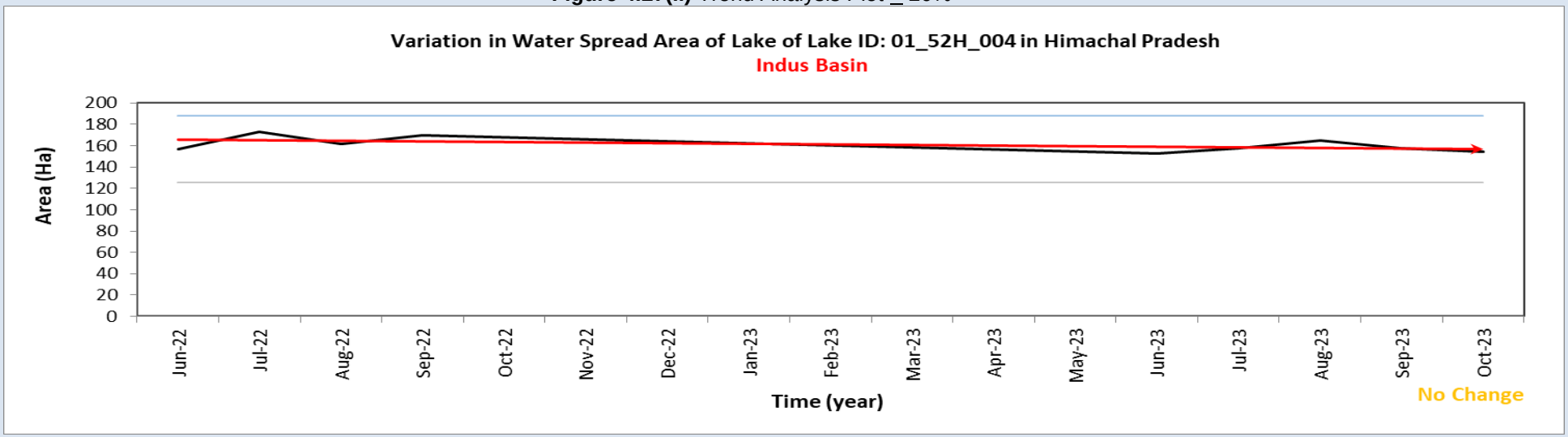


Figure 4.28(i) Trend Analysis Plot ± 10%

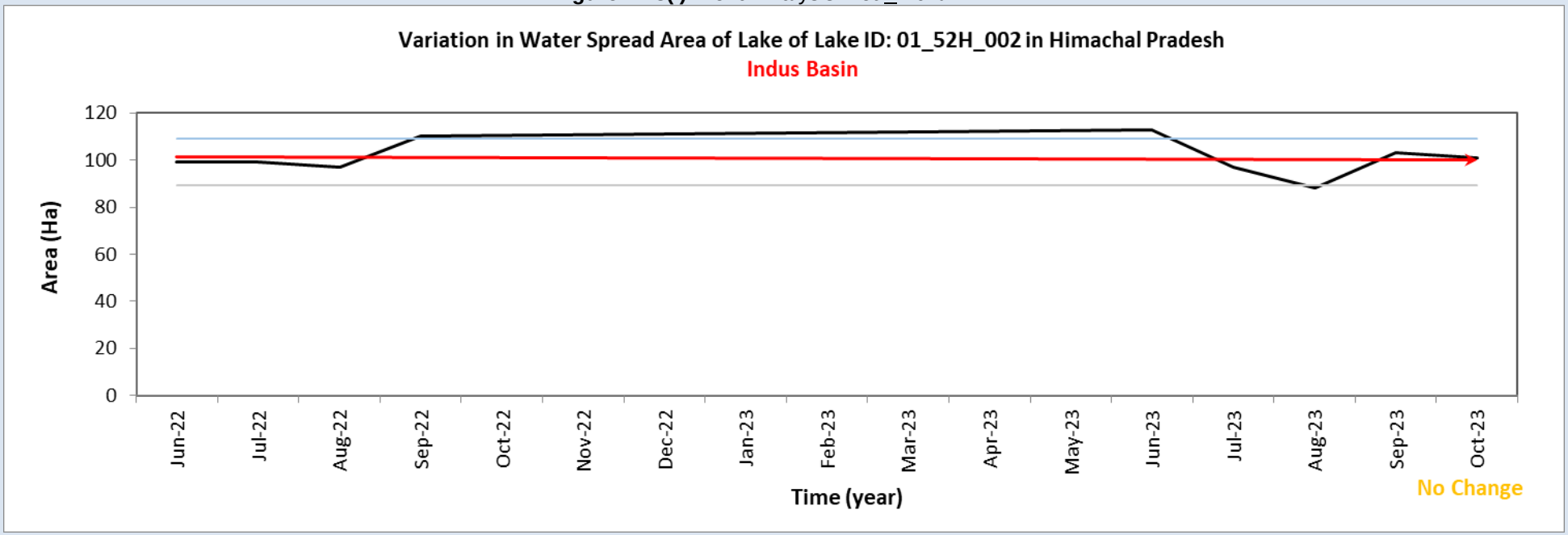
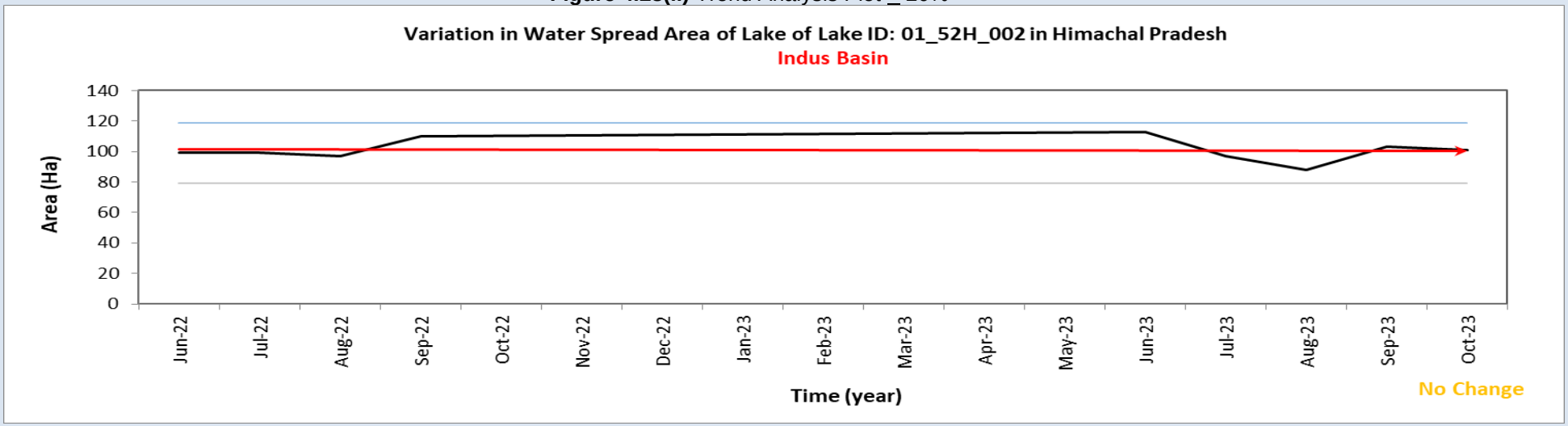


Figure 4.28(ii) Trend Analysis Plot ± 20%



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

Figure 4.29(i) Trend Analysis Plot ± 10%

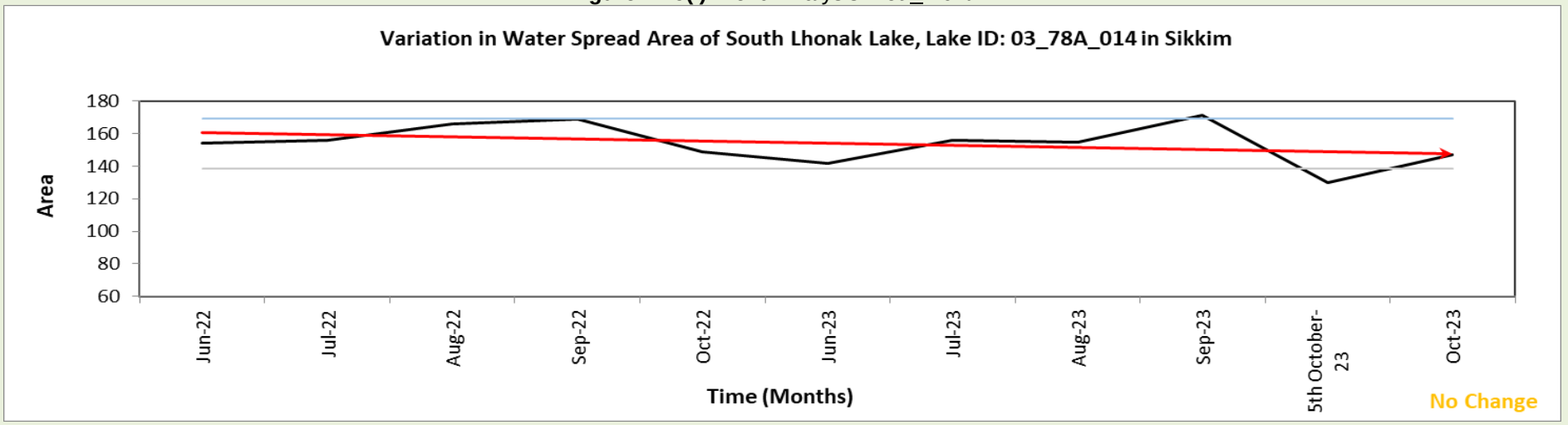


Figure 4.29(ii) Trend Analysis Plot±20%

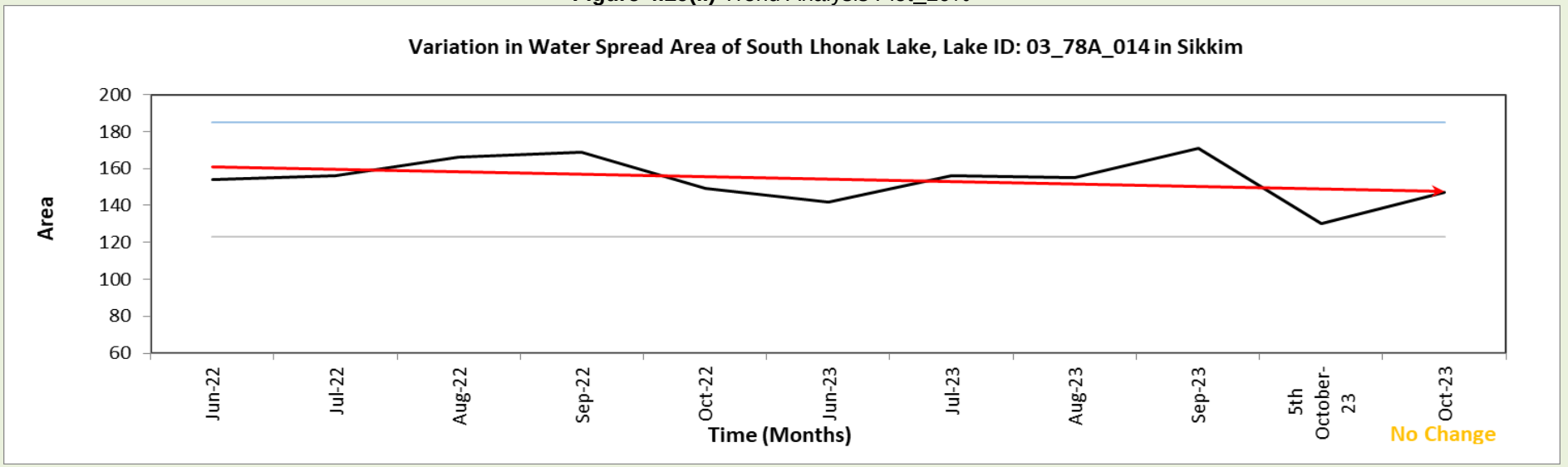


Figure 4.30(i) Trend Analysis Plot ± 10%

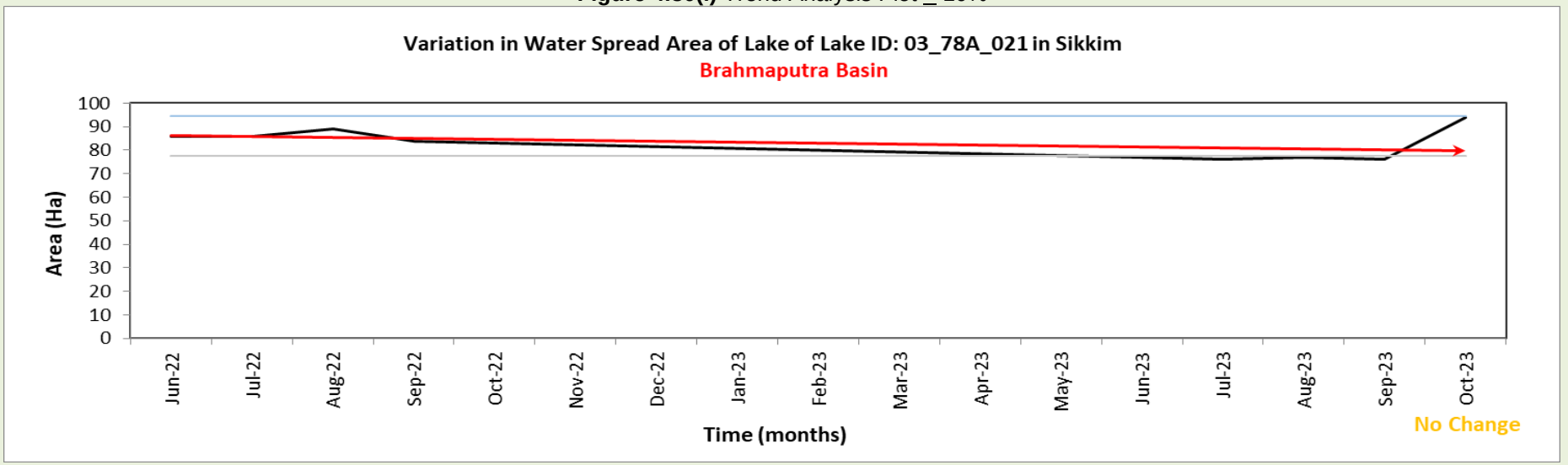


Figure 4.30(ii) Trend Analysis Plot ± 20%

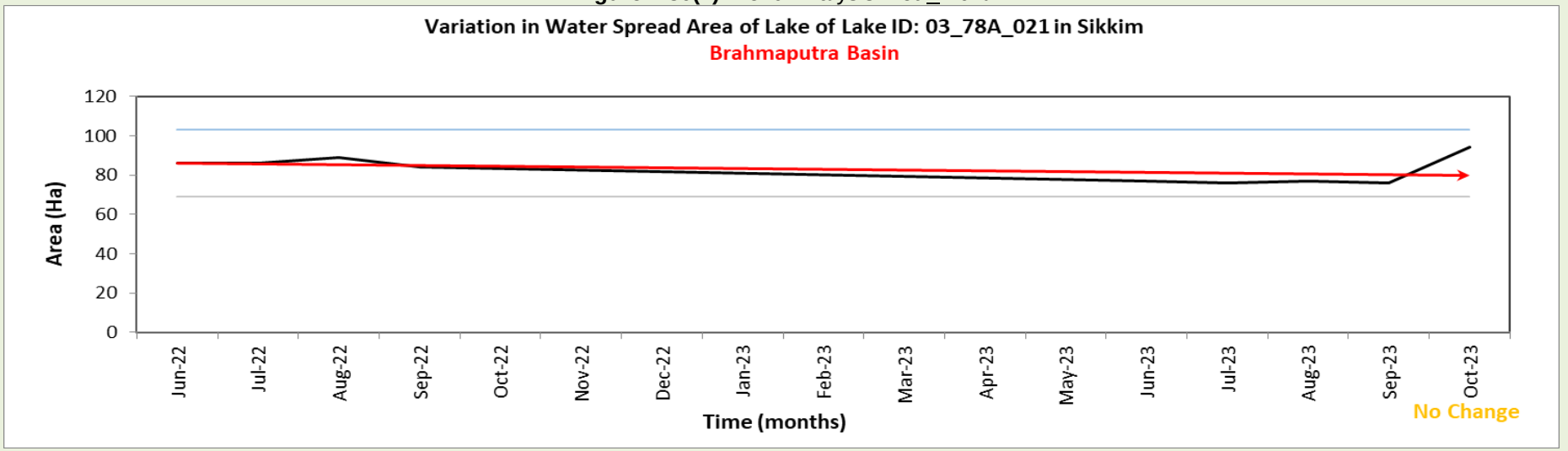


Figure 4.31(i) Trend Analysis Plot ± 10%

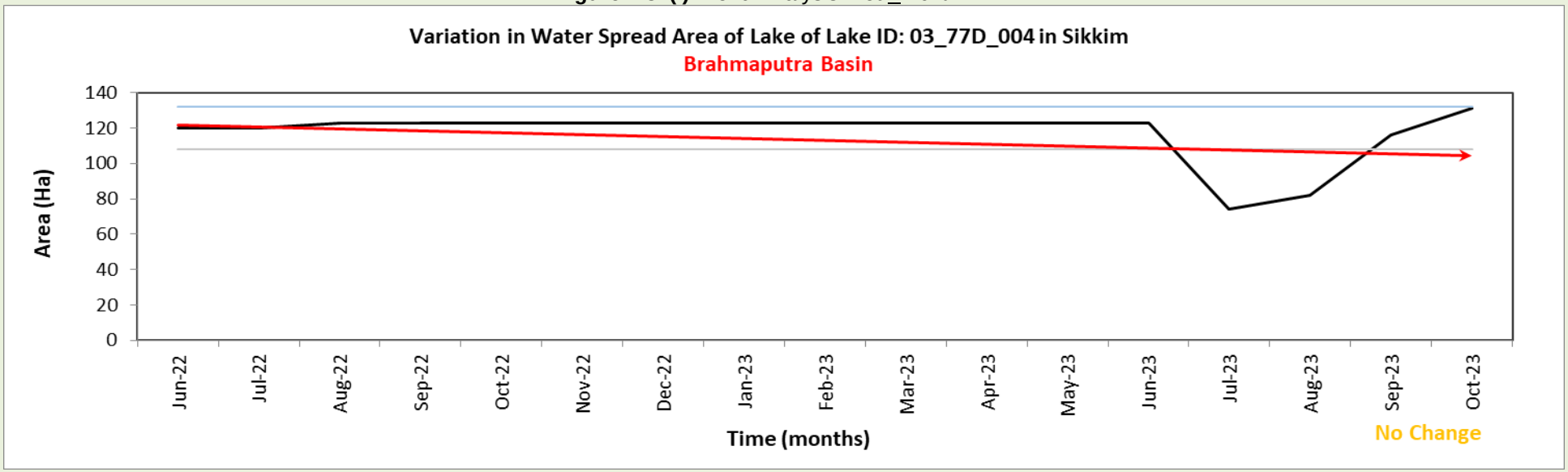


Figure 4.31(ii) Trend Analysis Plot ± 20%

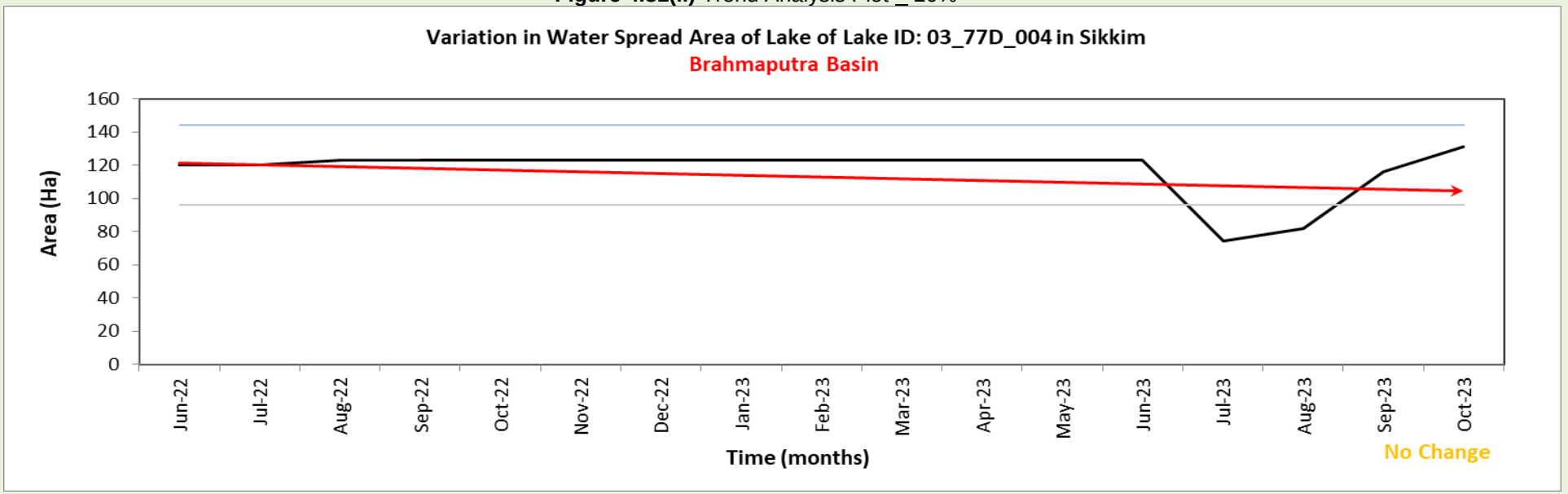


Figure 4.32(i) Trend Analysis Plot ± 10%

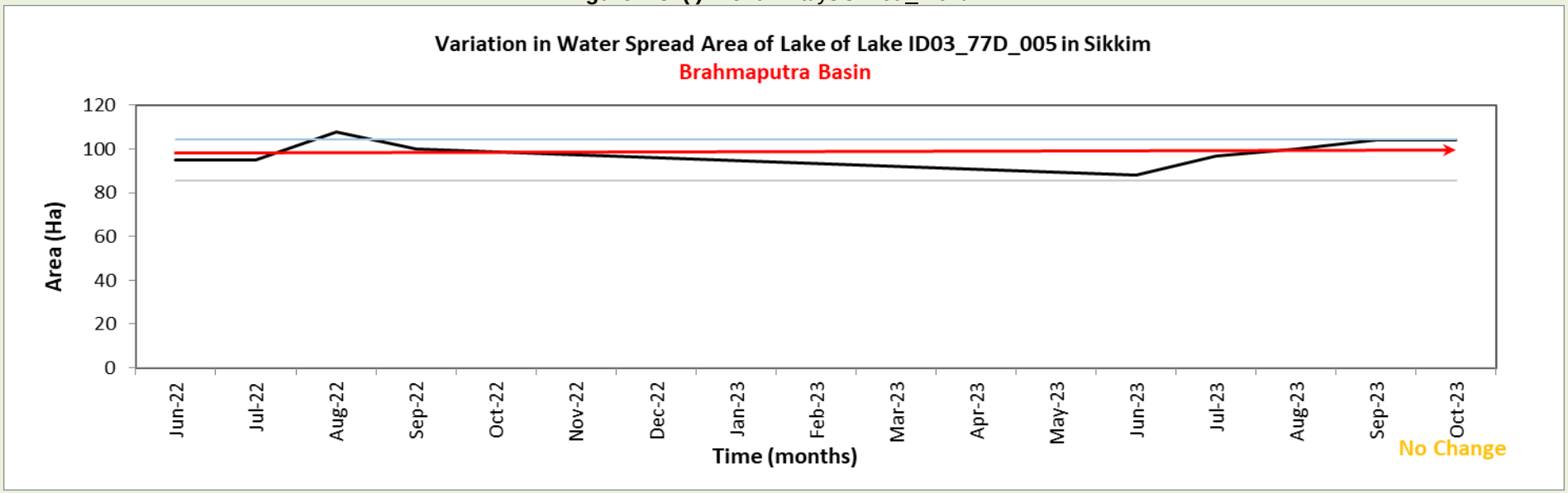


Figure 4.32(ii) Trend Analysis Plot ± 20%

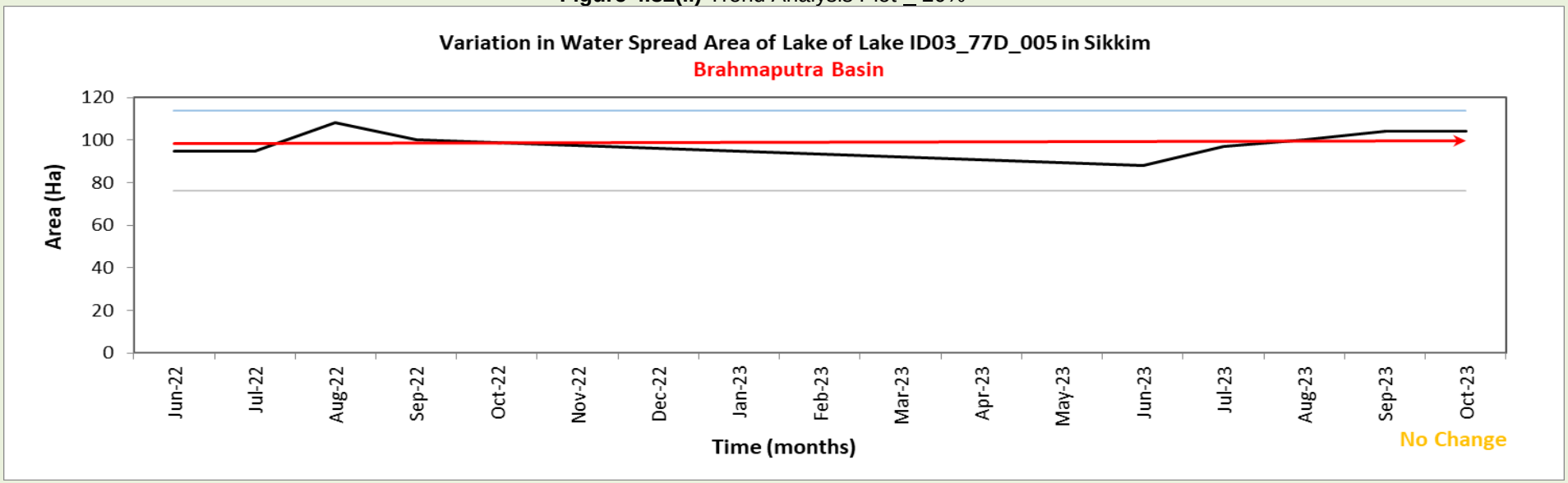


Figure 4.33(i) Trend Analysis Plot ± 10%

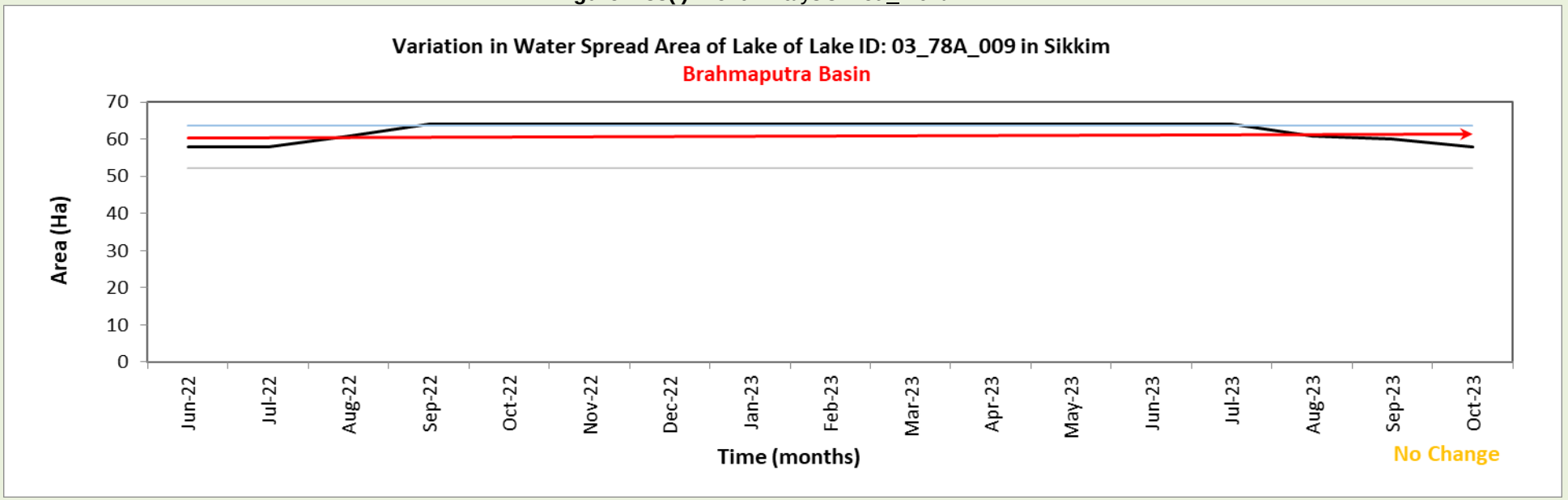


Figure 4.33(ii) Trend Analysis Plot ± 20%

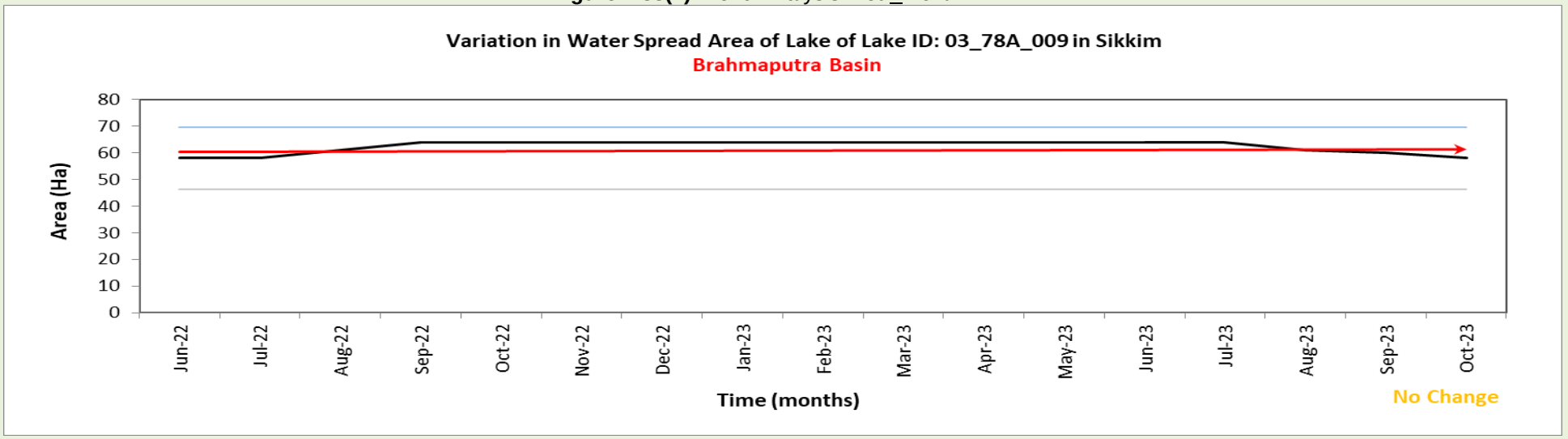


Figure 4.34(i) Trend Analysis Plot ± 10%

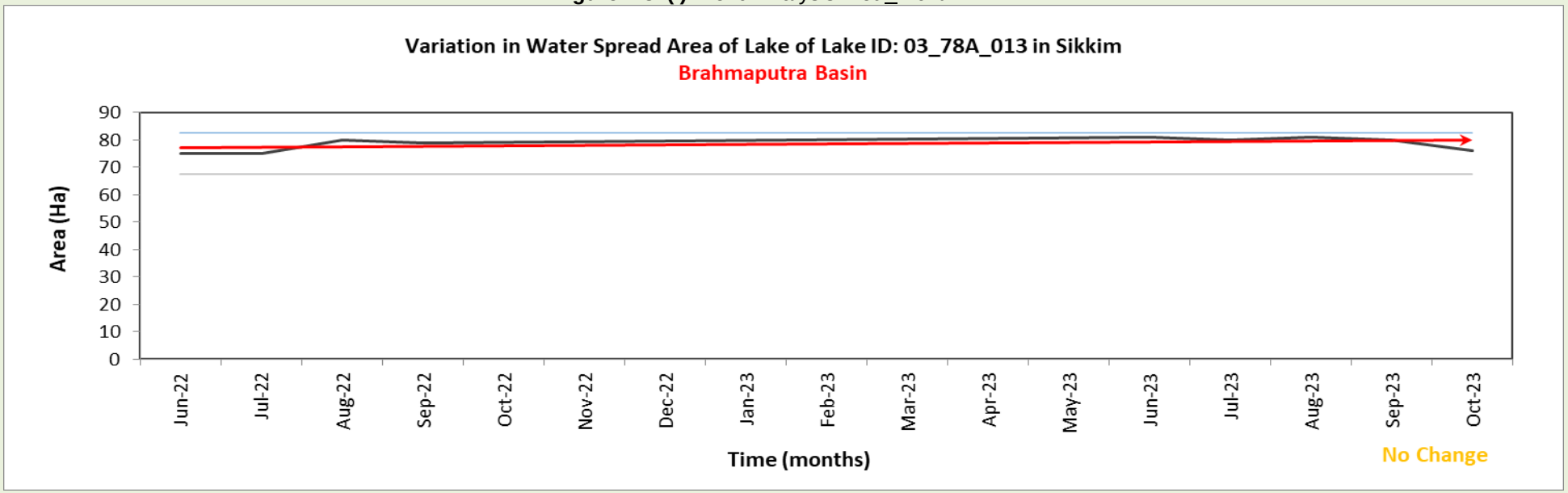


Figure 4.34(ii) Trend Analysis Plot ± 20%

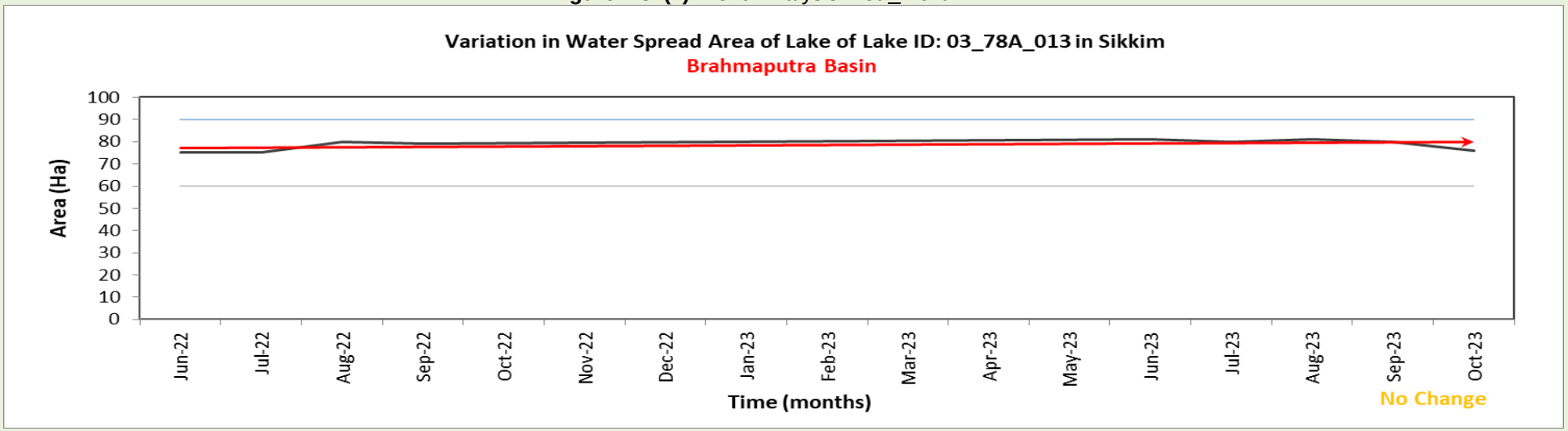


Figure 4.35(i) Trend Analysis Plot ± 10%

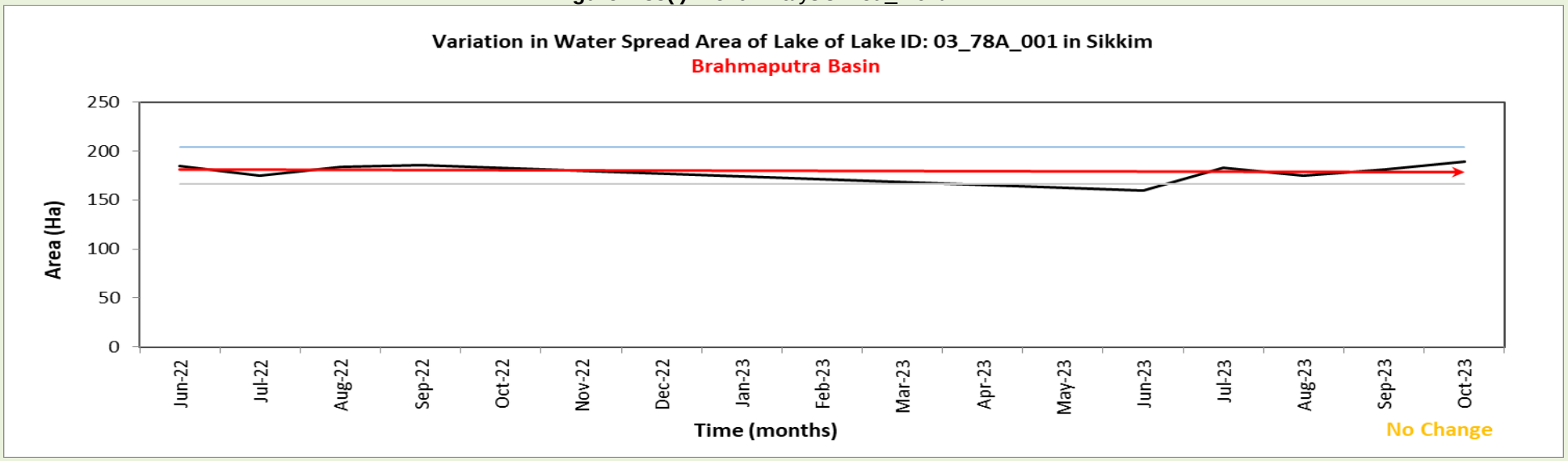


Figure 4.35(ii) Trend Analysis Plot ± 20%

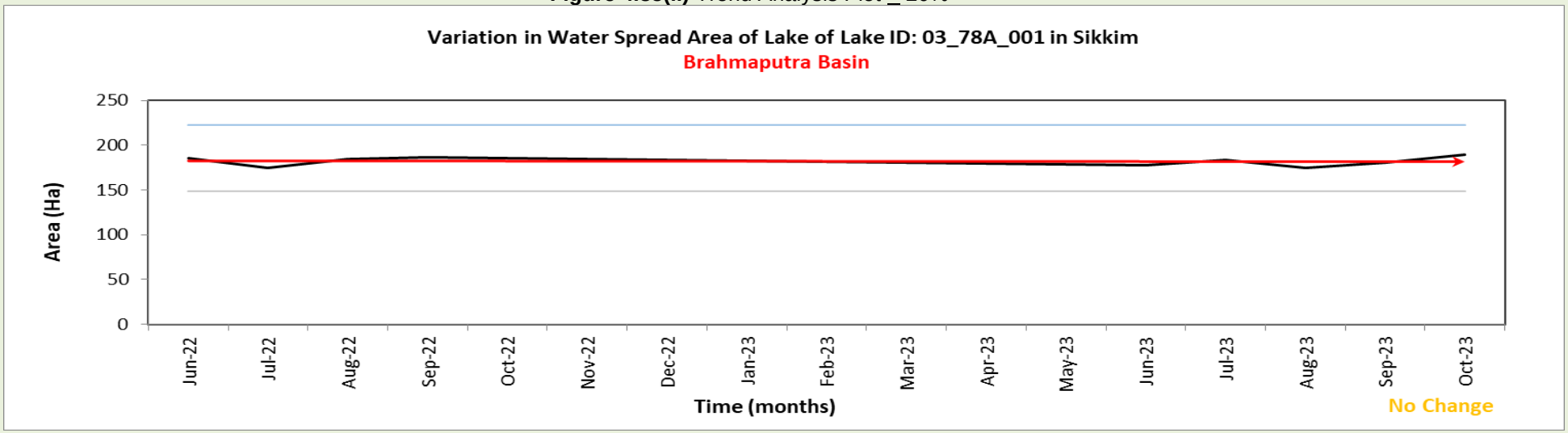


Figure 4.36(i) Trend Analysis Plot ± 10%

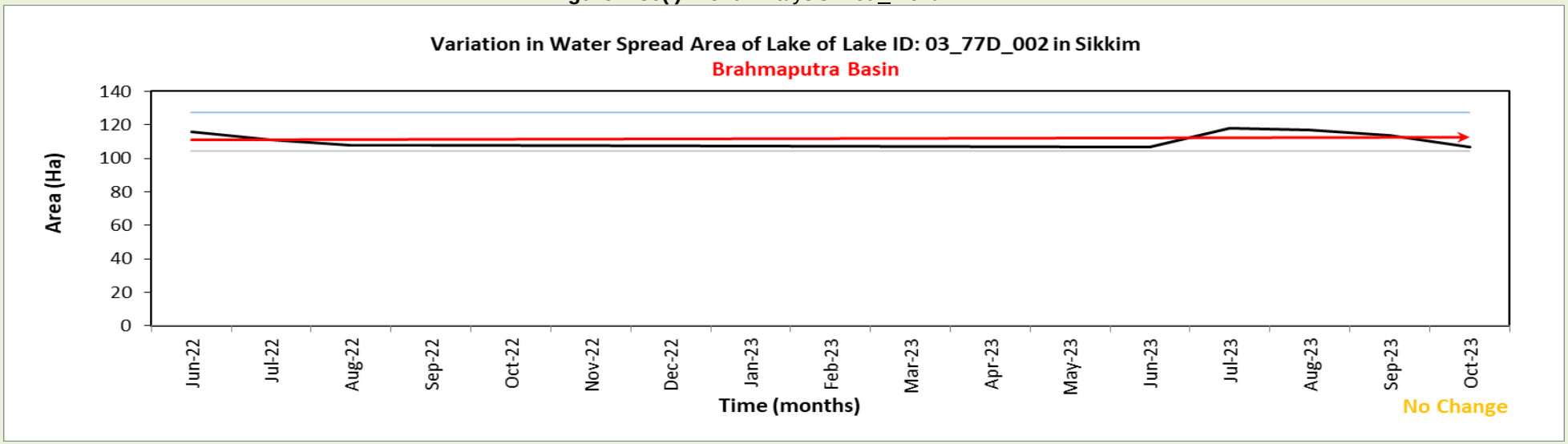


Figure 4.36(ii) Trend Analysis Plot ± 20%

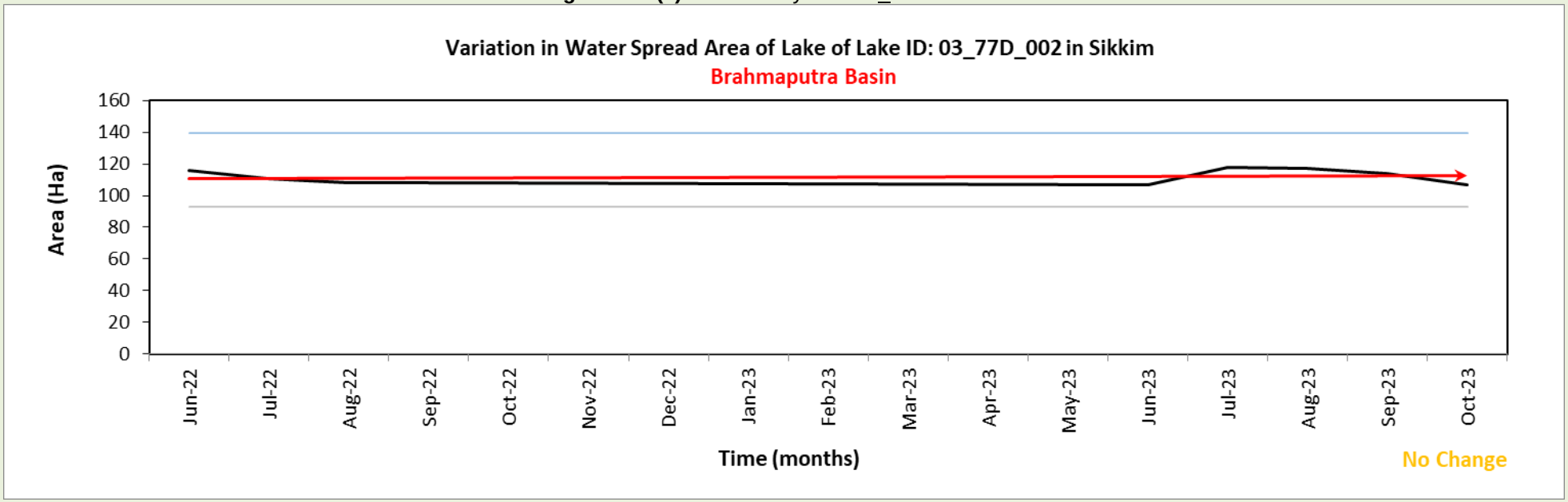


Figure 4.37(i) Trend Analysis Plot ± 10%

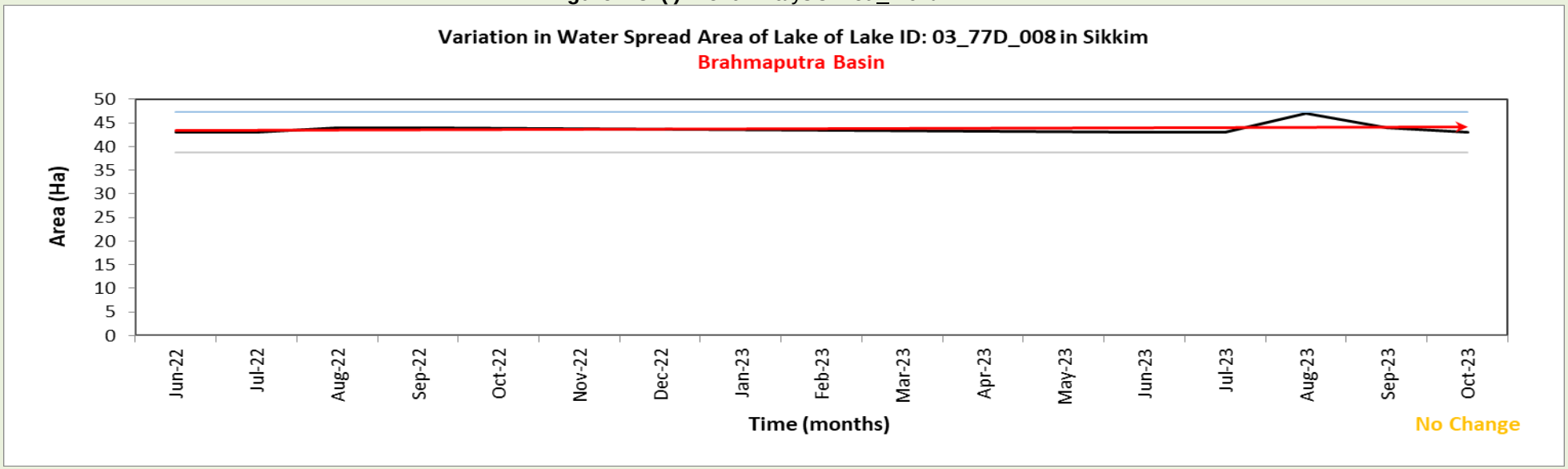


Figure 4.37(ii) Trend Analysis Plot ± 20%

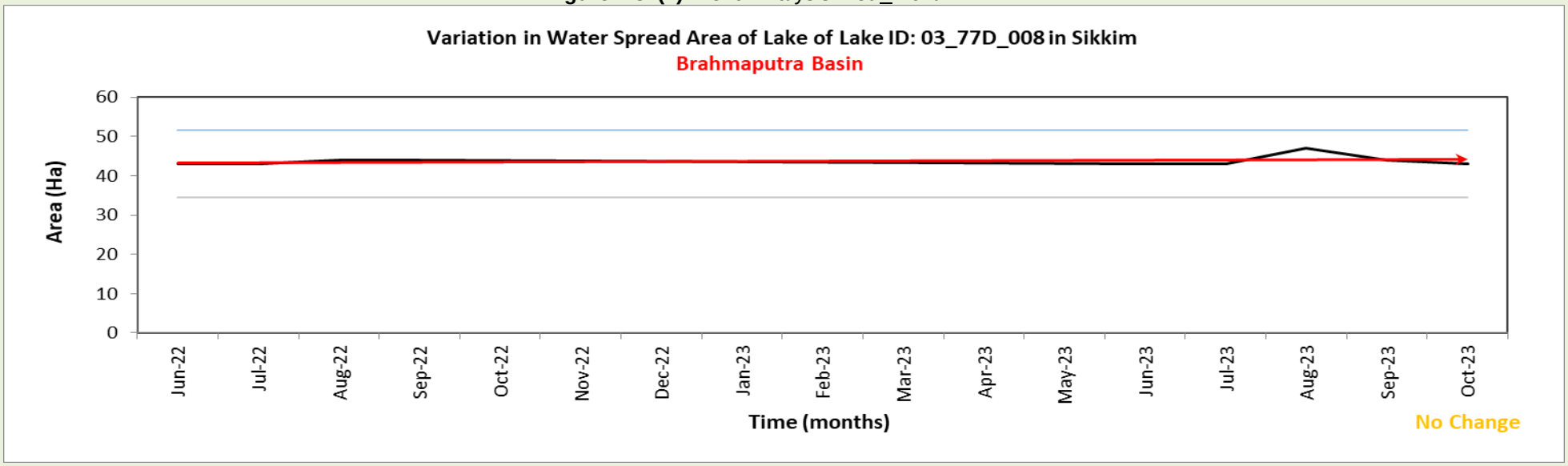


Figure 4.38(i) Trend Analysis Plot ± 10%

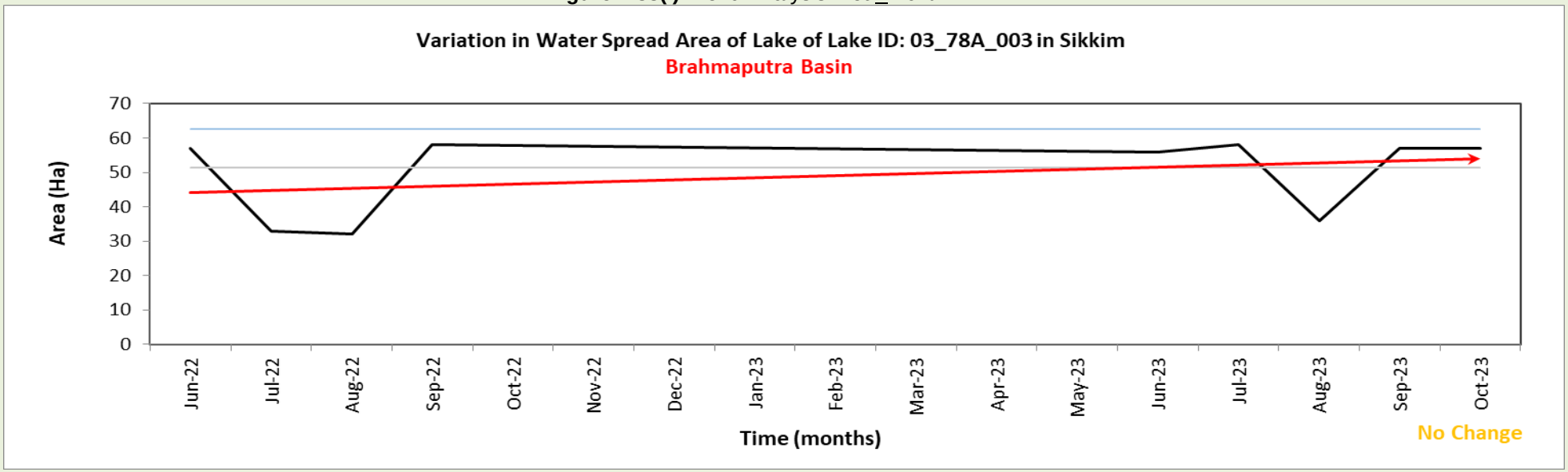
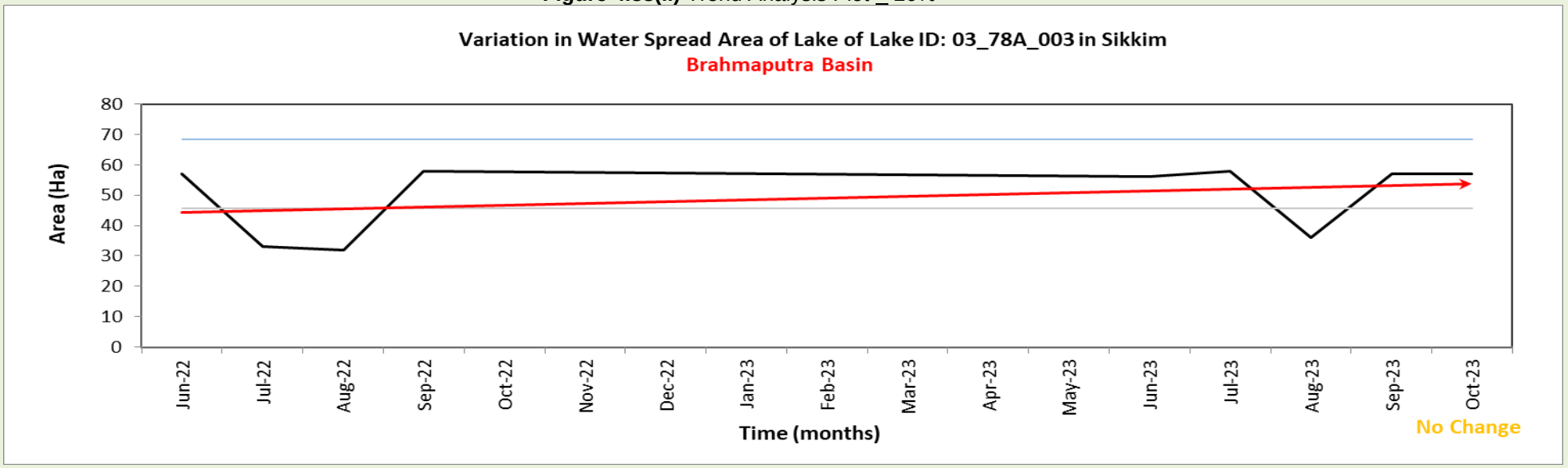


Figure 4.38(ii) Trend Analysis Plot ± 20%



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 ± 10% variation w.r.t. base year data of 2011

As per the analysis for trend of Glacial Lakes assuming a ±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 ±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**
	Total	**24**	**42**	**17**	**2**	**85**

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) ± 20% variation w.r.t. base year data of 2011

The output of trend analysis assuming a ±20 % variation in last data w.r.t base year data (2011) of water spread area, was exactly the same as that of ±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 ±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**
	Total	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.

Trend analysis for Change in Water spread area of Glacial Lakes (10-50 Ha) for ±10% & ±20% w.r.t base year data 2011

S.No.	States	Figure No.
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 ±10%

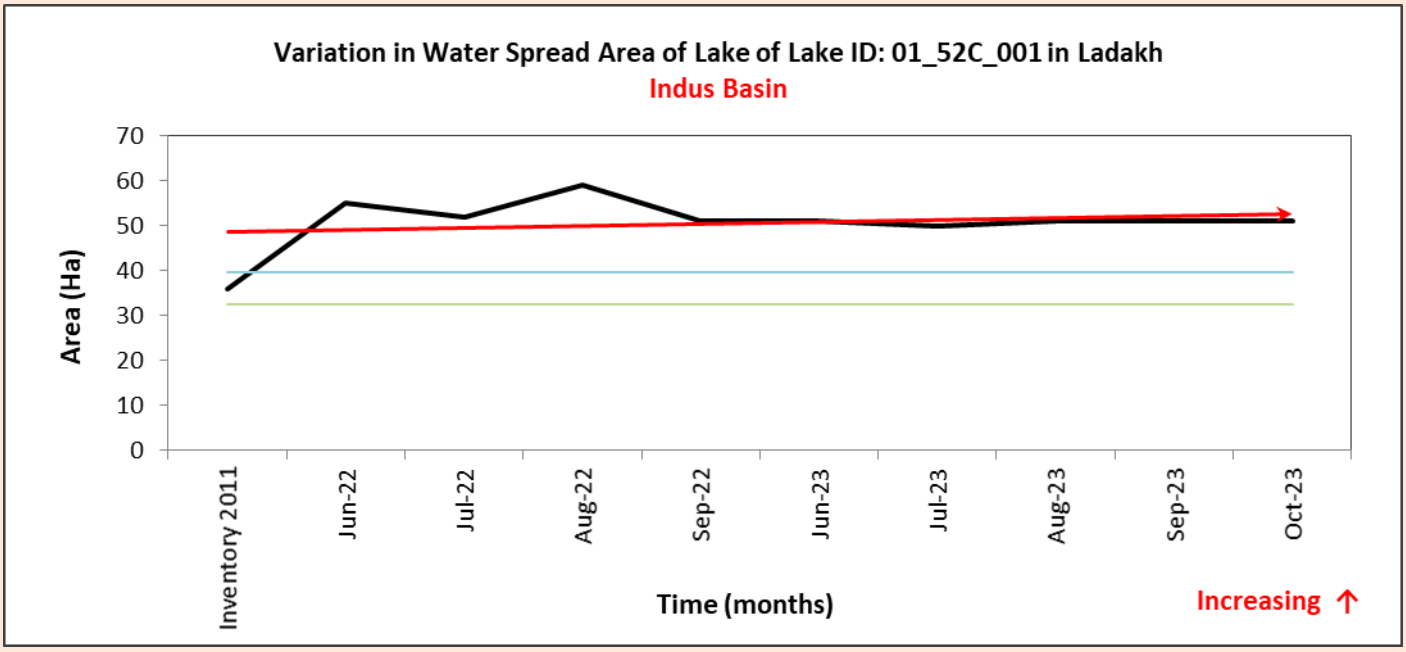


Figure 4.39(ii) Trend Analysis Plot ±20%

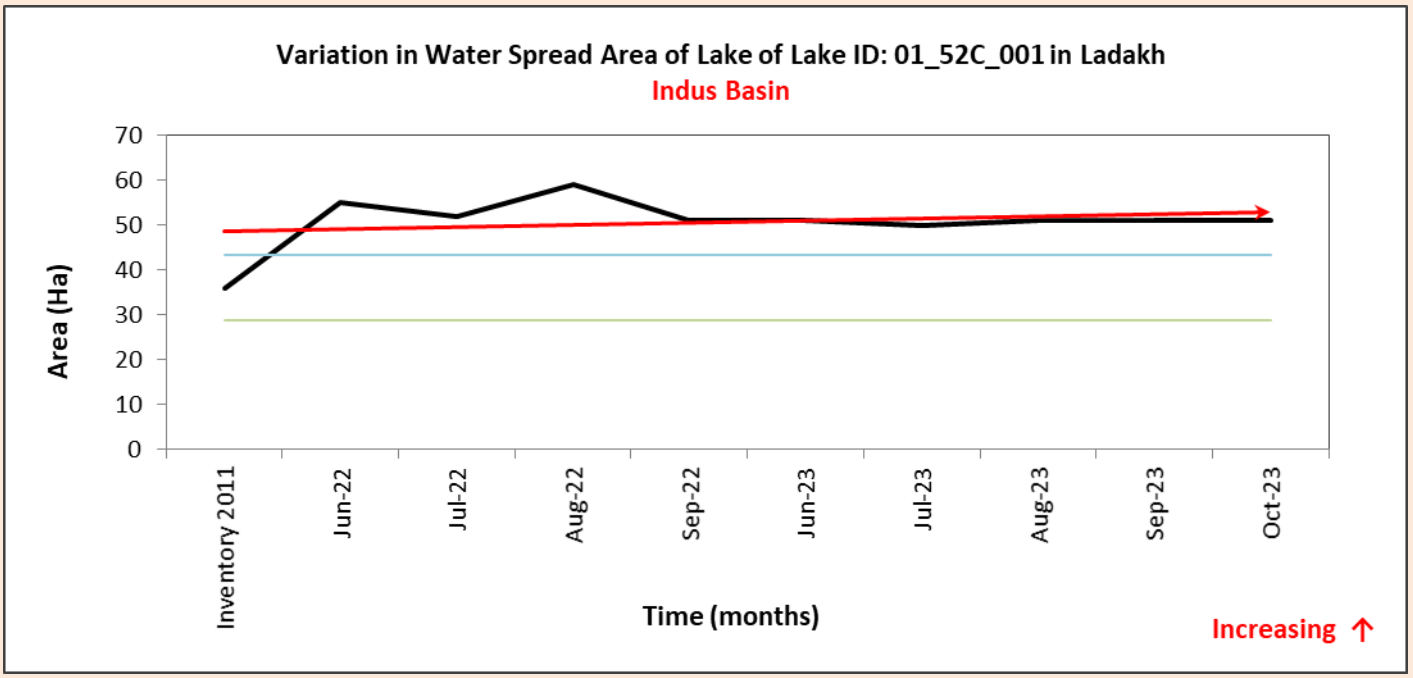


Figure 4.40(i) Trend Analysis Plot ±10%

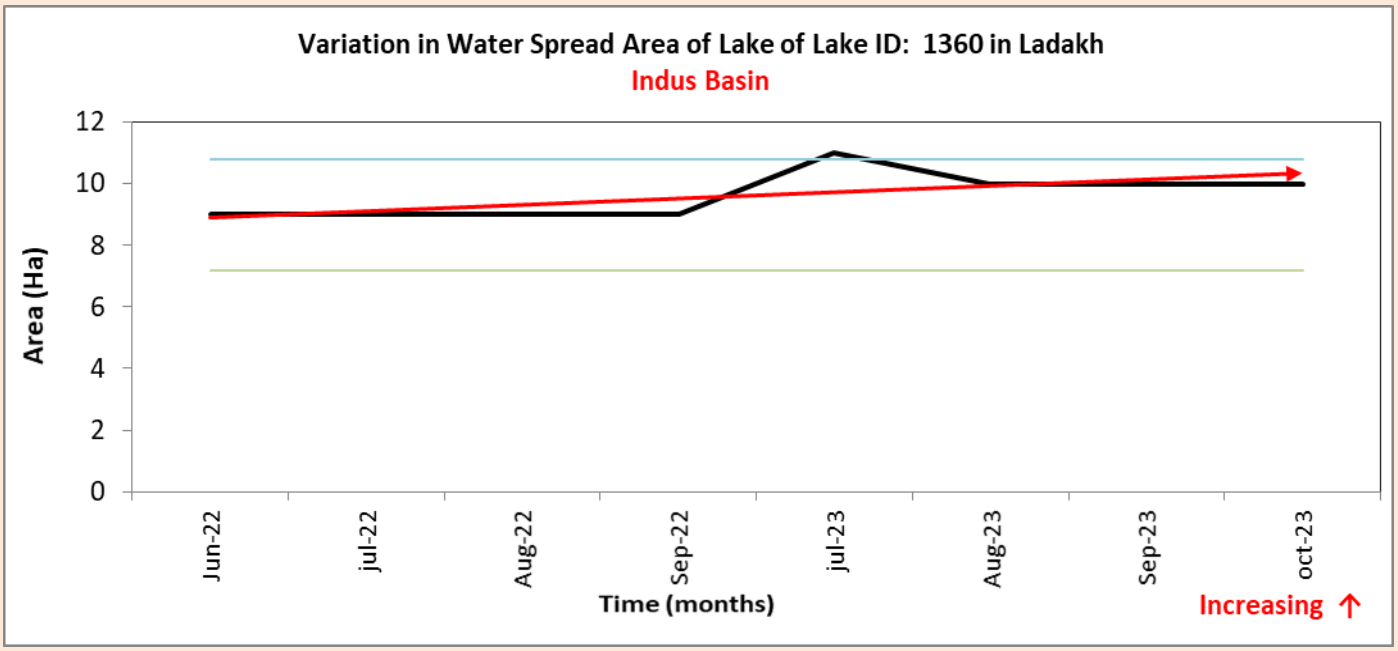


Figure 4.40(ii) Trend Analysis Plot ±20%

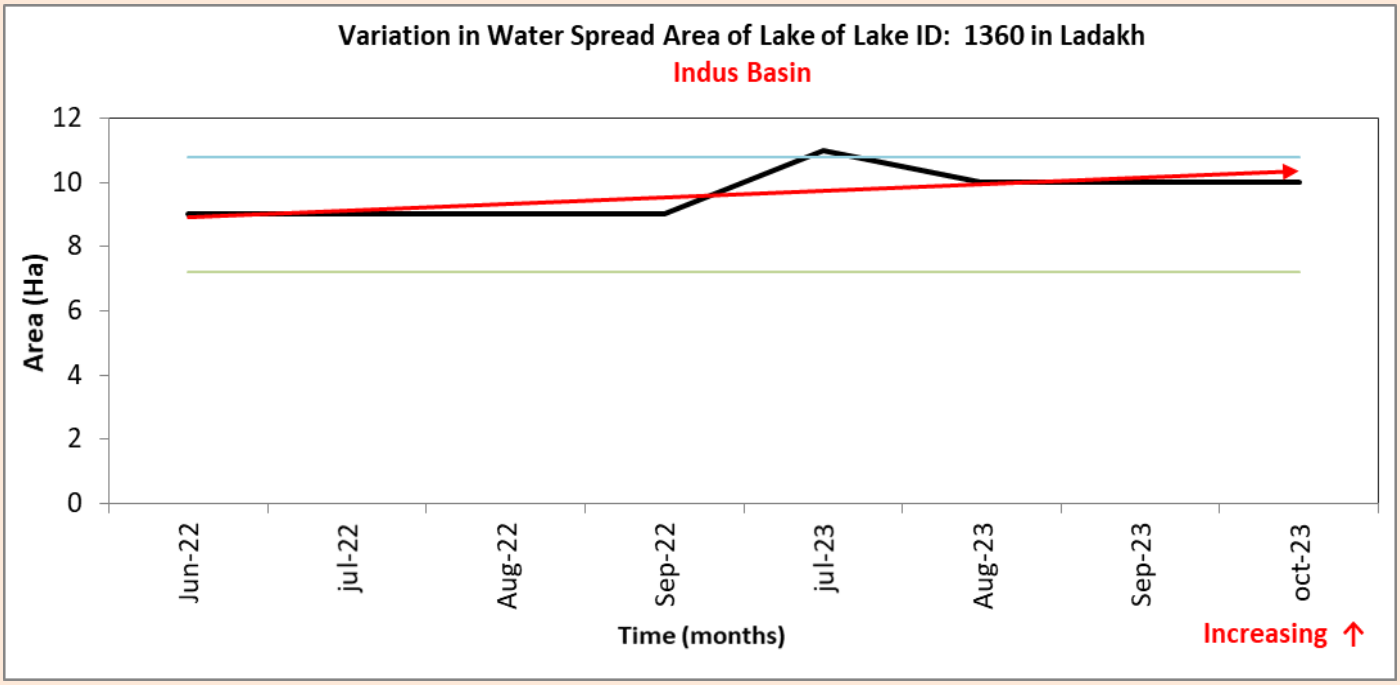


Figure 4.41(i) Trend Analysis Plot ±10%

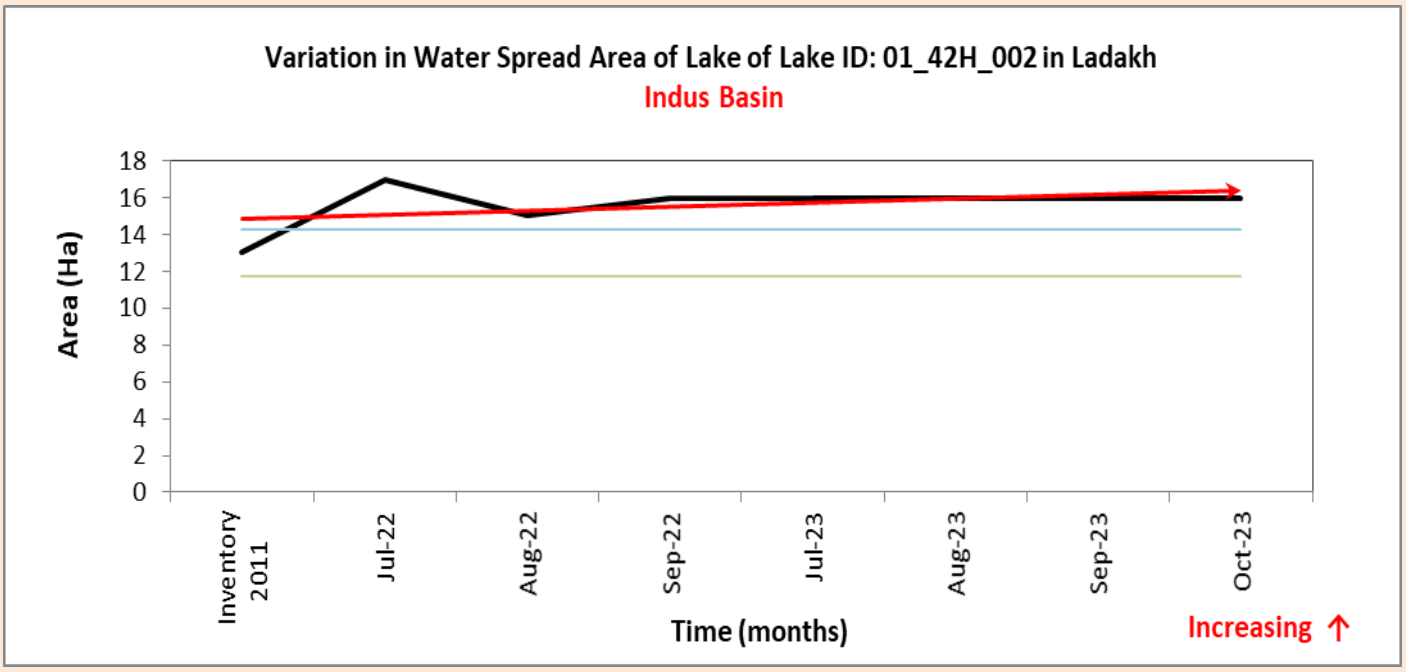


Figure 4.41(ii) Trend Analysis Plot ±20%

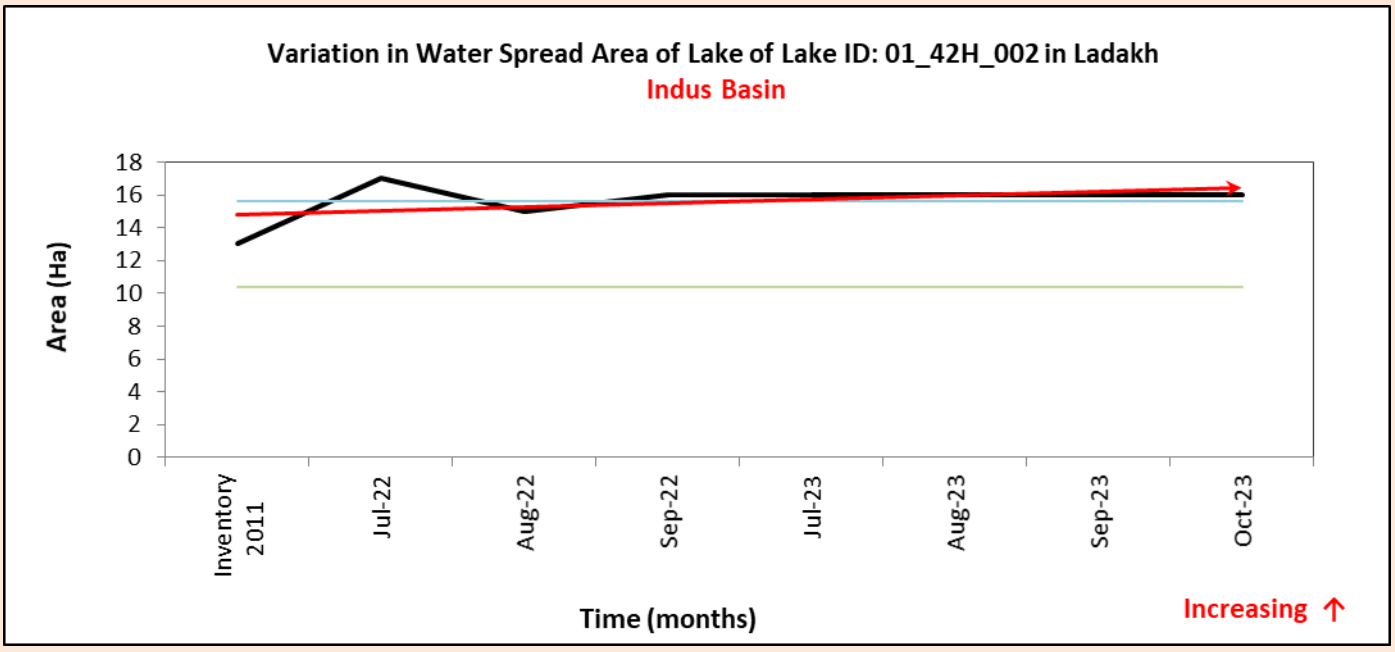


Figure 4.42(i) Trend Analysis Plot ±10%

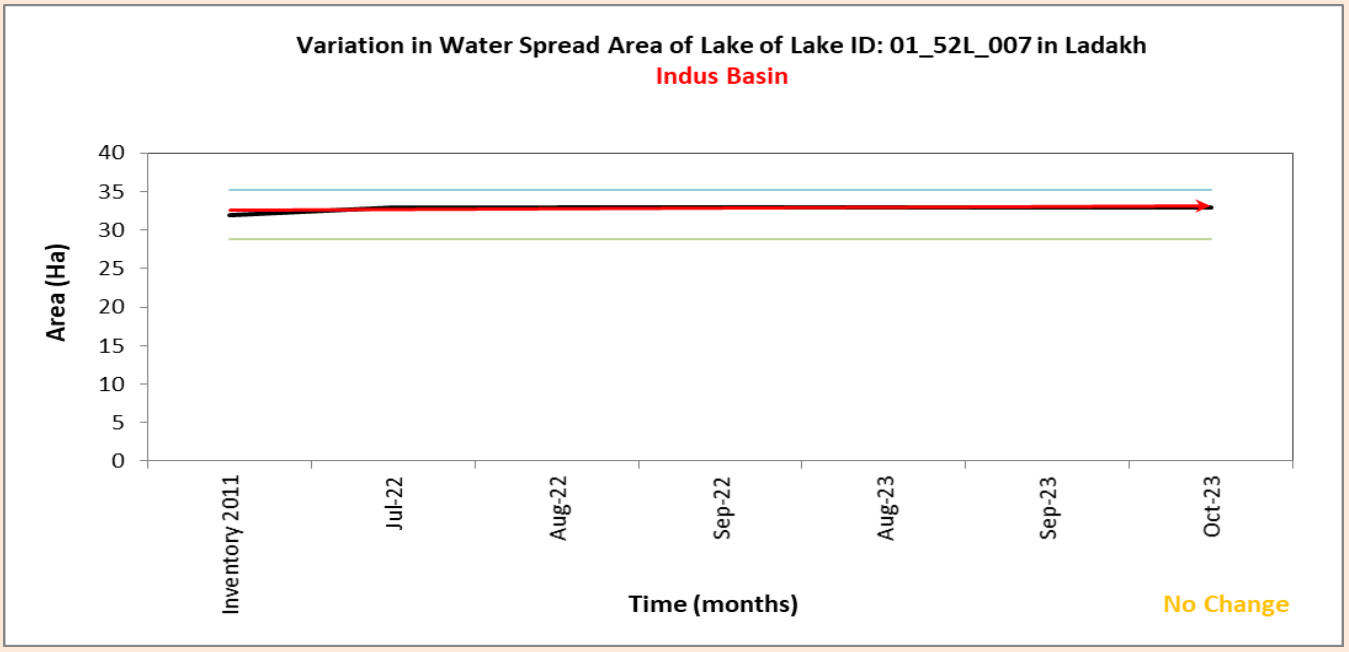


Figure 4.42(ii) Trend Analysis Plot ±20%

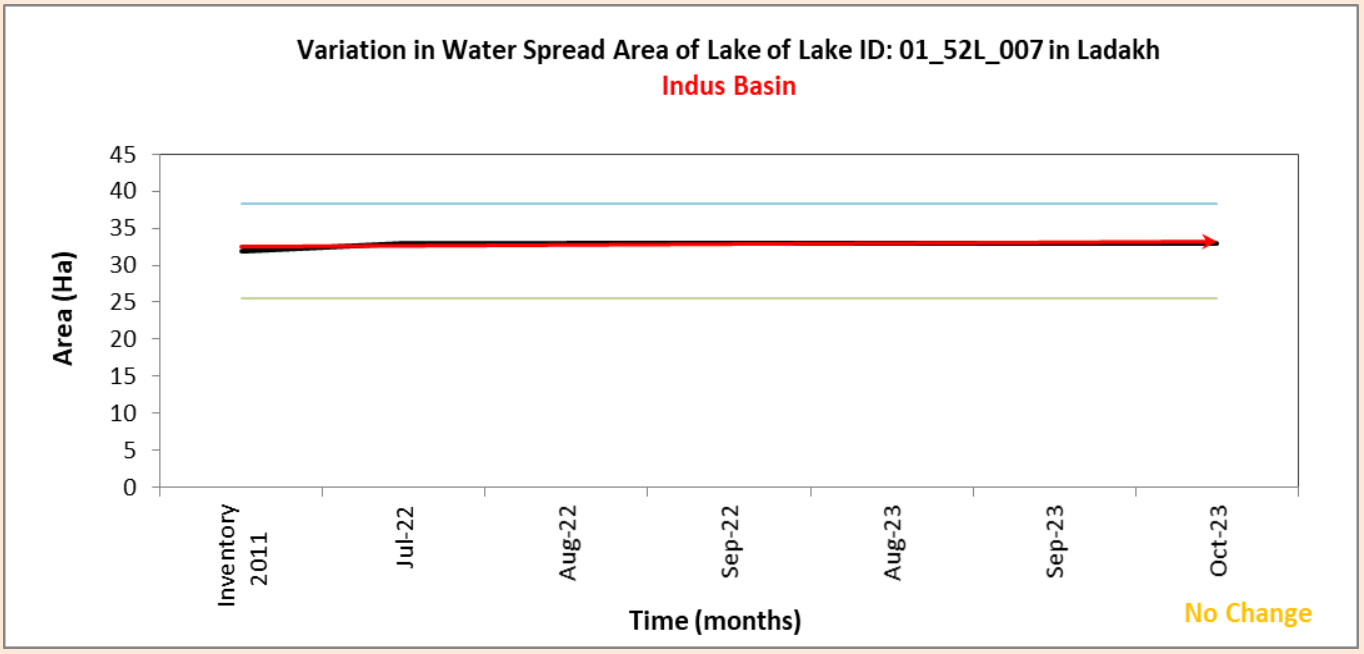


Figure 4.43(i) Trend Analysis Plot ±10%

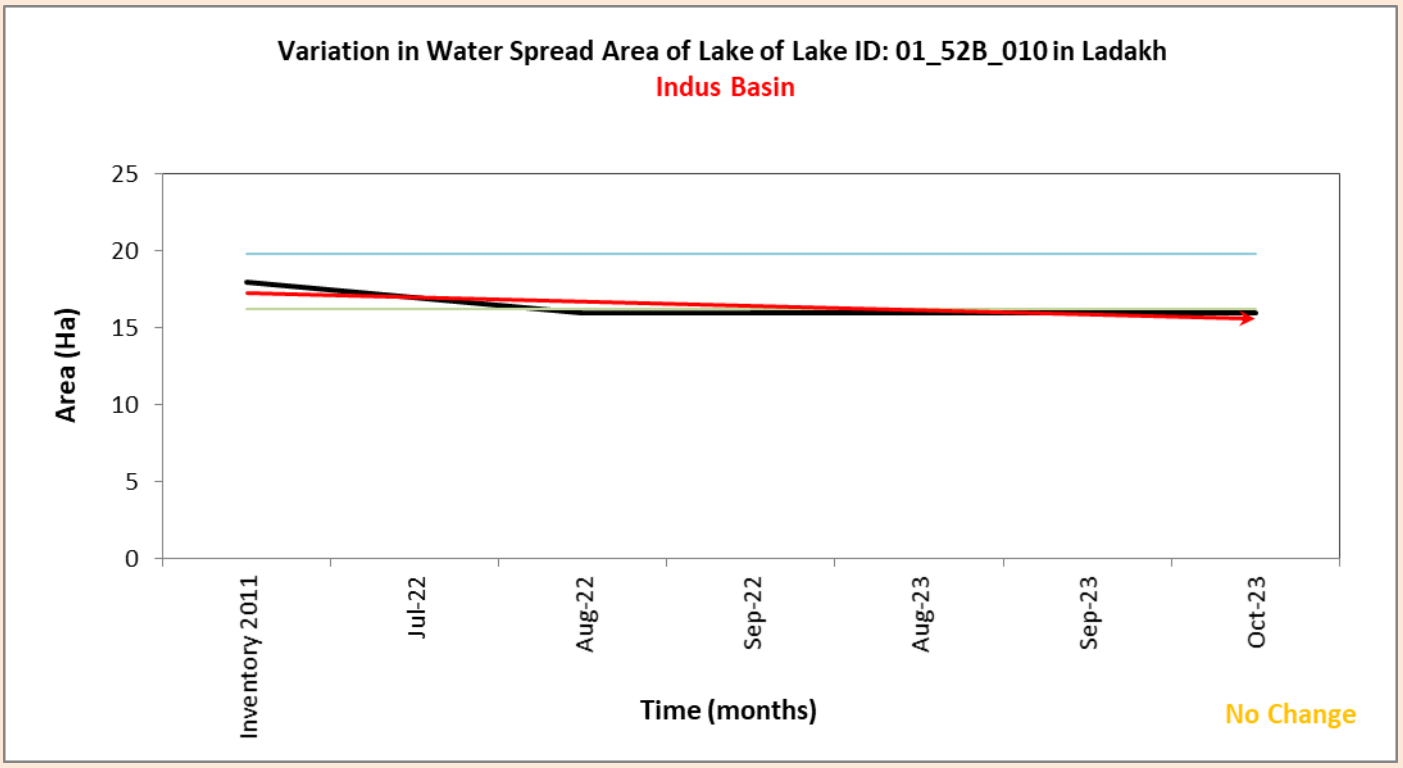


Figure 4.43(ii) Trend Analysis Plot ±20%

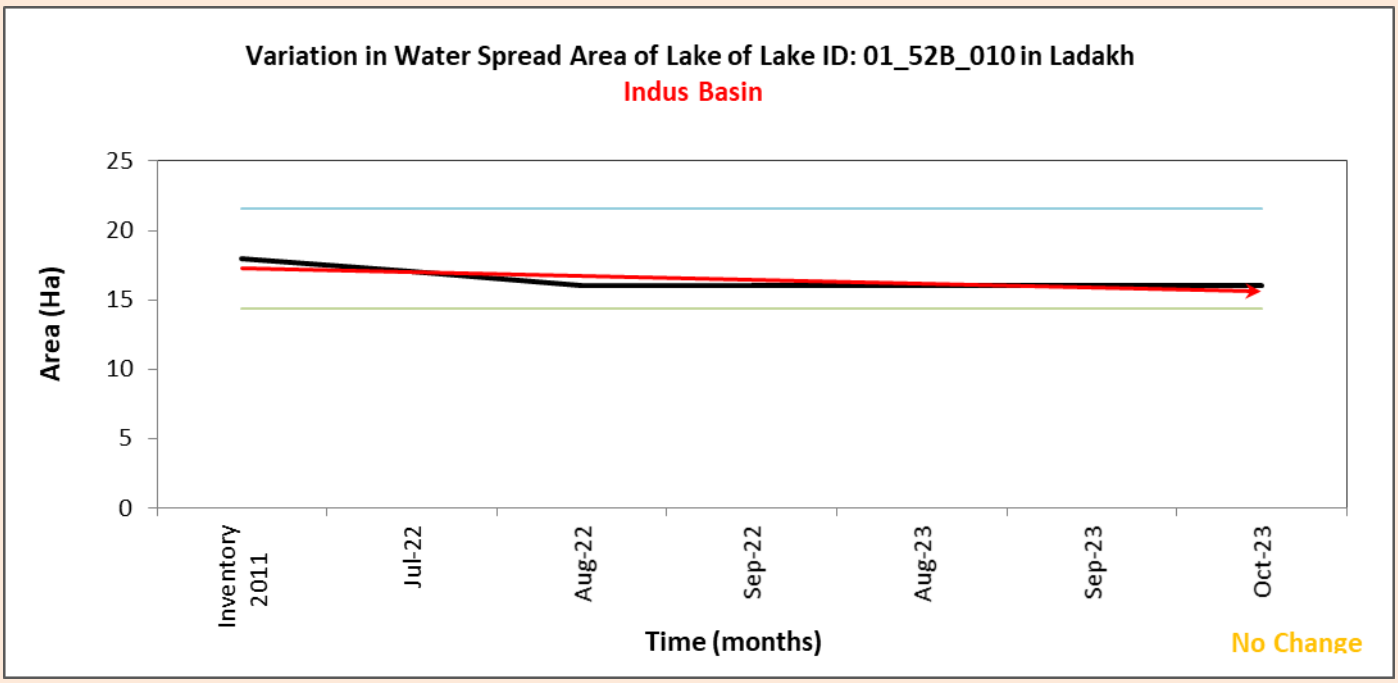


Figure 4.44(i) Trend Analysis Plot ±10%

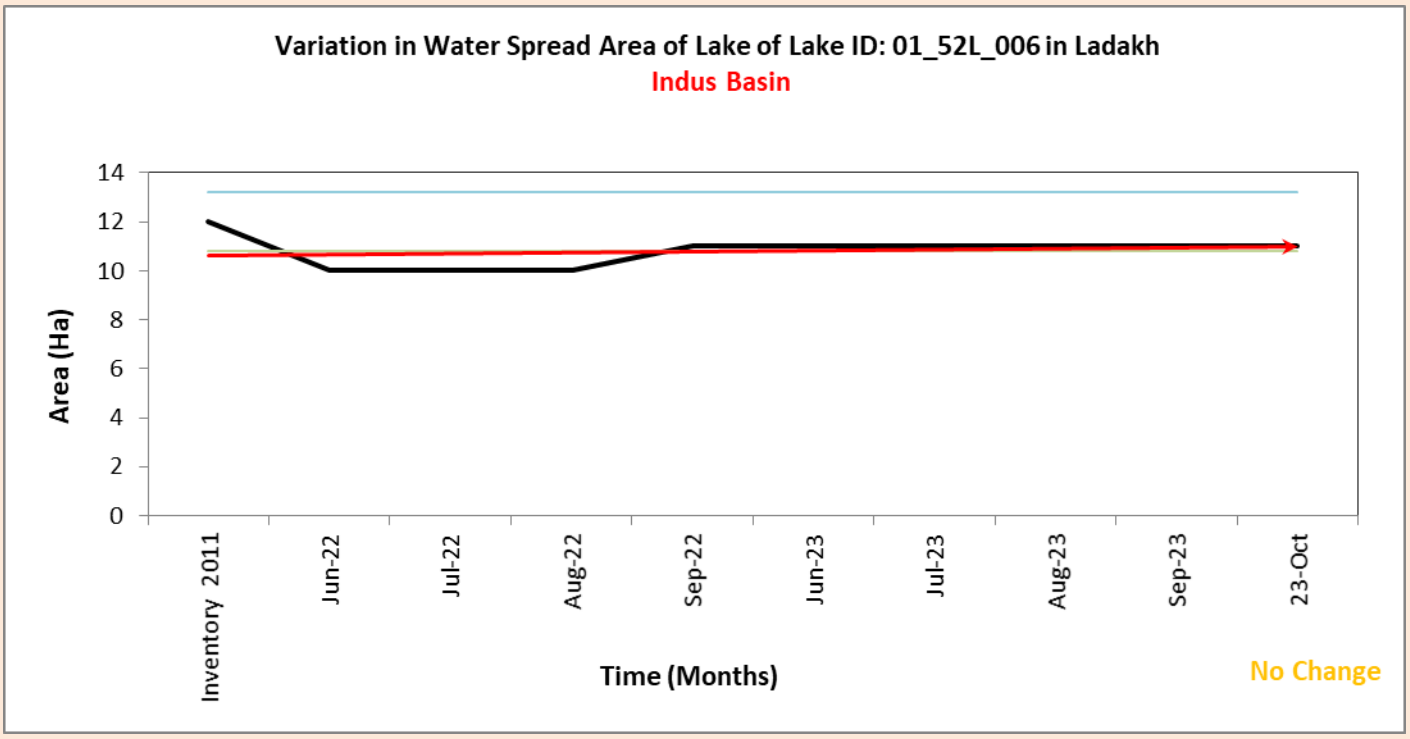


Figure 4.44(ii) Trend Analysis Plot ±20%

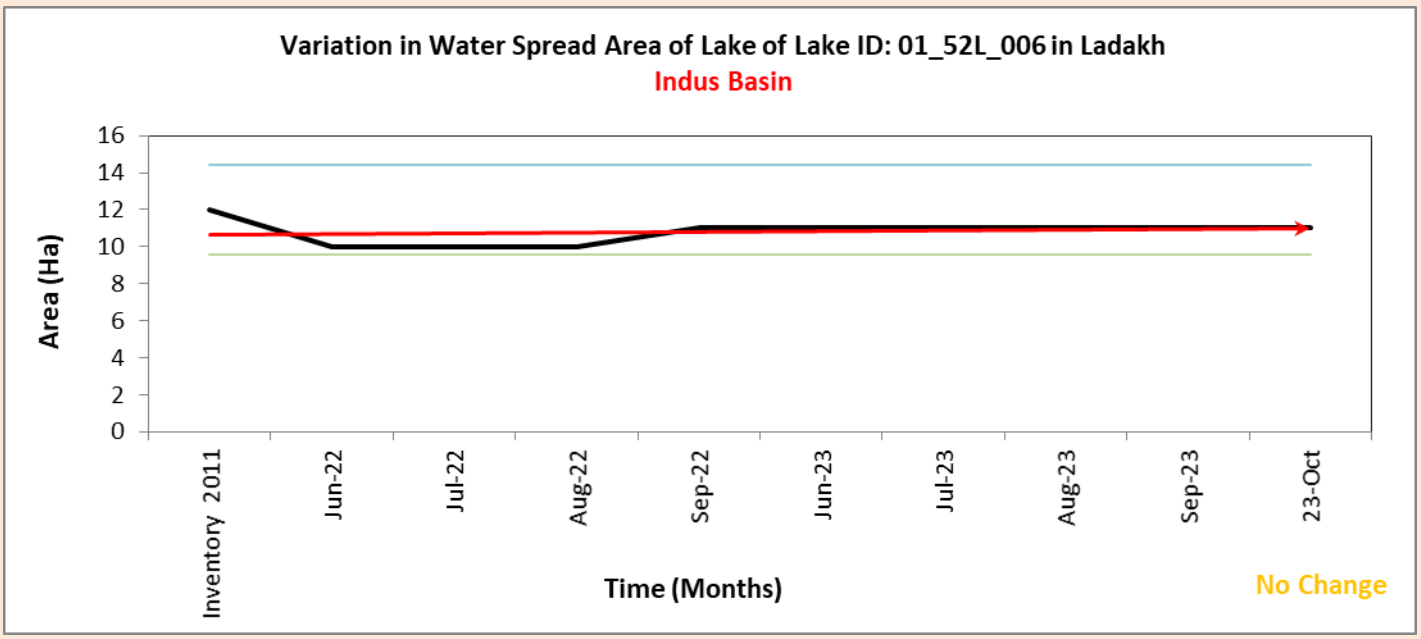


Figure 4.45(i) Trend Analysis Plot ±10%

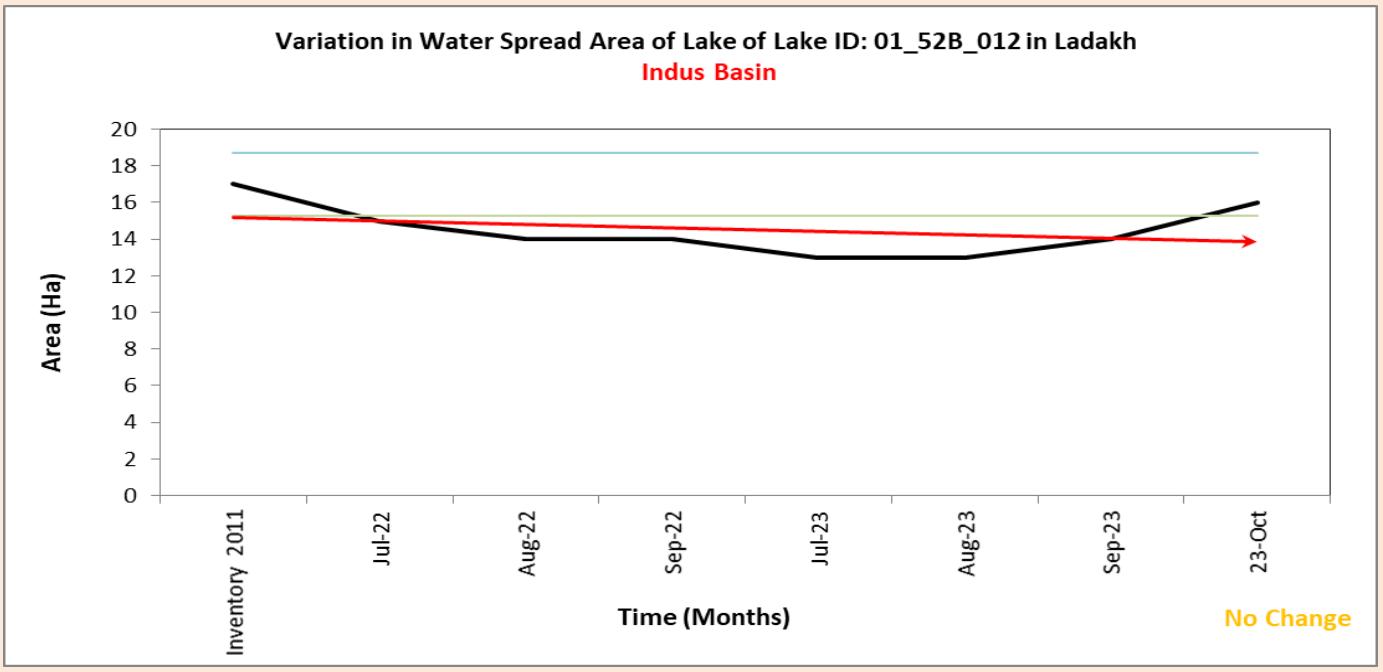


Figure 4.45(ii) Trend Analysis Plot ±20%

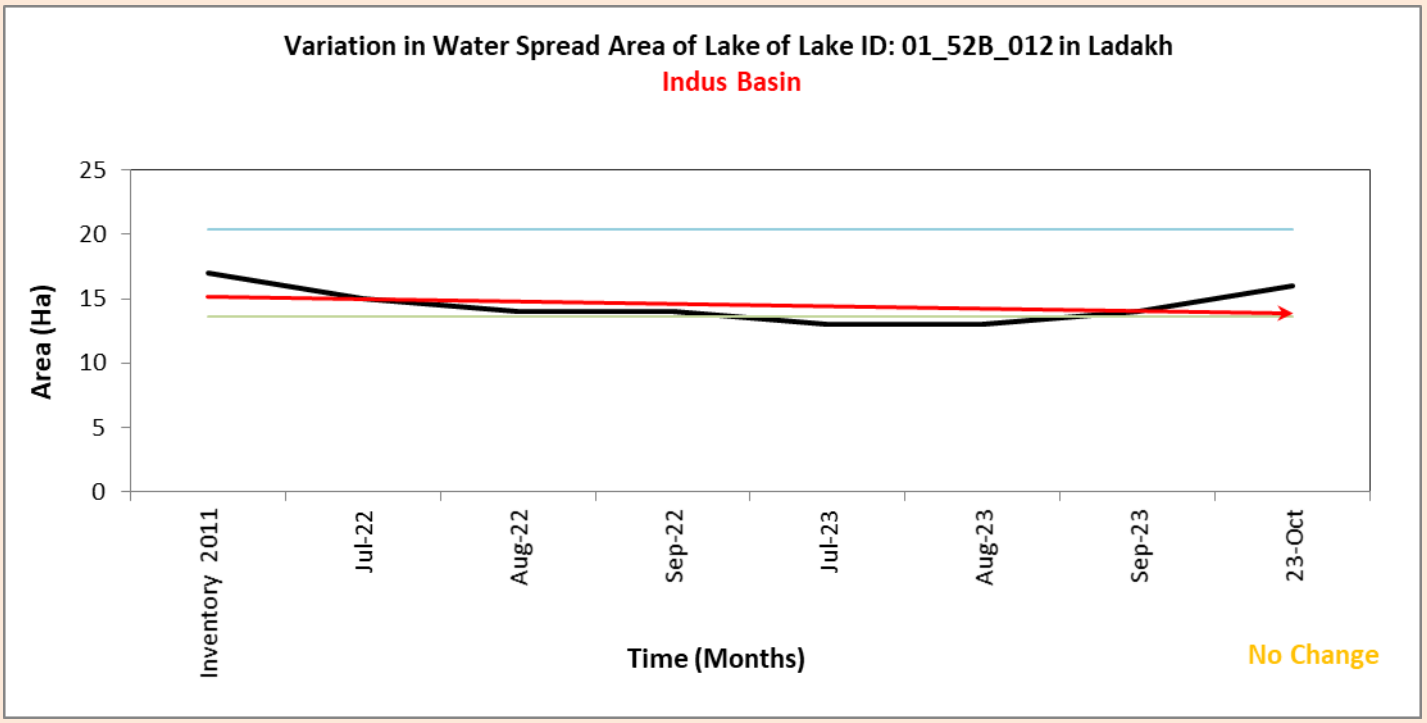


Figure 4.46(i) Trend Analysis Plot ±10%

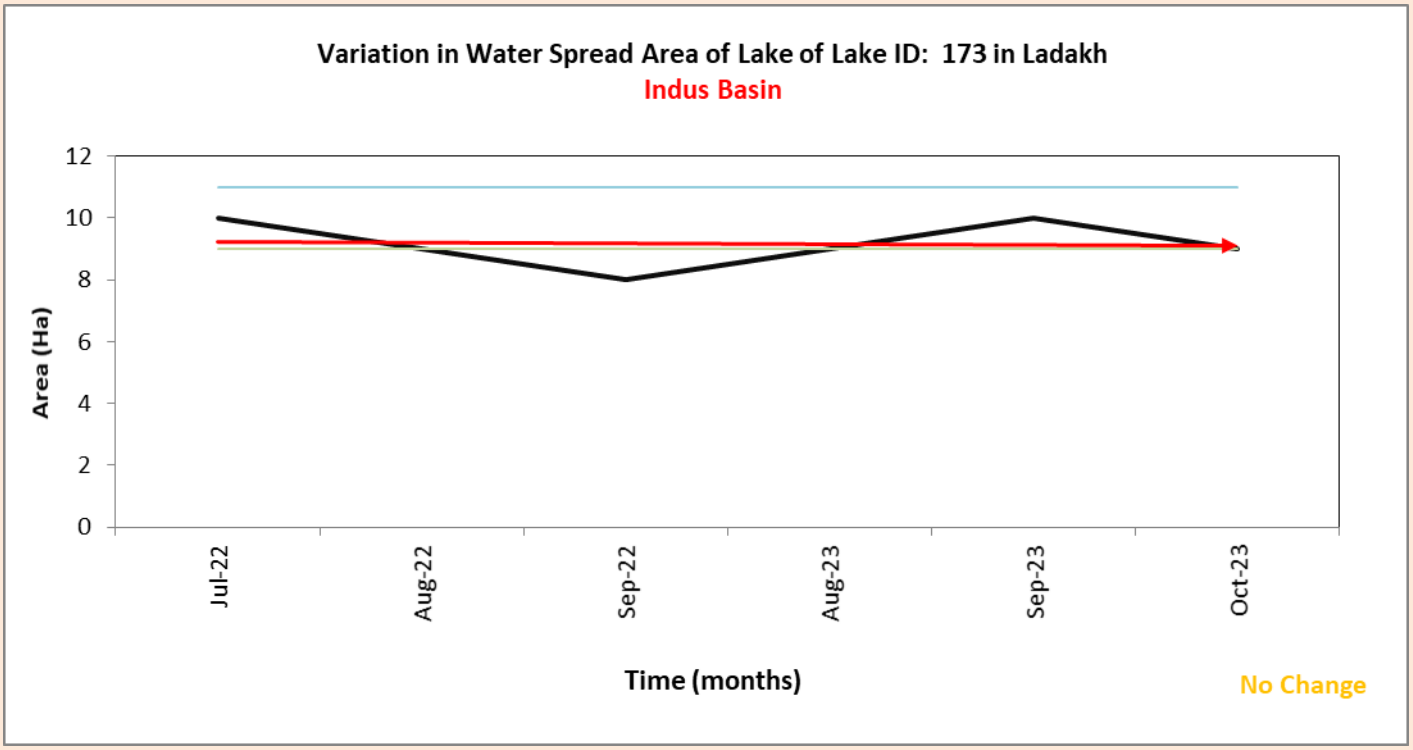


Figure 4.46(ii) Trend Analysis Plot ±10%

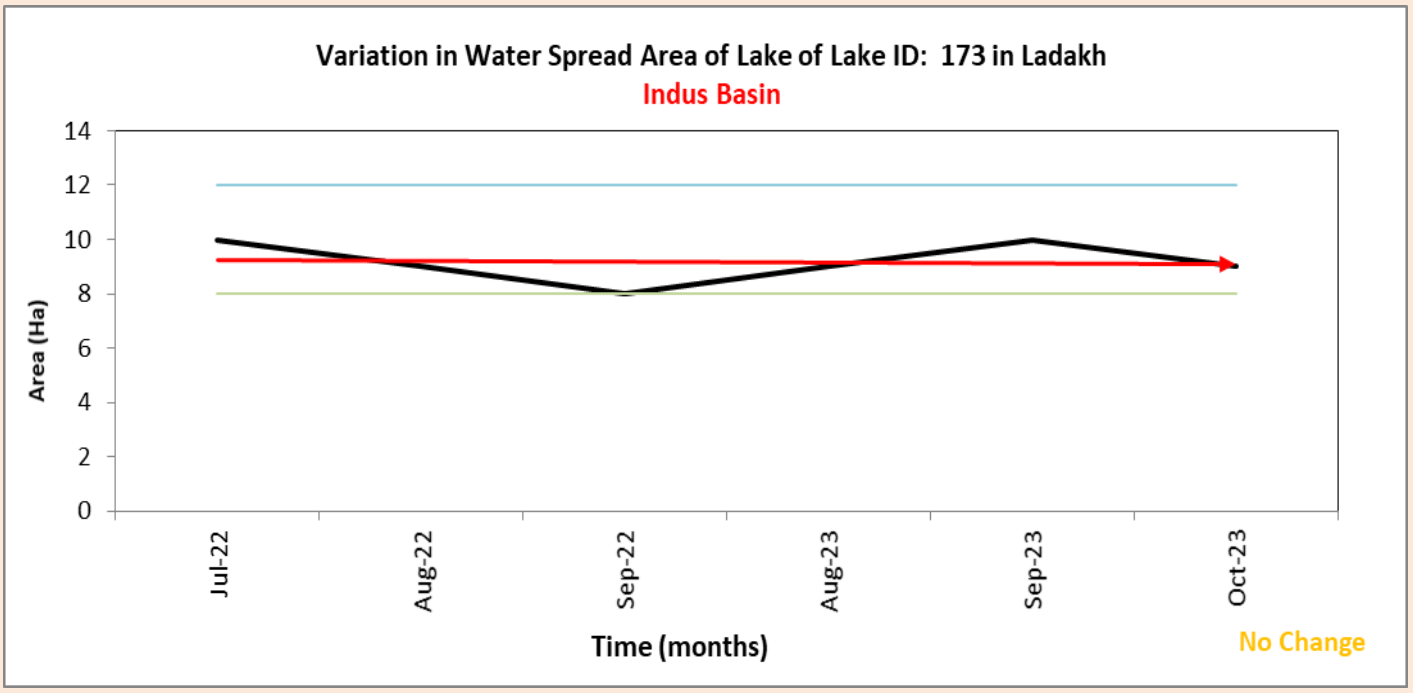


Figure 4.47(i) Trend Analysis Plot ±10%

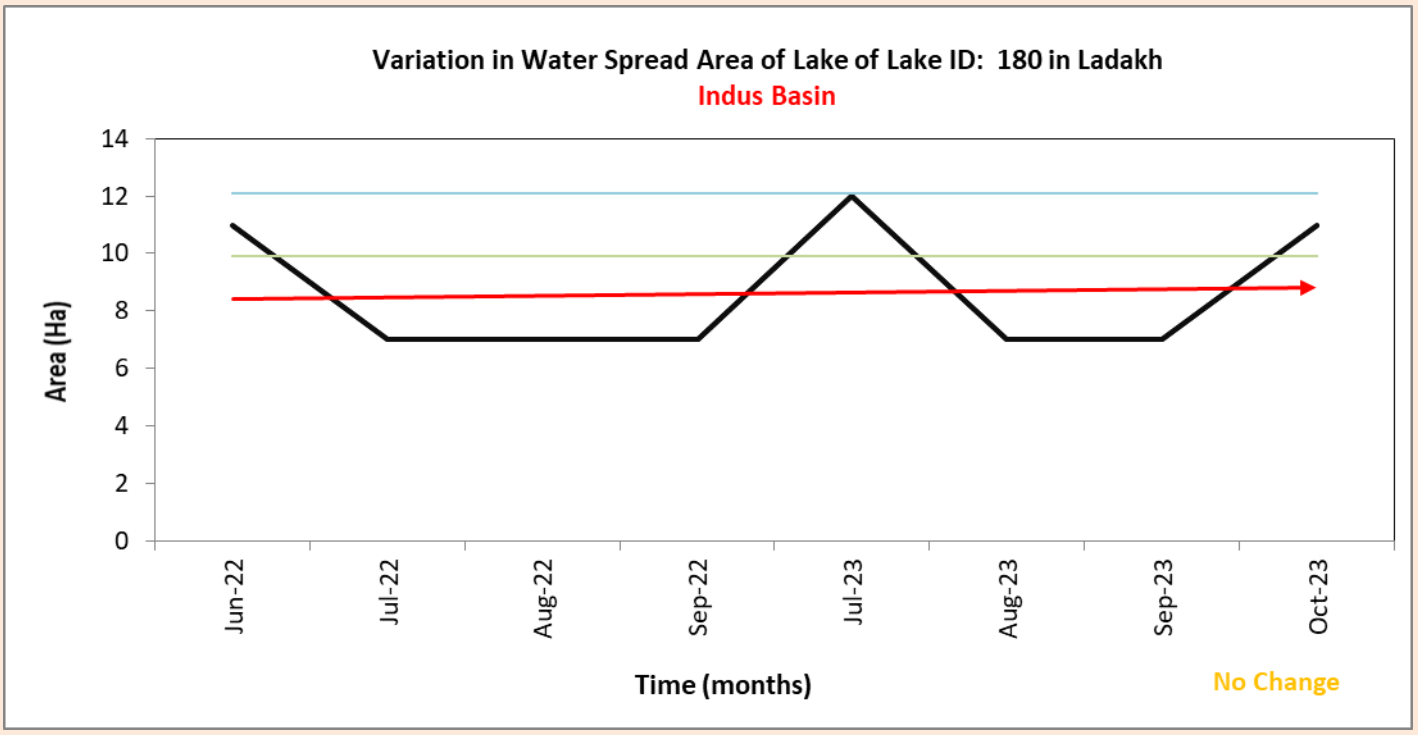


Figure 4.47(ii) Trend Analysis Plot ±20%

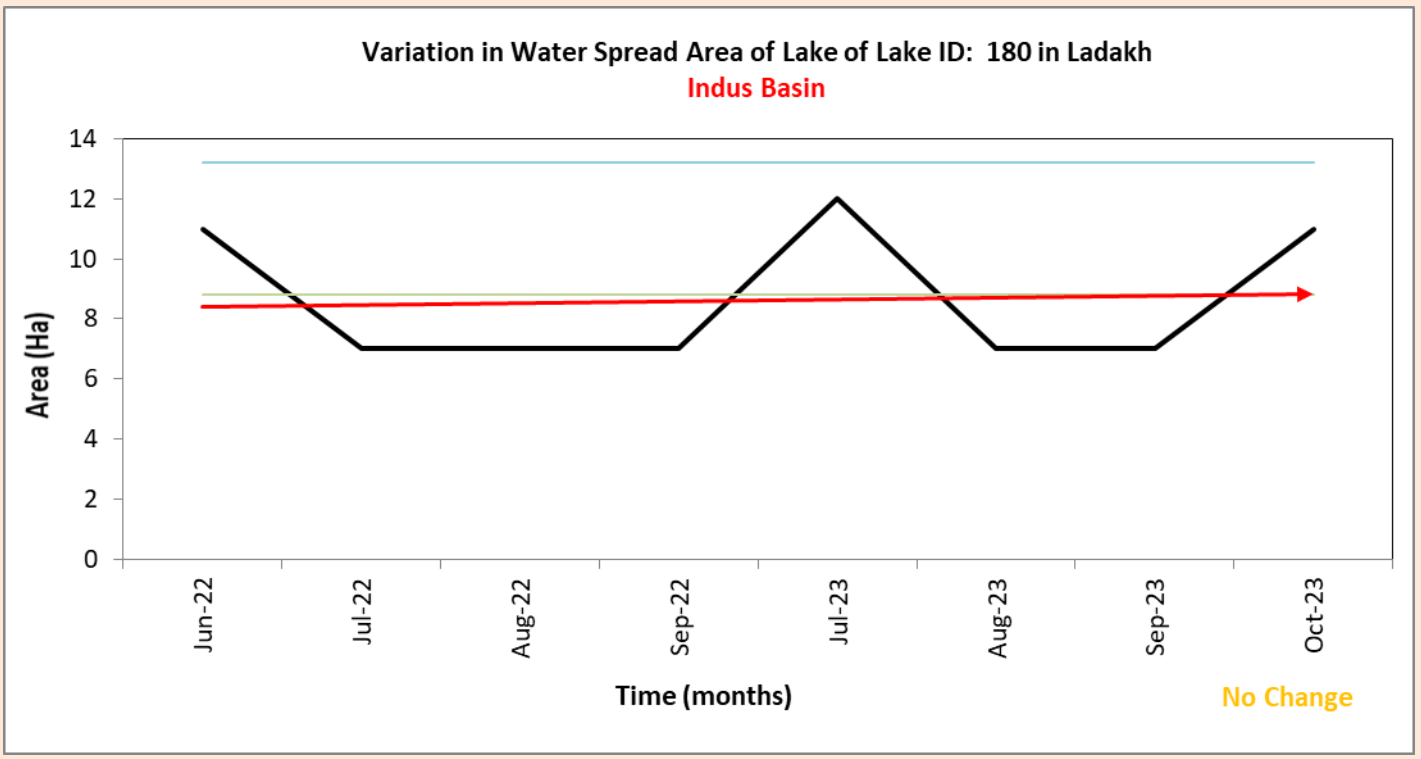


Figure 4.48(i) Trend Analysis Plot ±10%

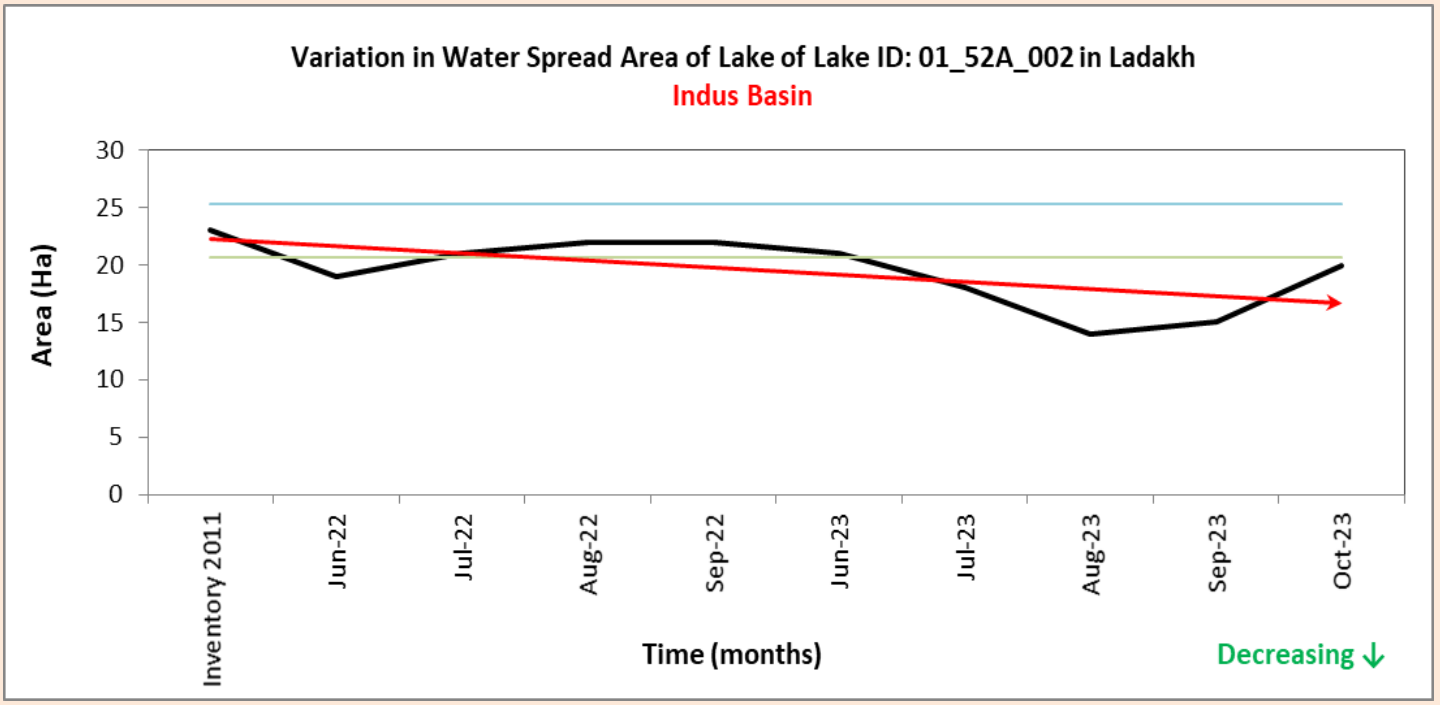


Figure 4.48(ii) Trend Analysis Plot ±20%

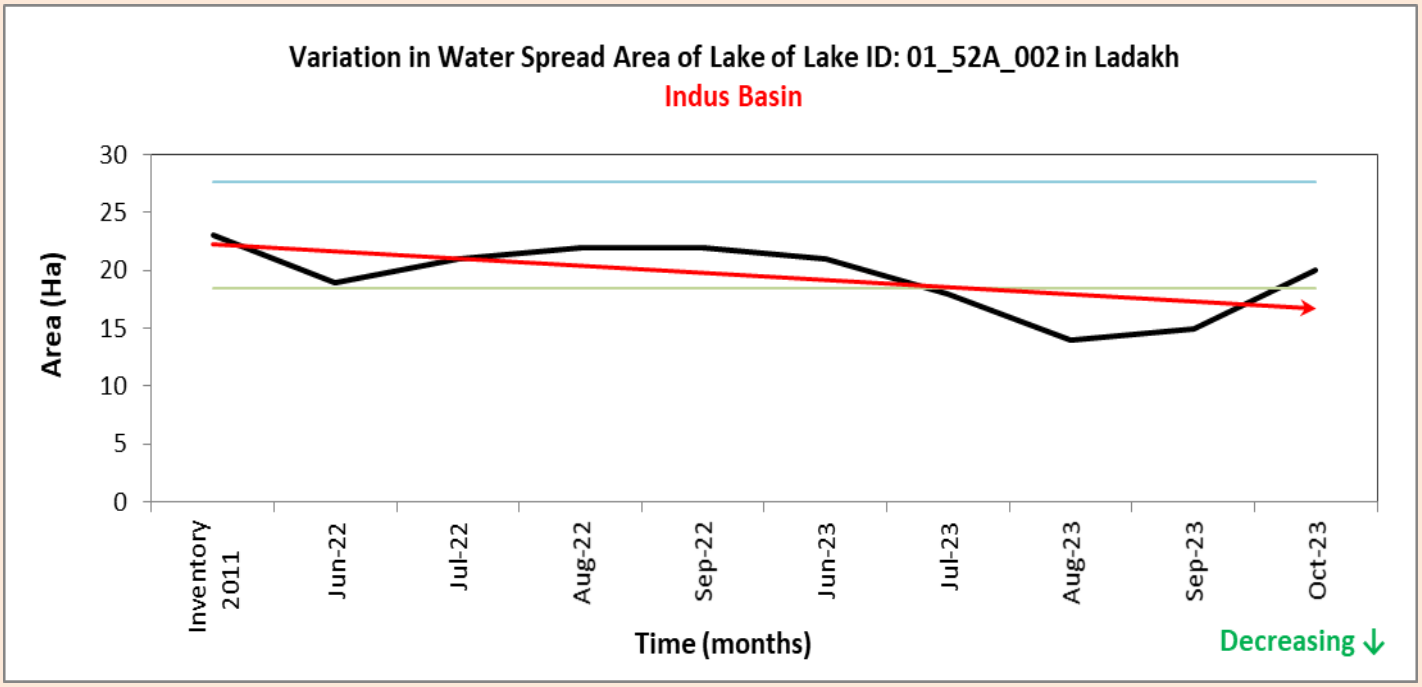


Figure 4.49(i) Trend Analysis Plot ±10%

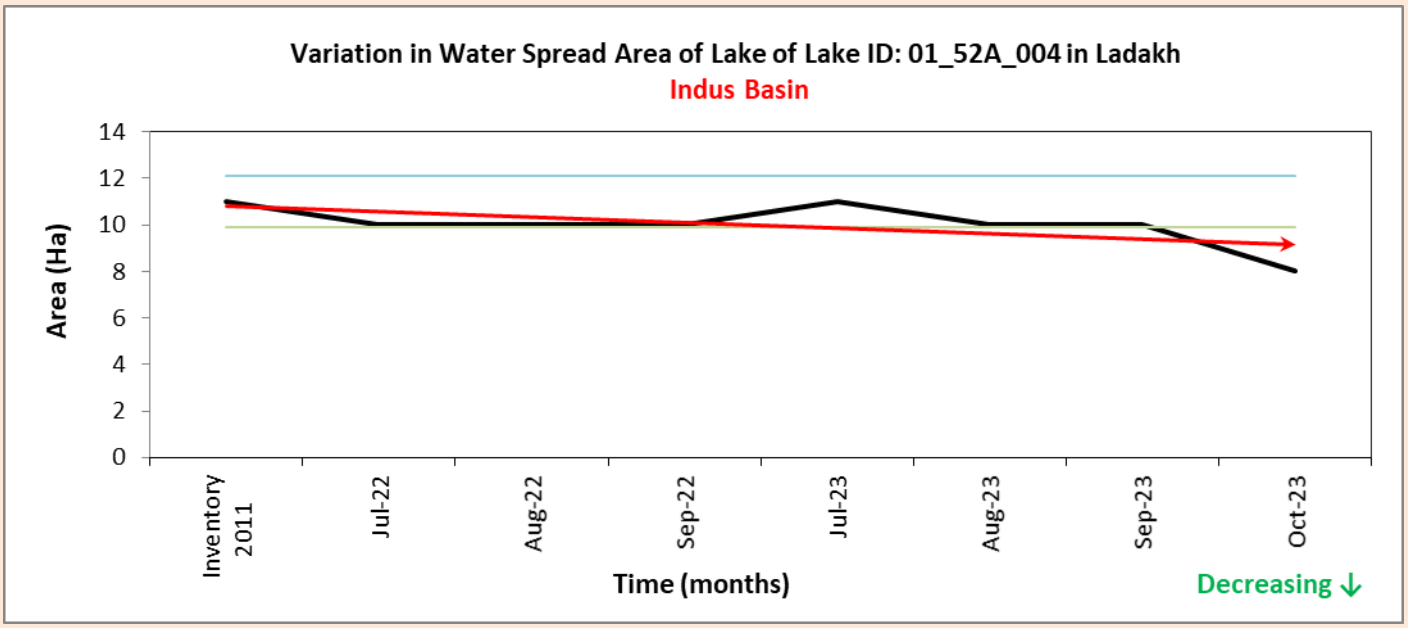


Figure 4.49(ii) Trend Analysis Plot ±20%

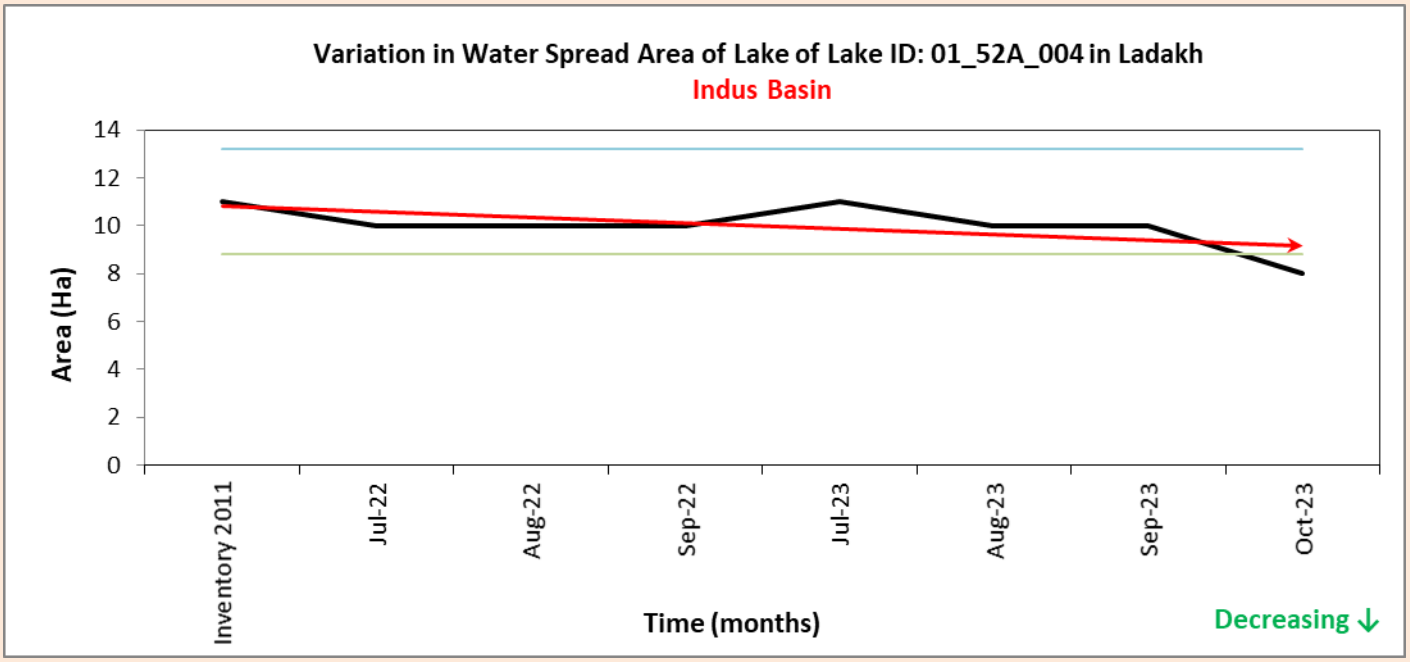


Figure 4.50(i) Trend Analysis Plot ±10%

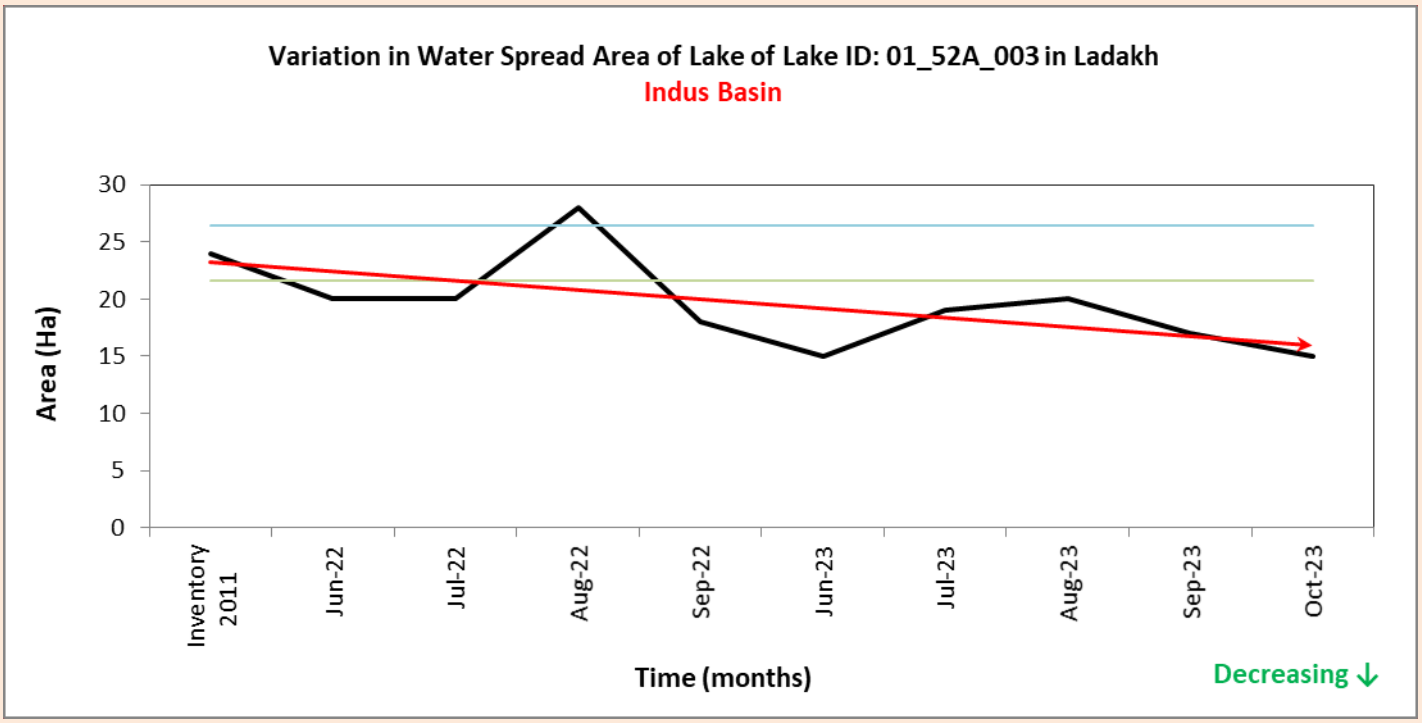
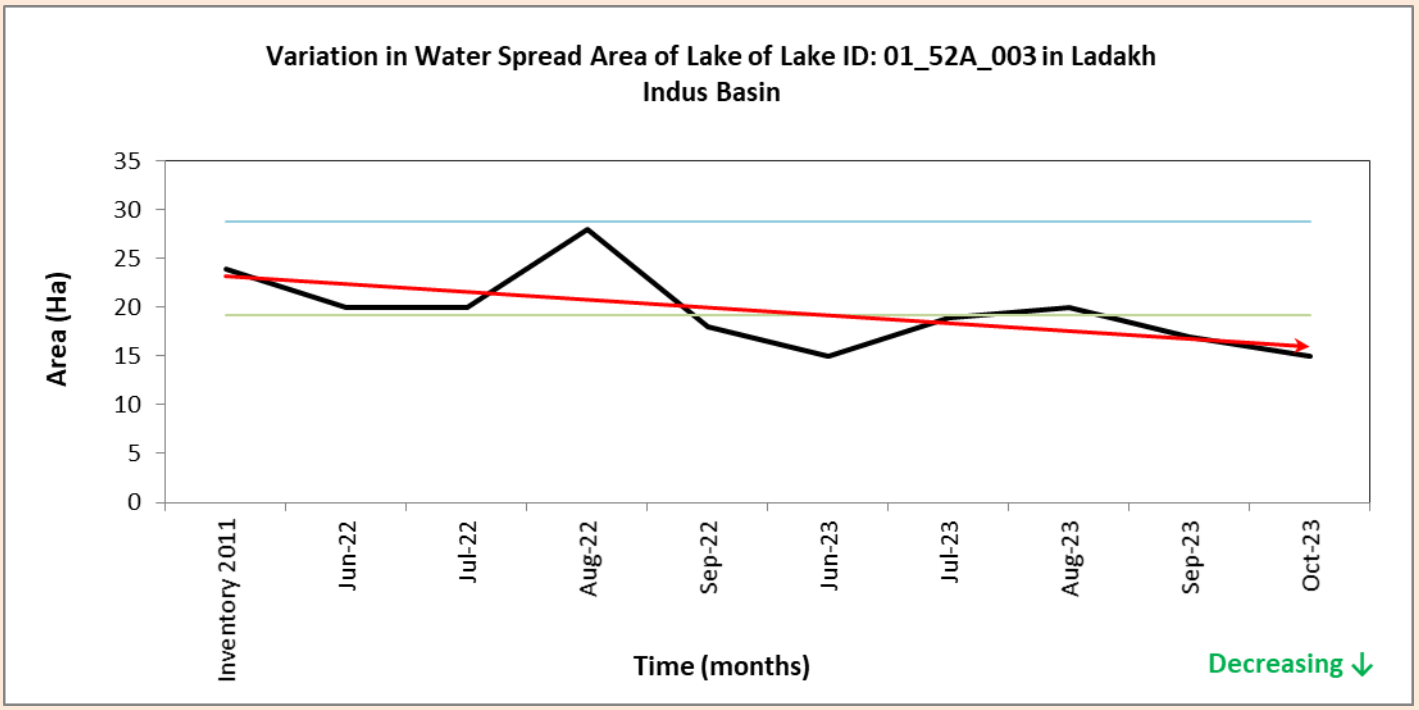


Figure 4.50(ii) Trend Analysis Plot ±20%



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 ±10%

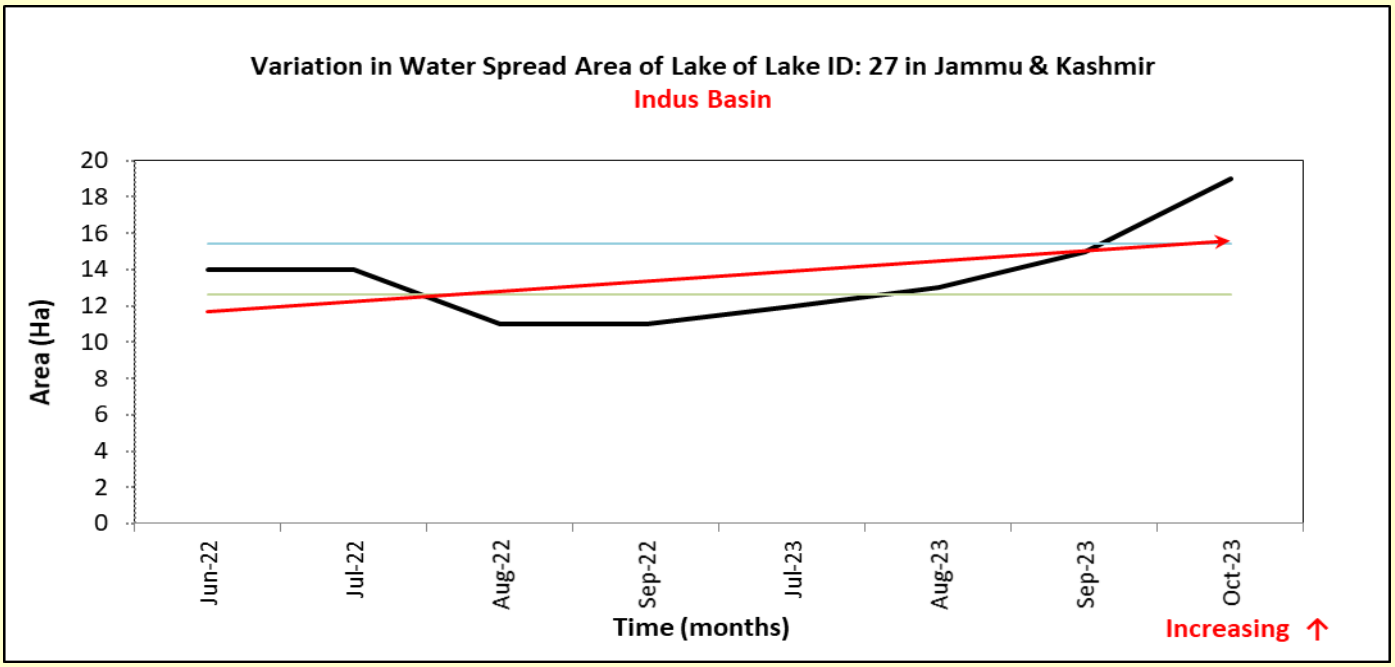


Figure 4.51(ii) Trend Analysis Plot ±10%

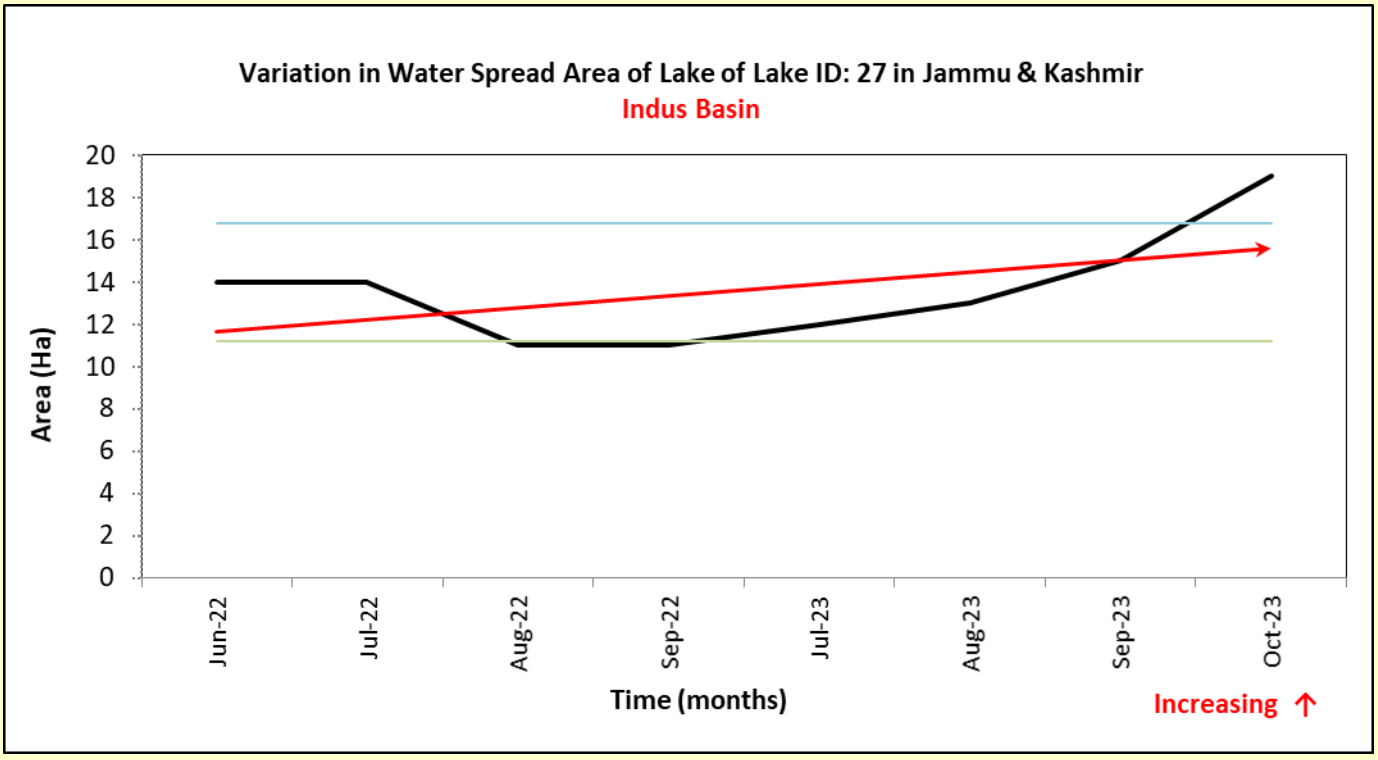


Figure 4.52(i) Trend Analysis Plot ±10%

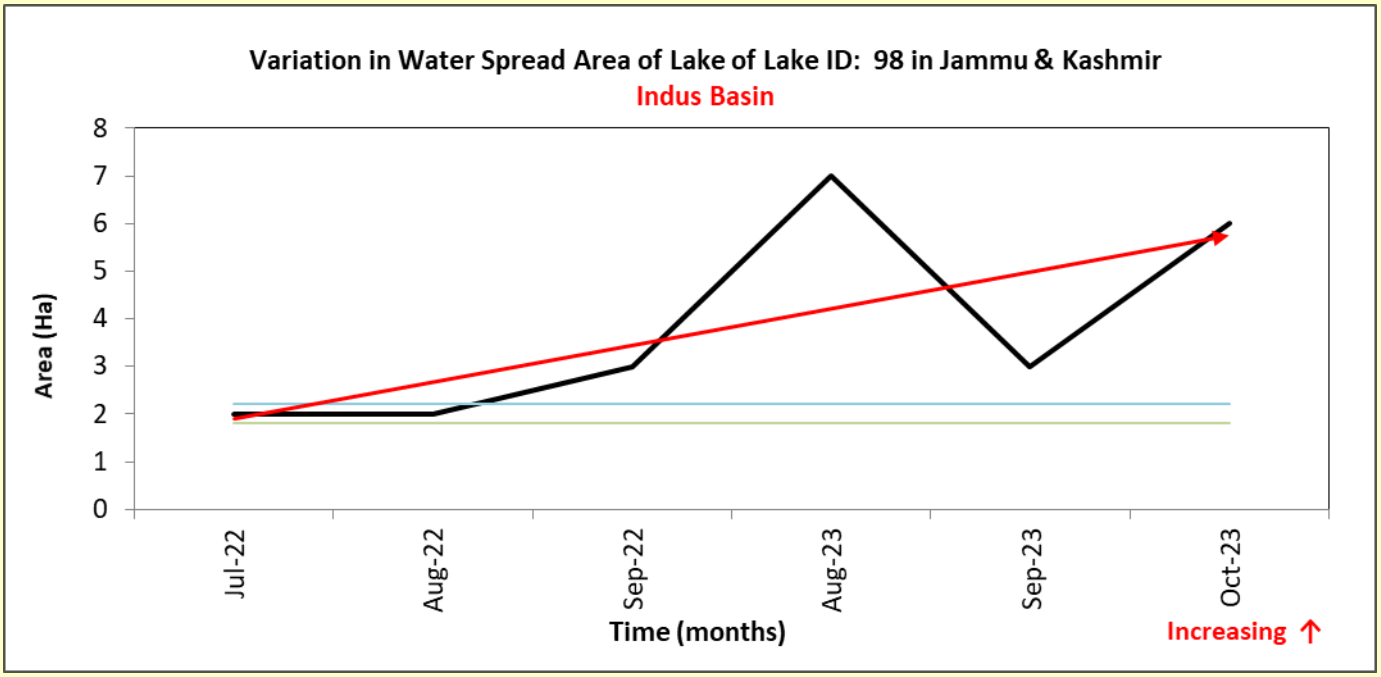


Figure 4.52(ii) Trend Analysis Plot ±20%

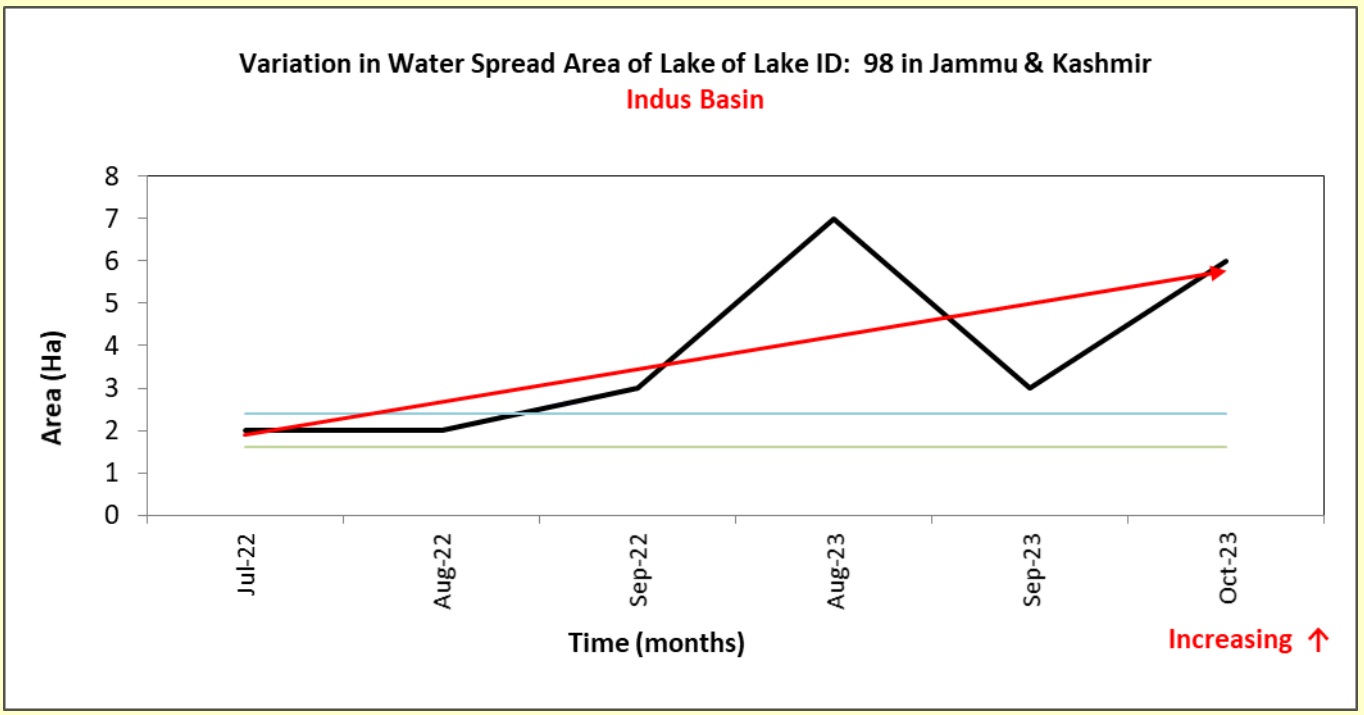


Figure 4.53(i) Trend Analysis Plot ±10%

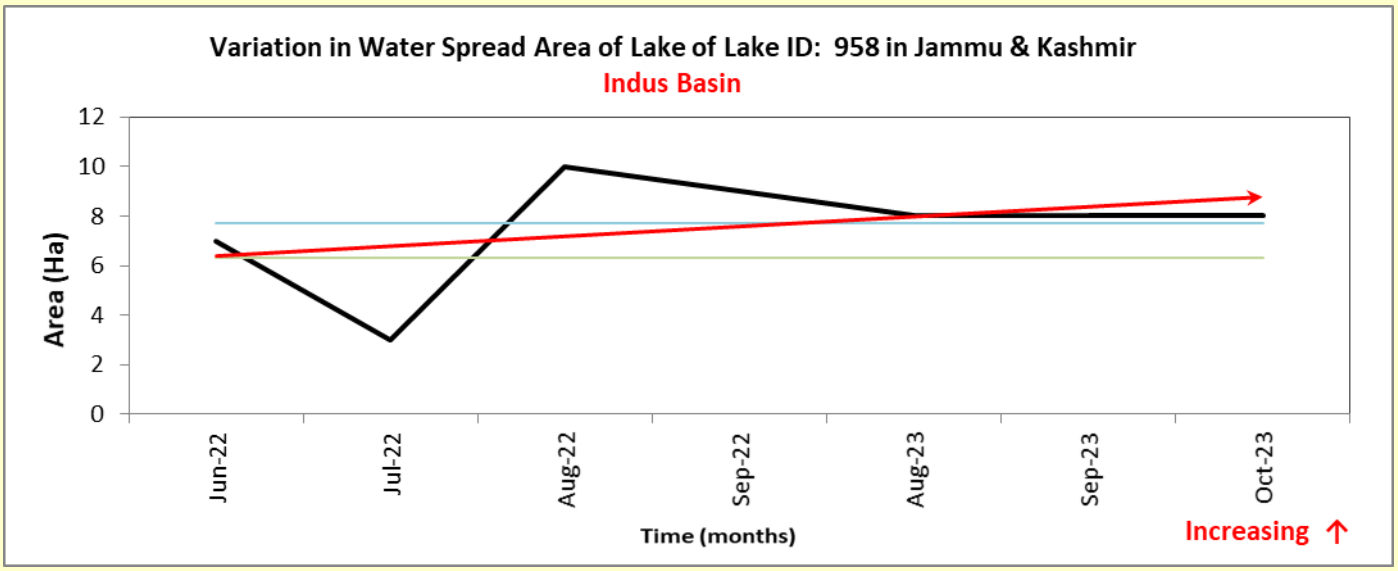


Figure 4.53(ii) Trend Analysis Plot ±20%

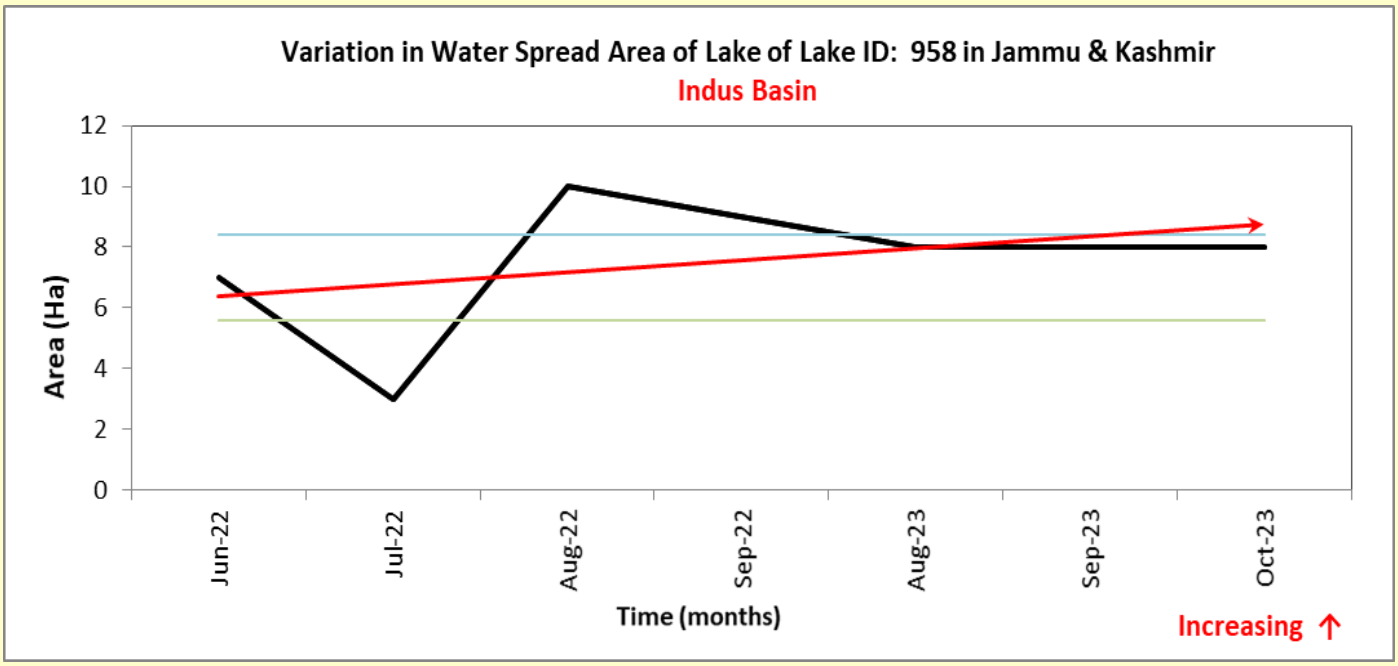


Figure 4.54(i) Trend Analysis Plot ±10%

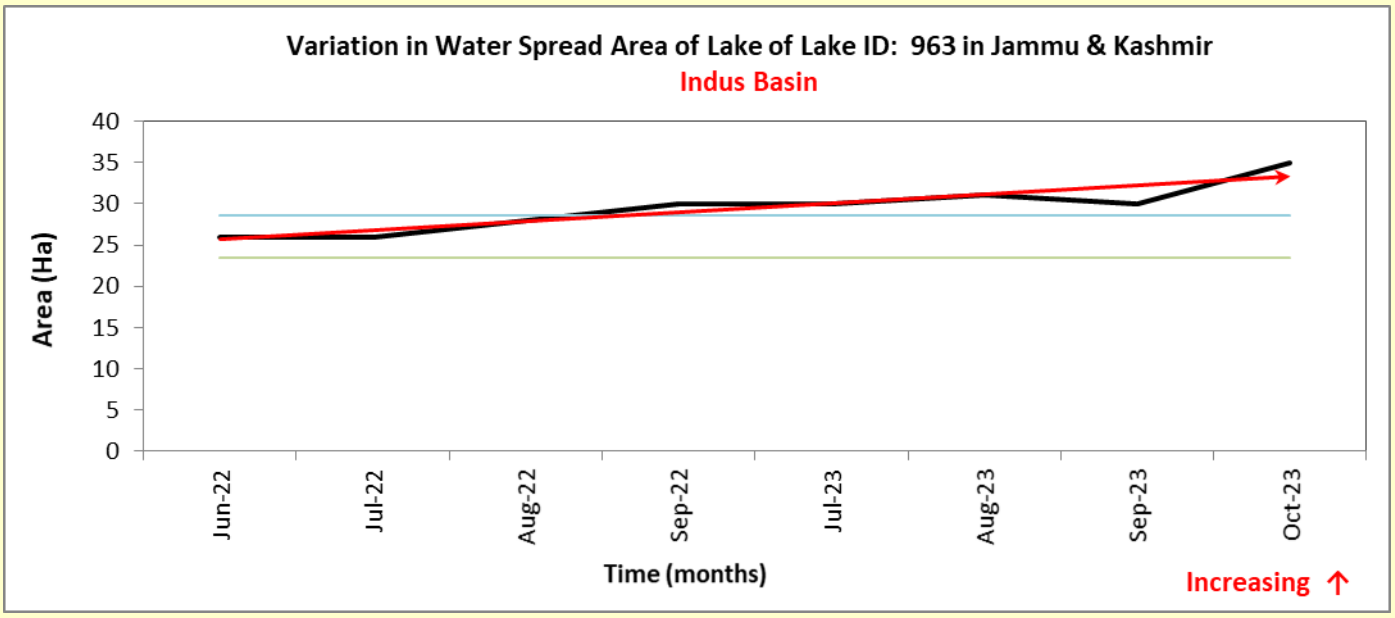


Figure 4.54(ii) Trend Analysis Plot ±20%

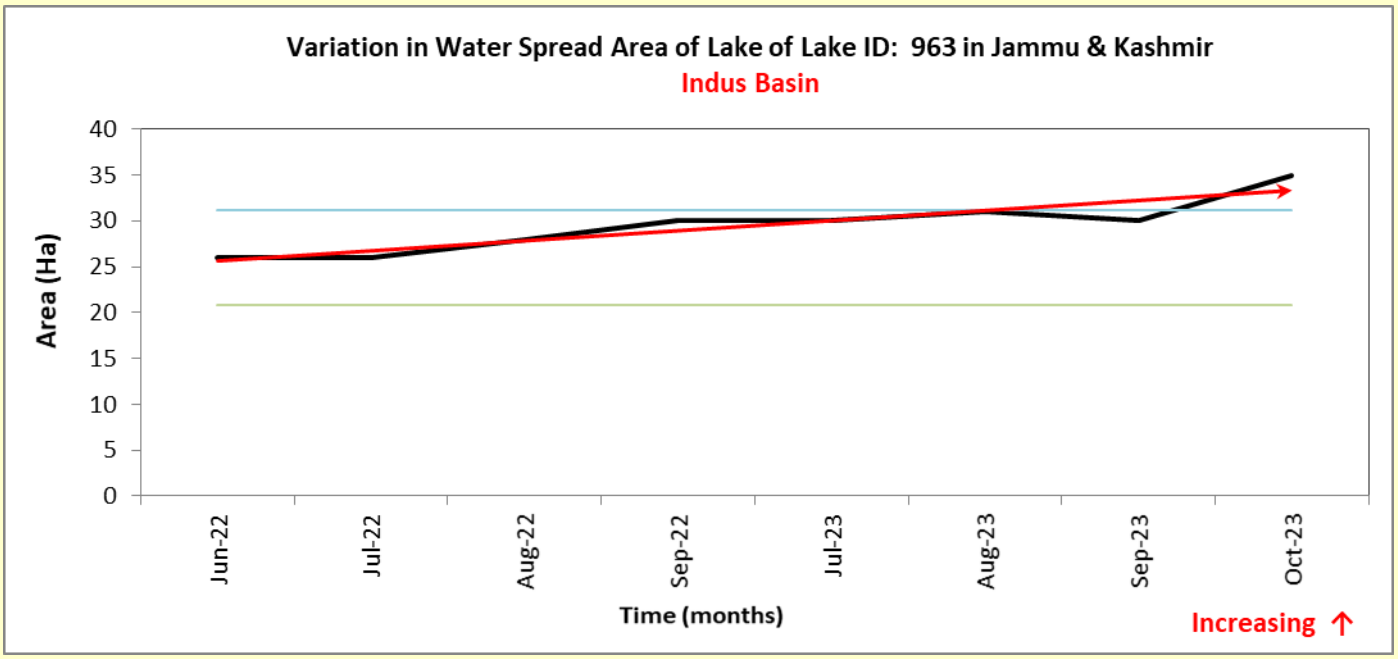


Figure 4.55(i) Trend Analysis Plot ±10%

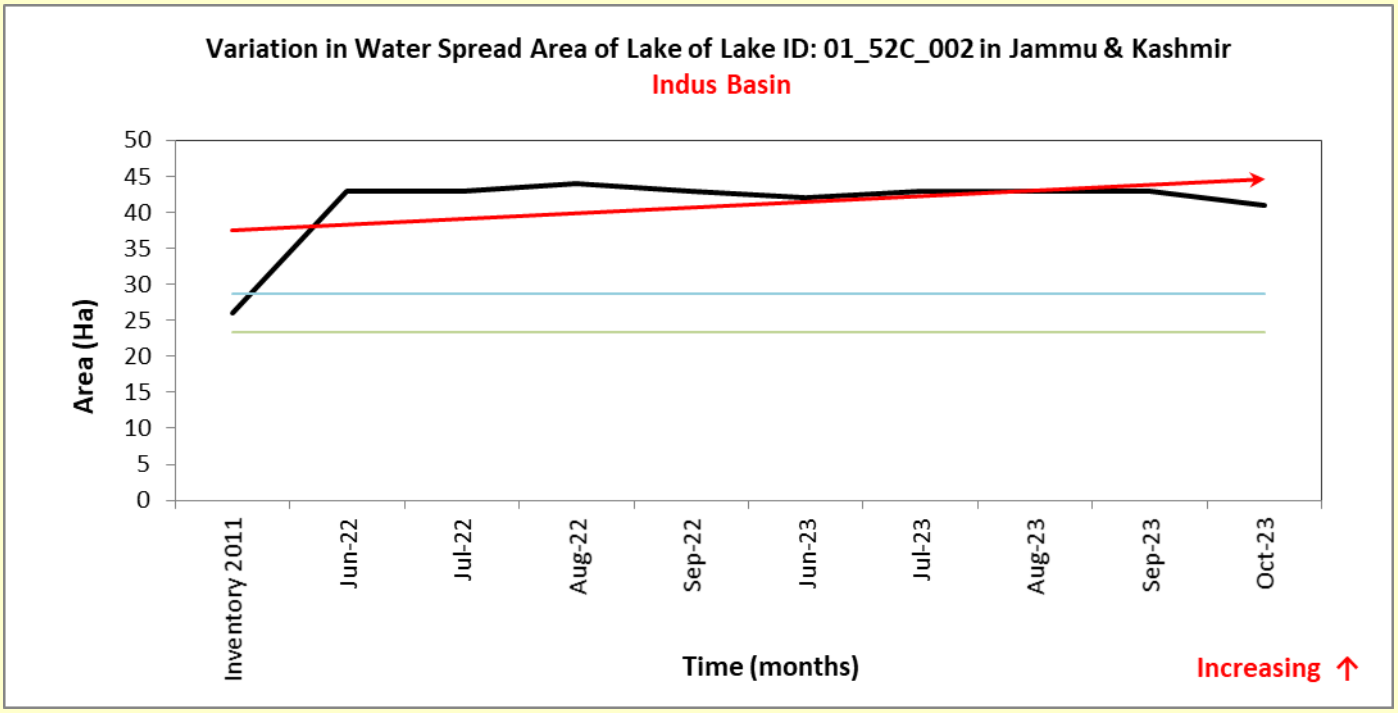


Figure 4.55(ii) Trend Analysis Plot ±20%

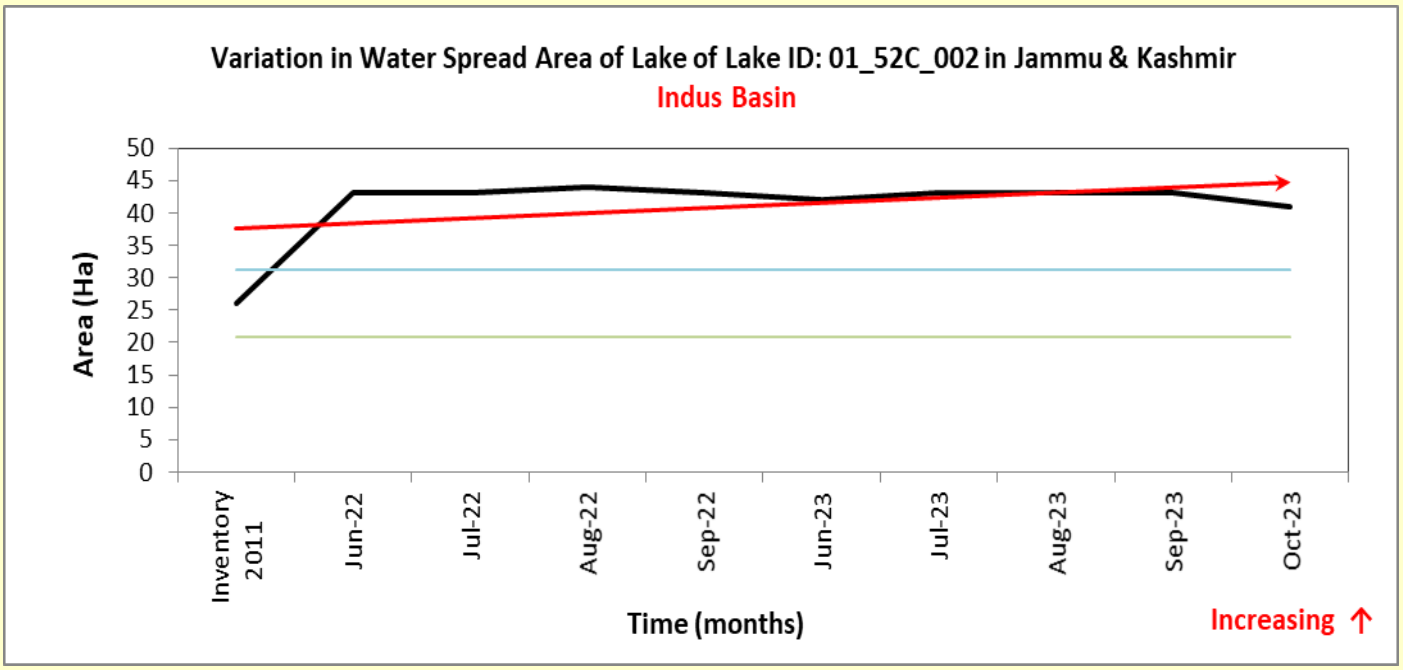


Figure 4.56(i) Trend Analysis Plot ±10%

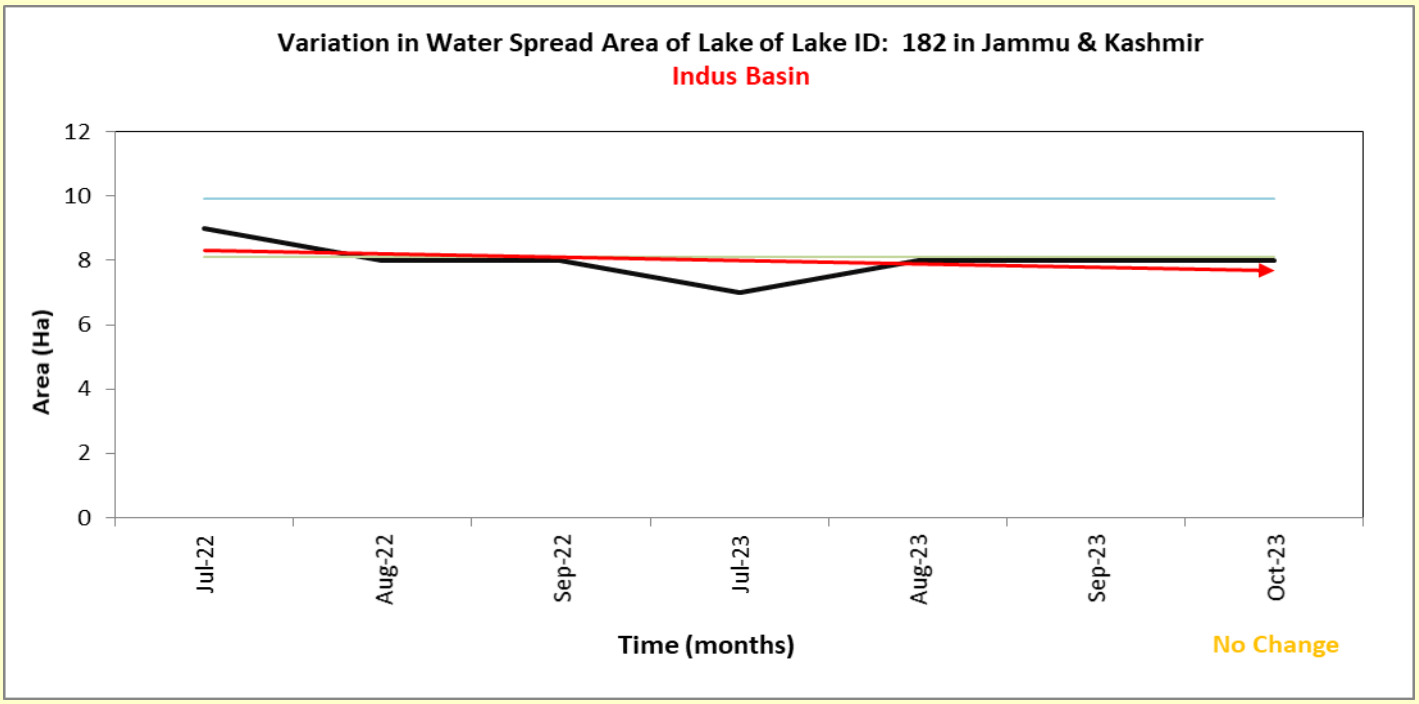


Figure 4.56(ii) Trend Analysis Plot ±20%

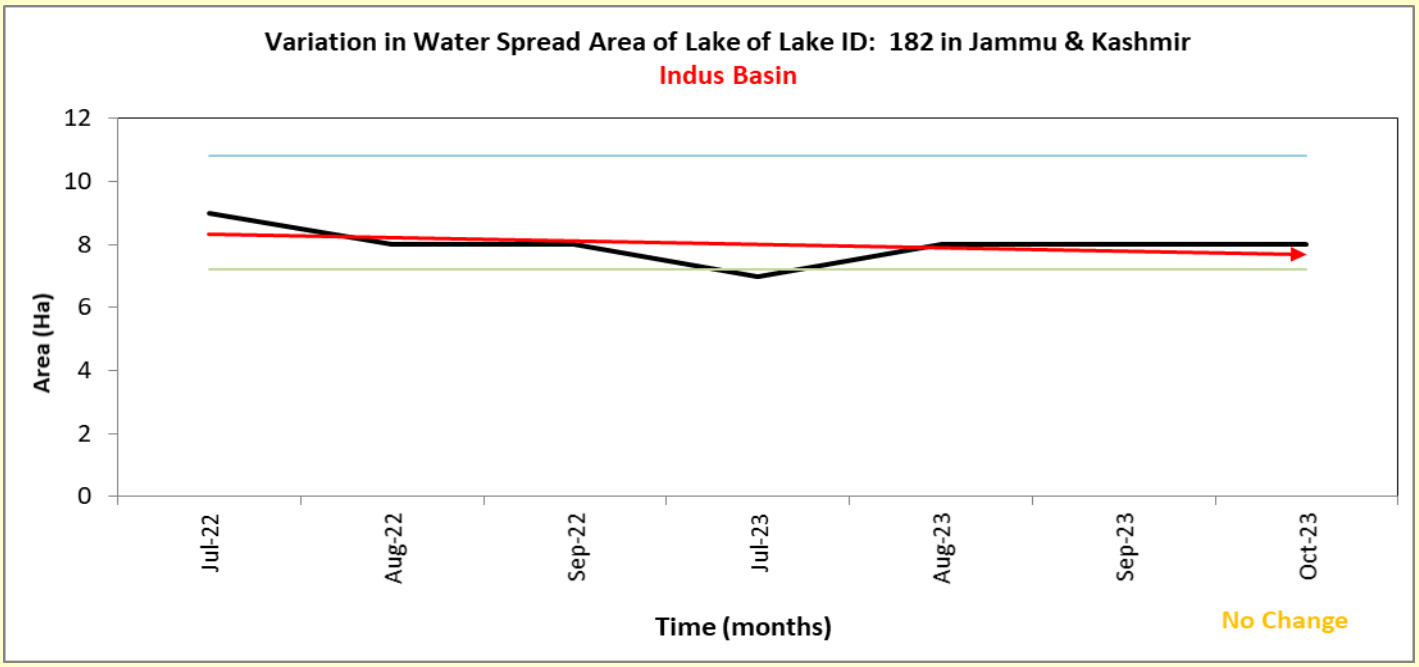


Figure 4.57(i) Trend Analysis Plot ±10%

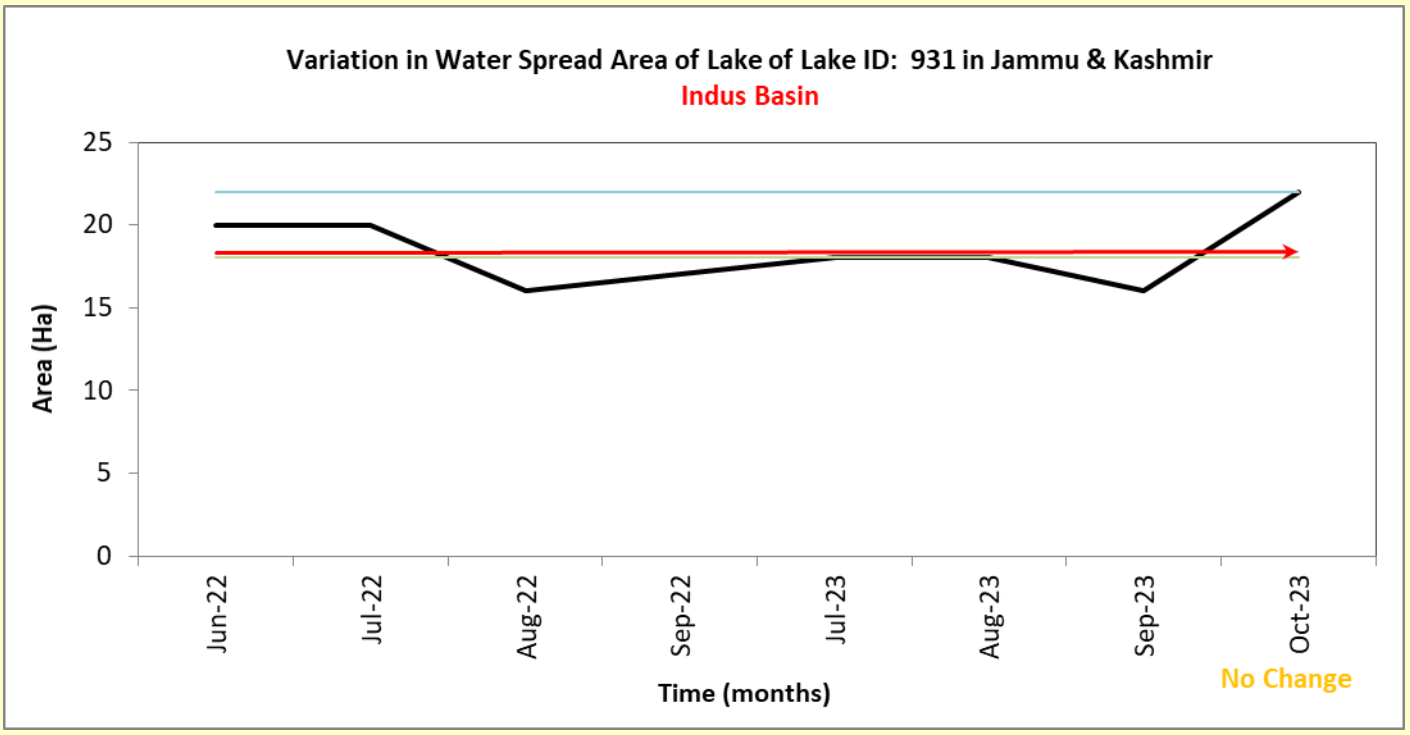


Figure 4.57(ii) Trend Analysis Plot ±20%

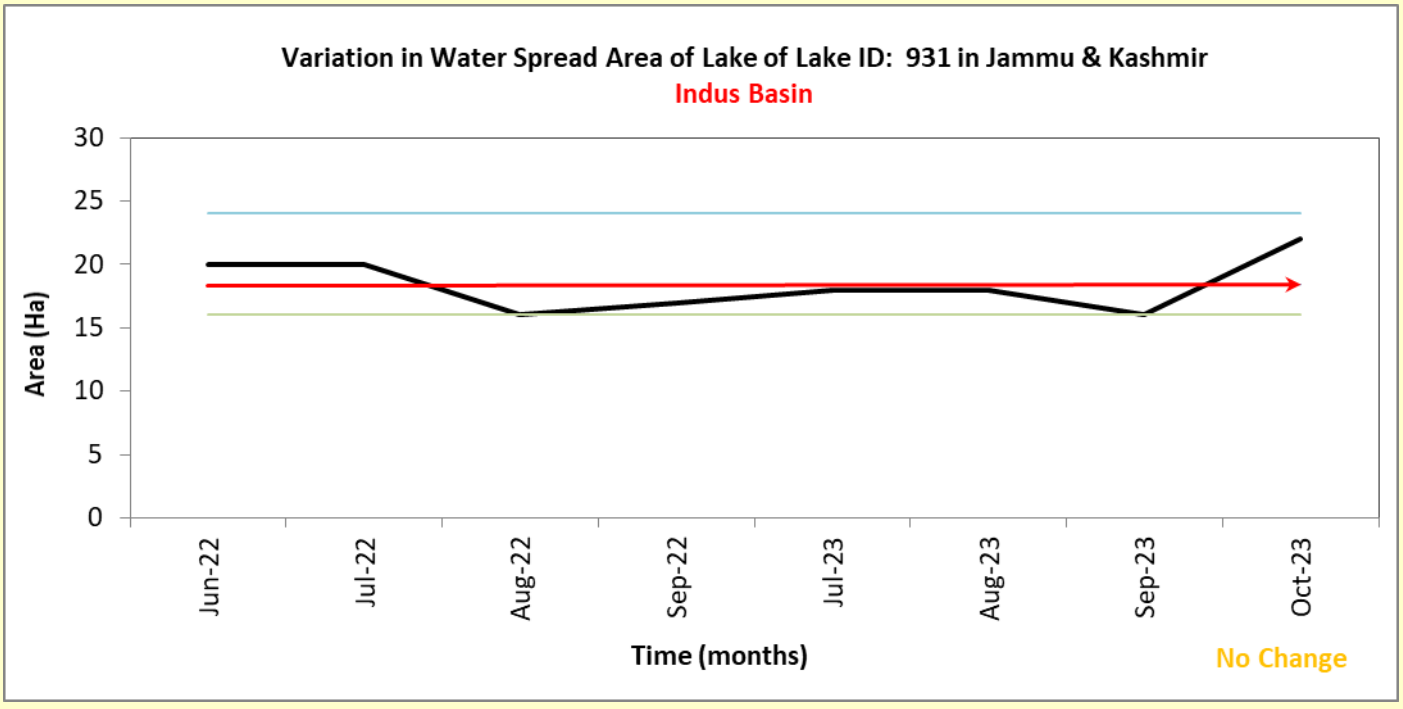


Figure 4.58(i) Trend Analysis Plot ±10%

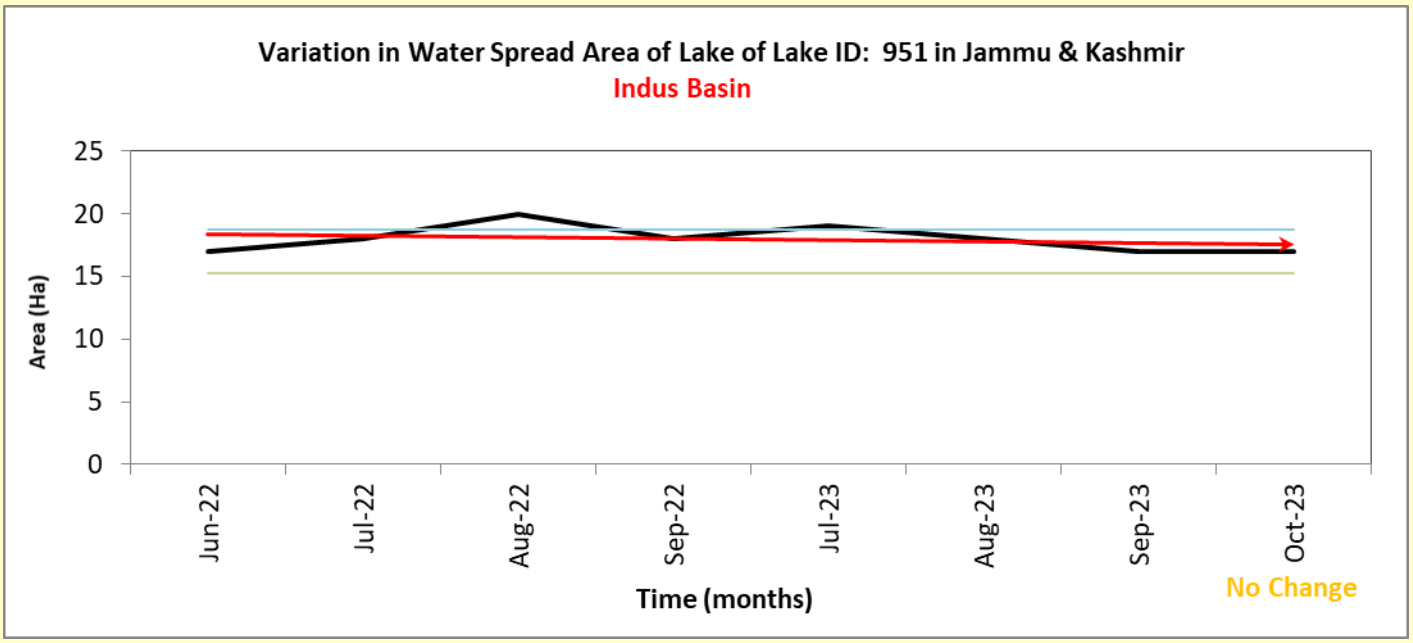


Figure 4.58(ii) Trend Analysis Plot ±20%

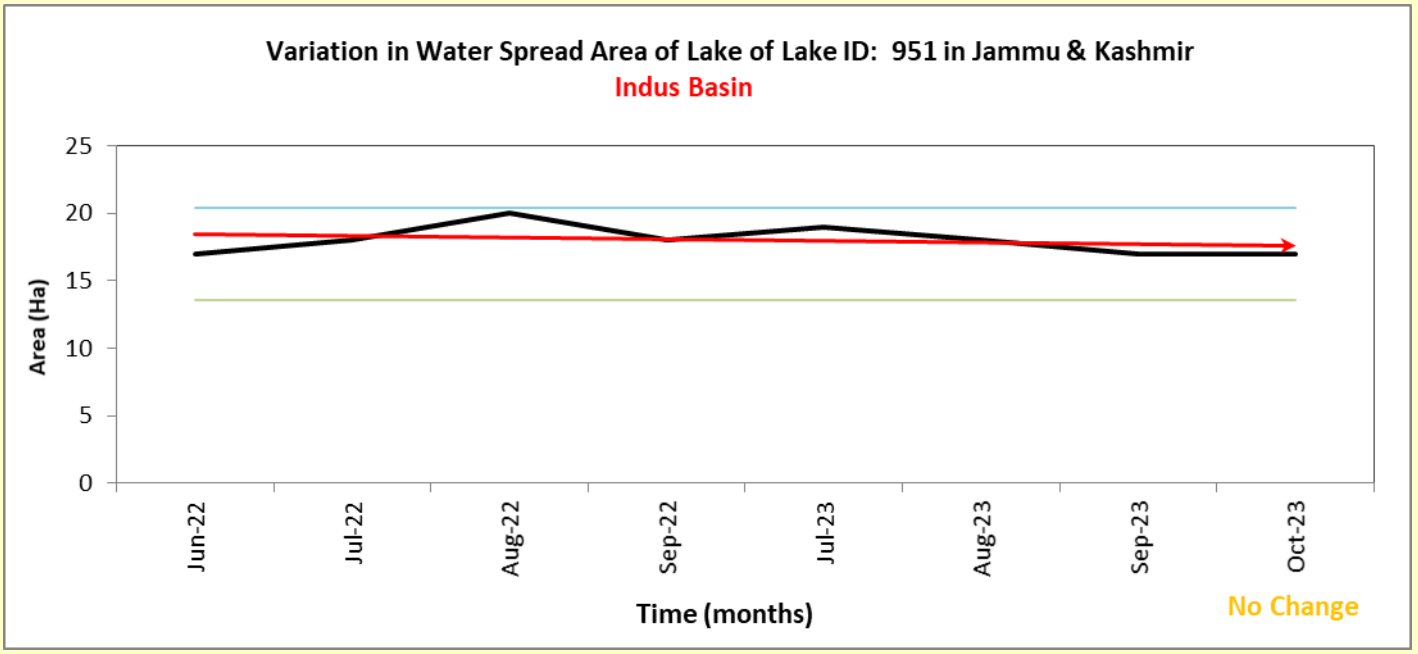


Figure 4.59(i) Trend Analysis Plot ±10%

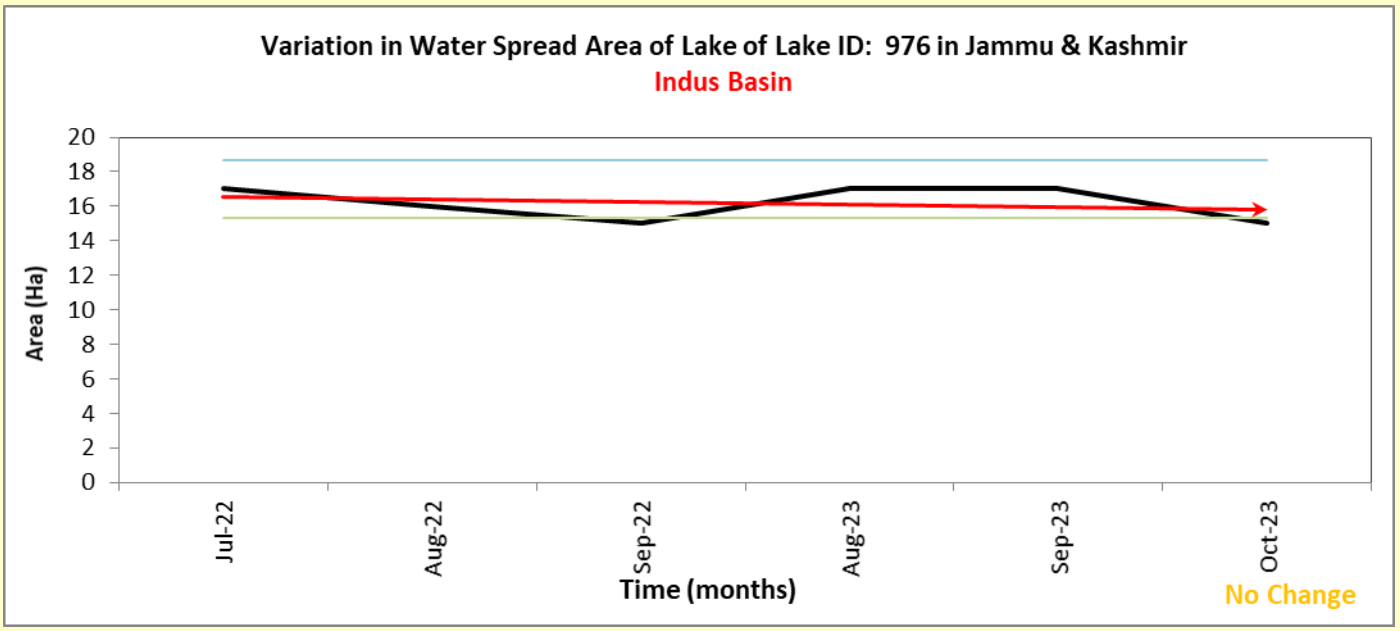


Figure 4.59(ii) Trend Analysis Plot ±20%

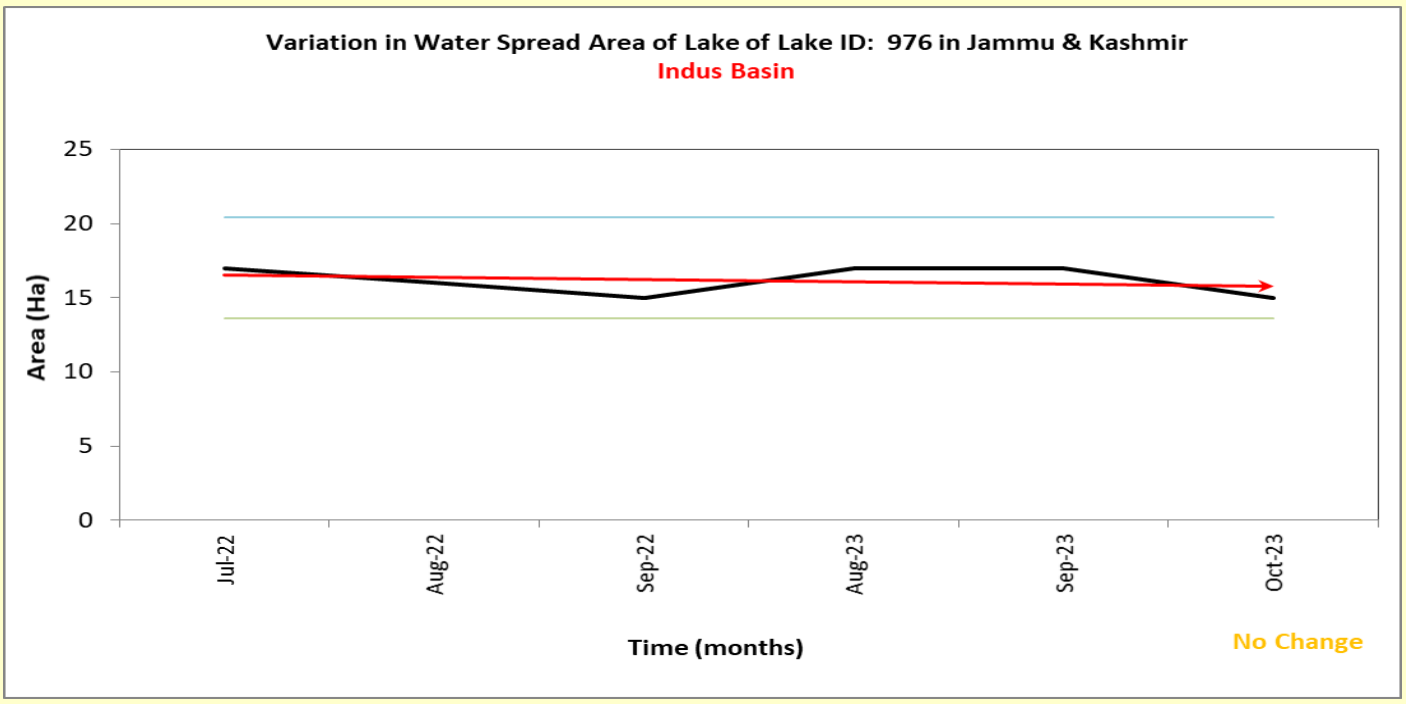


Figure 4.60(i) Trend Analysis Plot ±10%

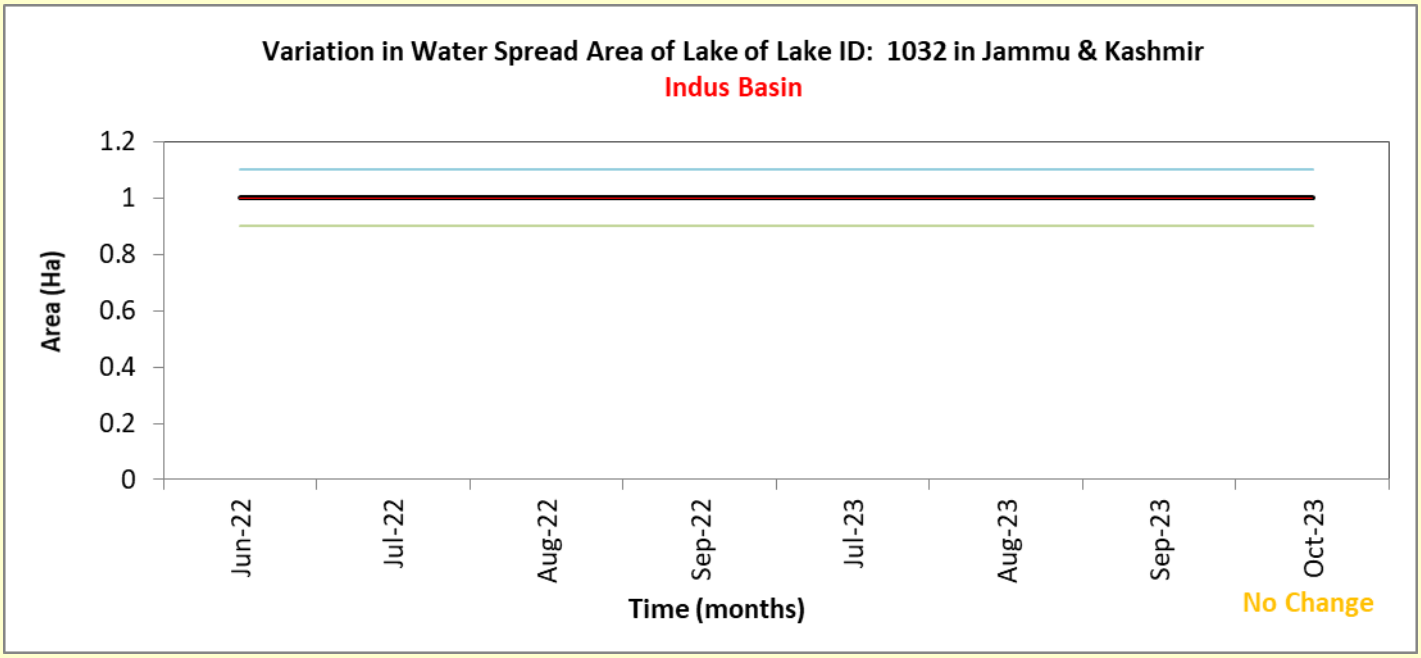


Figure 4.60(ii) Trend Analysis Plot ±10%

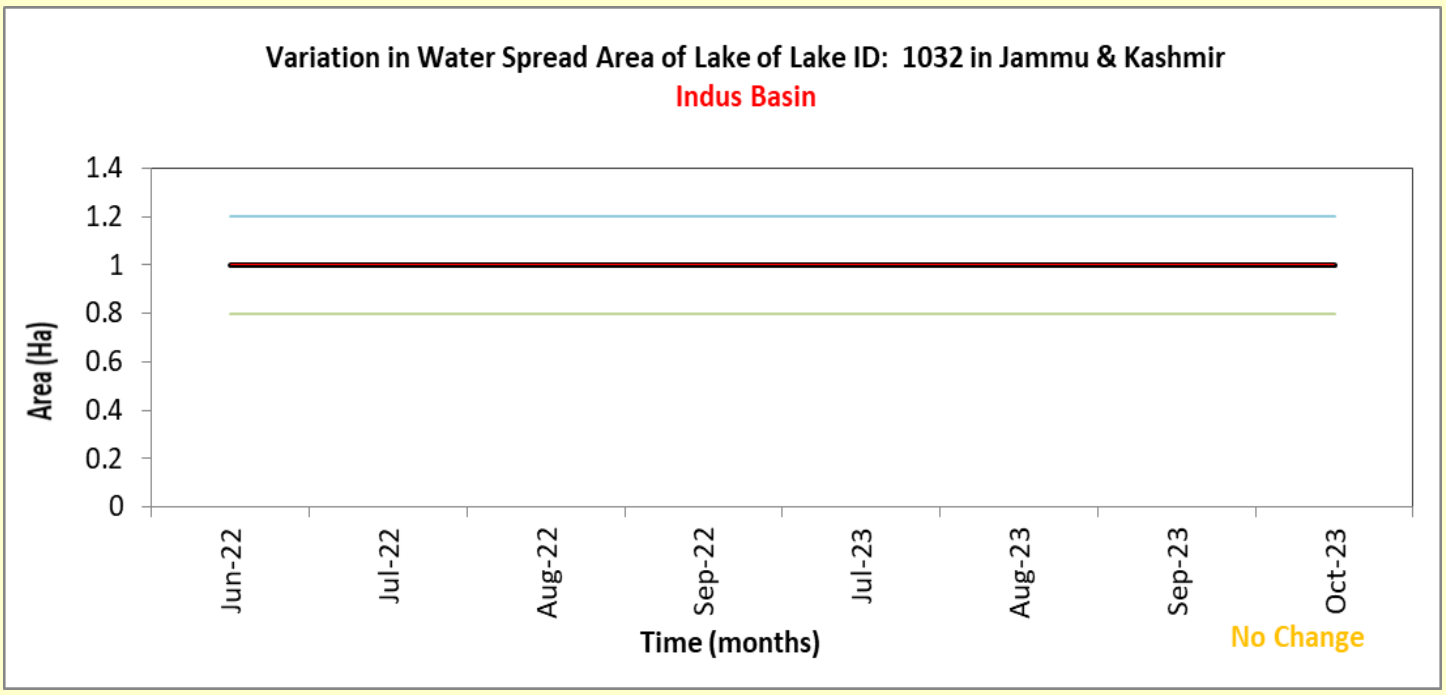


Figure 4.61(i) Trend Analysis Plot ±10%

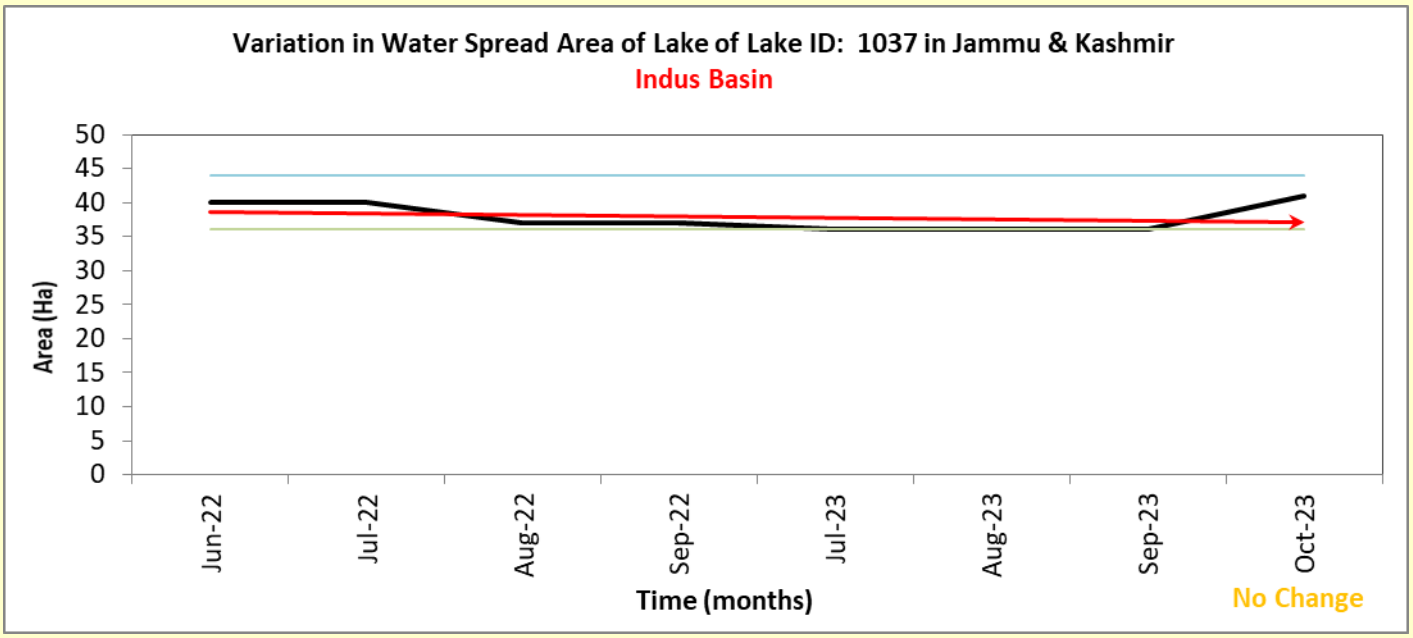


Figure 4.61(ii) Trend Analysis Plot ±20%

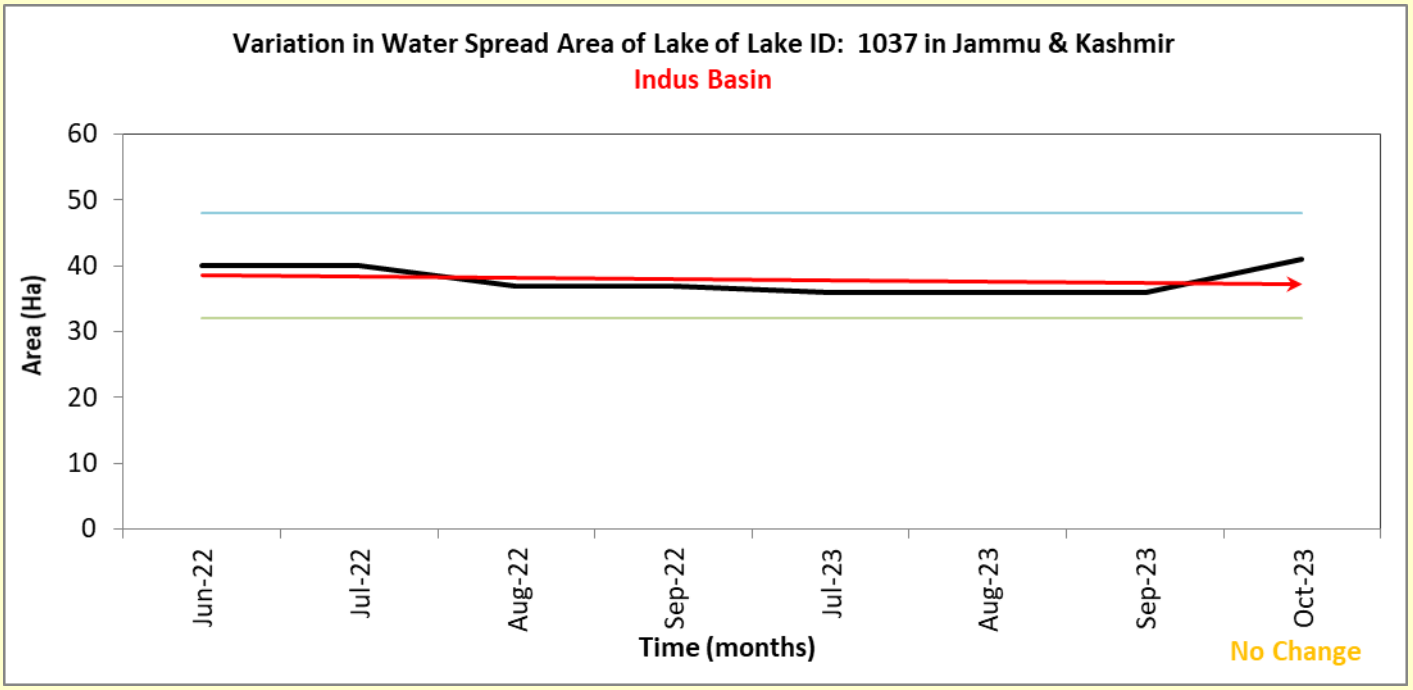


Figure 4.62(i) Trend Analysis Plot ±10%

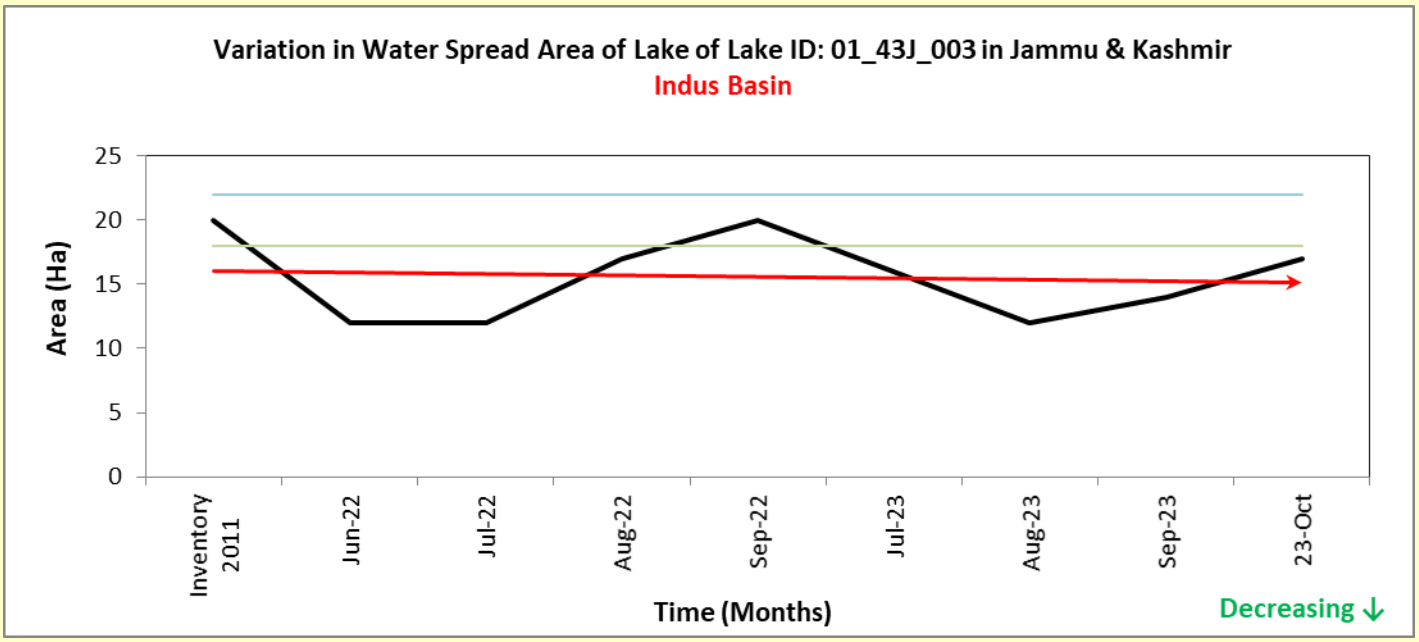


Figure 4.62(ii) Trend Analysis Plot ±20%

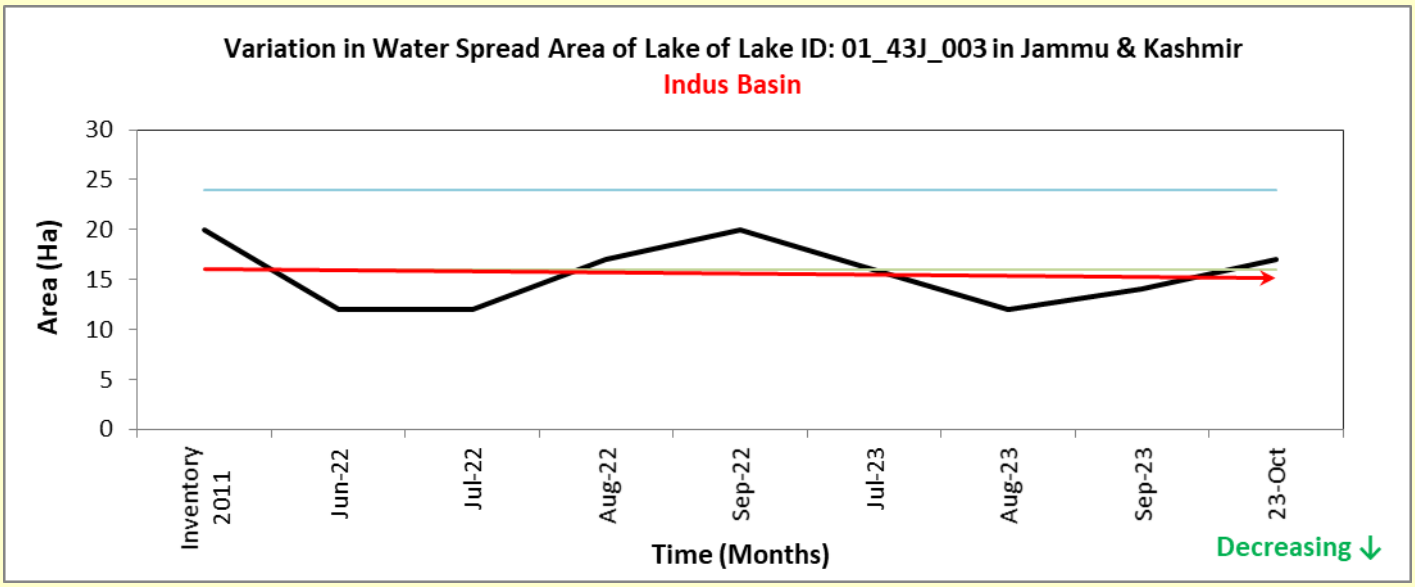


Figure 4.63(i) Trend Analysis Plot ±10%

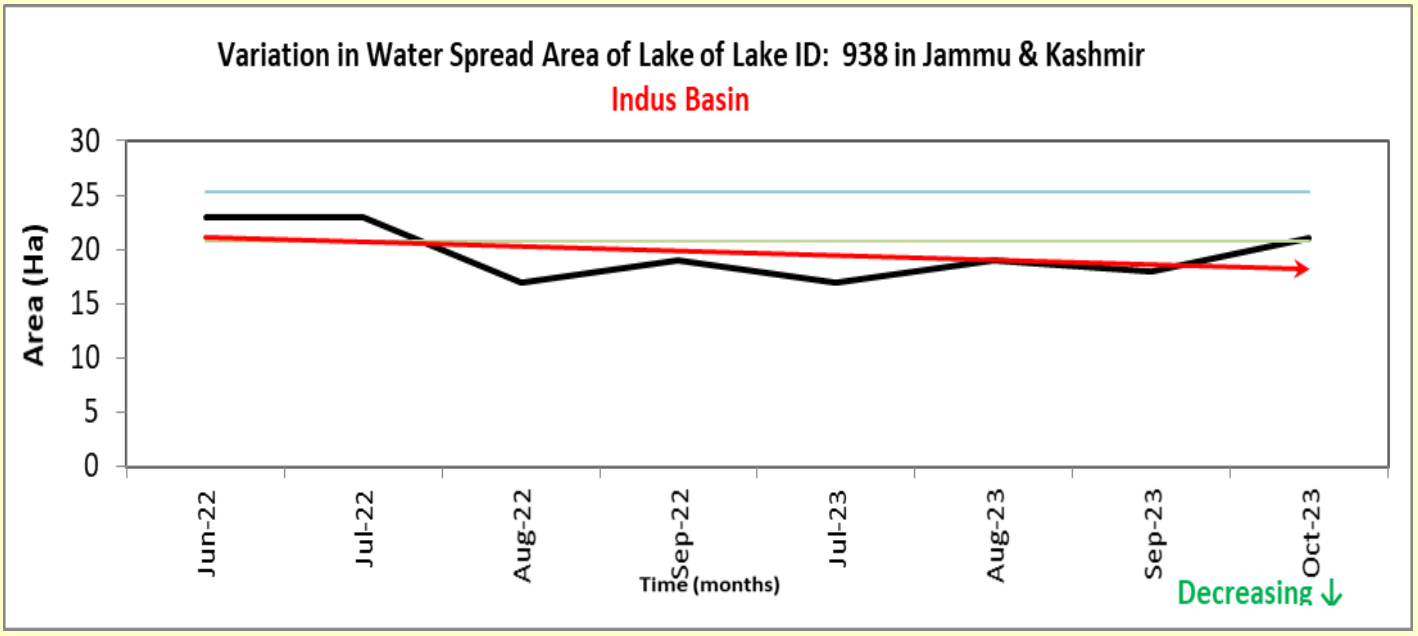


Figure 4.63(ii) Trend Analysis Plot ±20%

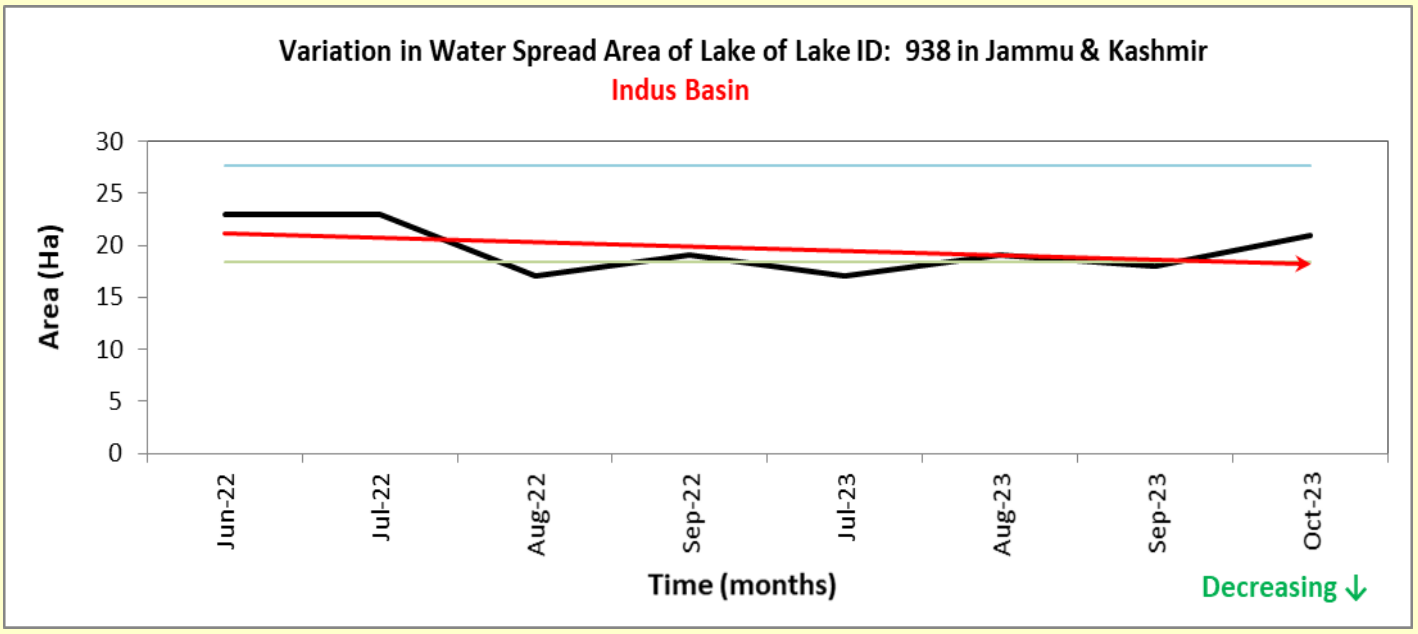


Figure 4.64(i) Trend Analysis Plot ±10%

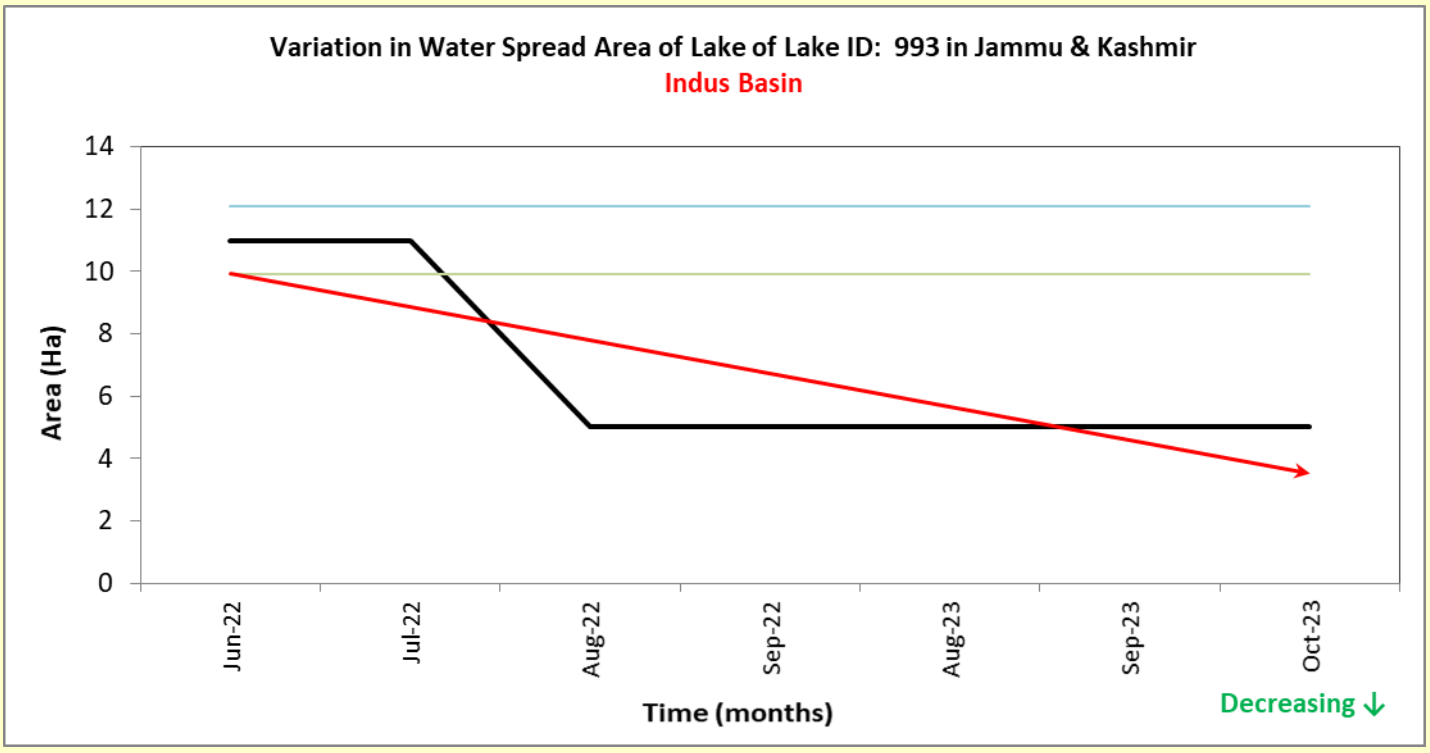


Figure. 64(ii) Trend Analysis Plot ±20%

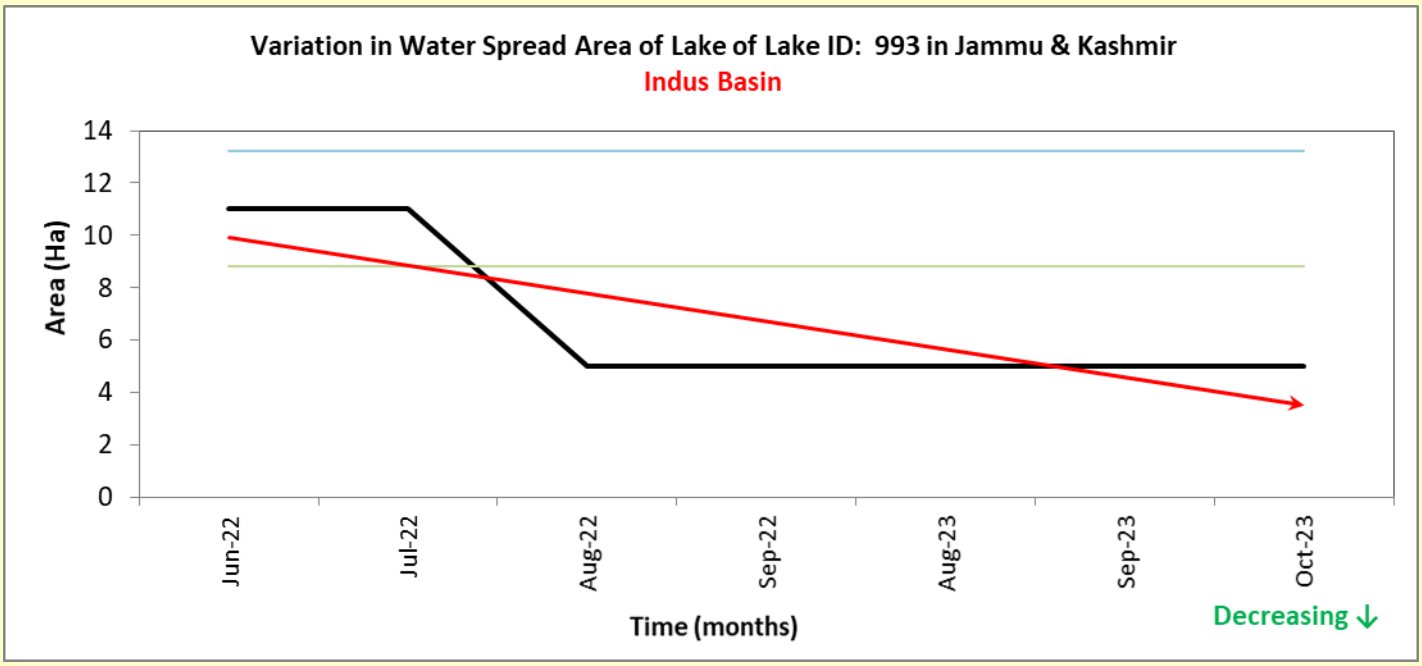


Figure 4.65(i) Trend Analysis Plot ±10%

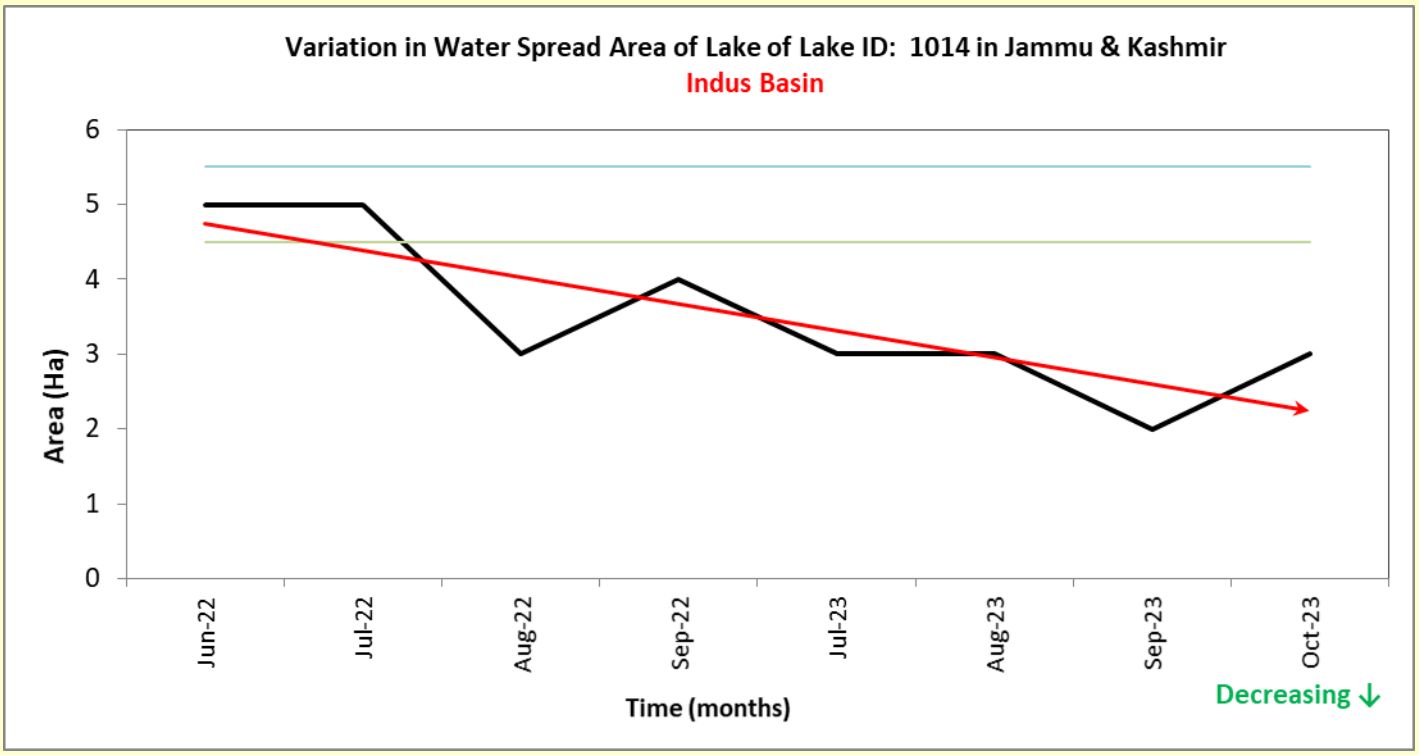
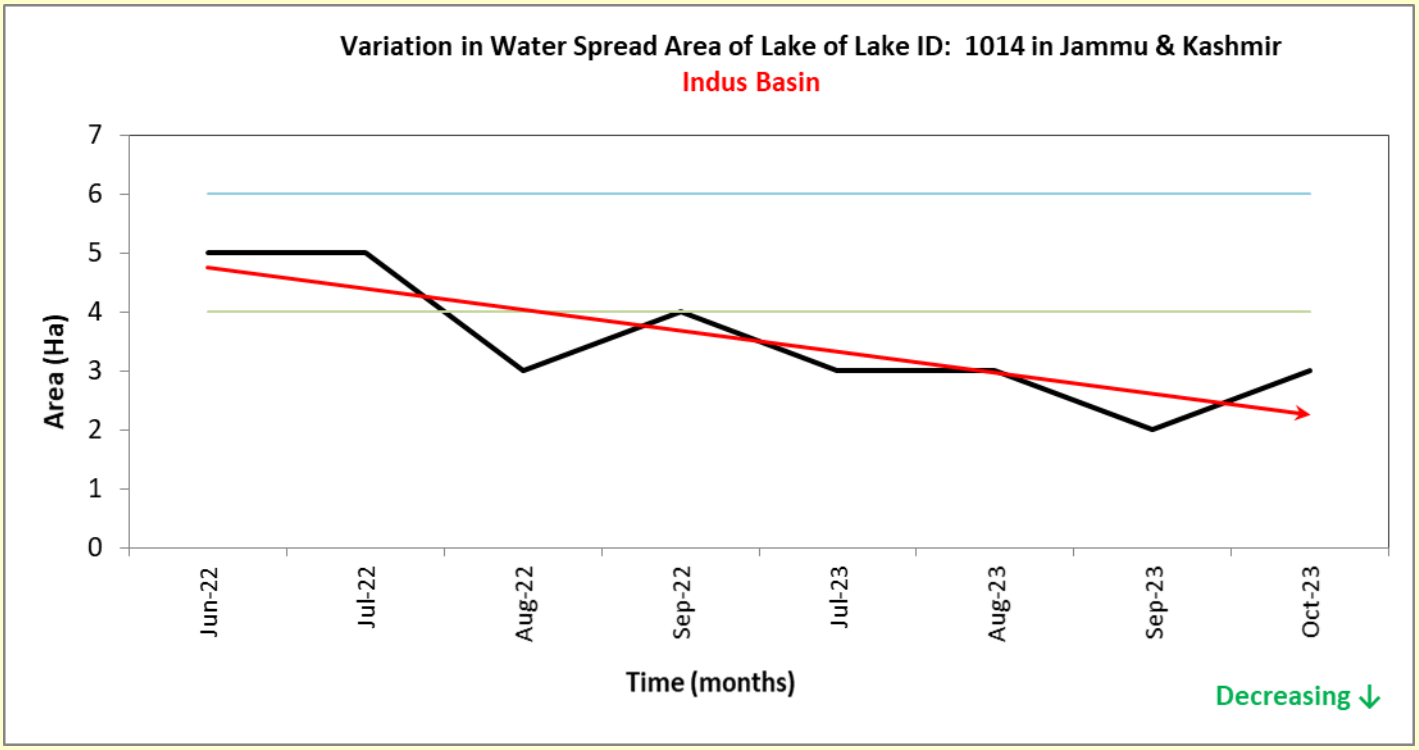


Figure 4.65(ii) Trend Analysis Plot ±20%



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 ±10%

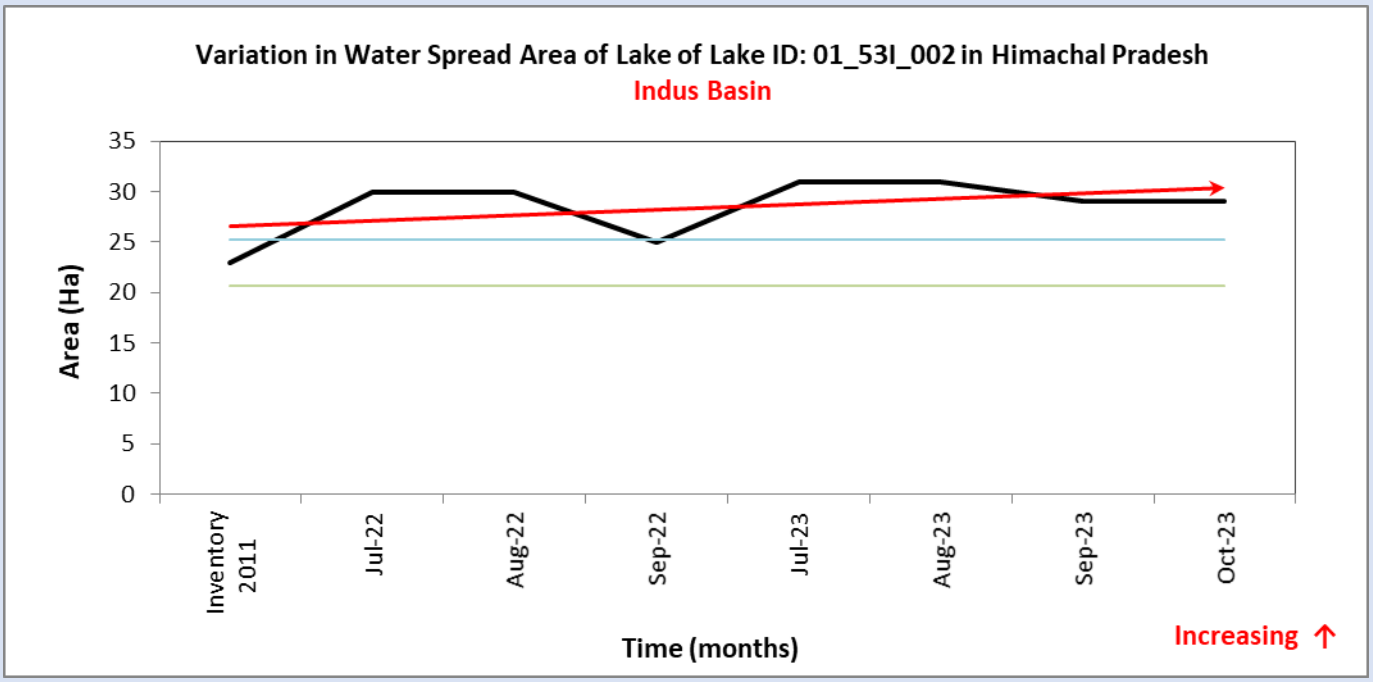


Figure 4.66(ii) Trend Analysis Plot ±10%

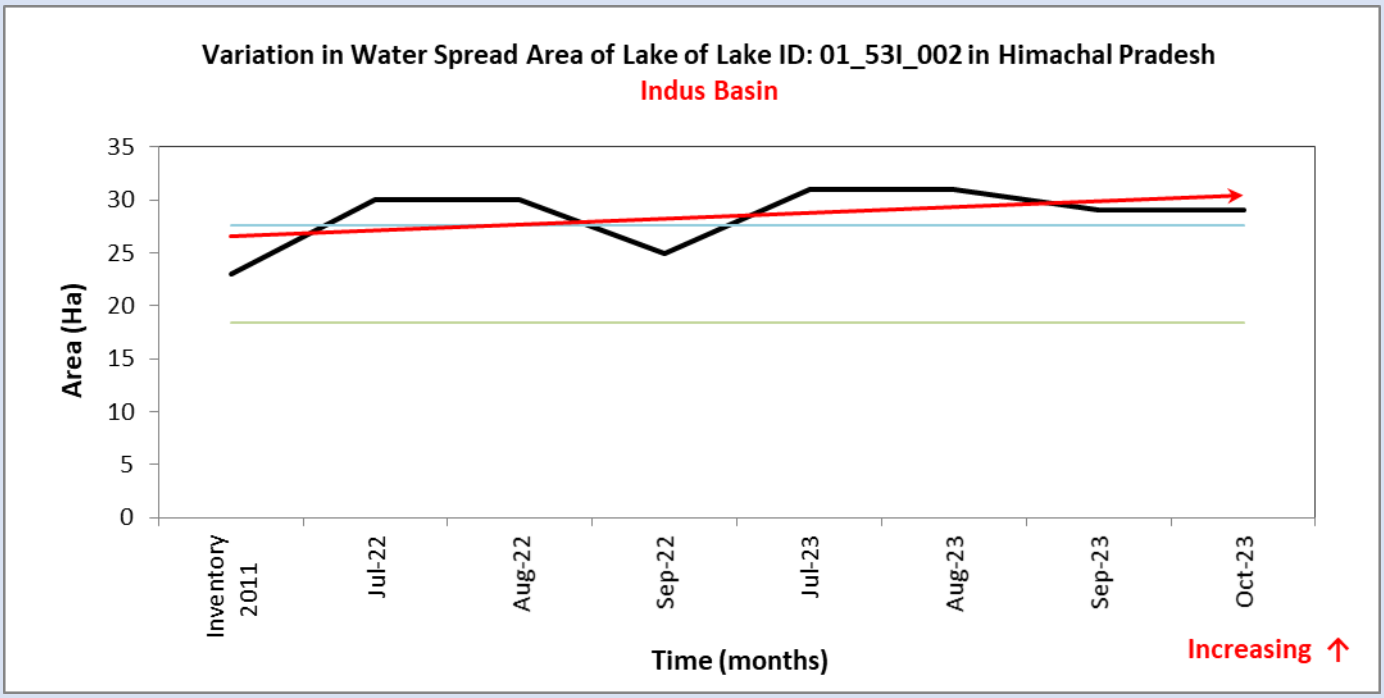


Figure 4.67(i) Trend Analysis Plot ±10%

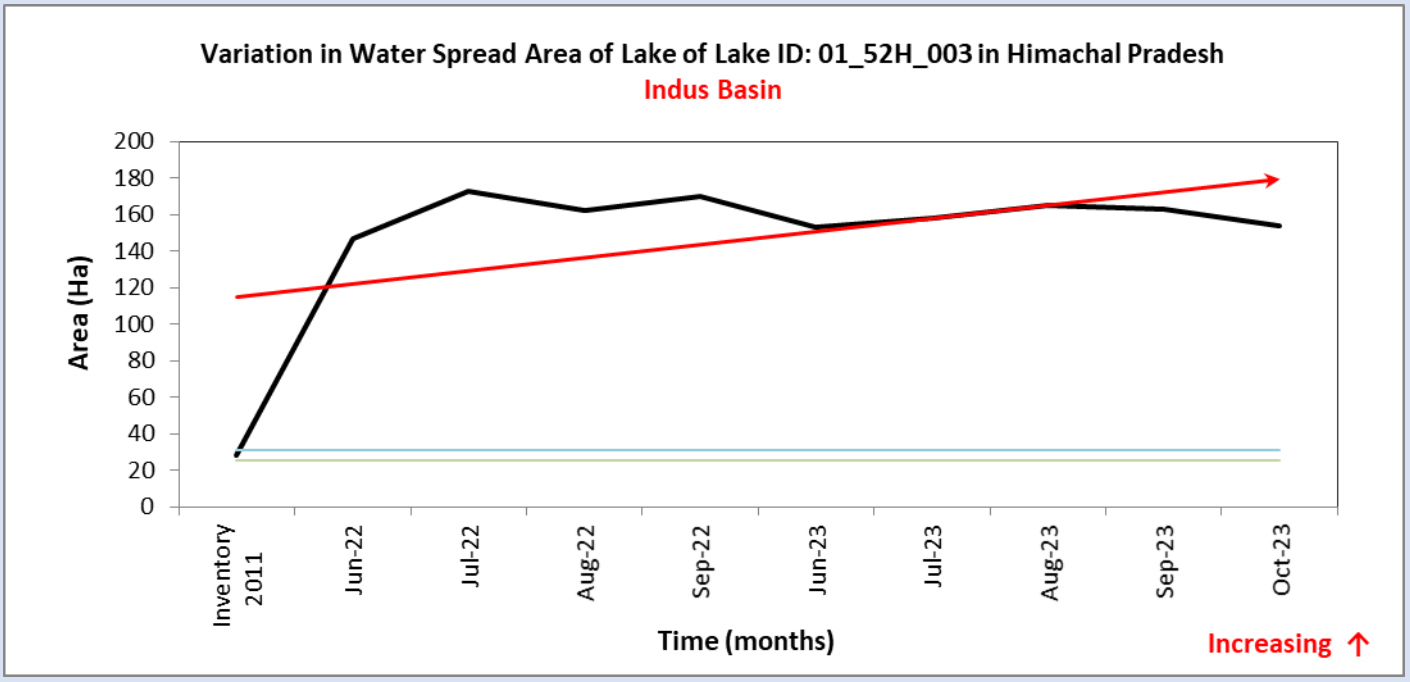


Figure 4.67(ii) Trend Analysis Plot ±20%

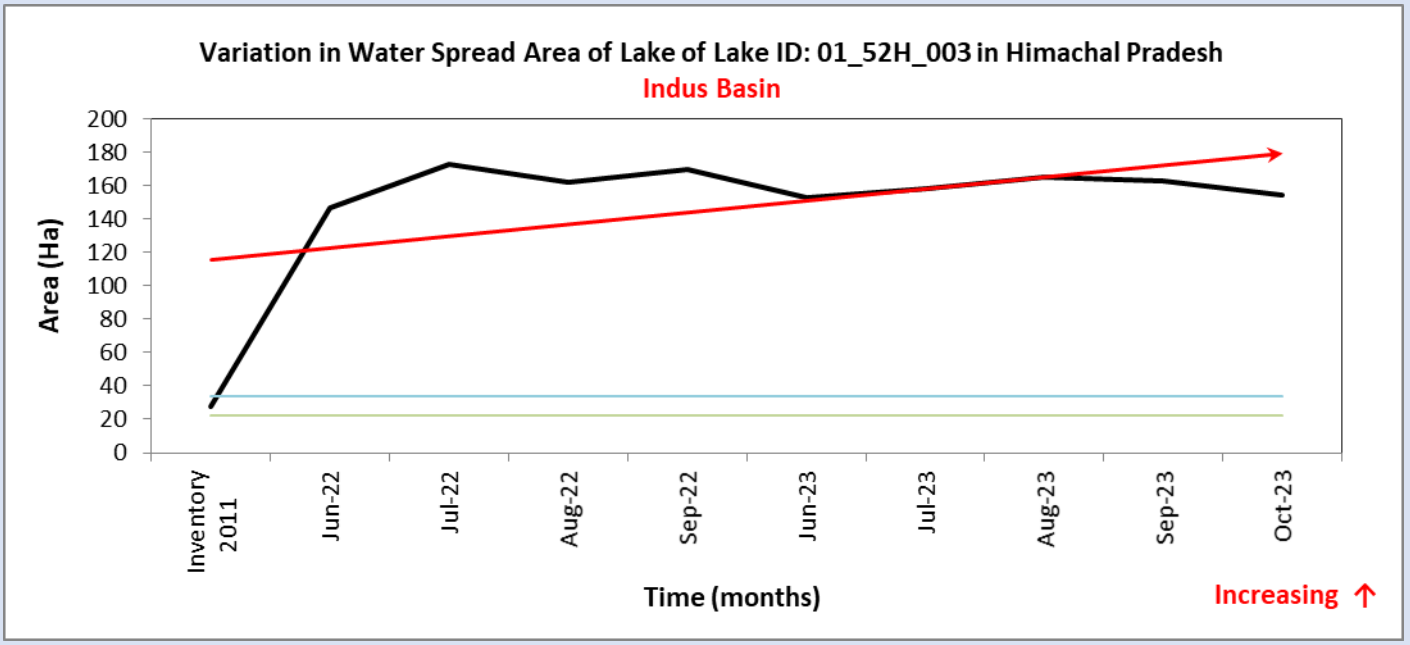


Figure 4.68(i) Trend Analysis Plot ±10%

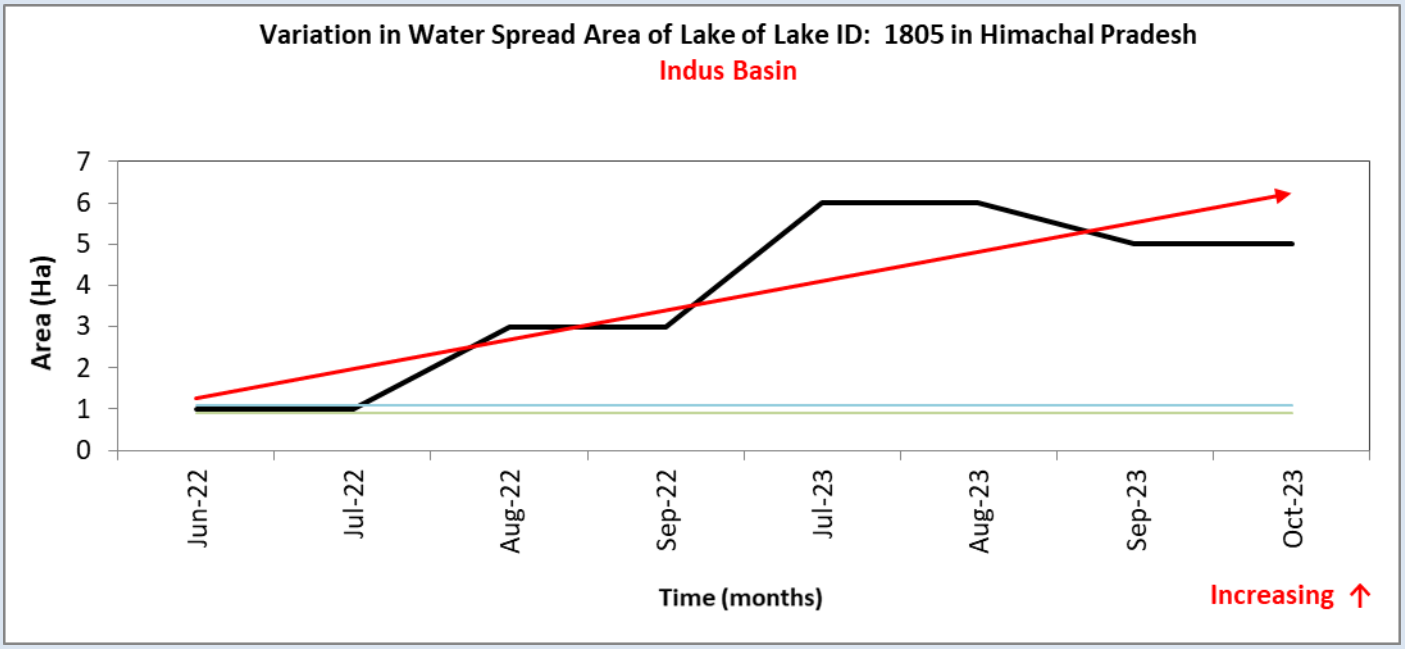


Figure 4.68(ii) Trend Analysis Plot ±20%

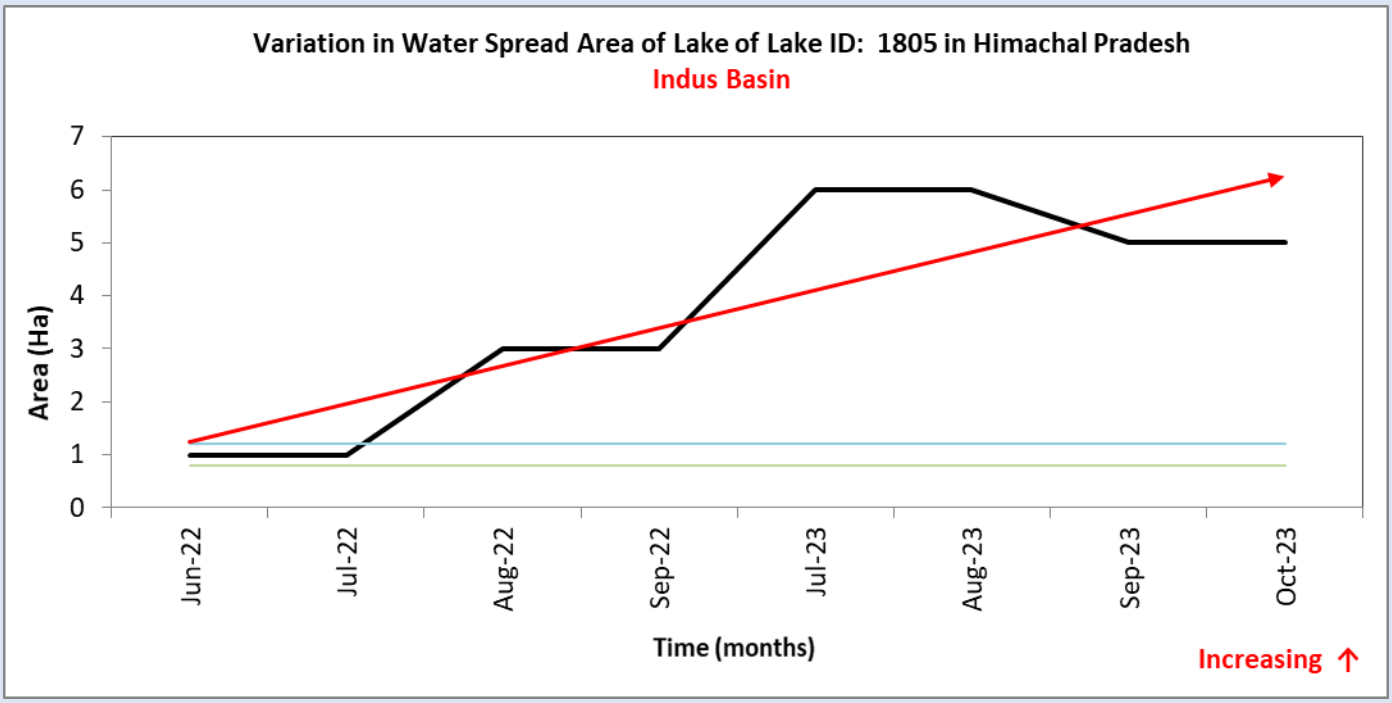


Figure 4.69(i) Trend Analysis Plot ±10%

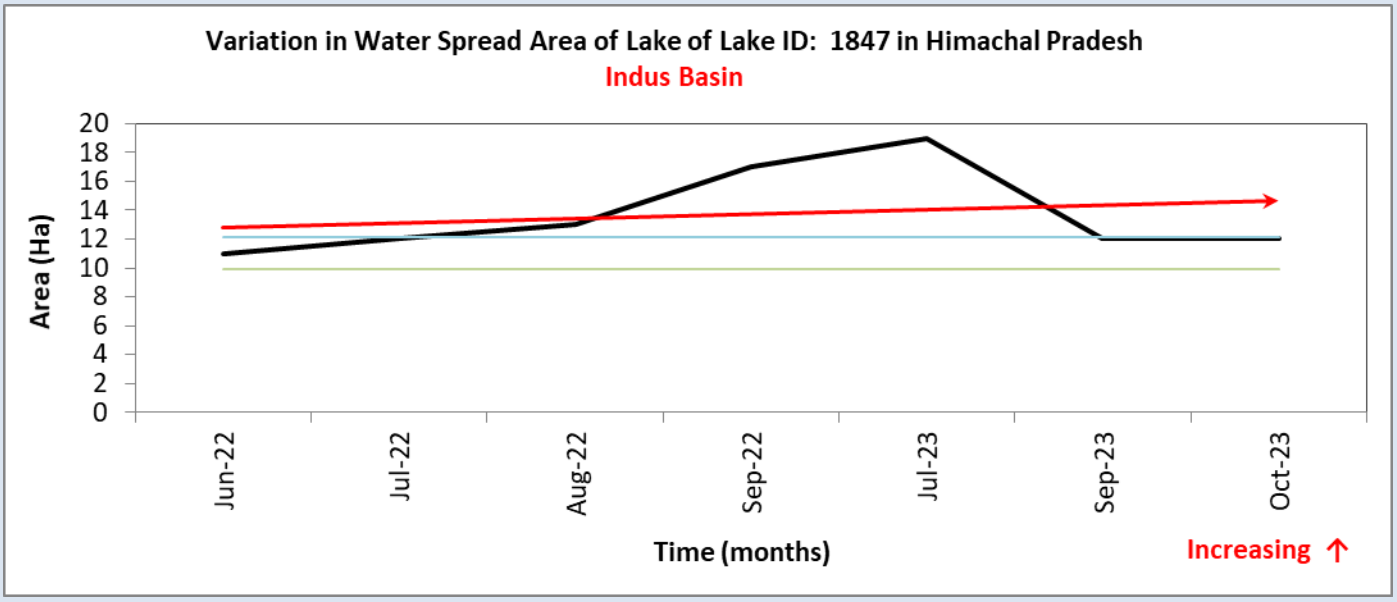


Figure 4.69(ii) Trend Analysis Plot ±20%

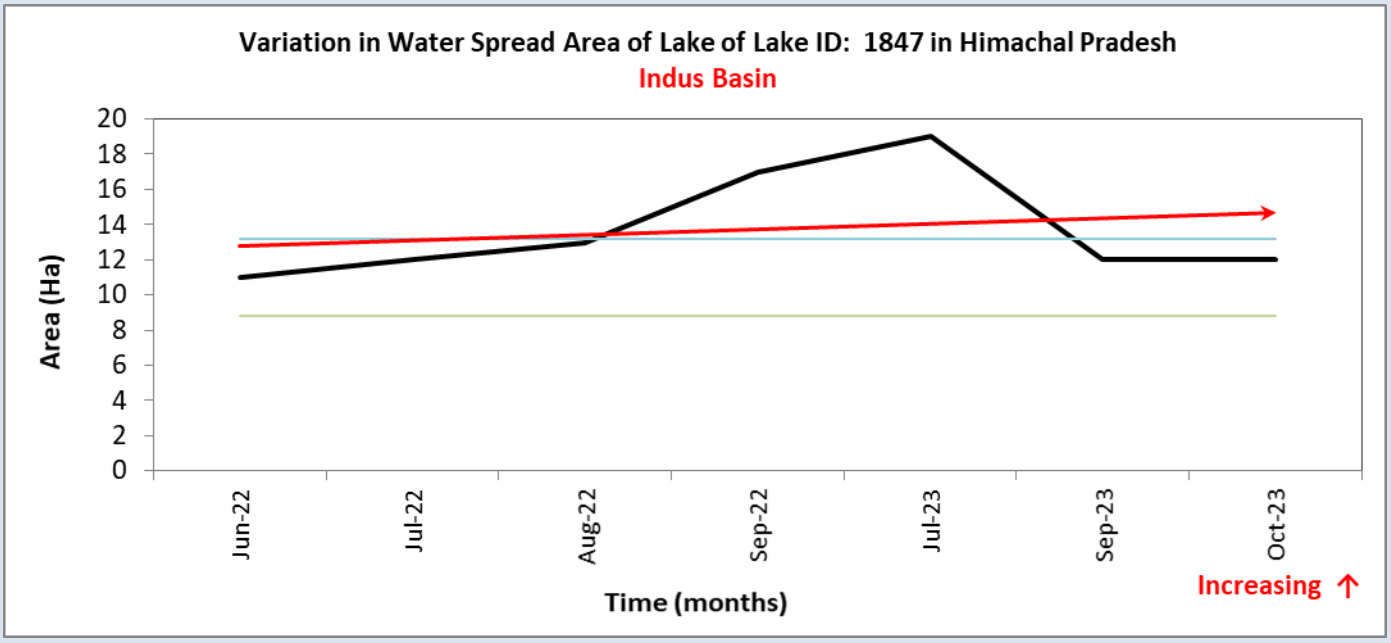


Figure 4.70(i) Trend Analysis Plot ±10%

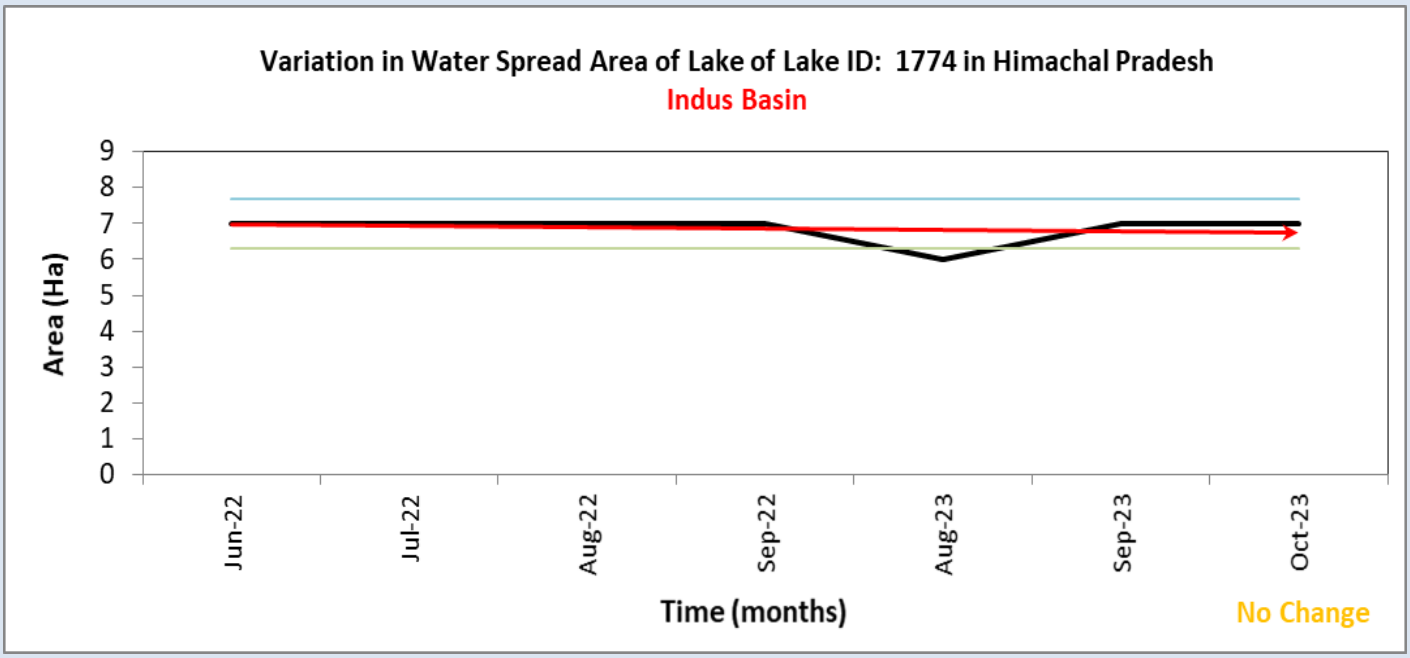


Figure 4.70(ii) Trend Analysis Plot ±20%

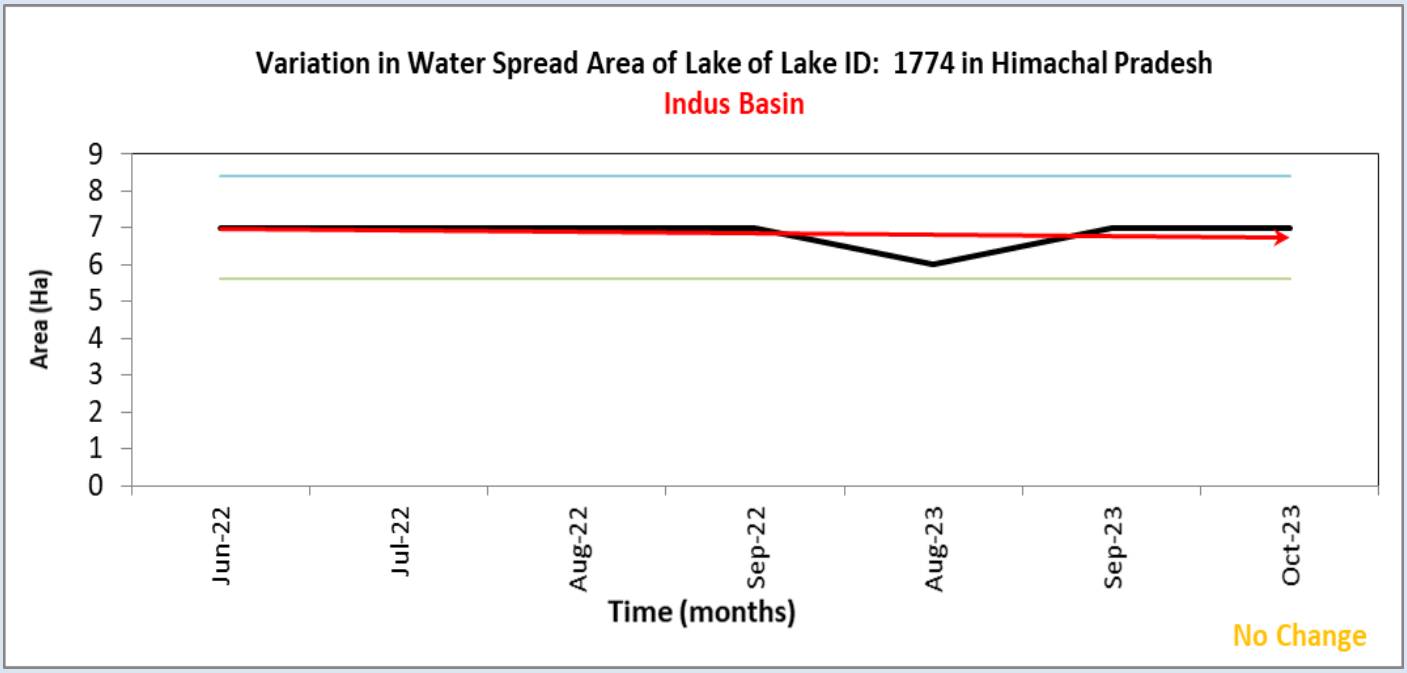


Figure 4.71(i) Trend Analysis Plot ±10%

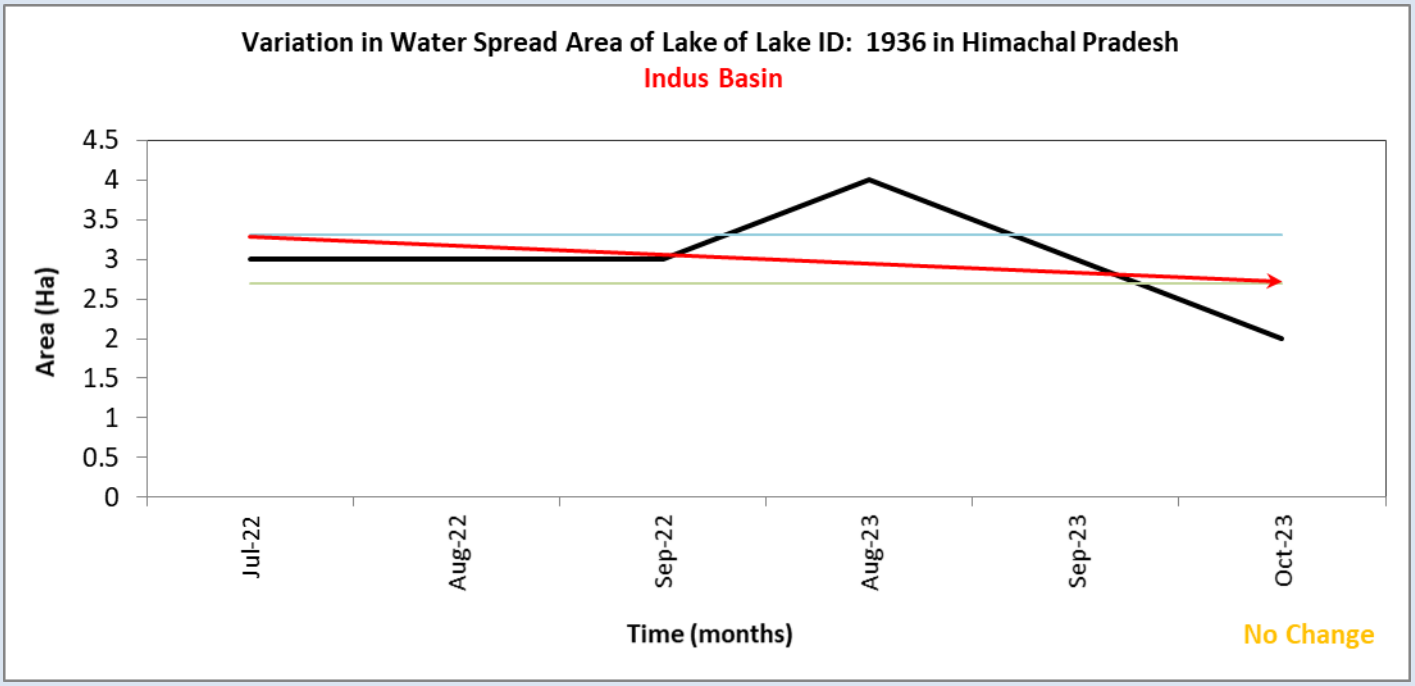


Figure 4.71(ii). Trend Analysis Plot ±20%

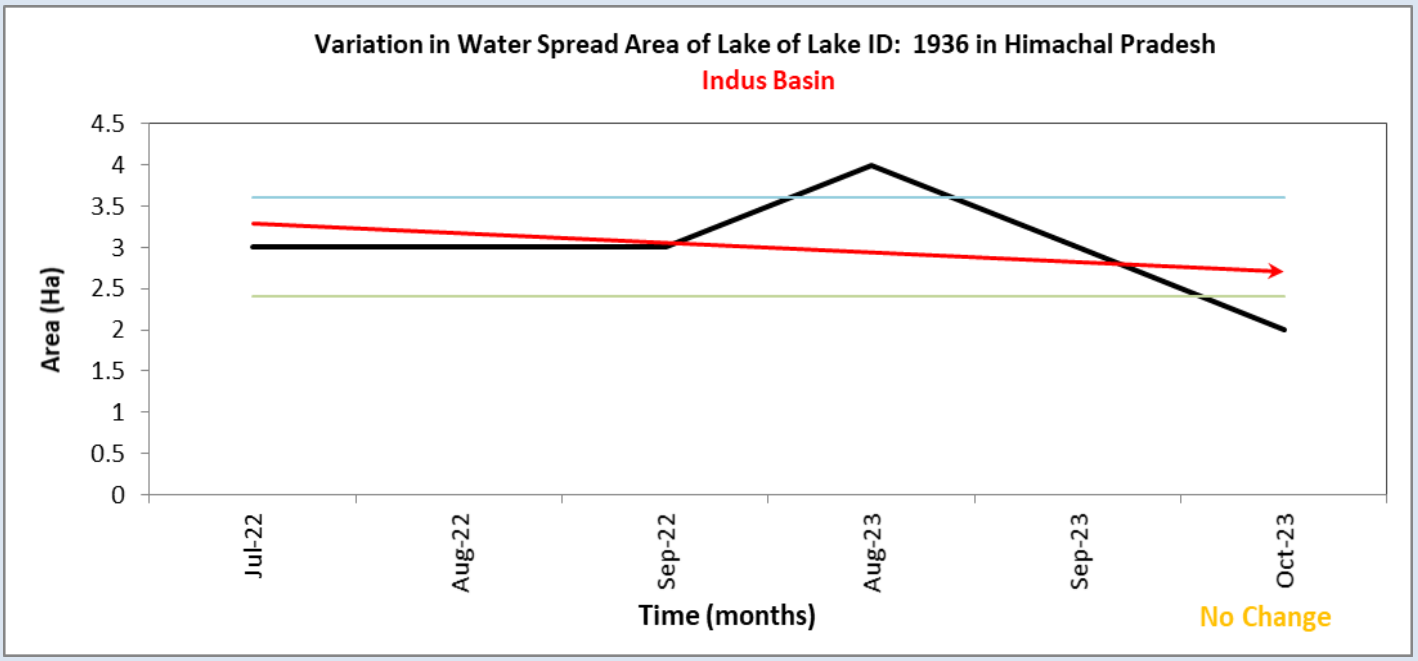


Figure 4.72(i) Trend Analysis Plot ±10%

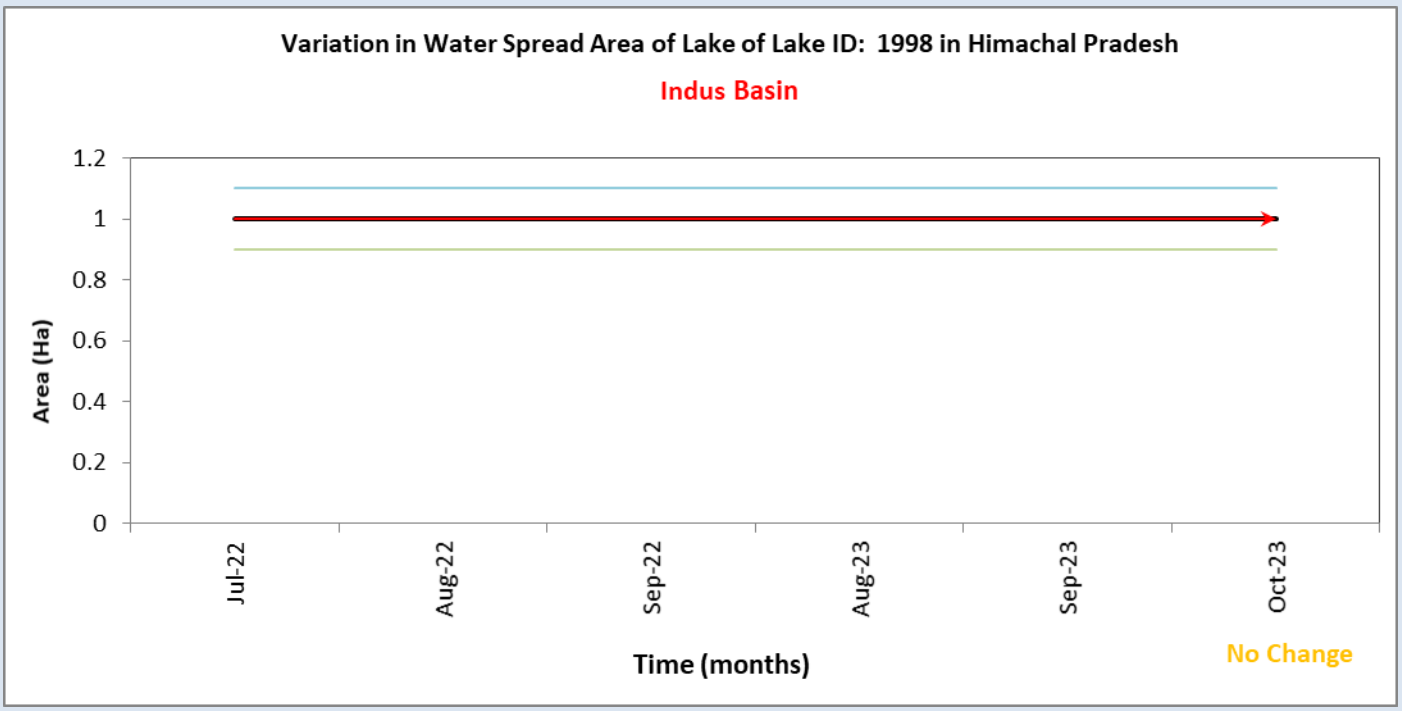


Figure 4.72(ii) Trend Analysis Plot ±20%

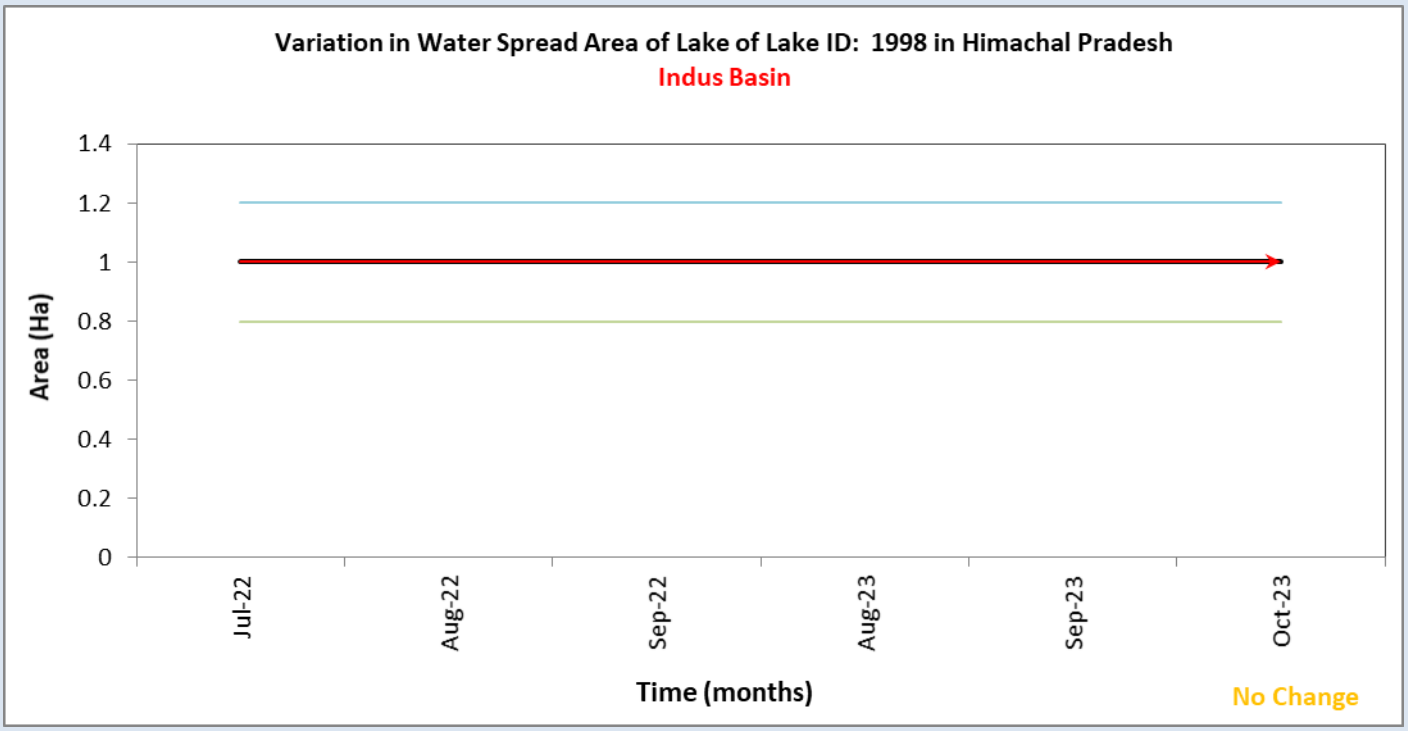


Figure 4.73(i) Trend Analysis Plot ±10%

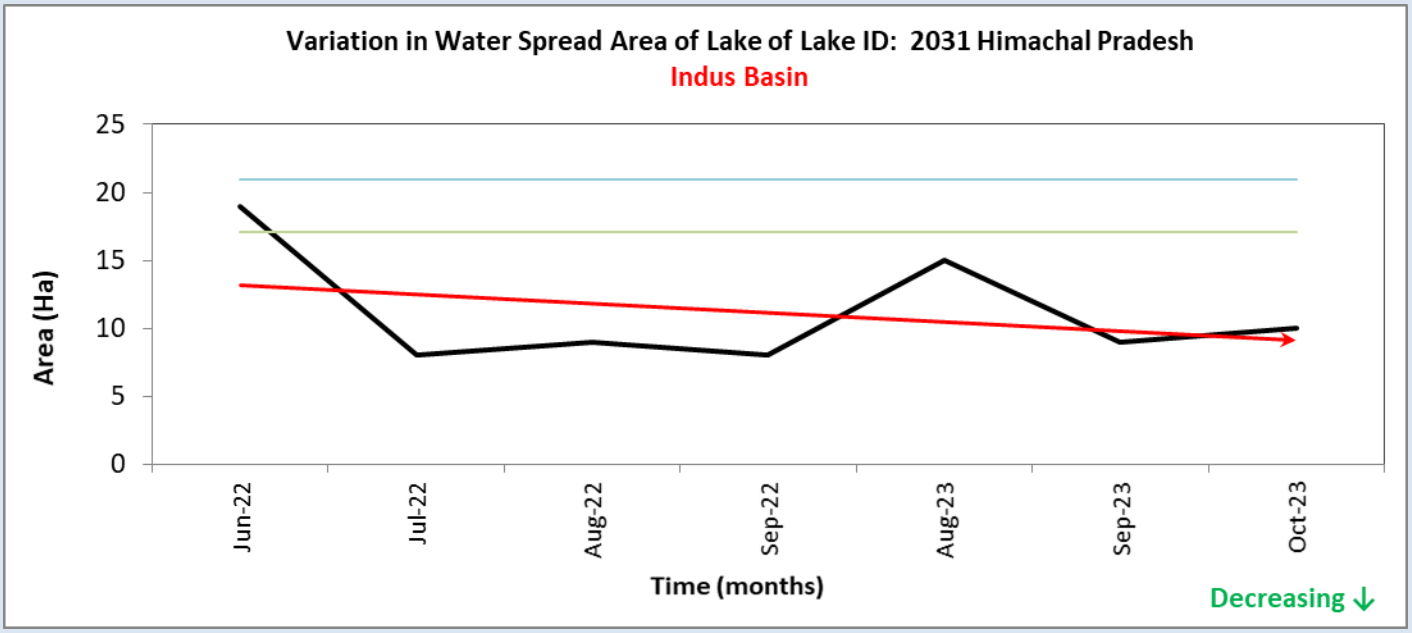
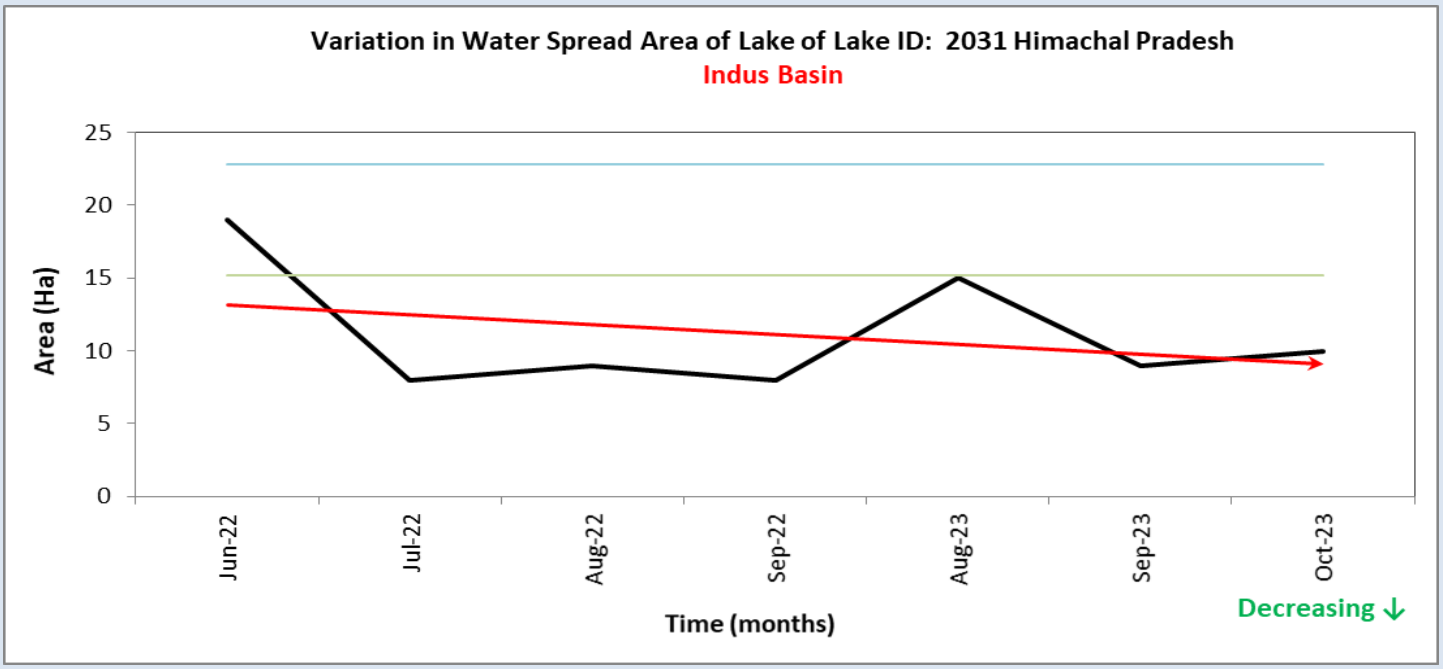


Figure 4.73(ii). Trend Analysis Plot ±20%



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 ±10%

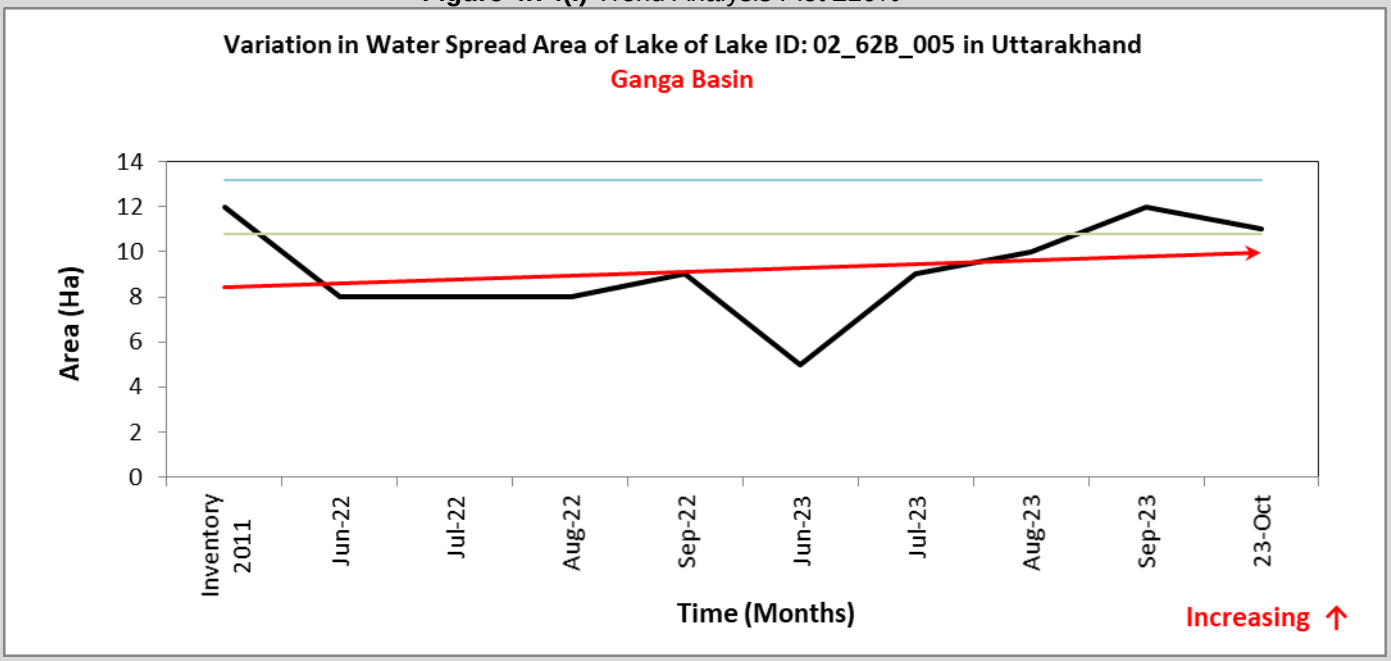


Figure 4.74(ii) Trend Analysis Plot ±20%

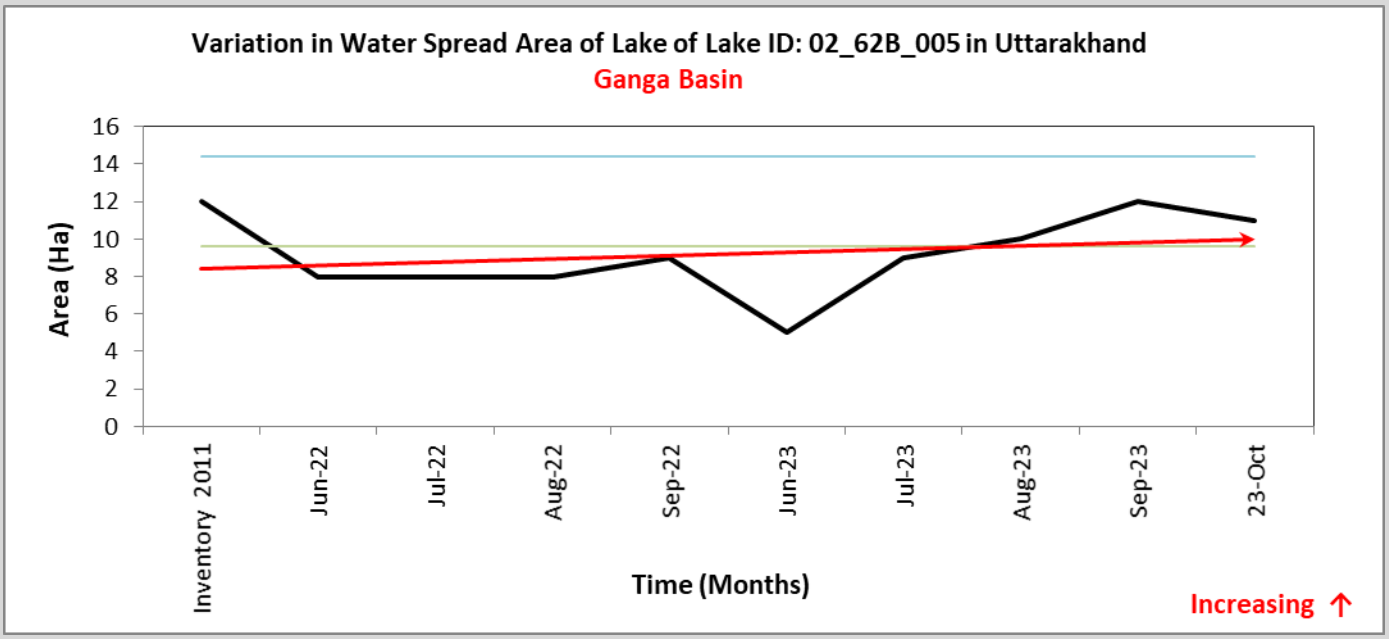


Figure 4.75(i) Trend Analysis Plot ±10%

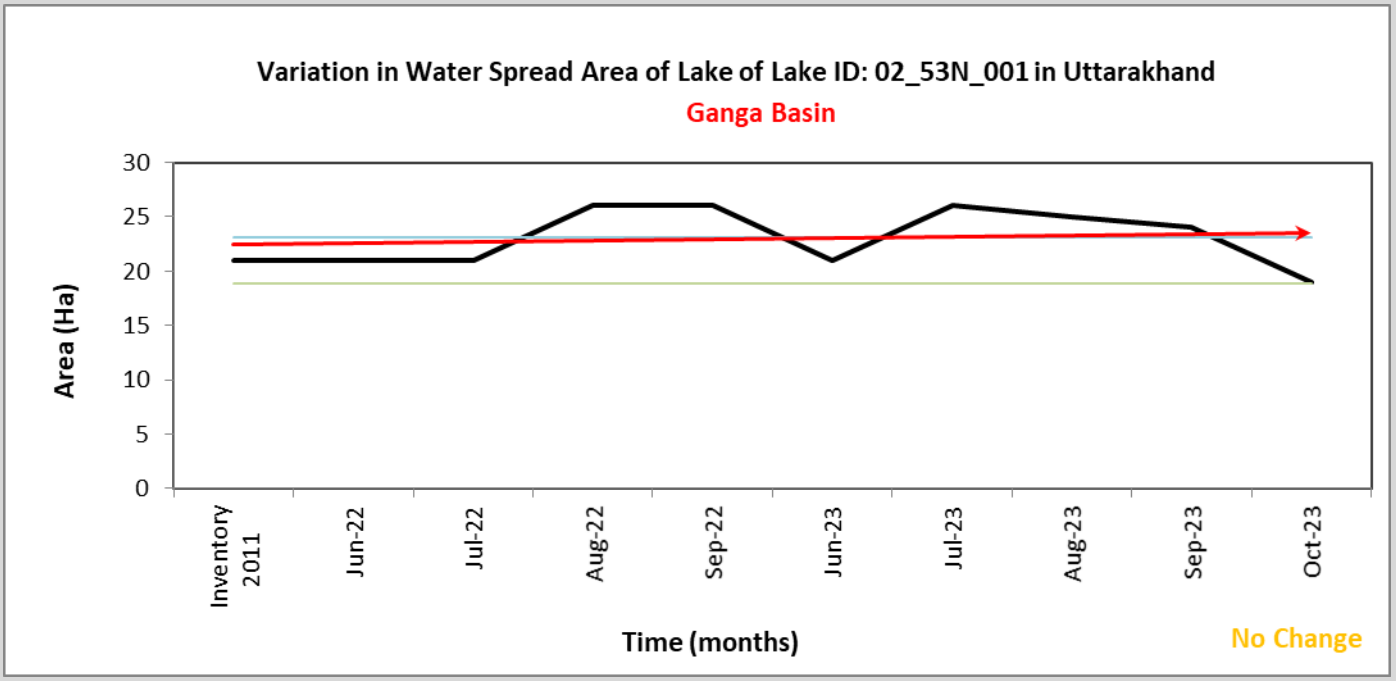


Figure 4.75(ii) Trend Analysis Plot ±20%

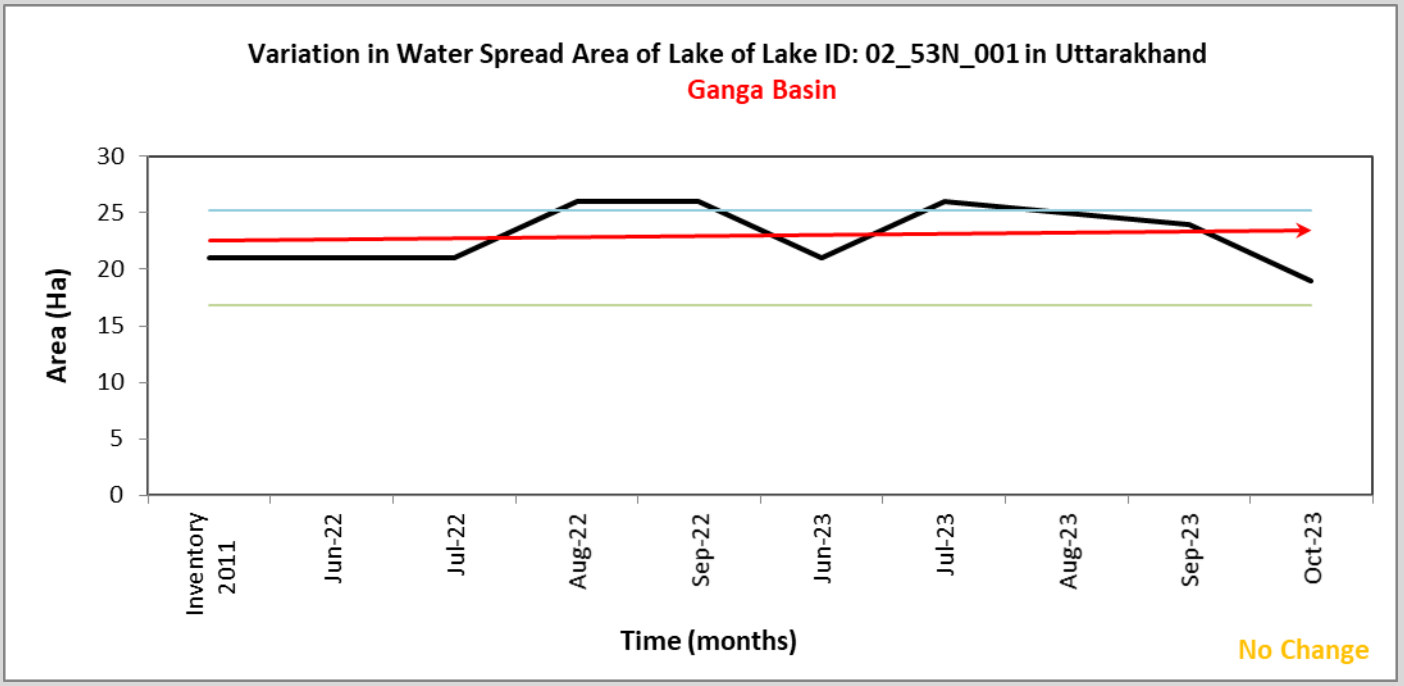


Figure 4.76(i) Trend Analysis Plot ±10%

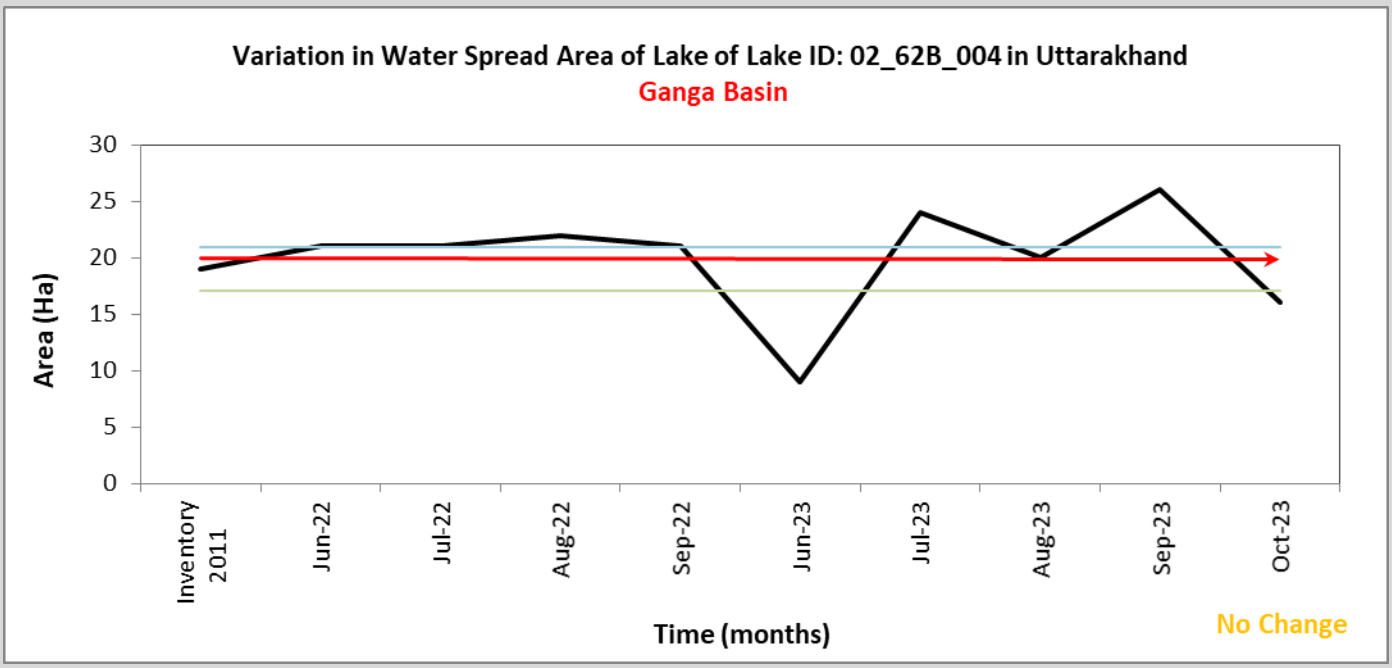


Figure 4.76(ii) Trend Analysis Plot ±20%

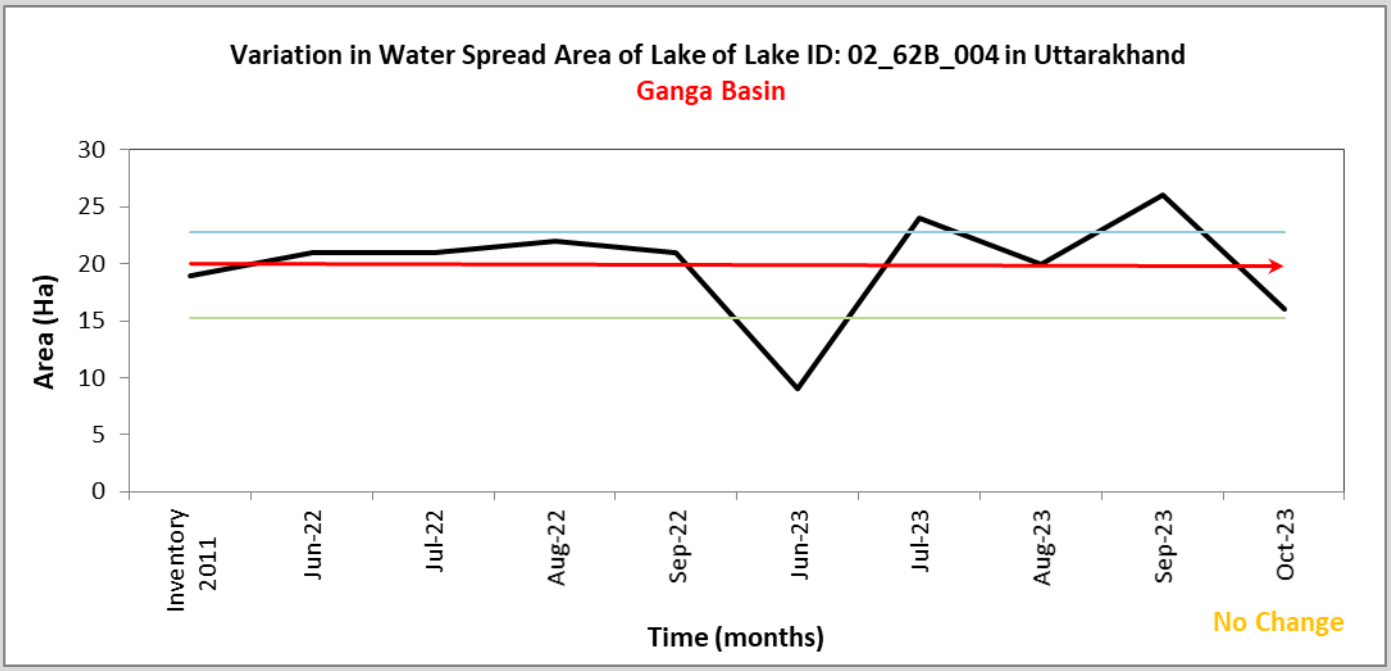


Figure 4.77(i) Trend Analysis Plot ±10%

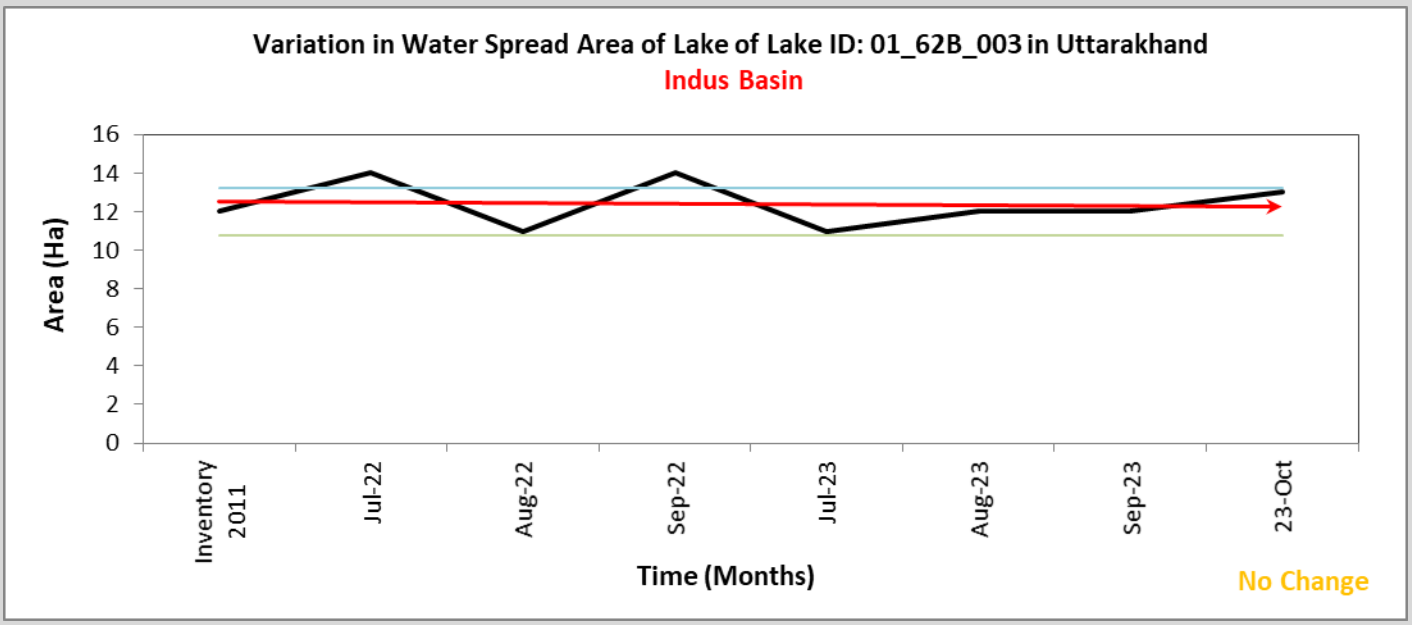


Figure 4.77(ii) Trend Analysis Plot ±20%

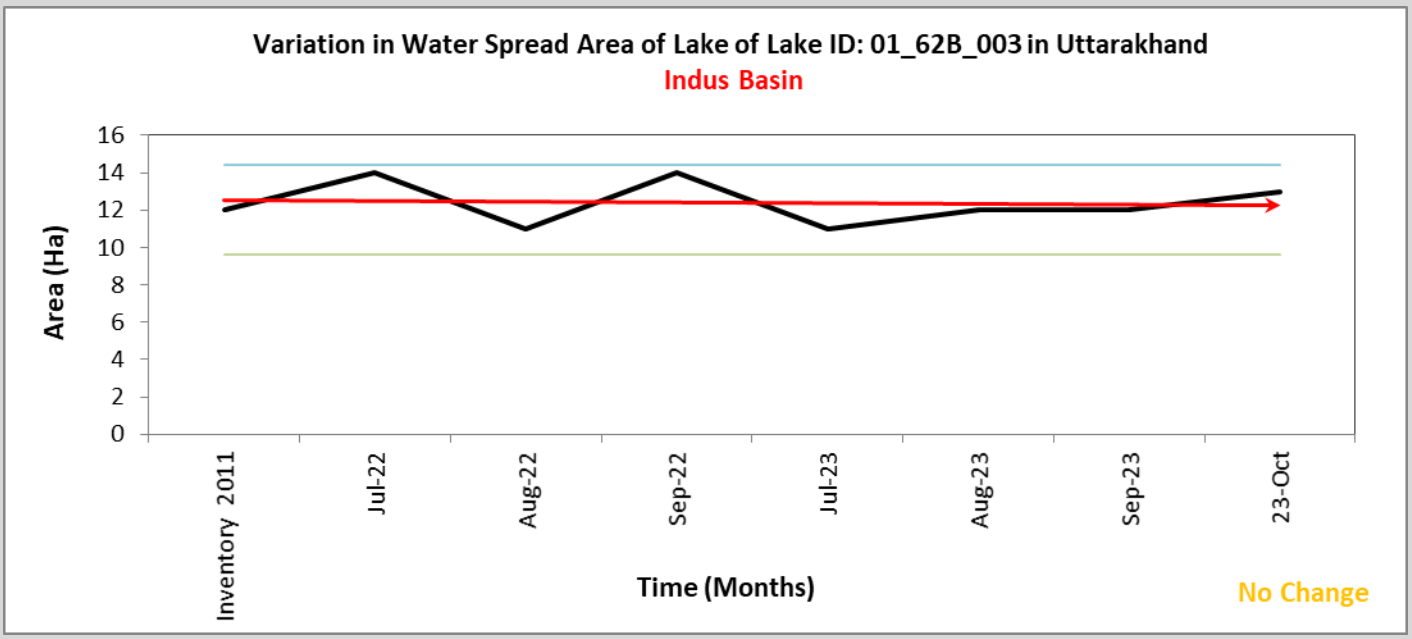


Figure 4.78(i) Trend Analysis Plot ±10%

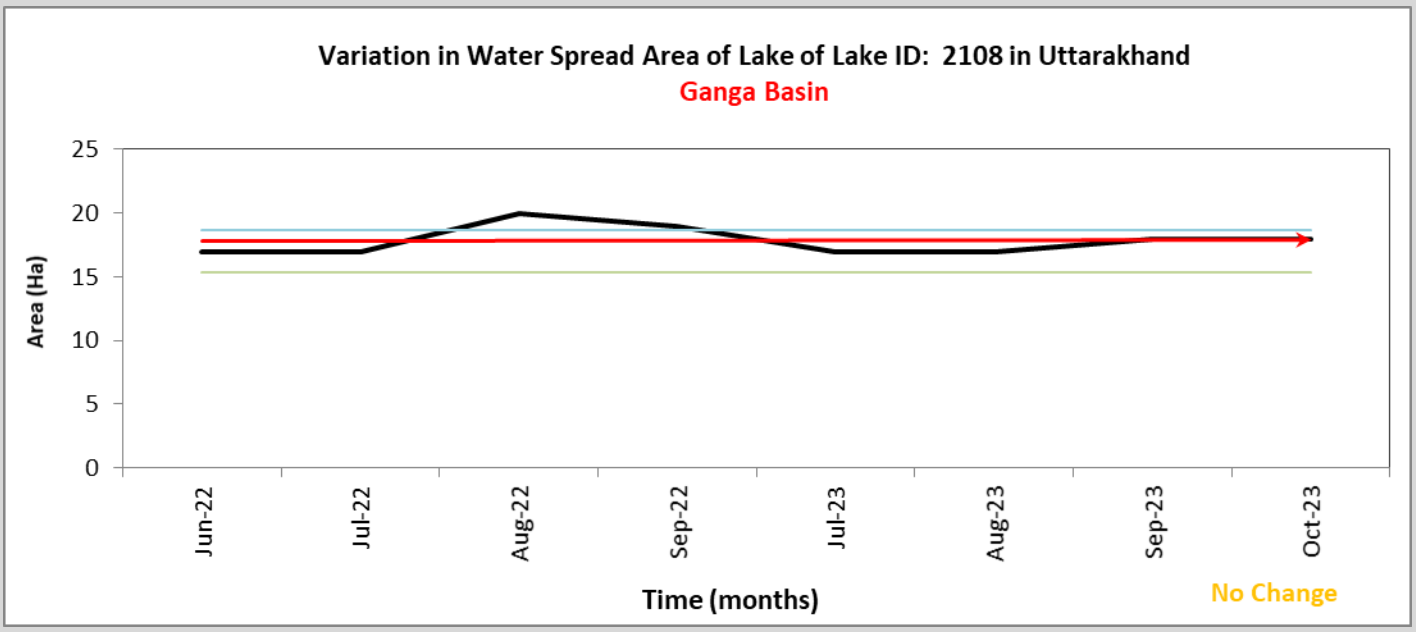


Figure 4.78(ii) Trend Analysis Plot ±20%

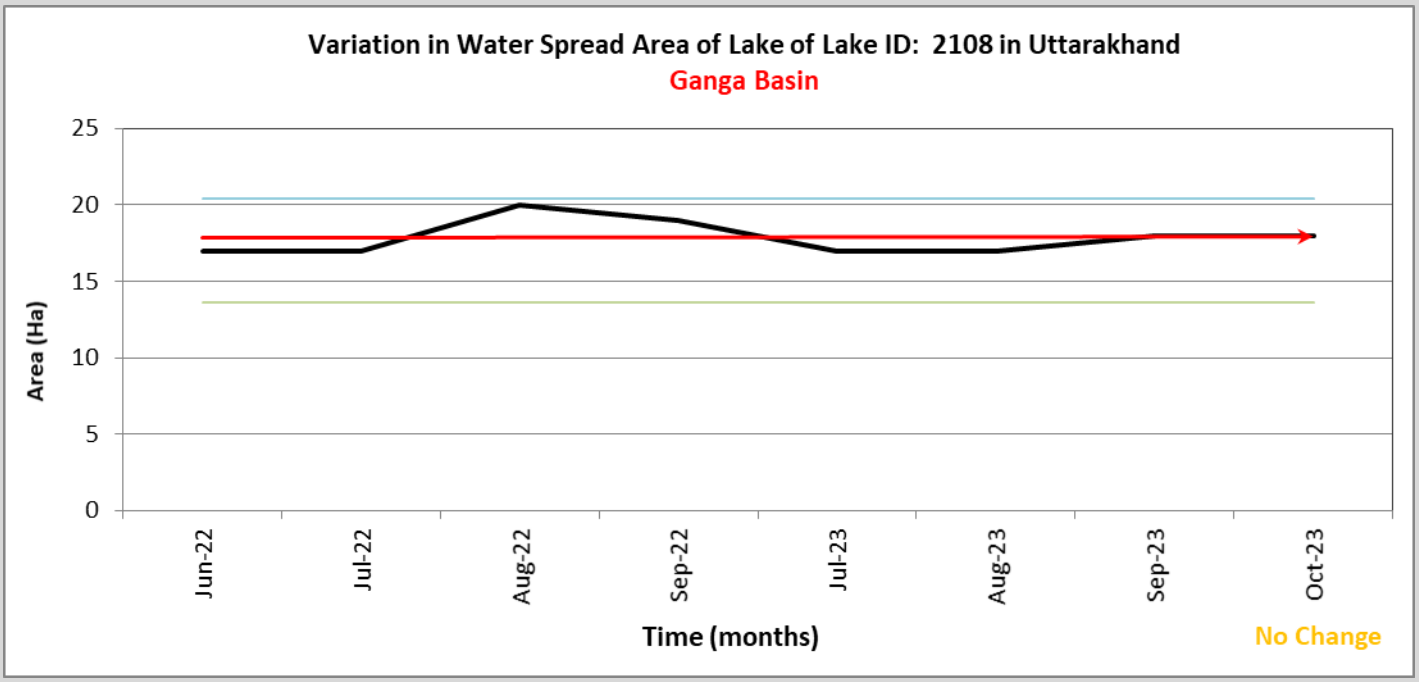


Figure 4.79(i) Trend Analysis Plot ±10%

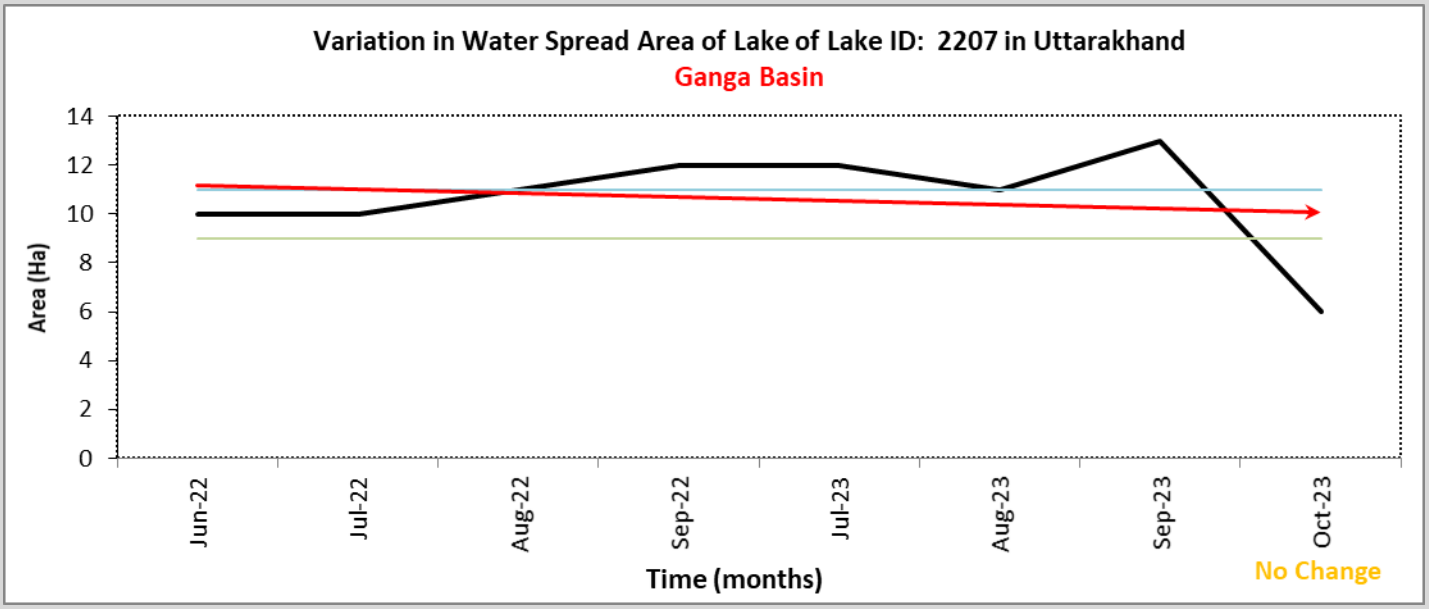


Figure 4.79(ii) Trend Analysis Plot ±20%

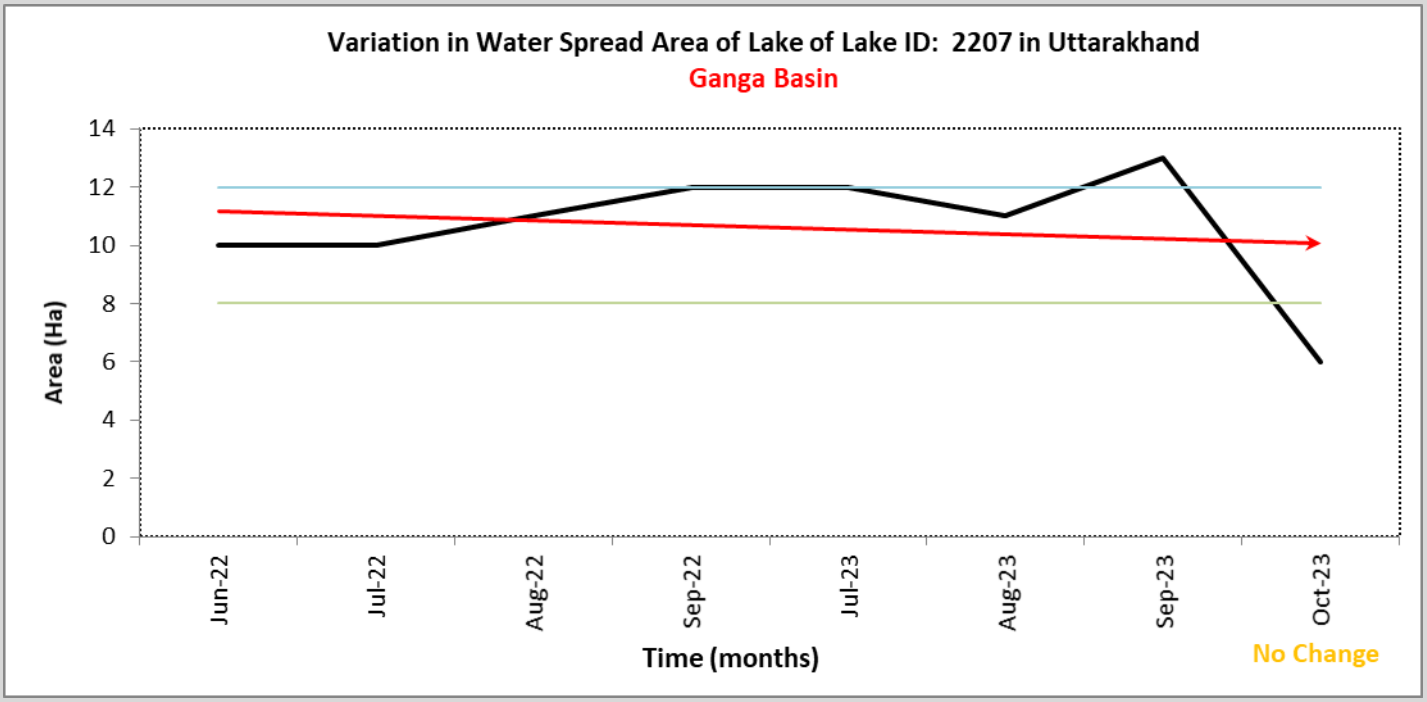


Figure 4.80(i) Trend Analysis Plot ±10%

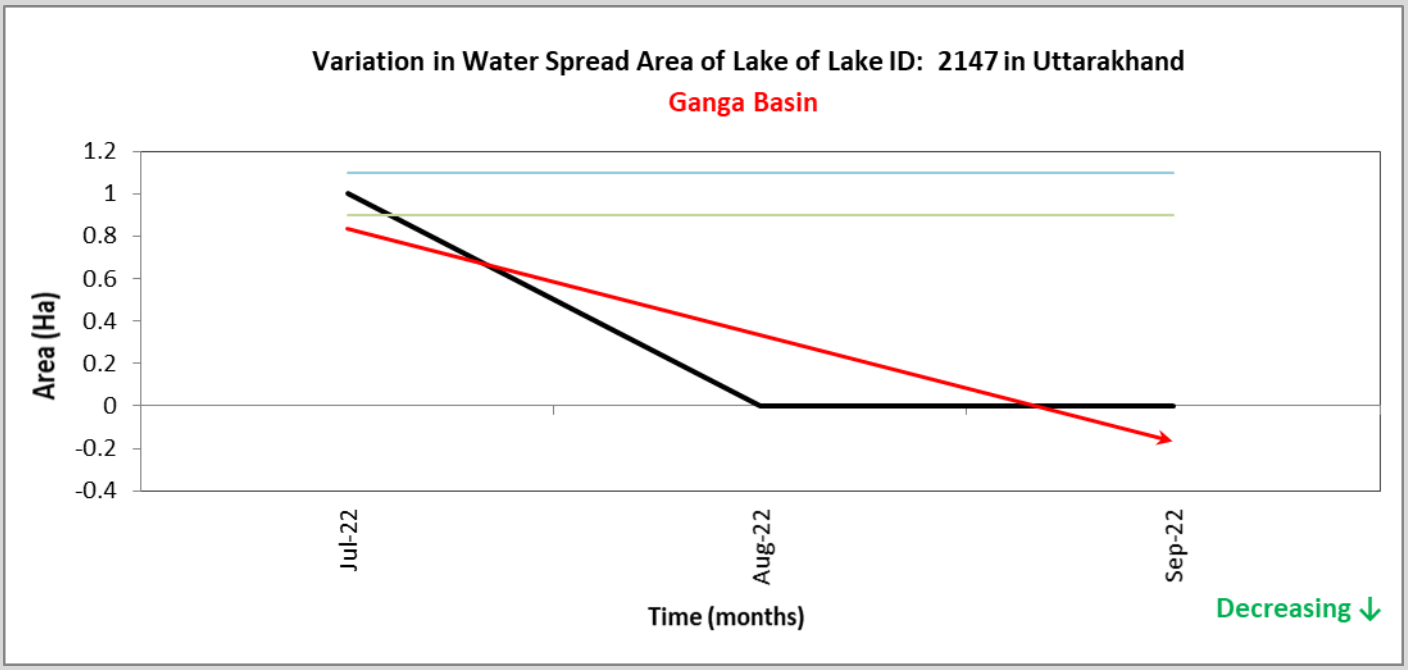
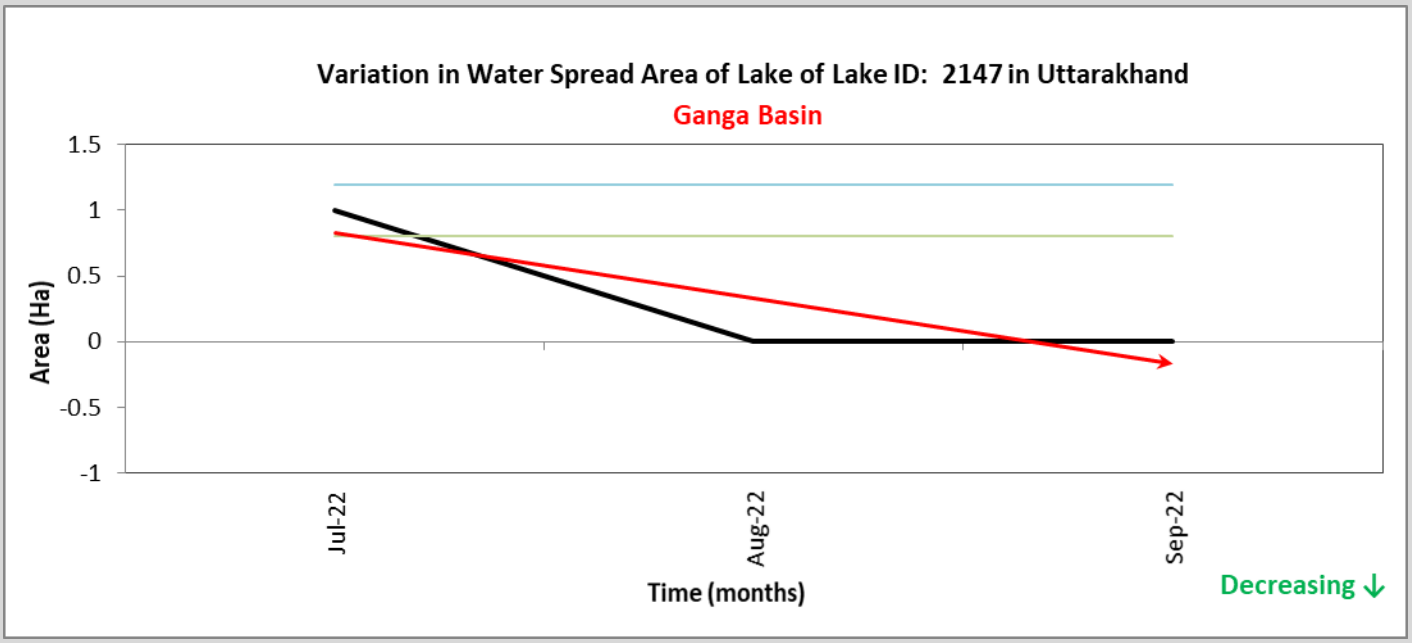


Figure 4.80(ii) Trend Analysis Plot ±20%



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 ±10%

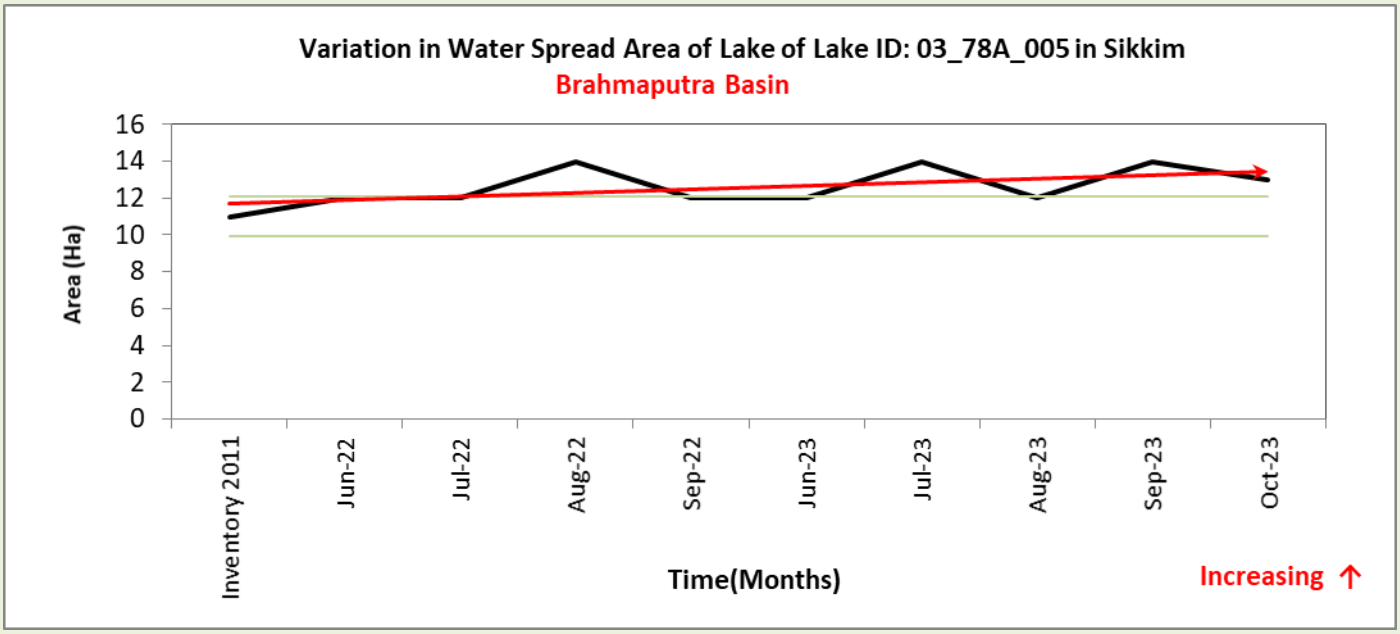


Figure 4.81(ii). Trend Analysis Plot ±20%

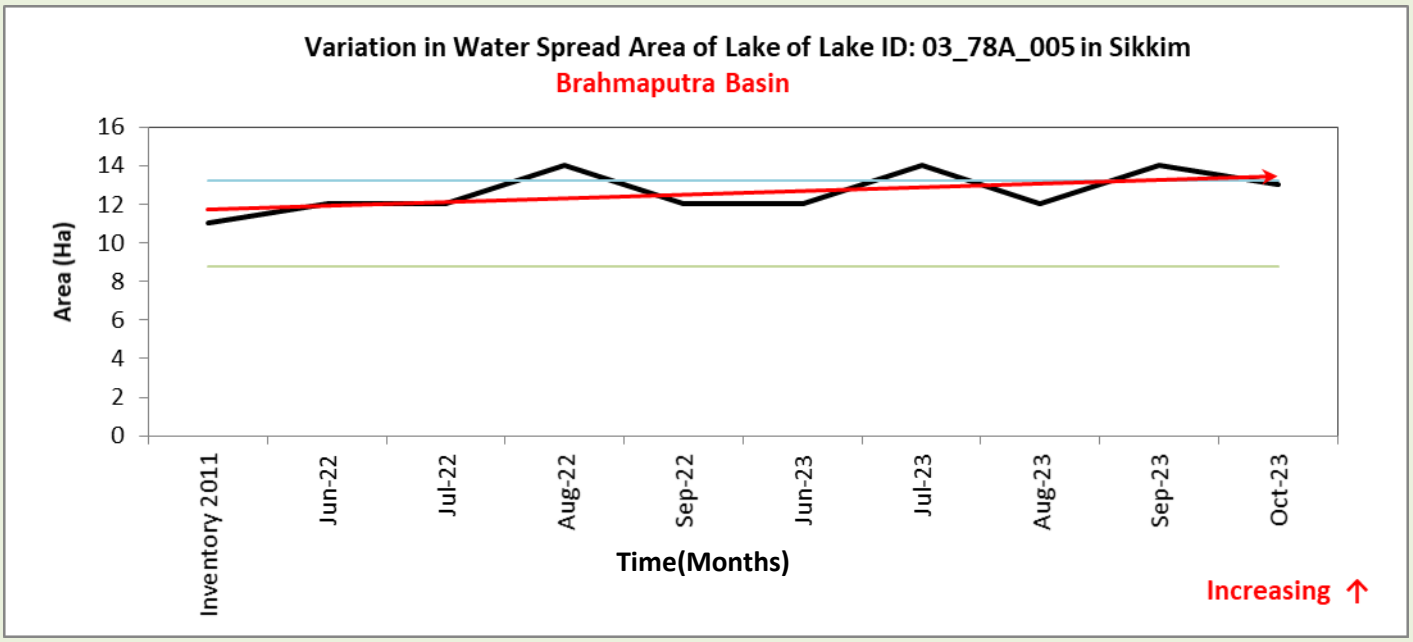


Figure 4.82(i) Trend Analysis Plot ±10%

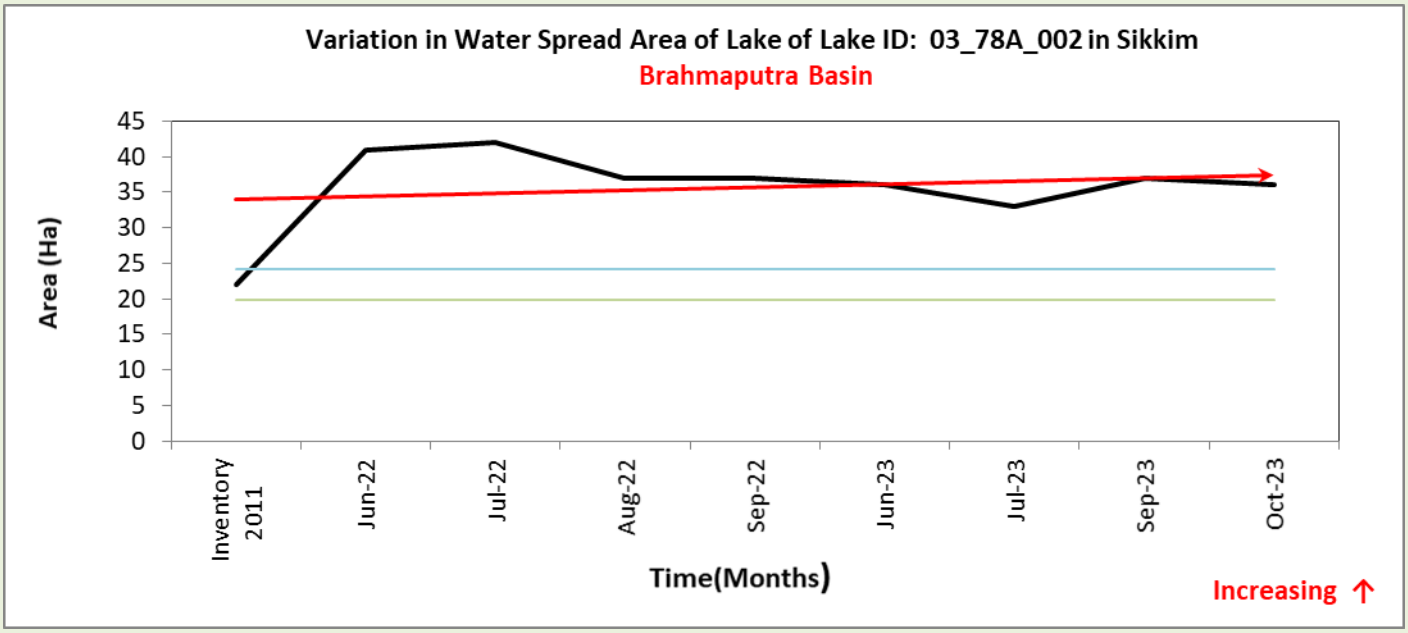


Figure 4.82(ii) Trend Analysis Plot ±20%

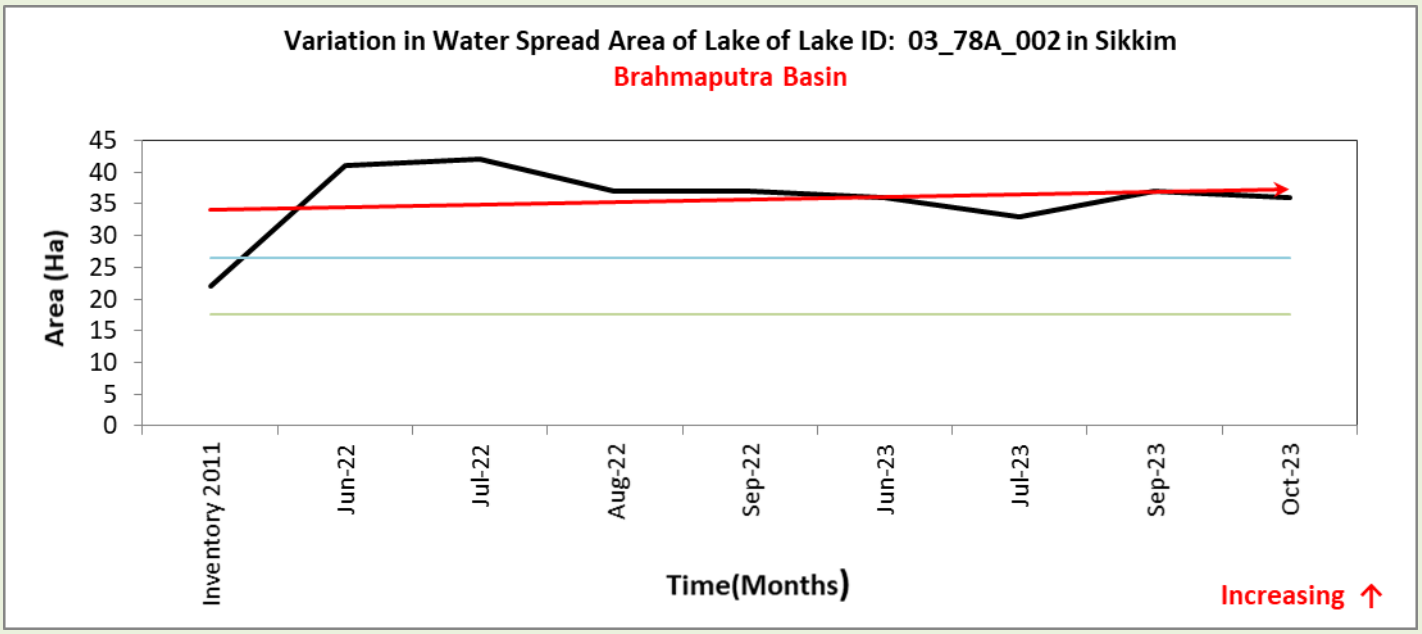


Figure 4.83(i) Trend Analysis Plot ±10%

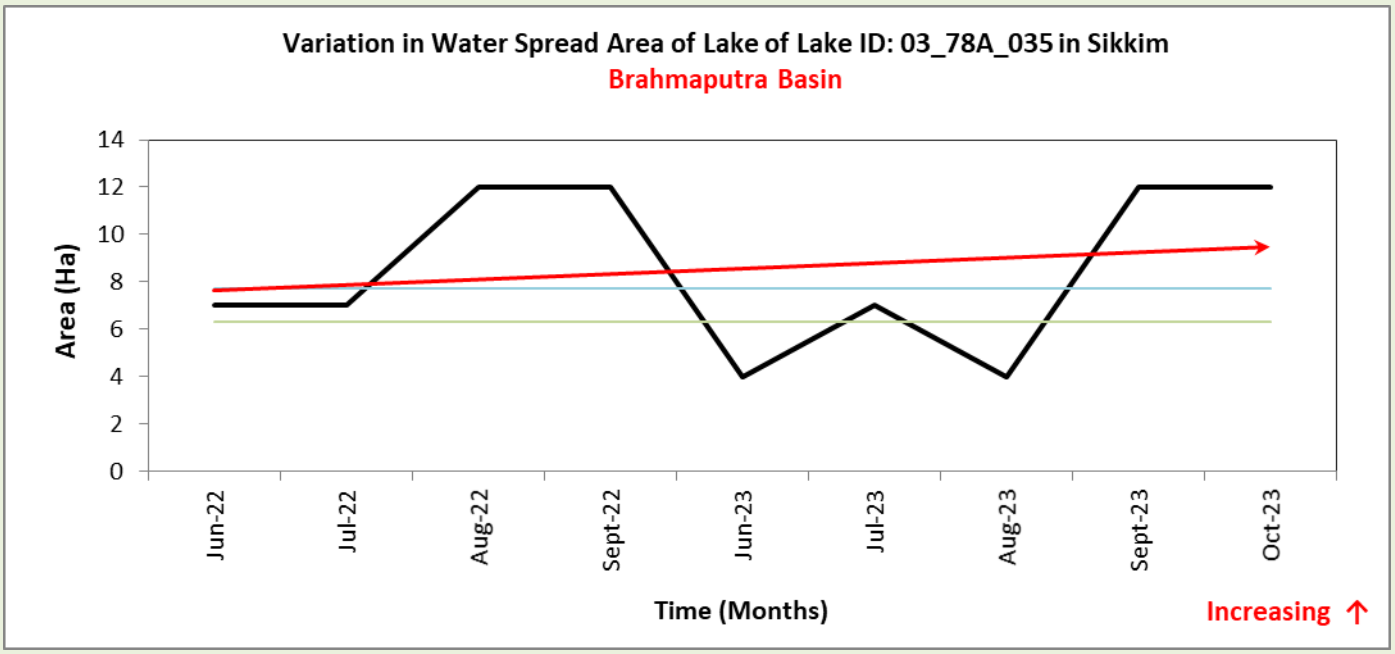


Figure 4.83(ii) Trend Analysis Plot ±20%

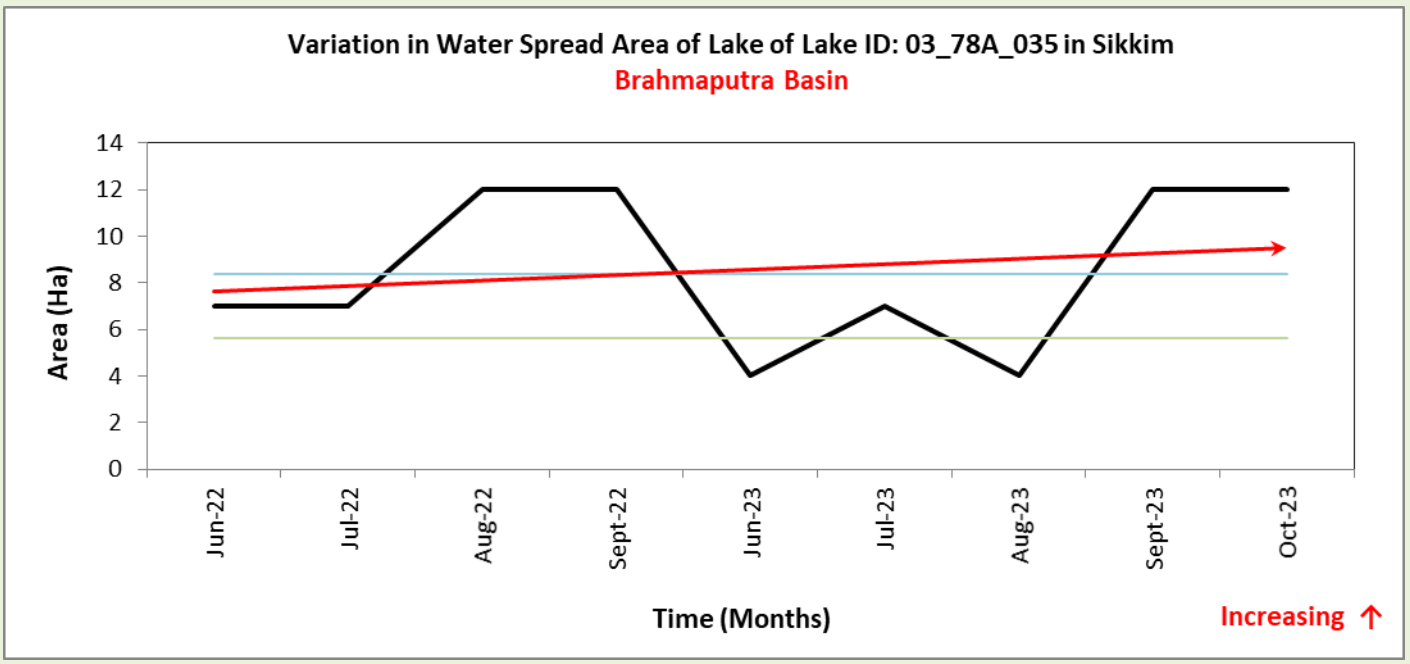


Figure 4.84(i) Trend Analysis Plot ±10%

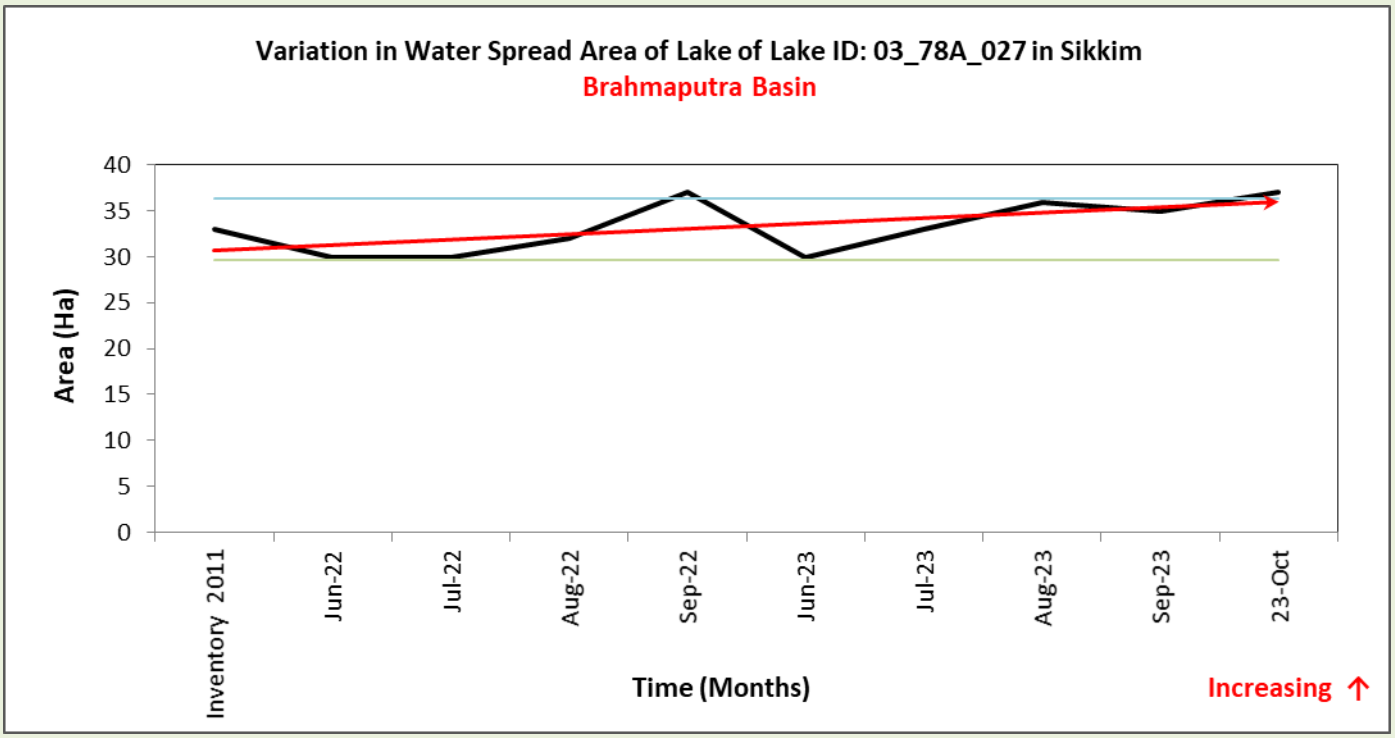


Figure 4.84(ii) Trend Analysis Plot ±20%

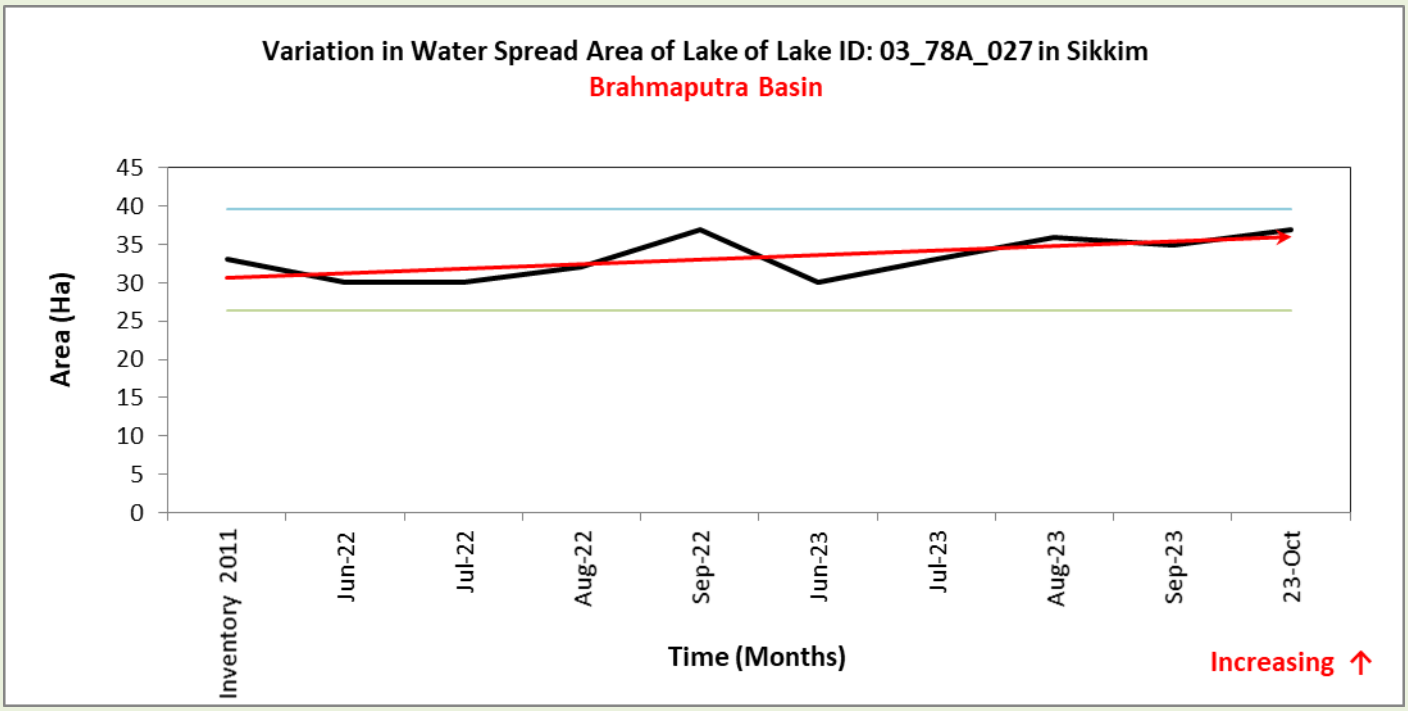


Figure 4.85(i) Trend Analysis Plot ±10%

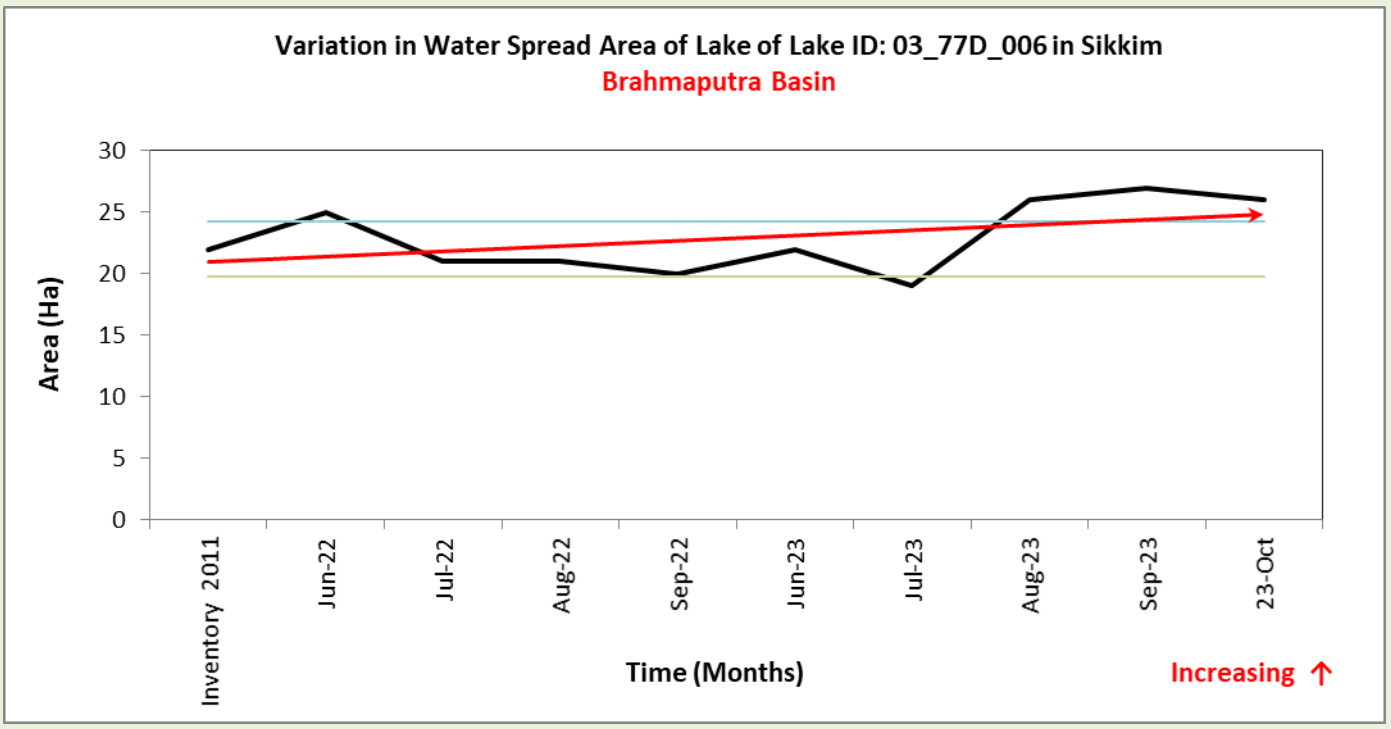


Figure 4.85(ii) Trend Analysis Plot ±10%

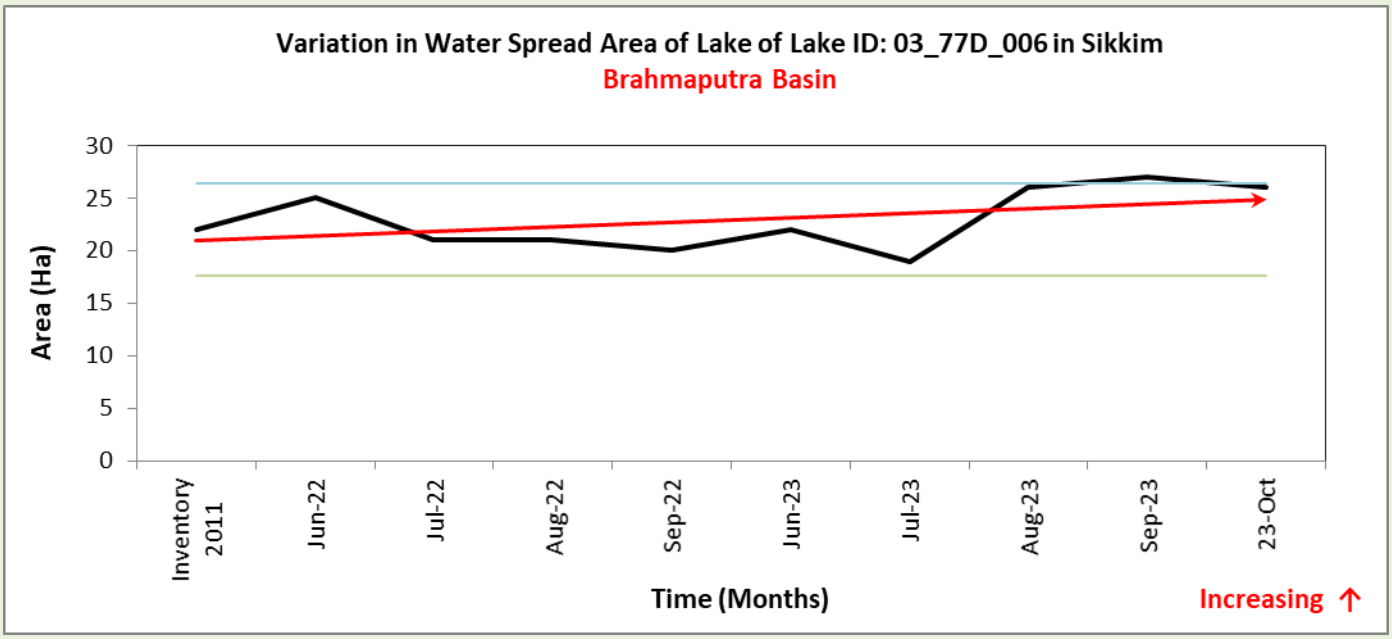


Figure 4.86(i) Trend Analysis Plot ±10%

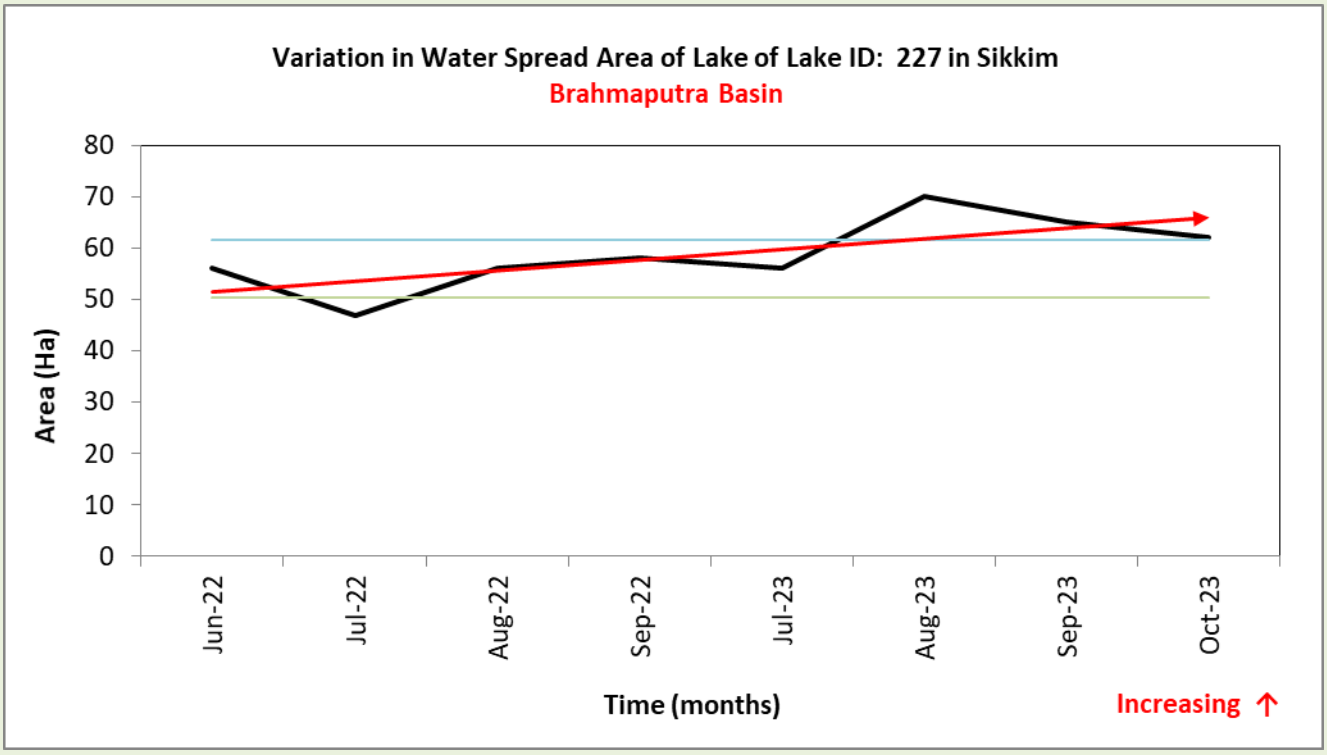


Figure 4.86(ii) Trend Analysis Plot ±20%

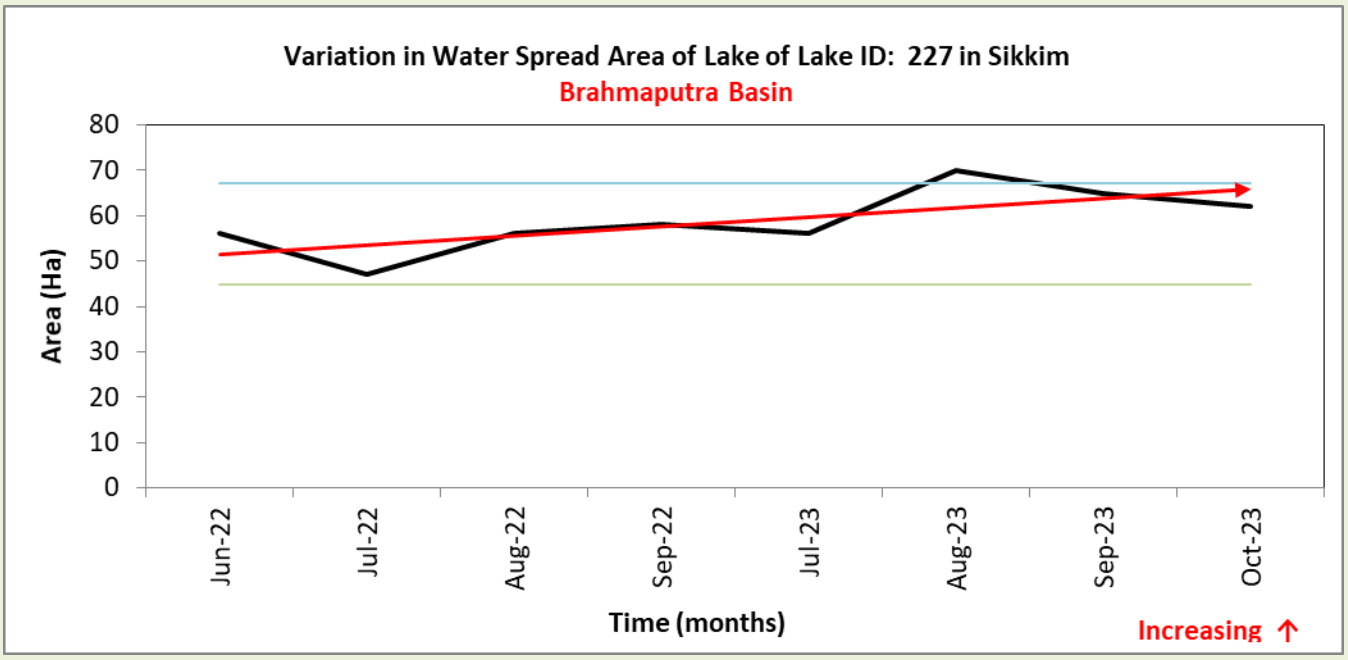


Figure 4.87(i) Trend Analysis Plot ±10%

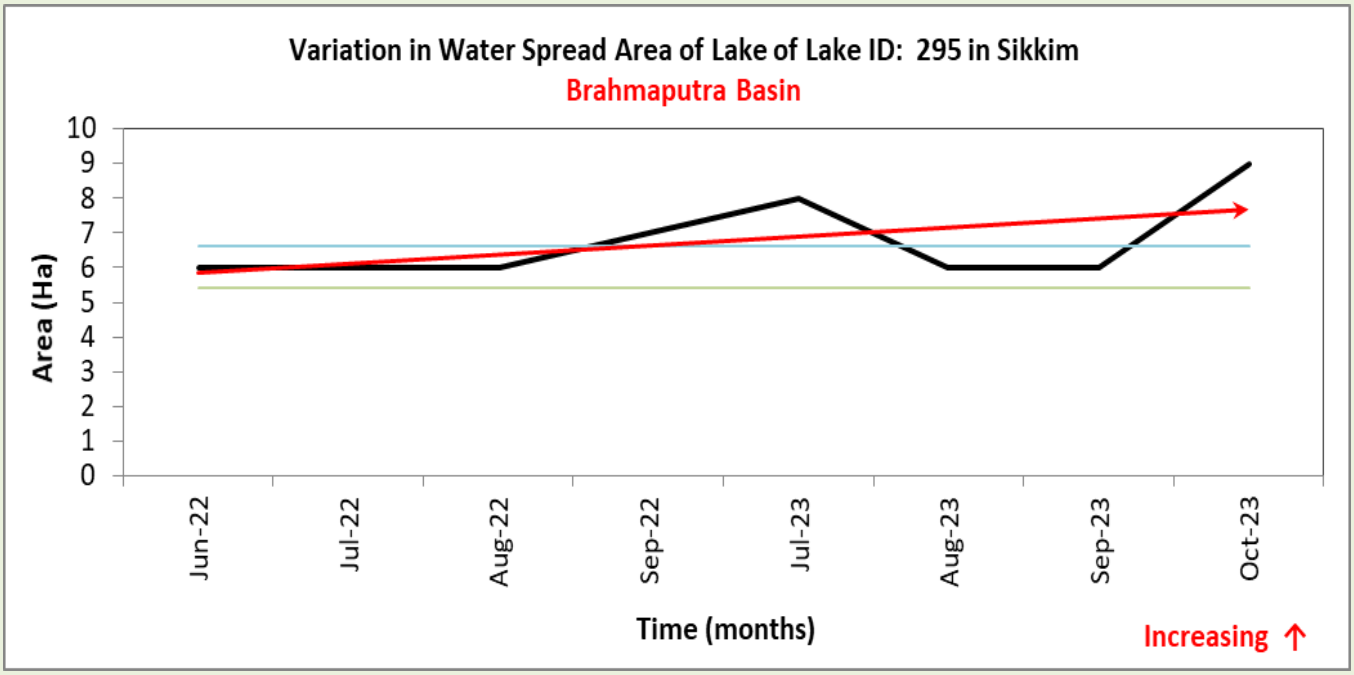


Figure 4.87(ii) Trend Analysis Plot ±10%

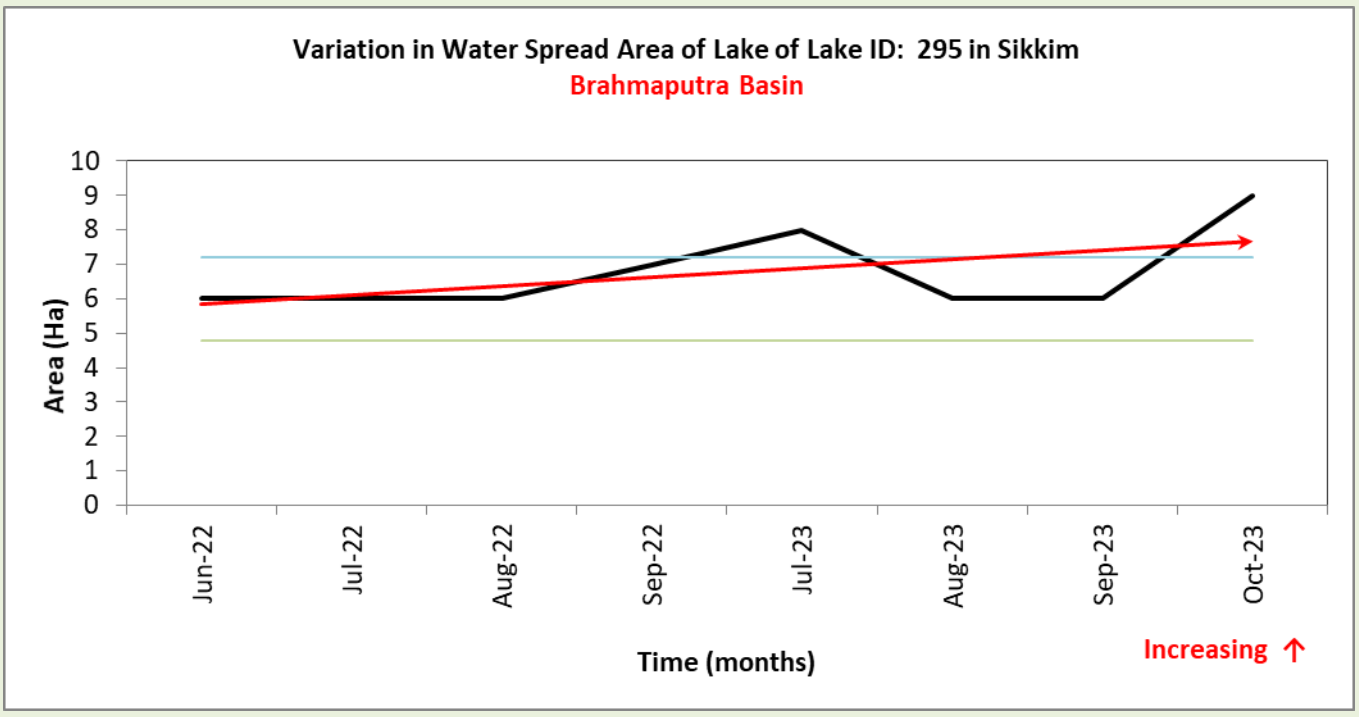


Figure 4.88(i) Trend Analysis Plot ±10%

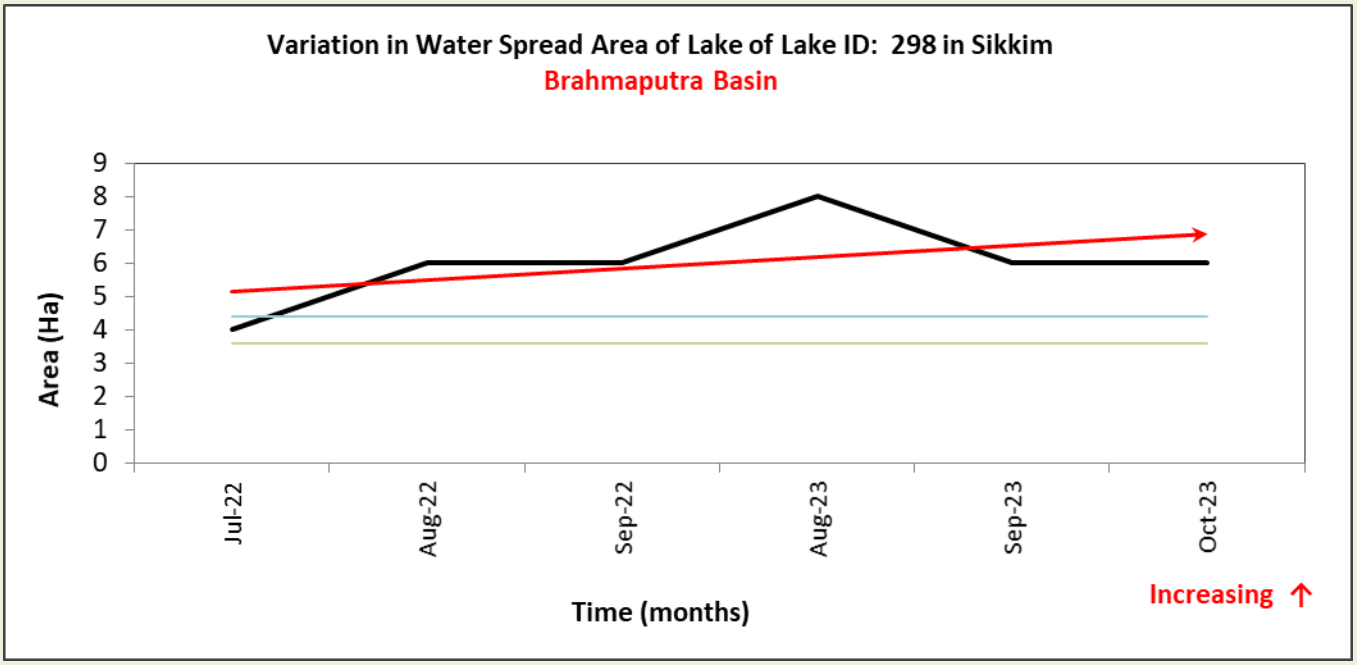


Figure 4.88(ii) Trend Analysis Plot ±20%

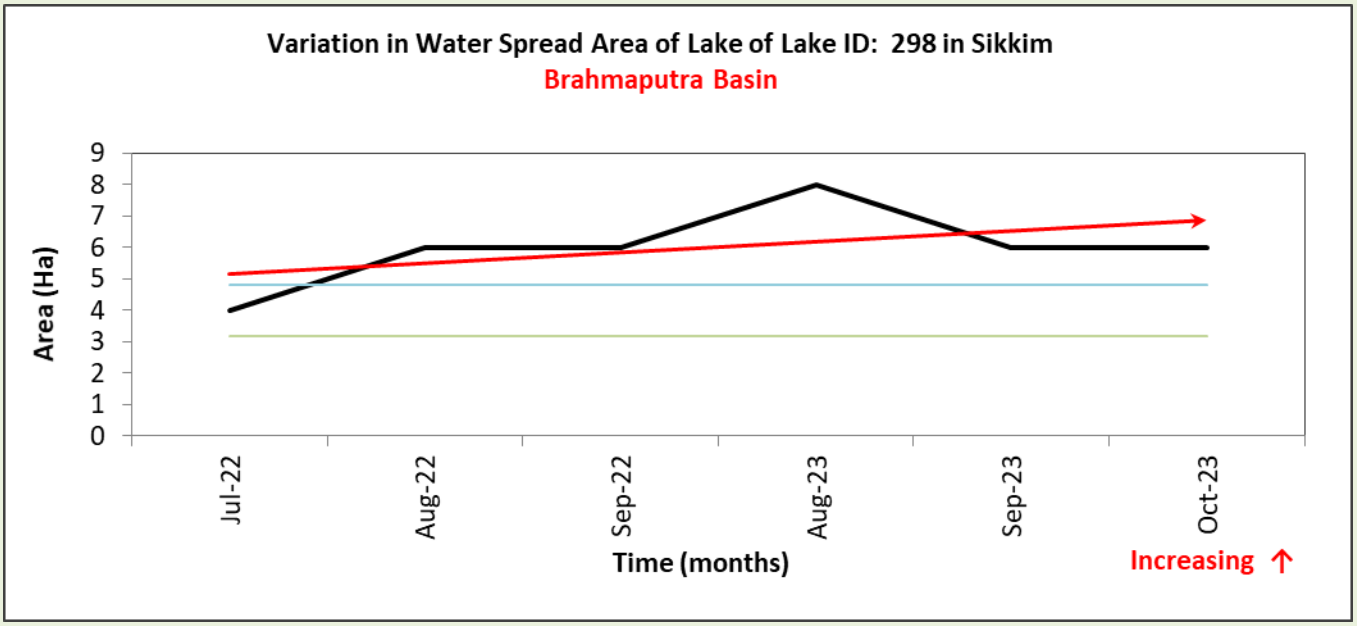


Figure 4.89(i) Trend Analysis Plot ±10%

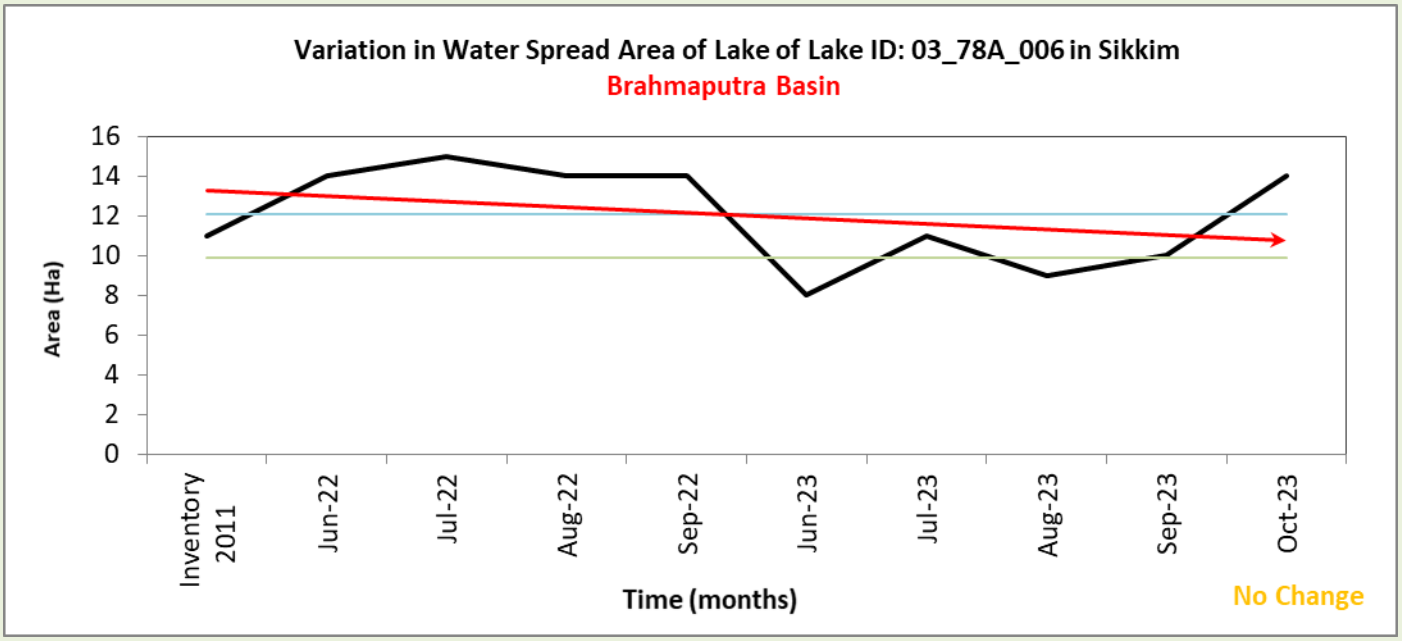


Figure 4.89(ii) Trend Analysis Plot ±20%

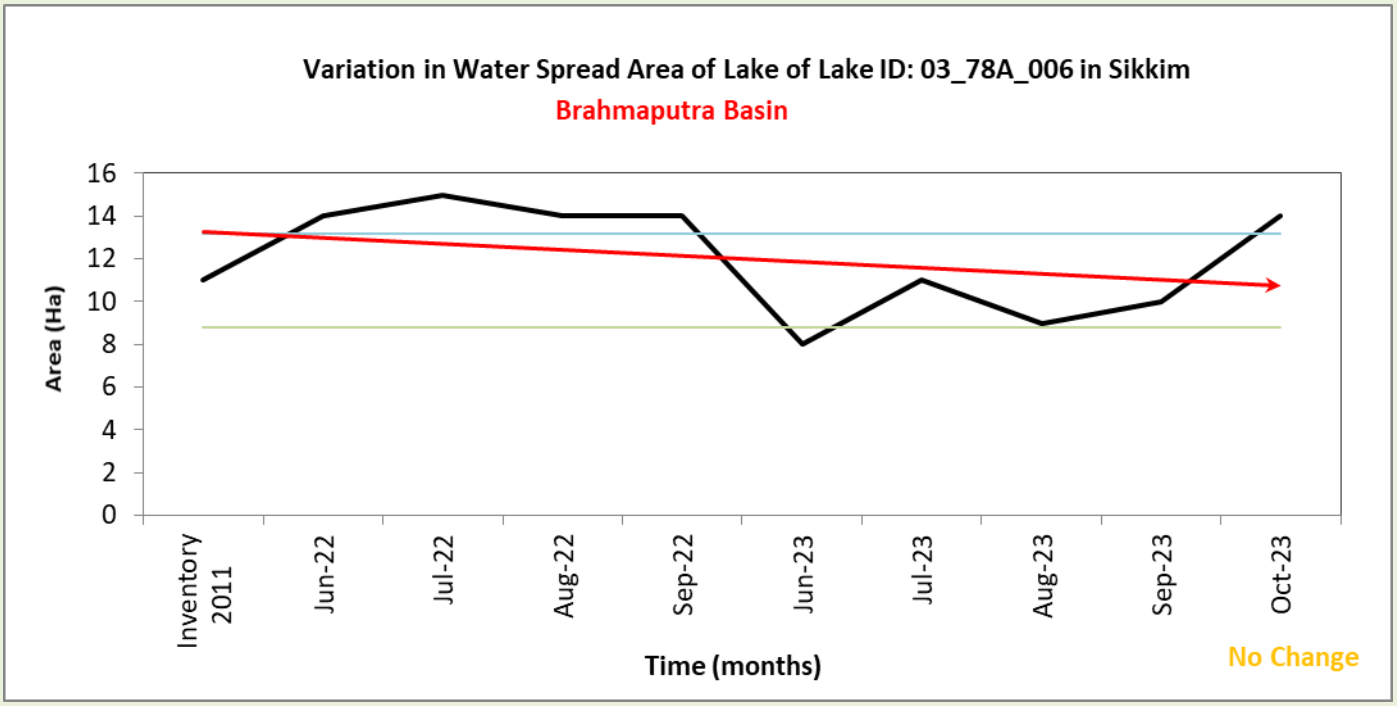


Figure 4.90(i) Trend Analysis Plot ±10%

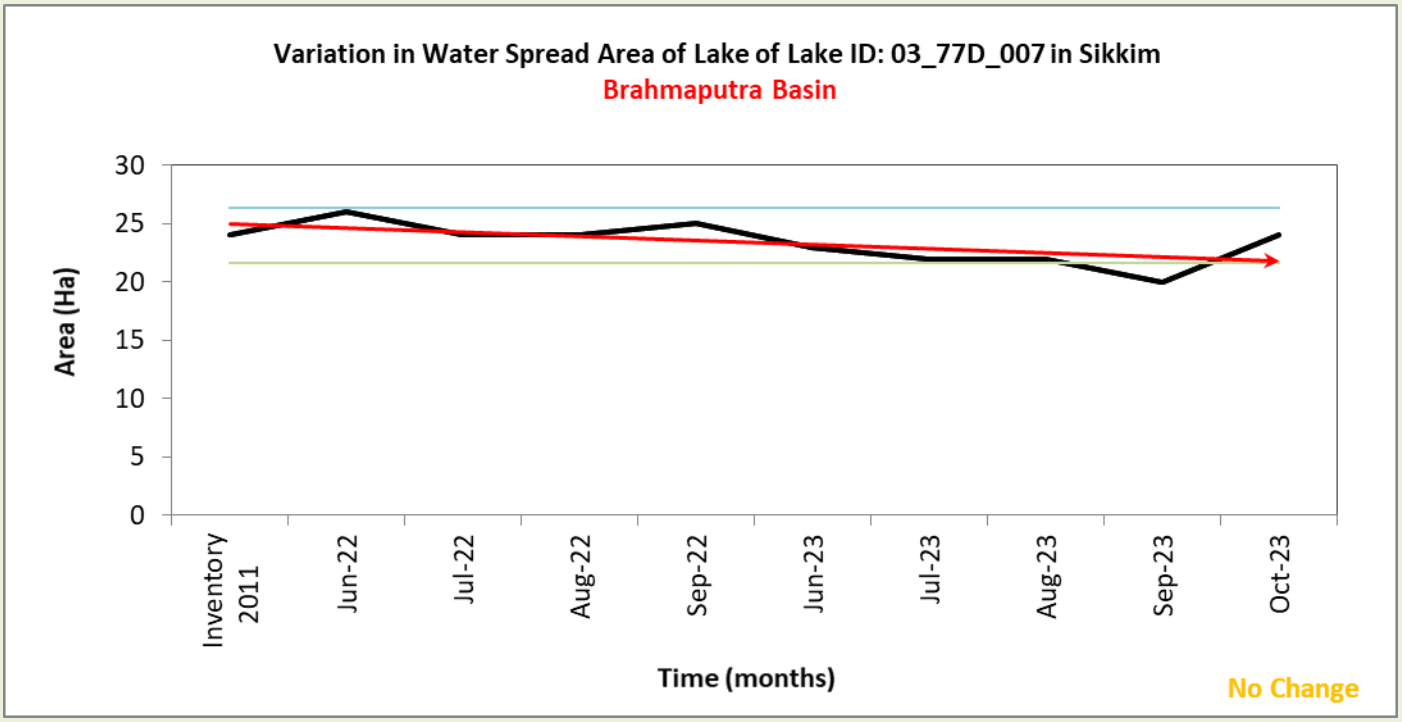


Figure 4.90(ii) Trend Analysis Plot ±20%

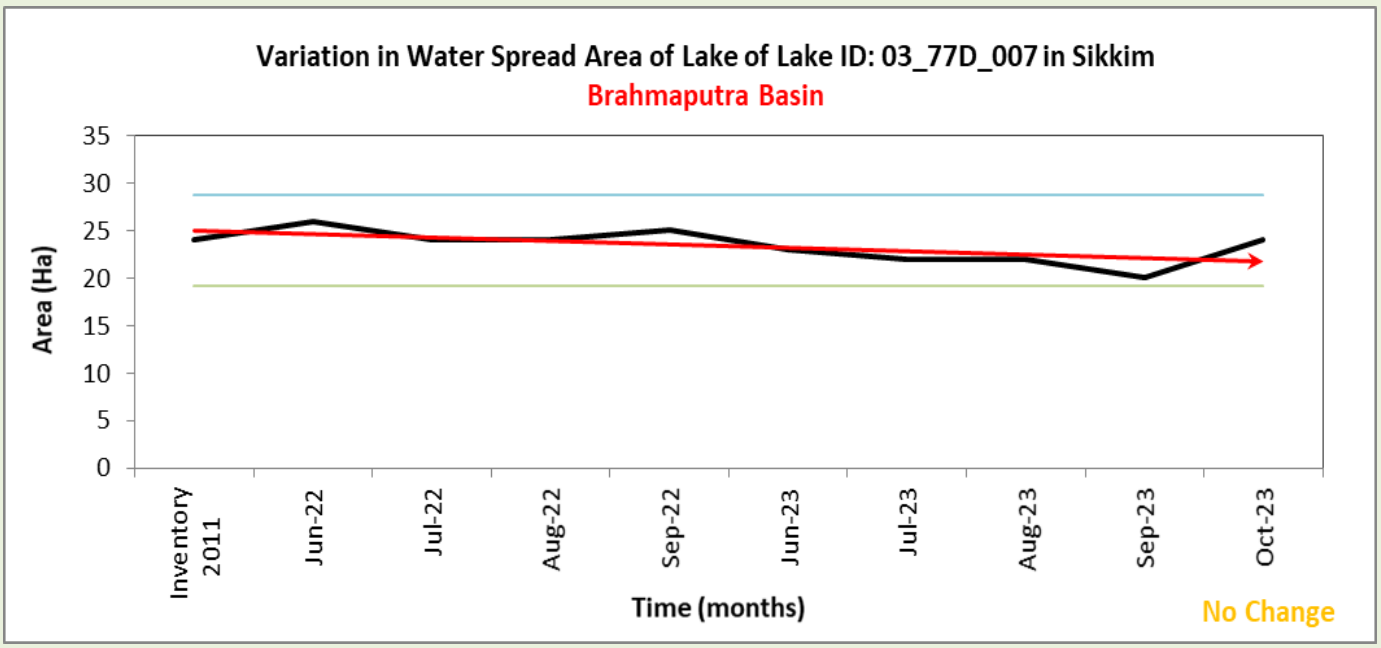


Figure 4.91(i) Trend Analysis Plot ±10%

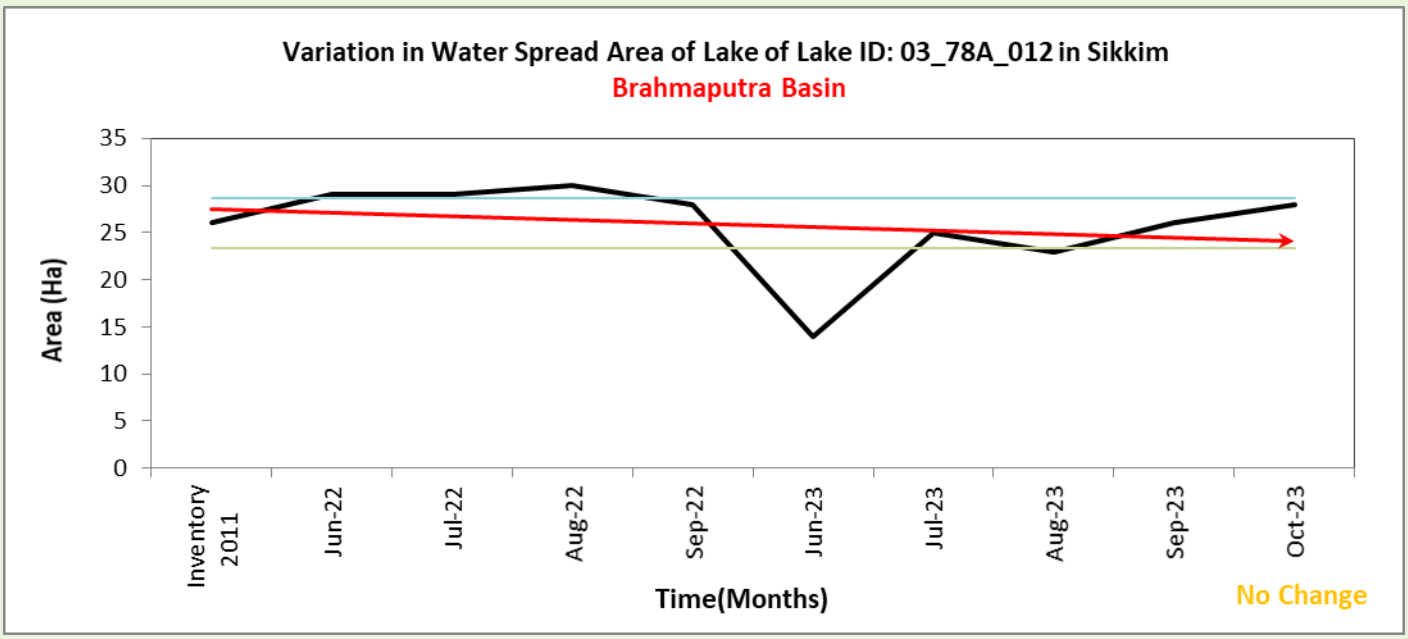


Figure 4.91(ii) Trend Analysis Plot ±10%

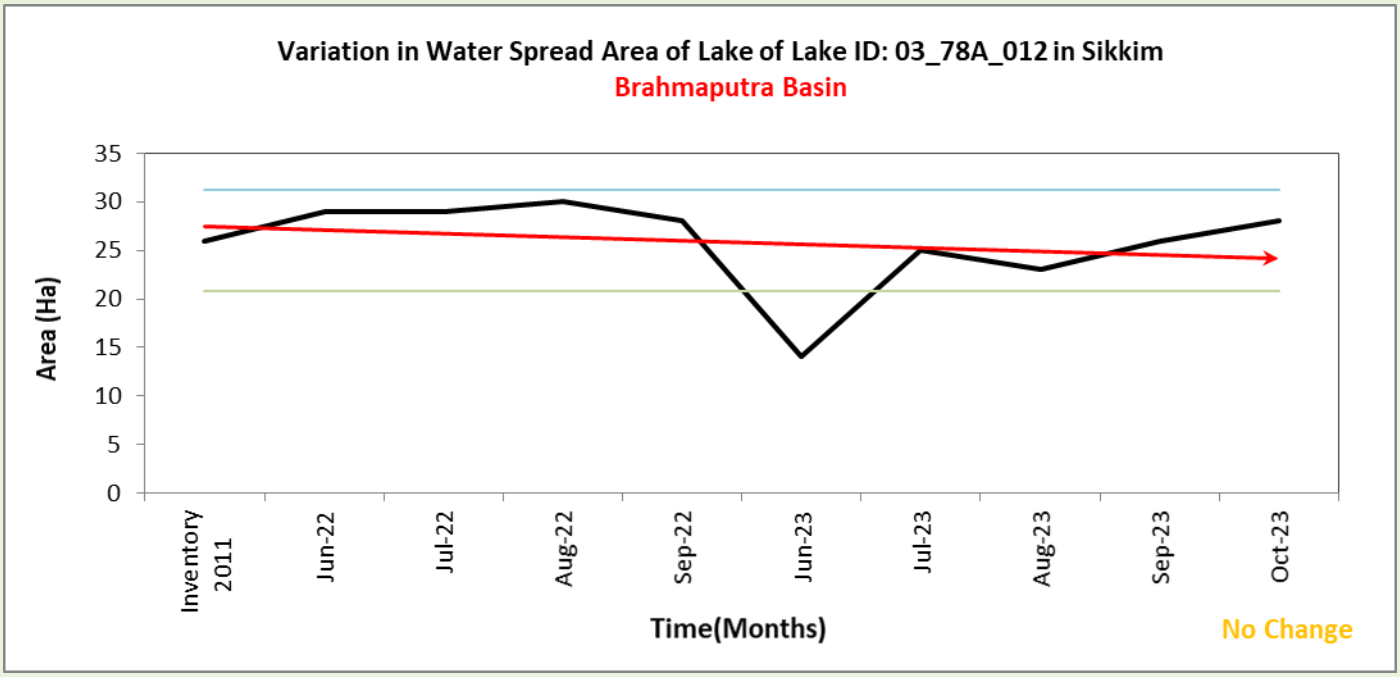


Figure 4.92(i) Trend Analysis Plot ±10%

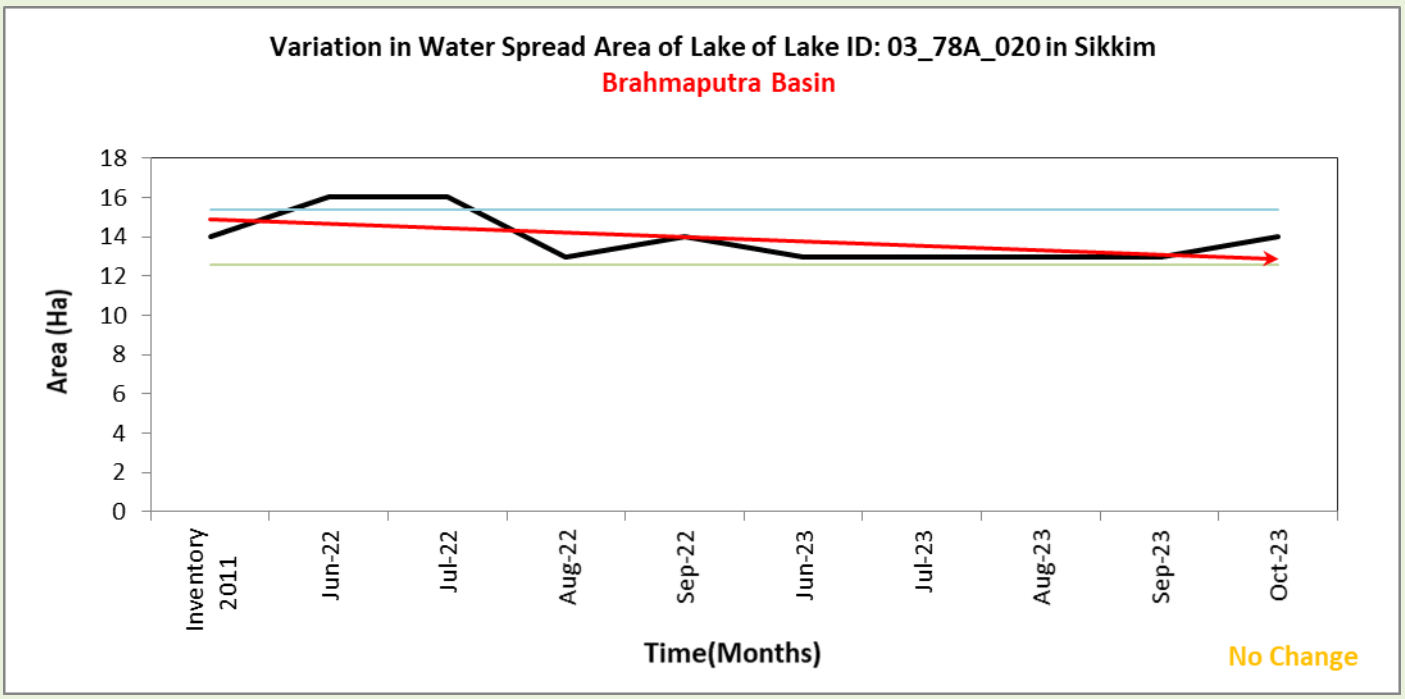


Figure 4.92(ii) Trend Analysis Plot ±20%

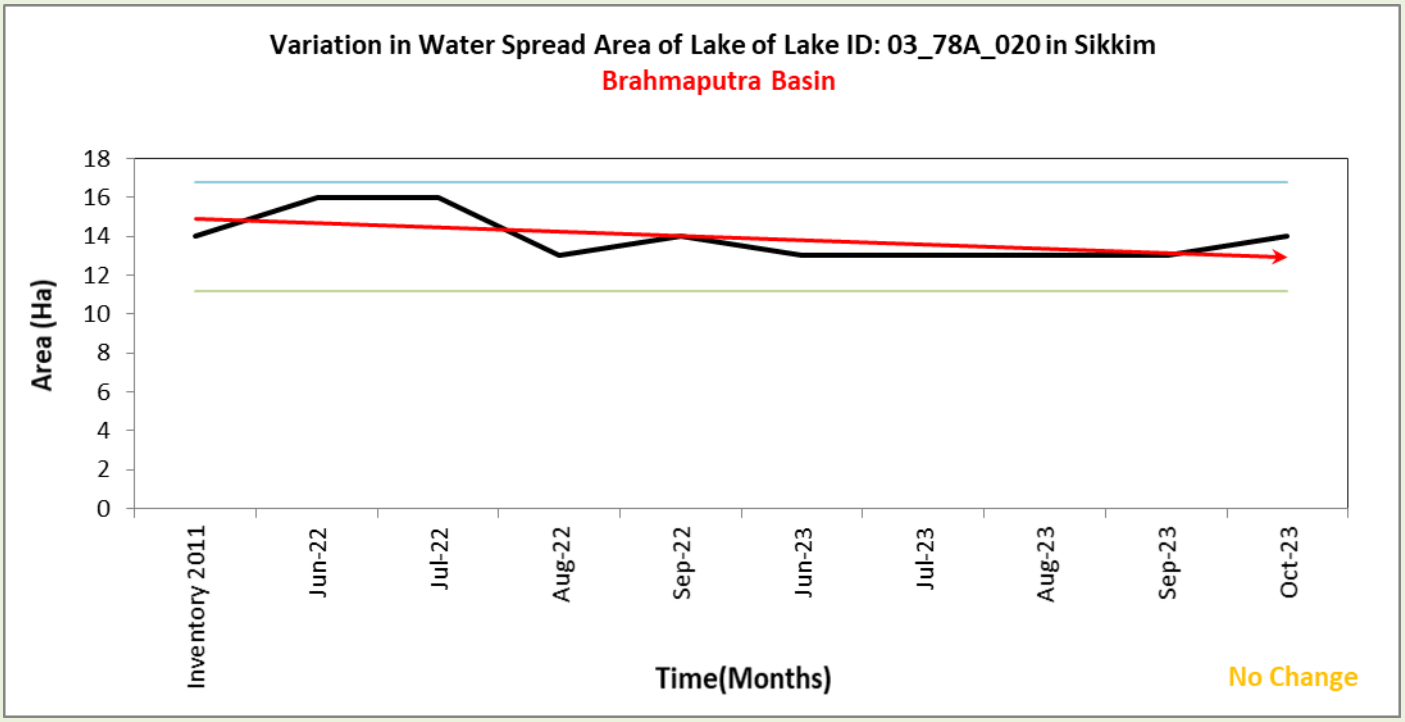


Figure 4.93(i) Trend Analysis Plot ±10%

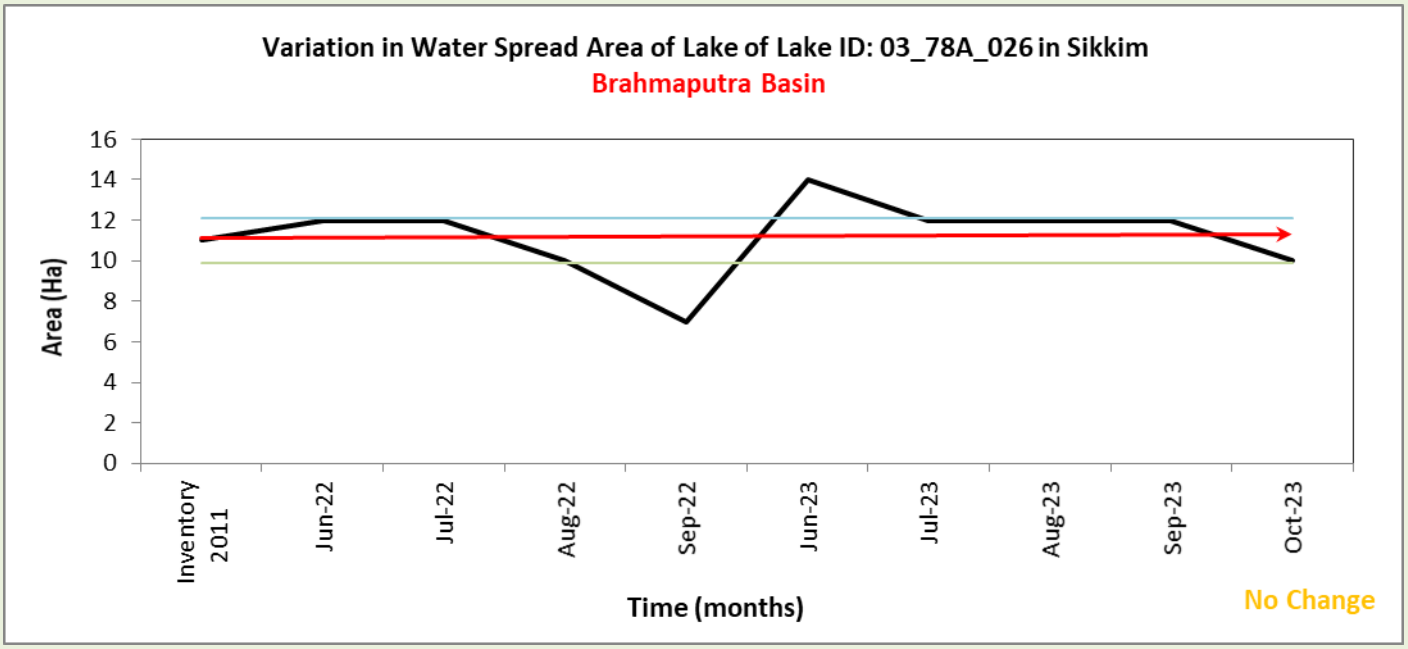


Figure 4.93(ii) Trend Analysis Plot ±20%

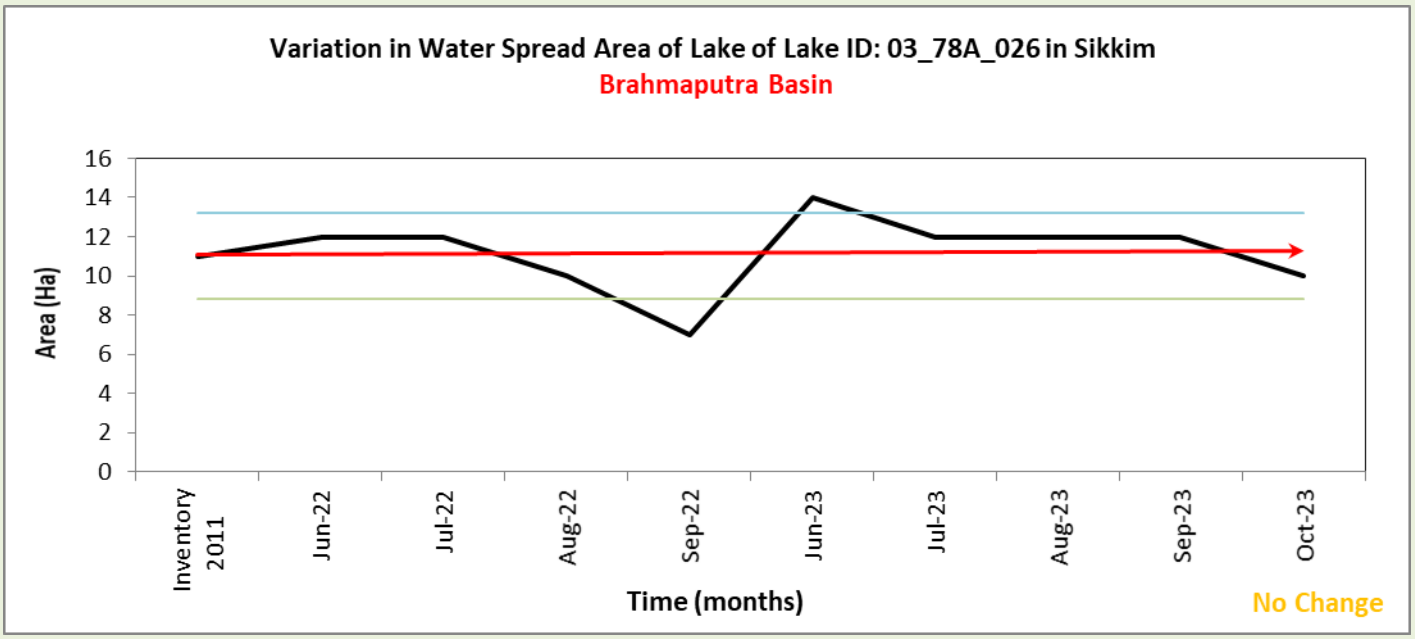


Figure 4.94(i) Trend Analysis Plot ±10%

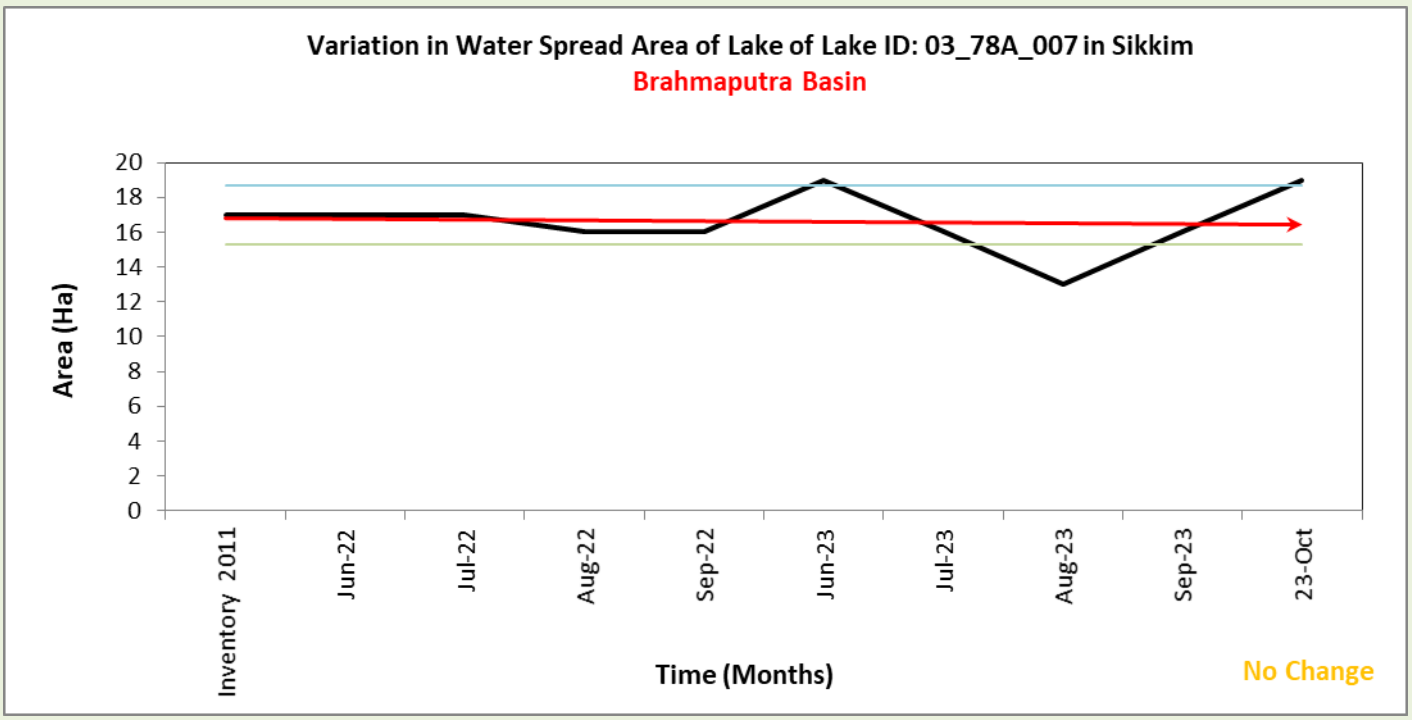


Figure 4.94(ii) Trend Analysis Plot ±20%

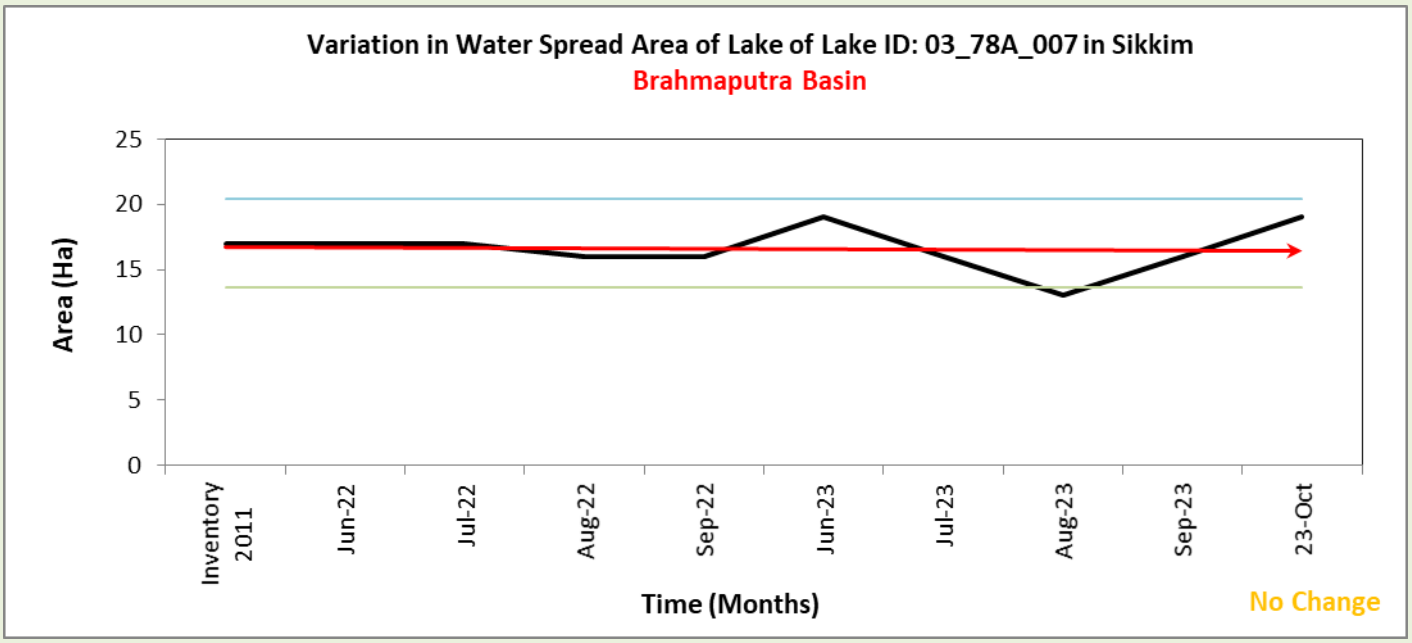


Figure 4.95(i) Trend Analysis Plot ±10%

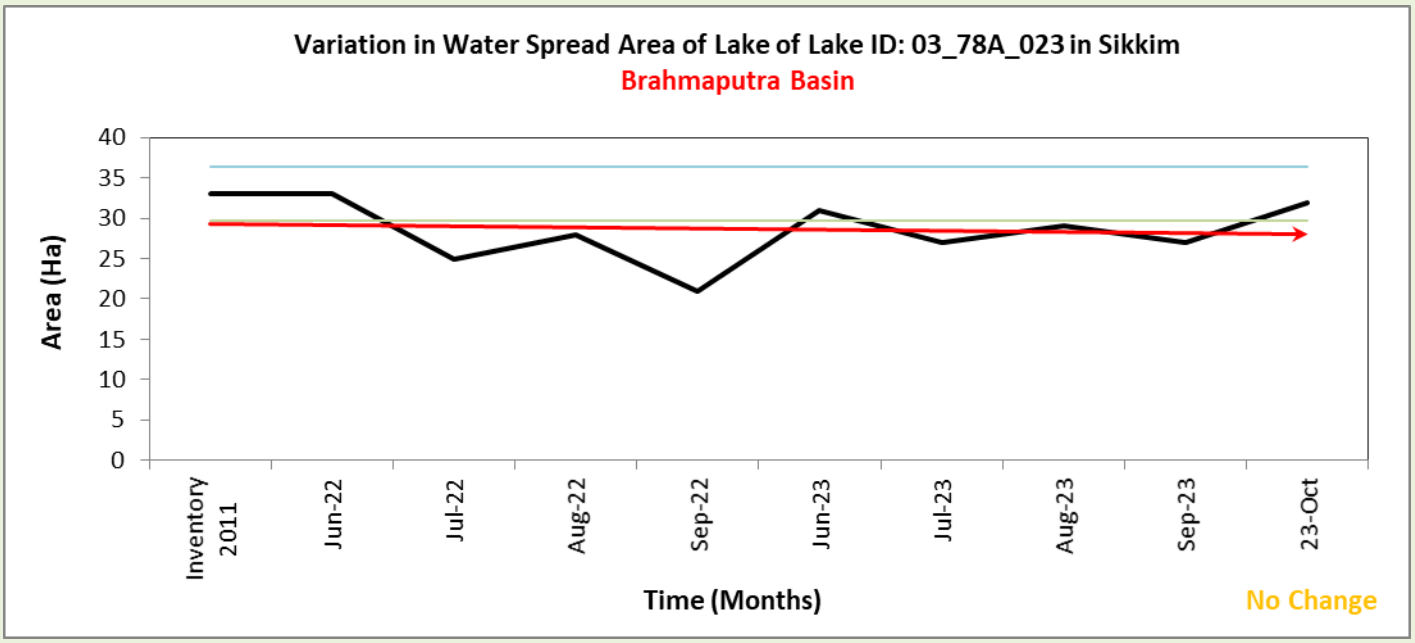


Figure 4.95(ii) Trend Analysis Plot ±20%

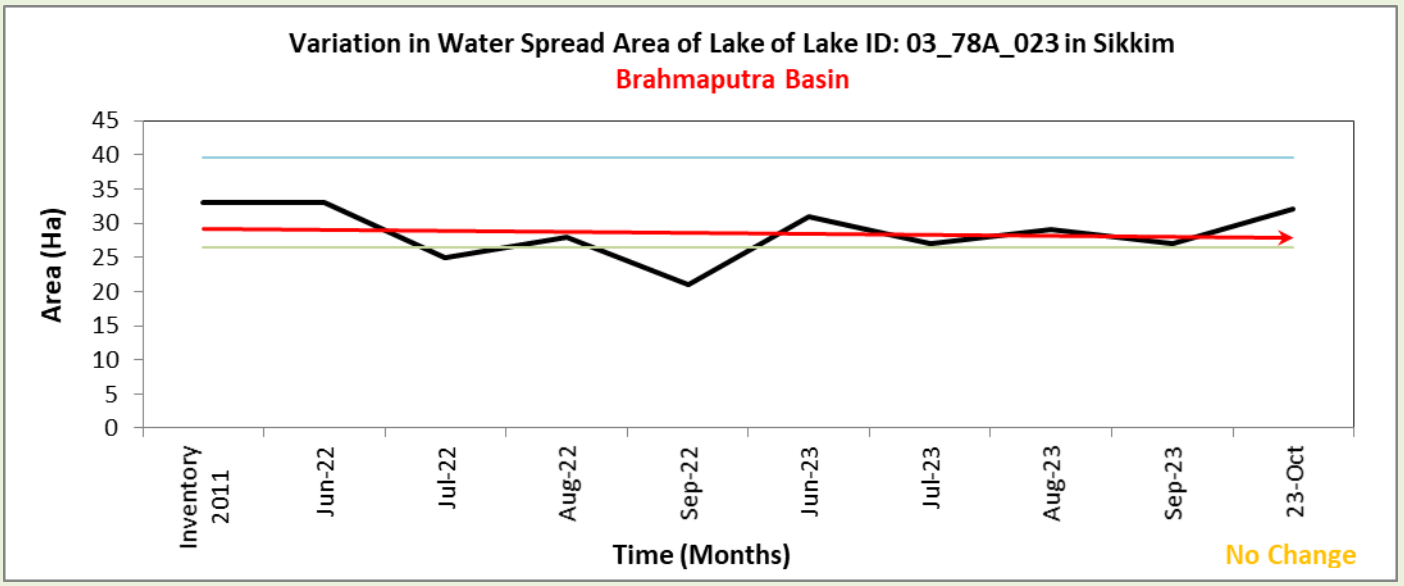


Figure 4.96(i) Trend Analysis Plot ±10%

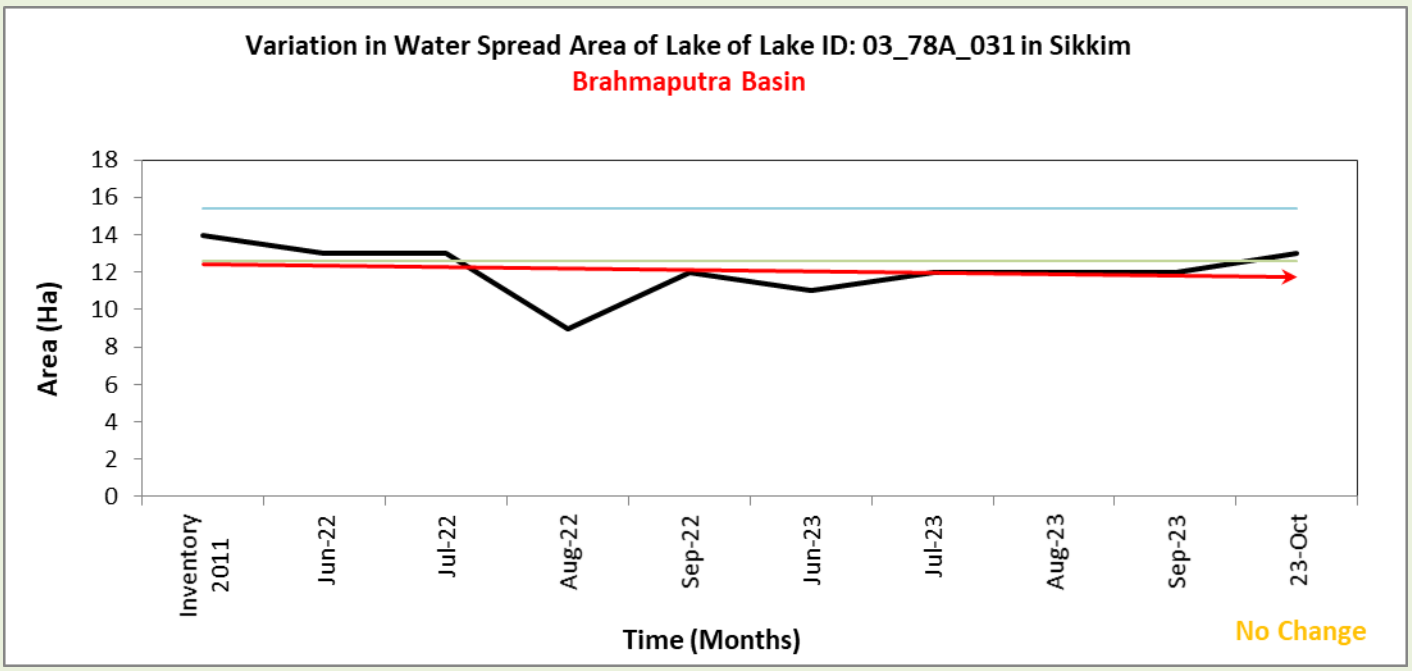


Figure 4.96(ii) Trend Analysis Plot ±20%

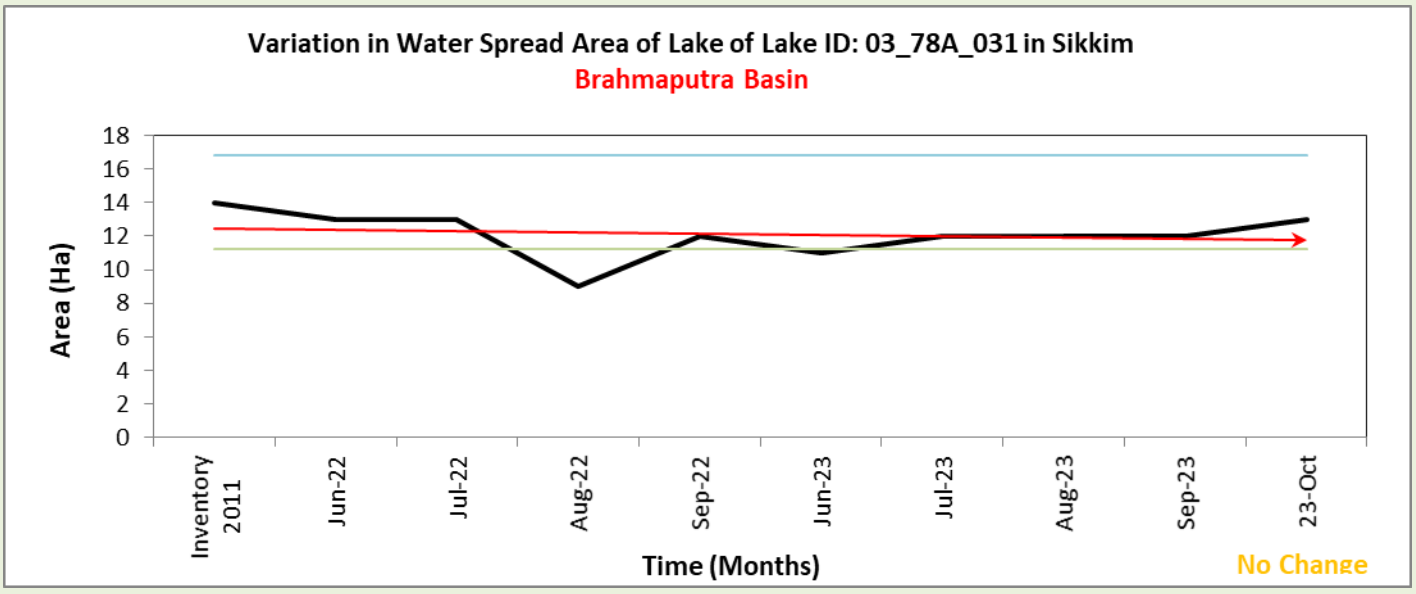


Figure 4.97(i) Trend Analysis Plot ±10%

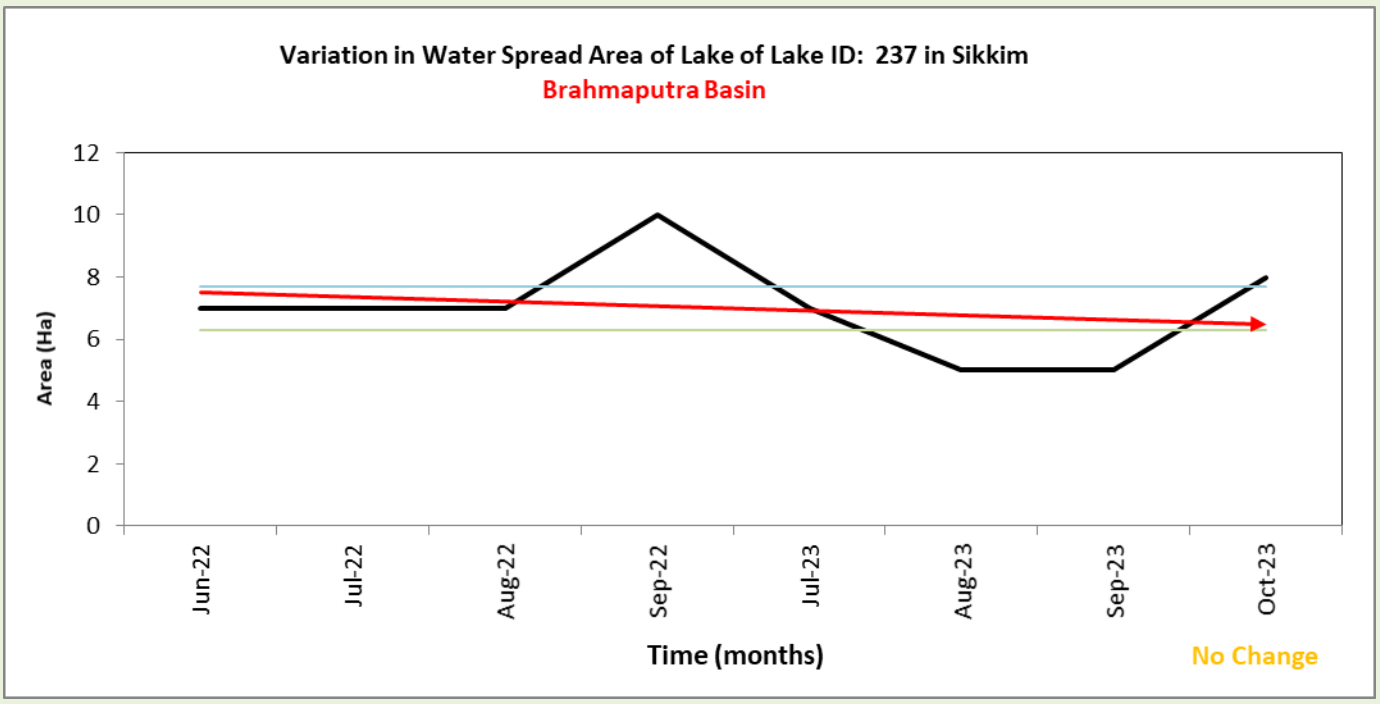


Figure 4.97(ii) Trend Analysis Plot ±20%

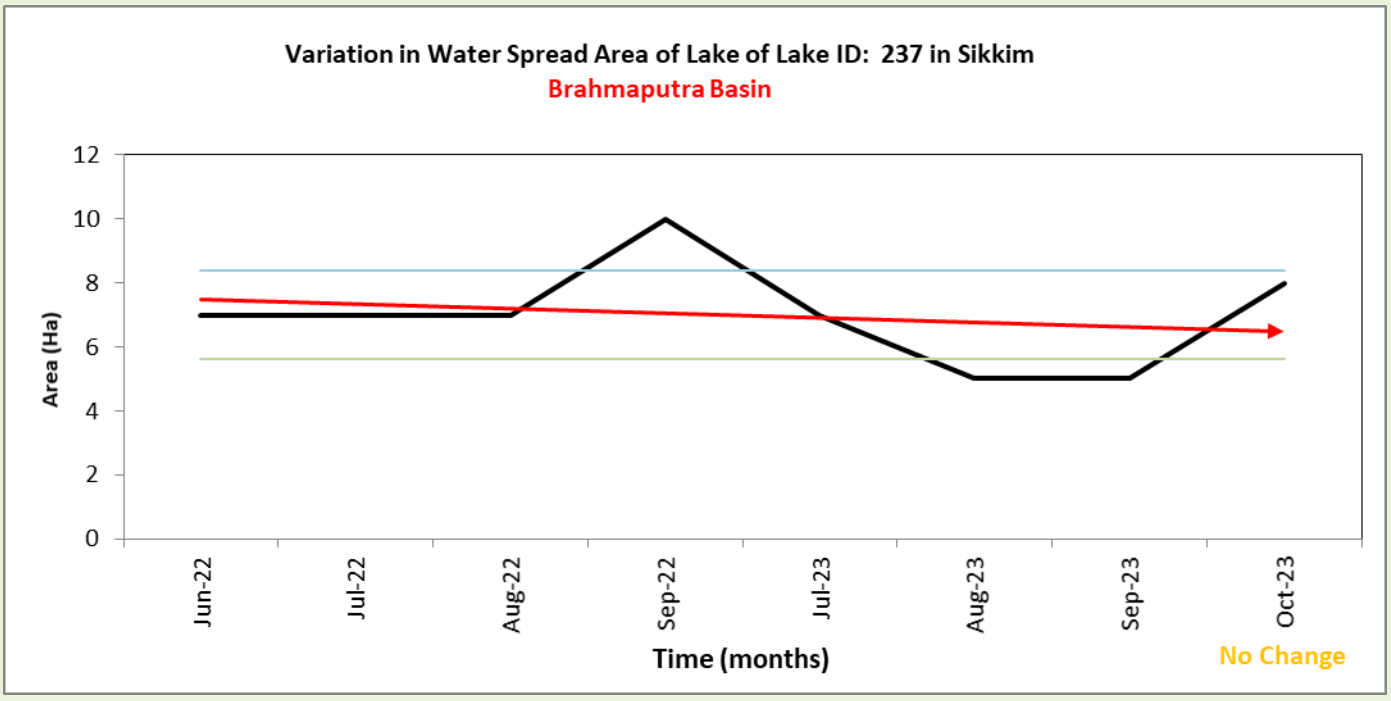


Figure 4.98(i) Trend Analysis Plot ±10%

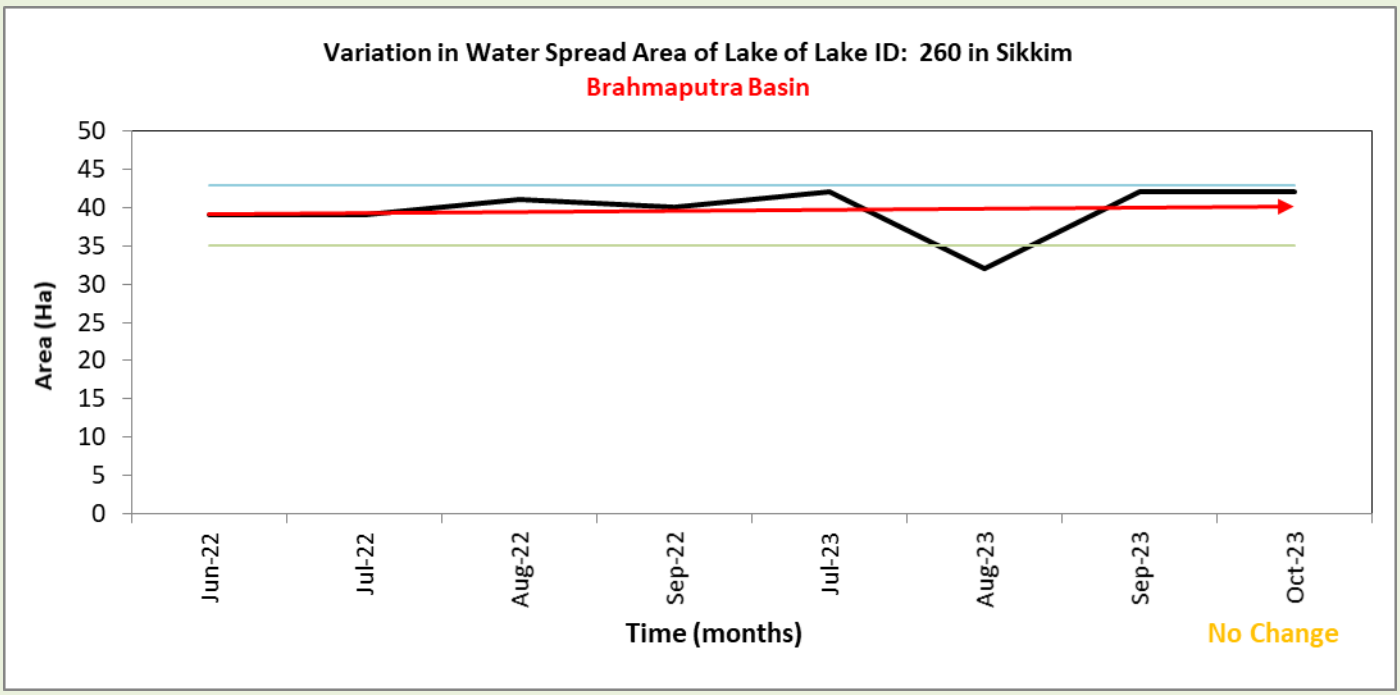


Figure 4.98(ii) Trend Analysis Plot 20%

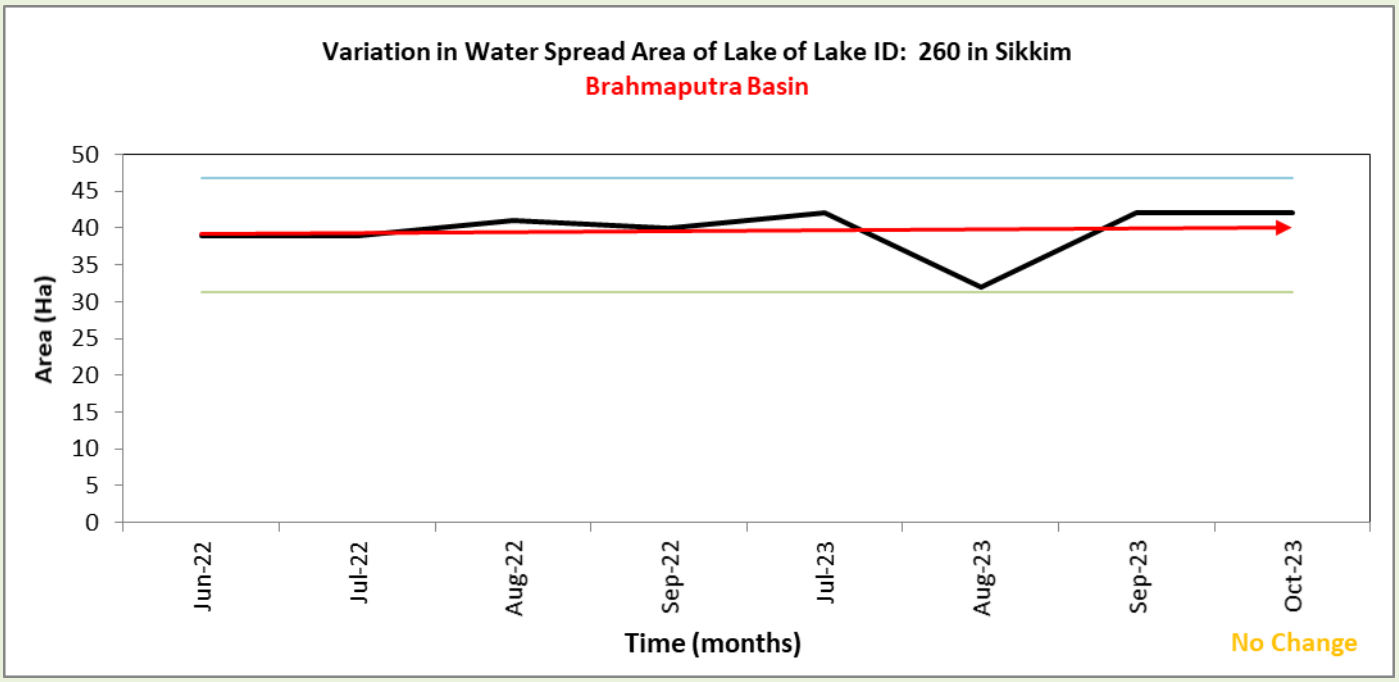


Figure 4.99(i) Trend Analysis Plot ±10%

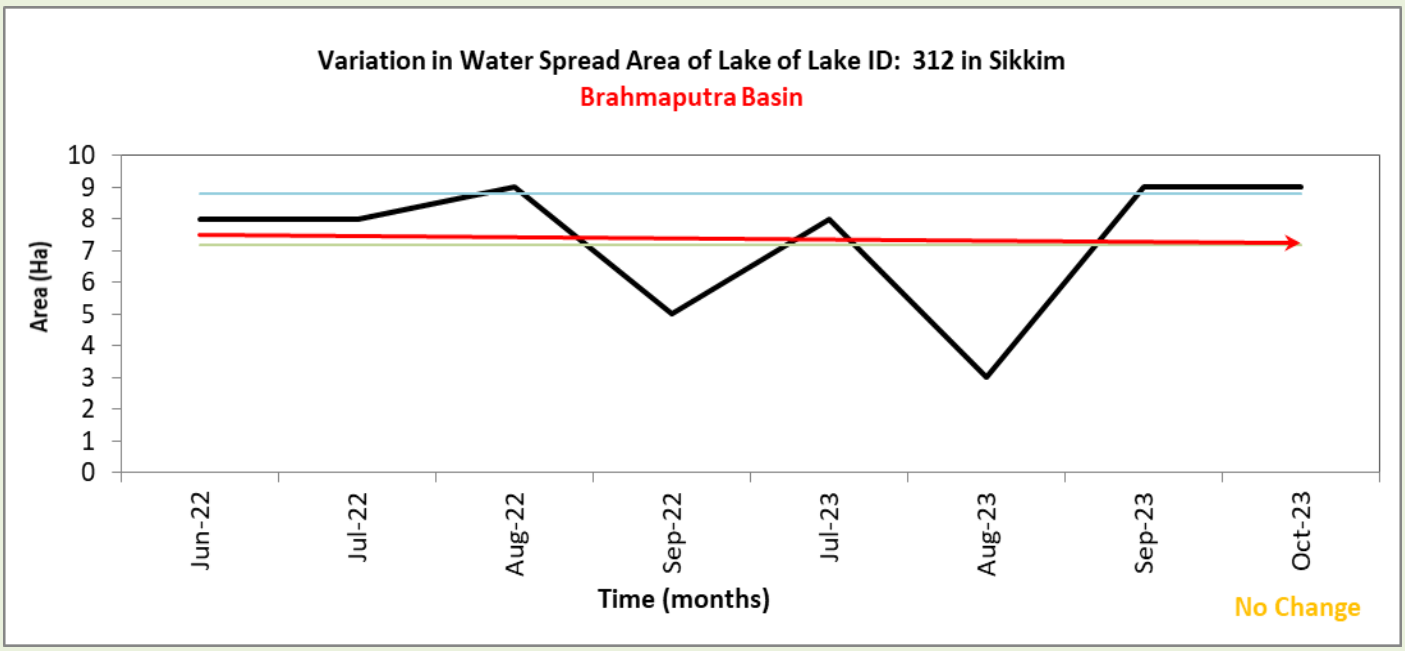


Figure 4.99(ii) Trend Analysis Plot ±20%

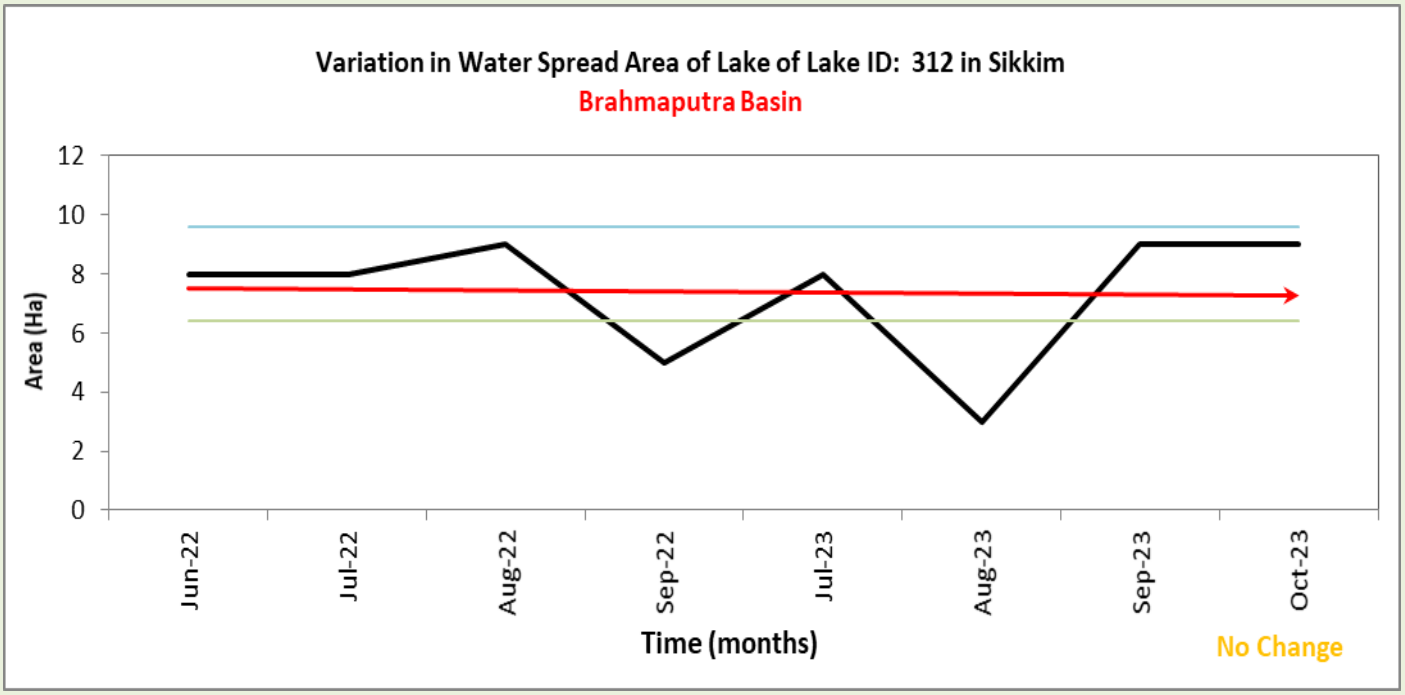


Figure 4.100(i) Trend Analysis Plot ±10%

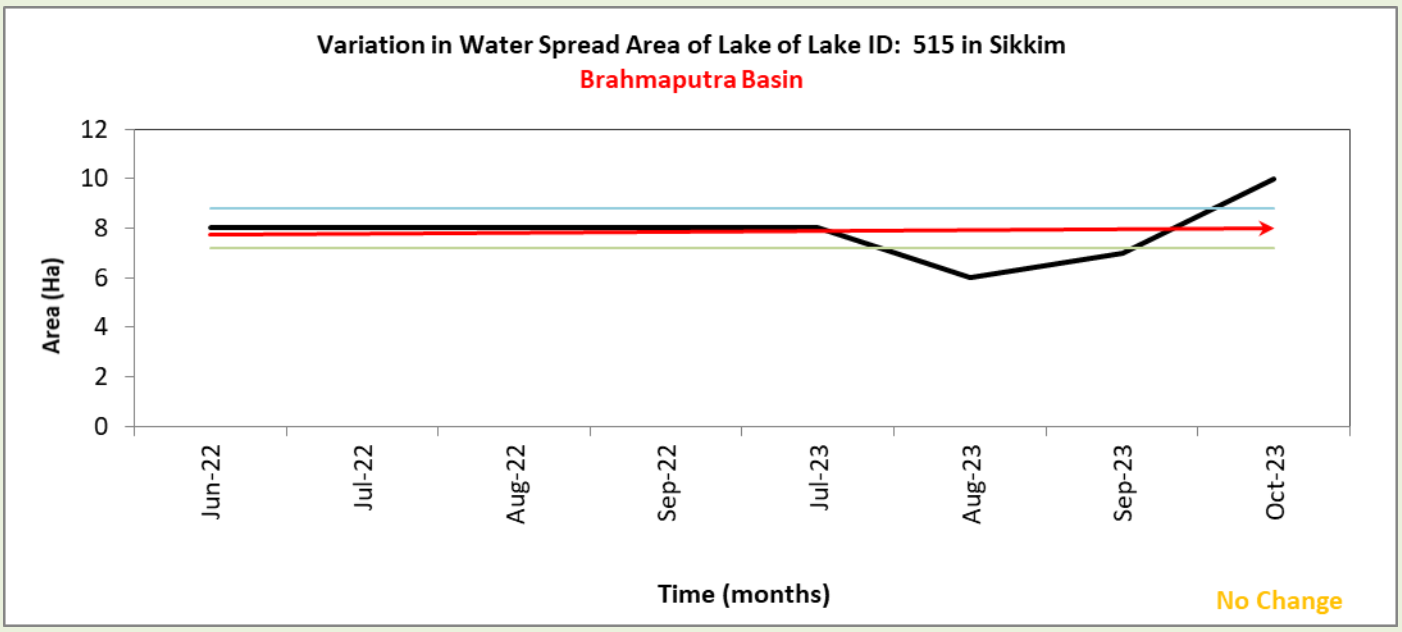


Figure 4.100(ii) Trend Analysis Plot ±20%

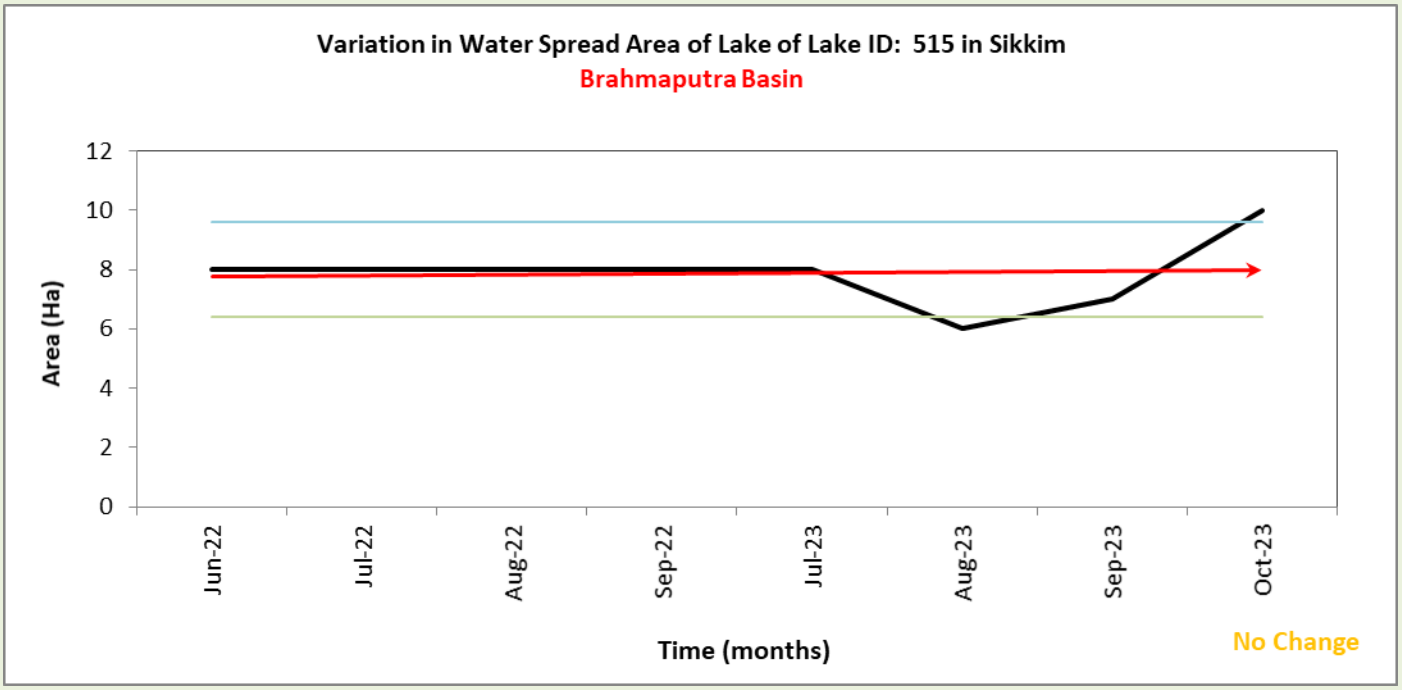


Figure 4.101(i) Trend Analysis Plot ±10%

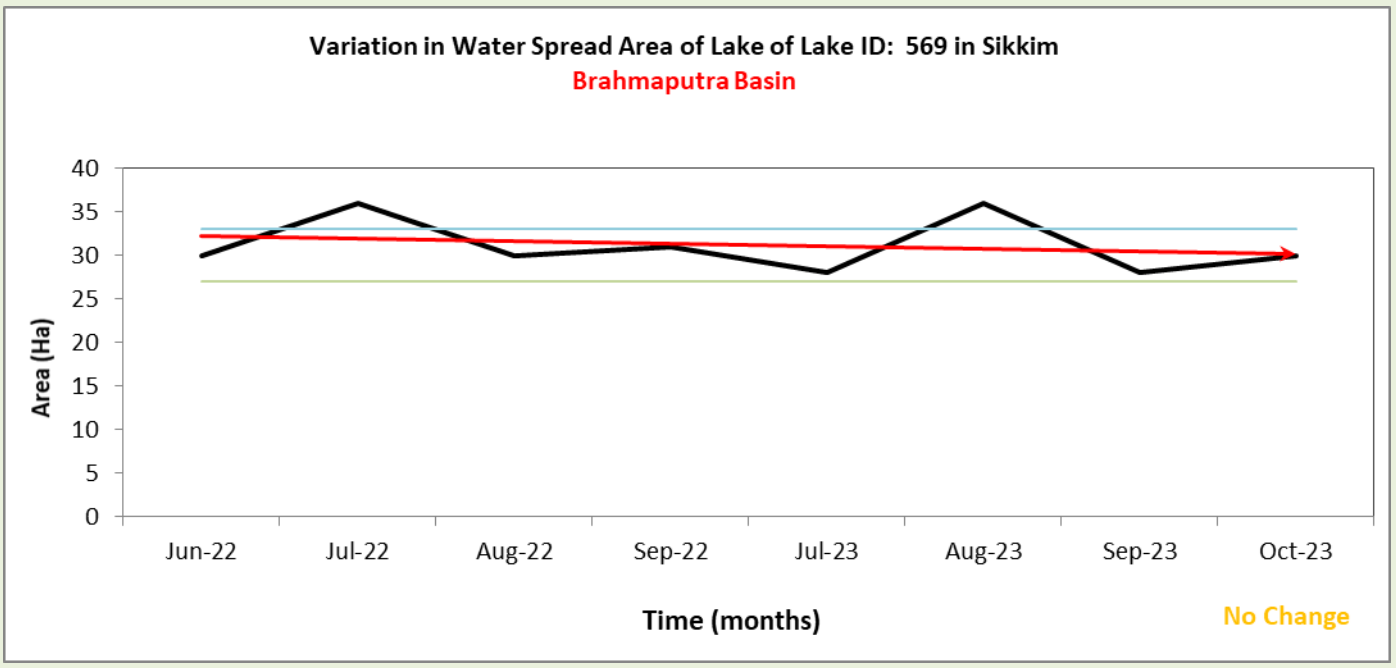


Figure 4.101(ii) Trend Analysis Plot 20%

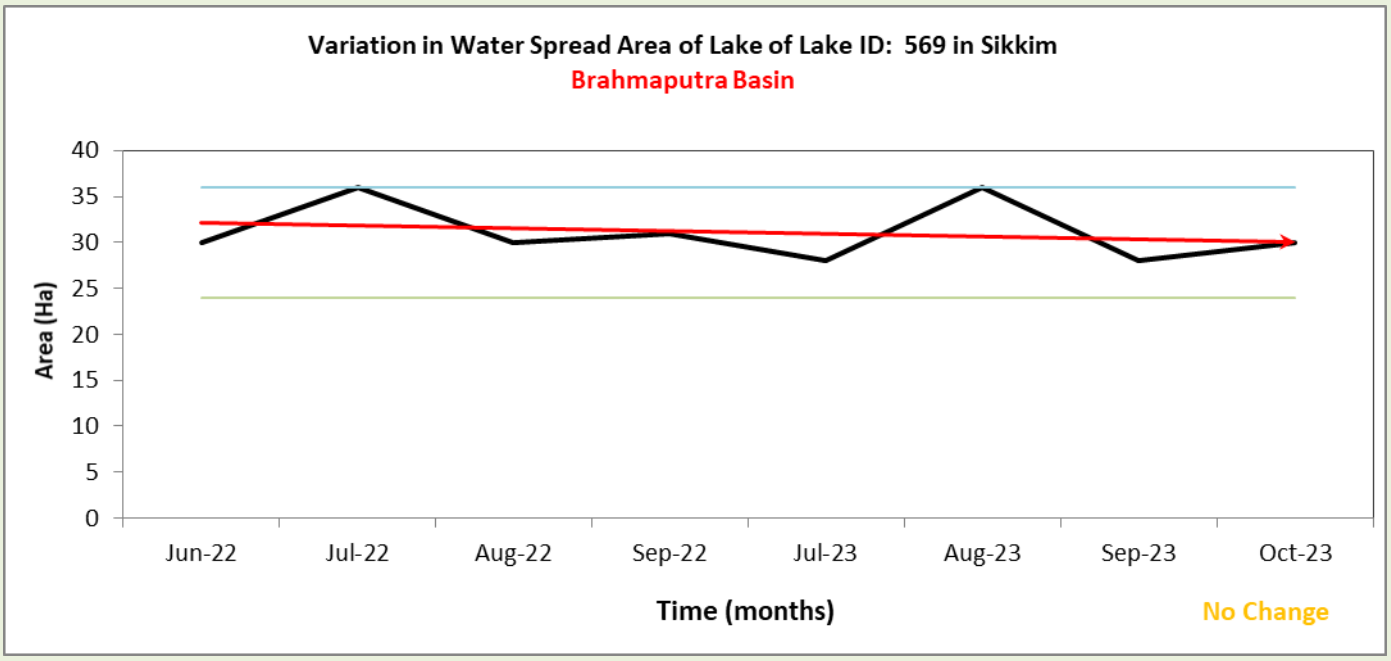


Figure 4.102(i) Trend Analysis Plot ±10%

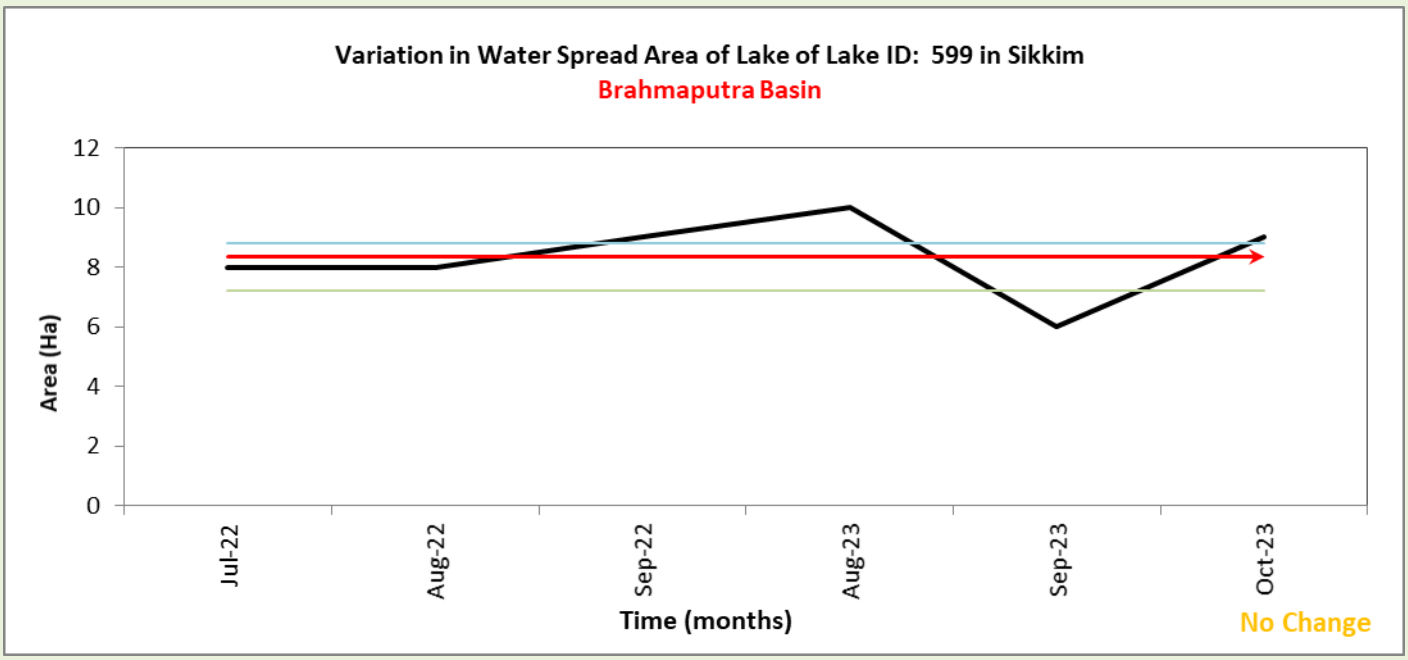


Figure 4.102(ii) Trend Analysis Plot ±20%

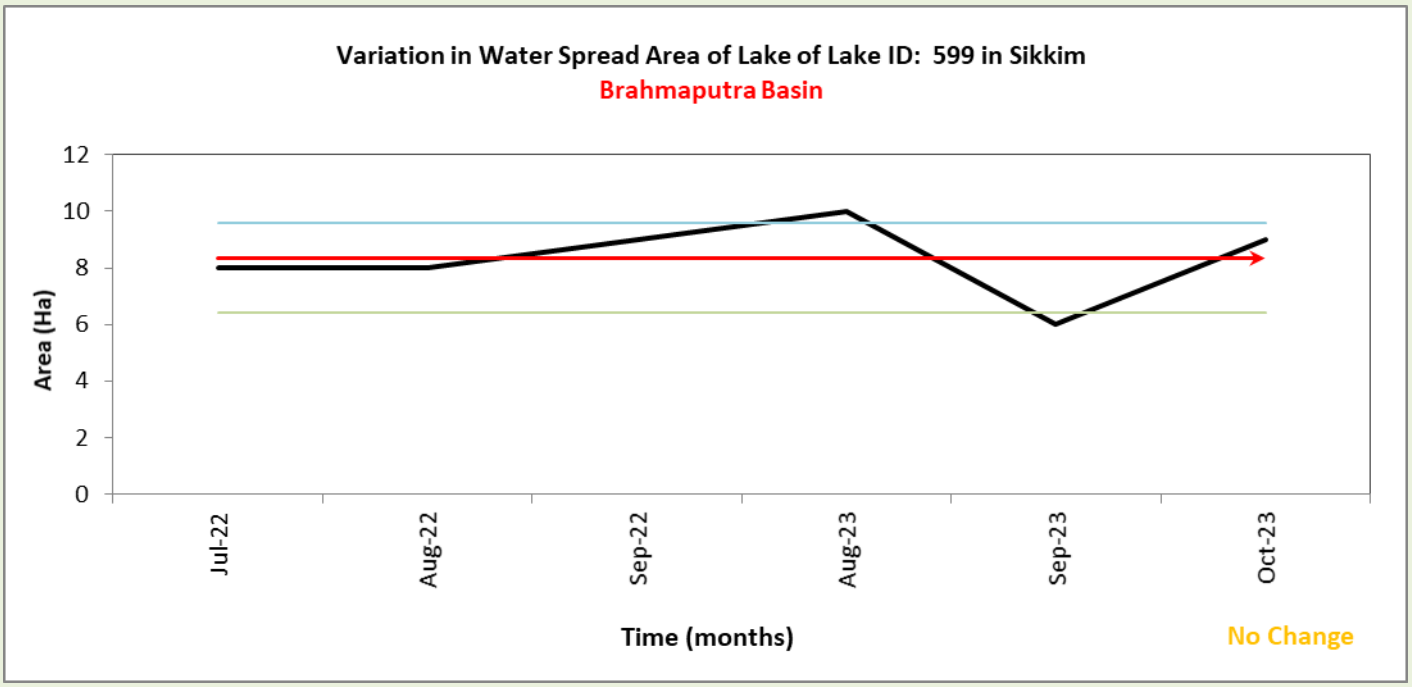


Figure 4.103(i) Trend Analysis Plot ±10%

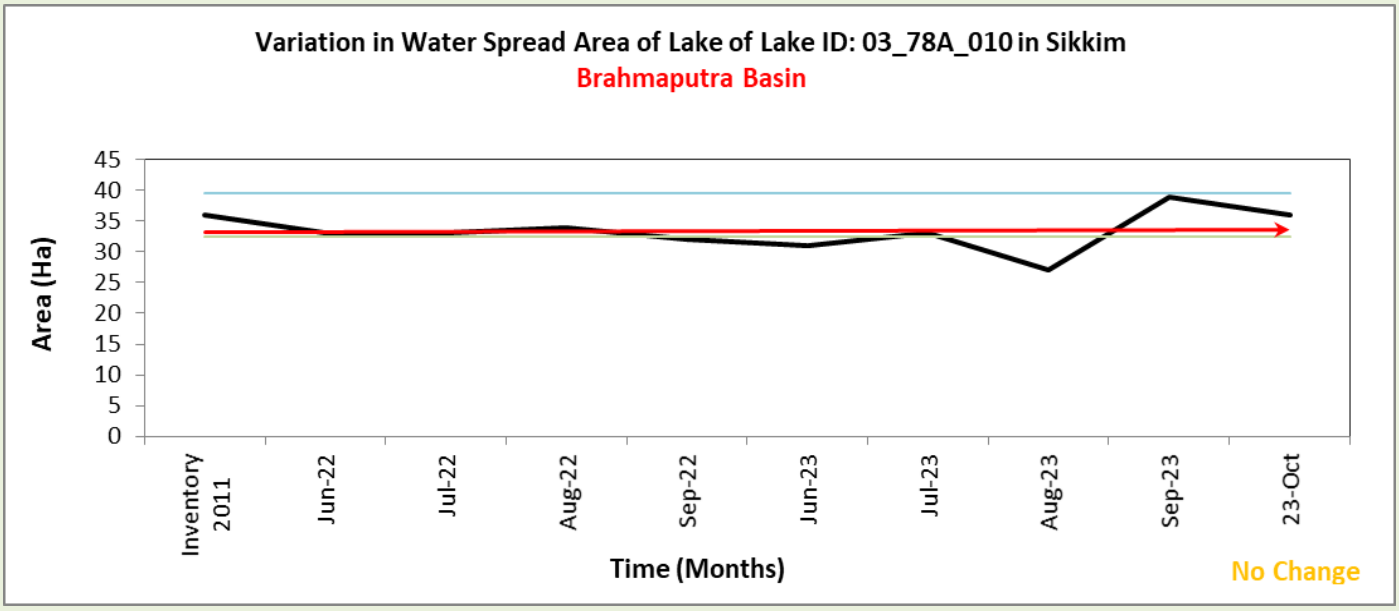


Figure 4.103(ii) Trend Analysis Plot ±20%

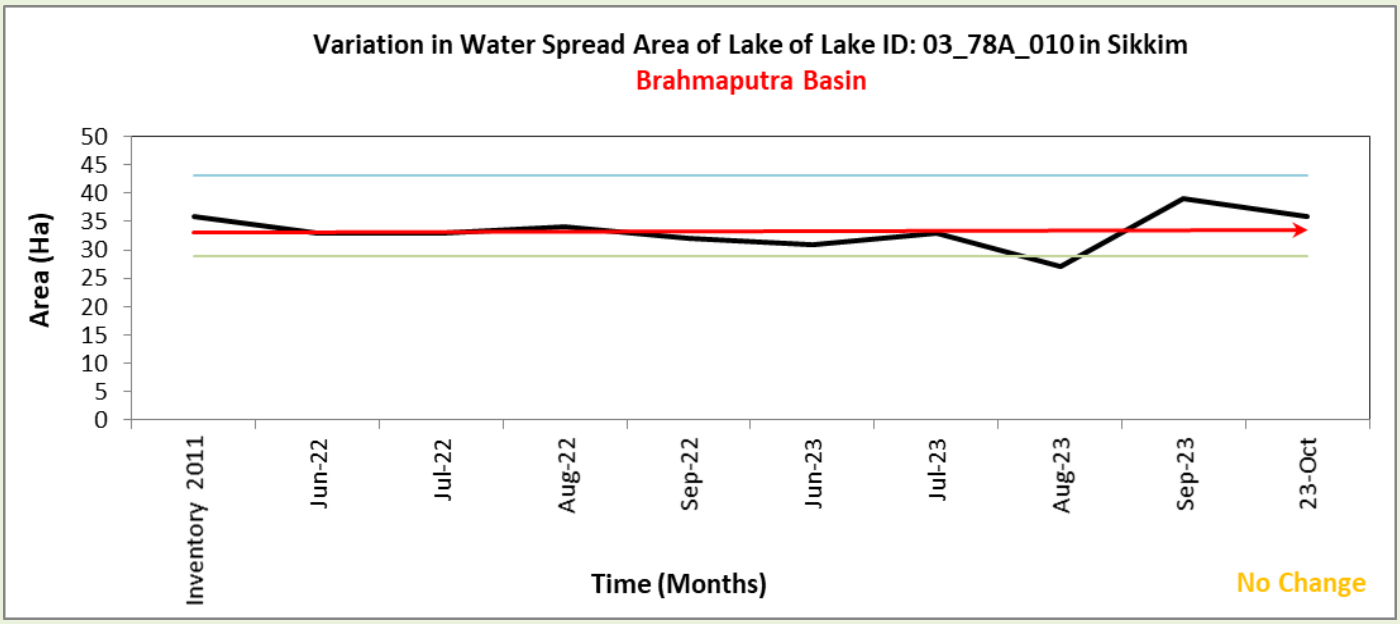


Figure 4.104(i) Trend Analysis Plot ±10%

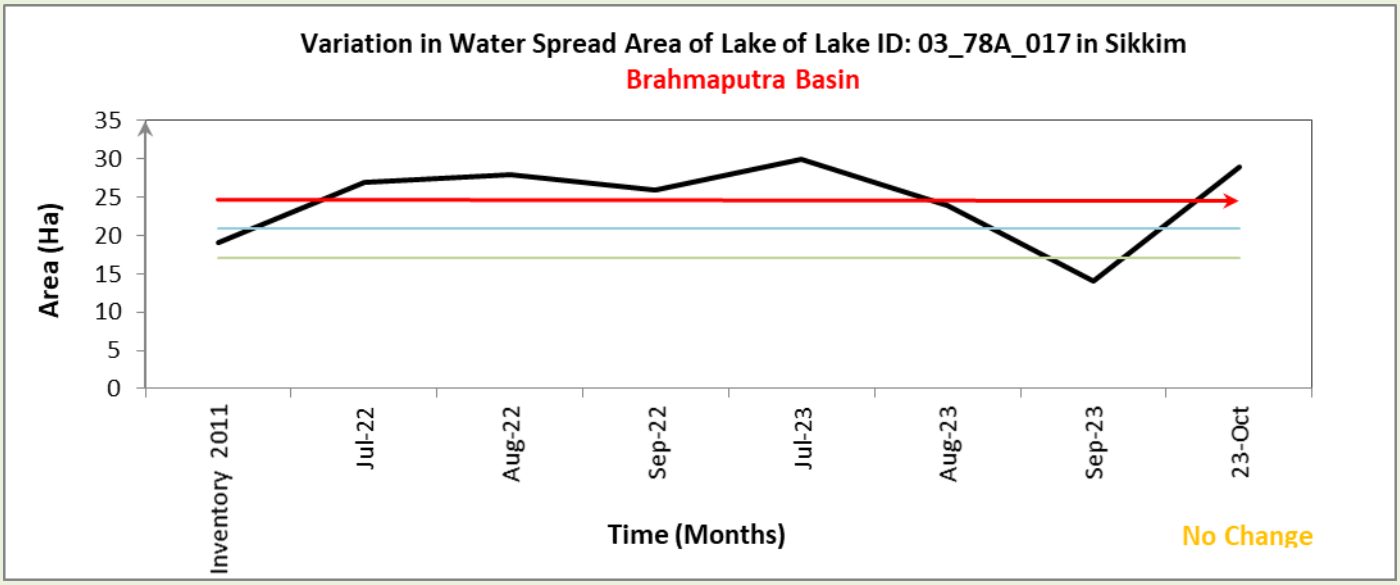


Figure 4.104(ii) Trend Analysis Plot ±20%

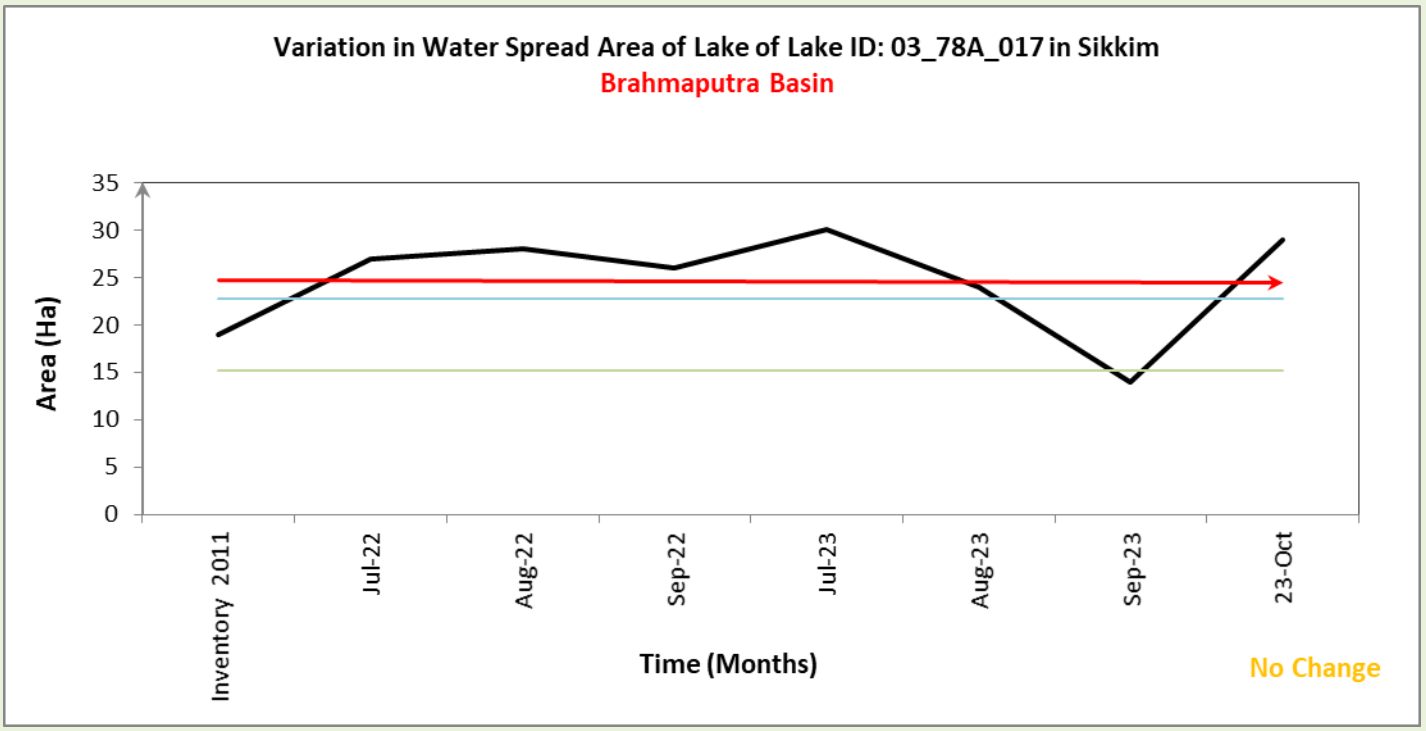


Figure 4.105(i) Trend Analysis Plot ±10%

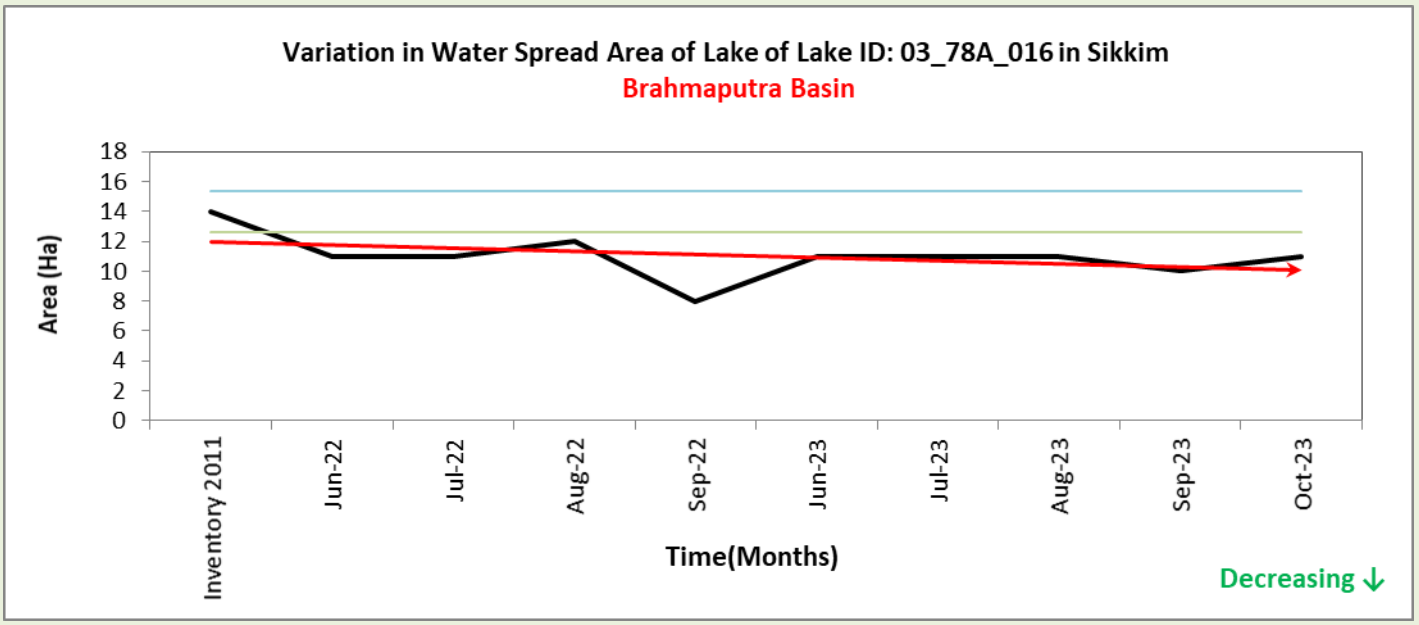


Figure 4.105(ii) Trend Analysis Plot ±20%

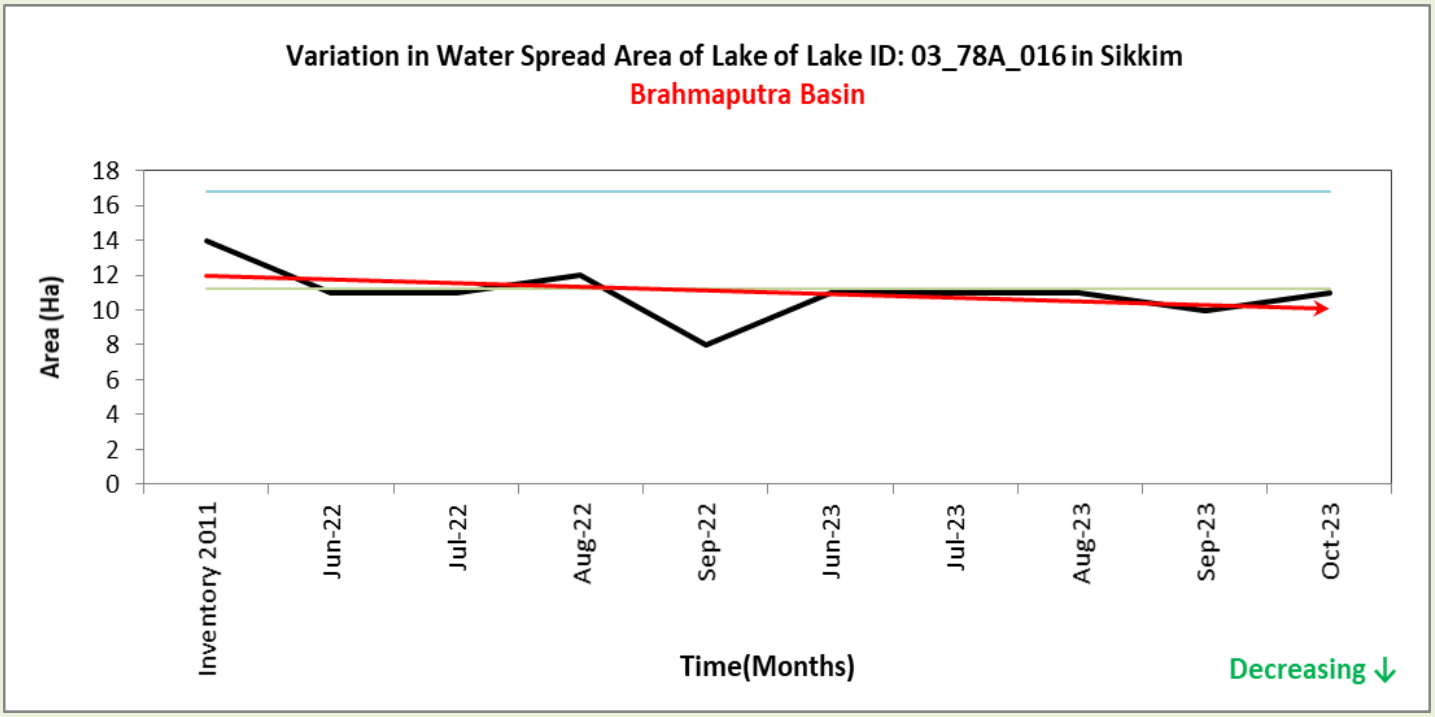


Figure 4.106(i) Trend Analysis Plot ±10%

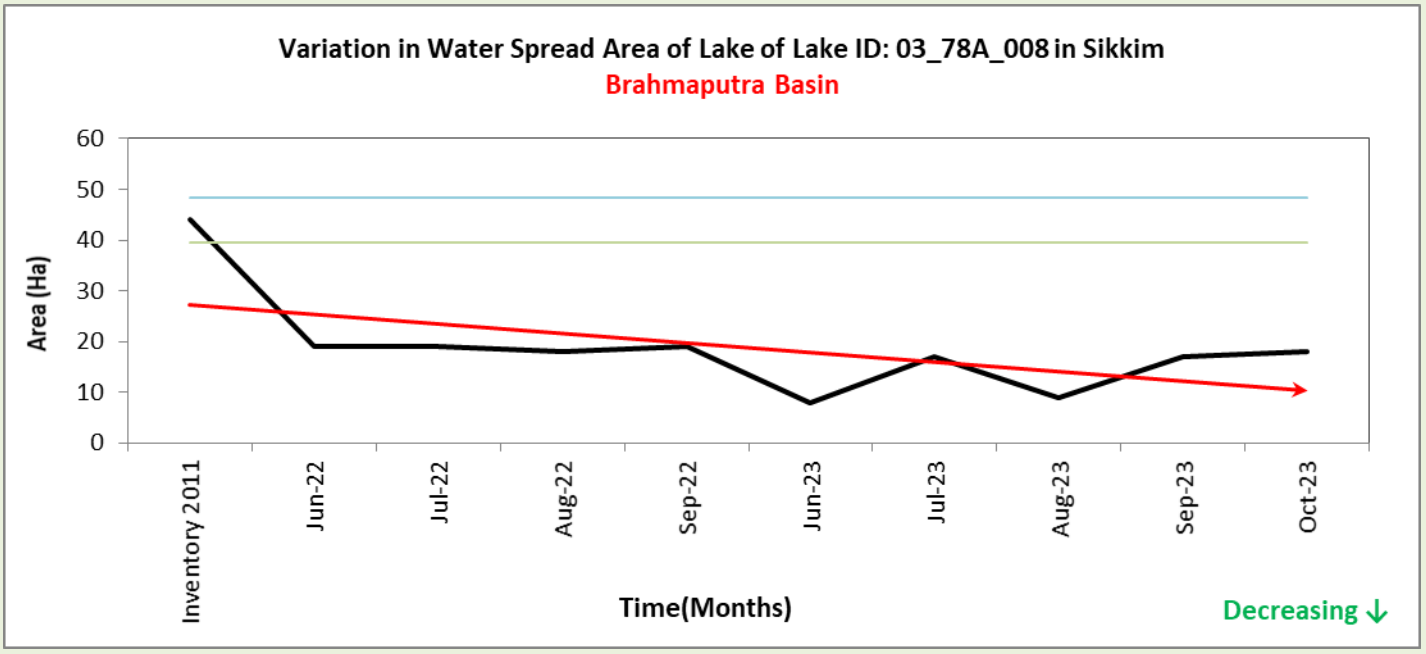


Figure 4.106(ii) Trend Analysis Plot ±20%

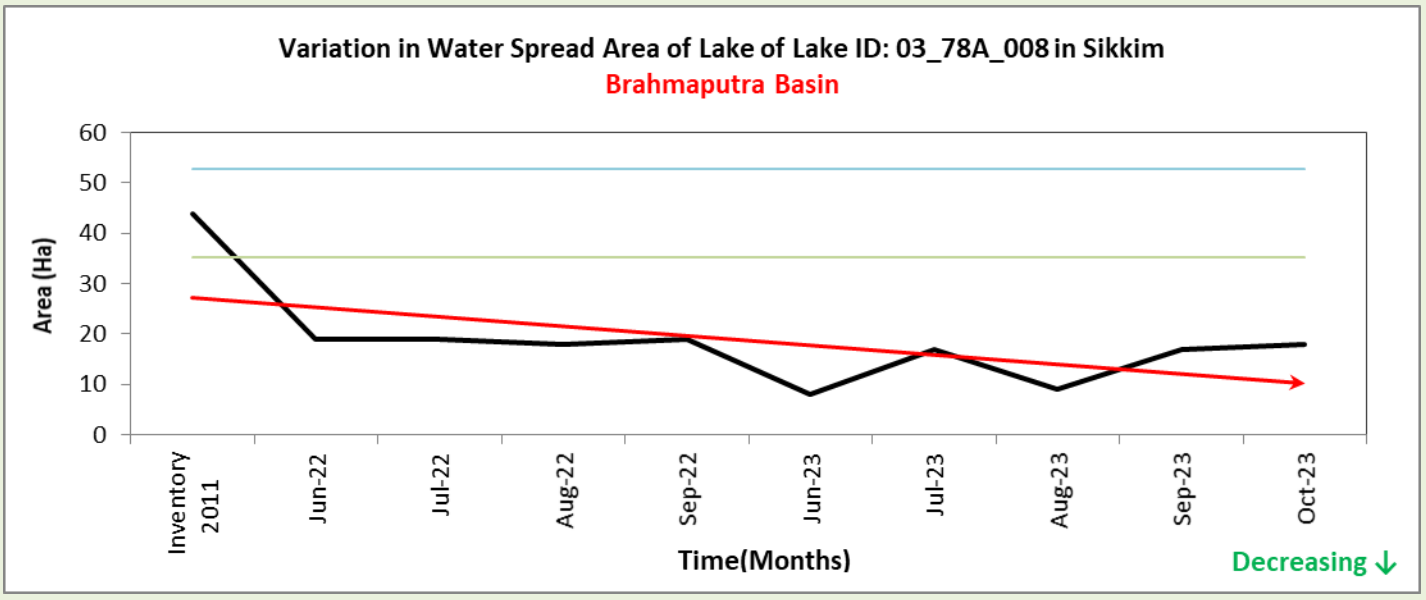


Figure 4.107(i) Trend Analysis Plot ±10%

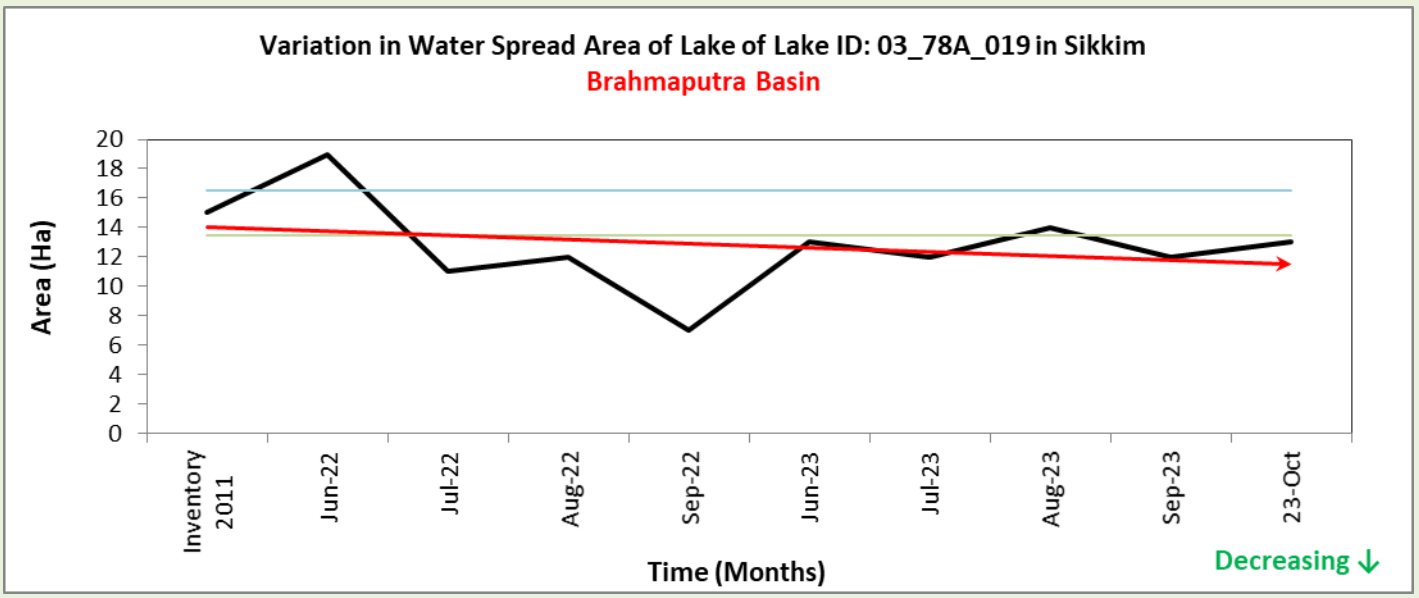


Figure 4.107(ii) Trend Analysis Plot 20%

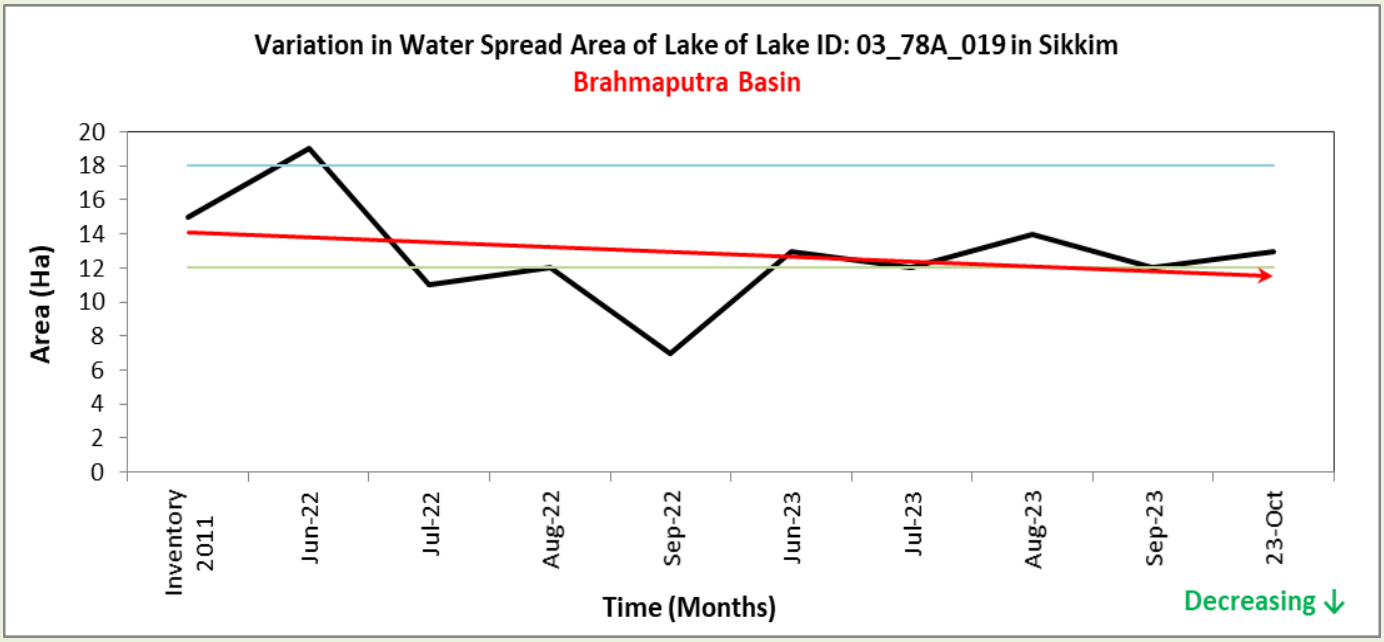


Figure 4.108(i) Trend Analysis Plot ±10%

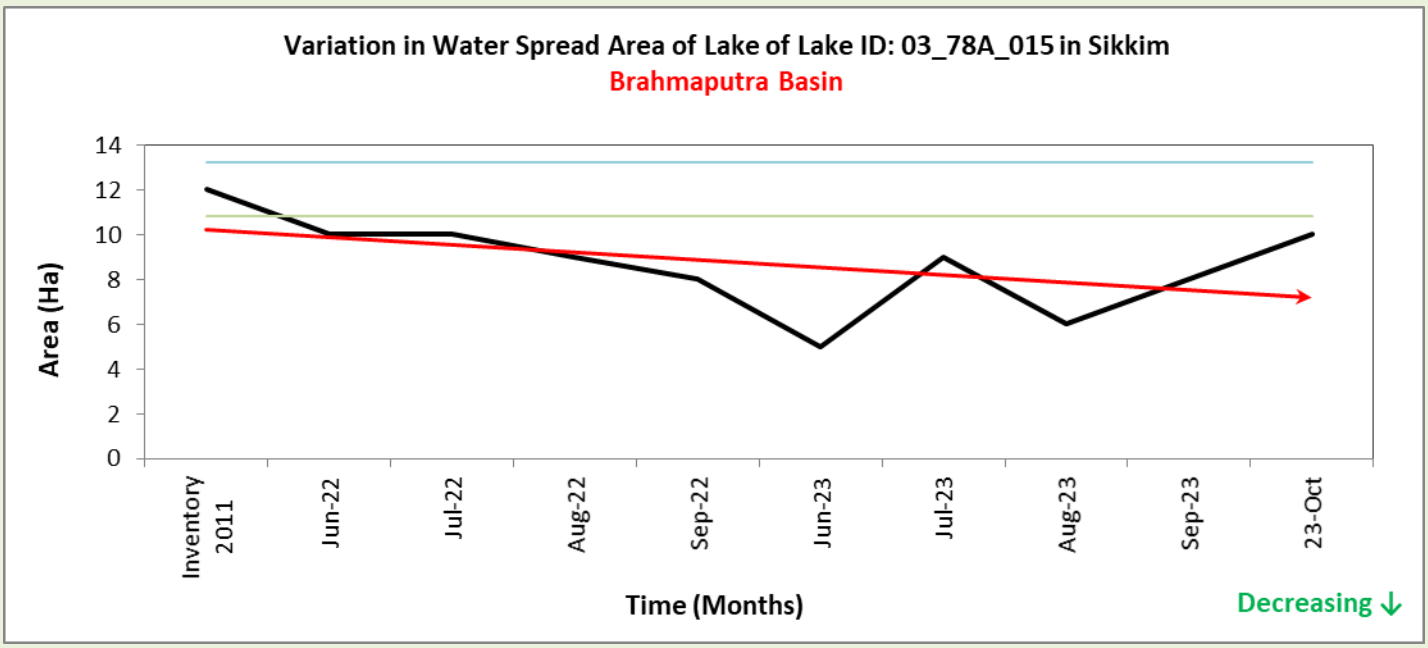


Figure 4.108(ii) Trend Analysis Plot ±20%

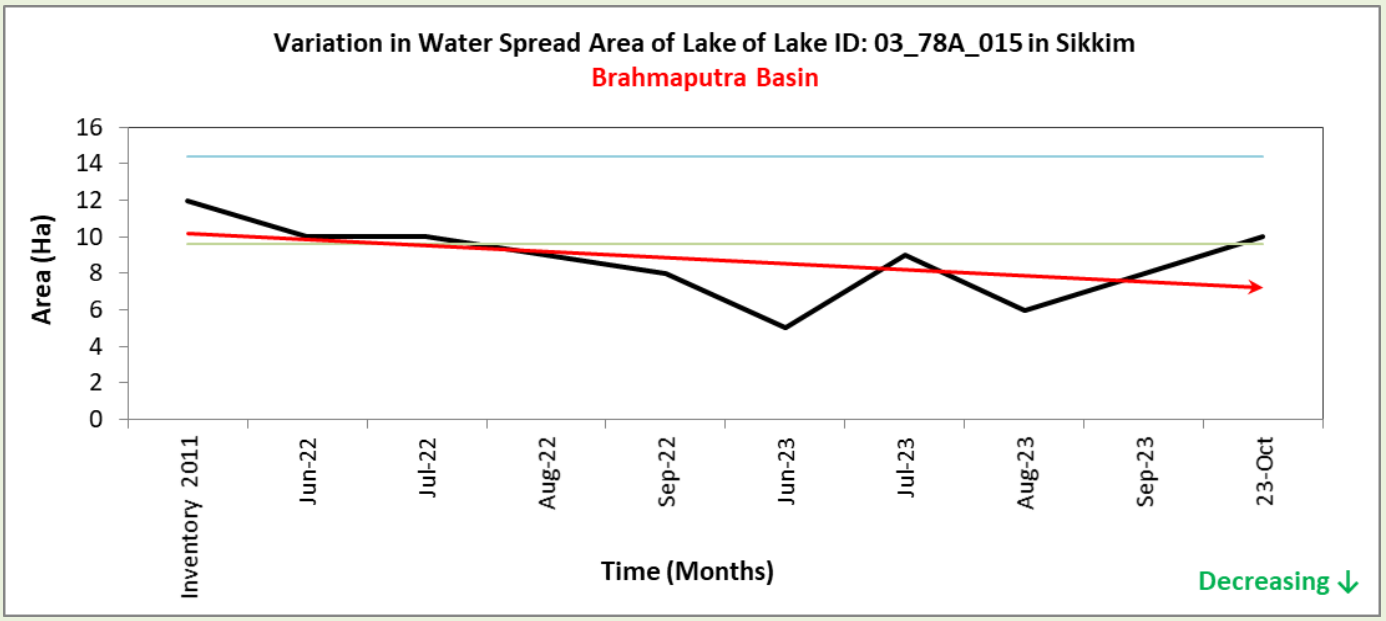


Figure 4.109(i) Trend Analysis Plot ±10%

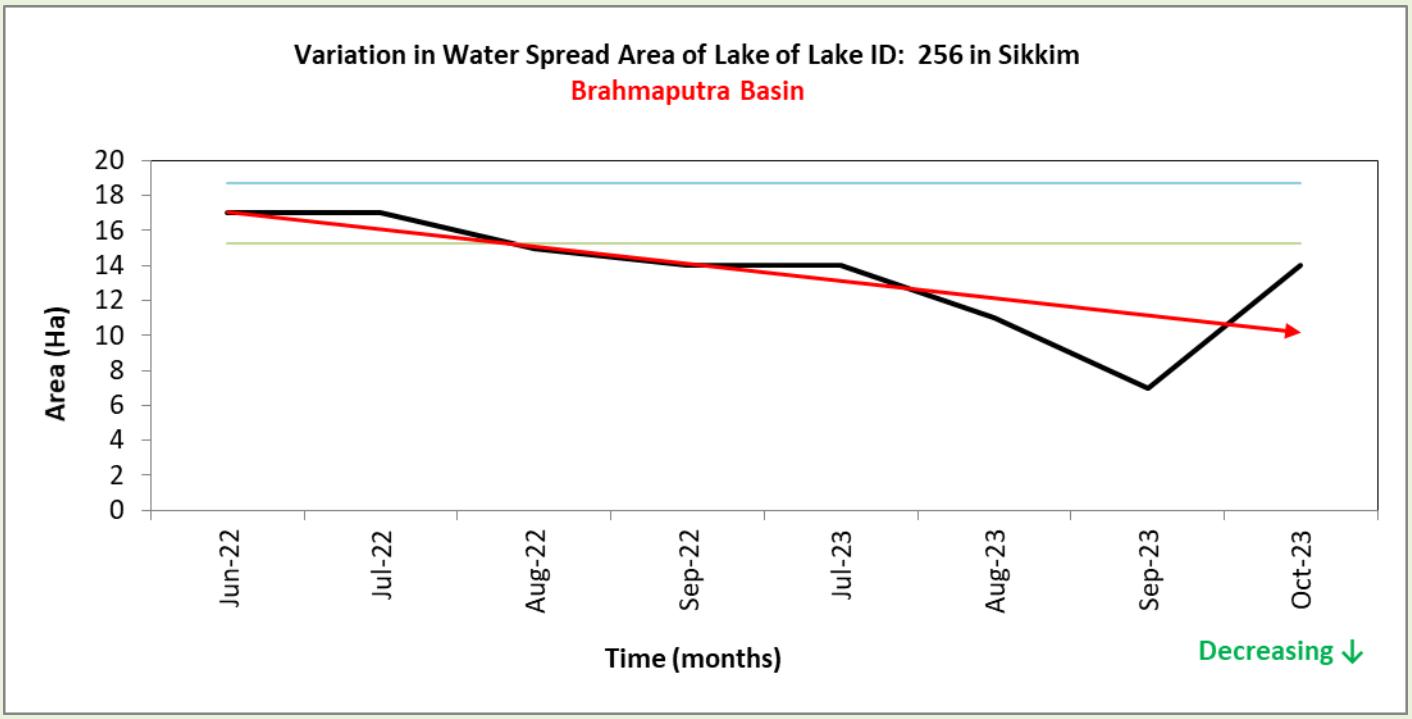


Figure 4.109(ii) Trend Analysis Plot ±20%

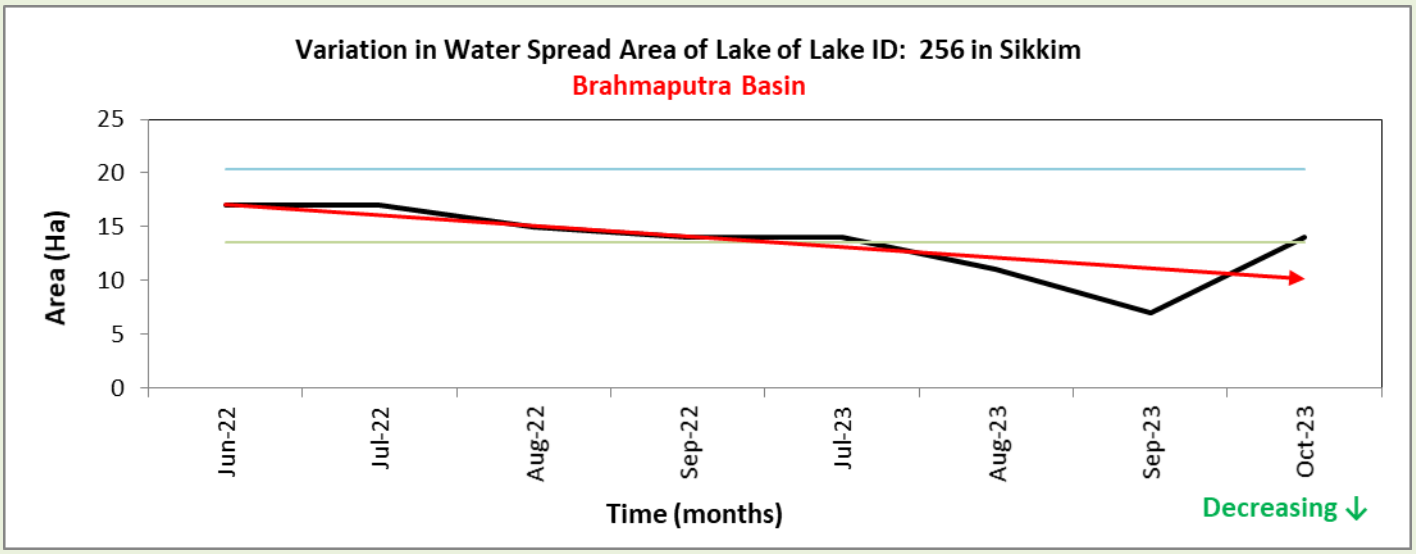


Figure 4.110(i) Trend Analysis Plot ±10%

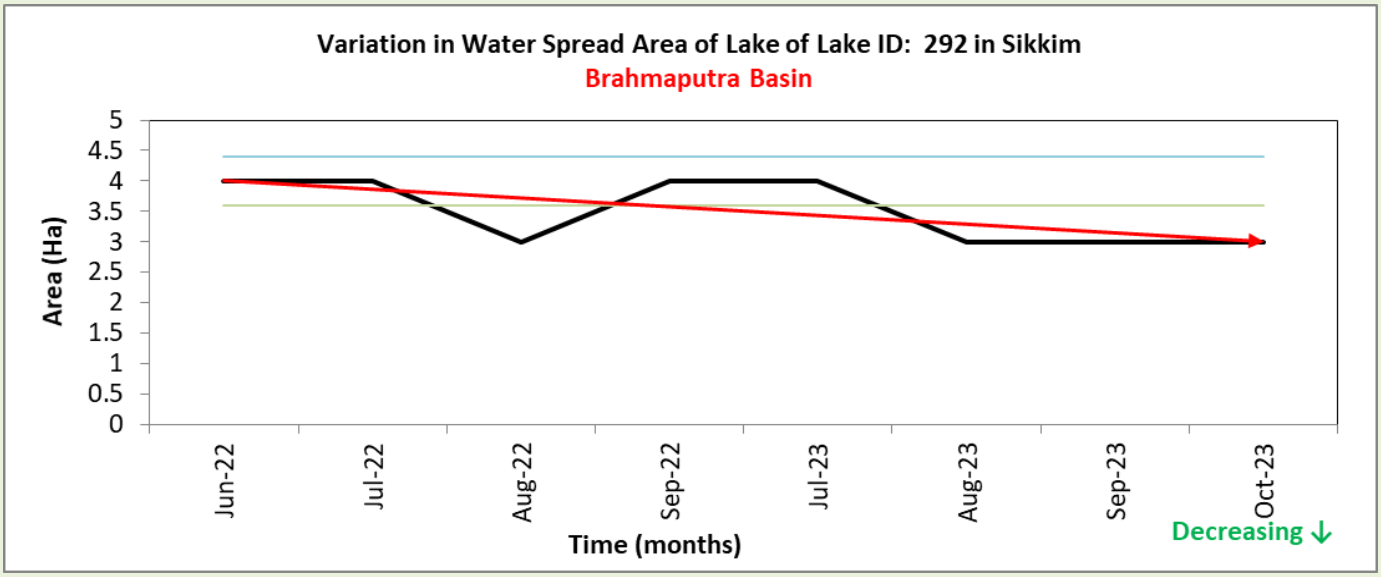


Figure 4.110(ii) Trend Analysis Plot ±20%

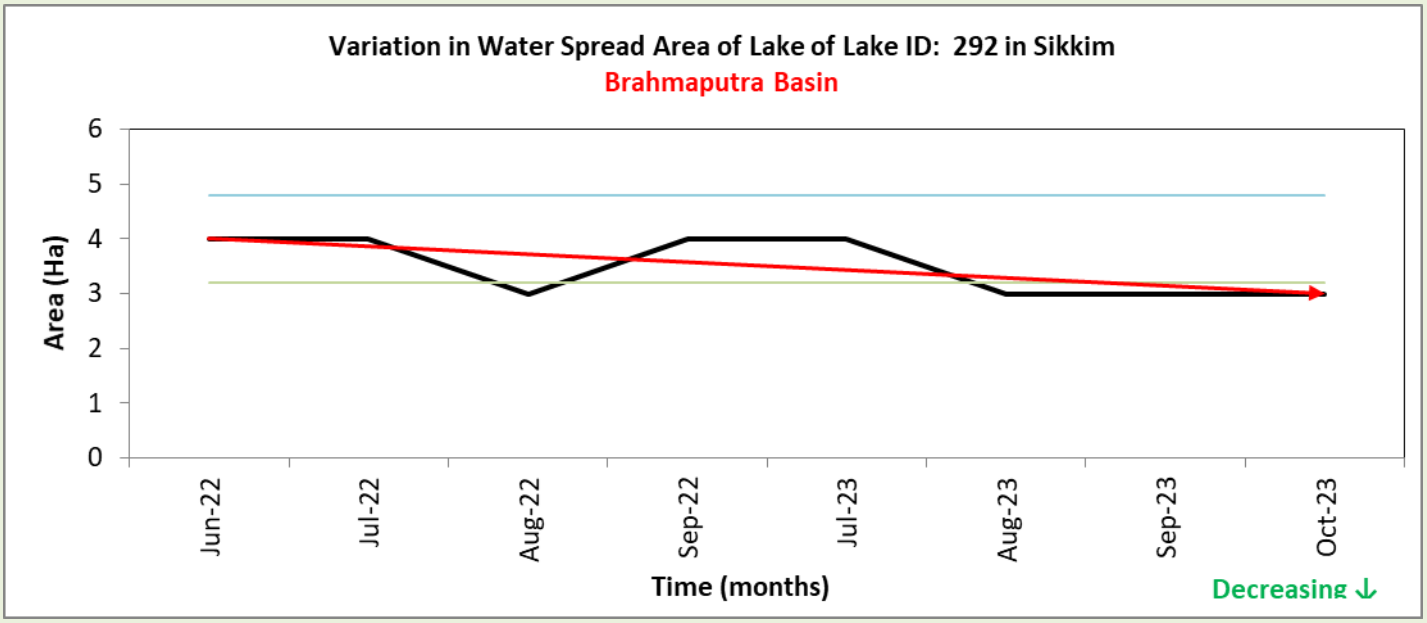


Figure 4.111(i) Trend Analysis Plot ±10%

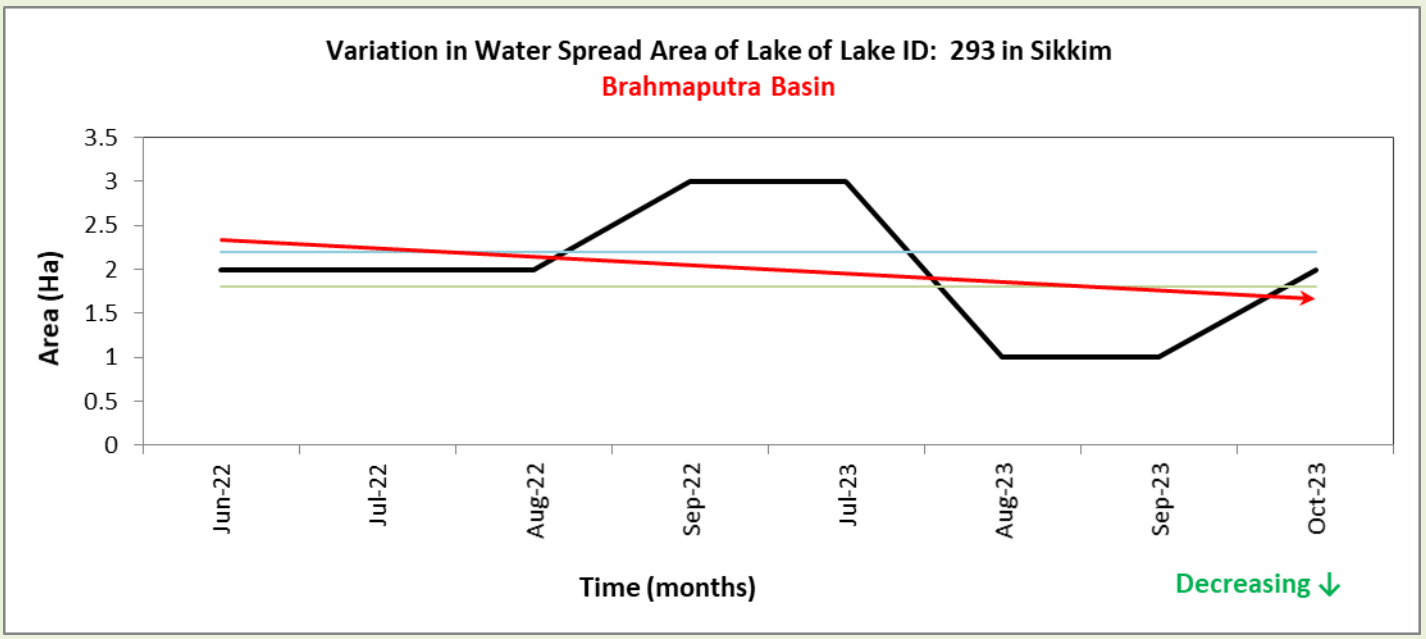


Figure 4.111(ii) Trend Analysis Plot ±20%

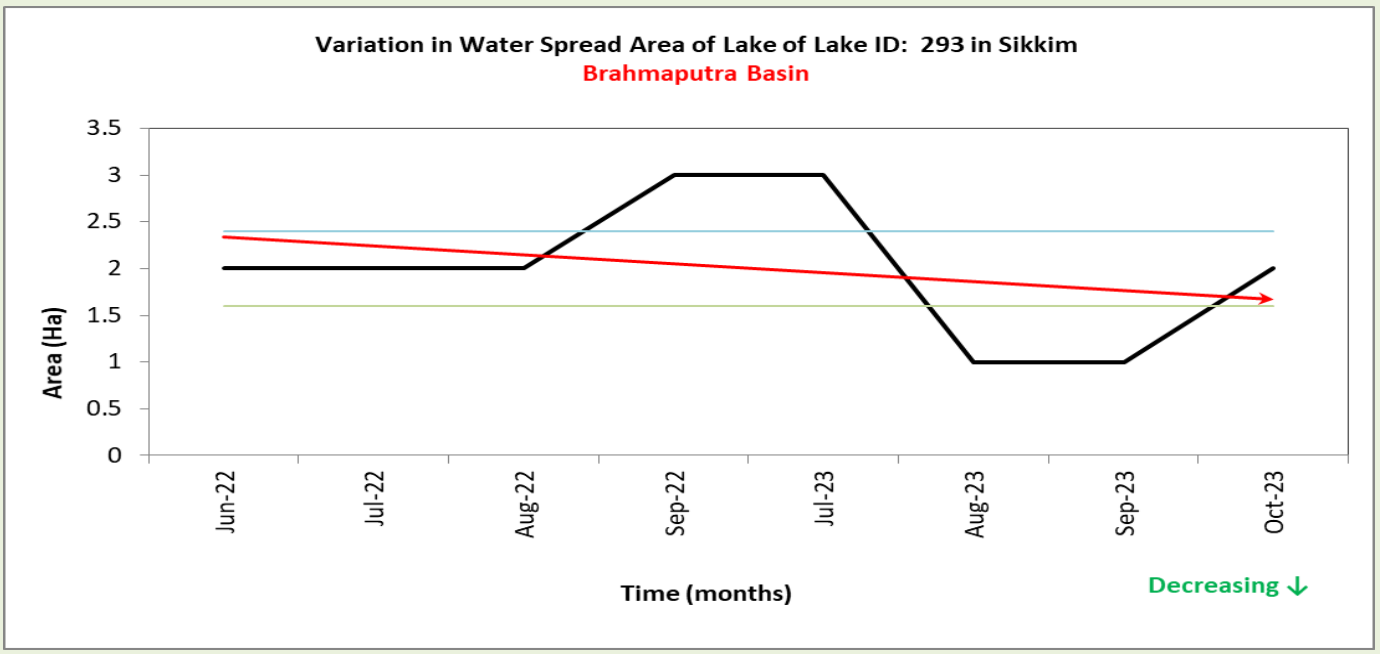


Figure 4.112(i) Trend Analysis Plot ±10%

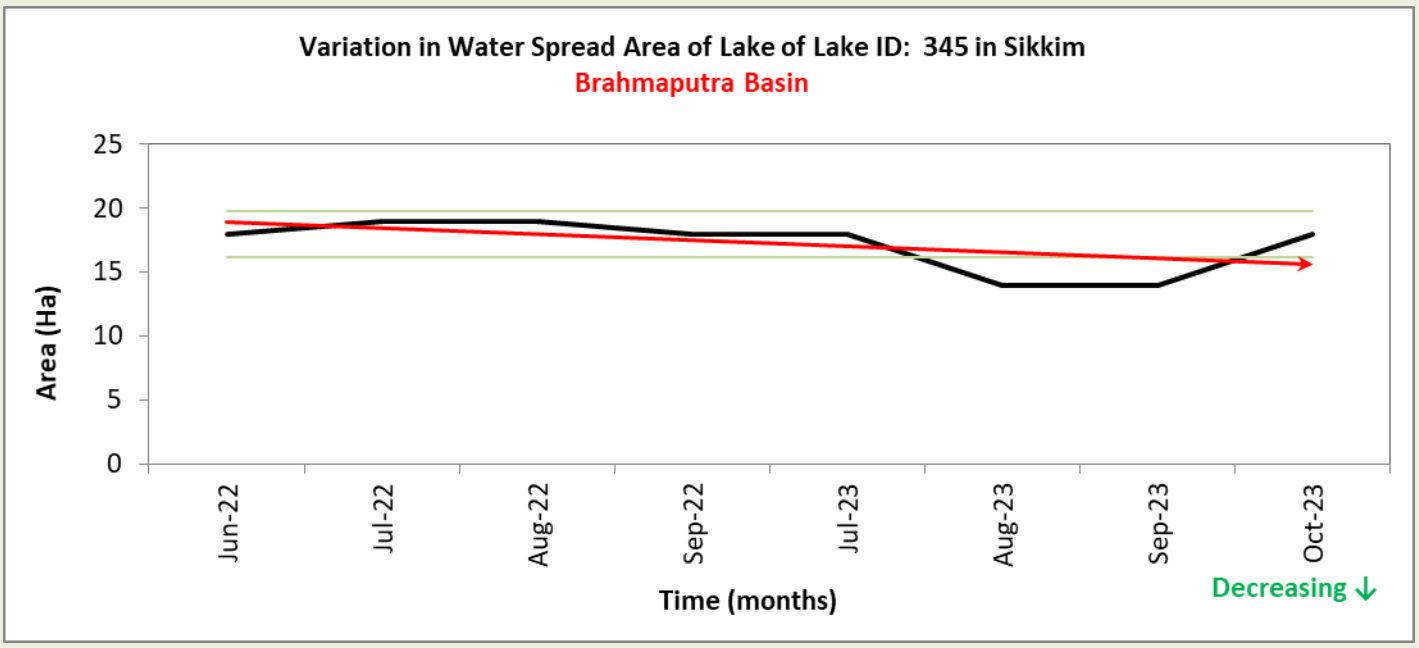
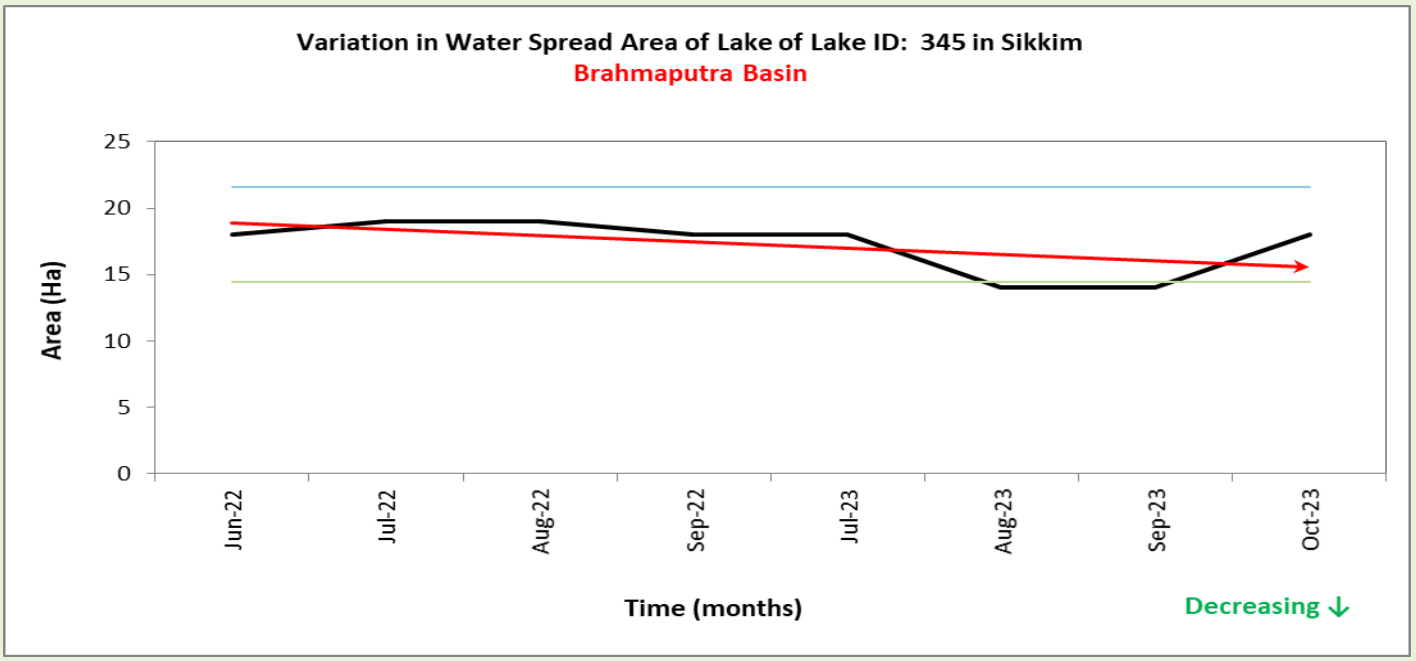


Figure 4.112(ii) Trend Analysis Plot ±20%



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%

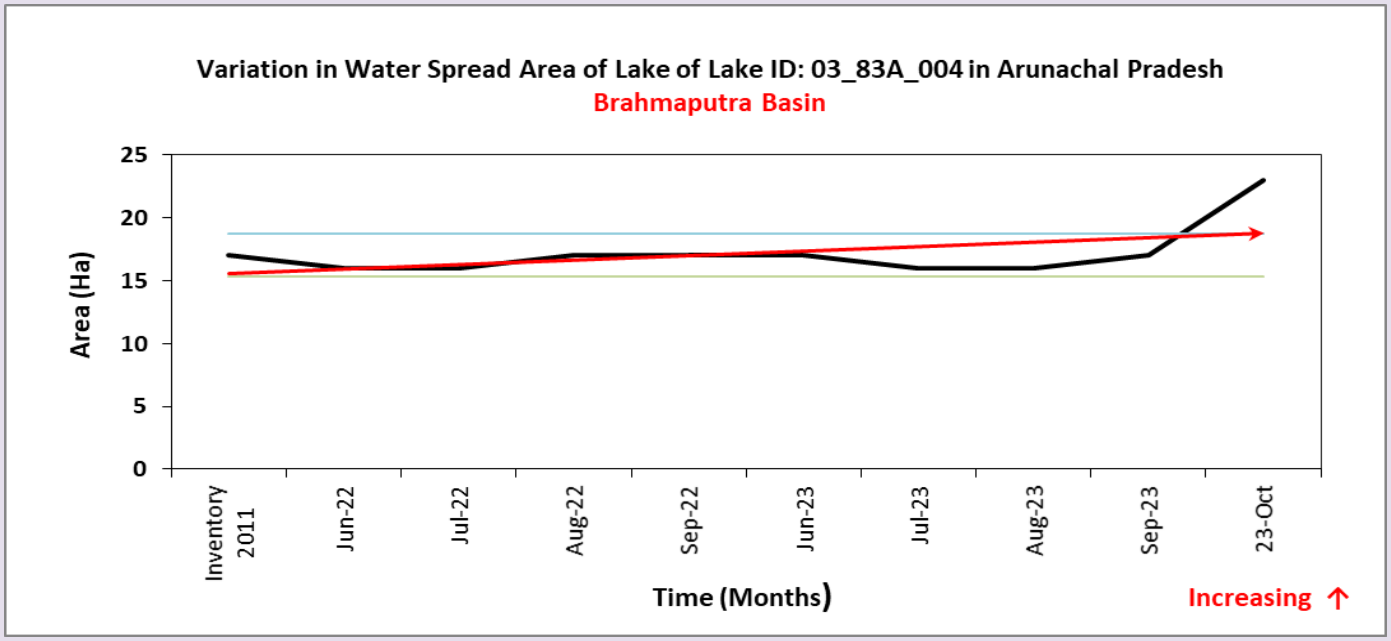


Figure 4.113(ii) Trend Analysis Plot 20%

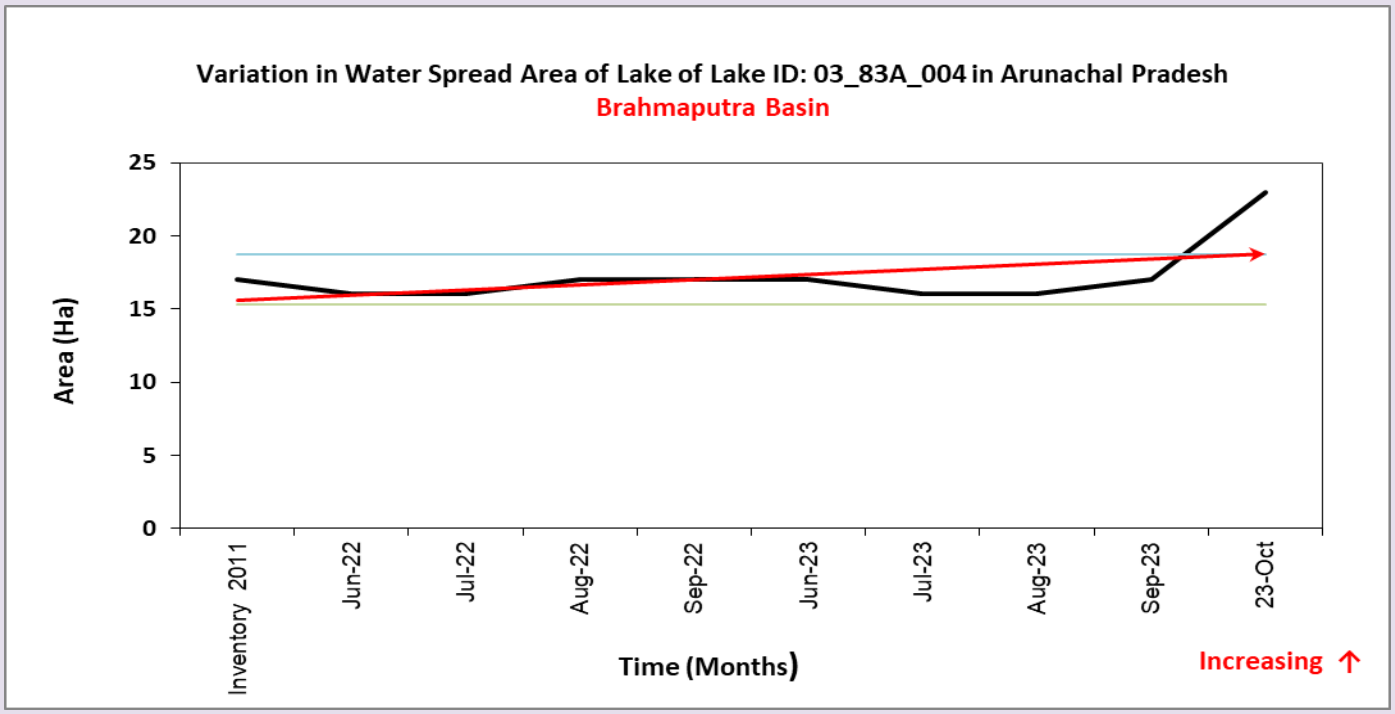


Figure 4.114(i) Trend Analysis Plot ±10%

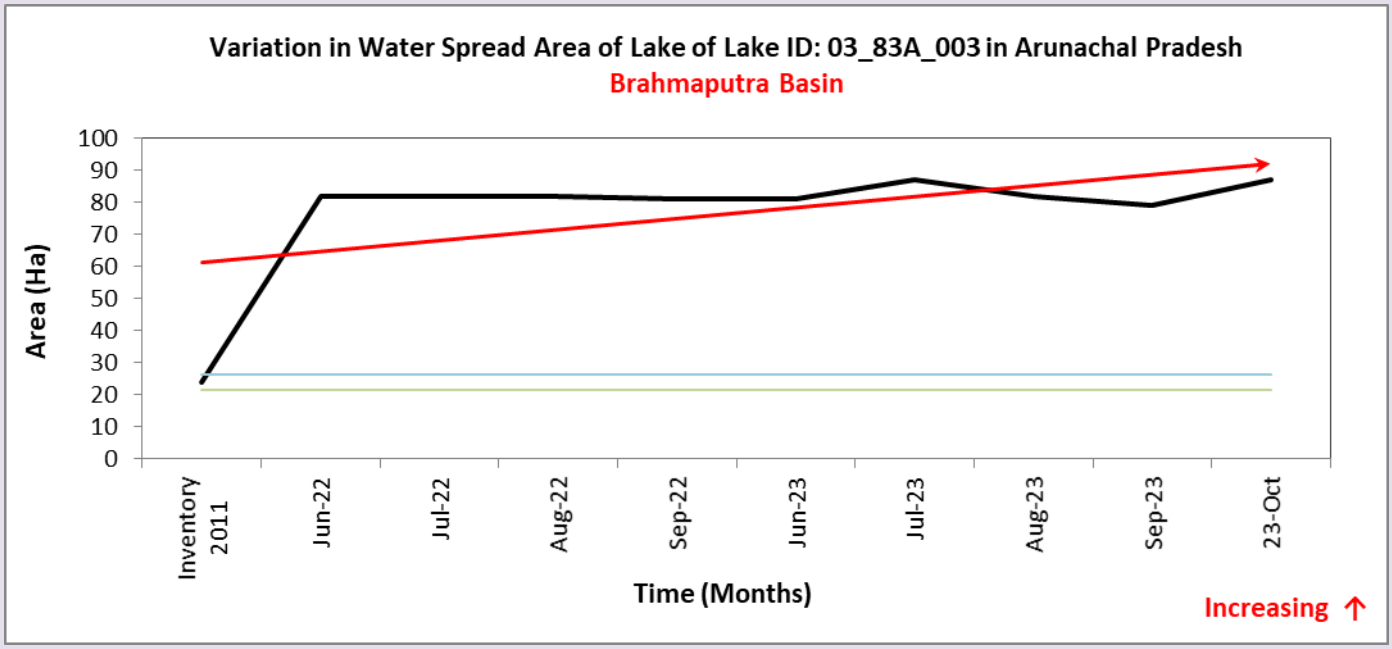


Figure 4.114(ii) Trend Analysis Plot ±20%

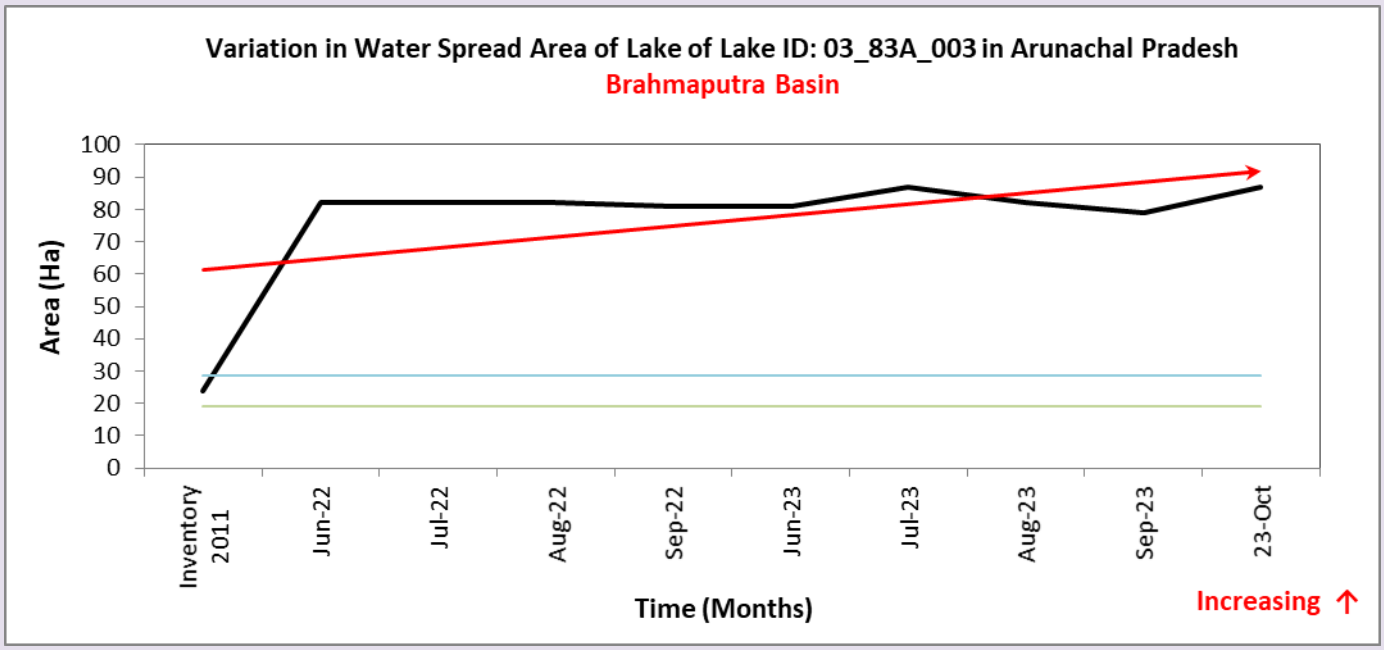


Figure 4.115(i) Trend Analysis Plot ±10%

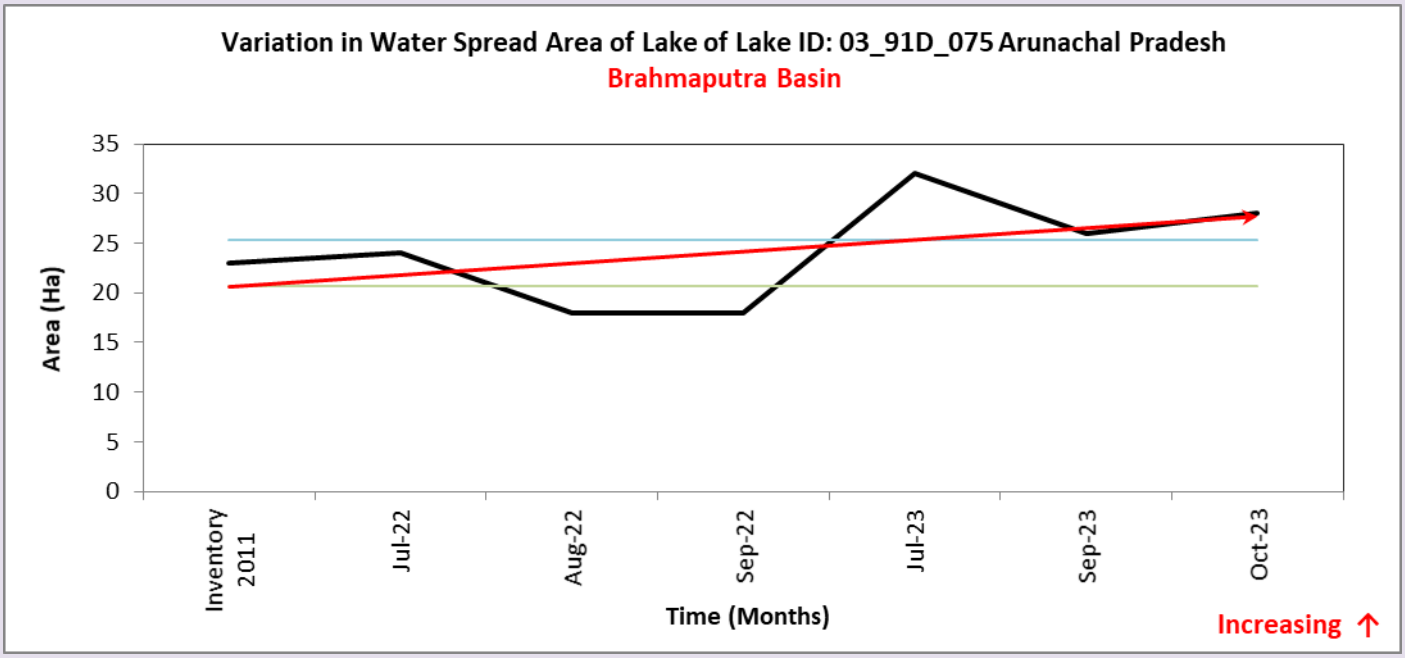


Figure 4.115(ii) Trend Analysis Plot ±20%

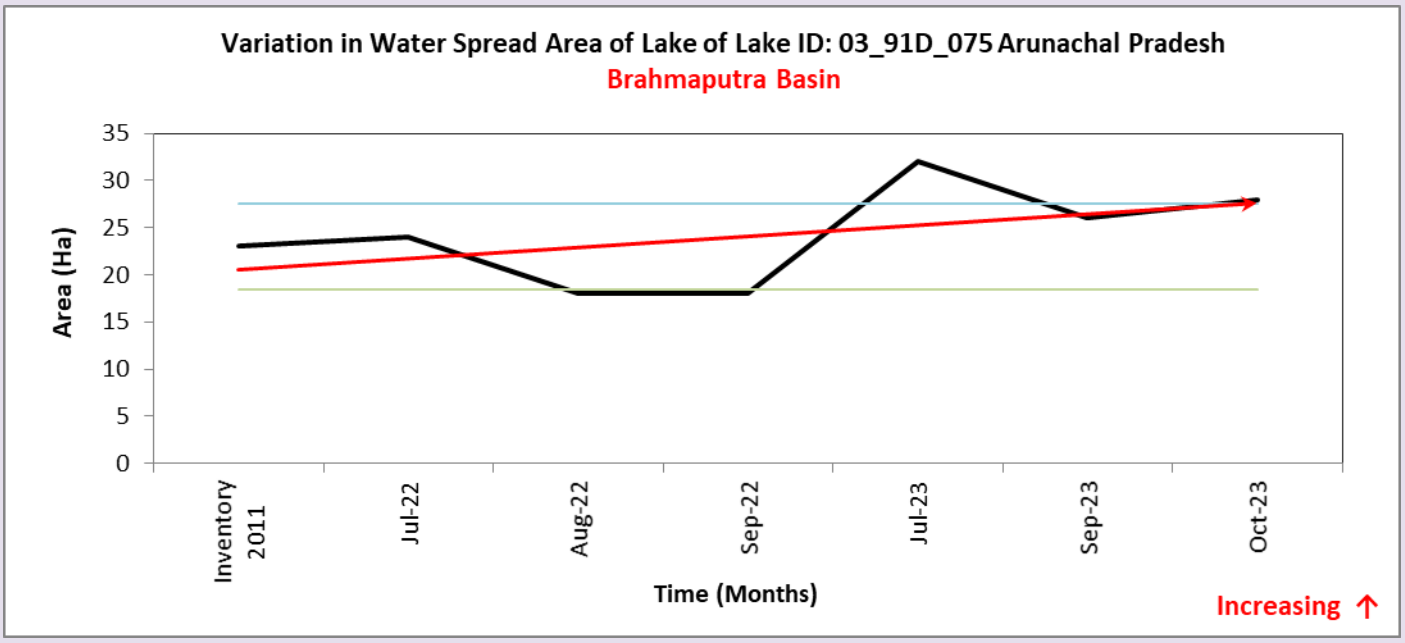


Figure 4.116(i) Trend Analysis Plot ±10%

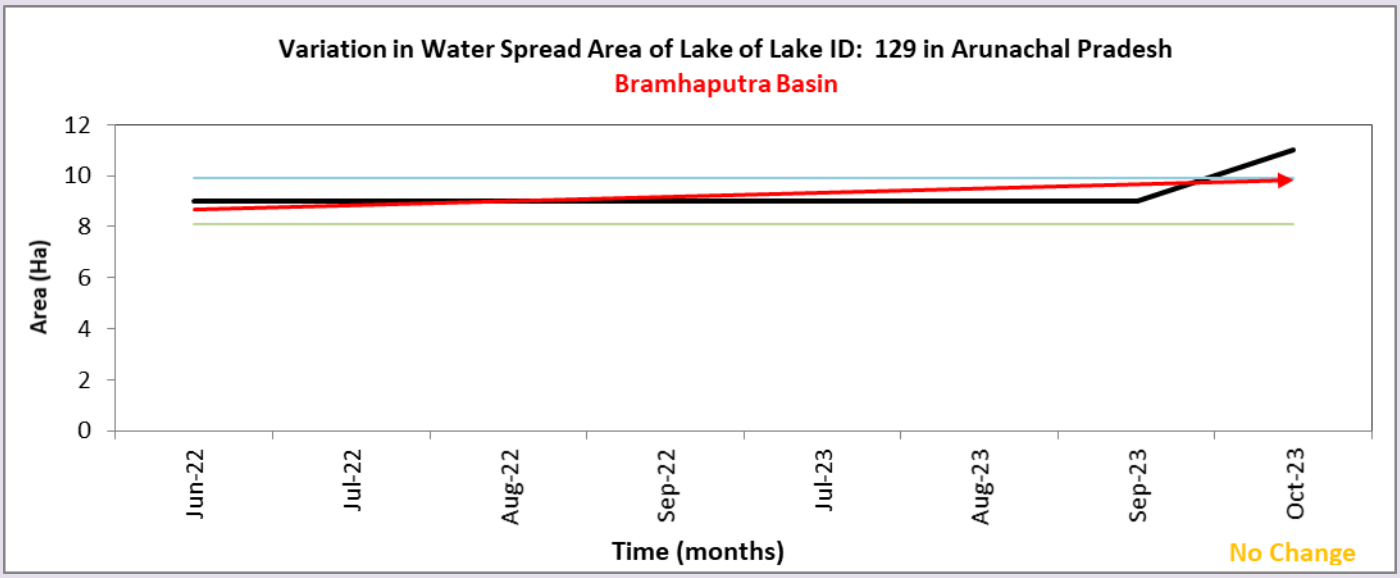


Figure 4.116(ii) Trend Analysis Plot ±20%

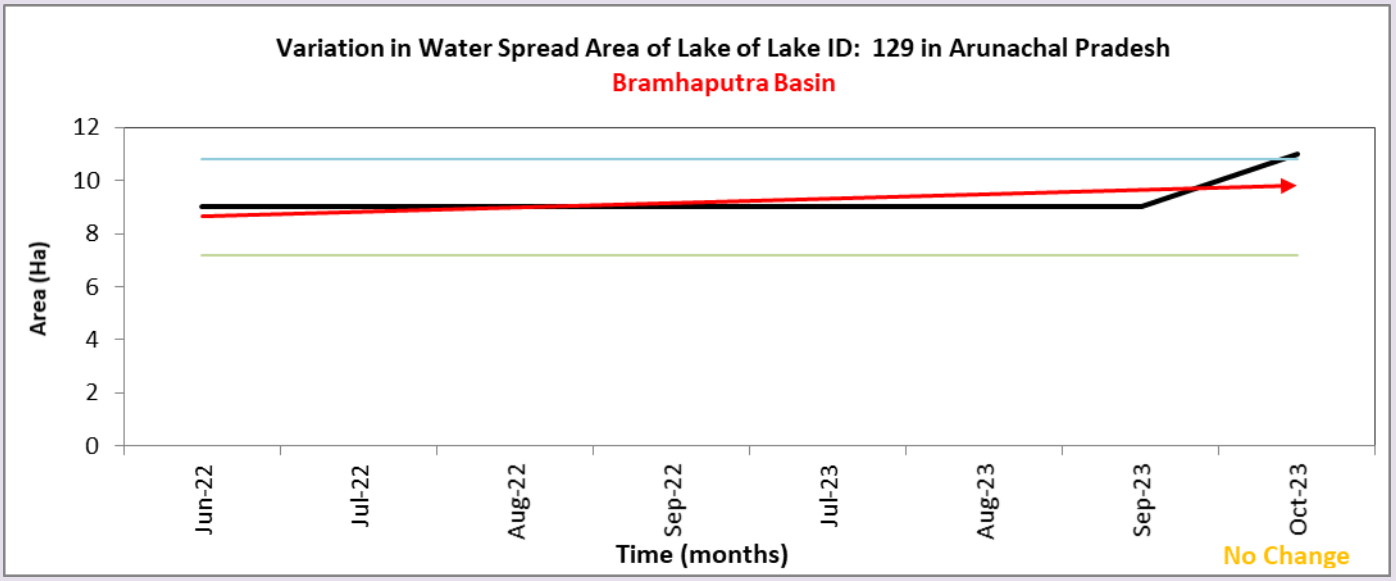


Figure 4.117(i) Trend Analysis Plot ±10%

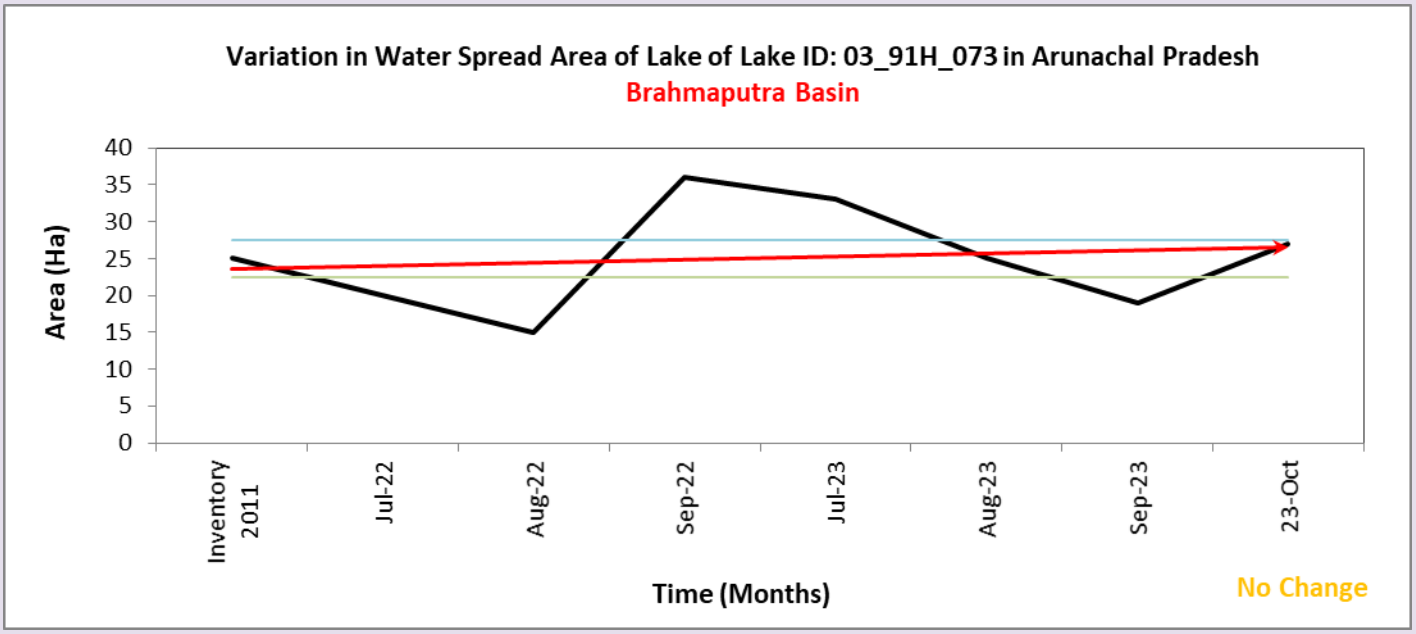


Figure 4.117(ii) Trend Analysis Plot ±20%

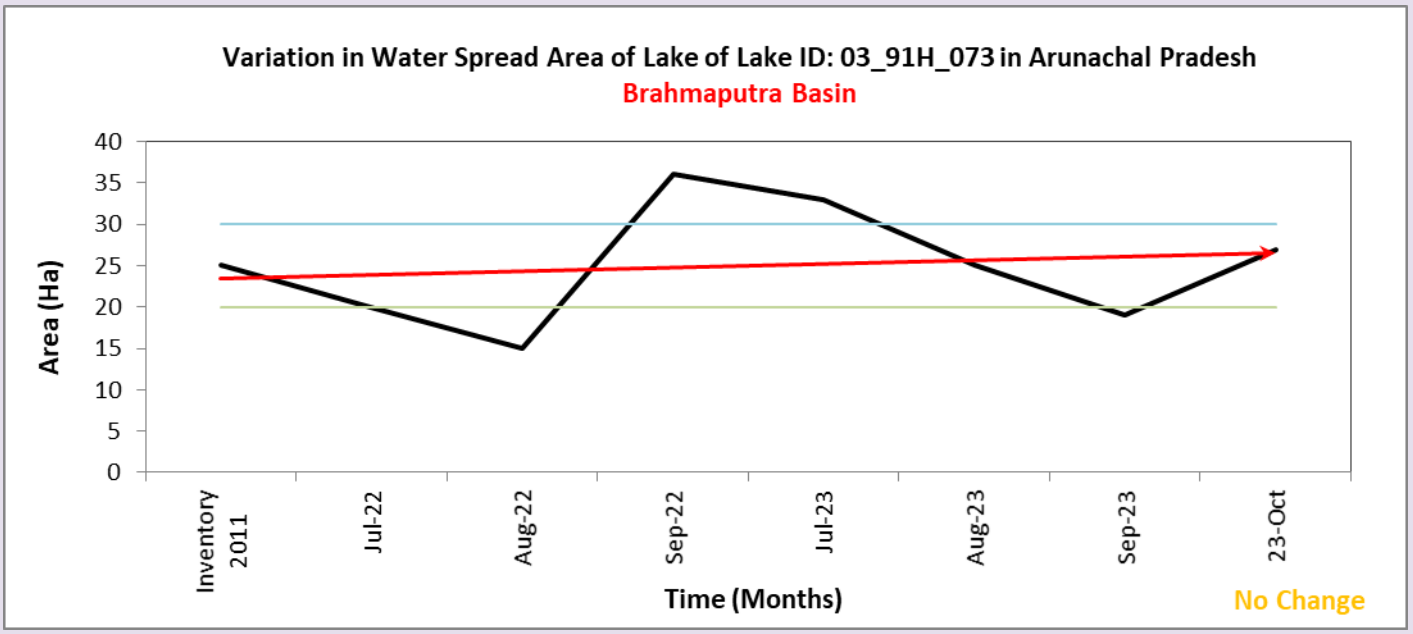


Figure 4.118(i) Trend Analysis Plot ±10%

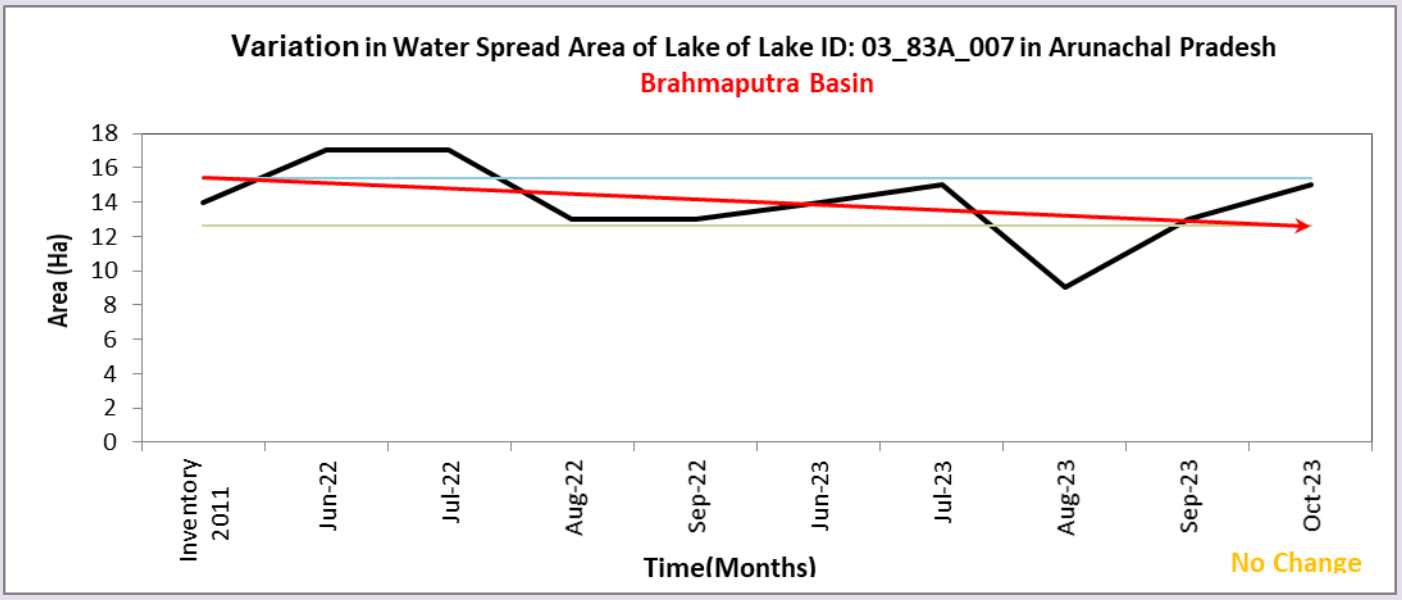


Figure 4.118(ii) Trend Analysis Plot ±20%

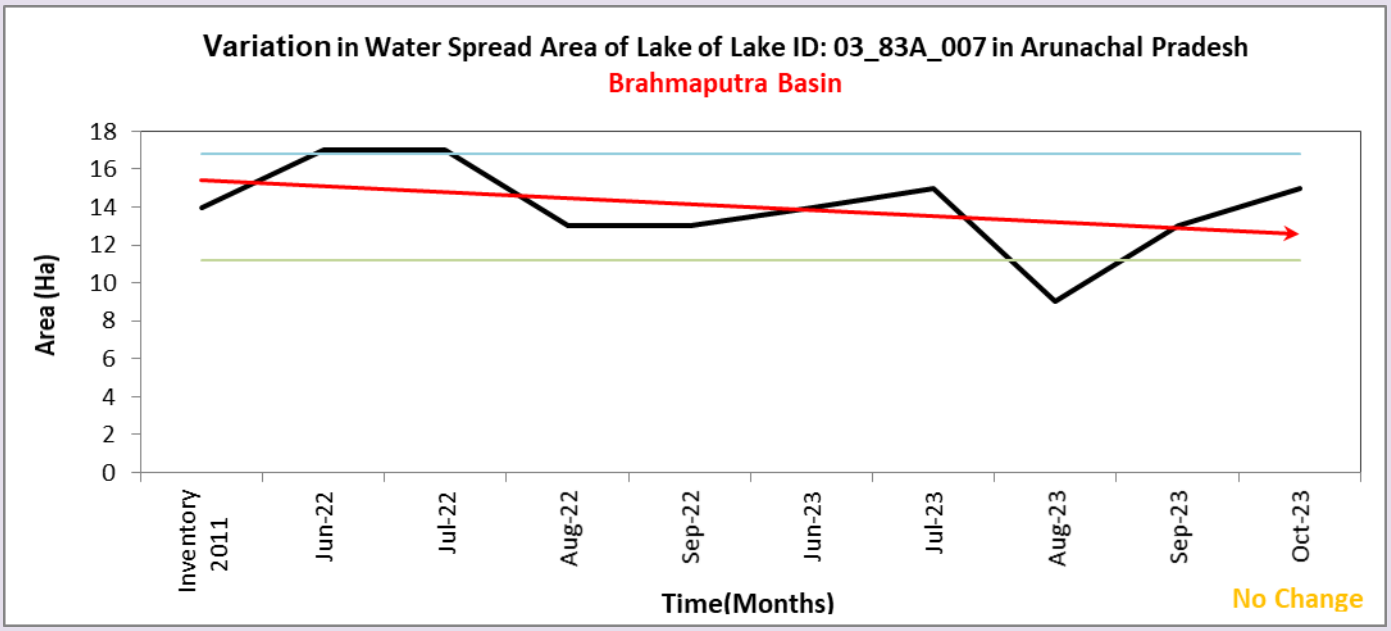


Figure 4.119(i) Trend Analysis Plot ±10%

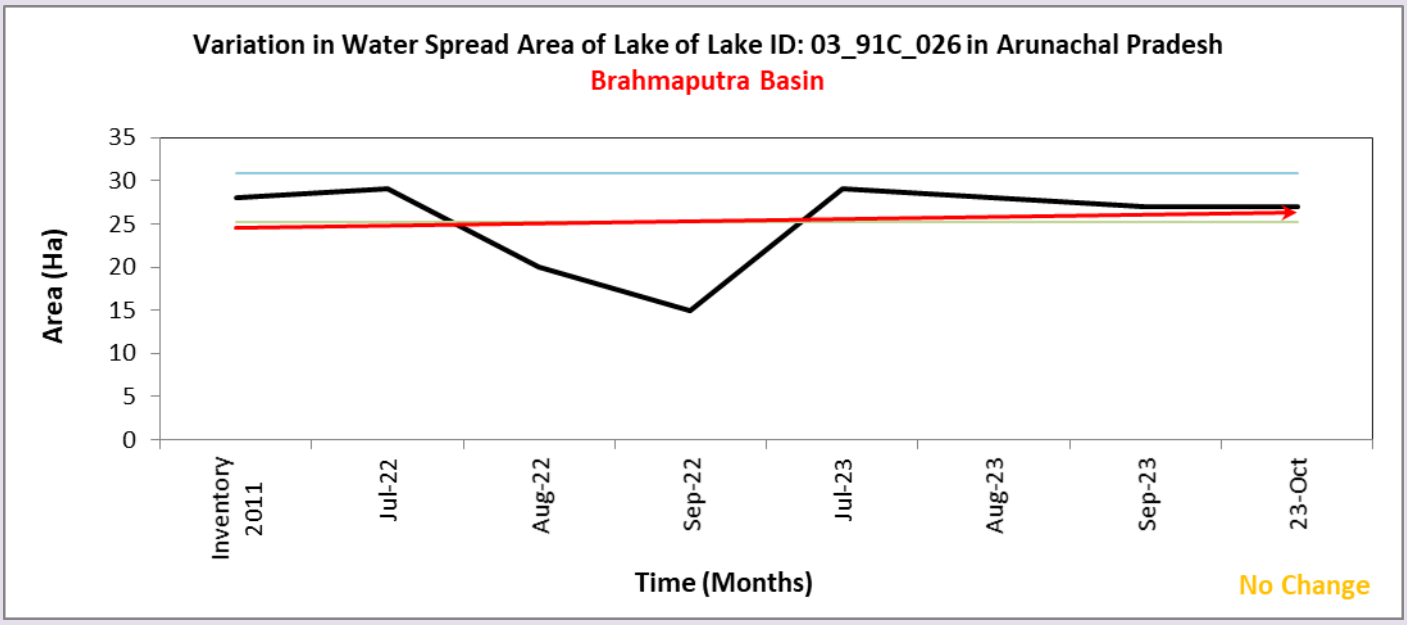


Figure 4.119(ii) Trend Analysis Plot ±20%

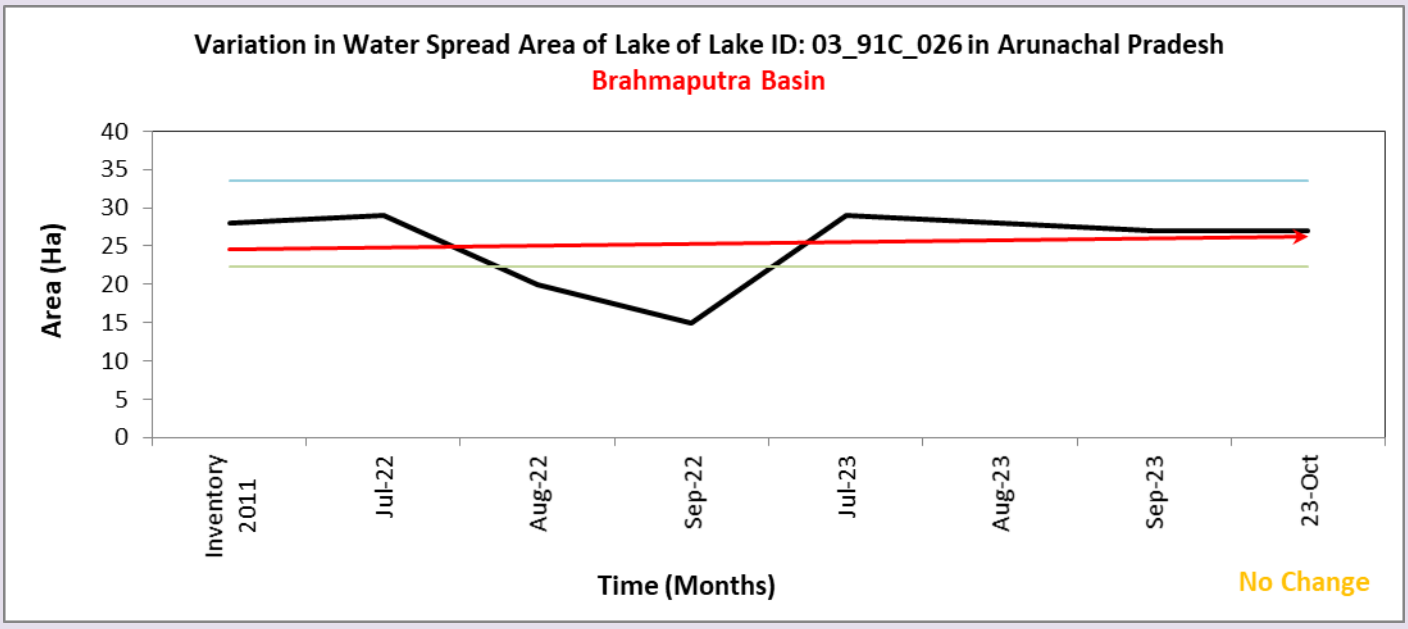


Figure 4.120(i) Trend Analysis Plot ±10%

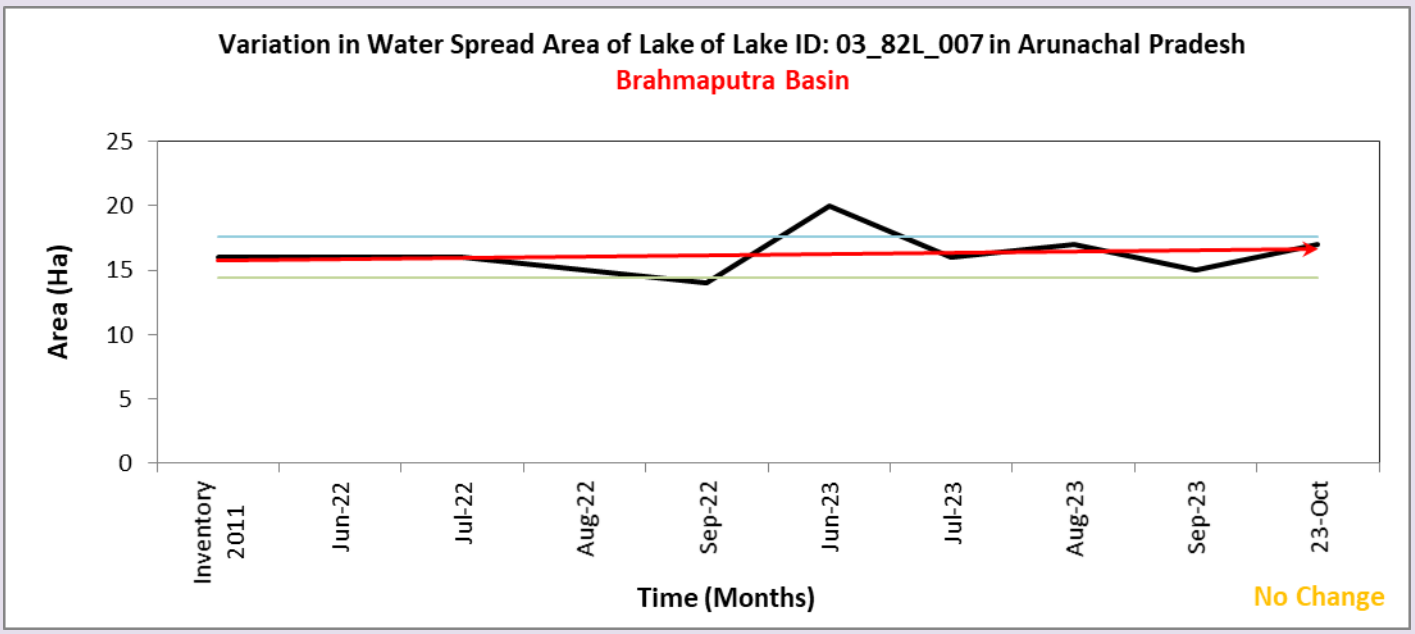


Figure 4.120(ii) Trend Analysis Plot ±20%

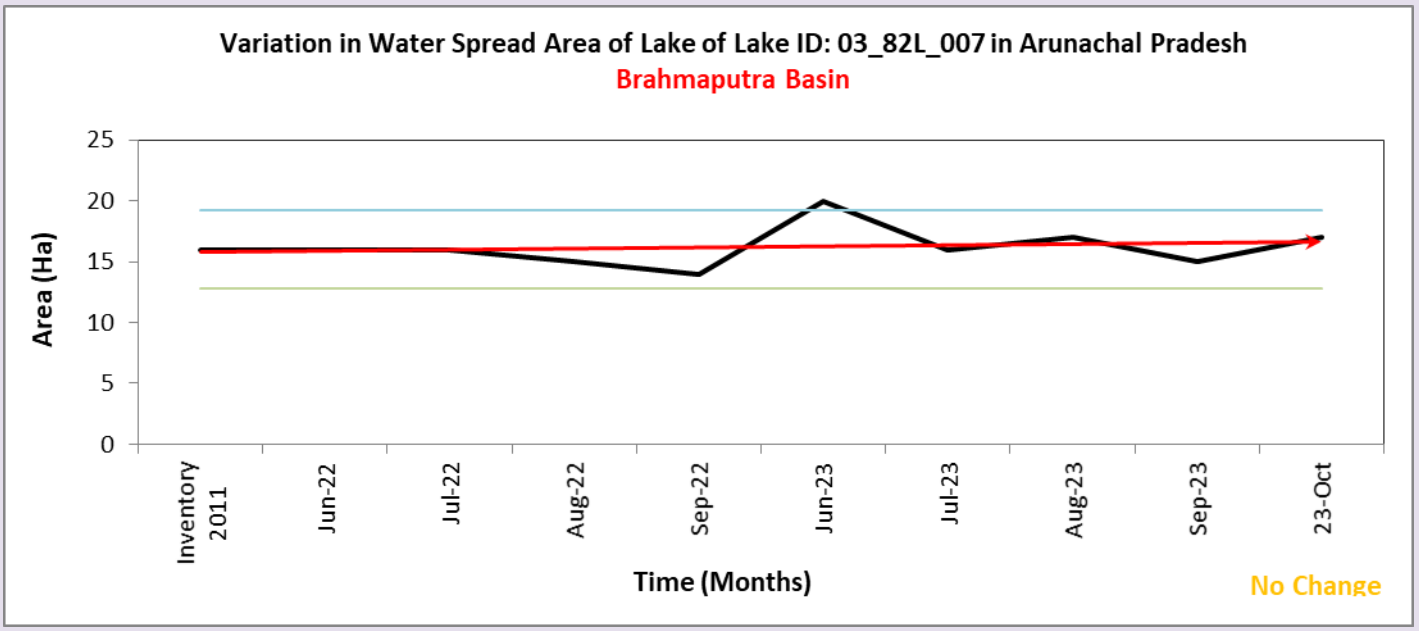


Figure 4.121(i) Trend Analysis Plot ±10%

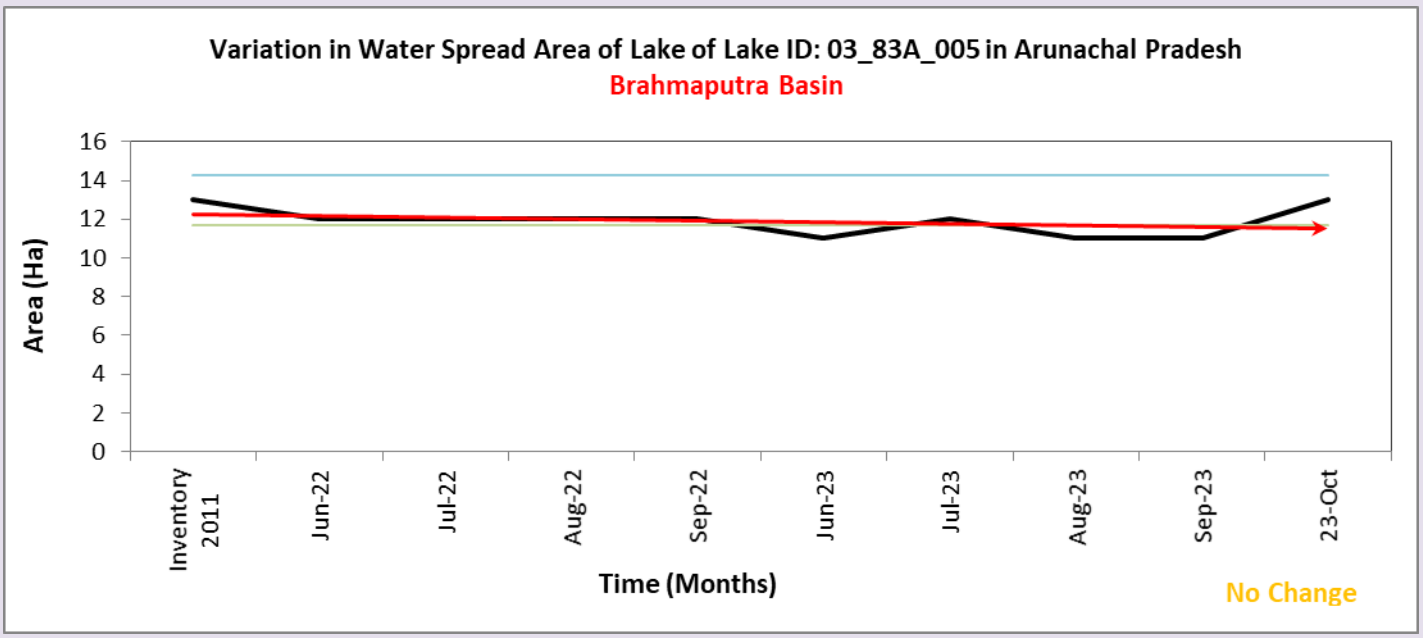
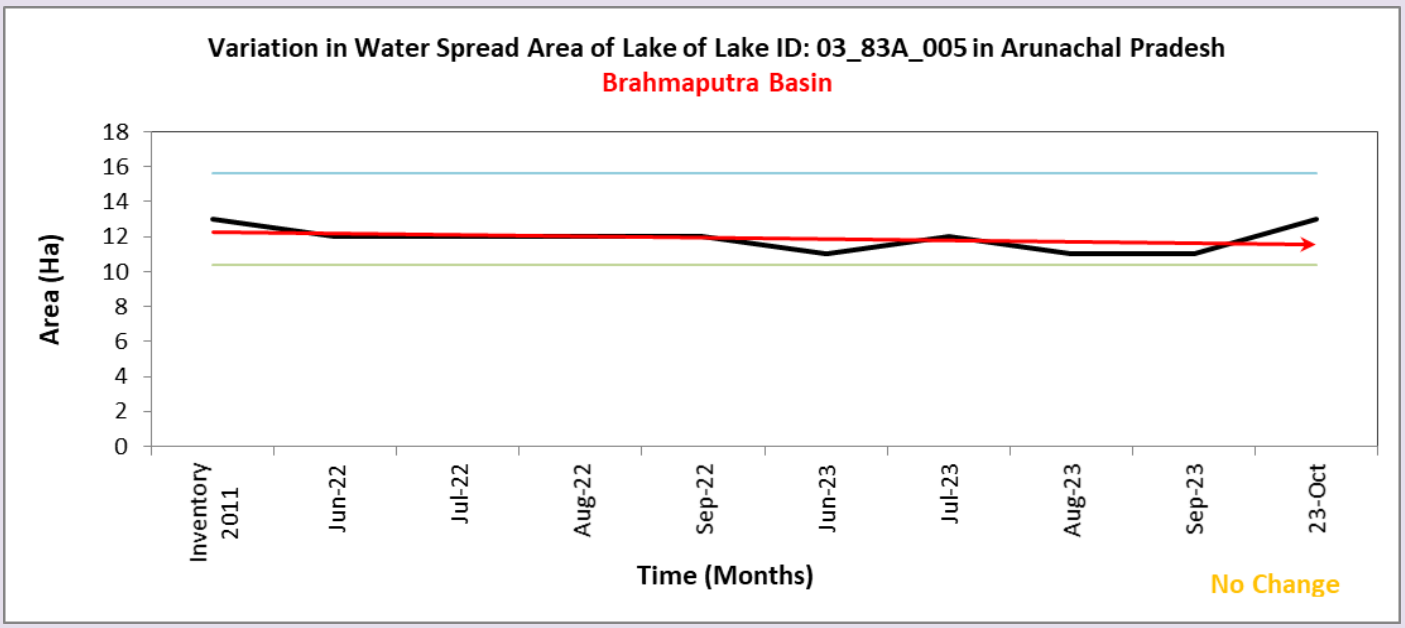


Figure 4.121(ii) Trend Analysis Plot ±20%



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

Trend analysis was carried on the monitoring data of the year 2022 and 2023, for a ± 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 ± 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 ±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**
	Total	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 (±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_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	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 ± 20% variation Base Year data June 2022

Trend analysis was carried out for ± 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 ± 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 ± 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 ±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**
	Total	17	47	19	2	**85**

Table No.4.21: 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 (2022-2023)

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	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.

Trend analysis for Change in Water spread area of Glacial Lakes (10-50 Ha) for ±10% & ±20% w.r.t base year data of June 2022

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 ±10%

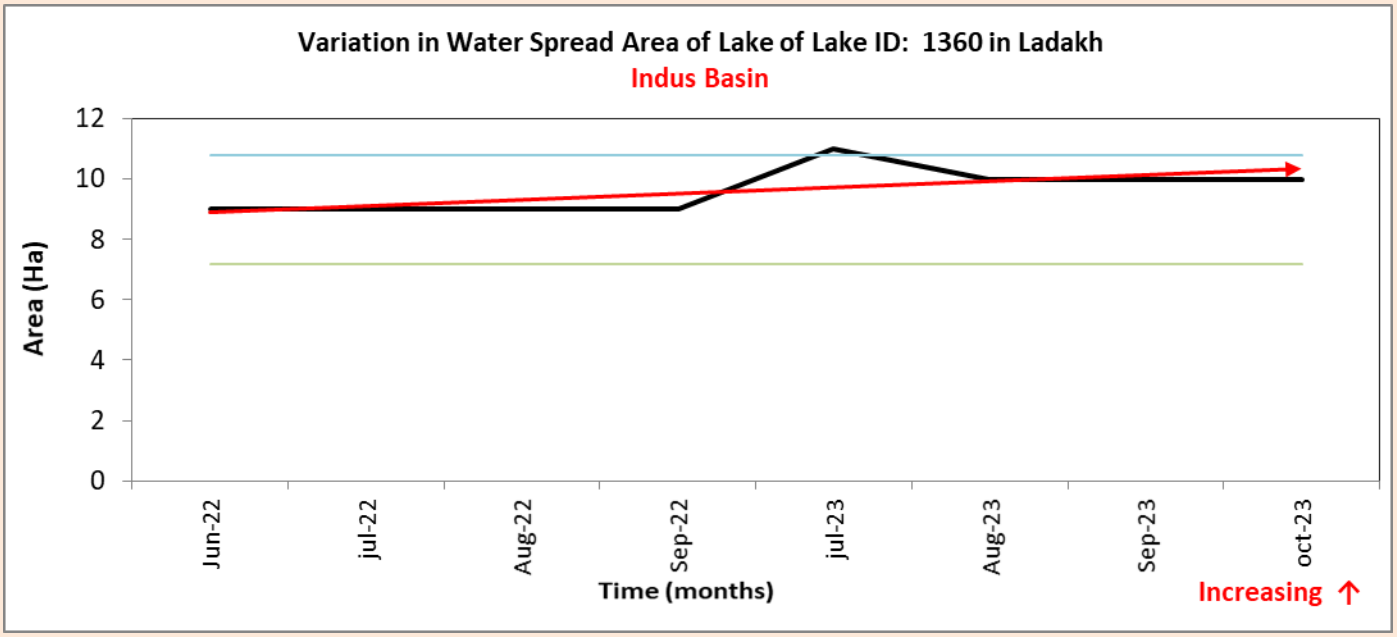


Figure 4.122(ii) Trend Analysis Plot ±20%

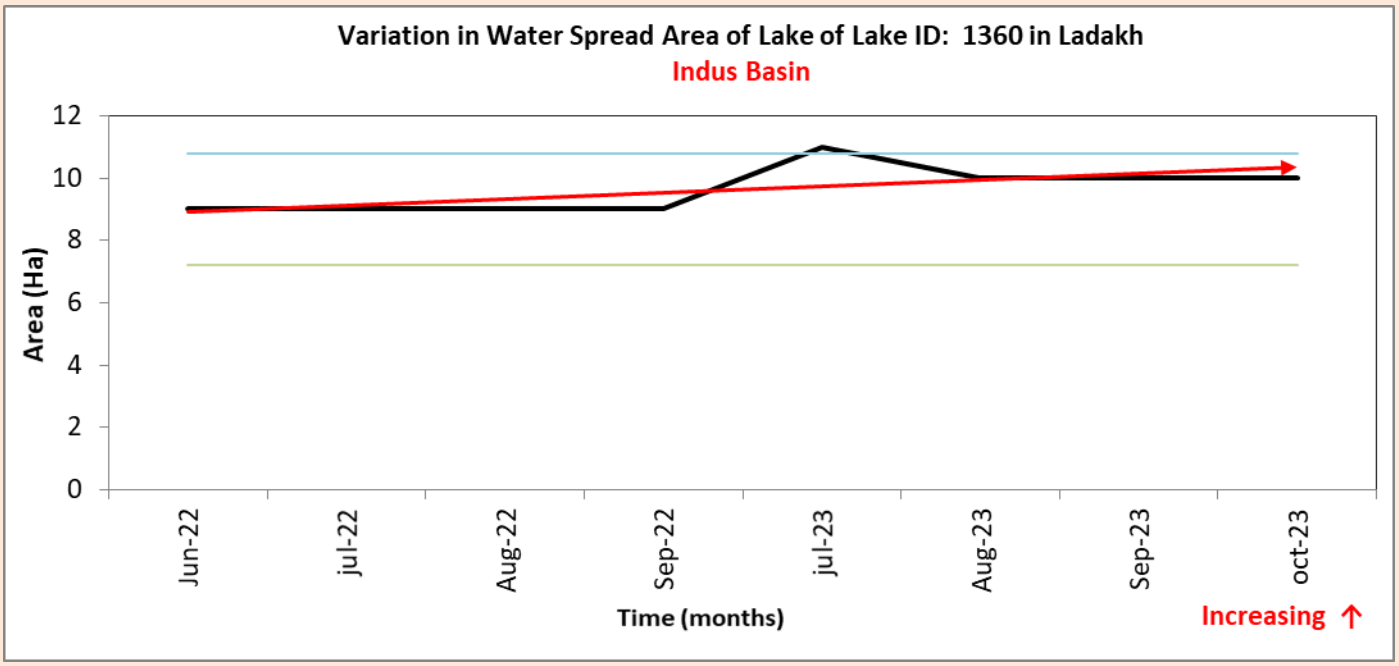


Figure 4.123(i) Trend Analysis Plot ±10%

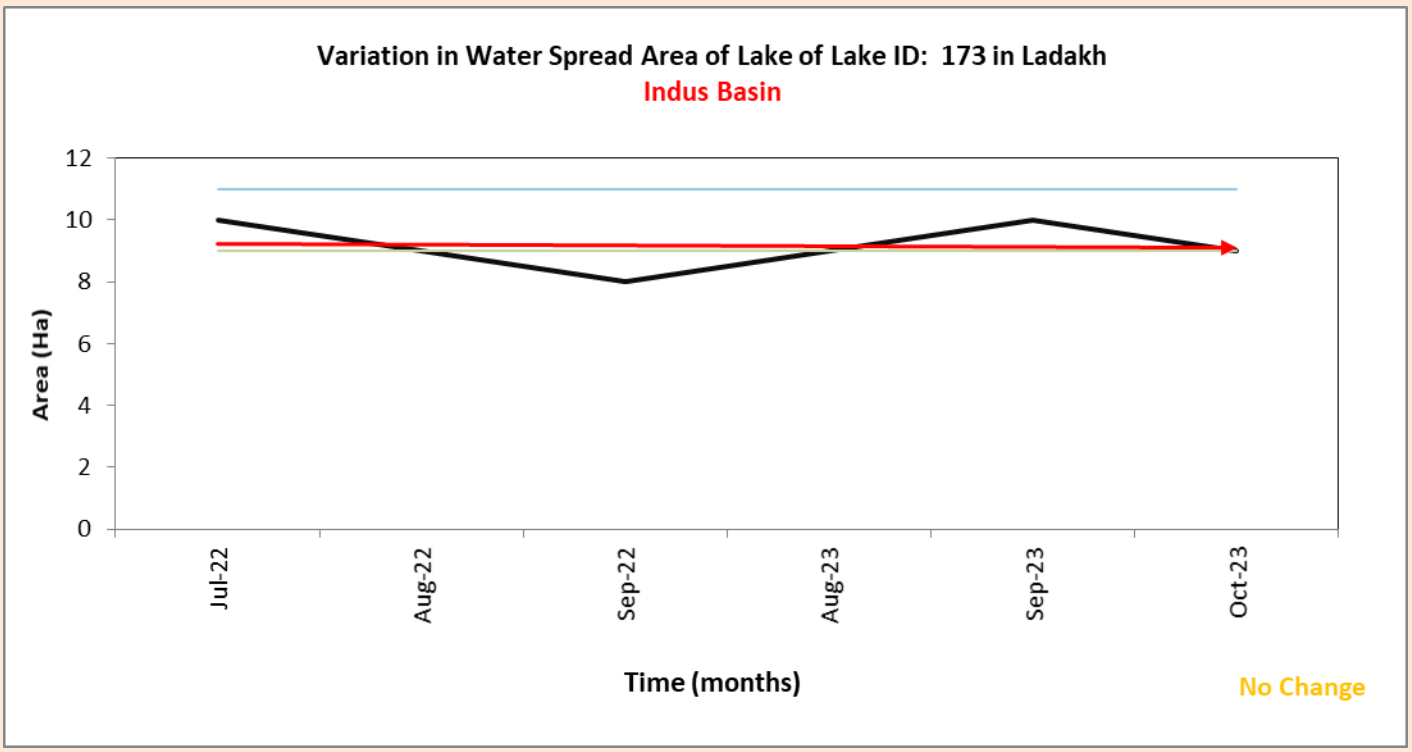


Figure 4.123(ii) Trend Analysis Plot ±20%

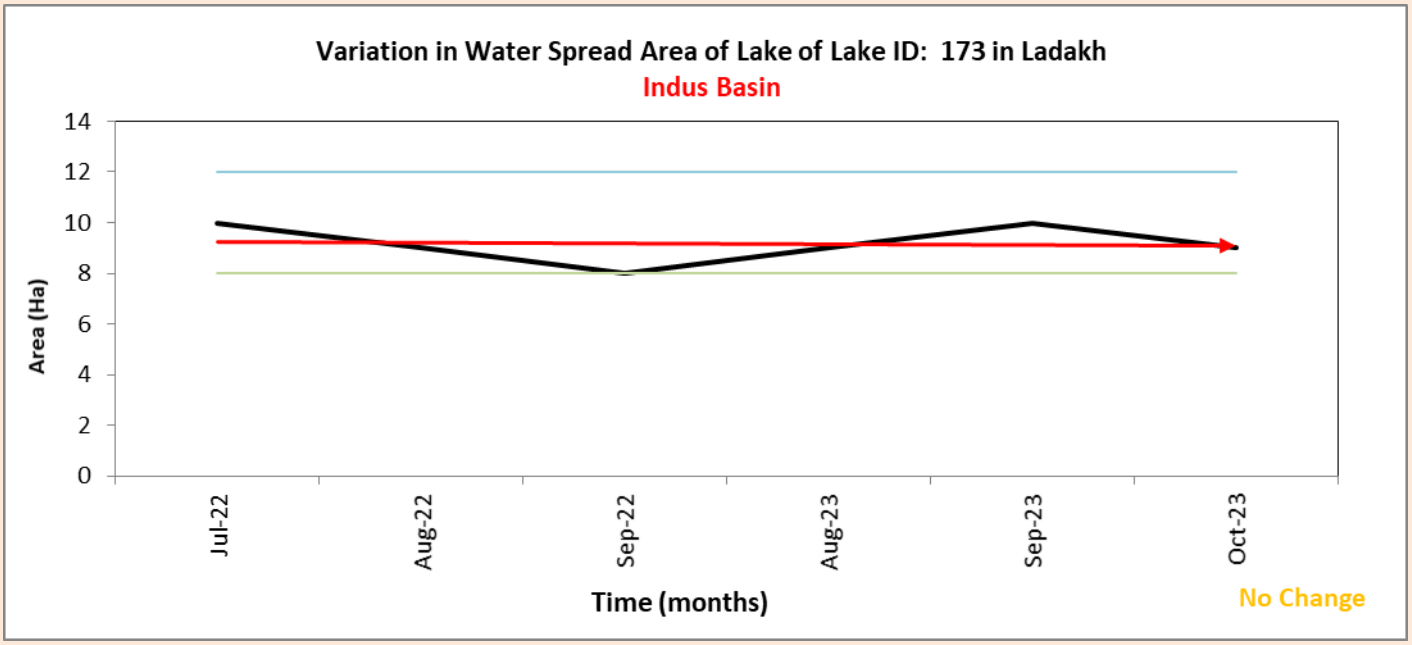


Figure 4.124(i) Trend Analysis Plot ±10%

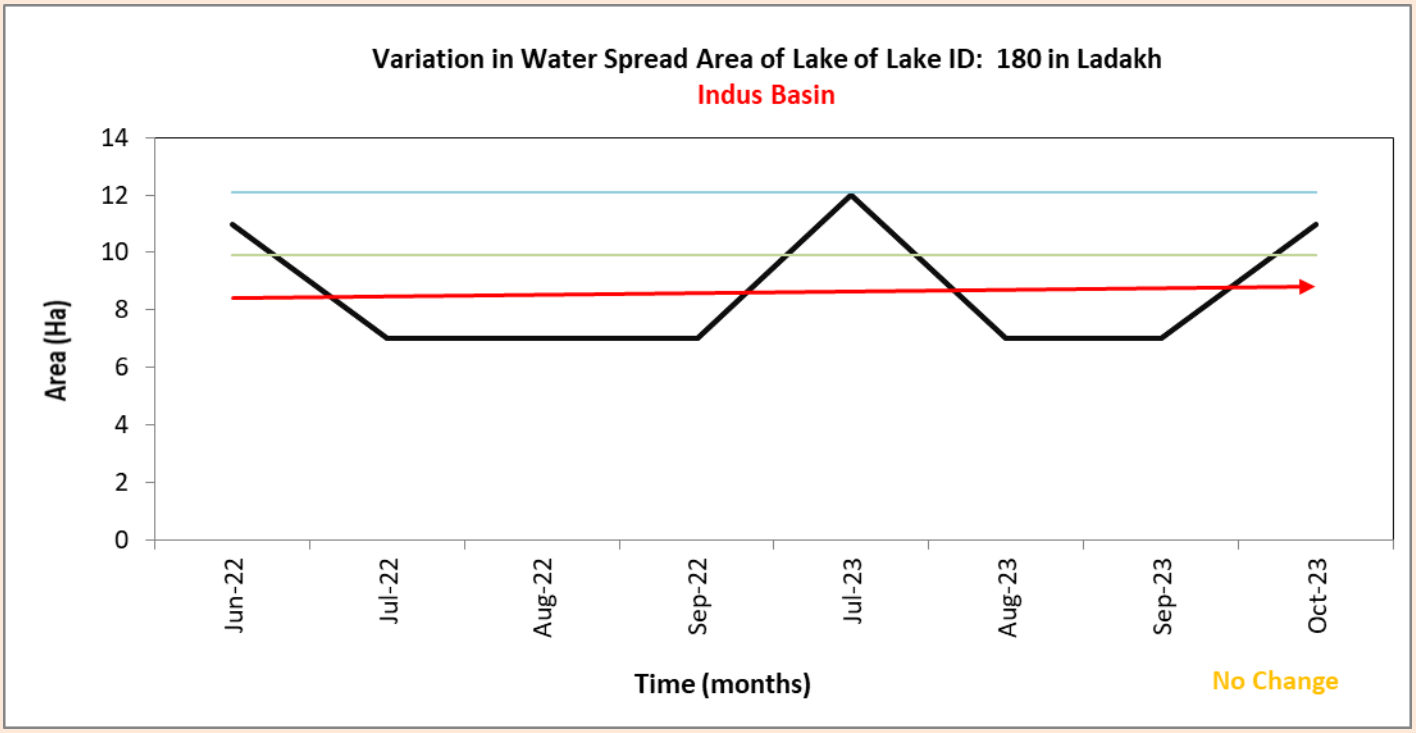


Figure 4.124(ii) Trend Analysis Plot ±20%

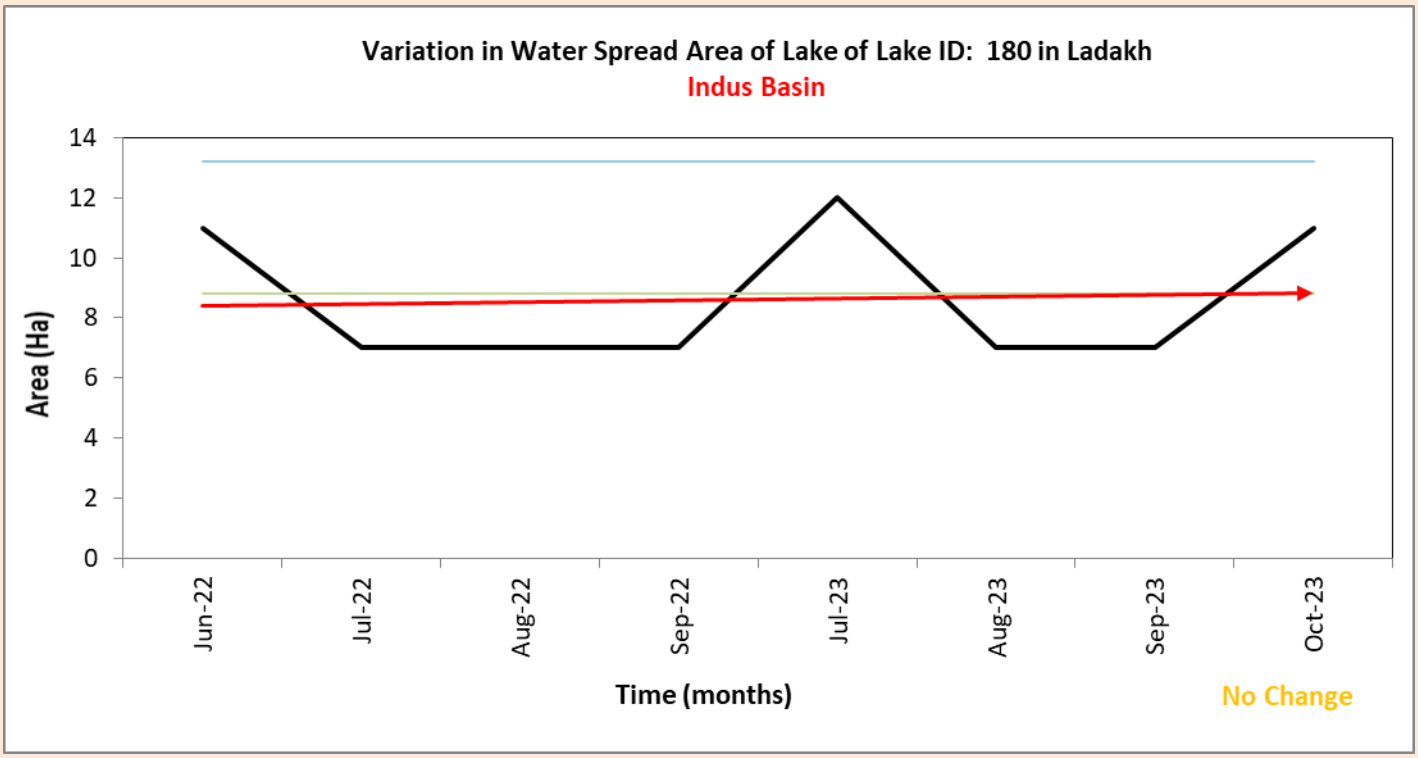


Figure 4.125(i) Trend Analysis Plot ±10%

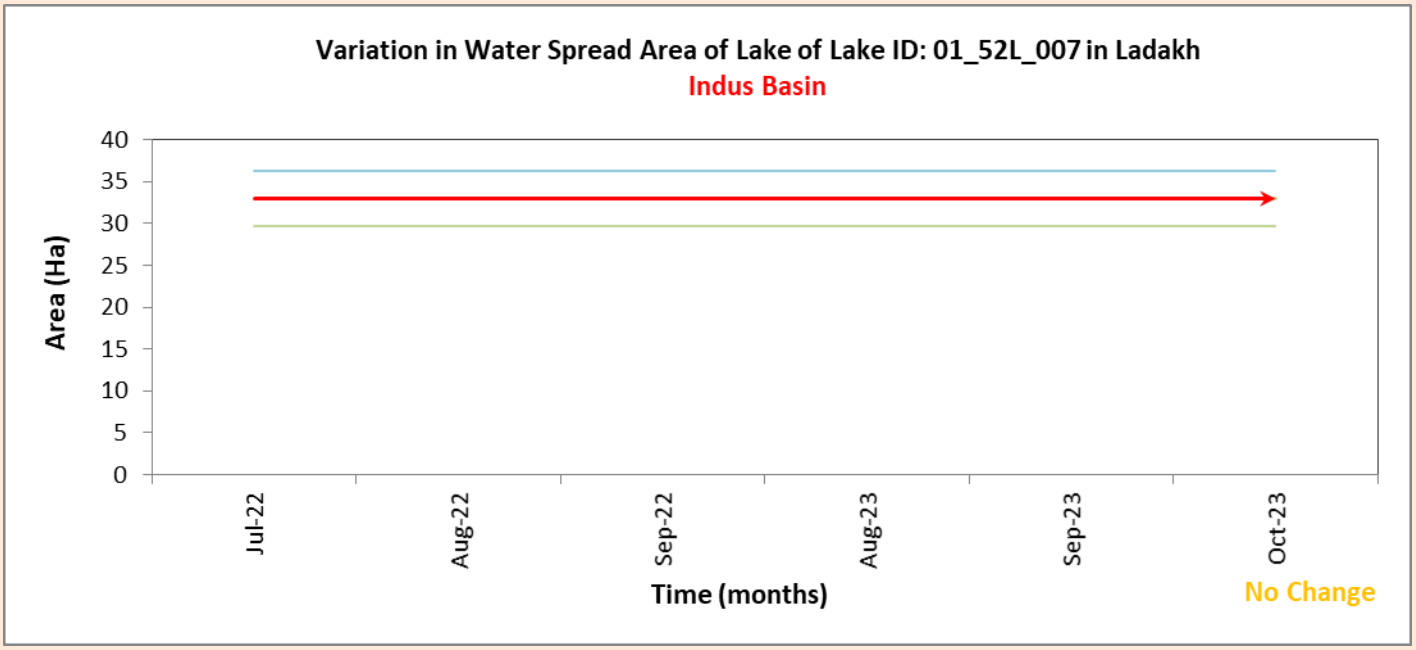


Figure 4.125(ii) Trend Analysis Plot ±20%

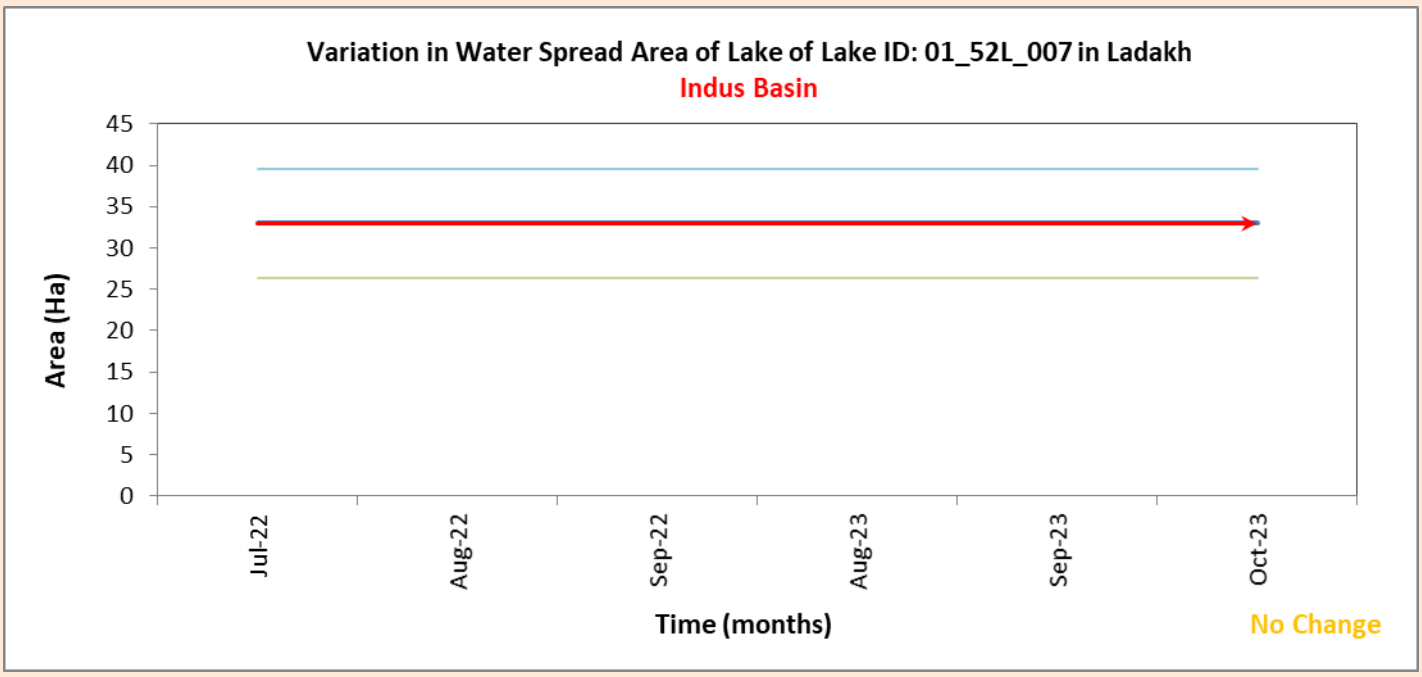


Figure 4.126(i) Trend Analysis Plot ±10%

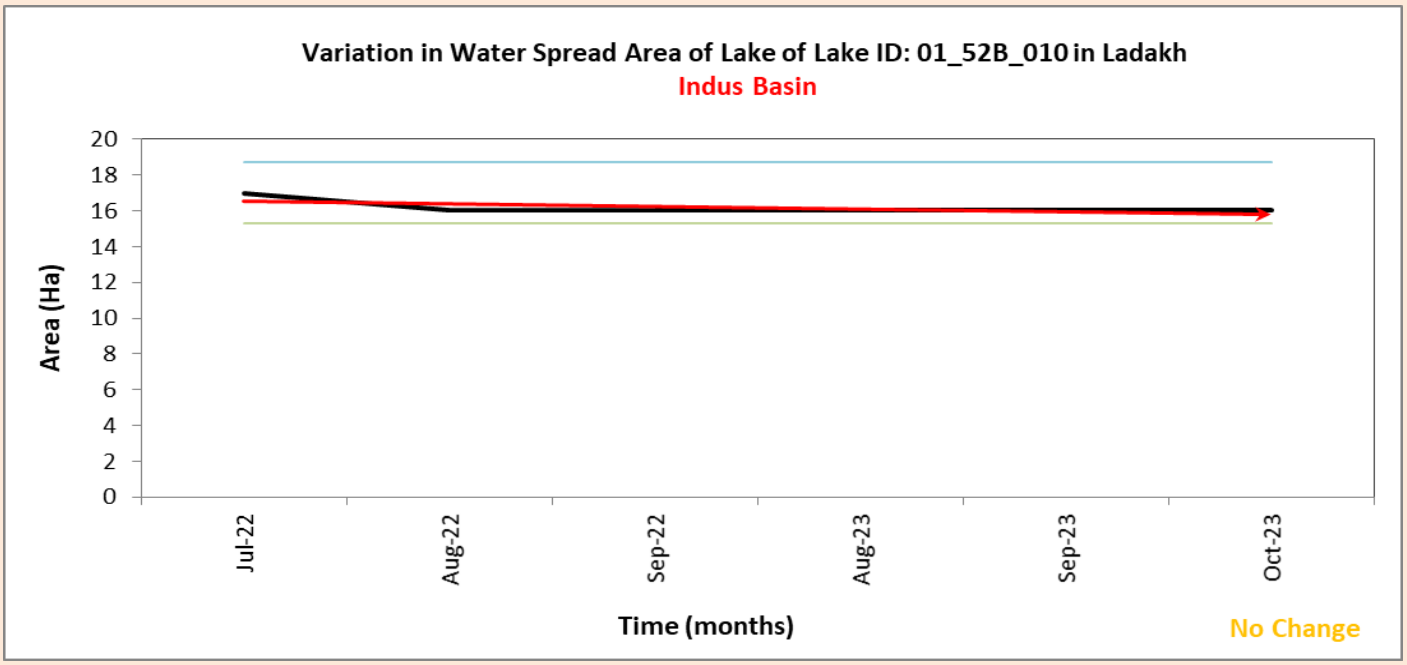


Figure 4.126(ii) Trend Analysis Plot ±20%

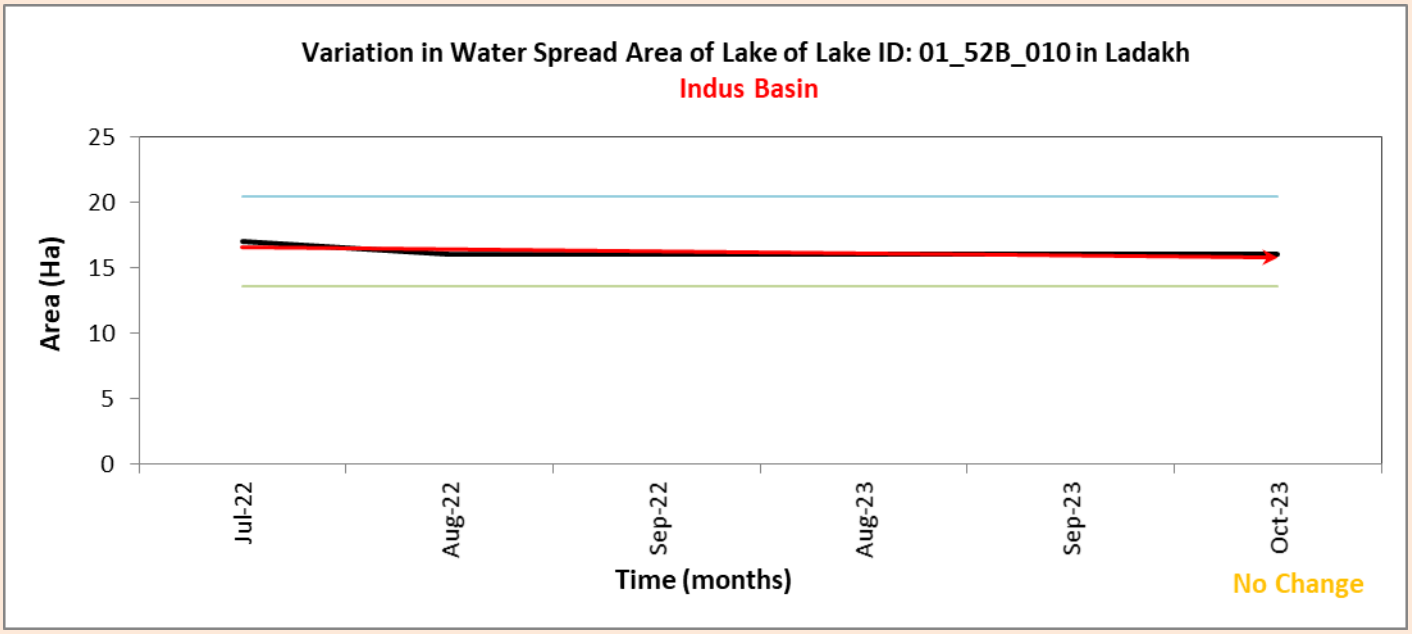


Figure 4.127(i) Trend Analysis Plot ±10%

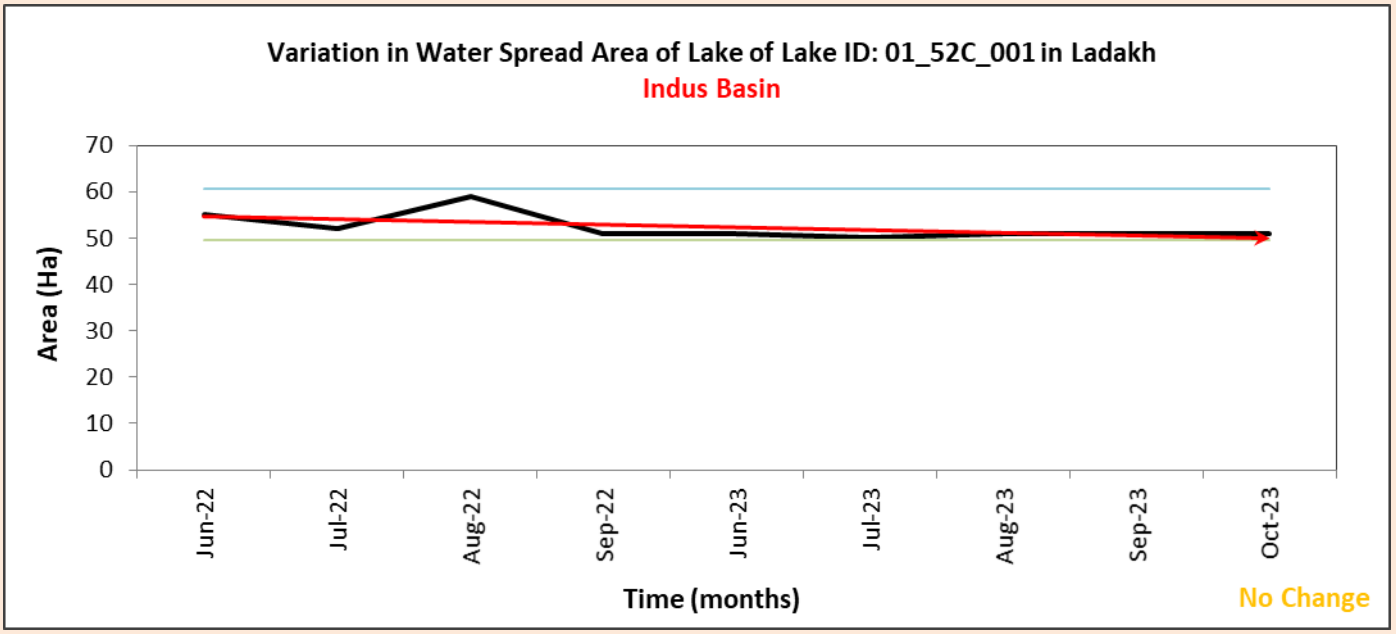


Figure 4.127(ii) Trend Analysis Plot ±20%

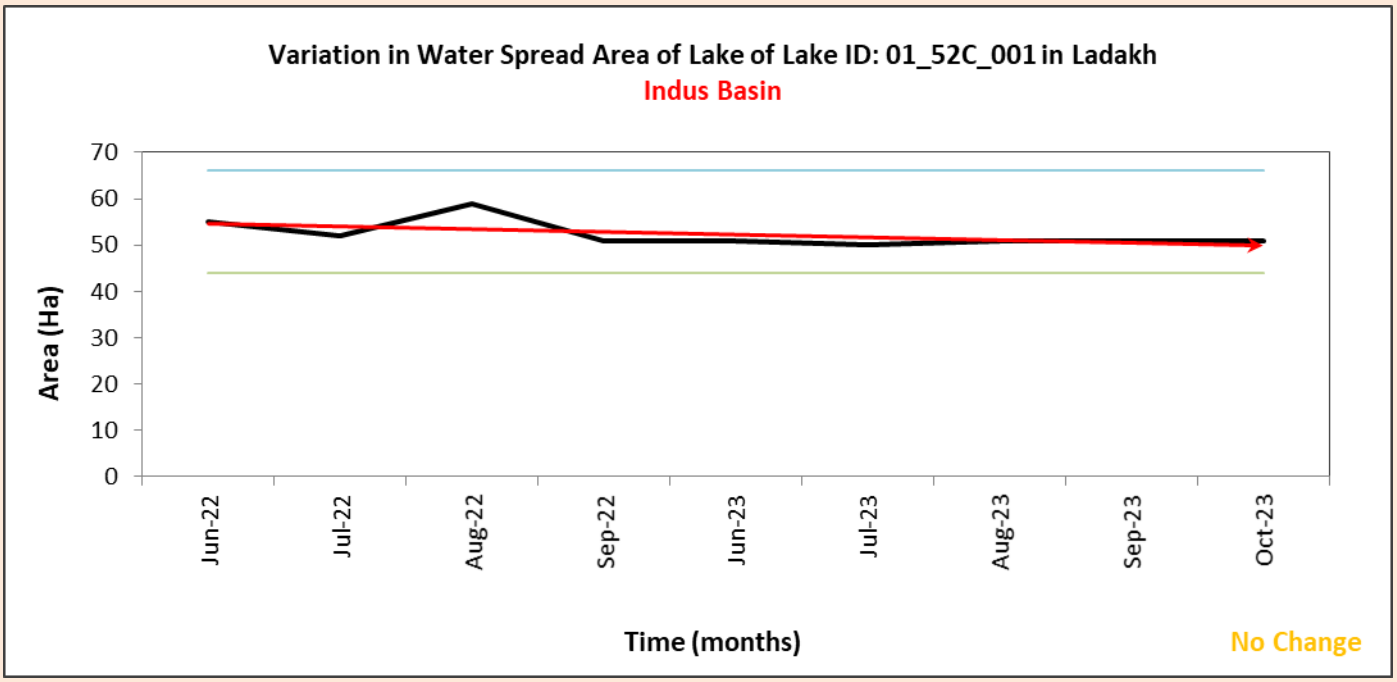


Figure 4.128(i) Trend Analysis Plot ±10%

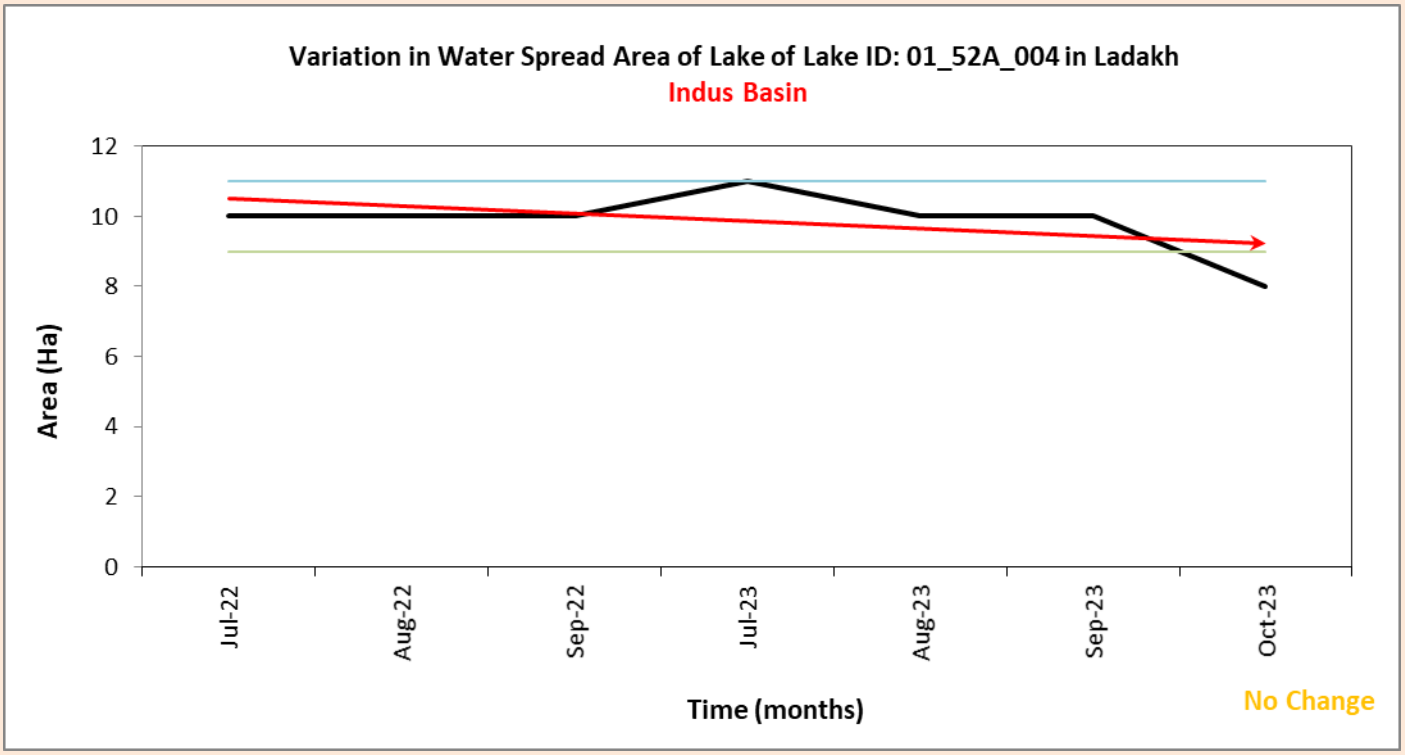


Figure 4.128(ii) Trend Analysis Plot ±20%

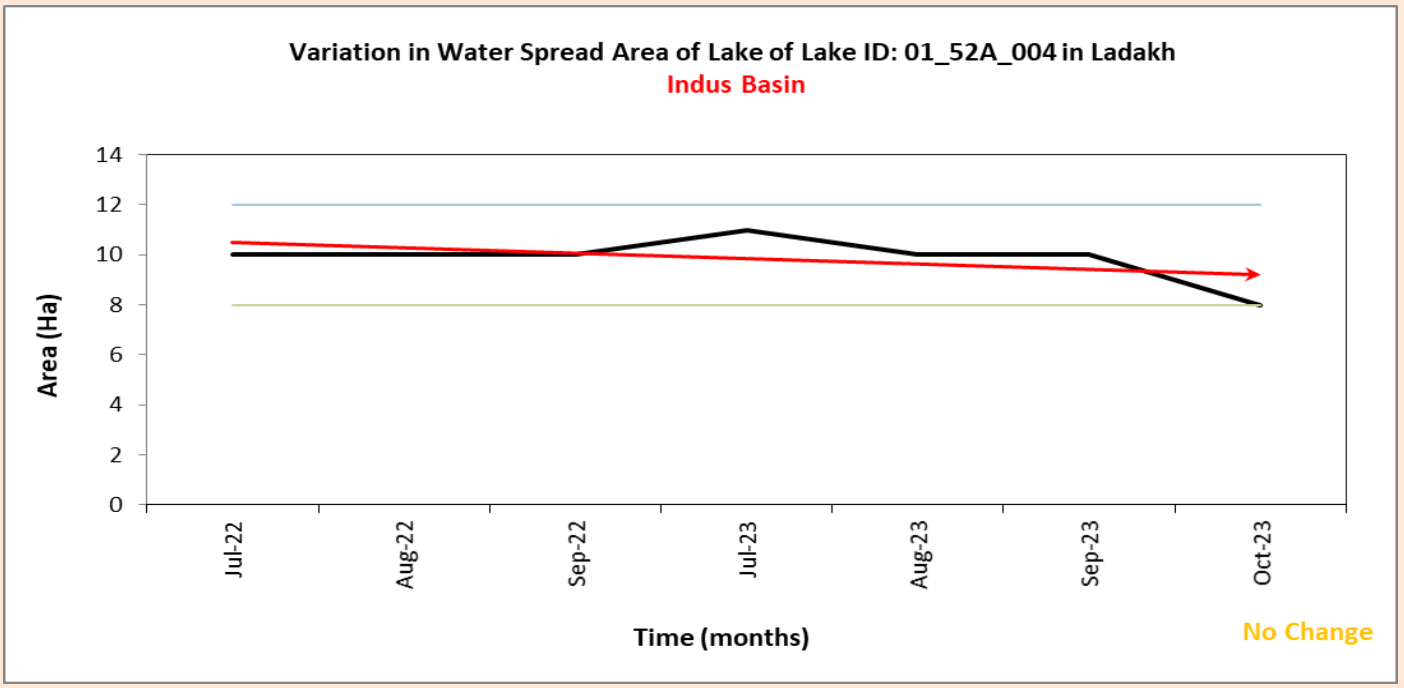


Figure 4.129(i) Trend Analysis Plot ±10%

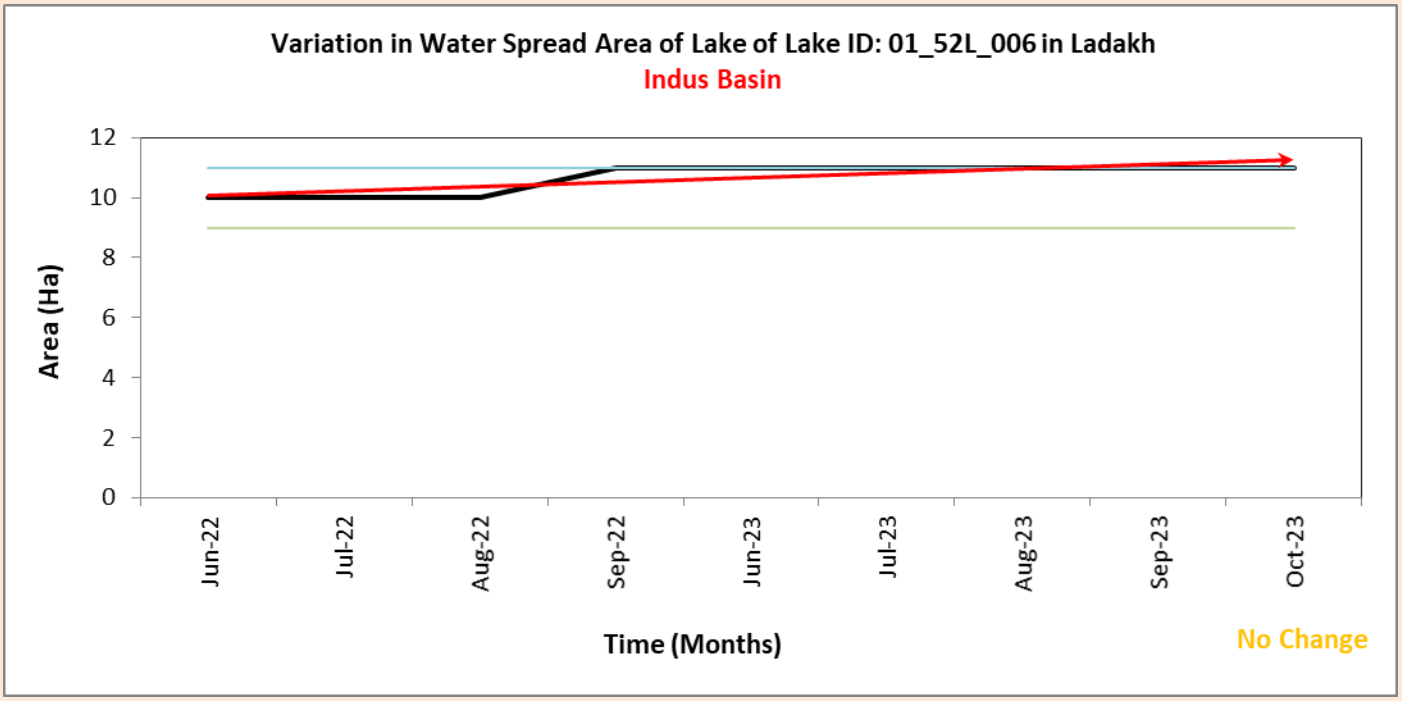


Figure 4.129(ii) Trend Analysis Plot ±20%

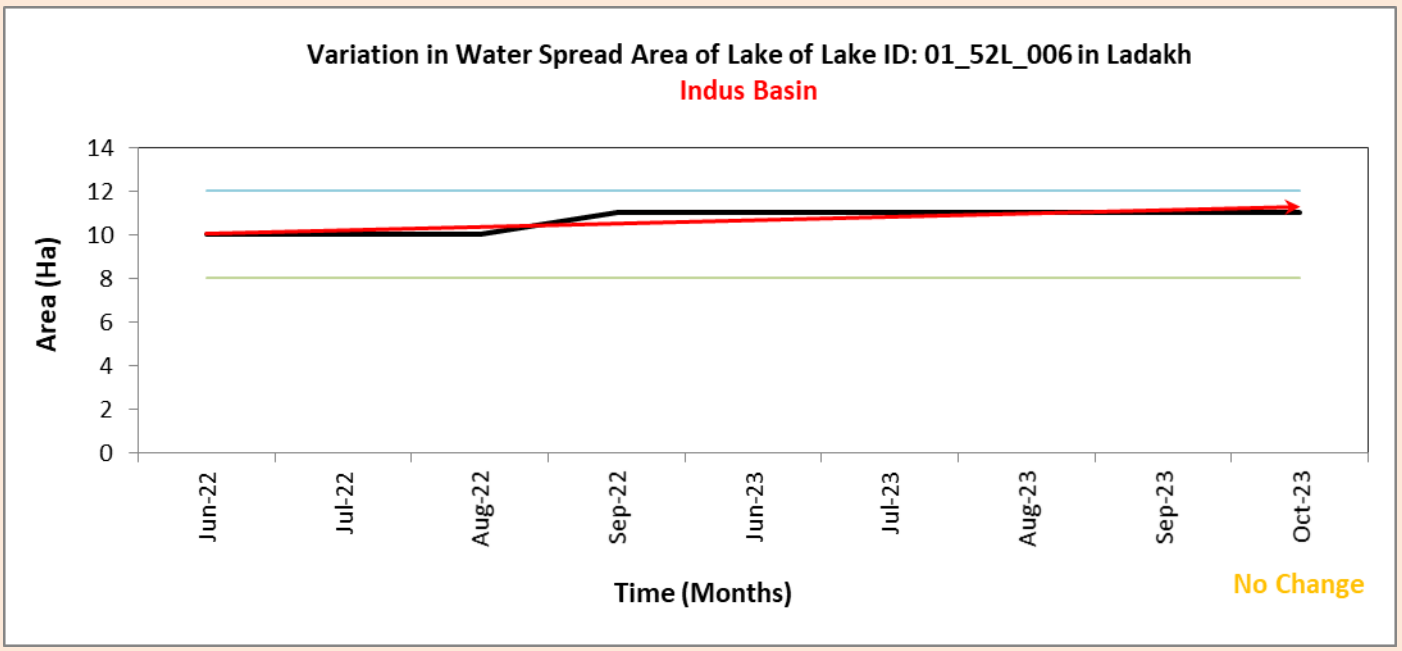


Figure 4.130(i) Trend Analysis Plot ±10%

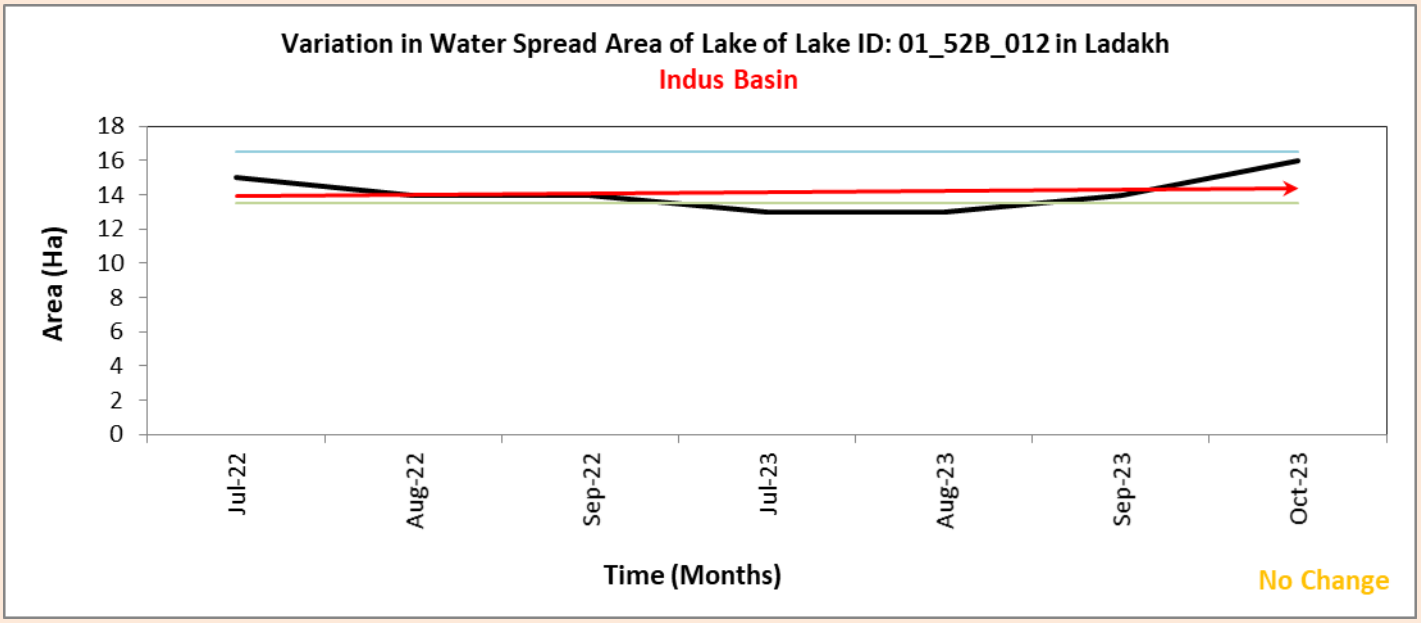


Figure 4.130(ii) Trend Analysis Plot ±20%

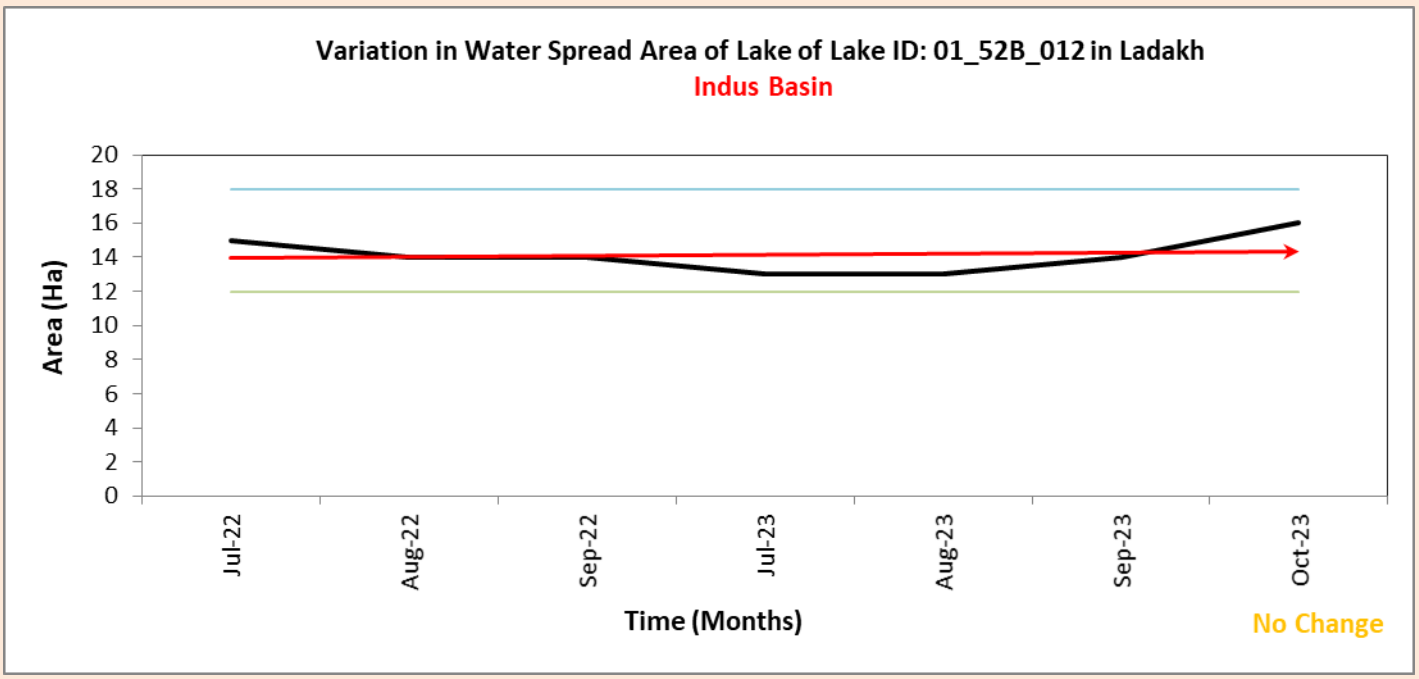


Figure 4.131(i) Trend Analysis Plot ±10%

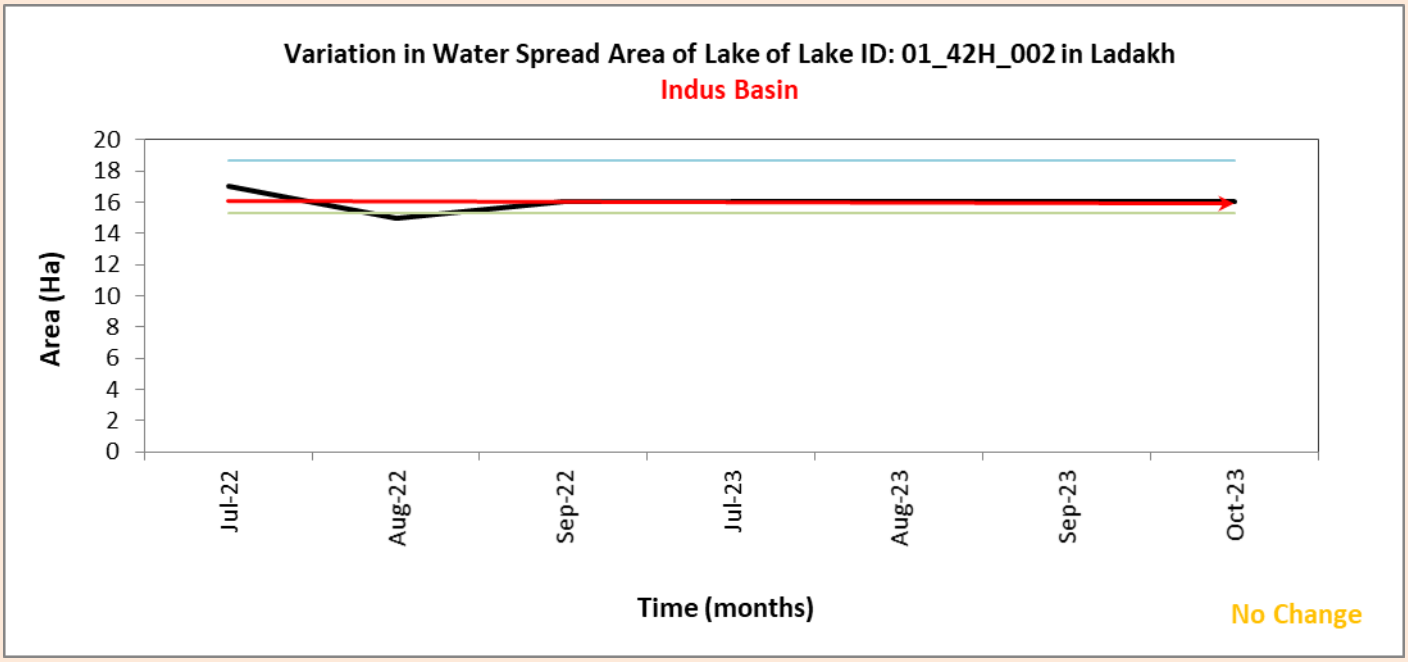


Figure 4.131(ii) Trend Analysis Plot ±20%

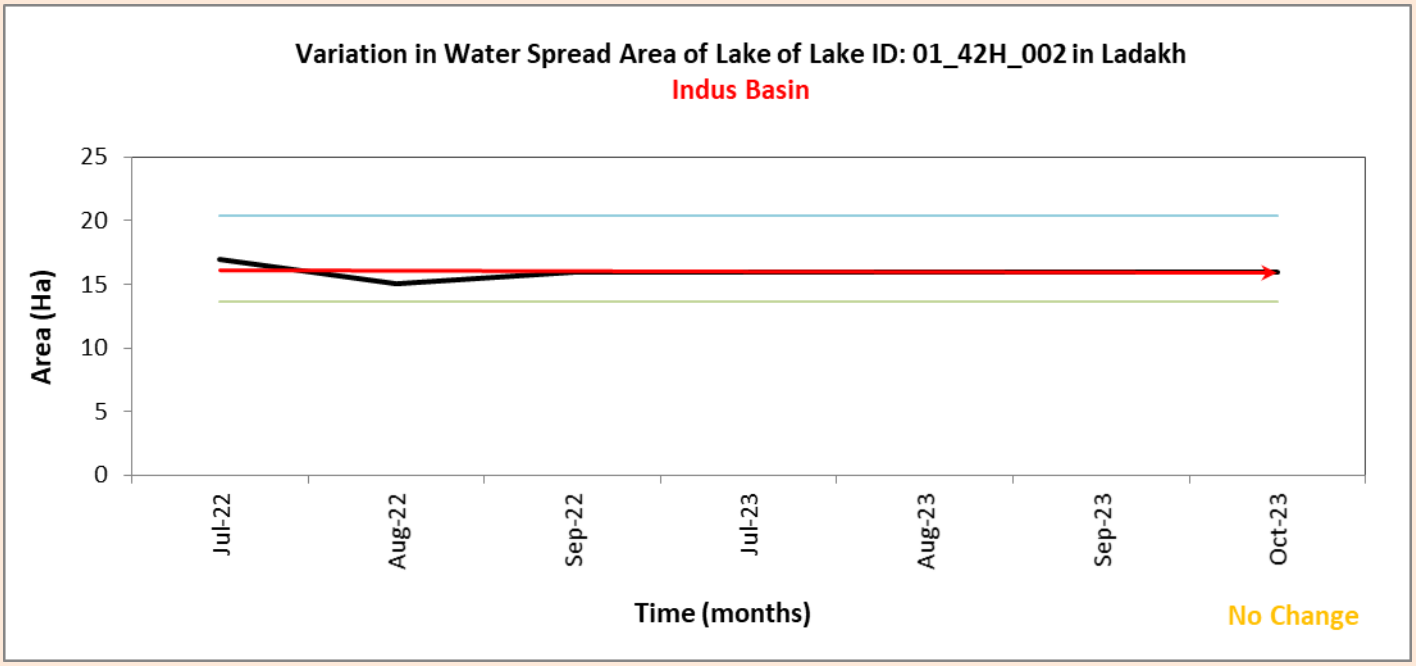


Figure 4.132(i) Trend Analysis Plot ±10%

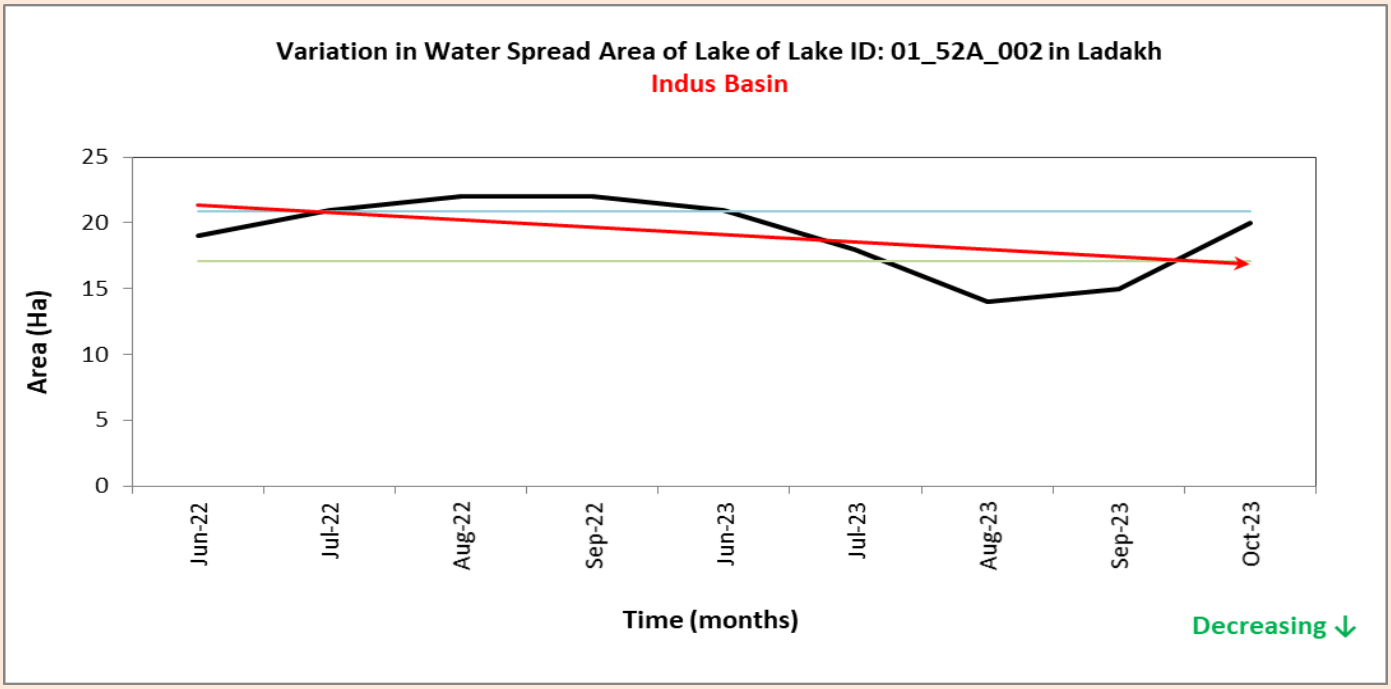


Figure 4.132(ii) Trend Analysis Plot ±20%

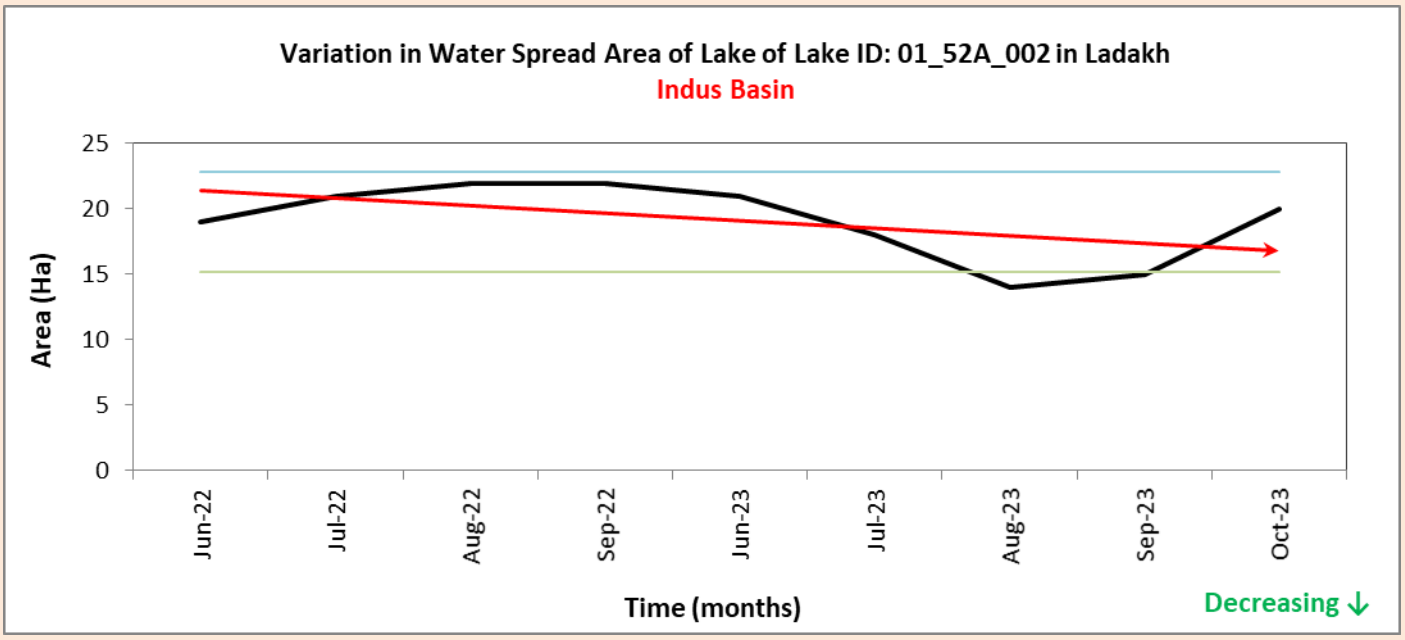


Figure 4.133(i) Trend Analysis Plot ±10%

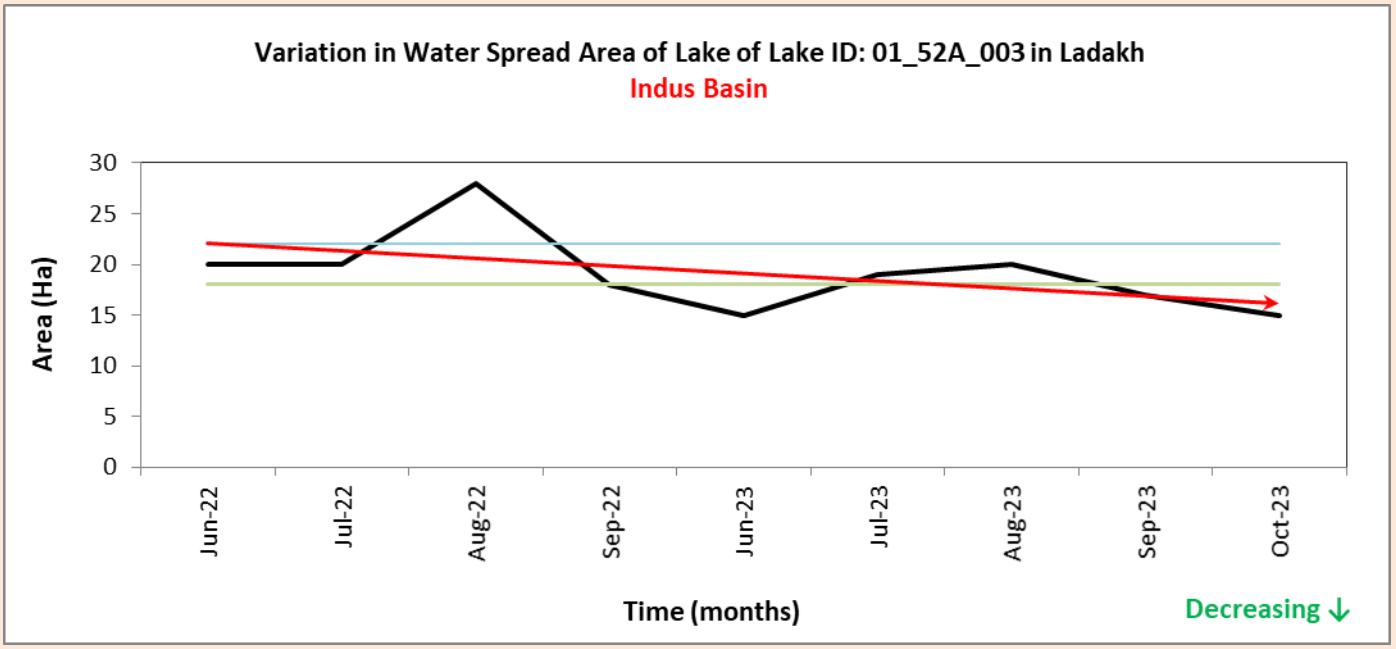
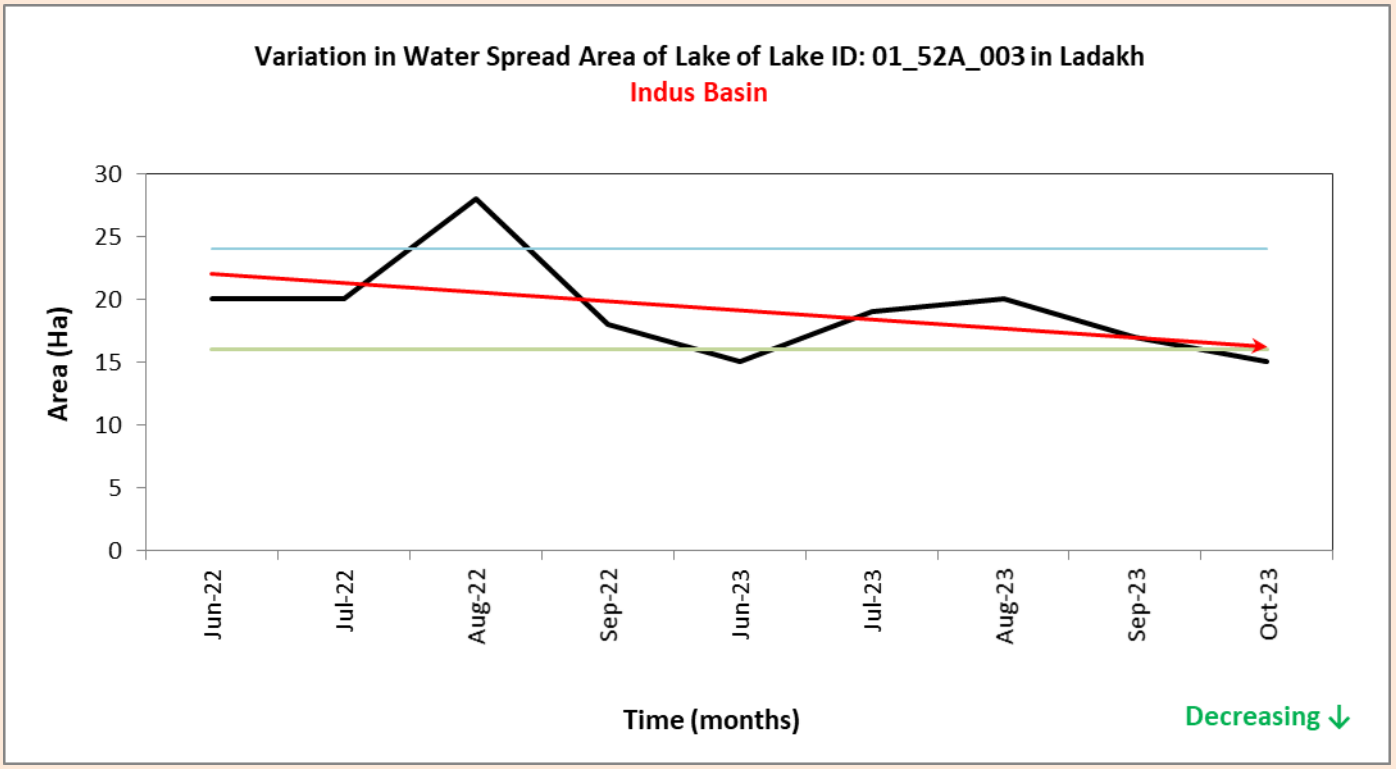


Figure 4.133(ii) Trend Analysis Plot ±20%



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 ±10%

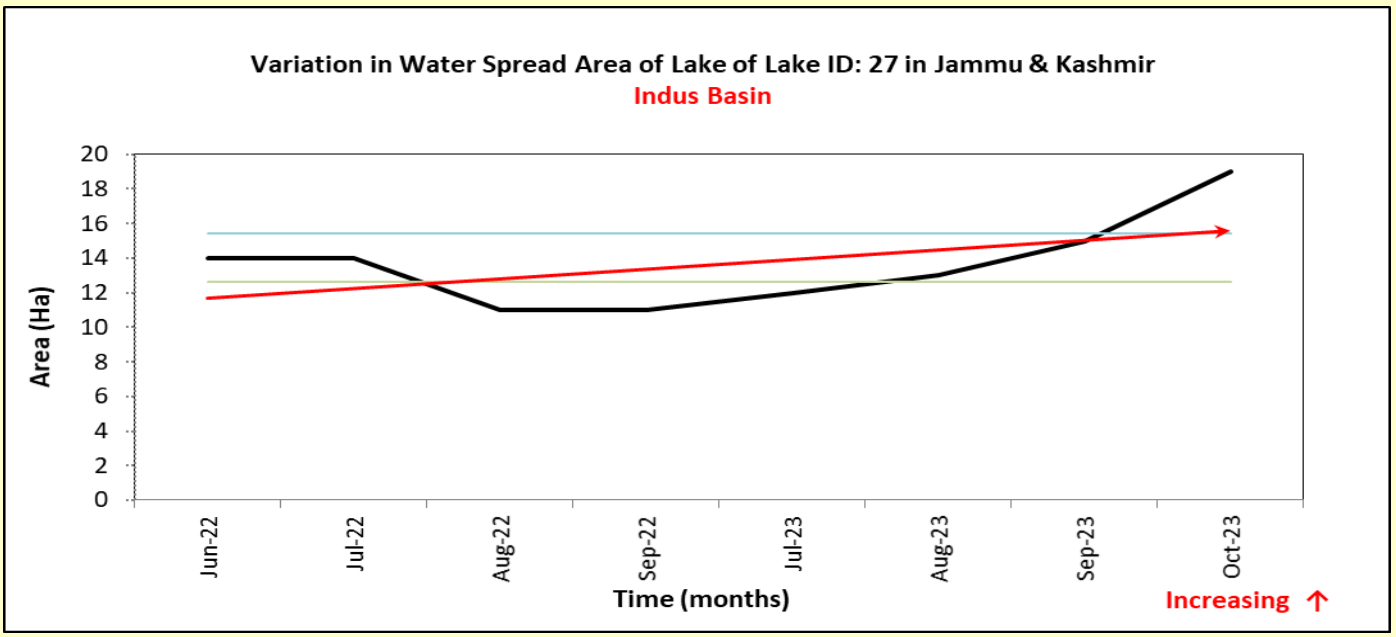


Figure 4.134(ii) Trend Analysis Plot ±20%

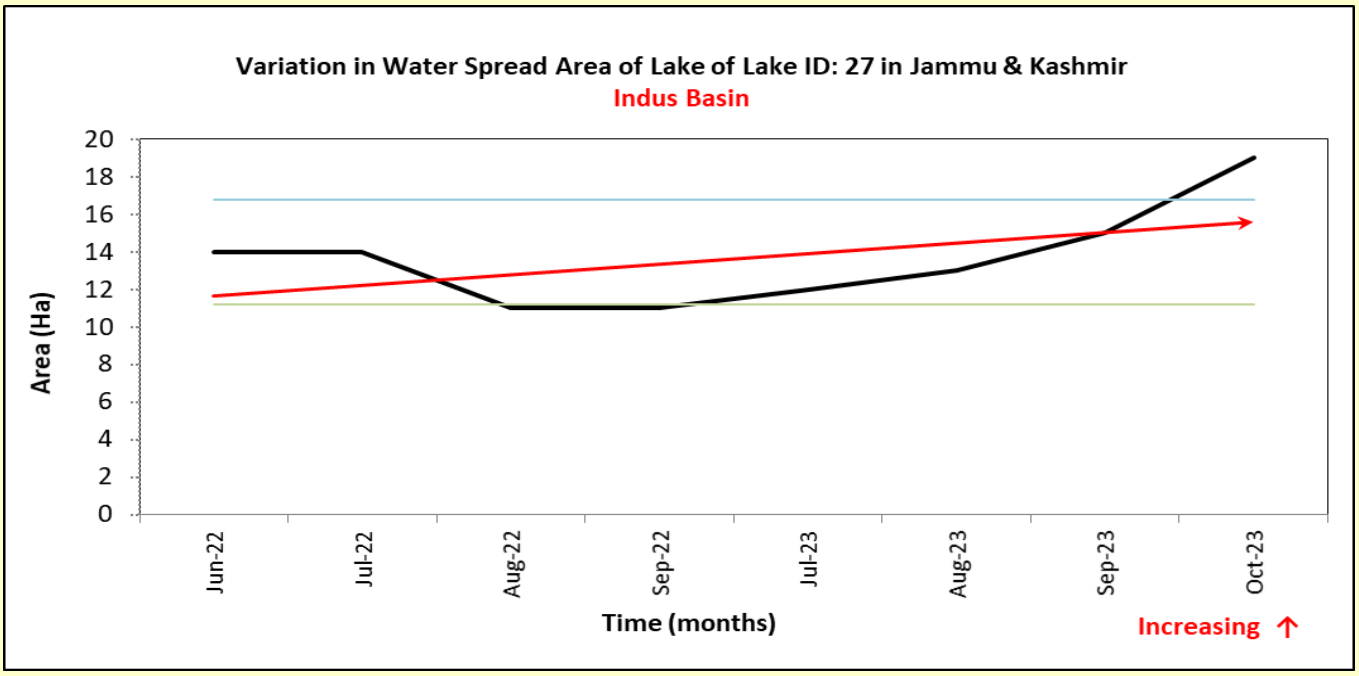


Figure 4.135(i) Trend Analysis Plot ±10%

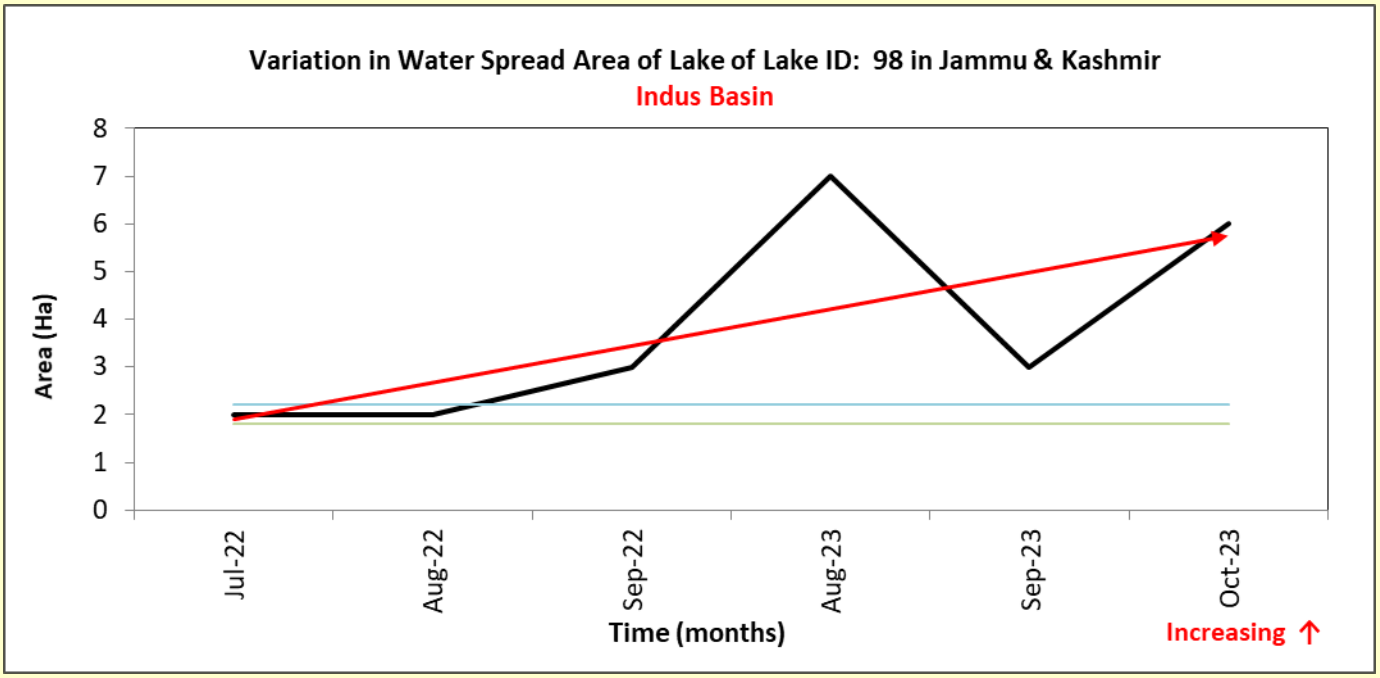


Figure 4.135(ii) Trend Analysis Plot ±20%

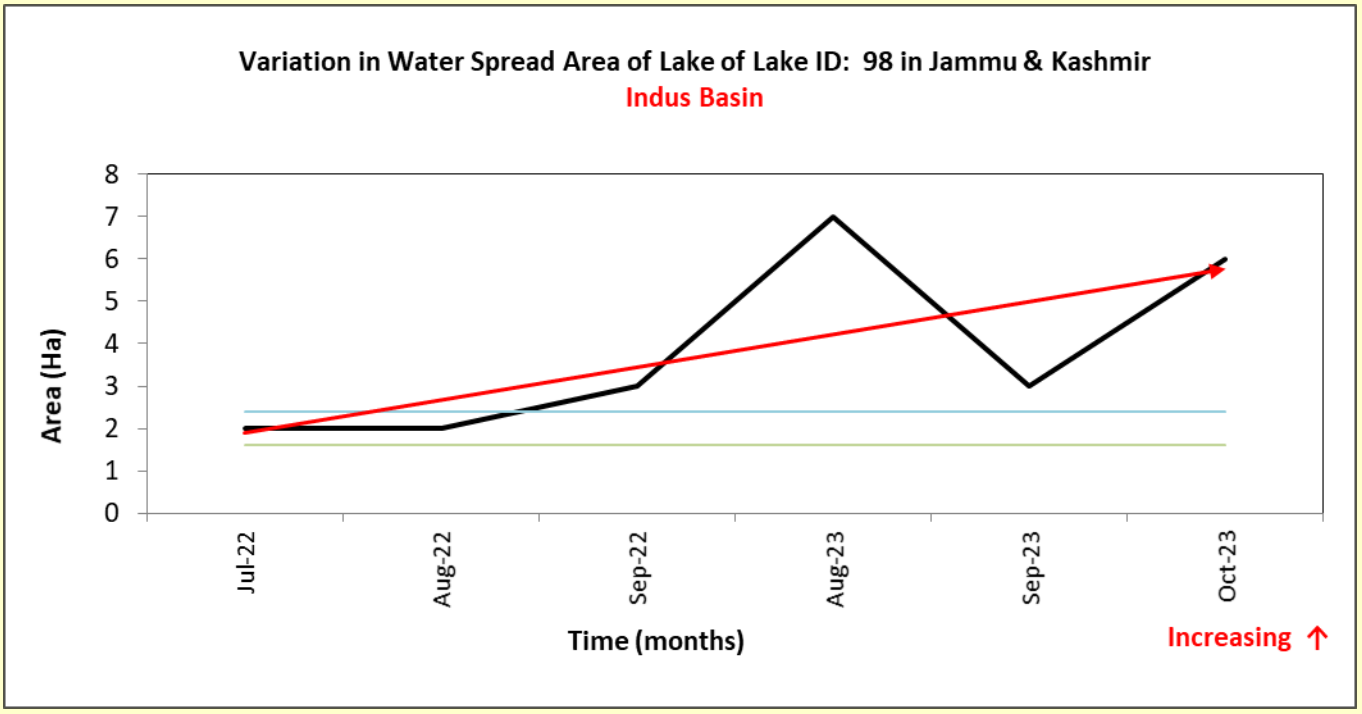


Figure 4.136(i) Trend Analysis Plot ±10%

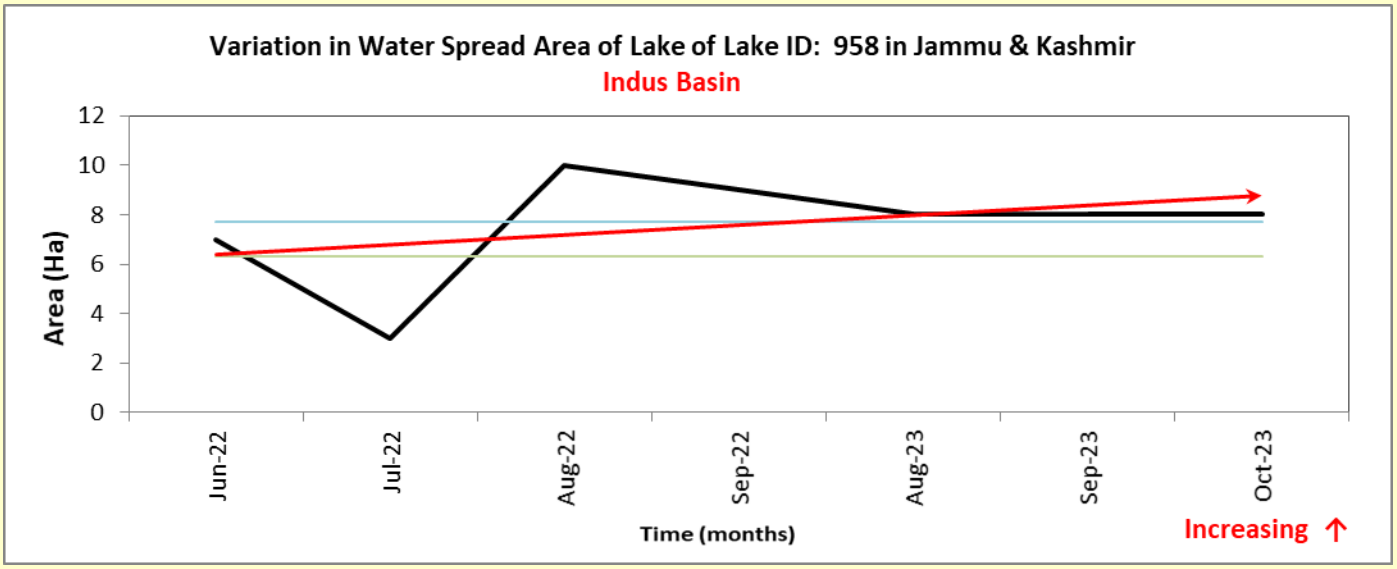


Figure 4.136(ii) Trend Analysis Plot ±20%

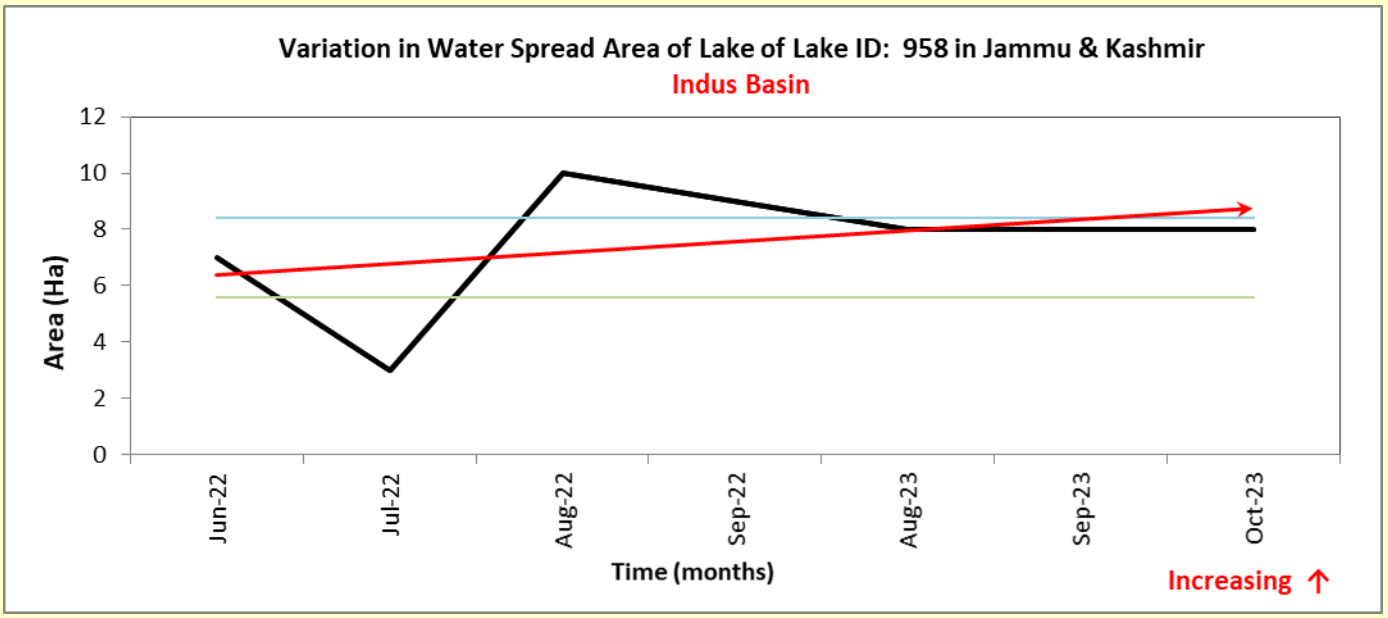


Figure 4.137(i) Trend Analysis Plot ±10%

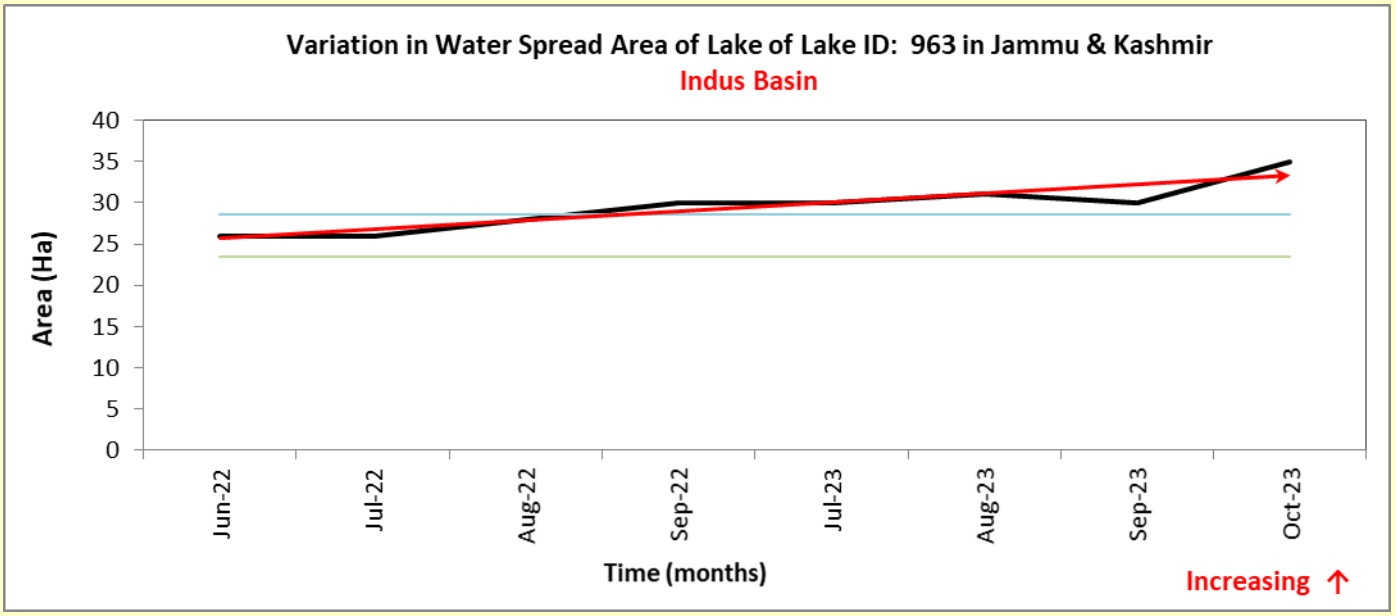


Figure 4.137(ii) Trend Analysis Plot ±20%

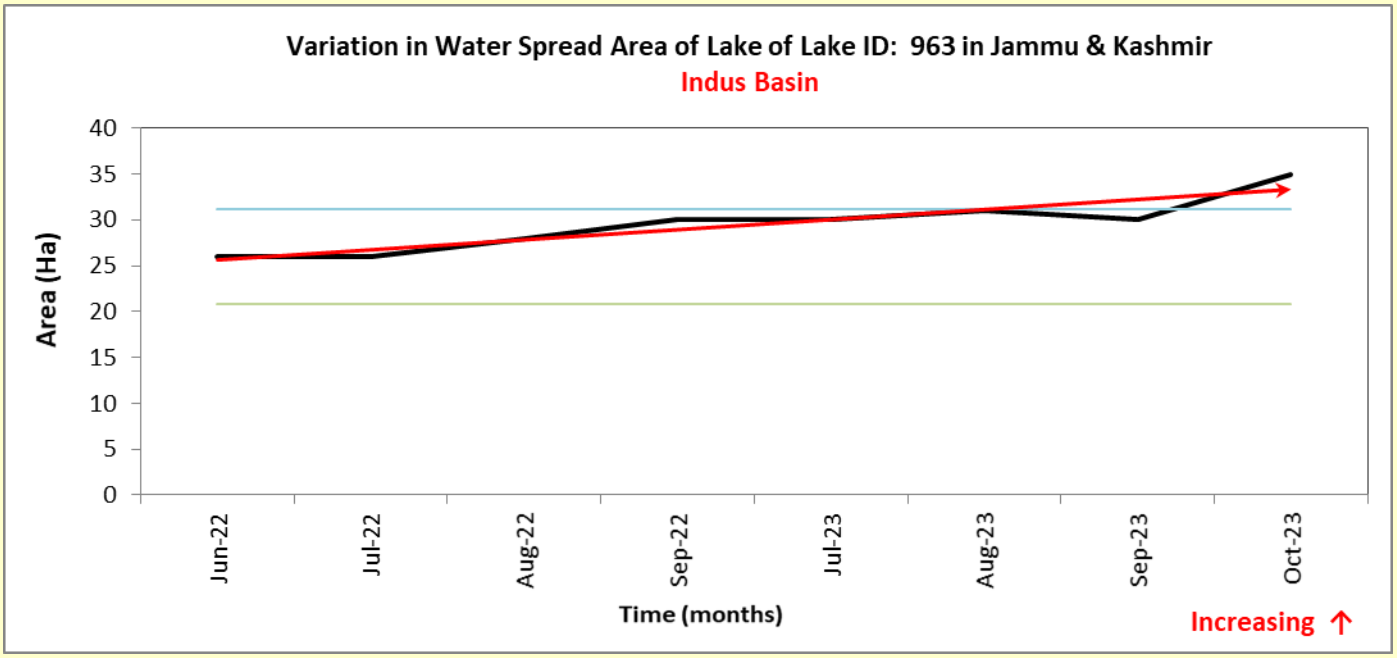


Figure 4.138(i) Trend Analysis Plot ±10%

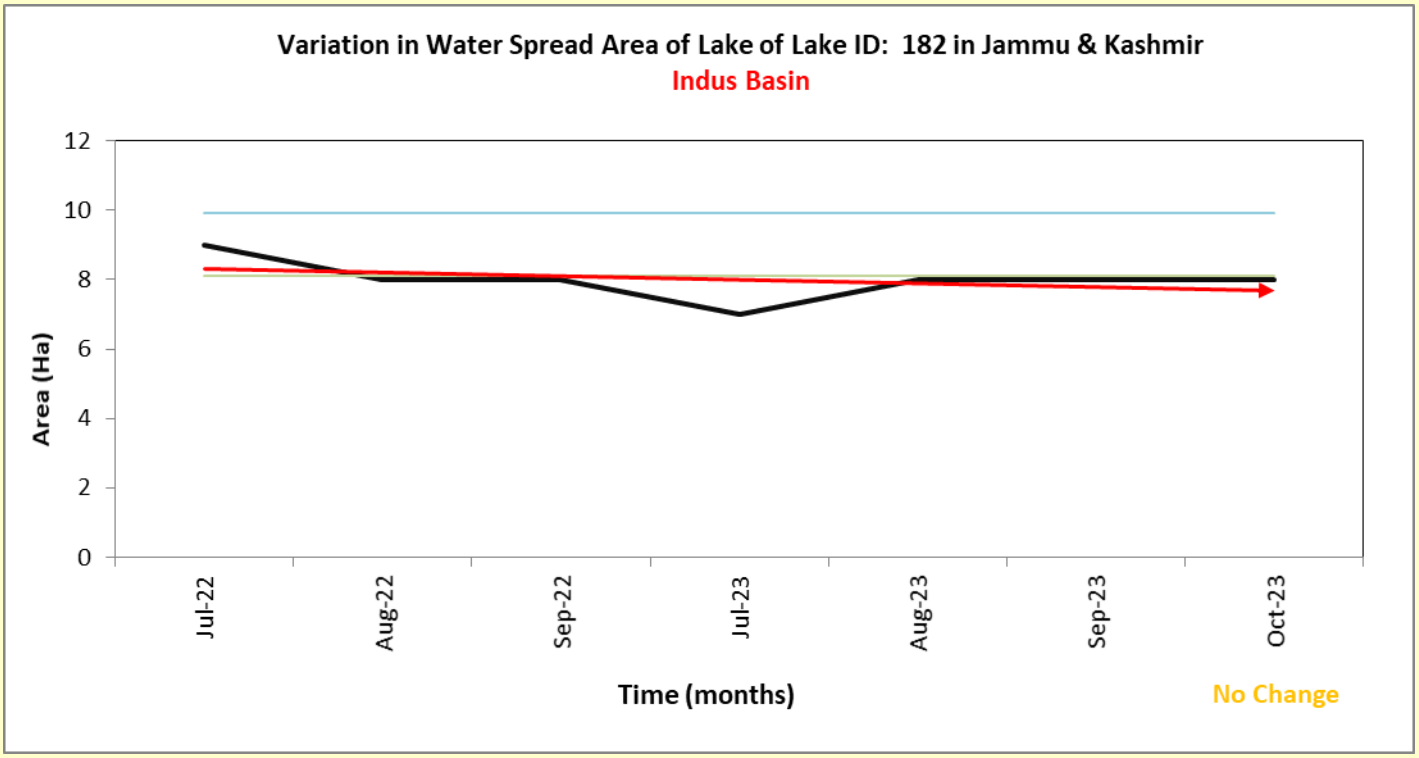


Figure 4.138(ii) Trend Analysis Plot ±20%

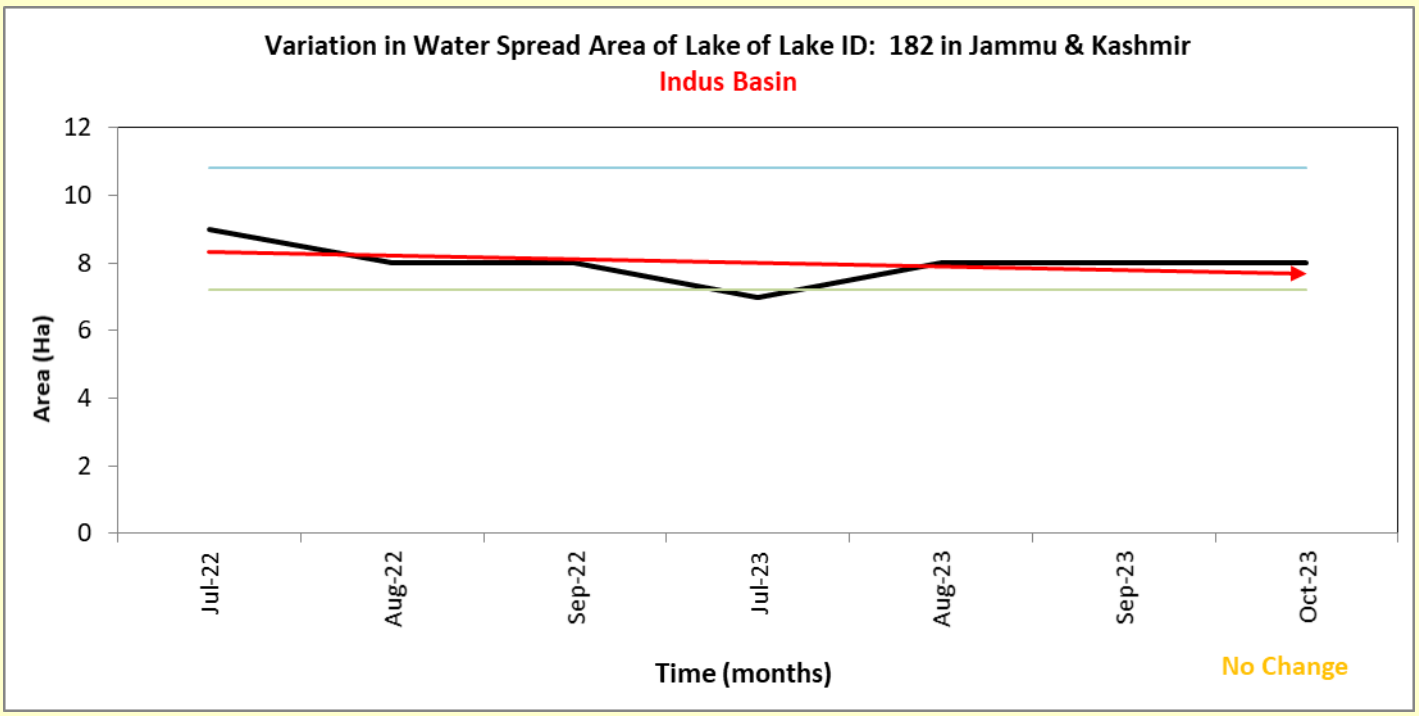


Figure 4.139(i) Trend Analysis Plot ±10%

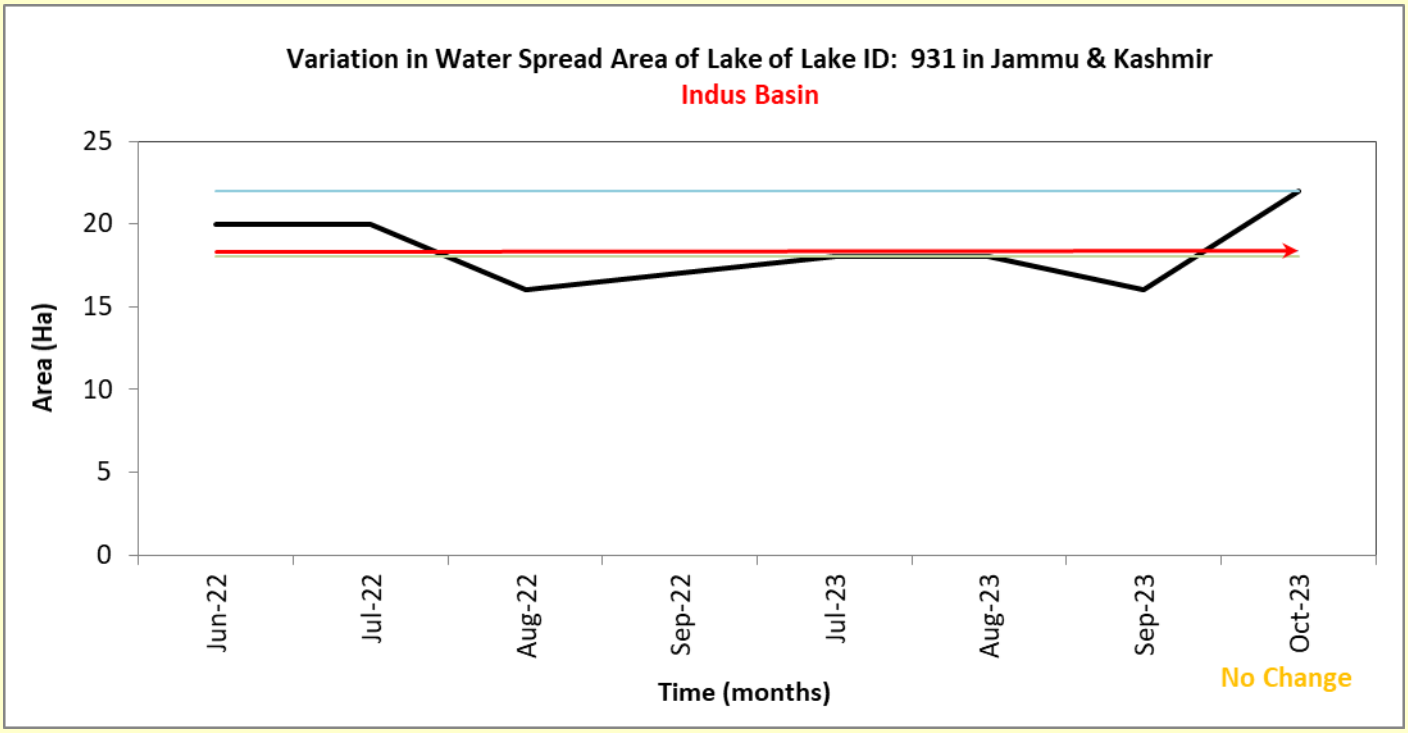


Figure 4.139(ii) Trend Analysis Plot ±20%

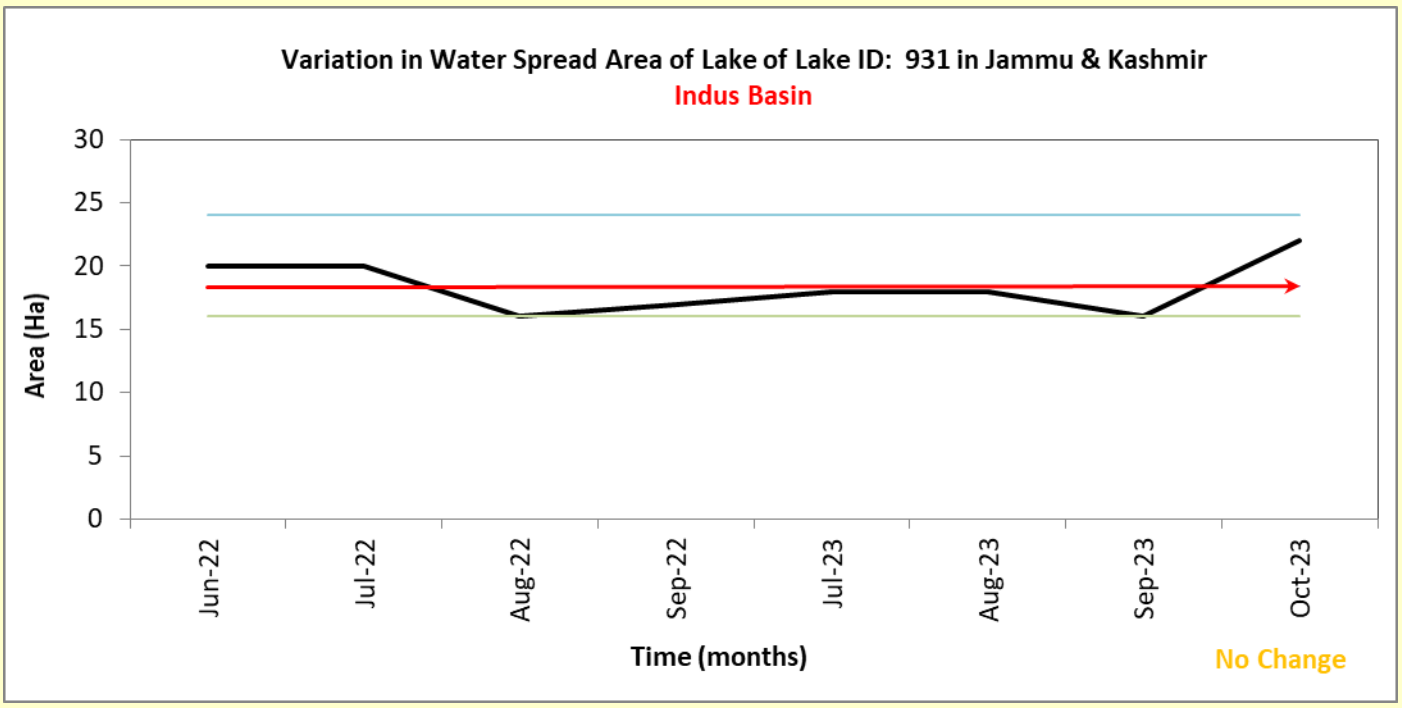


Figure 4.140(i) Trend Analysis Plot ±10%

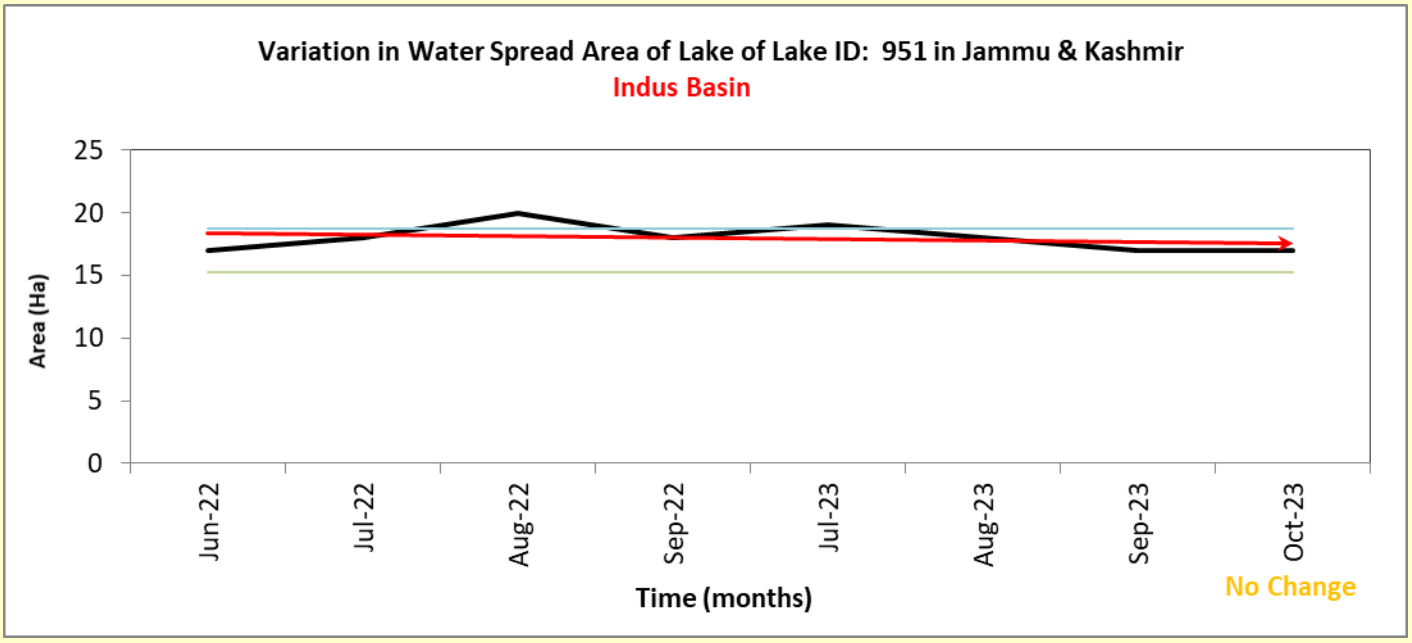


Figure 4.140(ii) Trend Analysis Plot ±20%

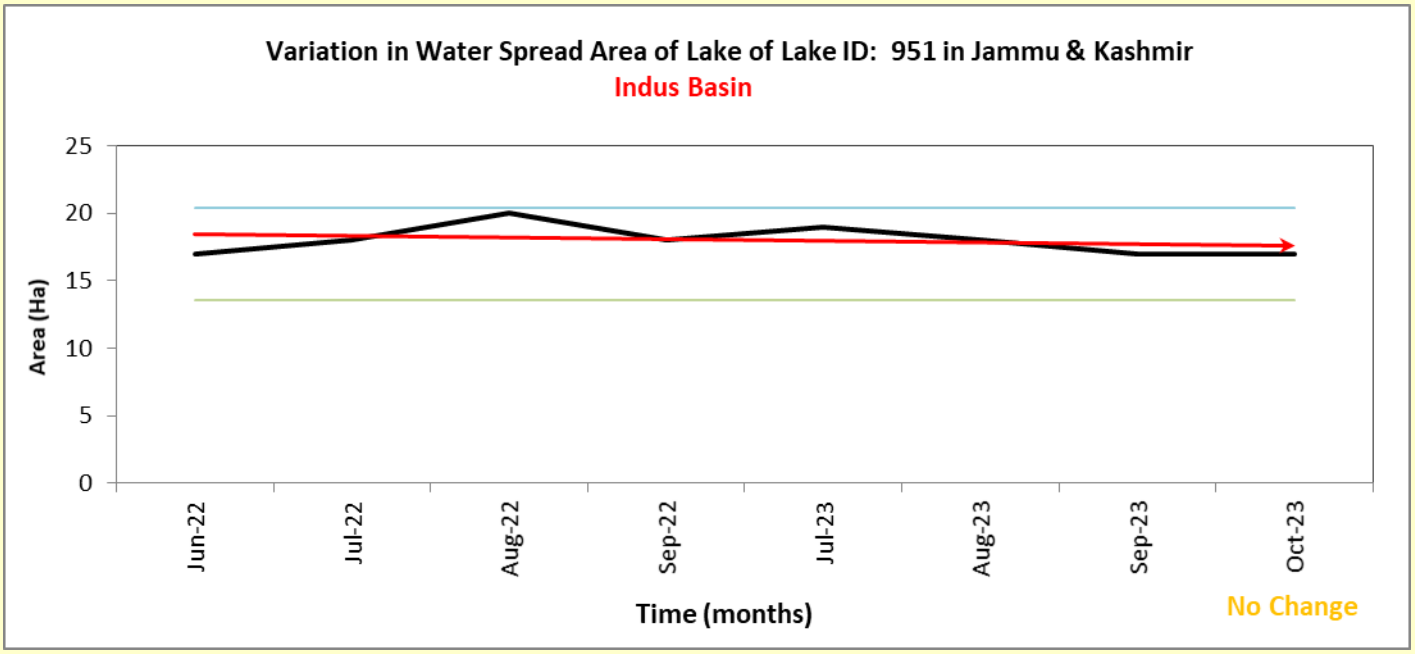


Figure 4.141(i) Trend Analysis Plot ±10%

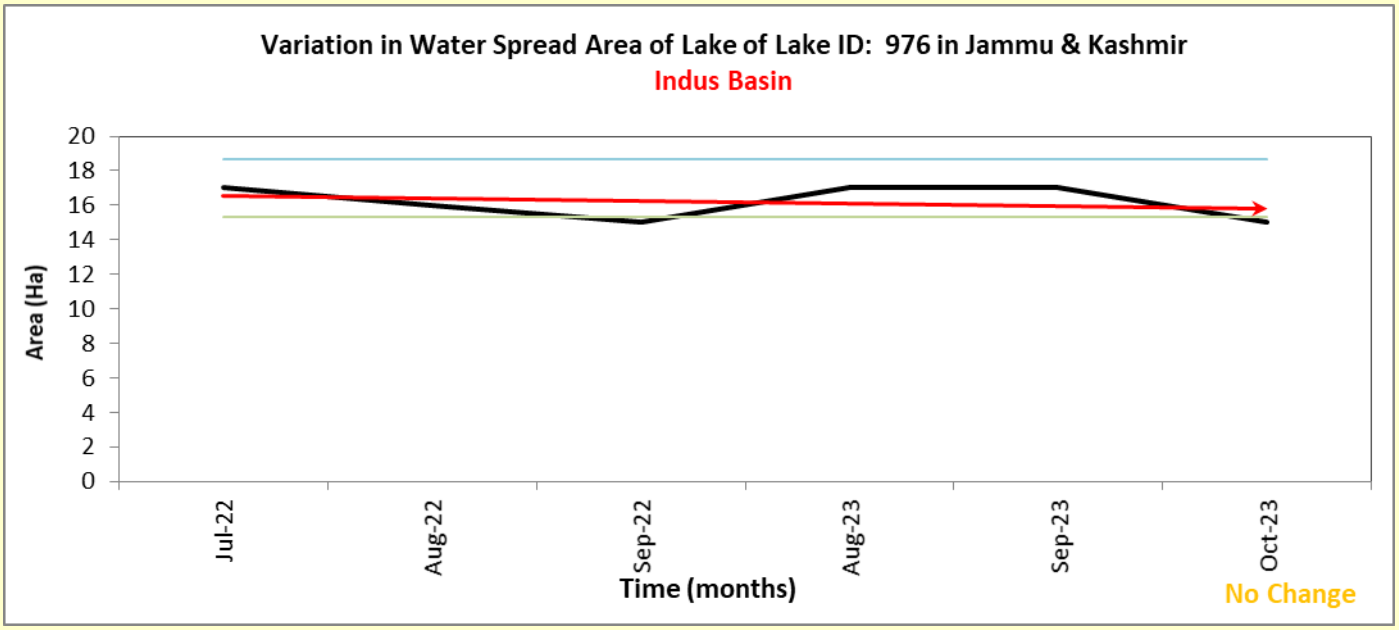


Figure 4.141(ii) Trend Analysis Plot ±20%

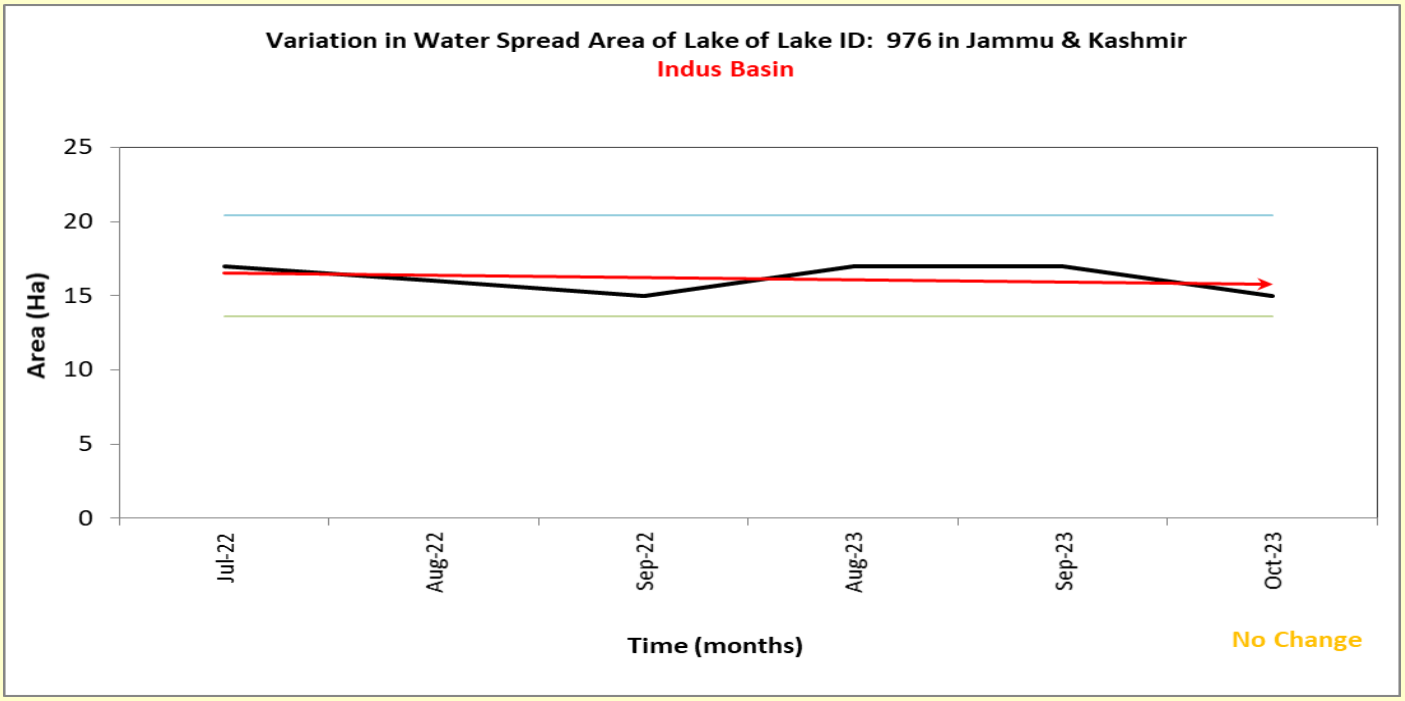


Figure 4.142(i) Trend Analysis Plot ±10%

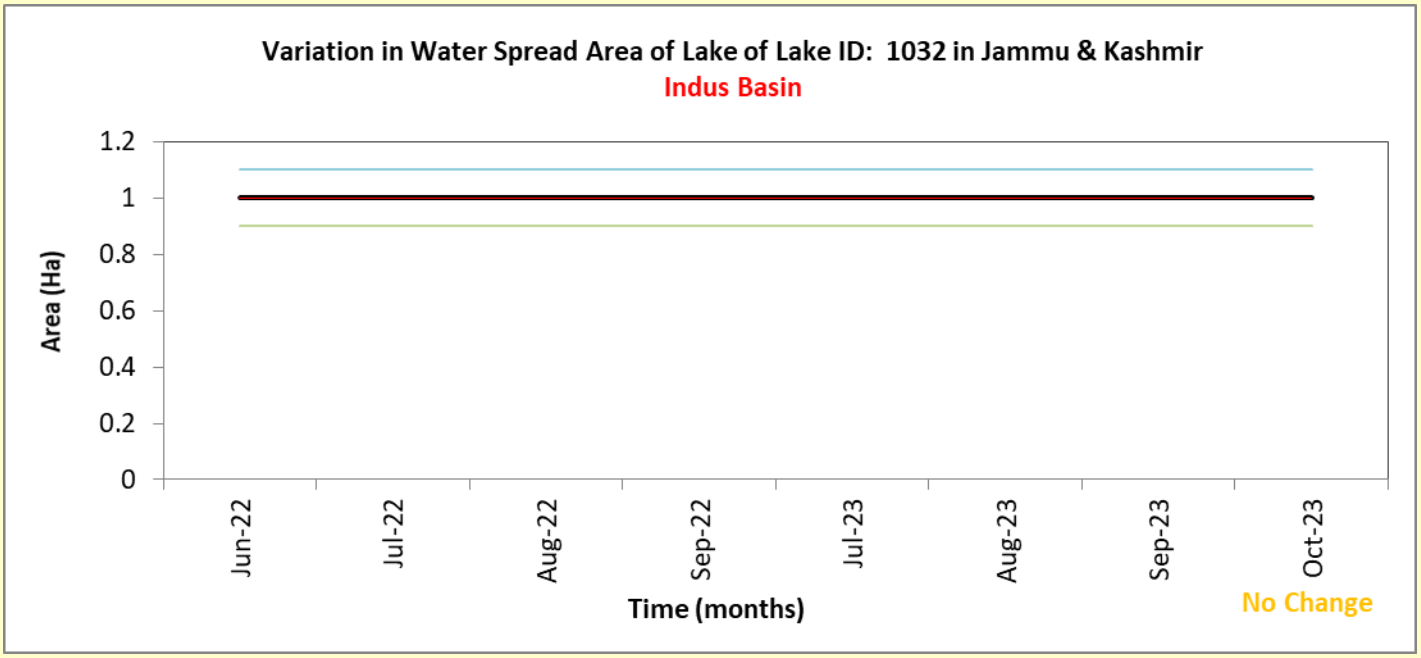


Figure 4.142(ii) Trend Analysis Plot ±20%

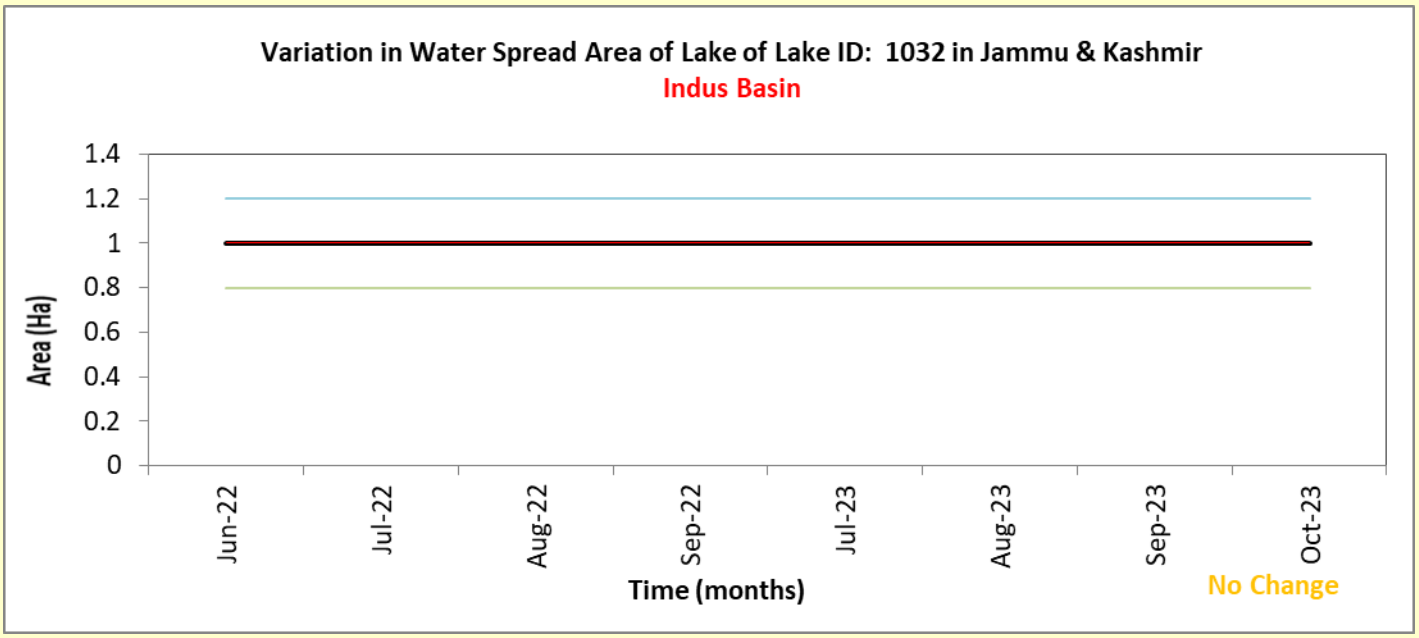


Figure 4.143(i) Trend Analysis Plot ±10%

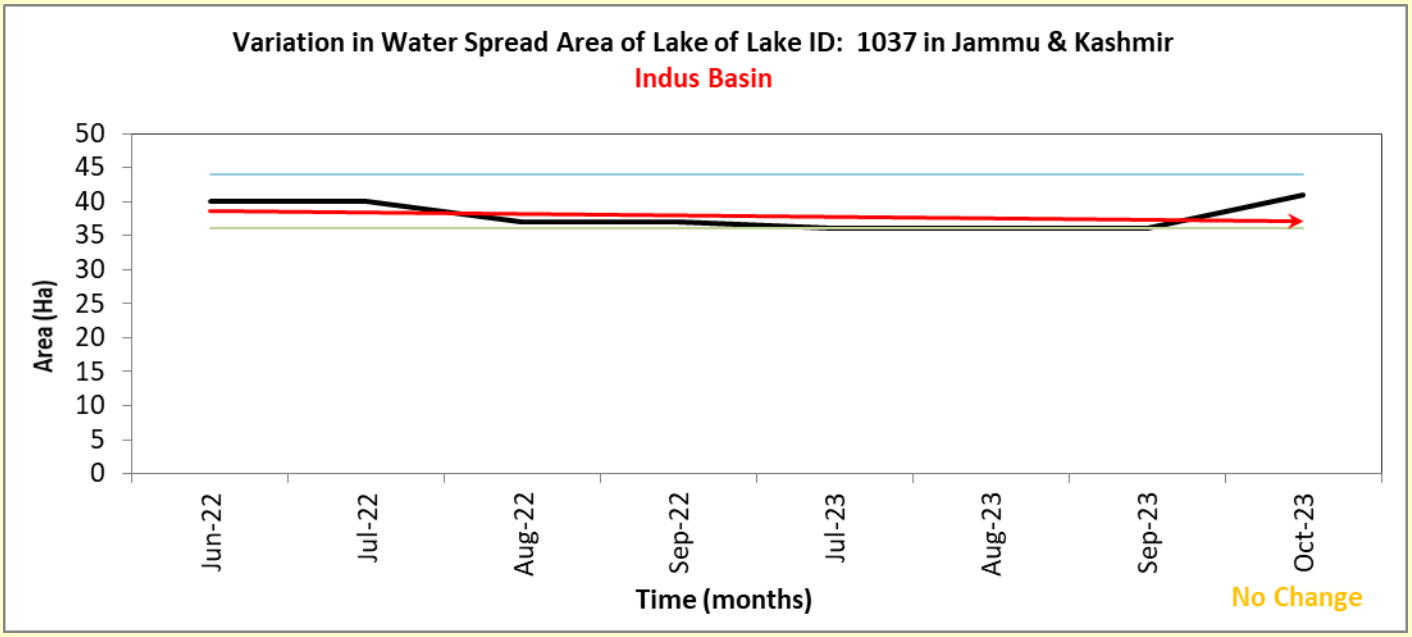


Figure 4.143(ii) Trend Analysis Plot ±20%

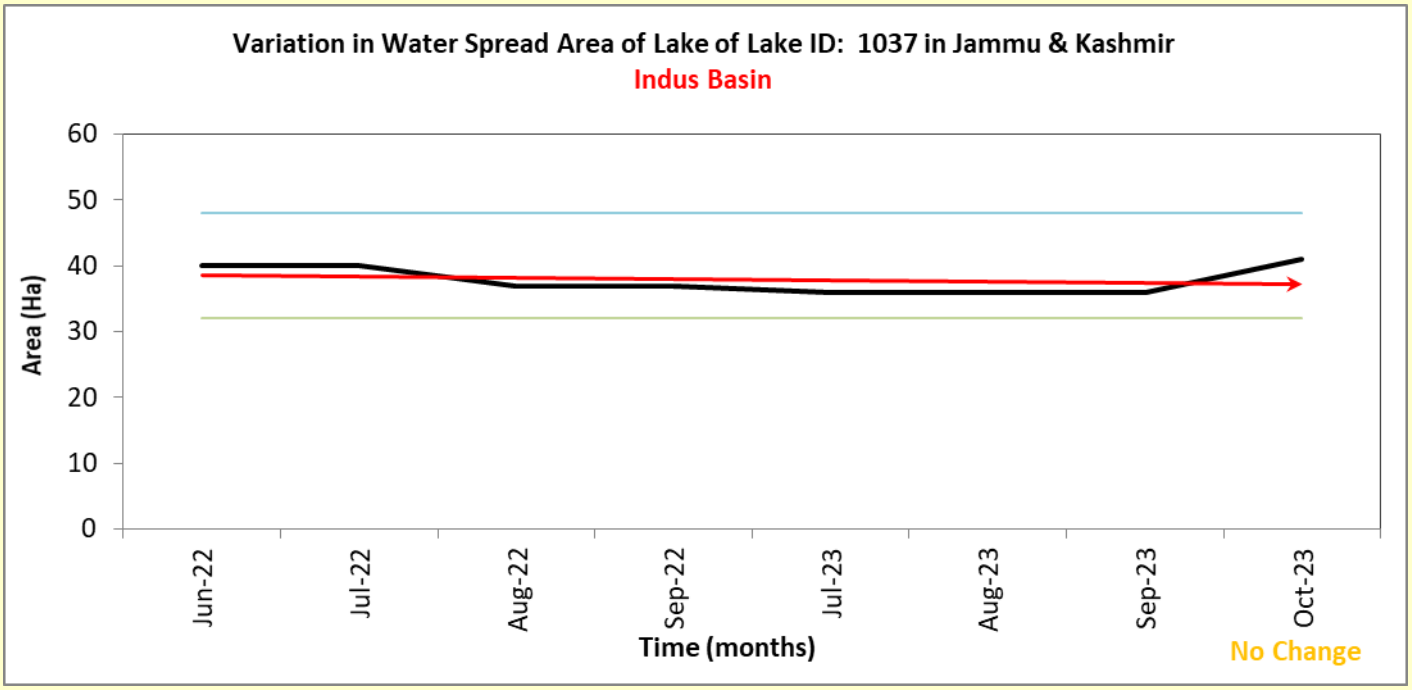


Figure 4.144(i) Trend Analysis Plot ±10%

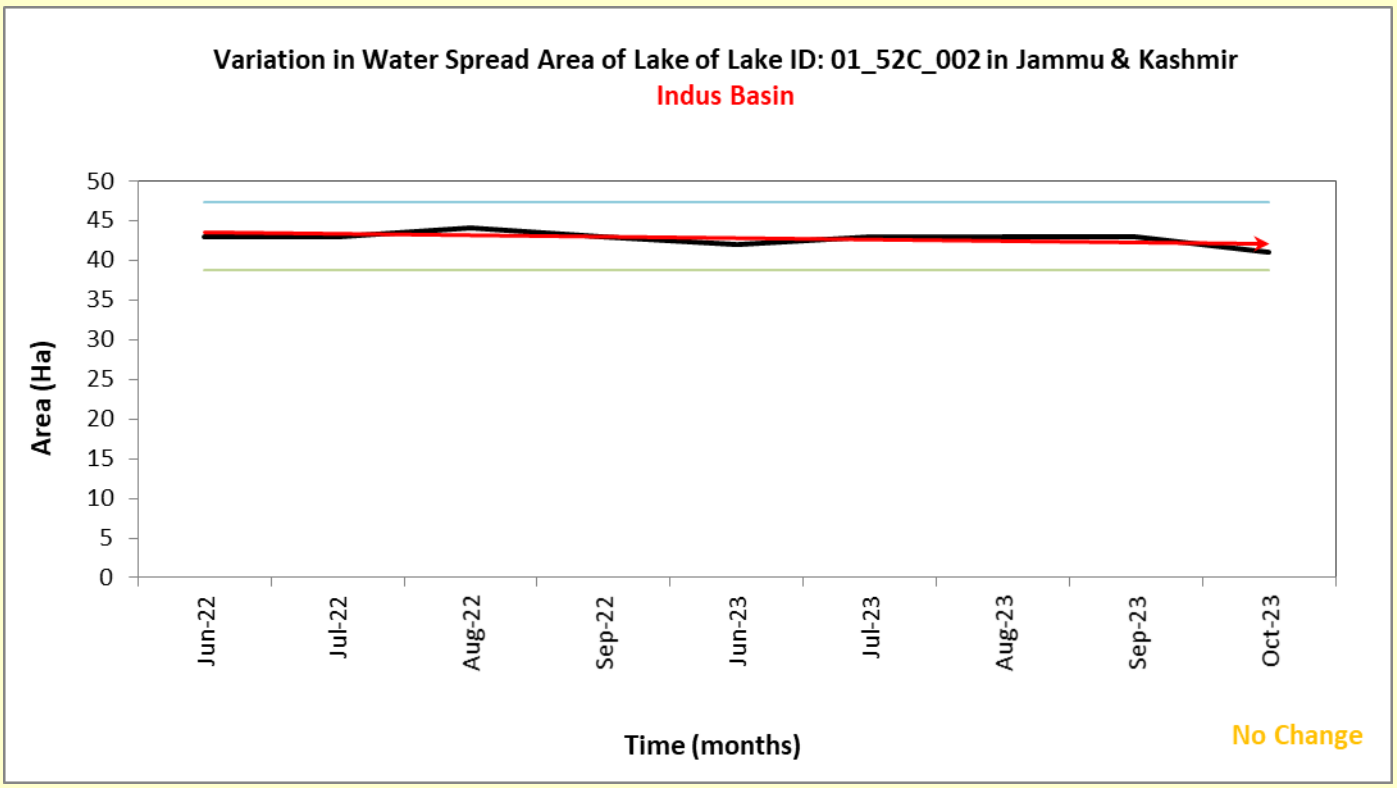


Figure 4.144(ii) Trend Analysis Plot ±20%

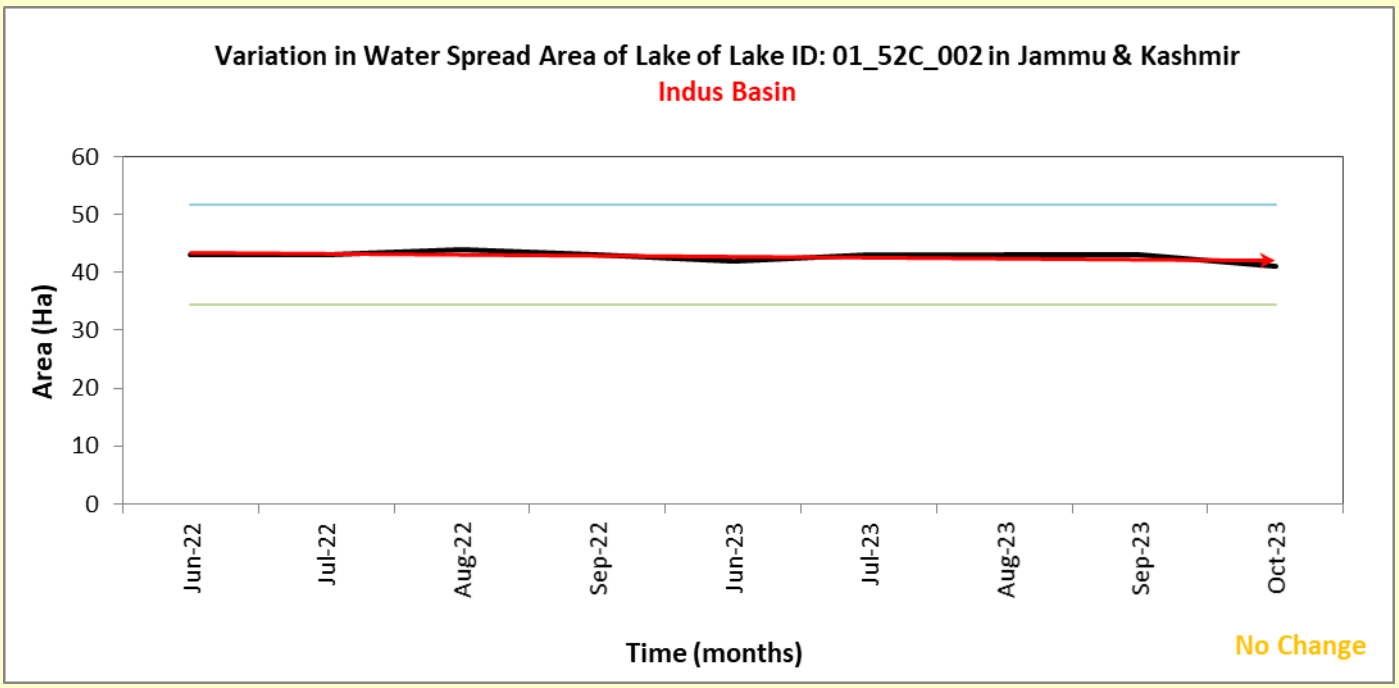


Figure 4.145(i) Trend Analysis Plot ±10%

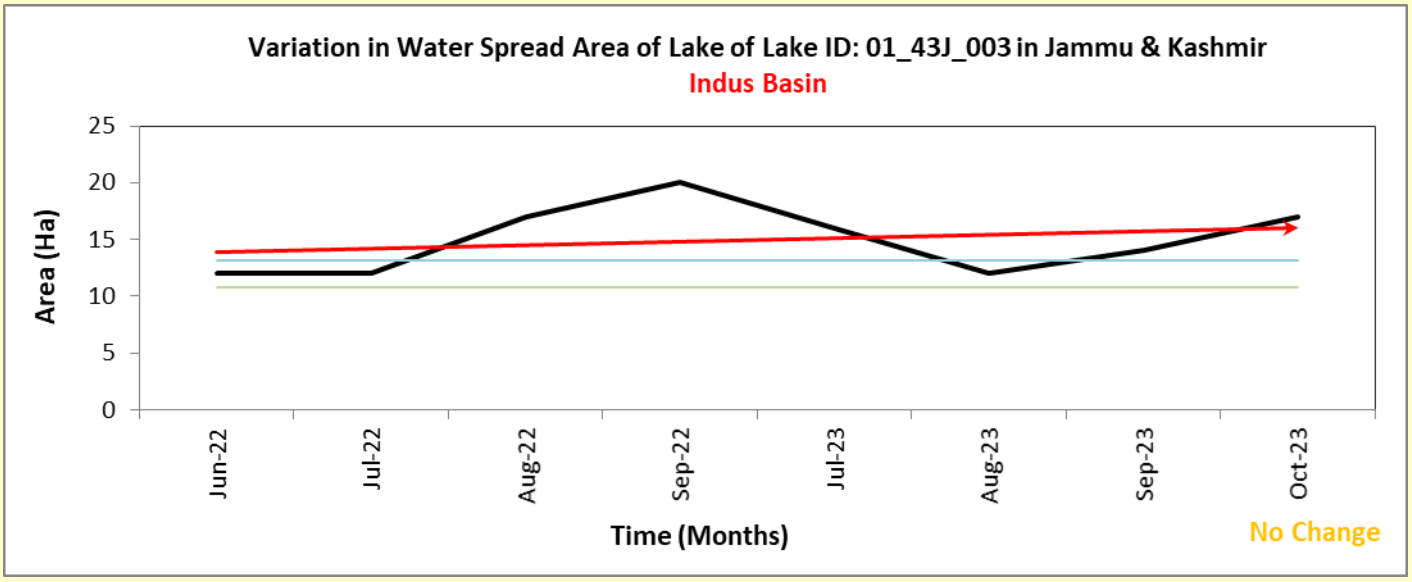


Figure 4.145(ii) Trend Analysis Plot ±20%

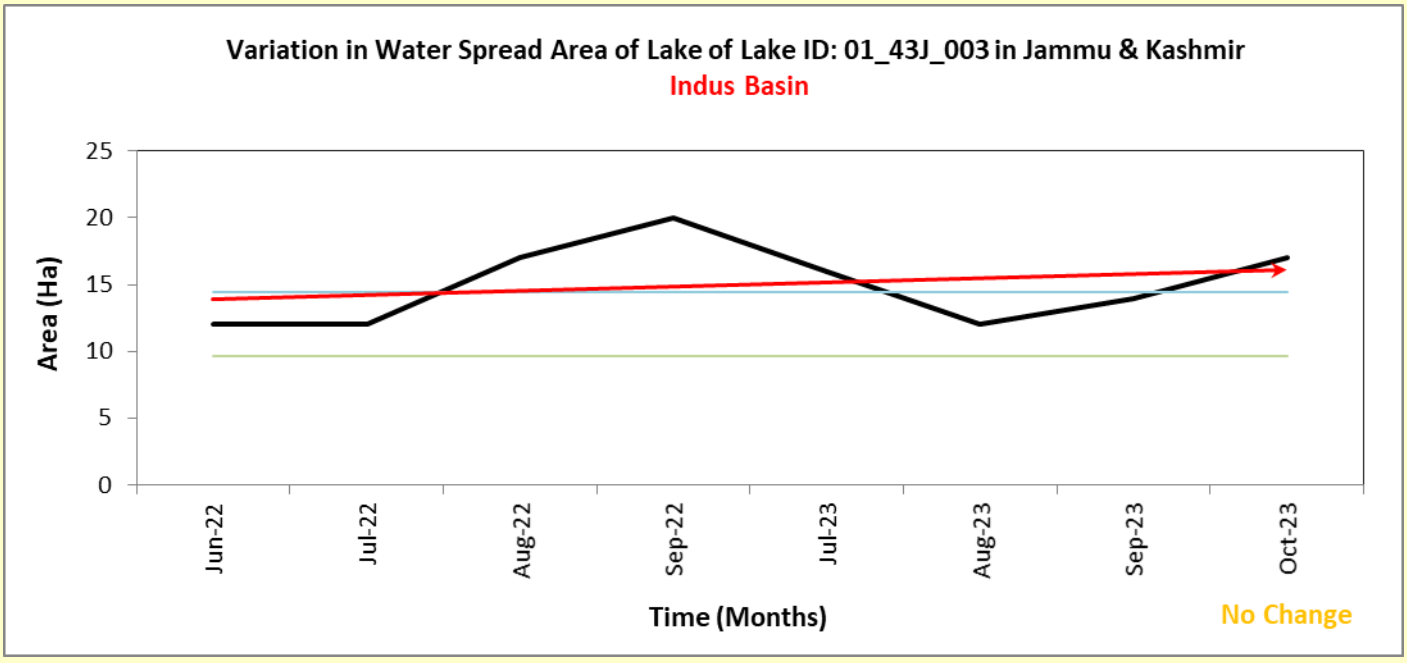


Figure 4.146(i) Trend Analysis Plot ±10%

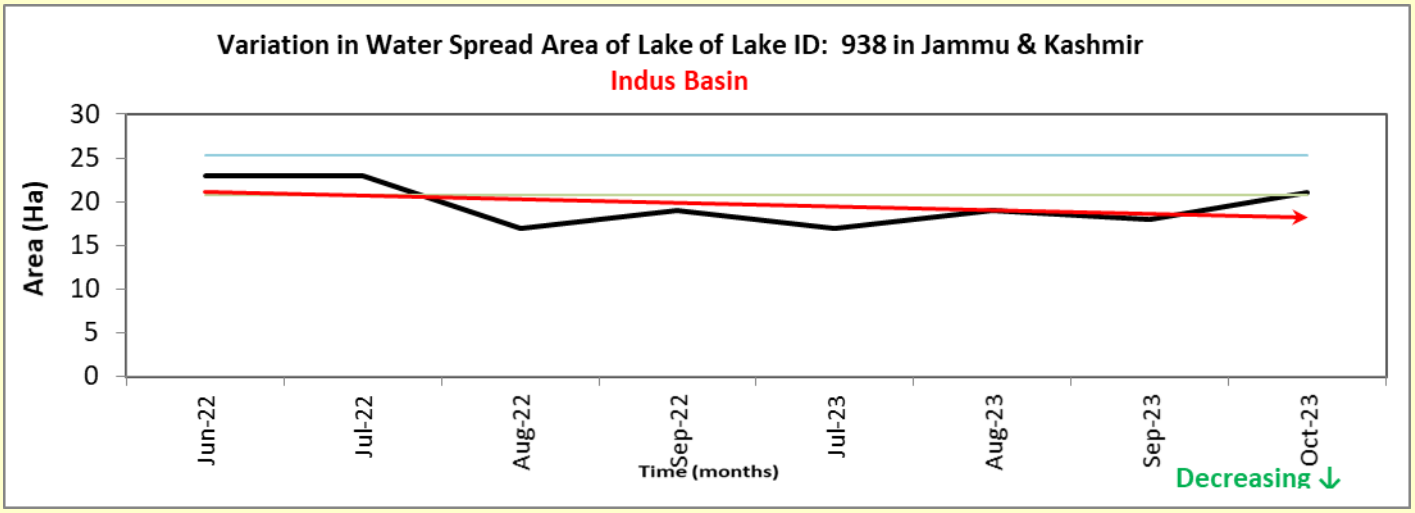


Figure 4.146(ii) Trend Analysis Plot ±20%

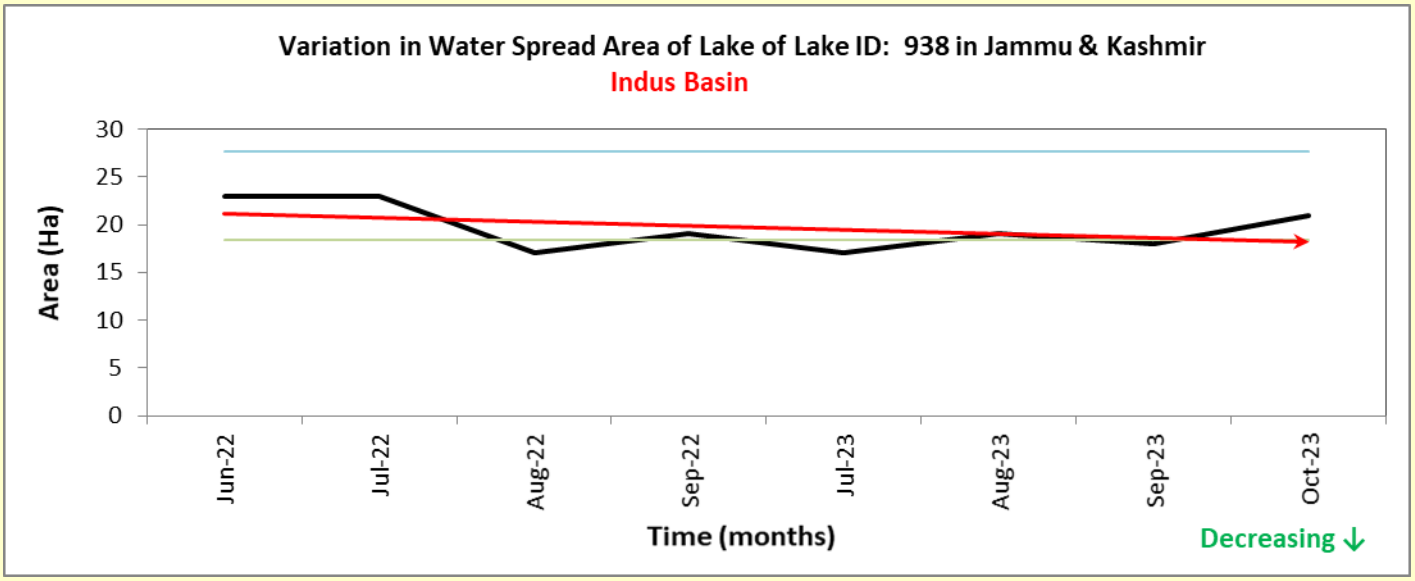


Figure 4.147(i) Trend Analysis Plot ±10%

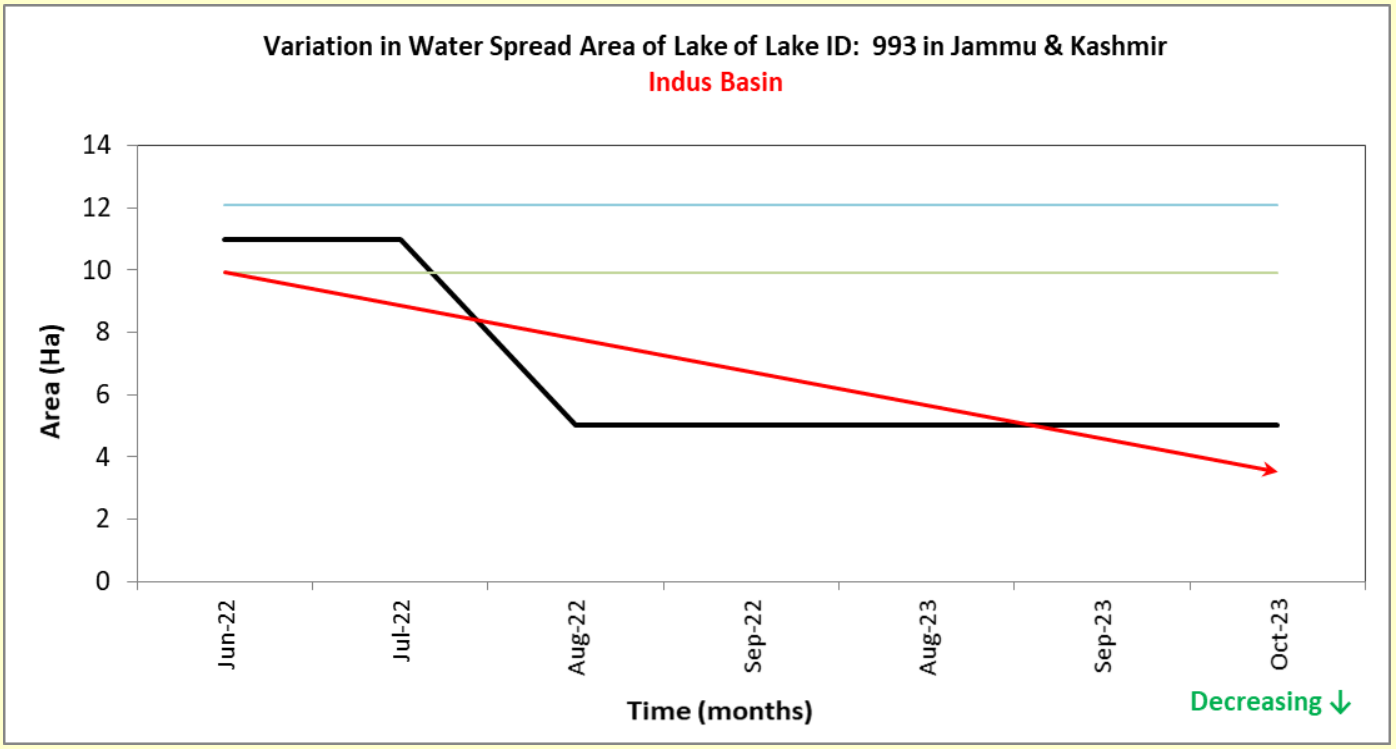


Figure 4.147(ii) Trend Analysis Plot ±20%

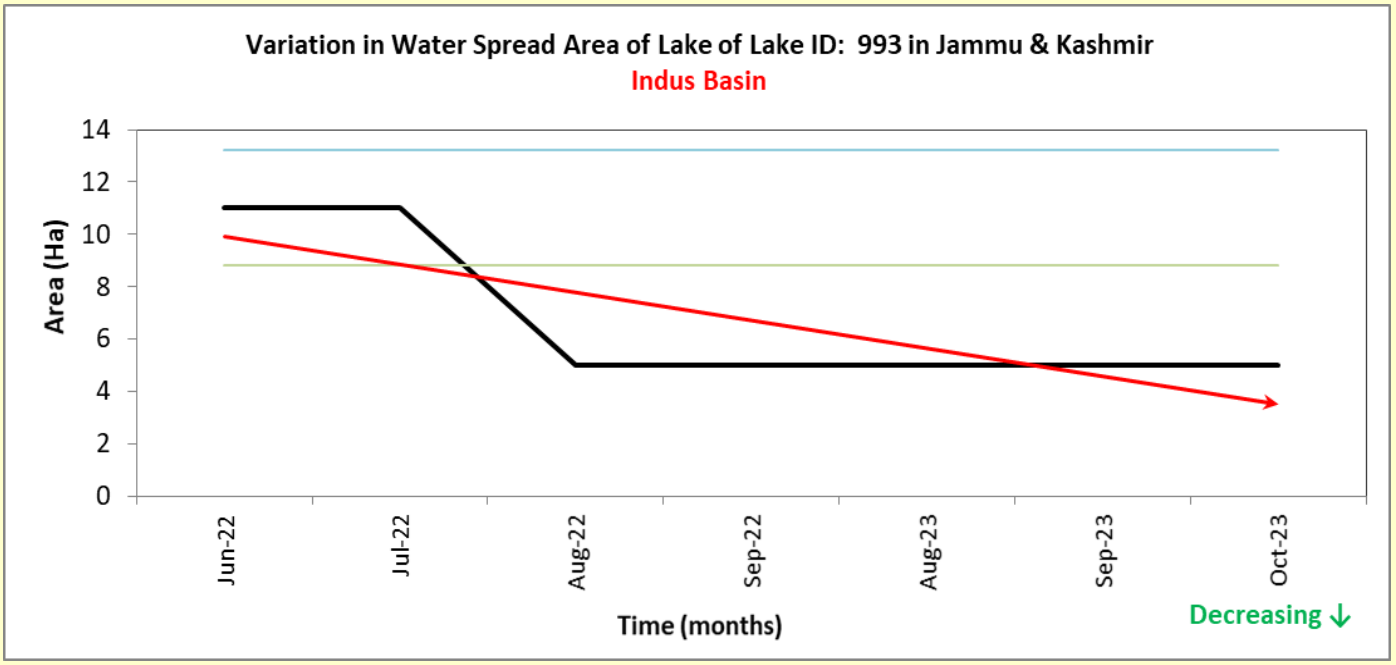


Figure 4.148(i) Trend Analysis Plot ±10%

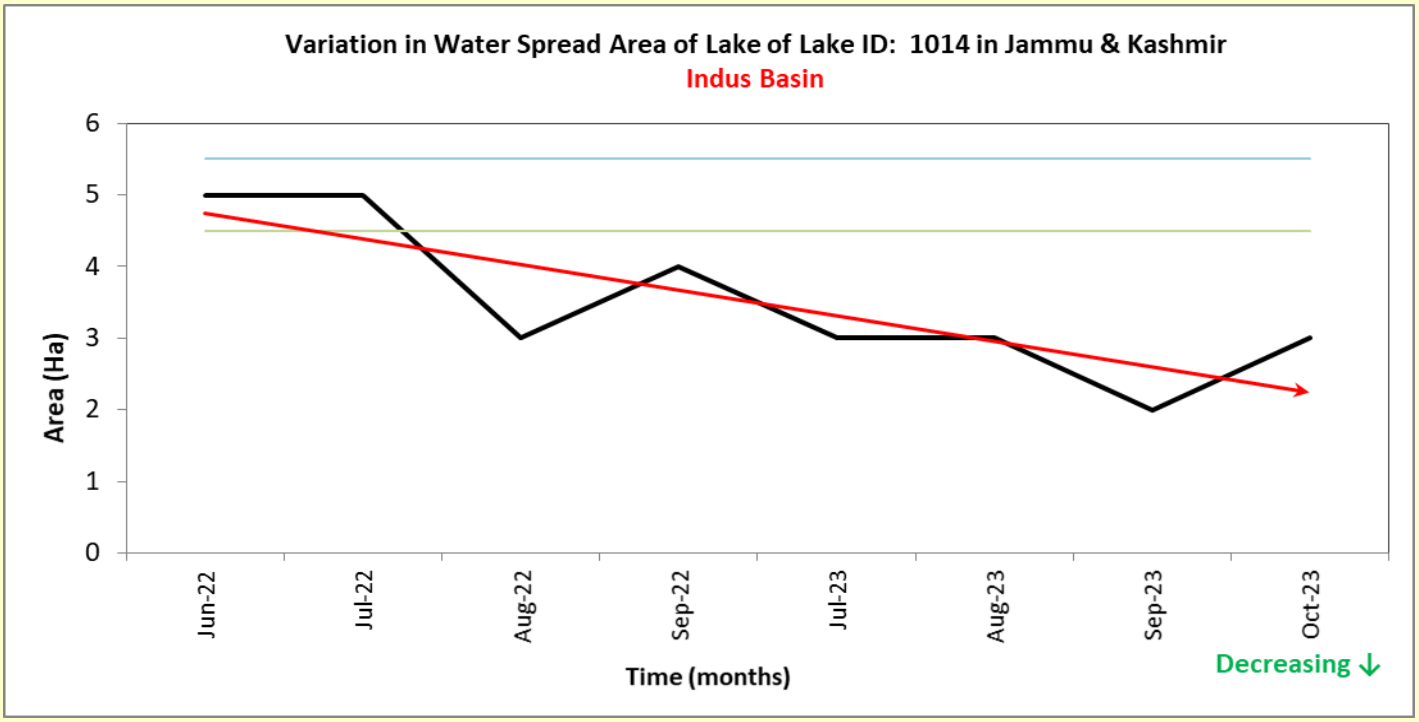
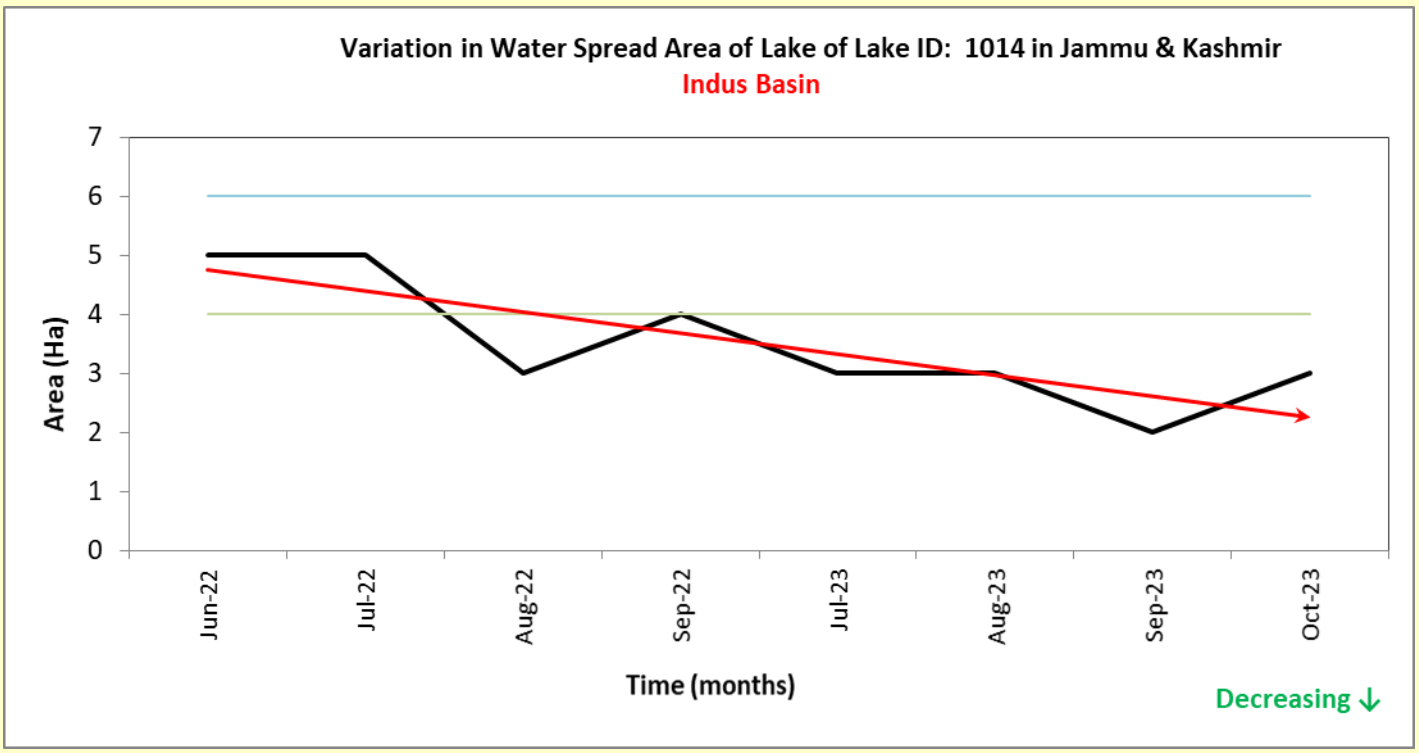


Figure 4.148(ii) Trend Analysis Plot ±10%



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 ±10%

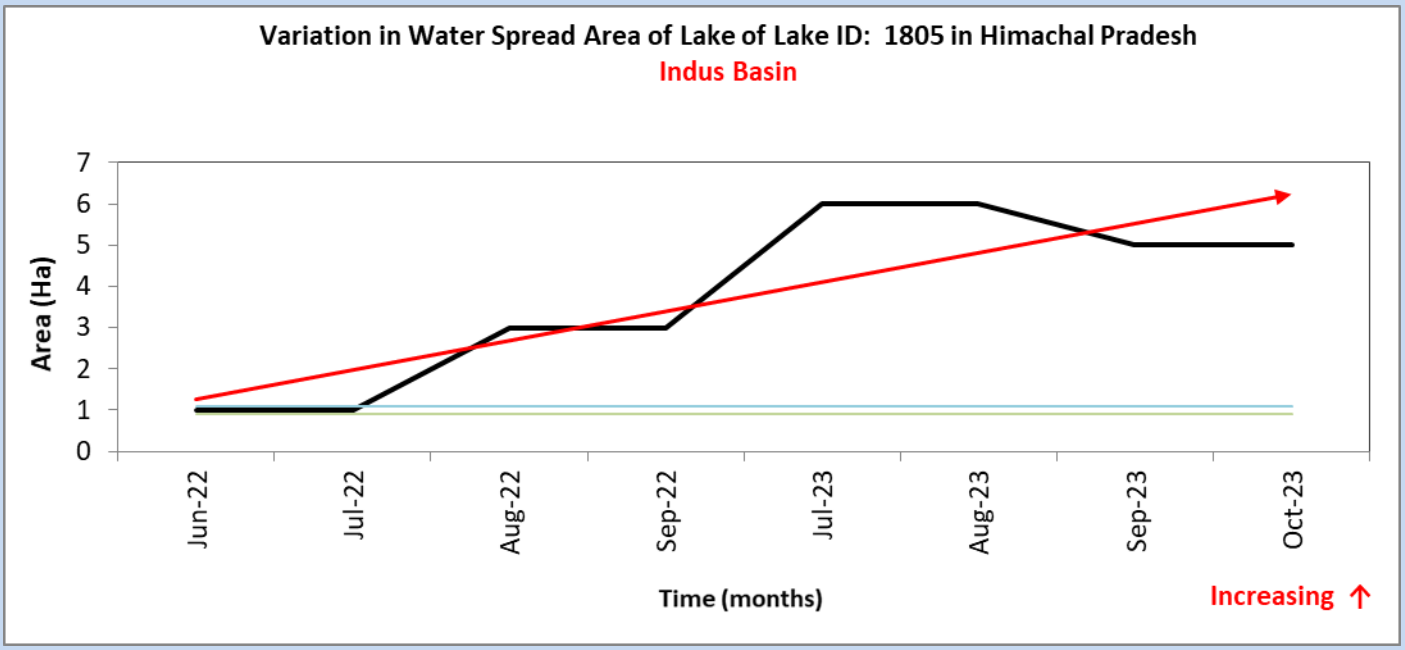


Figure 4.149(ii) Trend Analysis Plot ±20%

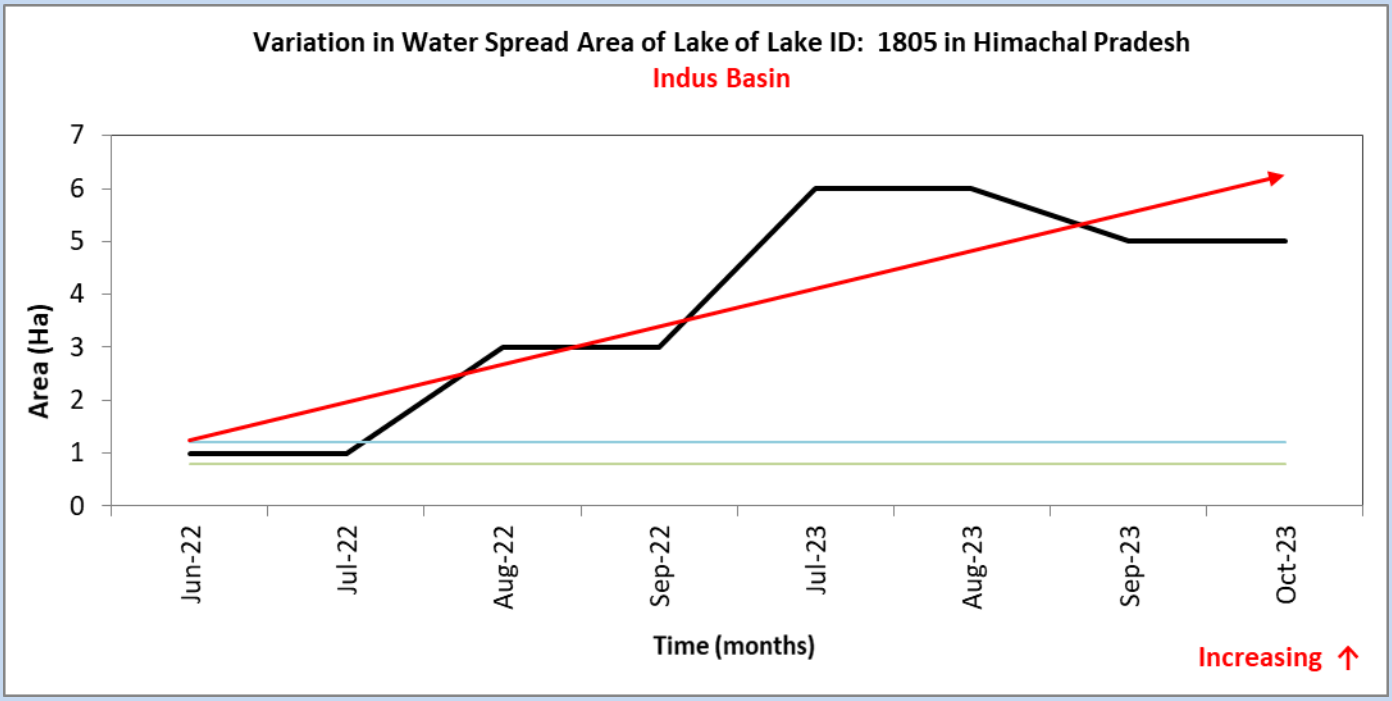


Figure 4.150(i) Trend Analysis Plot ±10%

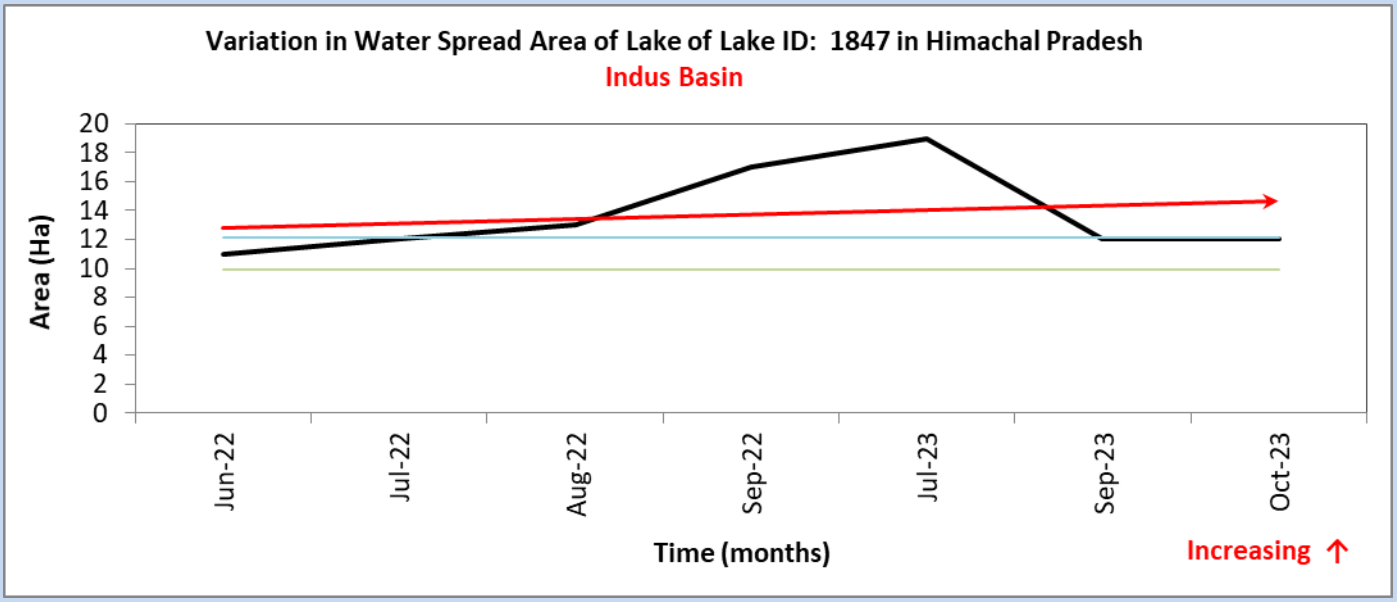


Figure 4.150(ii) Trend Analysis Plot ±20%

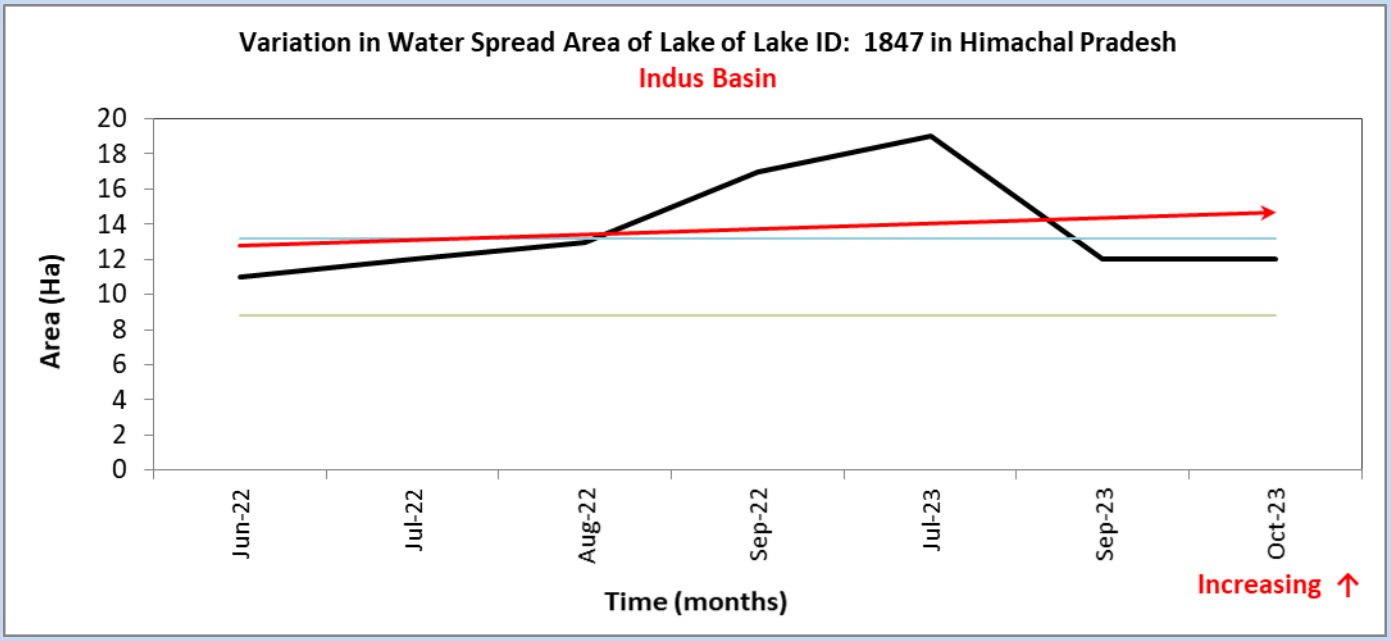


Figure 4.151(i) Trend Analysis Plot ±10%

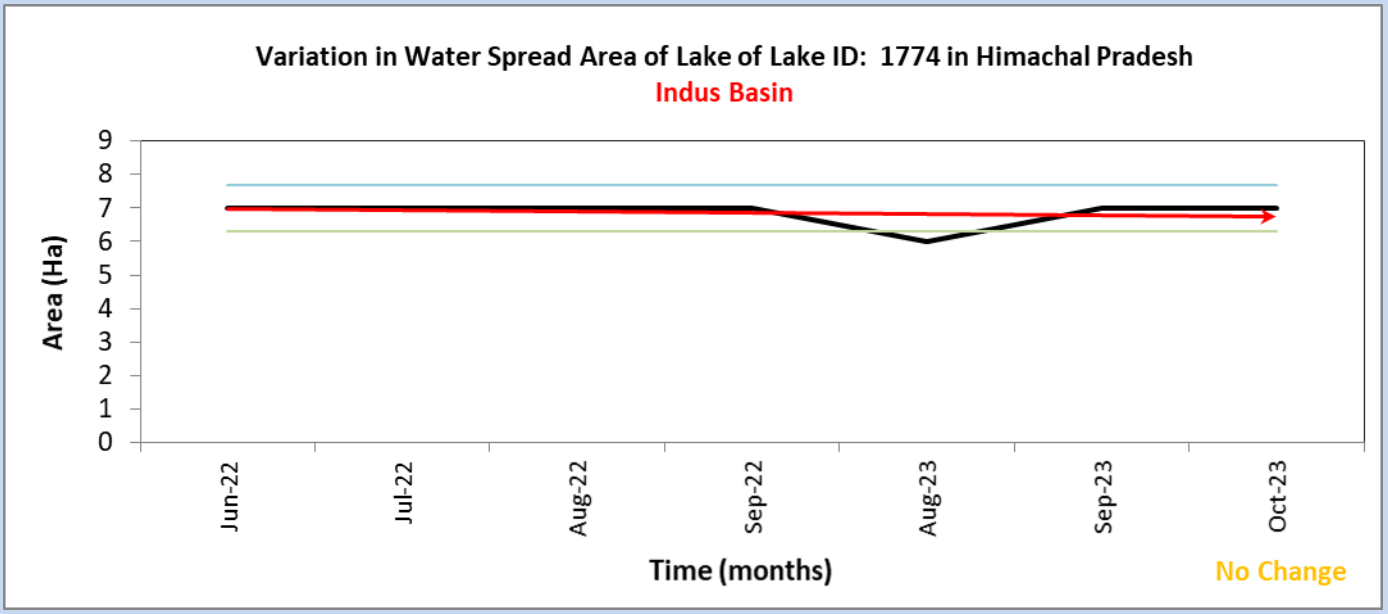


Figure 4.151(ii) Trend Analysis Plot ±20%

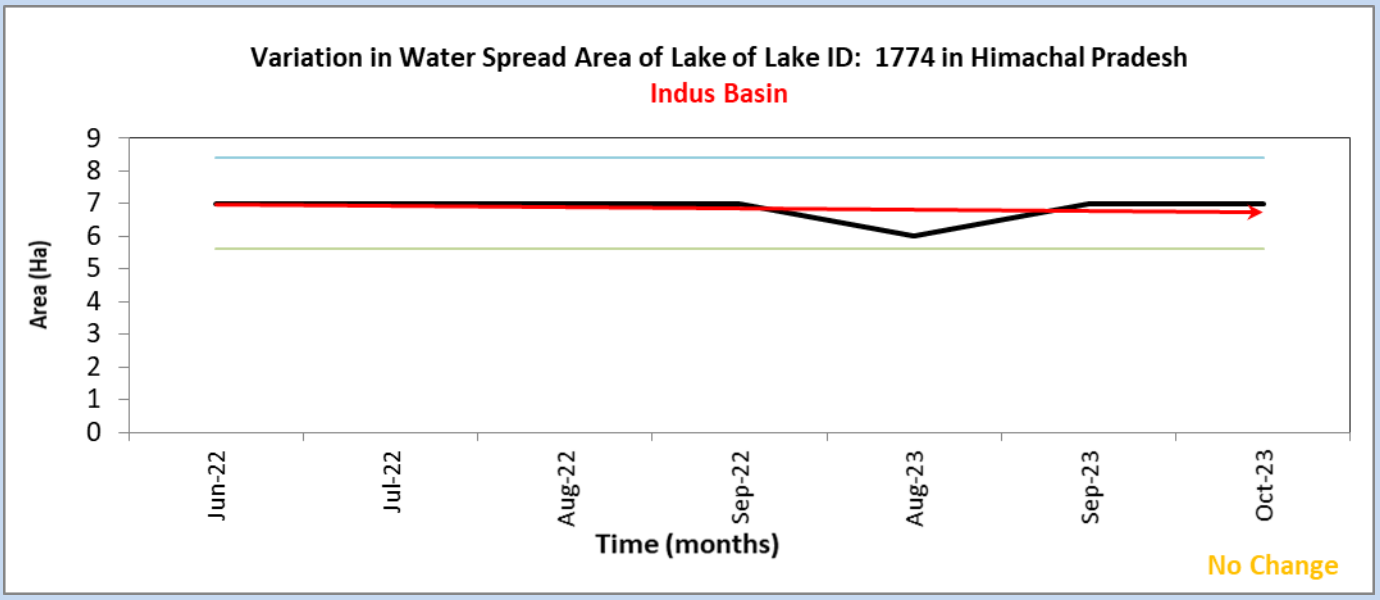


Figure 4.152(i) Trend Analysis Plot ±10%

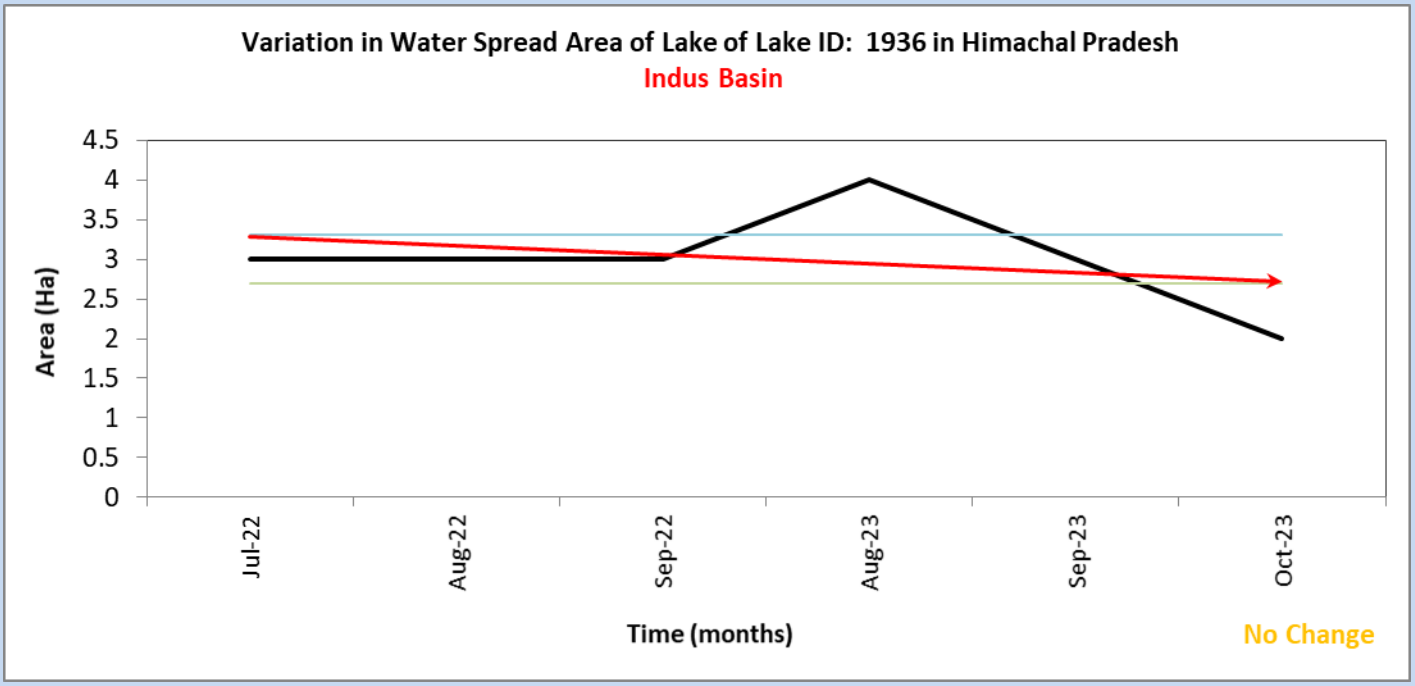


Figure 4.152(ii) Trend Analysis Plot ±20%

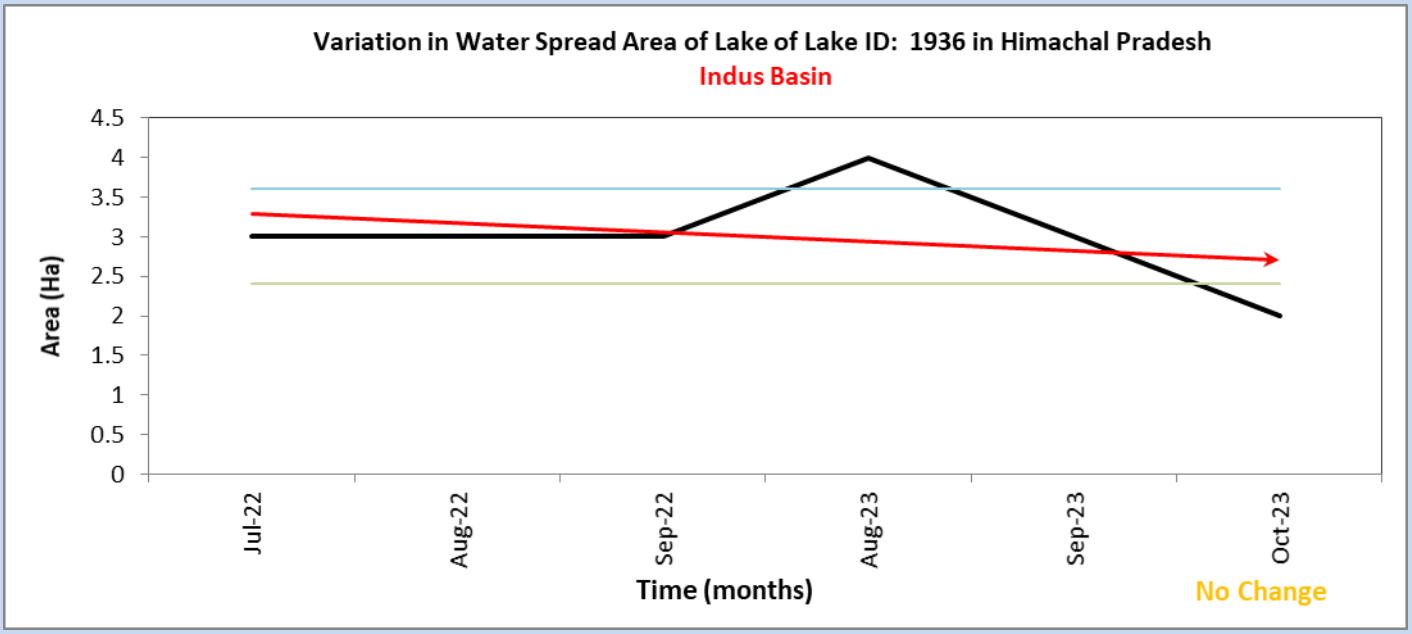


Figure 4.153(i) Trend Analysis Plot ±10%

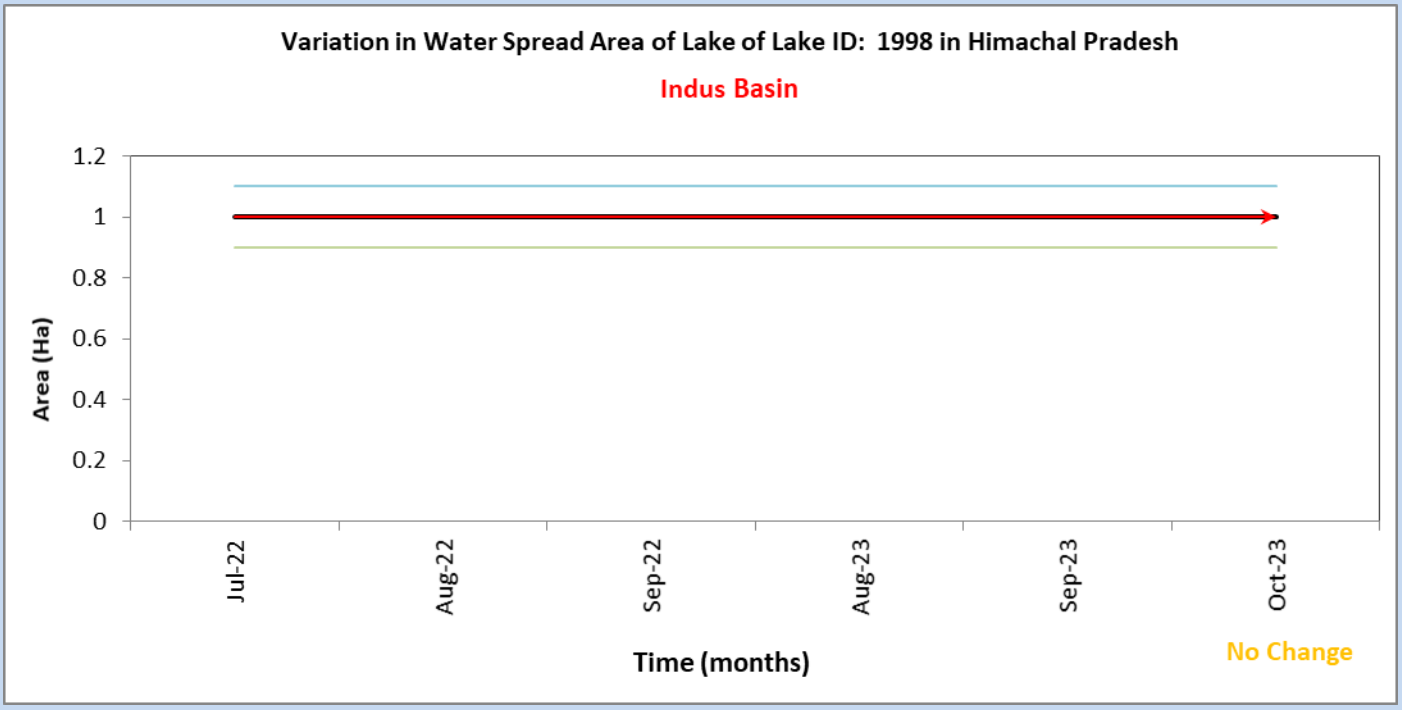


Figure 4.153(ii) Trend Analysis Plot ±20%

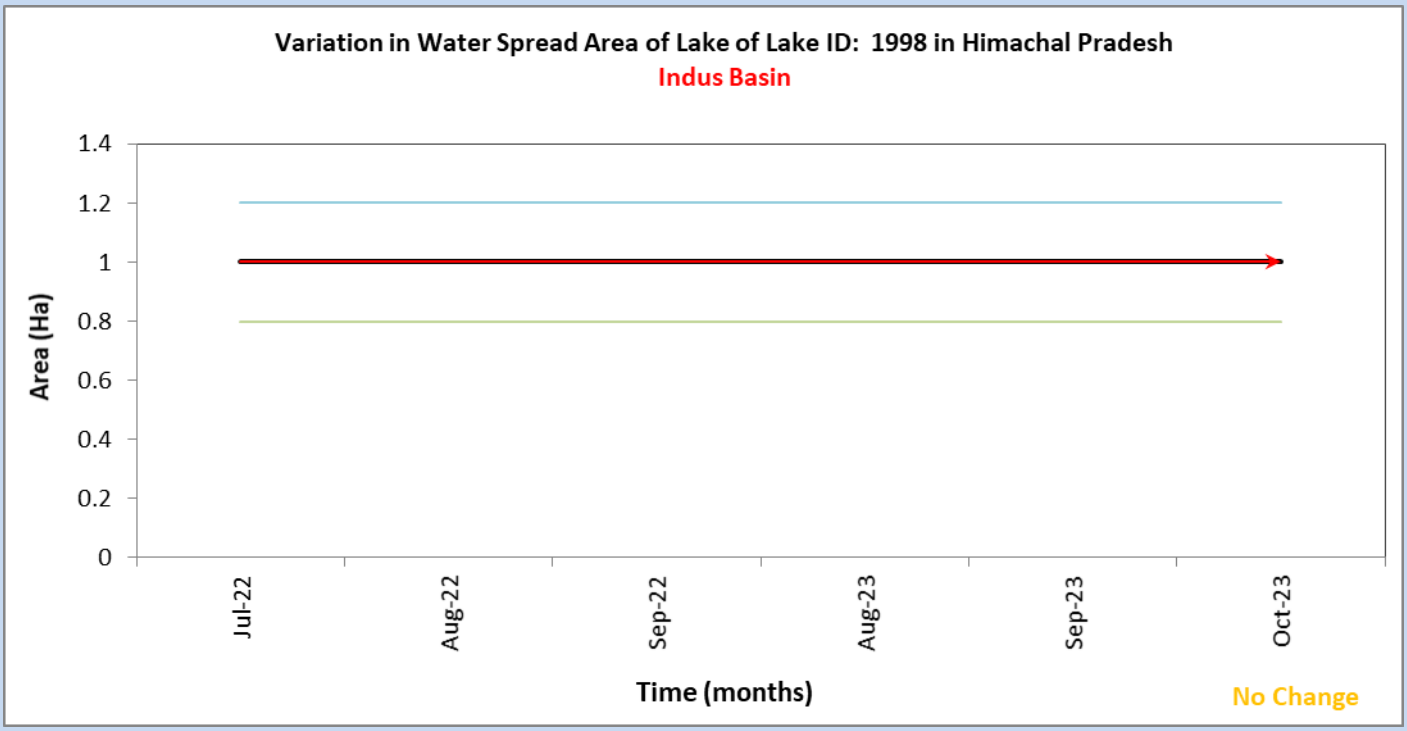


Figure 4.154(i) Trend Analysis Plot ±10%

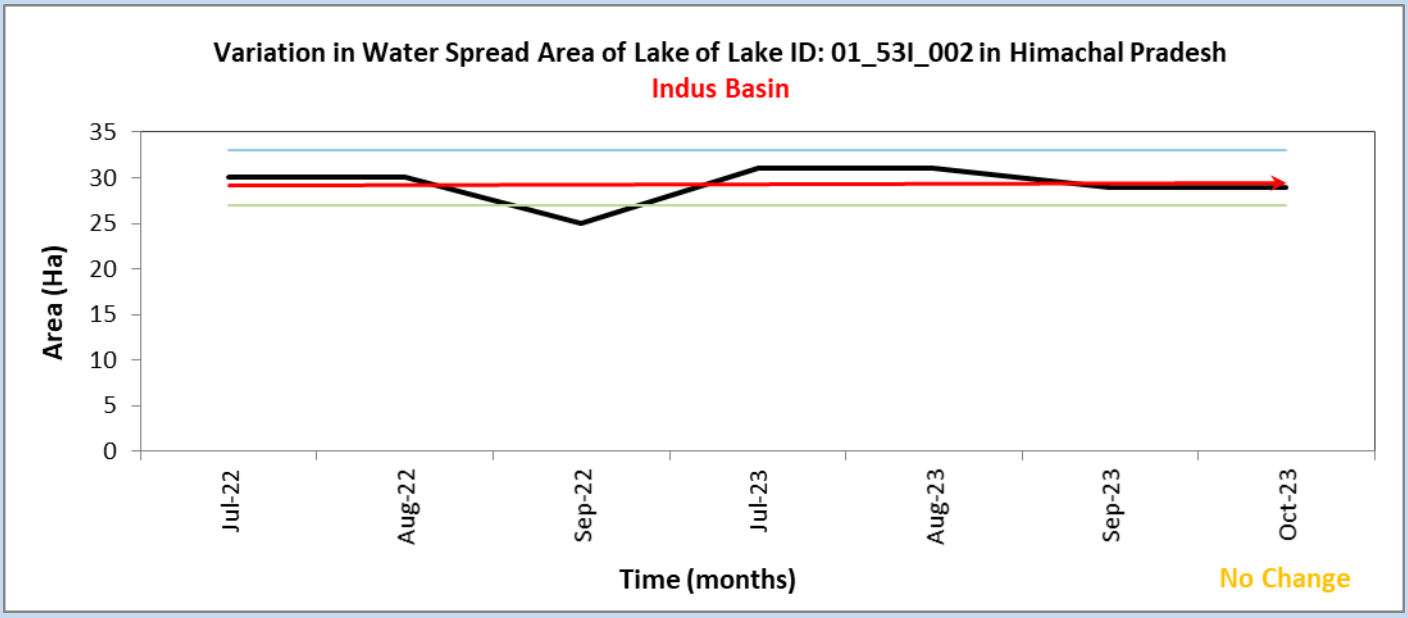


Figure 4.154(ii) Trend Analysis Plot ±20%

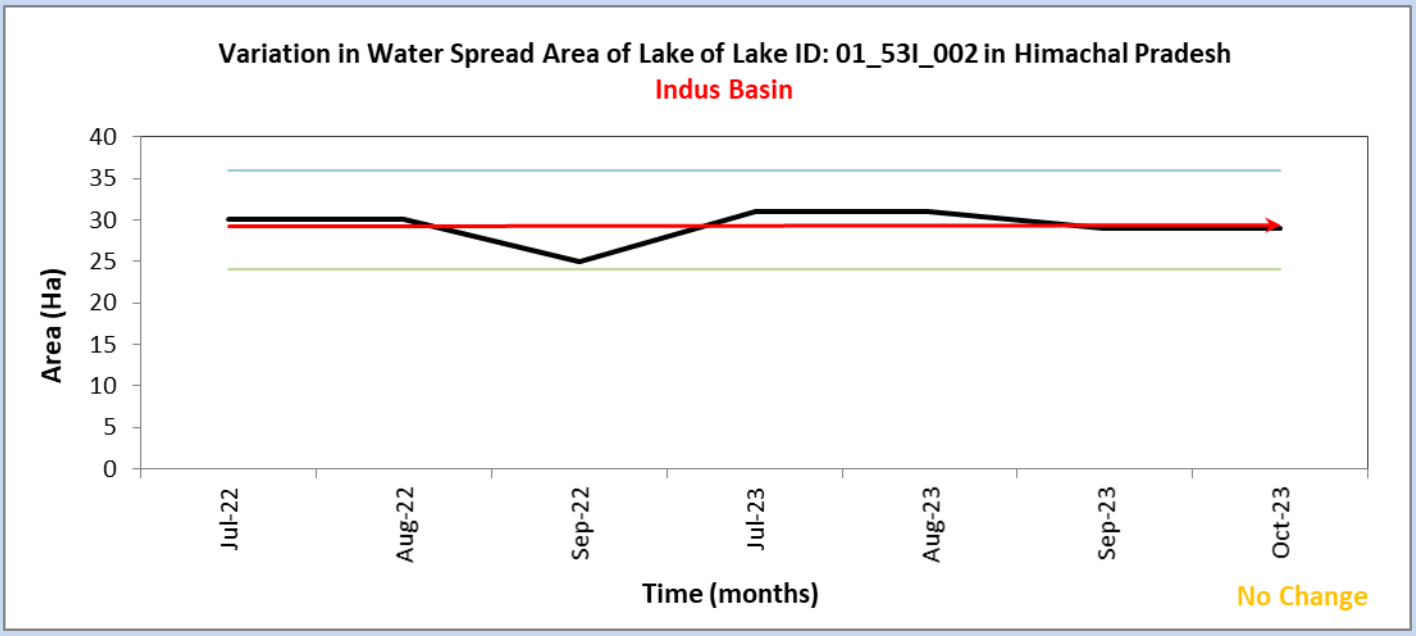


Figure 4.155(i) Trend Analysis Plot ±10%

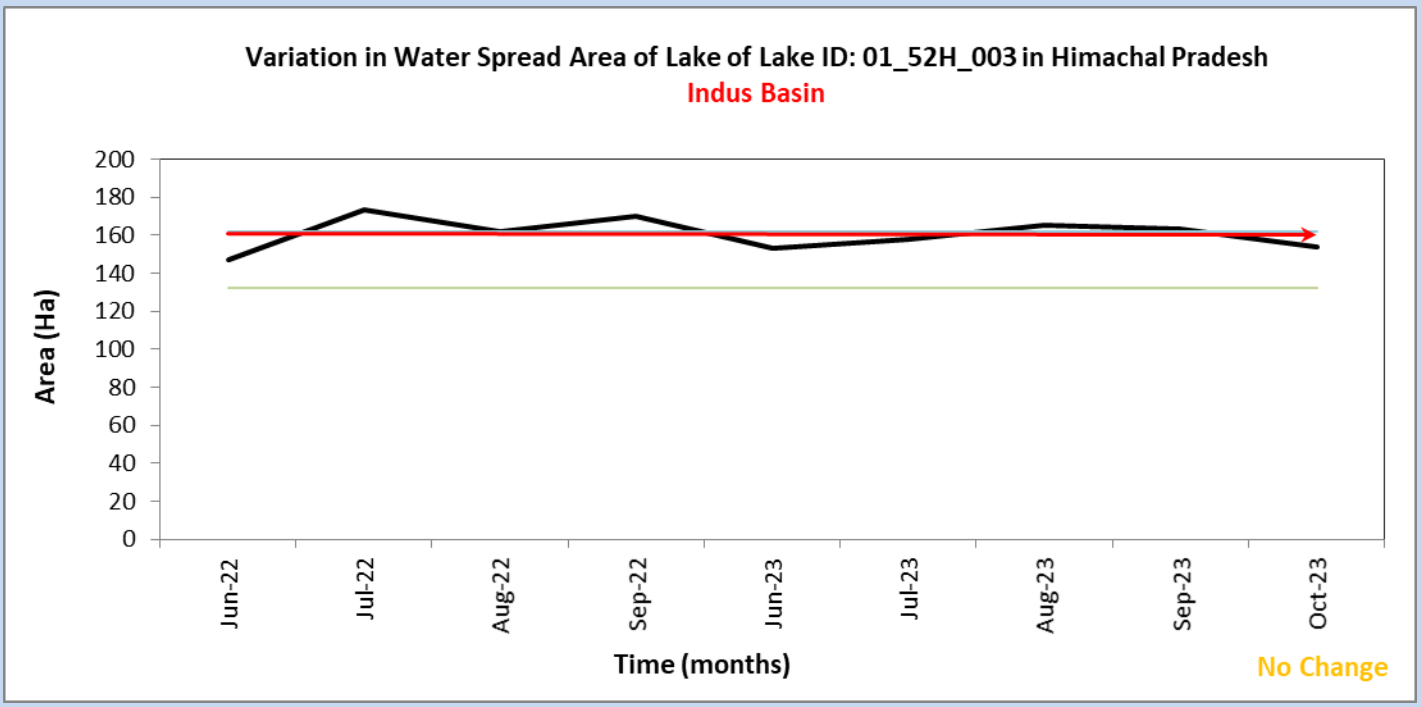


Figure 4.155(ii) Trend Analysis Plot ±20%

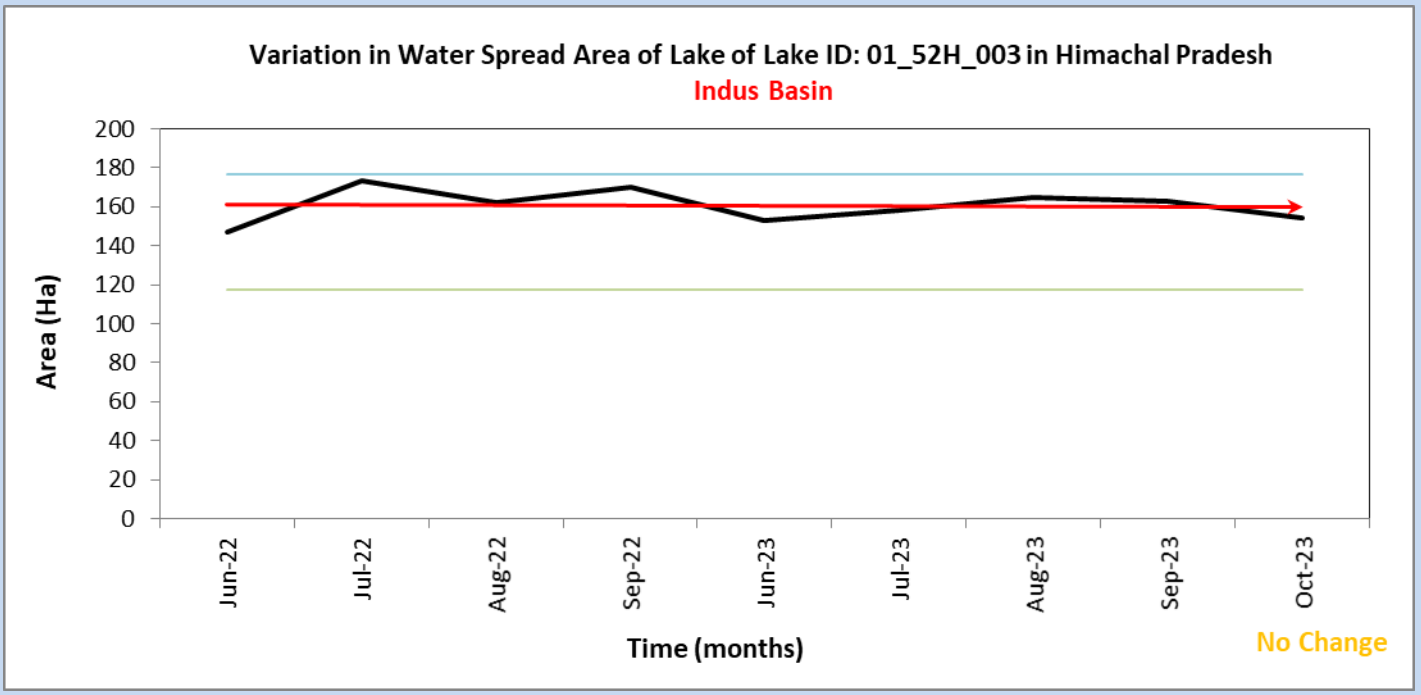


Figure 4.156(i) Trend Analysis Plot ±10%

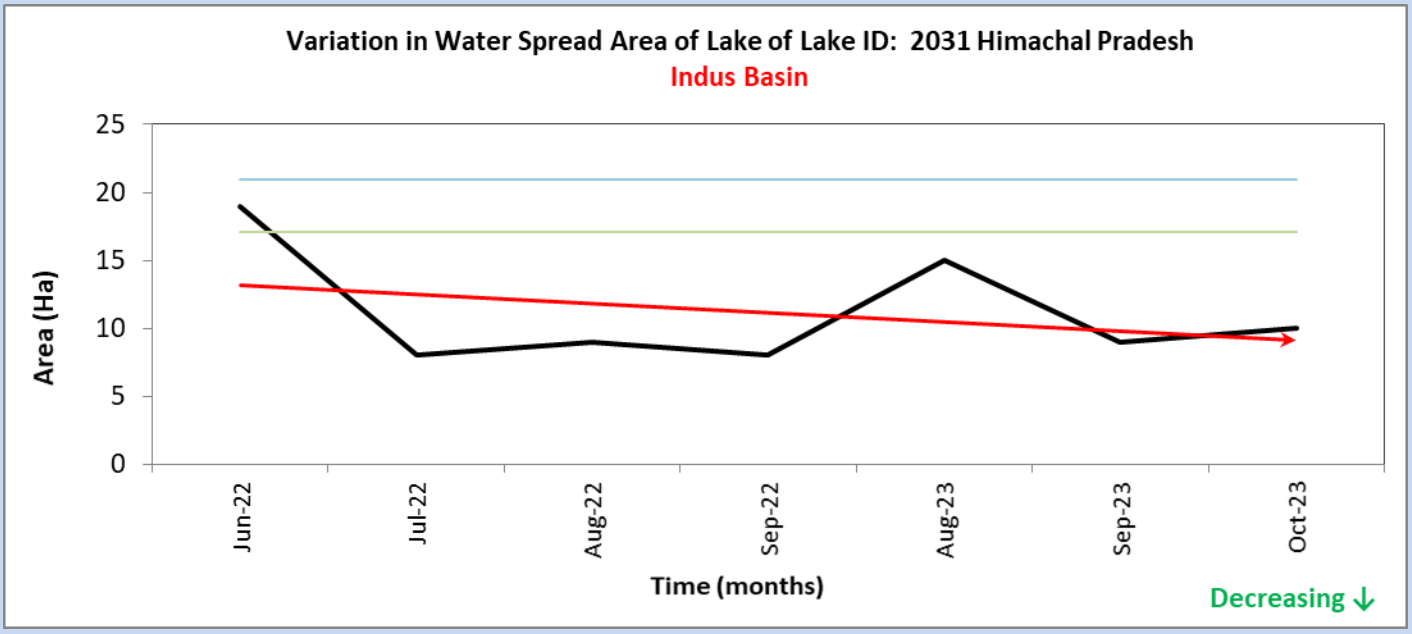
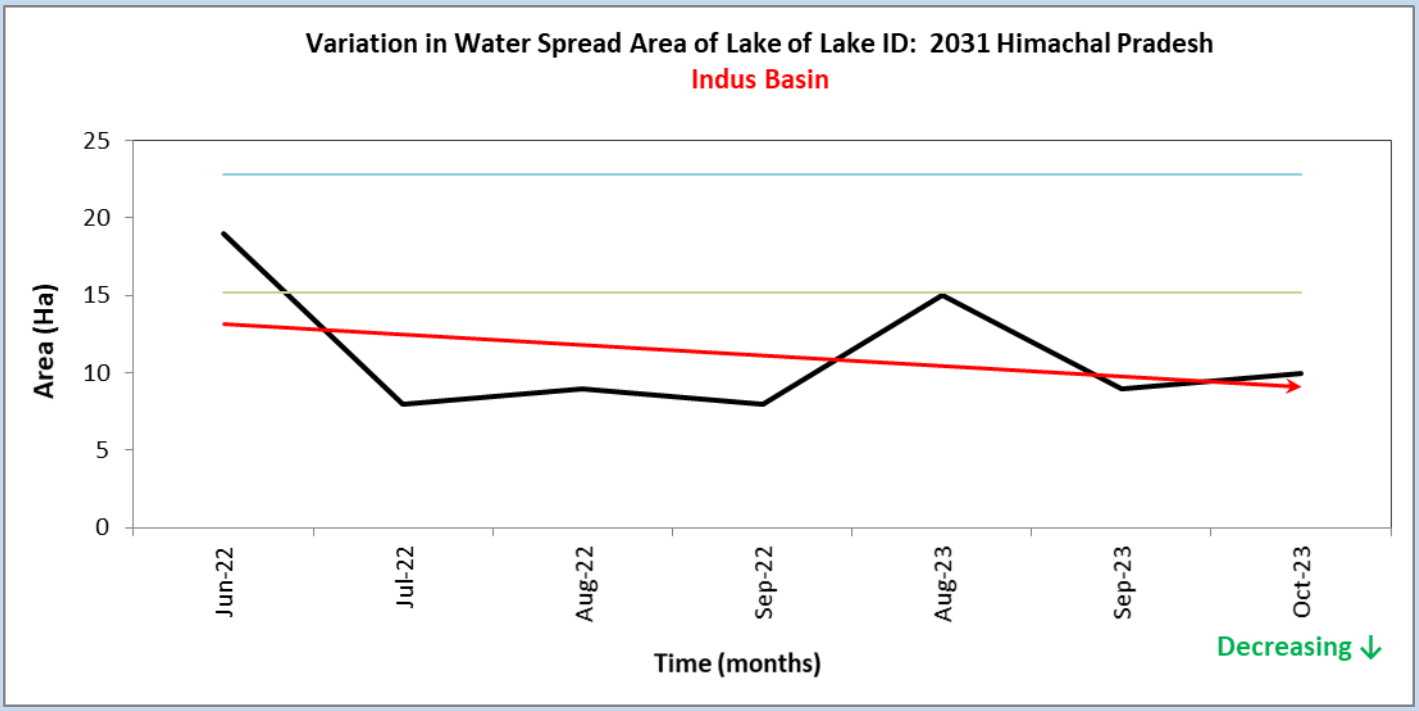


Figure 4.156(ii) Trend Analysis Plot ±20%



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 ±10%

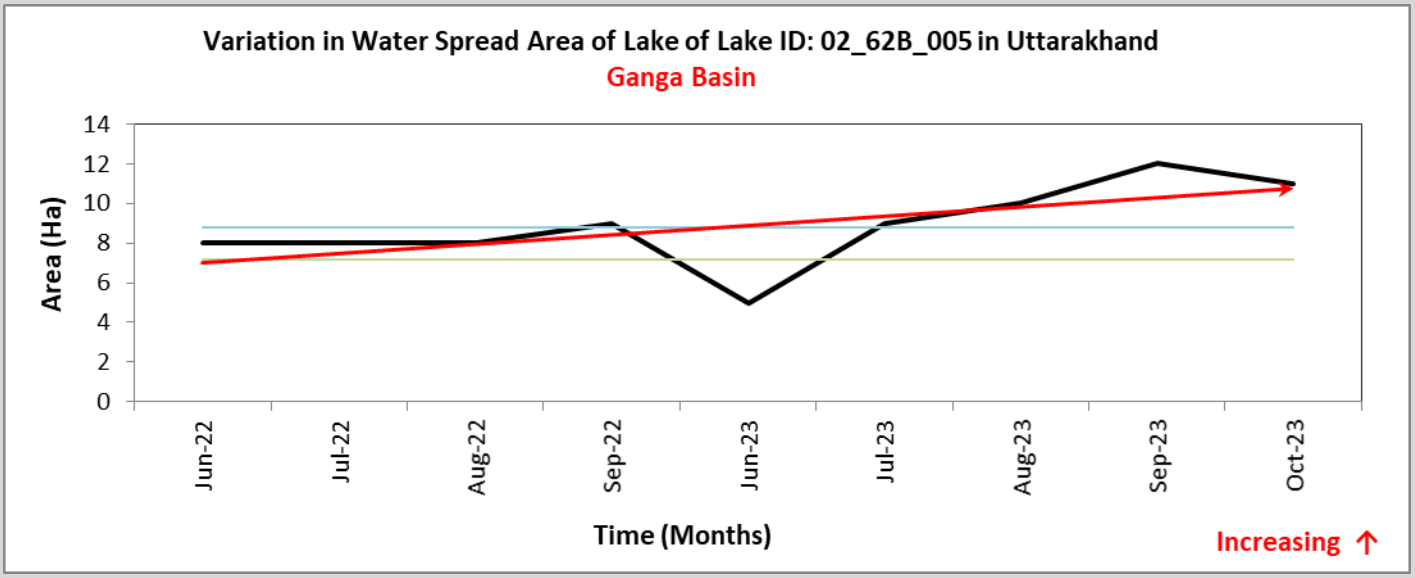


Figure 4.157(ii) Trend Analysis Plot ±20%

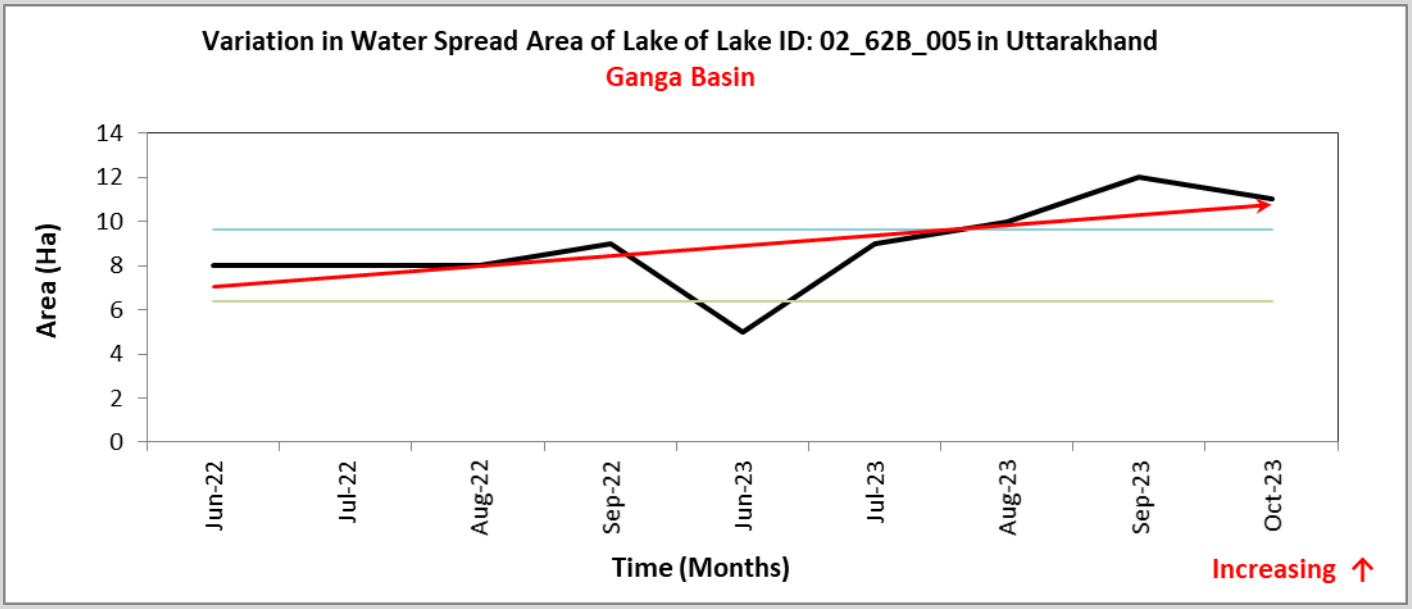


Figure 4.158(i) Trend Analysis Plot ±10%

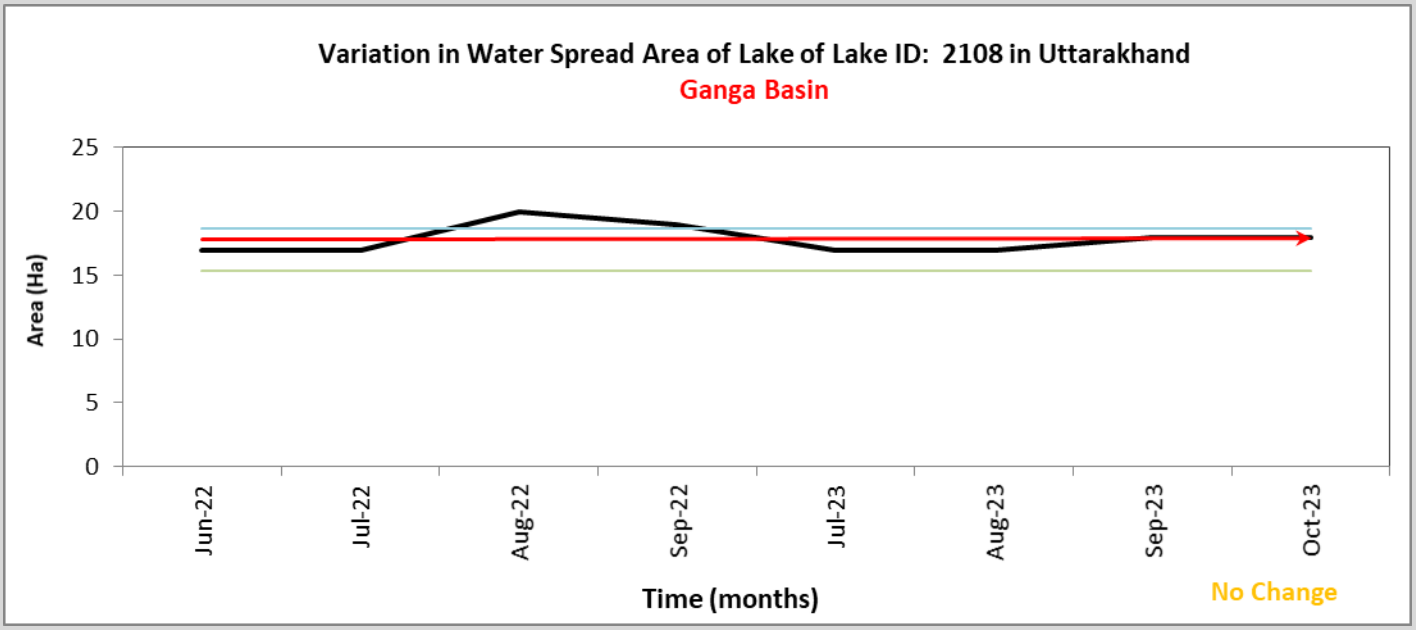


Figure 4.158(ii) Trend Analysis Plot ±20%

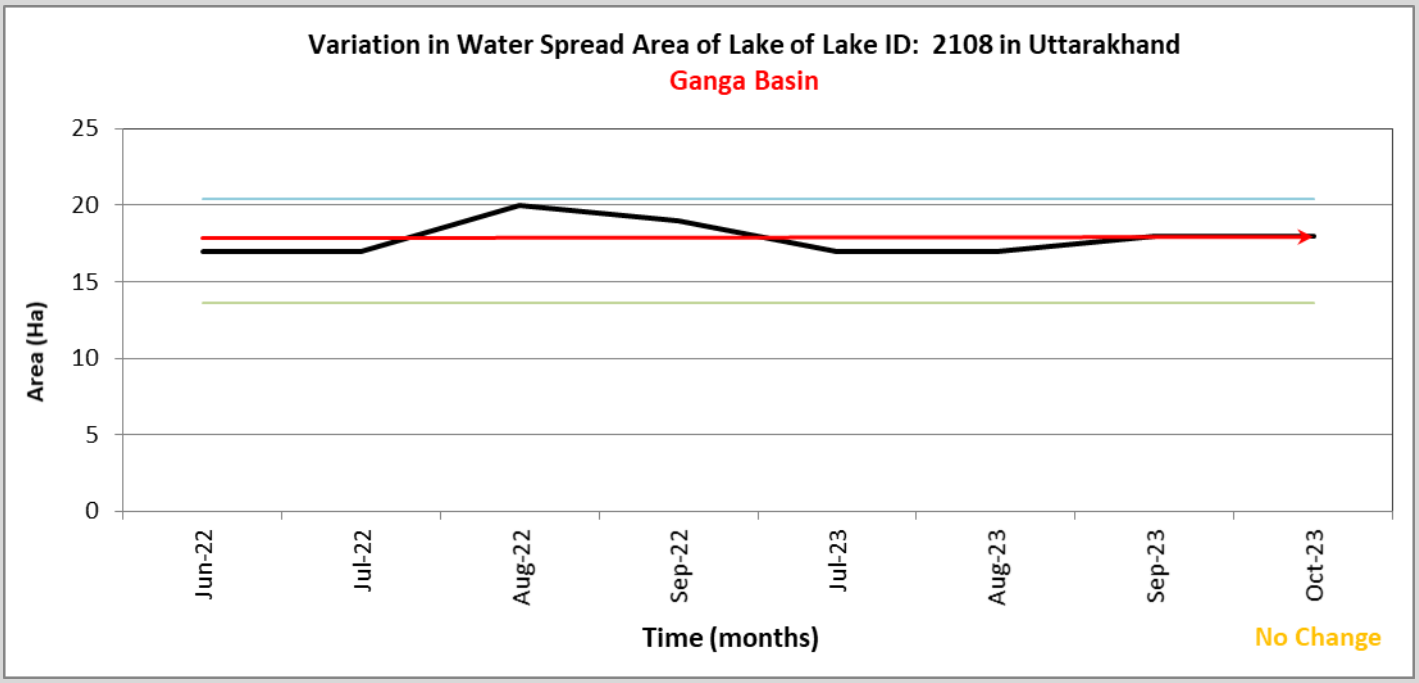


Figure 4.159(i) Trend Analysis Plot ±10%

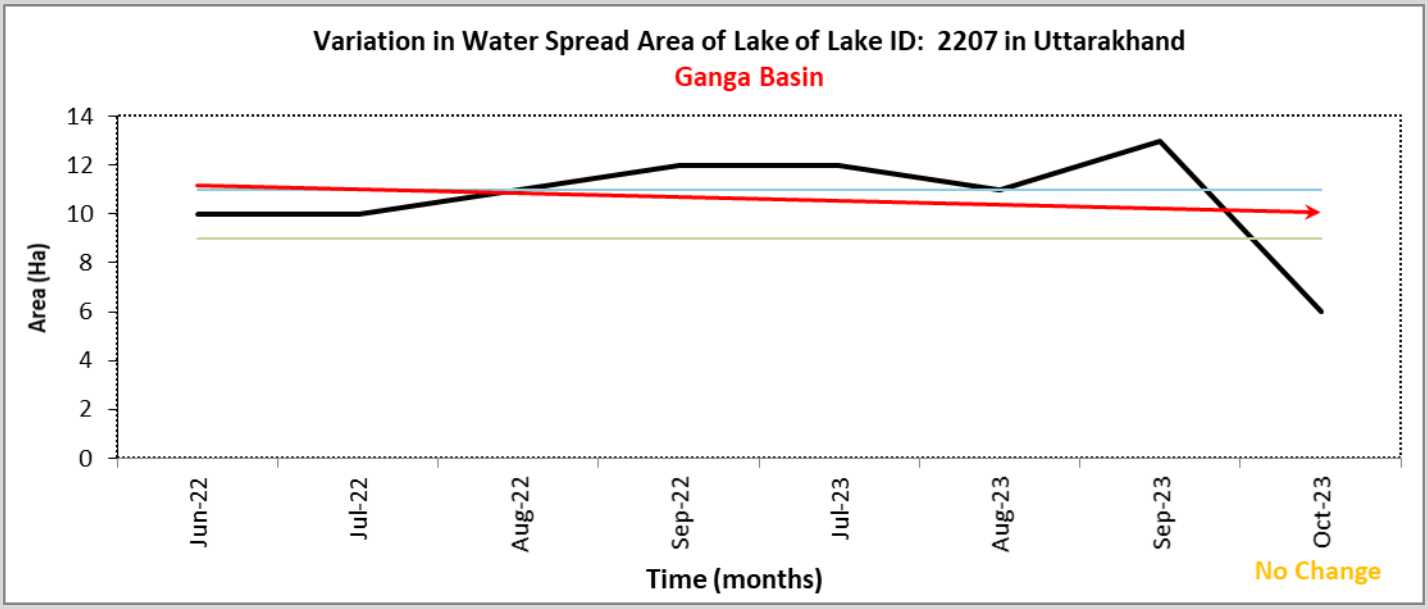


Figure 4.159(ii) Trend Analysis Plot ±20%

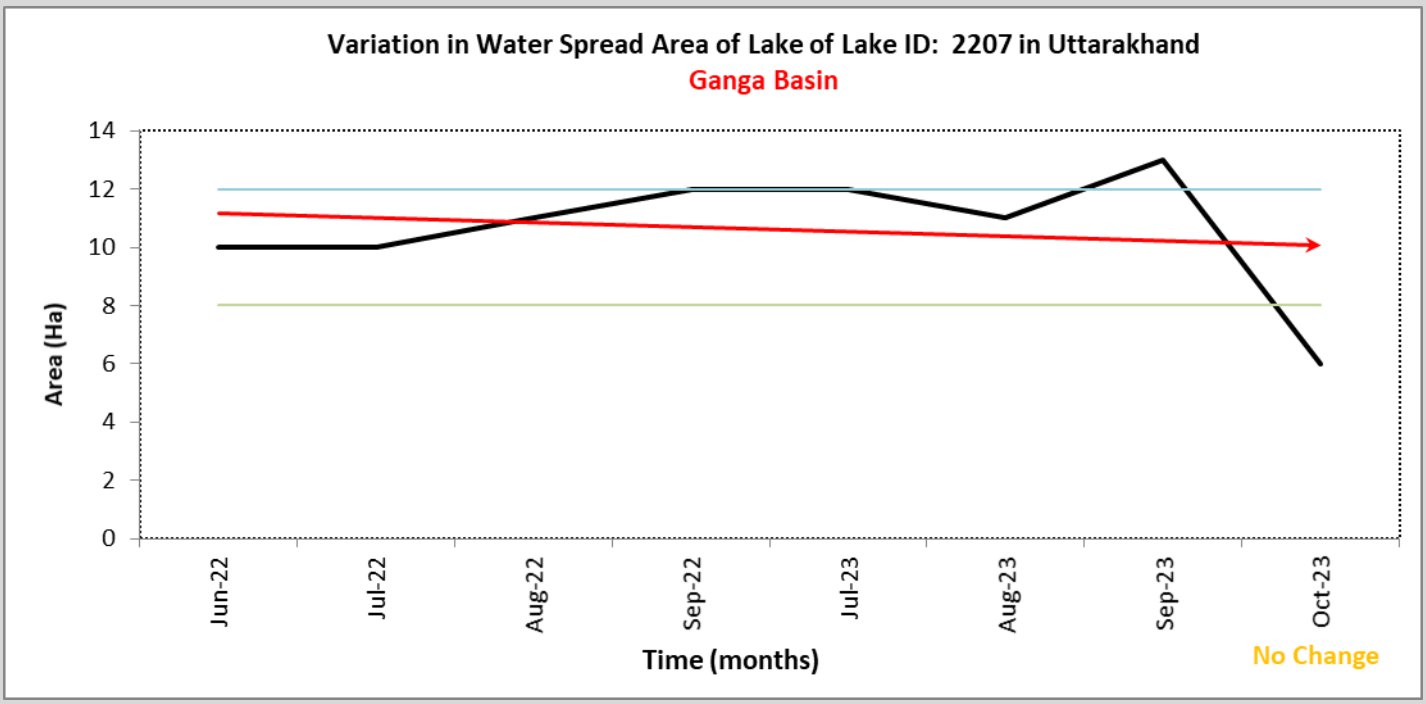


Figure 4.160(i) Trend Analysis Plot ±10%

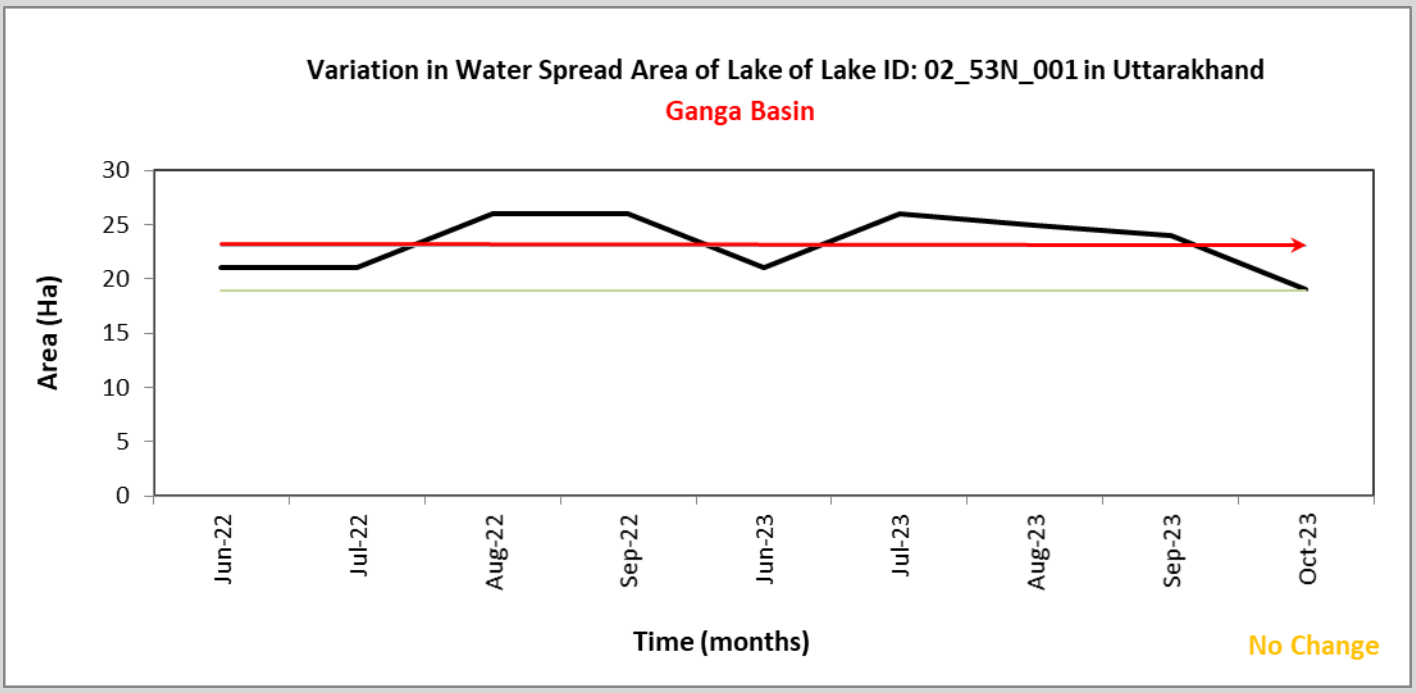


Figure 4.160(ii) Trend Analysis Plot ±20%

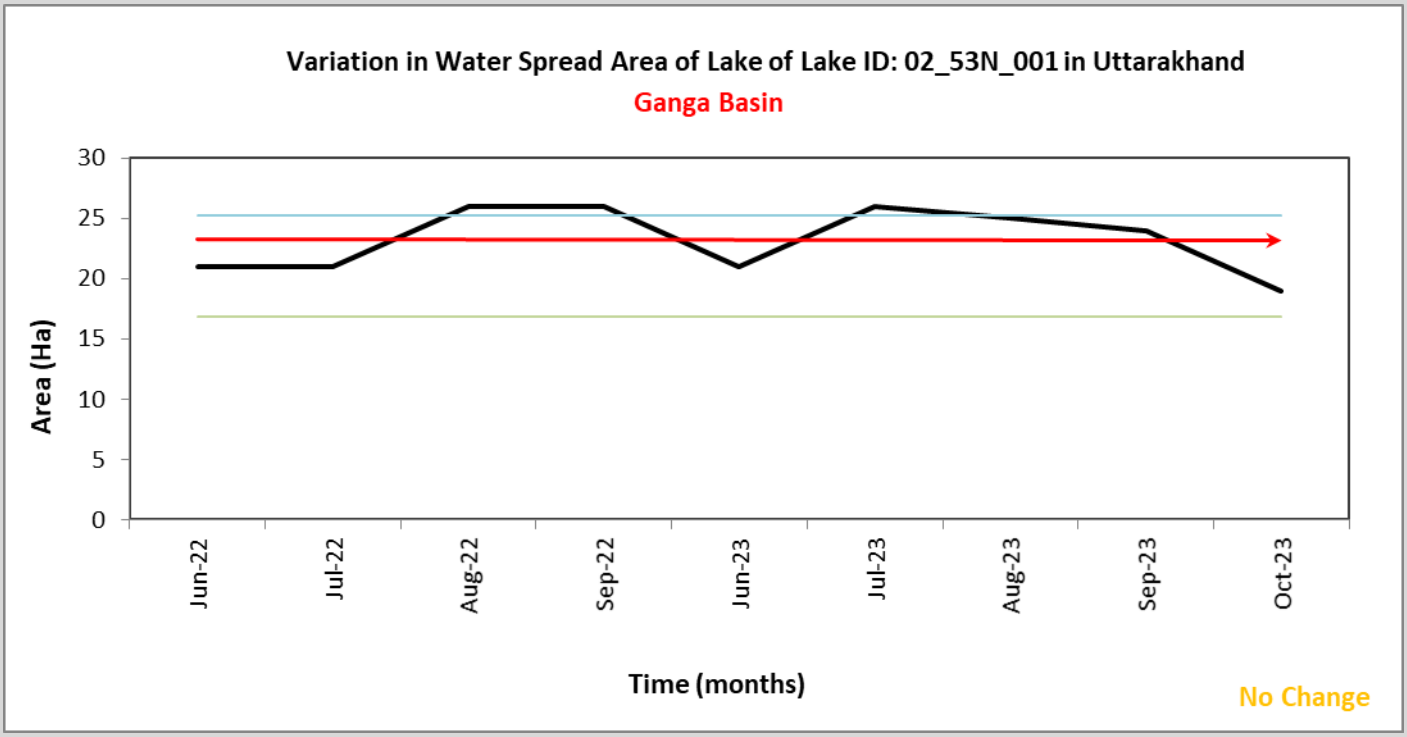


Figure 4.161(i) Trend Analysis Plot ±10%

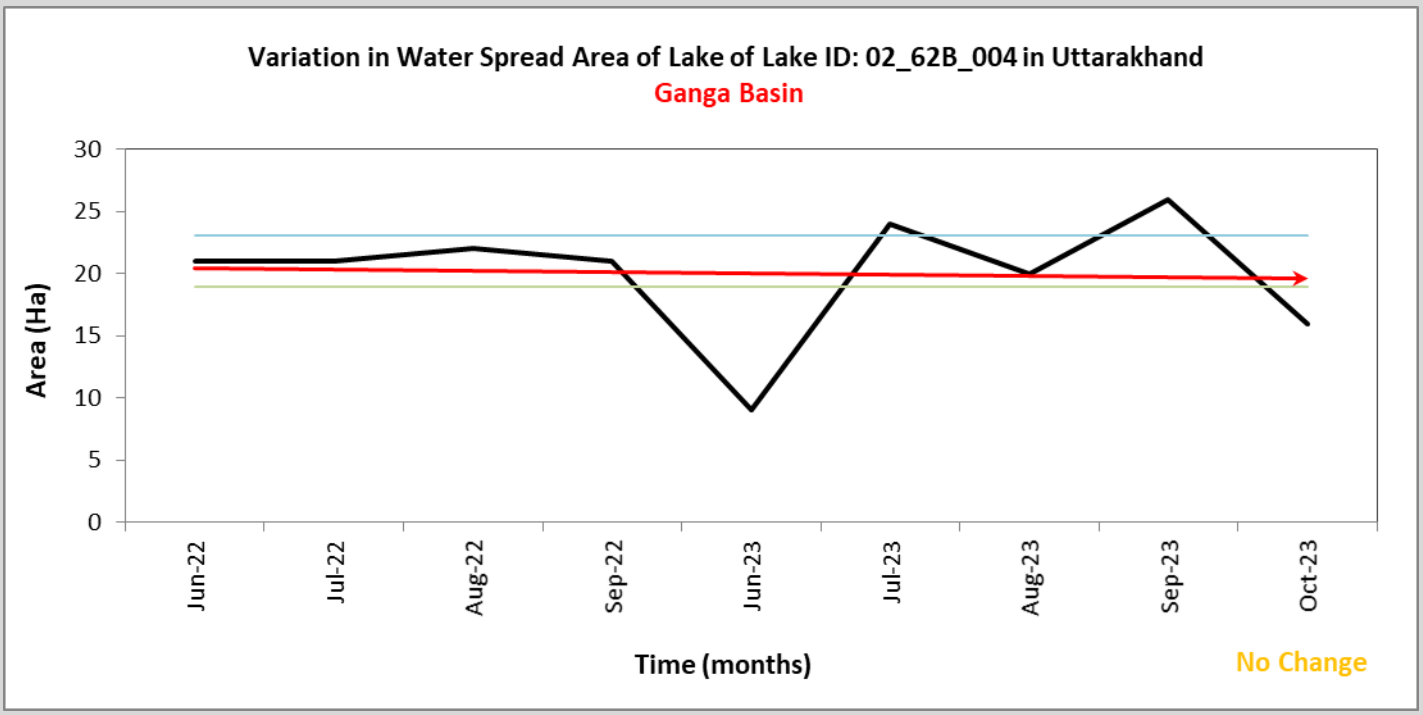


Figure 4.161(ii) Trend Analysis Plot ±20%

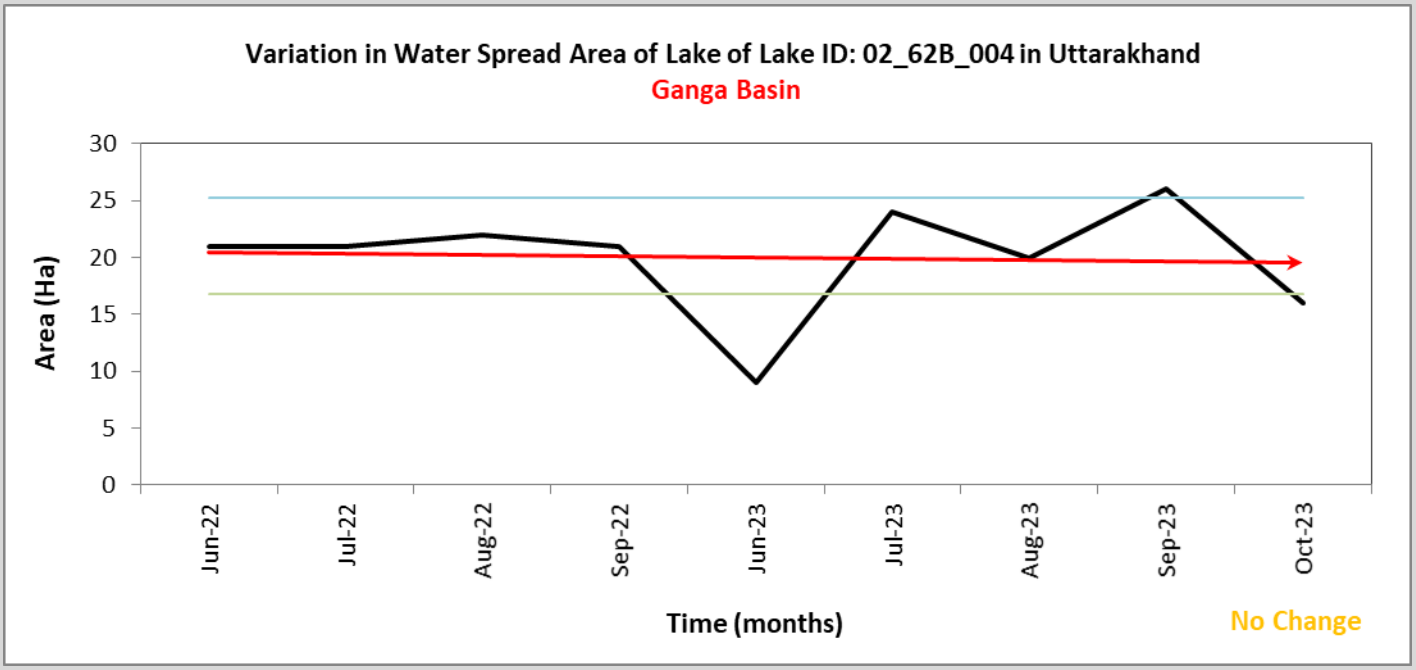


Figure 4.162(i) Trend Analysis Plot ±10%

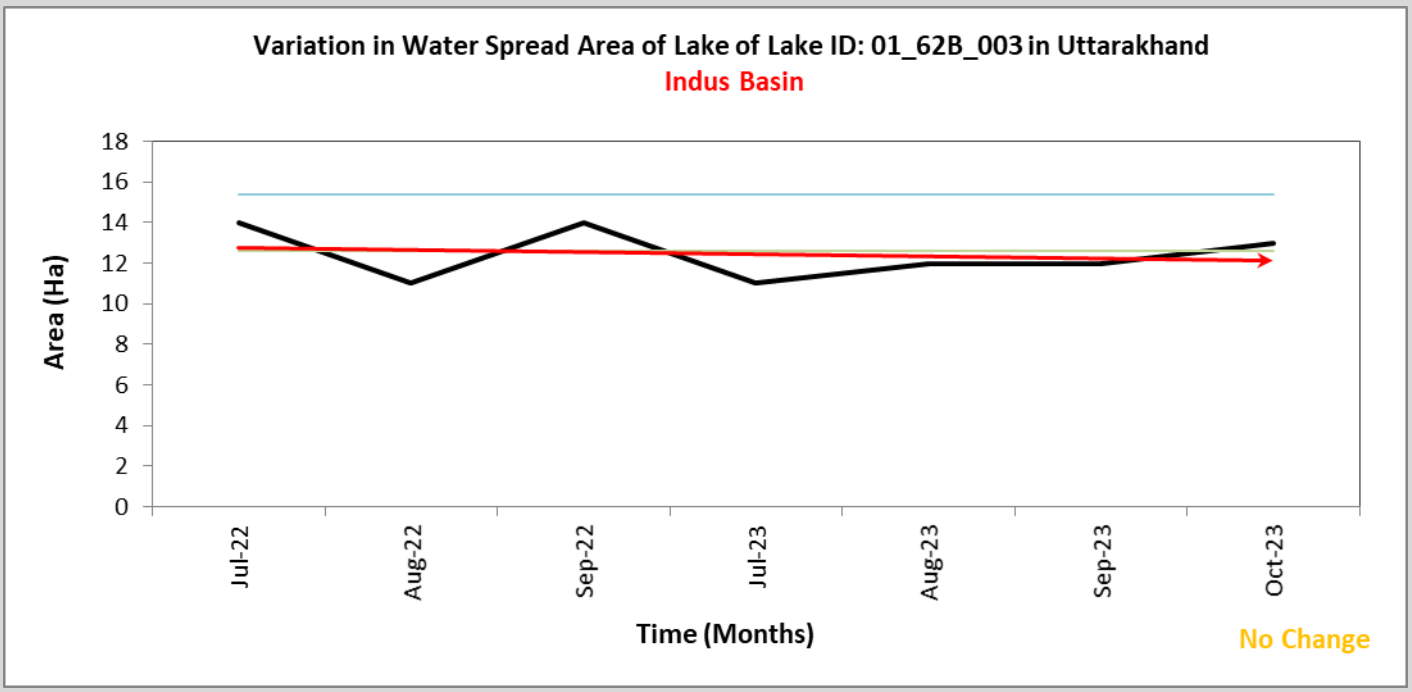


Figure 4.162(ii) Trend Analysis Plot ±20%

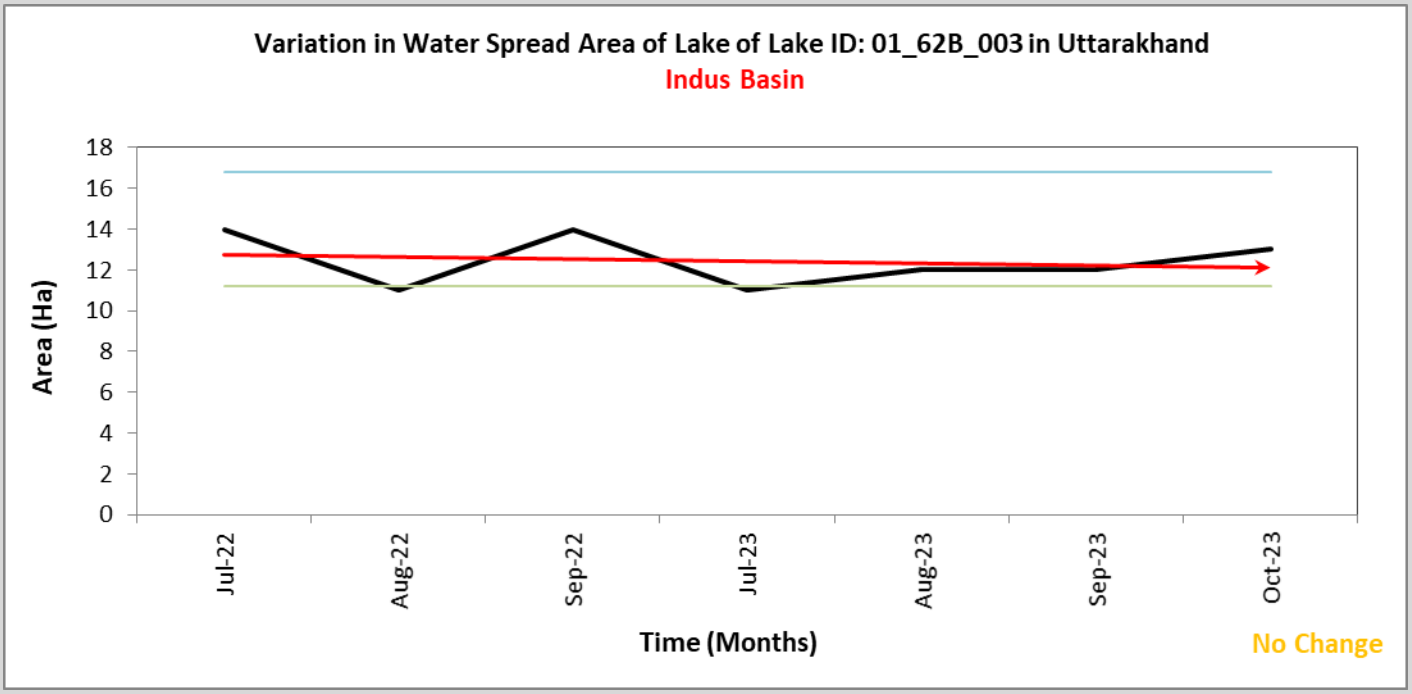


Figure 4.163(i) Trend Analysis Plot ±10%

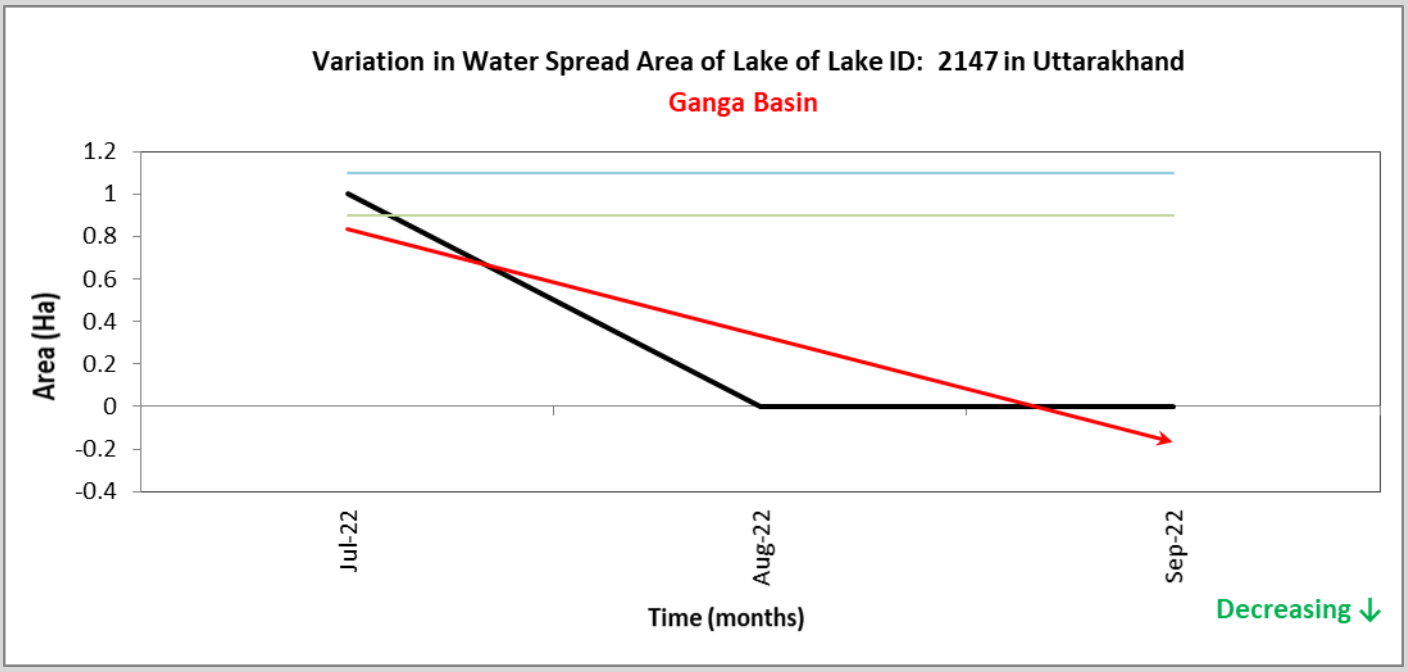
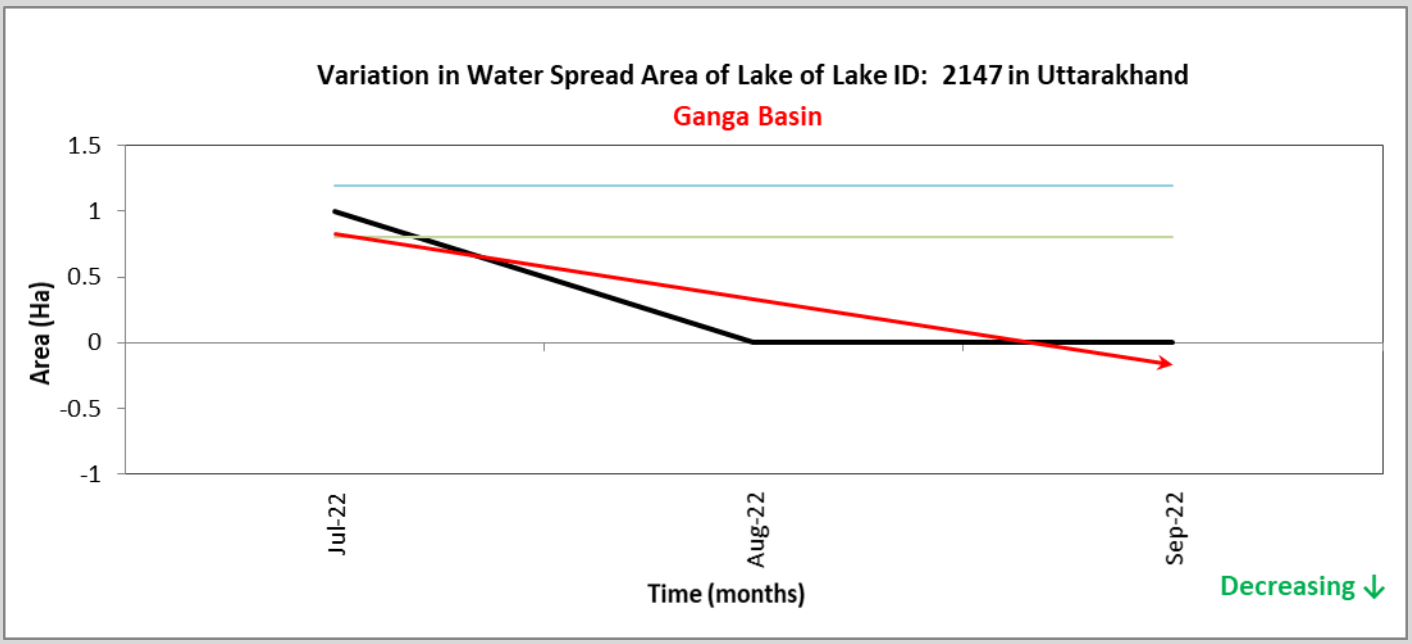


Figure 4.163(ii) Trend Analysis Plot ±20%



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 ±10%

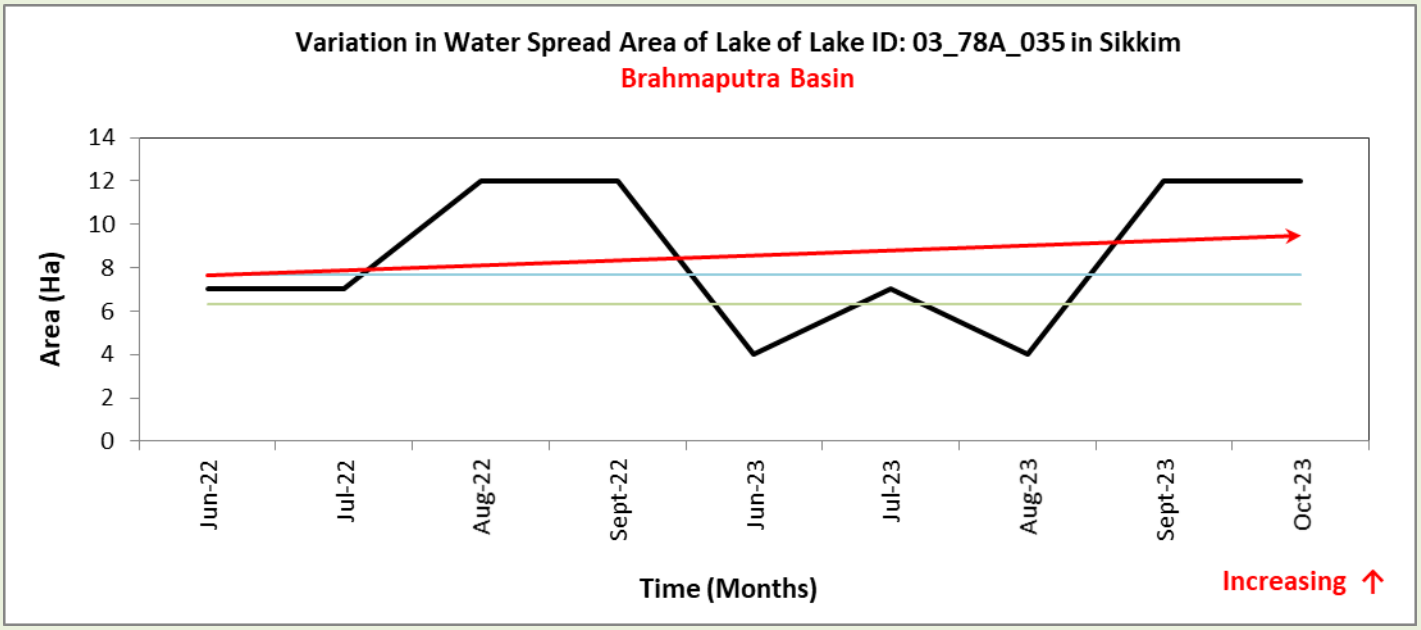


Figure 4.164(ii) Trend Analysis Plot ±20%

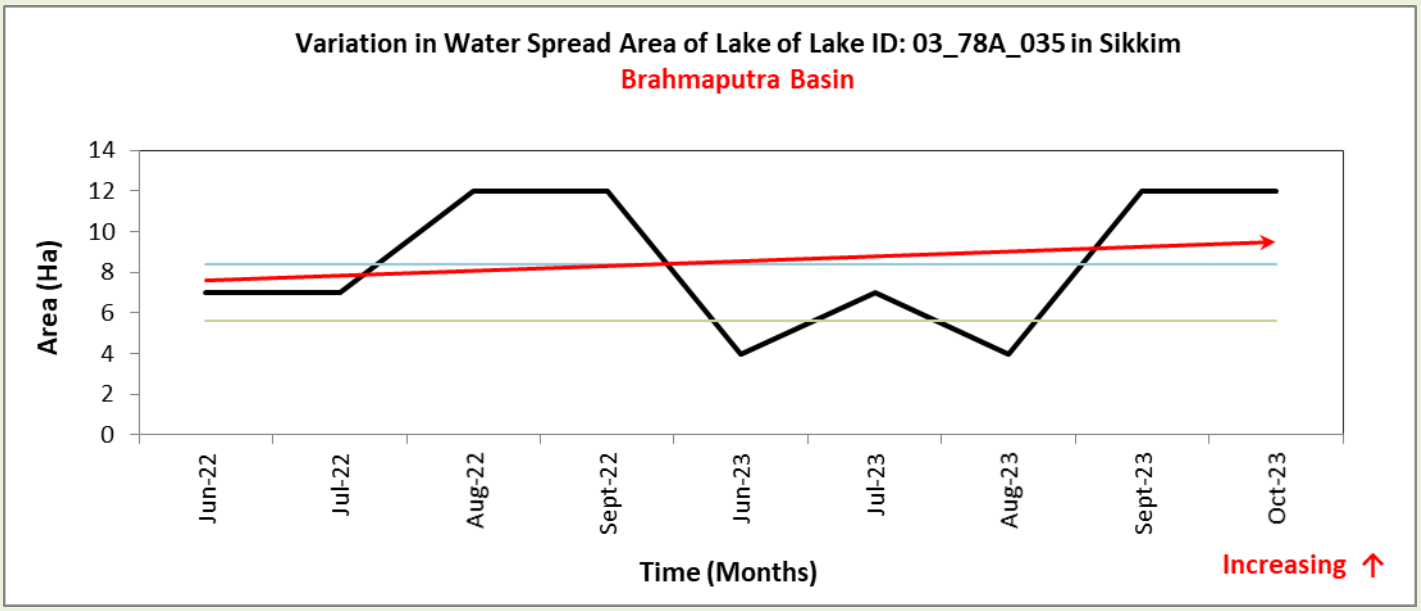


Figure 4.165(i) Trend Analysis Plot ±10%

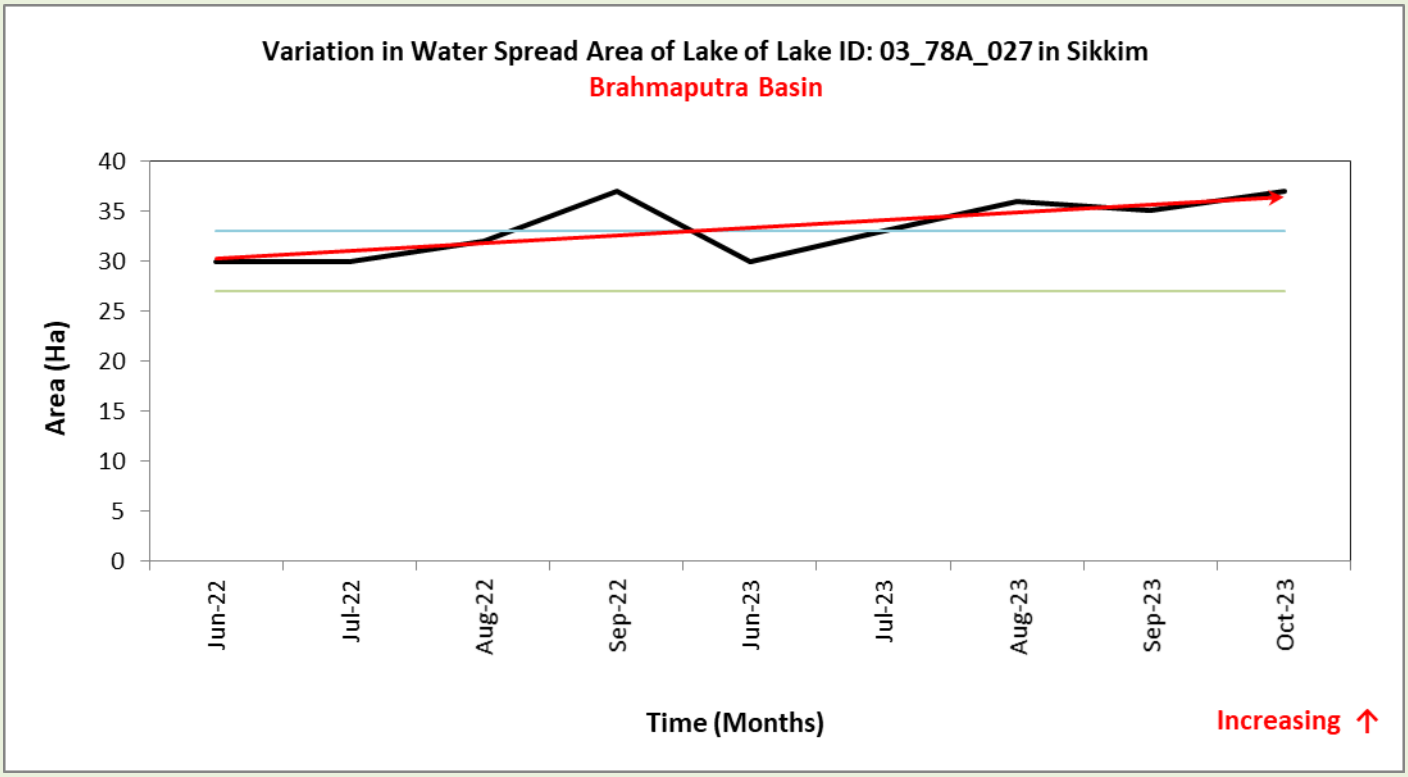


Figure 4.165(ii) Trend Analysis Plot ±20%

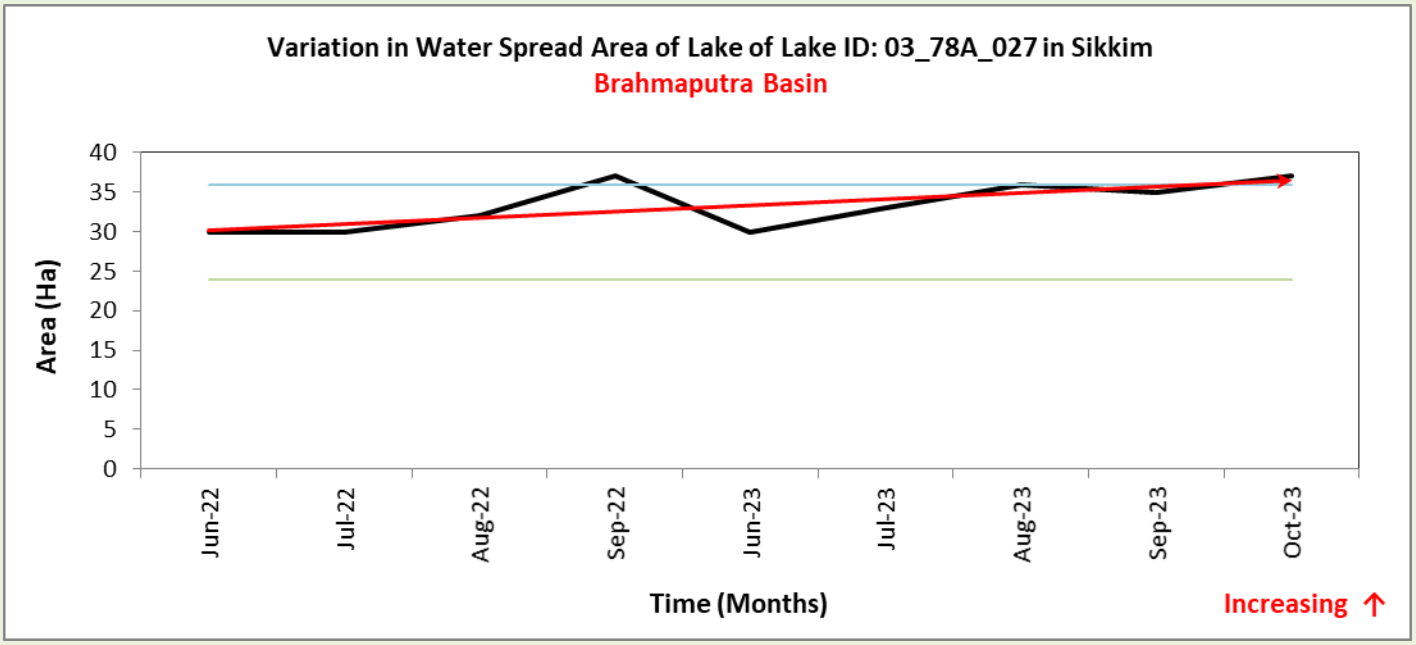


Figure 4.166(i) Trend Analysis Plot ±10%

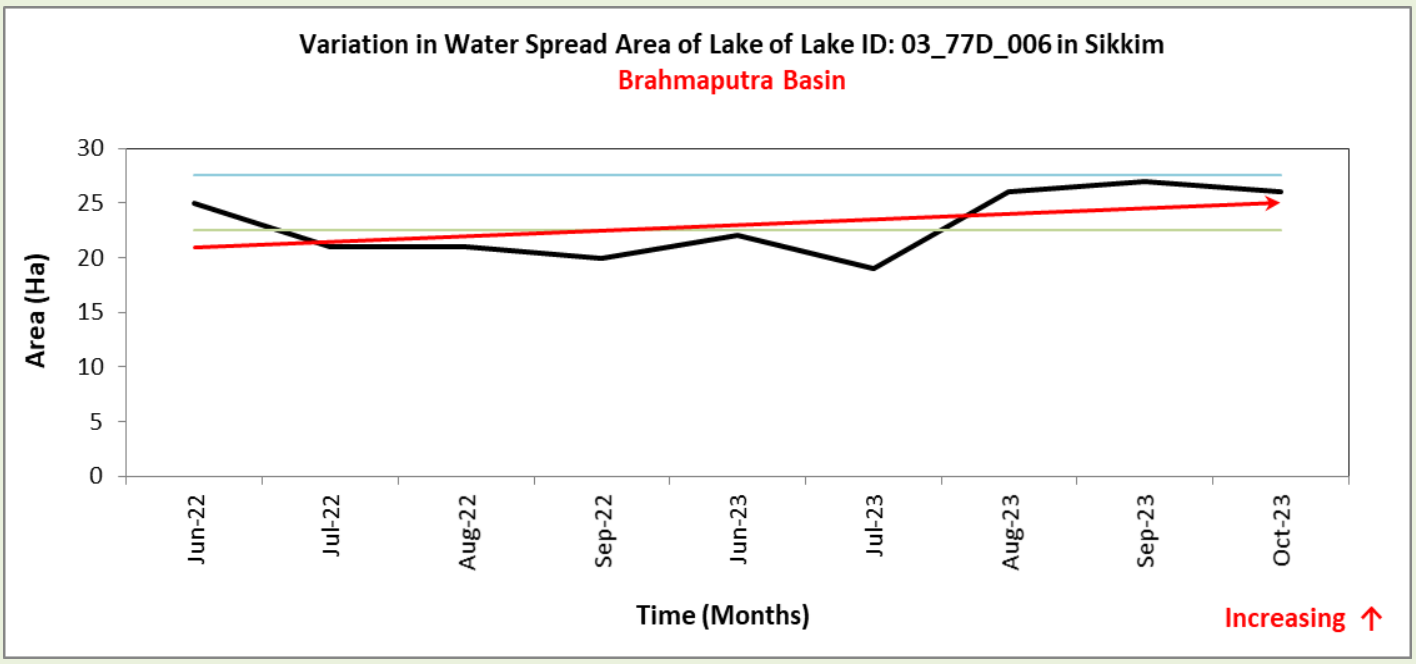


Figure 4.166(ii) Trend Analysis Plot ±20%

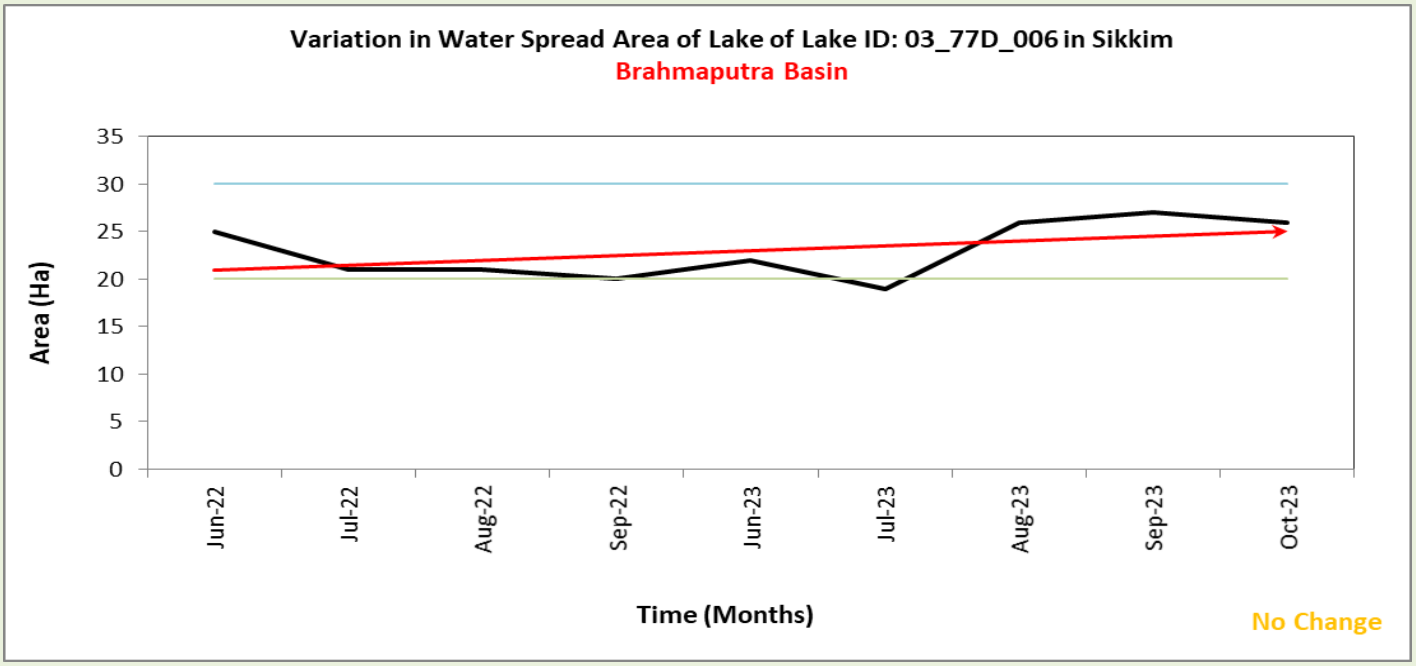


Figure 4.167(i) Trend Analysis Plot ±10%

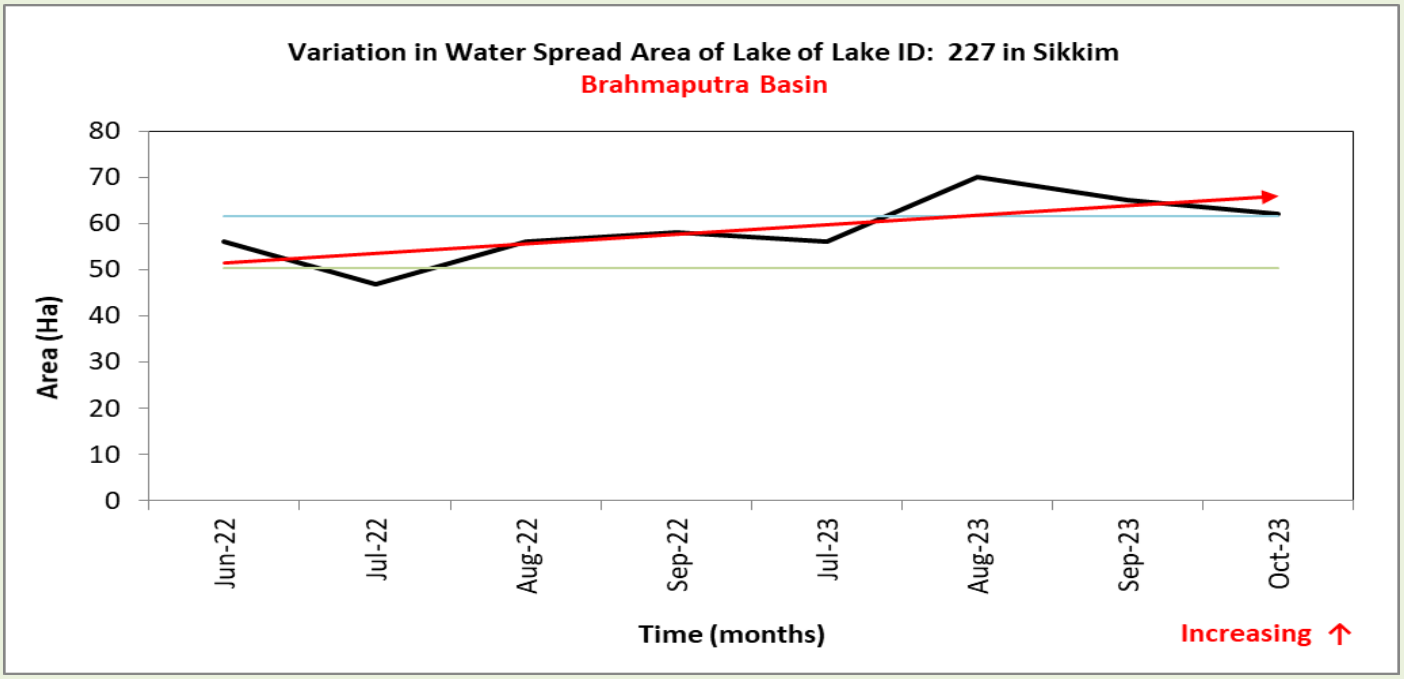


Figure 4.167(ii) Trend Analysis Plot ±20%

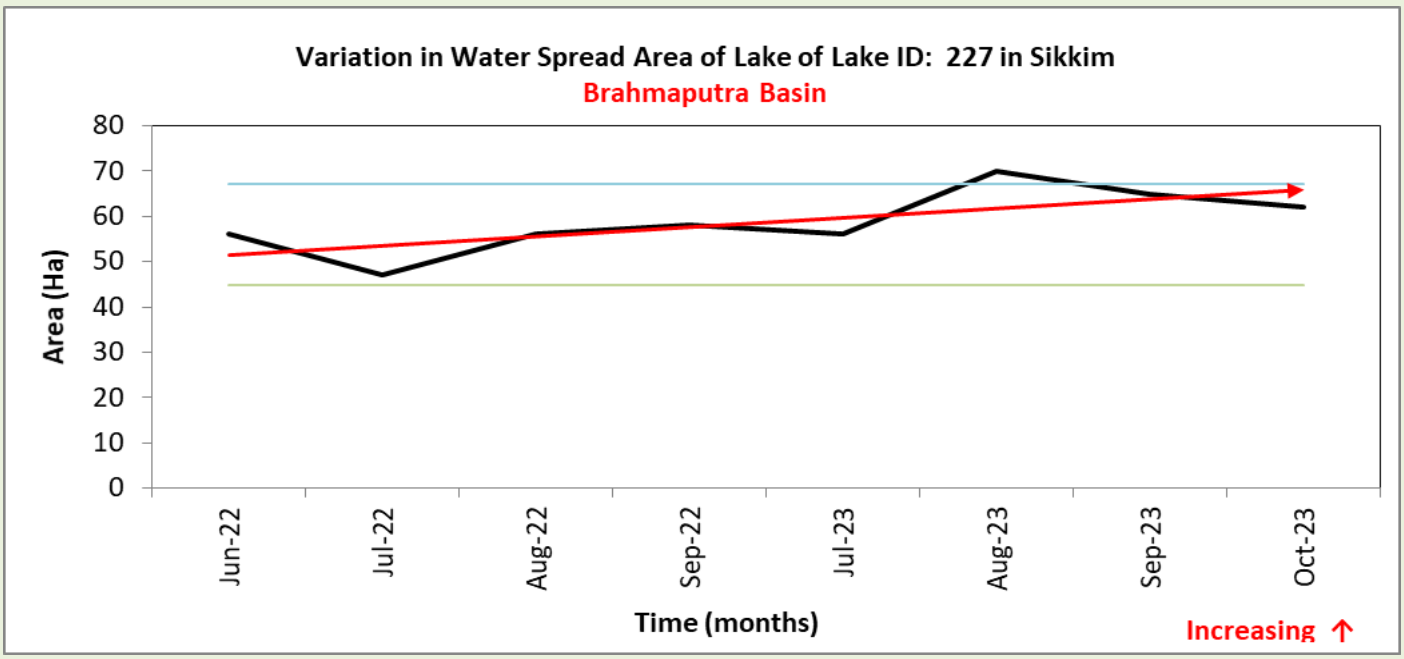


Figure 4.168(i) Trend Analysis Plot ±10%

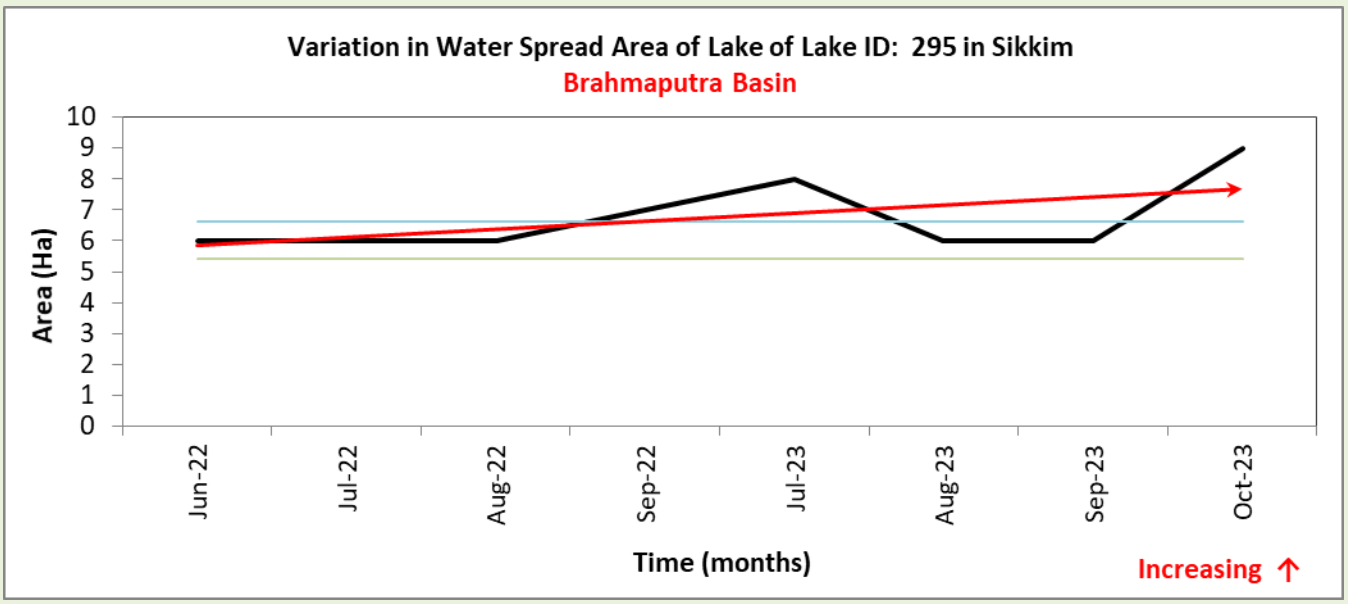


Figure 4.168(ii) Trend Analysis Plot ±20%

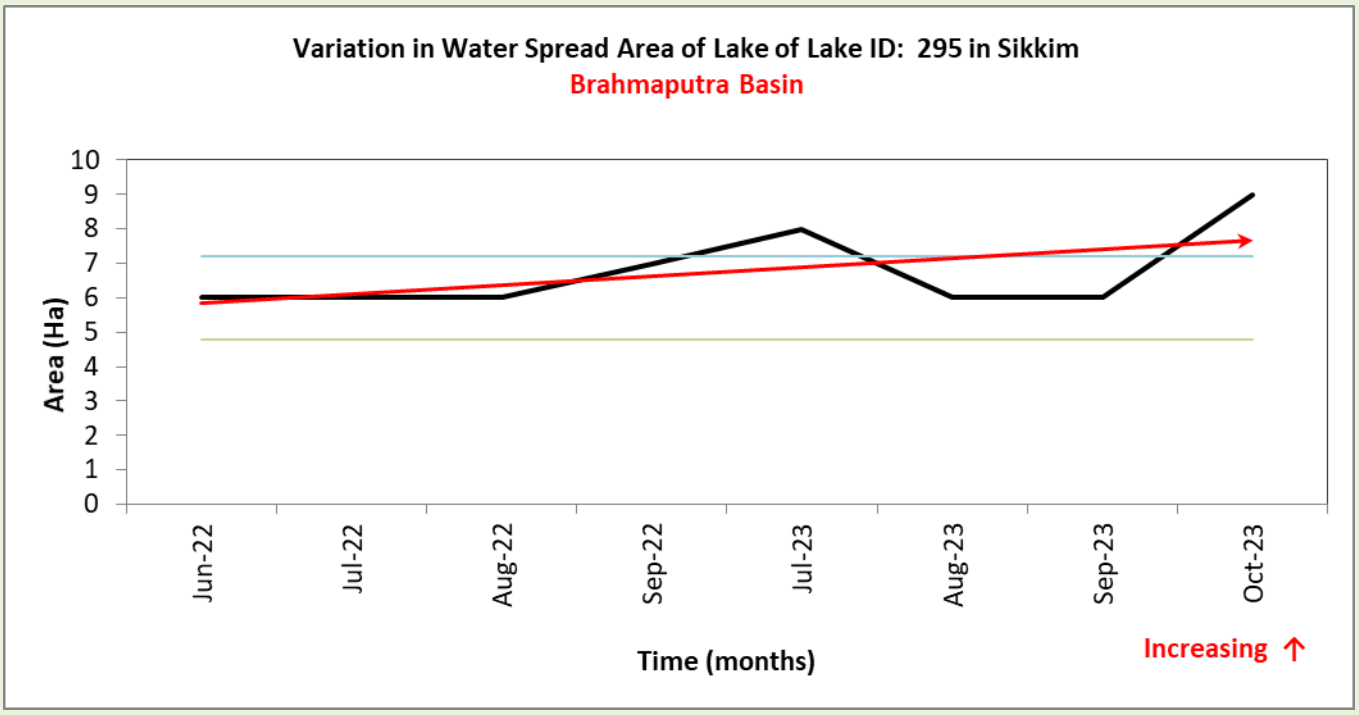


Figure 4.169(i) Trend Analysis Plot ±10%

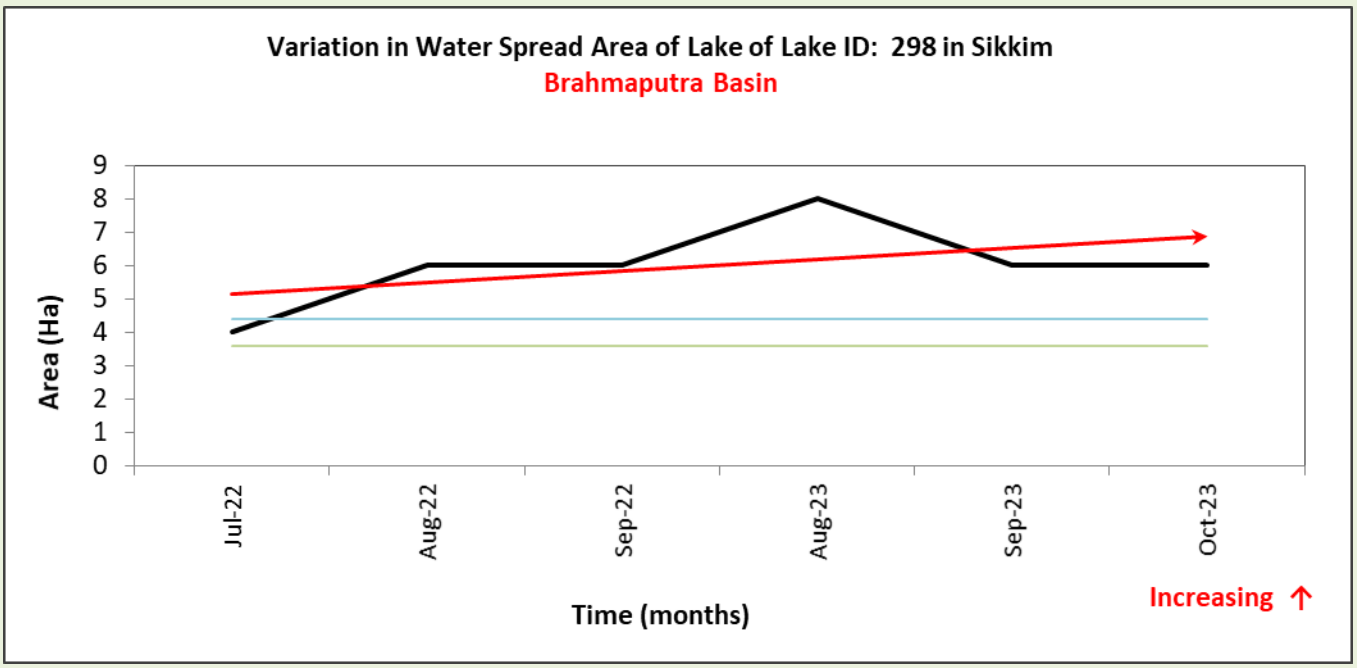


Figure 4.169(ii) Trend Analysis Plot ±20%

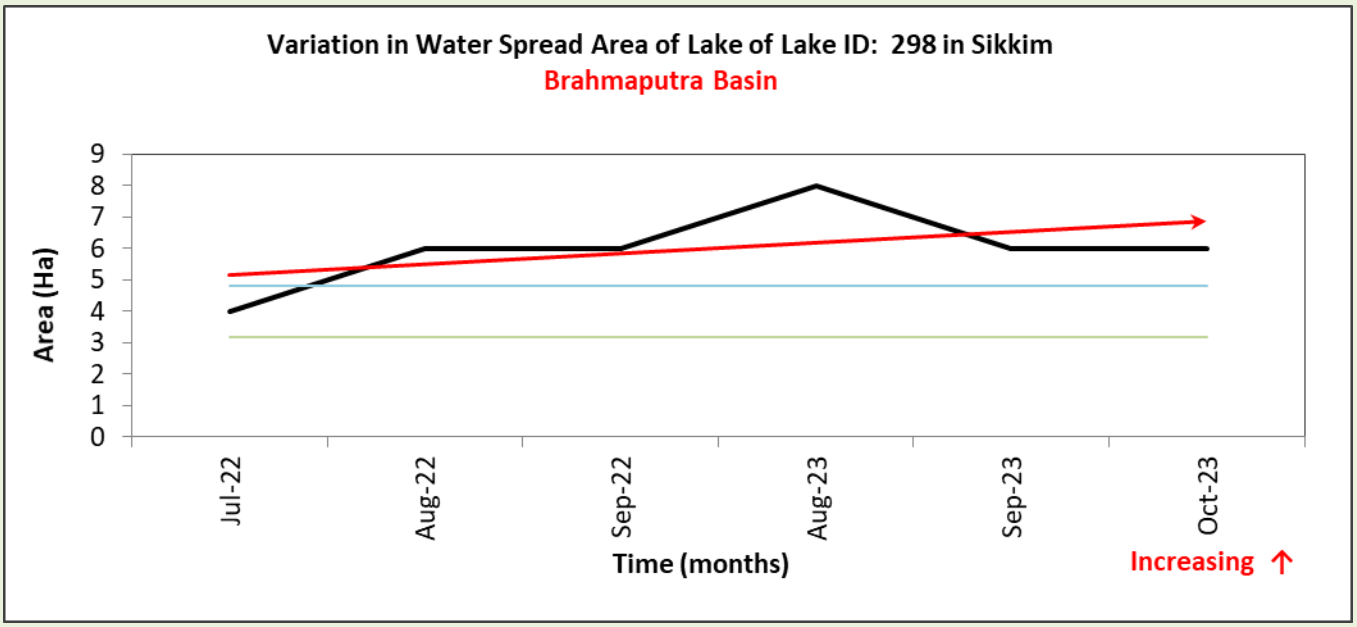


Figure 4.170(i) Trend Analysis Plot ±10%

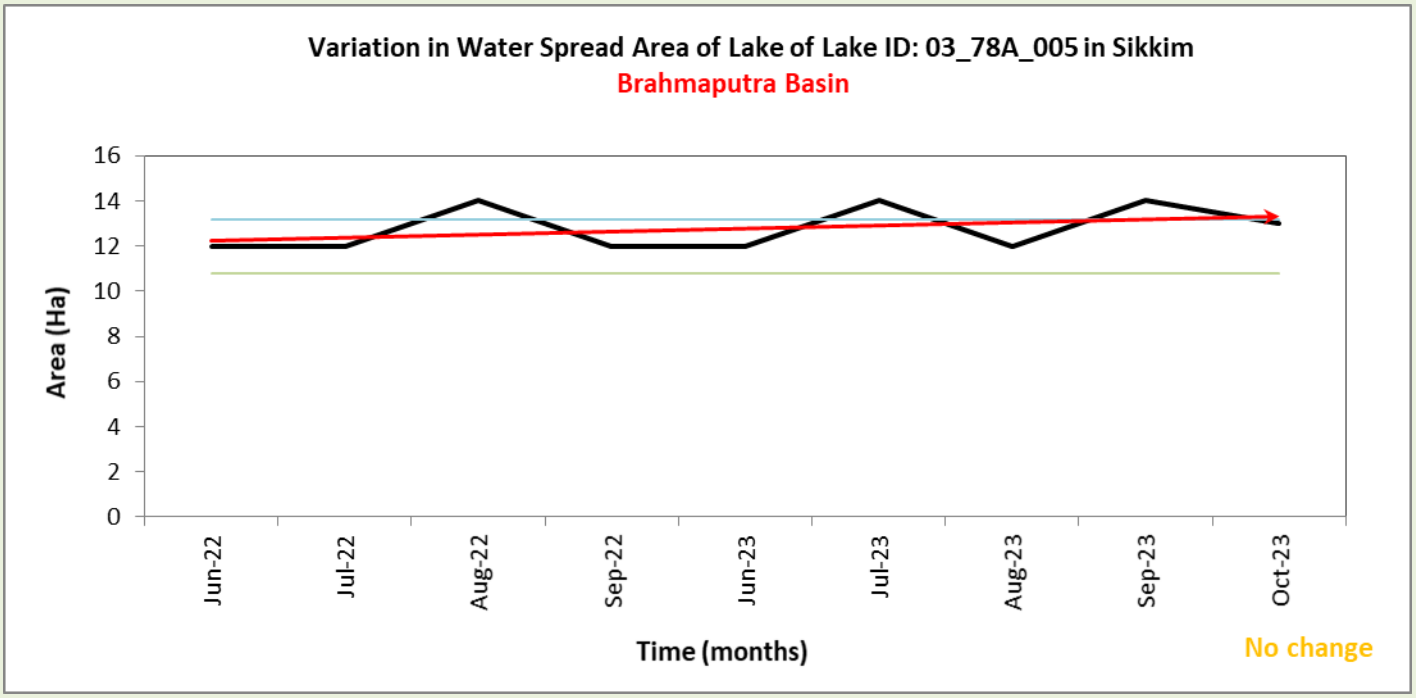


Figure 4.170(ii) Trend Analysis Plot ±20%

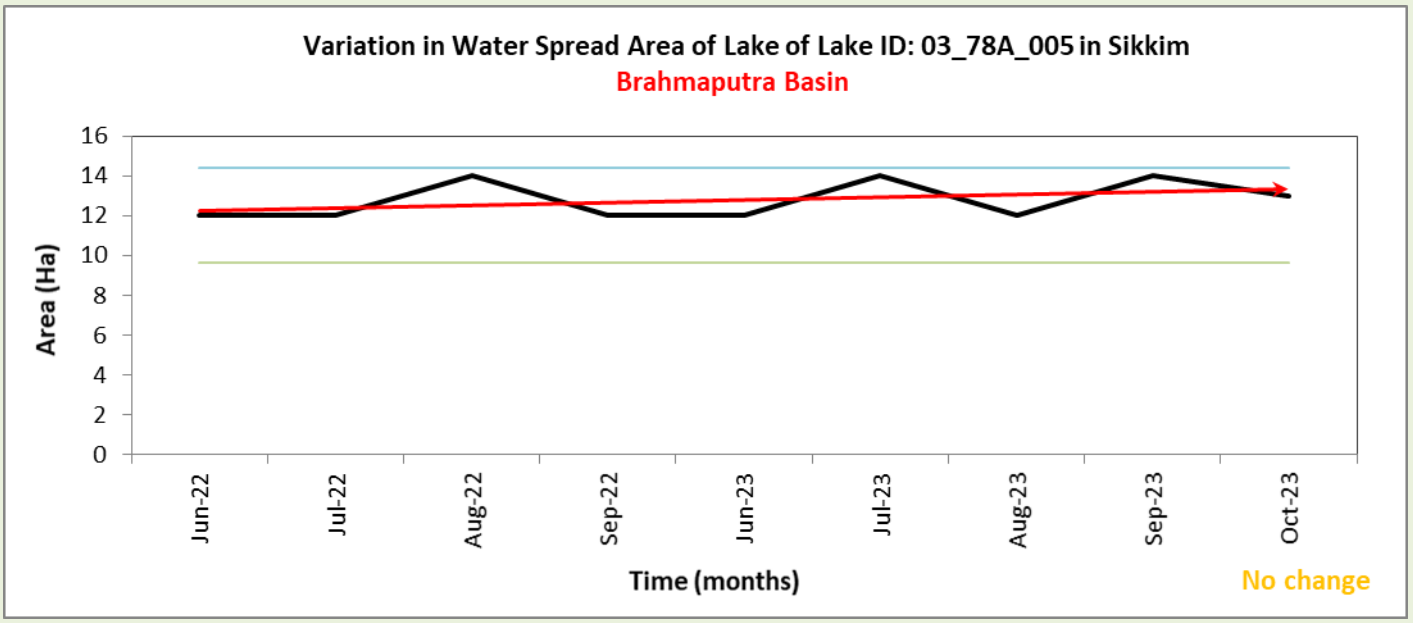


Figure 4.171(i) Trend Analysis Plot ±10%

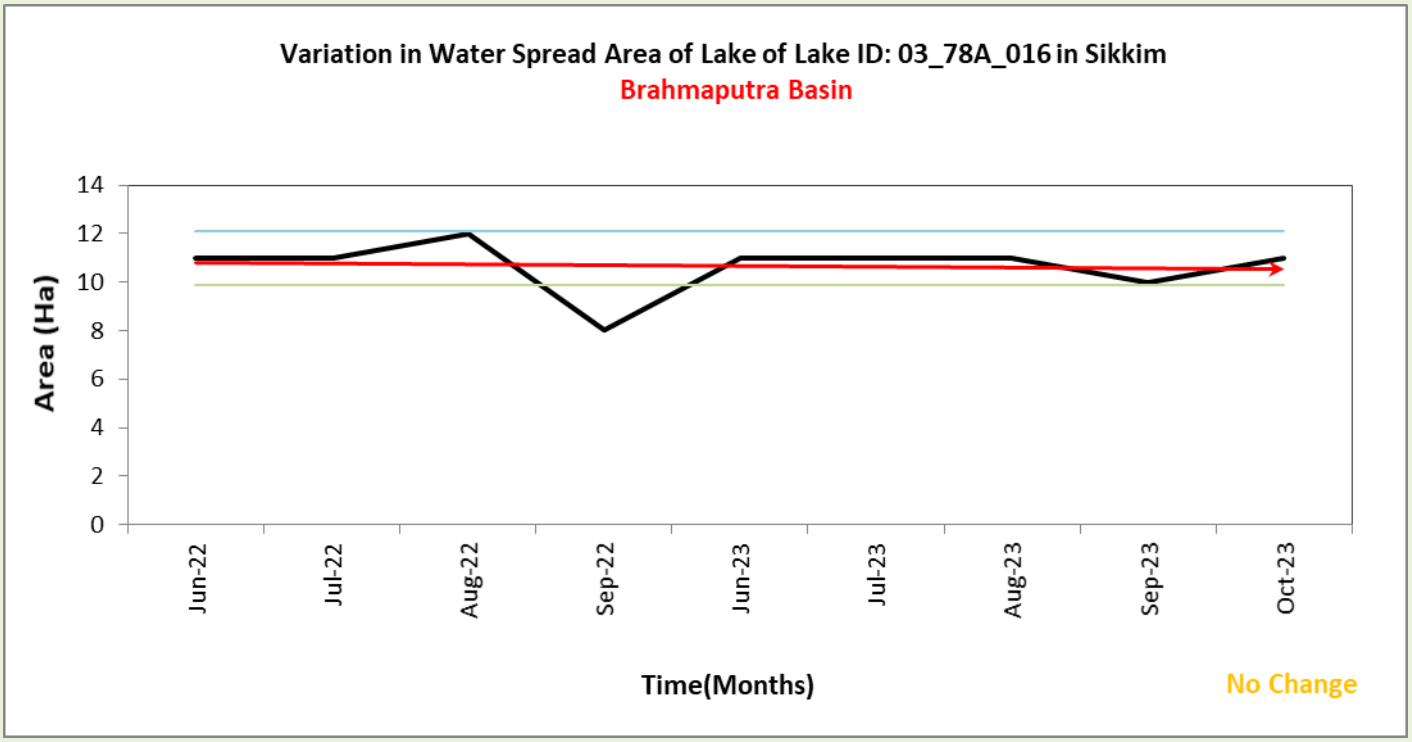


Figure 4.171(ii) Trend Analysis Plot ±20%

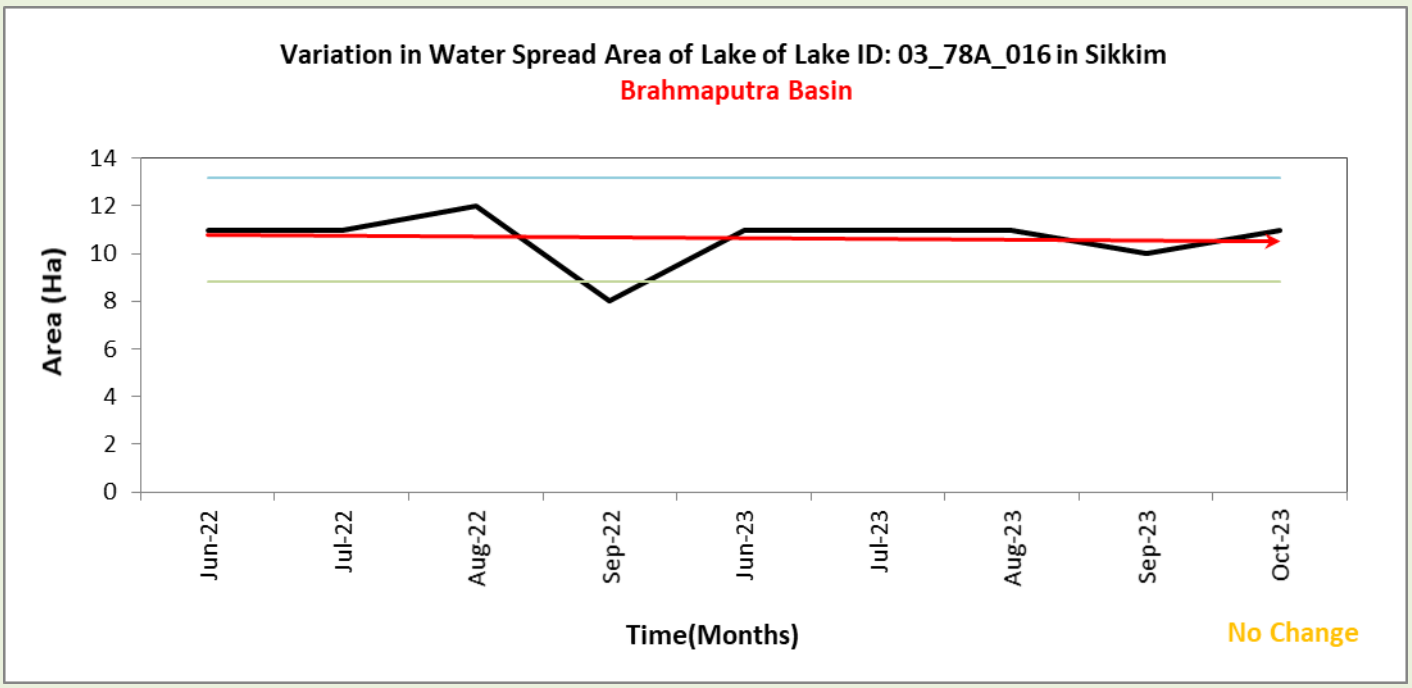


Figure 4.172(i) Trend Analysis Plot ±10%

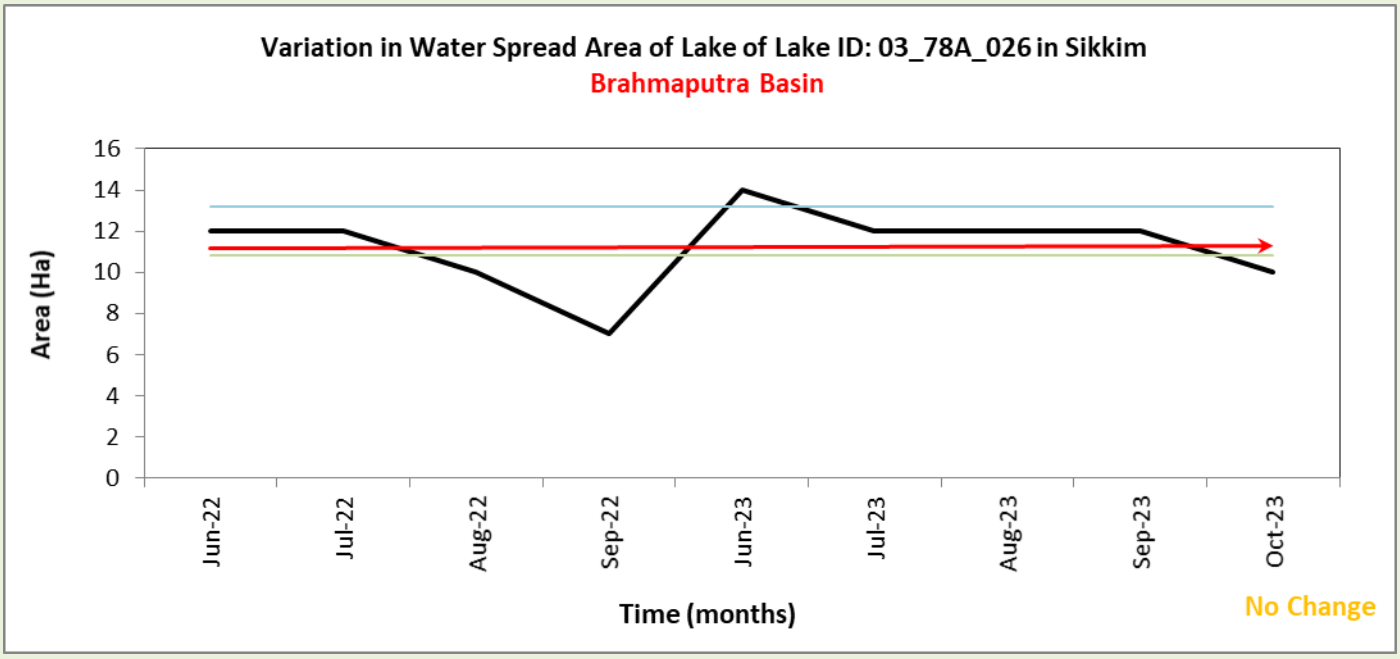


Figure 4.172(ii) Trend Analysis Plot ±20%

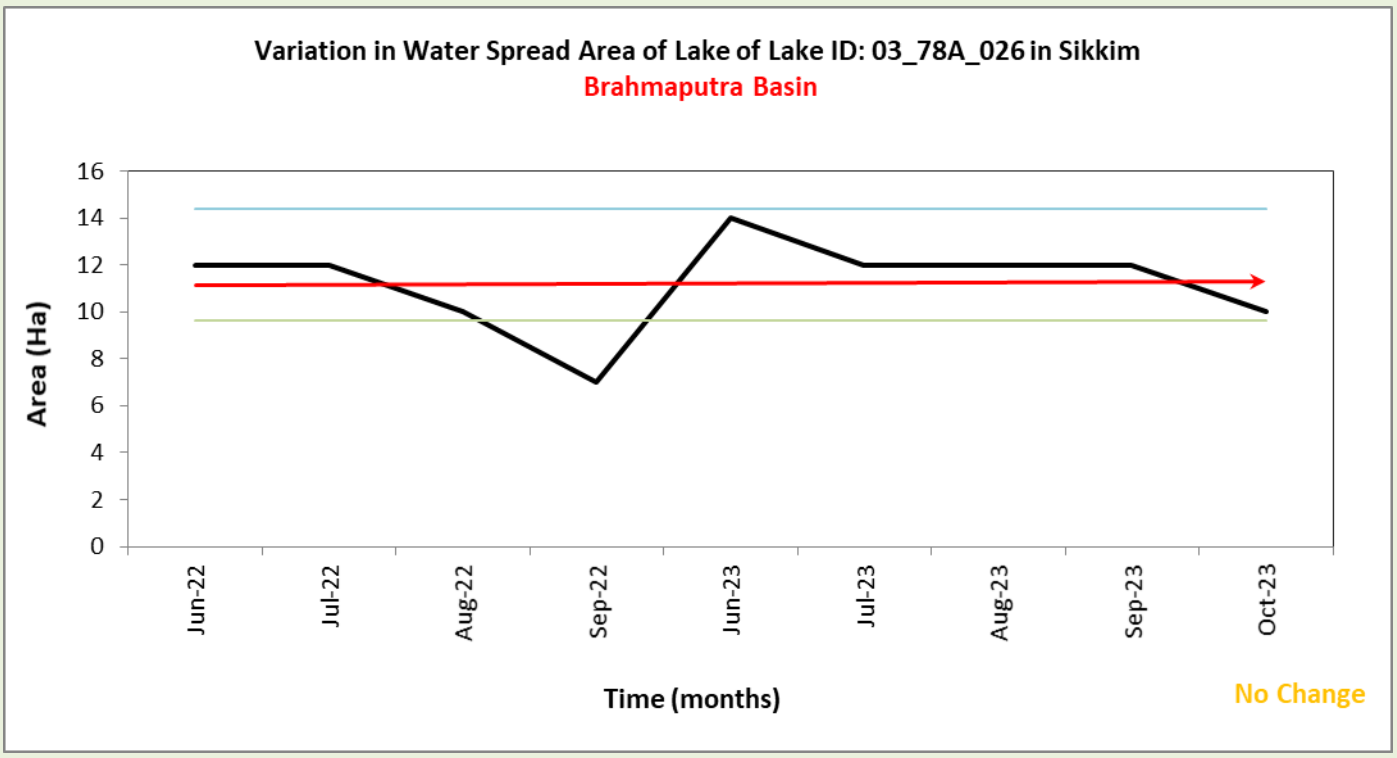


Figure 4.173(i) Trend Analysis Plot ±10%

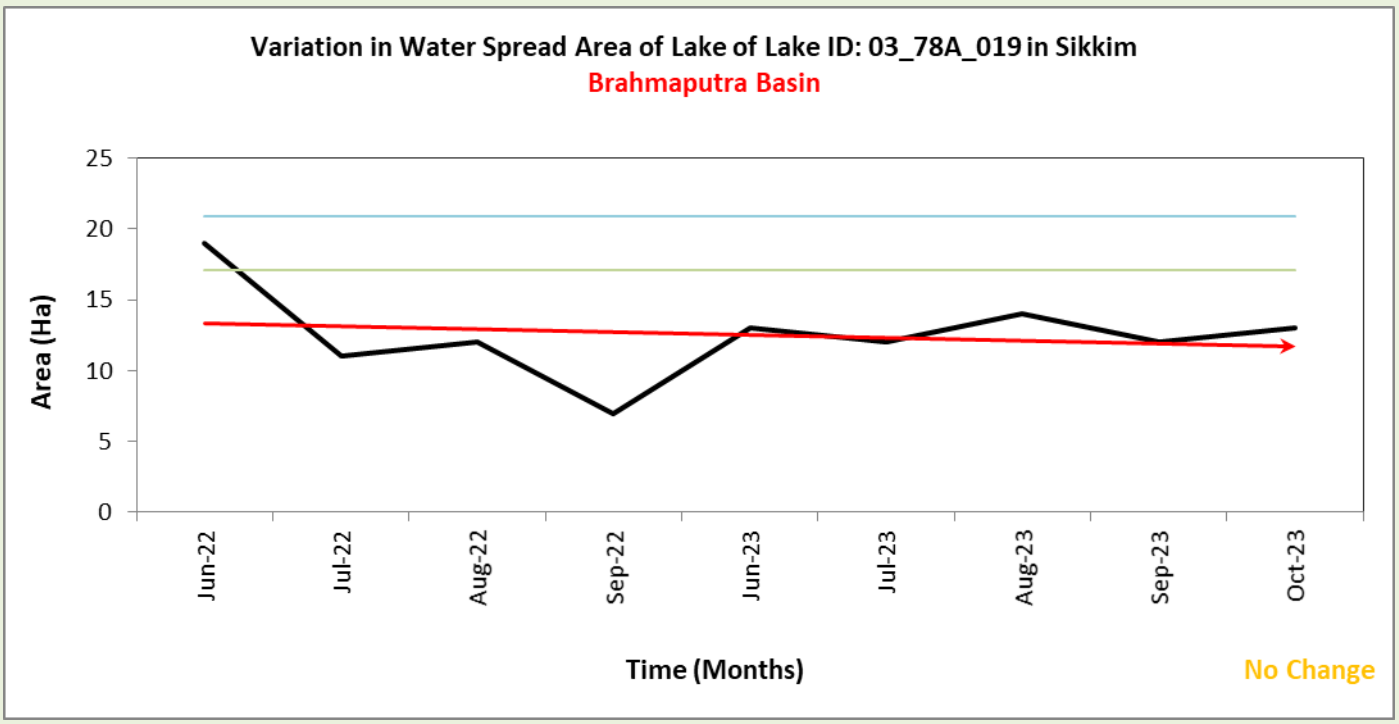


Figure 4.173(ii) Trend Analysis Plot ±20%

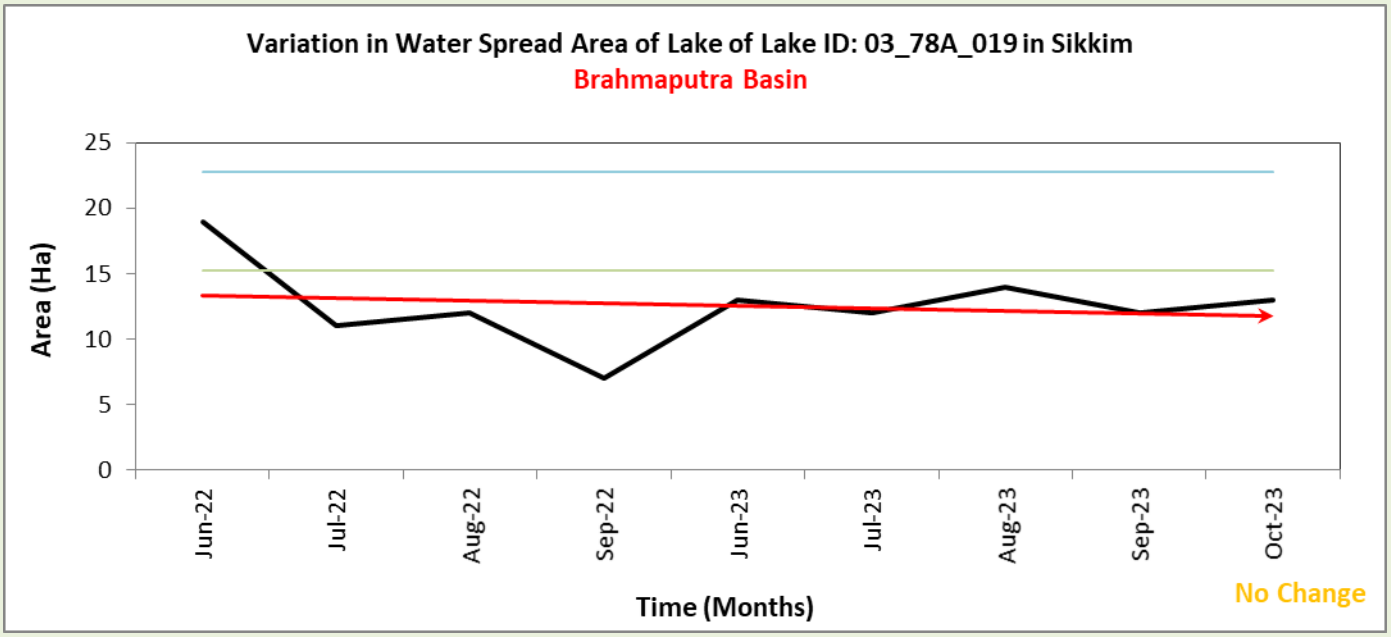


Figure 4.174(i) Trend Analysis Plot ±10%

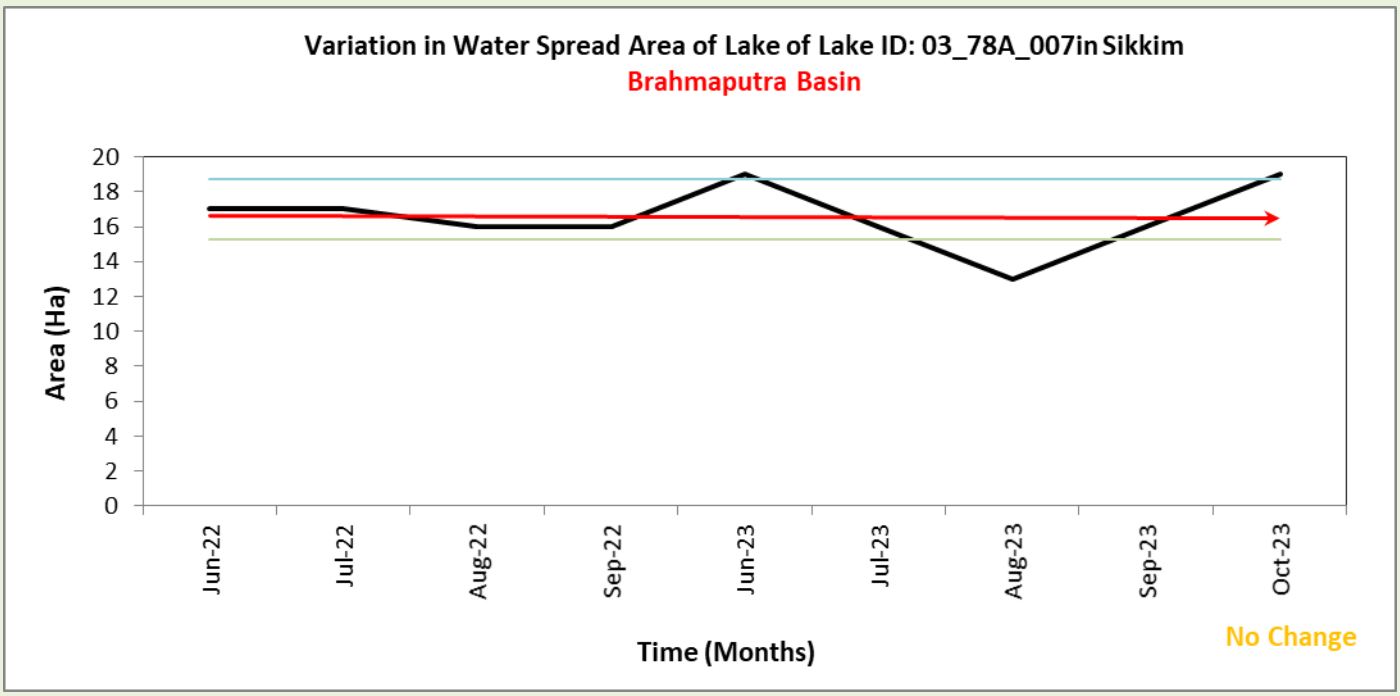


Figure 4.174(ii) Trend Analysis Plot ±20%

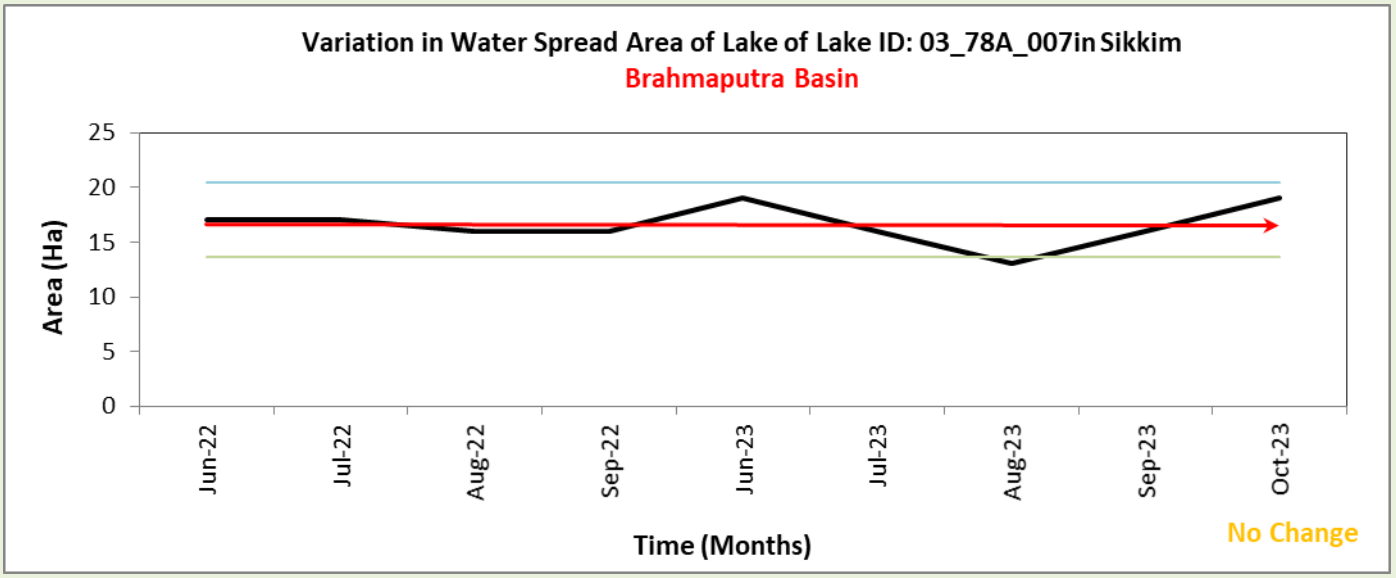


Figure 4.175(i) Trend Analysis Plot ±10%

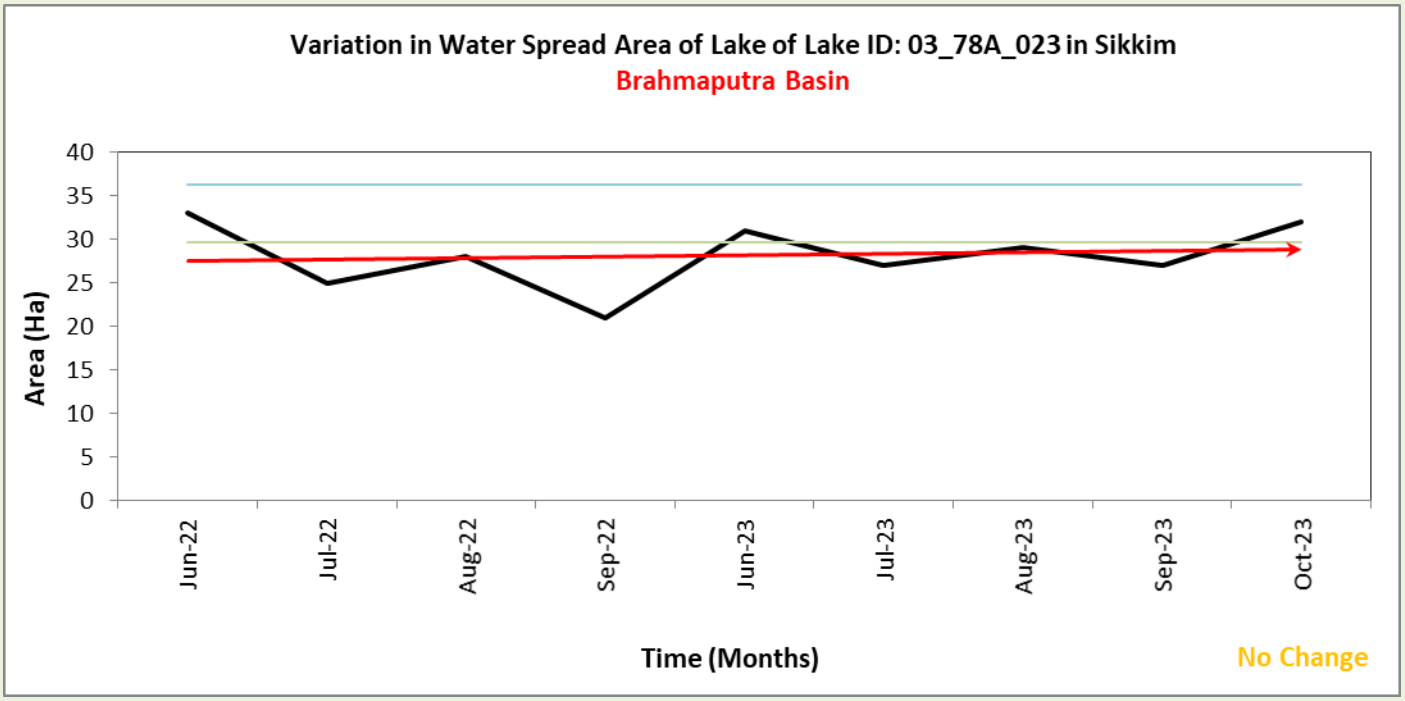


Figure 4.175(ii) Trend Analysis Plot ±20%

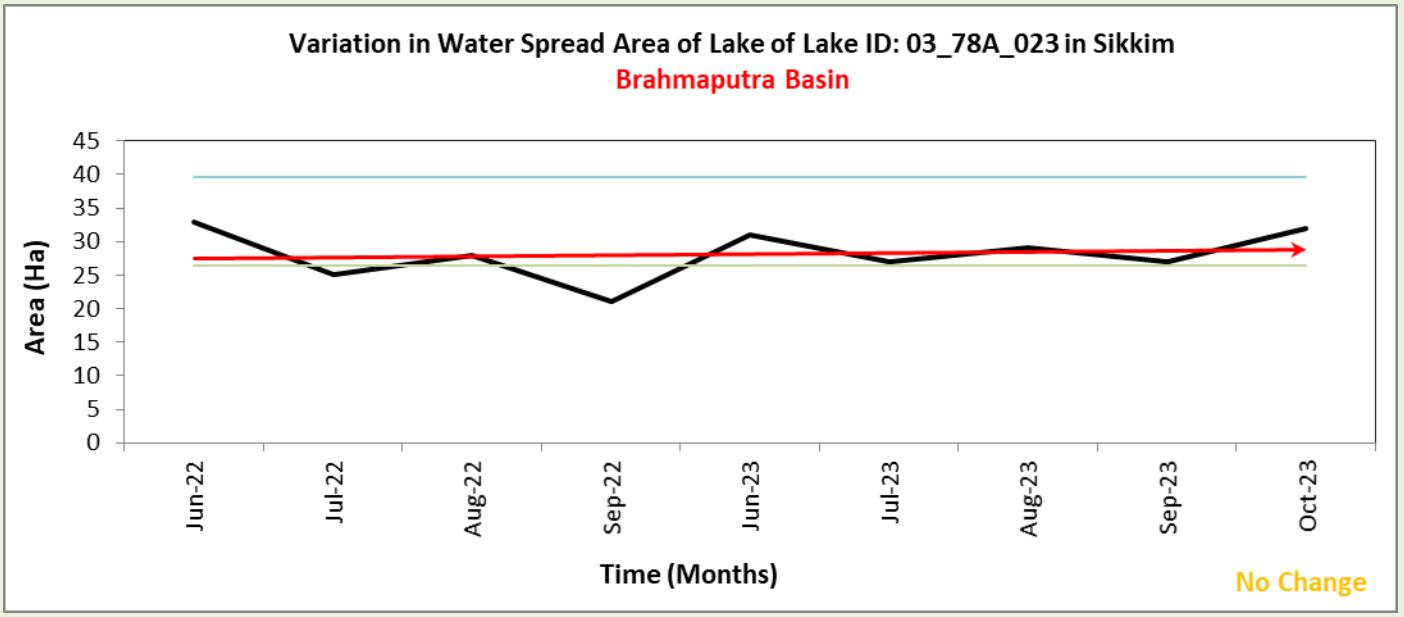


Figure 4.176(i) Trend Analysis Plot ±10%

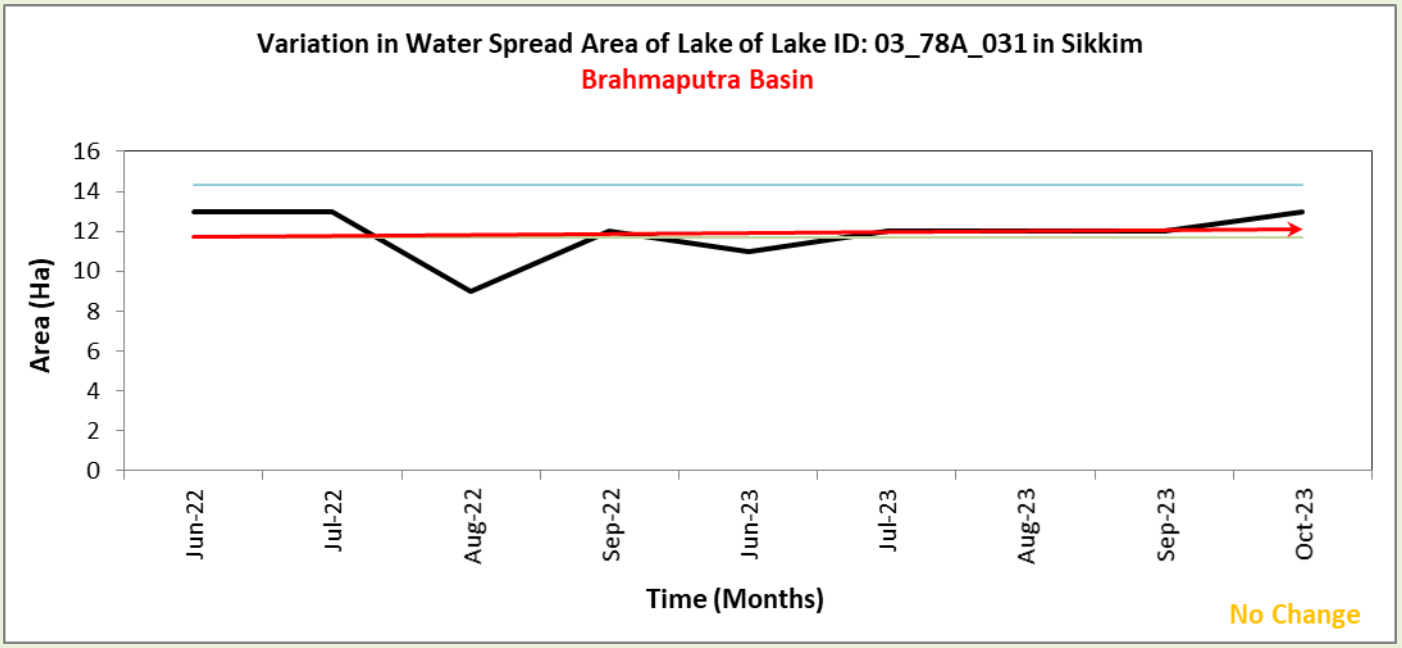


Figure 4.176(ii) Trend Analysis Plot ±20%

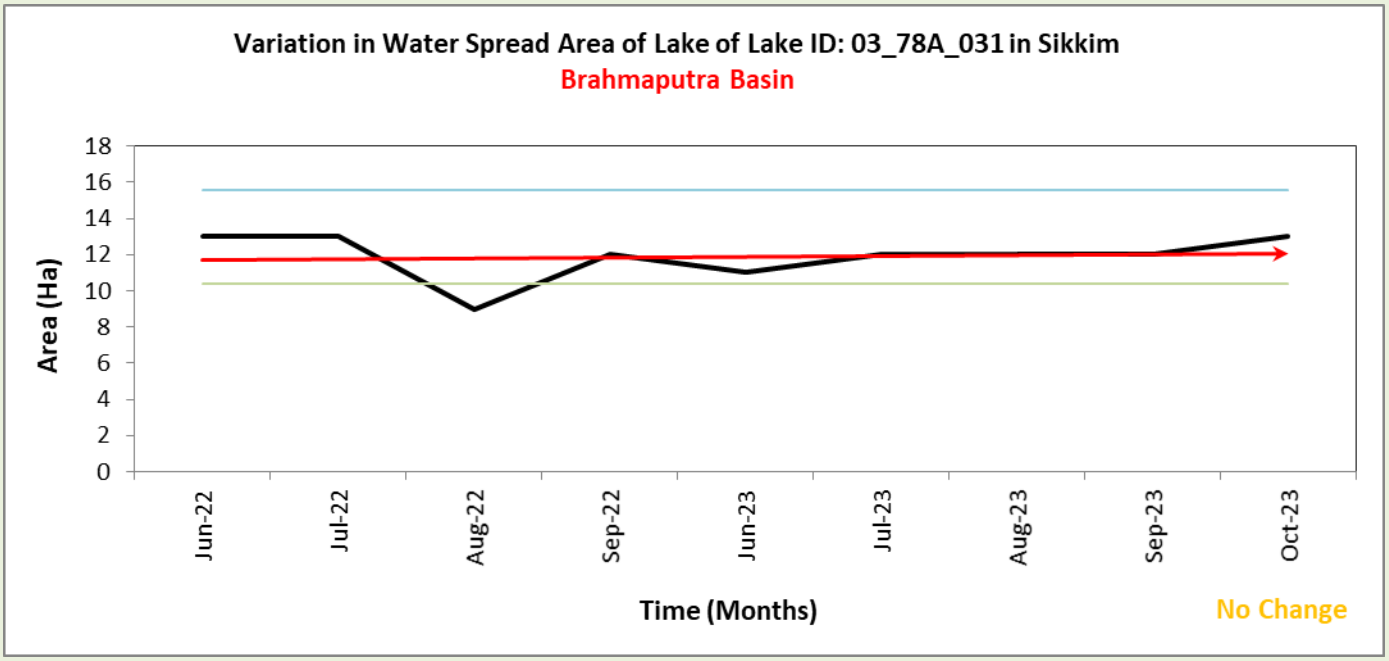


Figure 4.177(i) Trend Analysis Plot ±10%

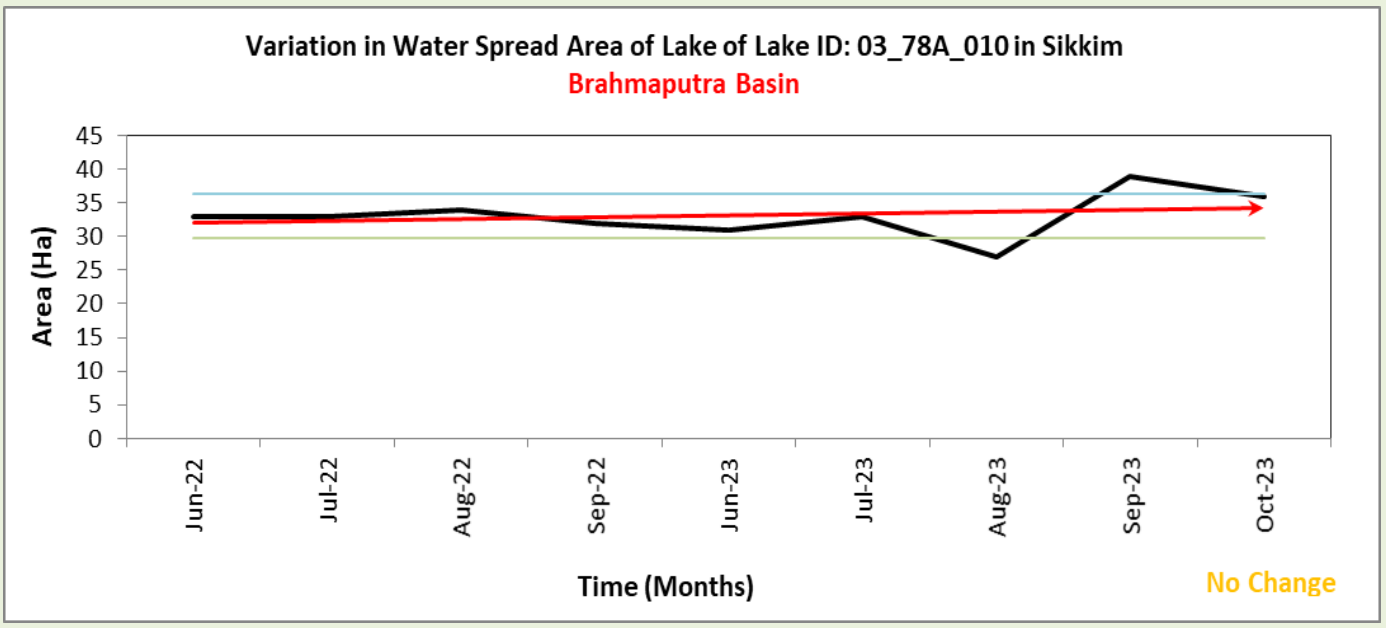


Figure 4.177(ii) Trend Analysis Plot ±20%

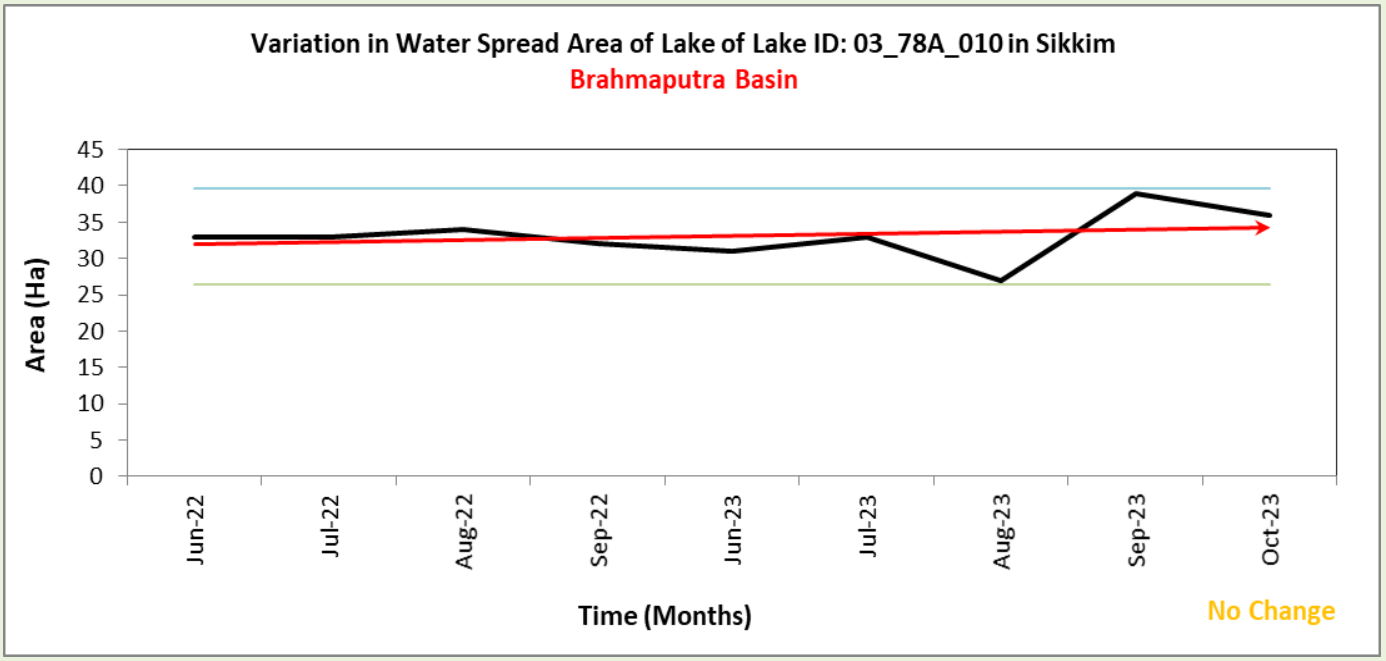


Figure 4.178(i) Trend Analysis Plot ±10%

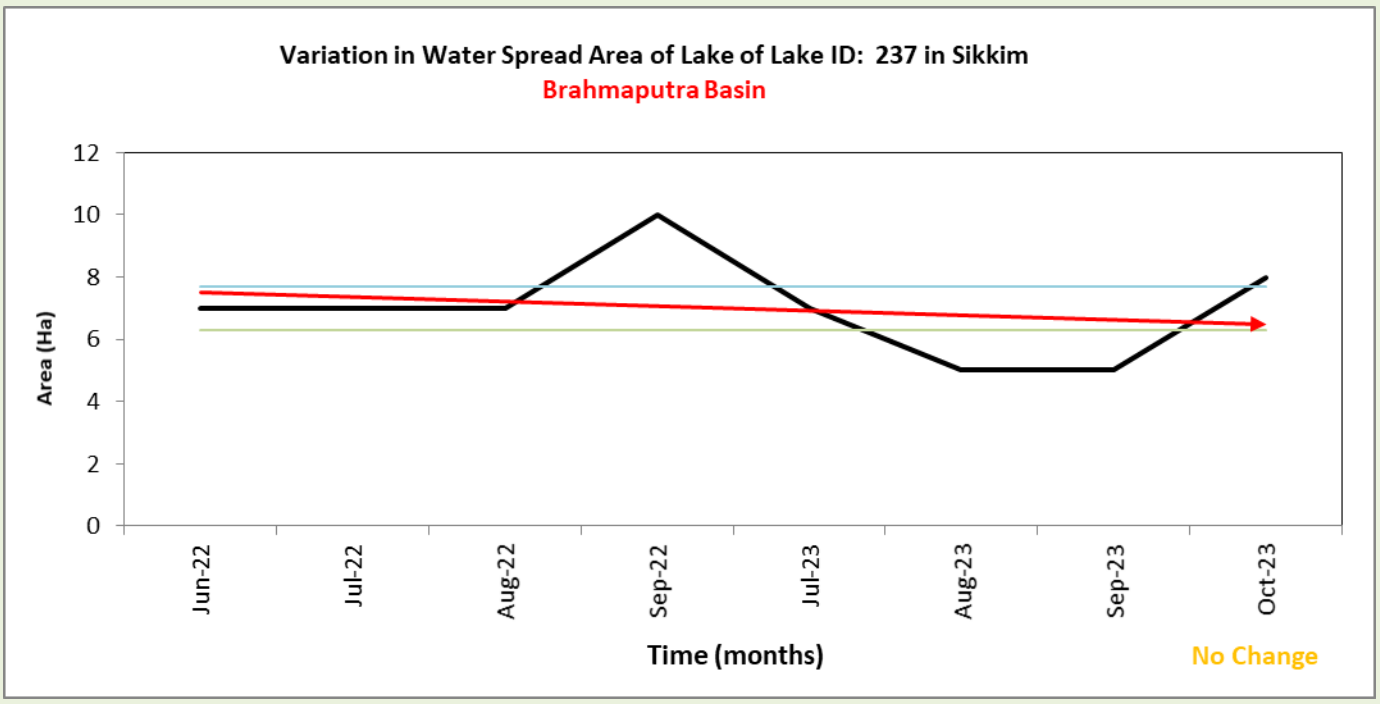


Figure 4.178(ii) Trend Analysis Plot ±20%

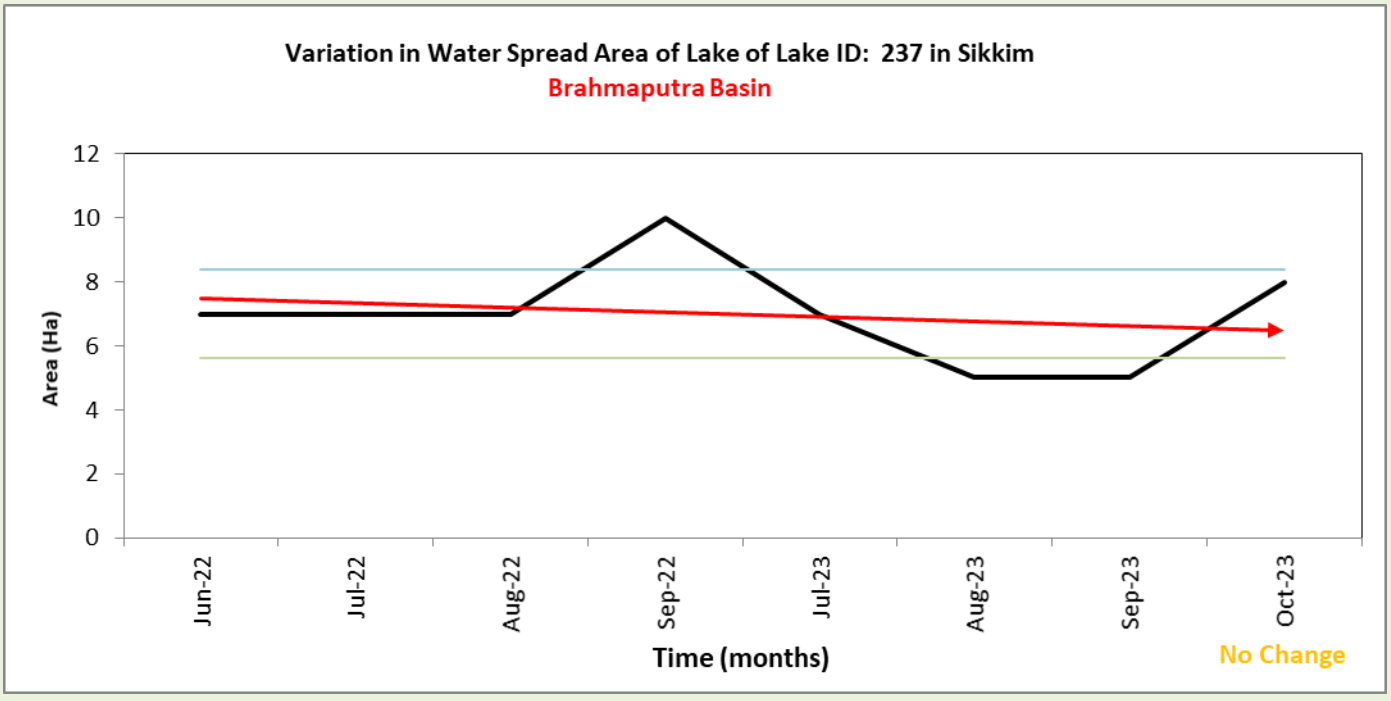


Figure 4.179(i) Trend Analysis Plot ±10%

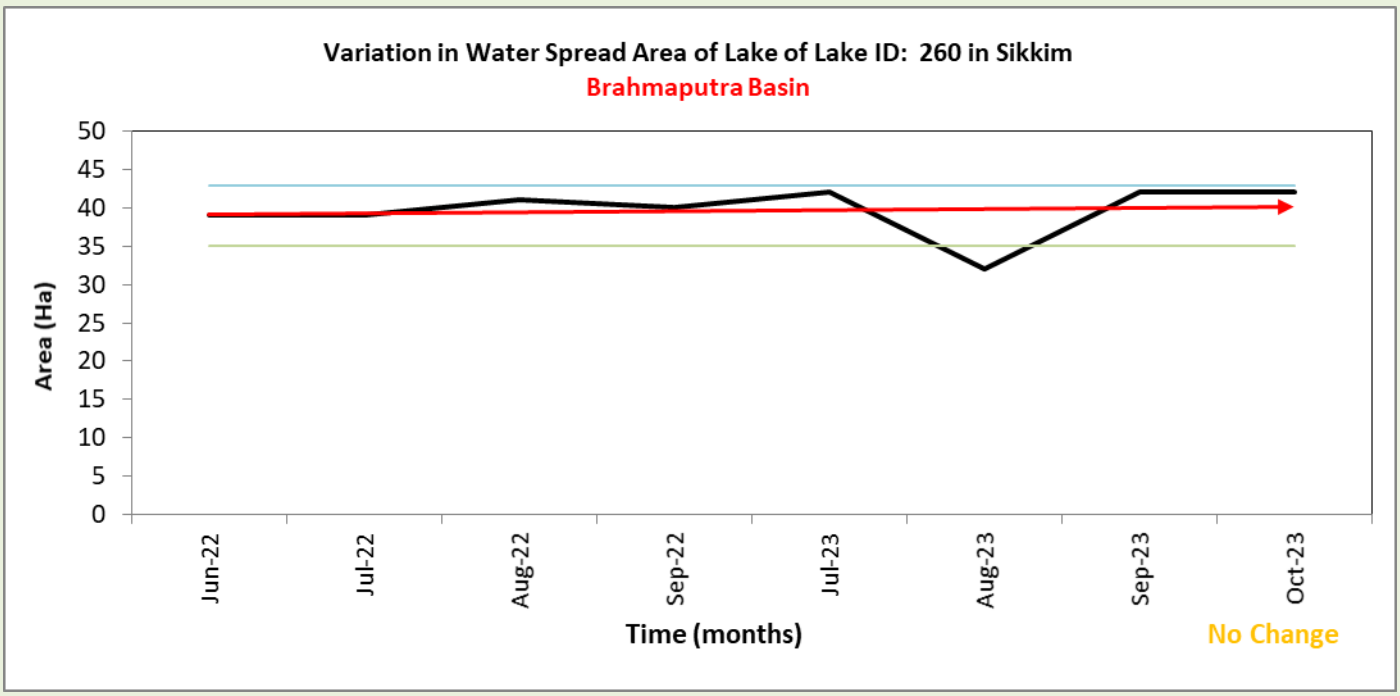


Figure 4.179(ii) Trend Analysis Plot ±20%

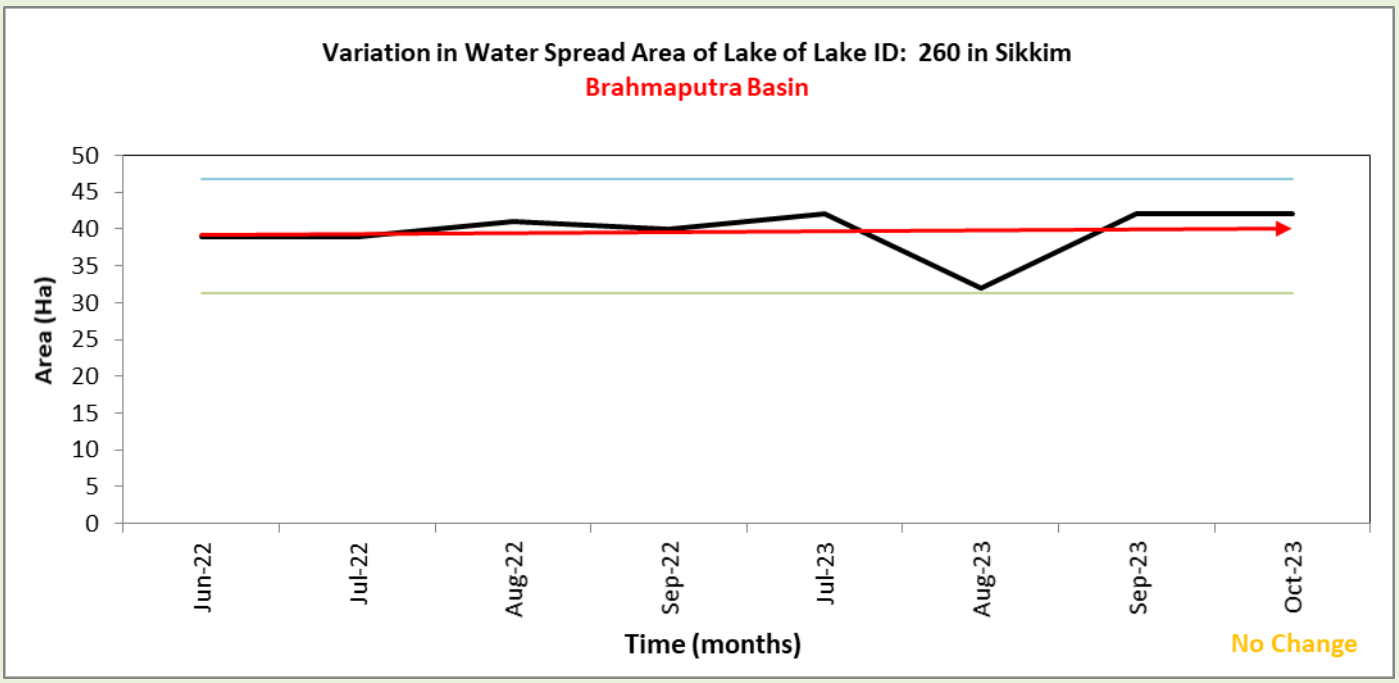


Figure 4.180(i) Trend Analysis Plot ±10%

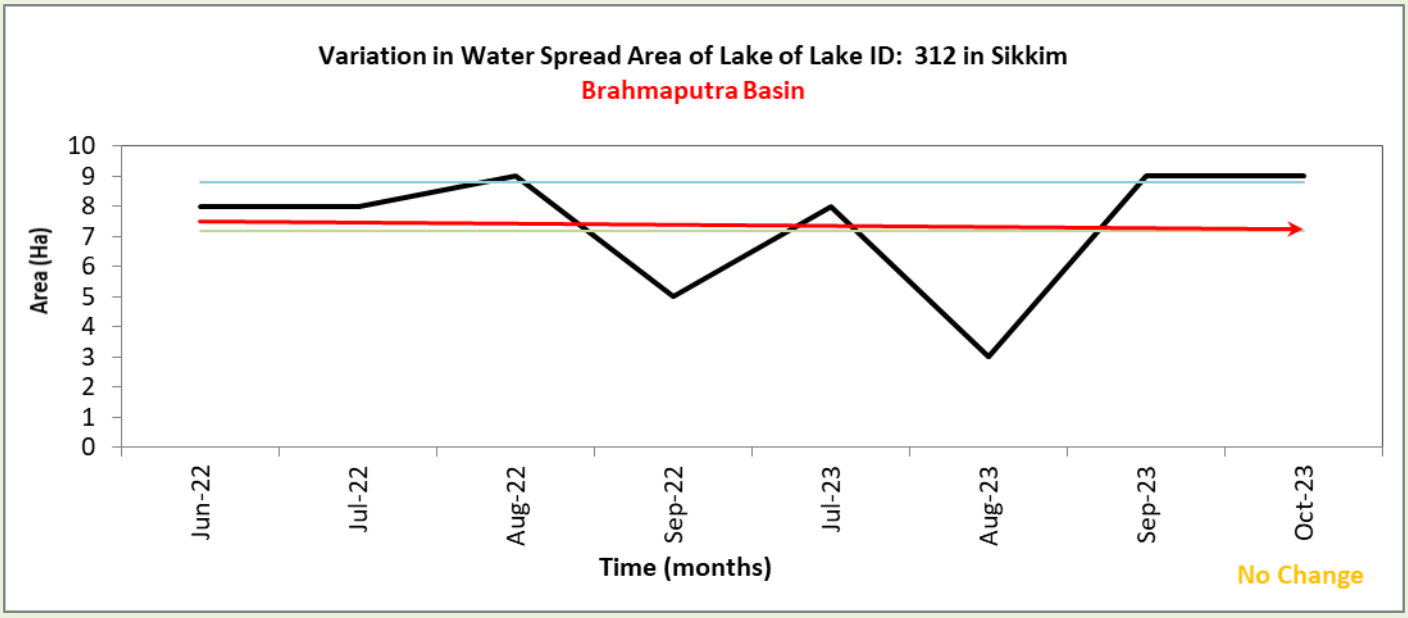


Figure 4.180(ii) Trend Analysis Plot ±20%

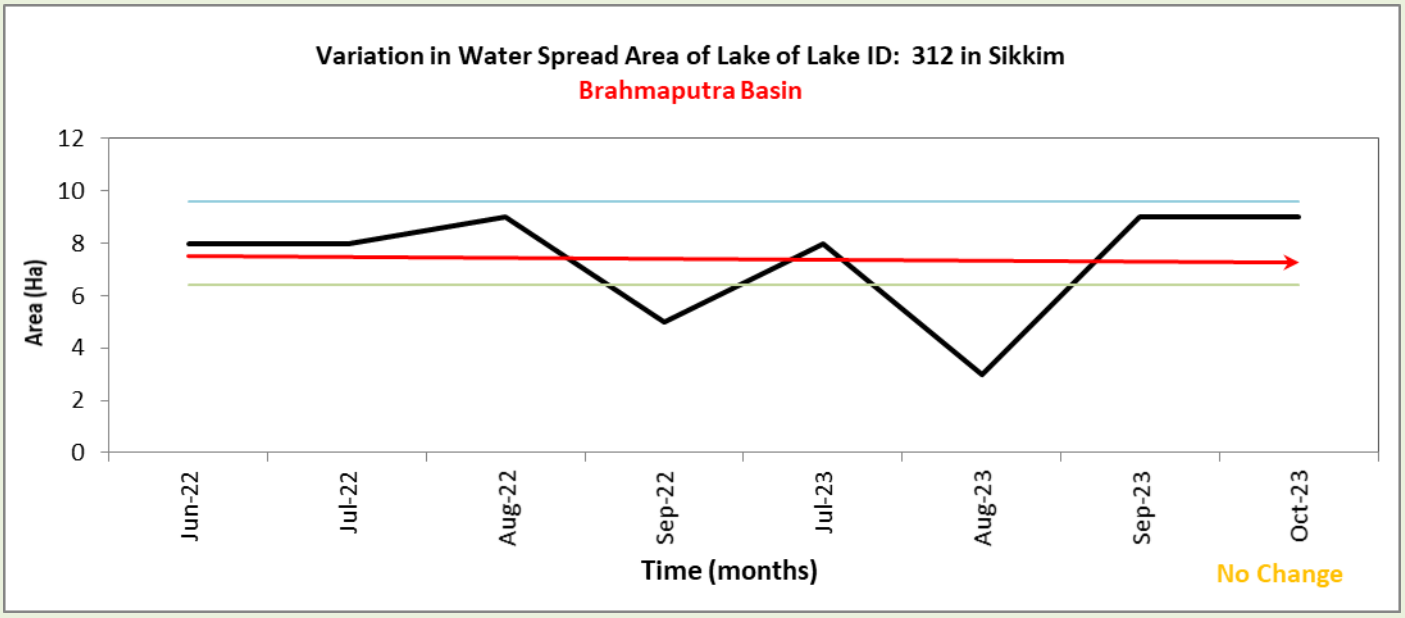


Figure 4.181(i) Trend Analysis Plot ±10%

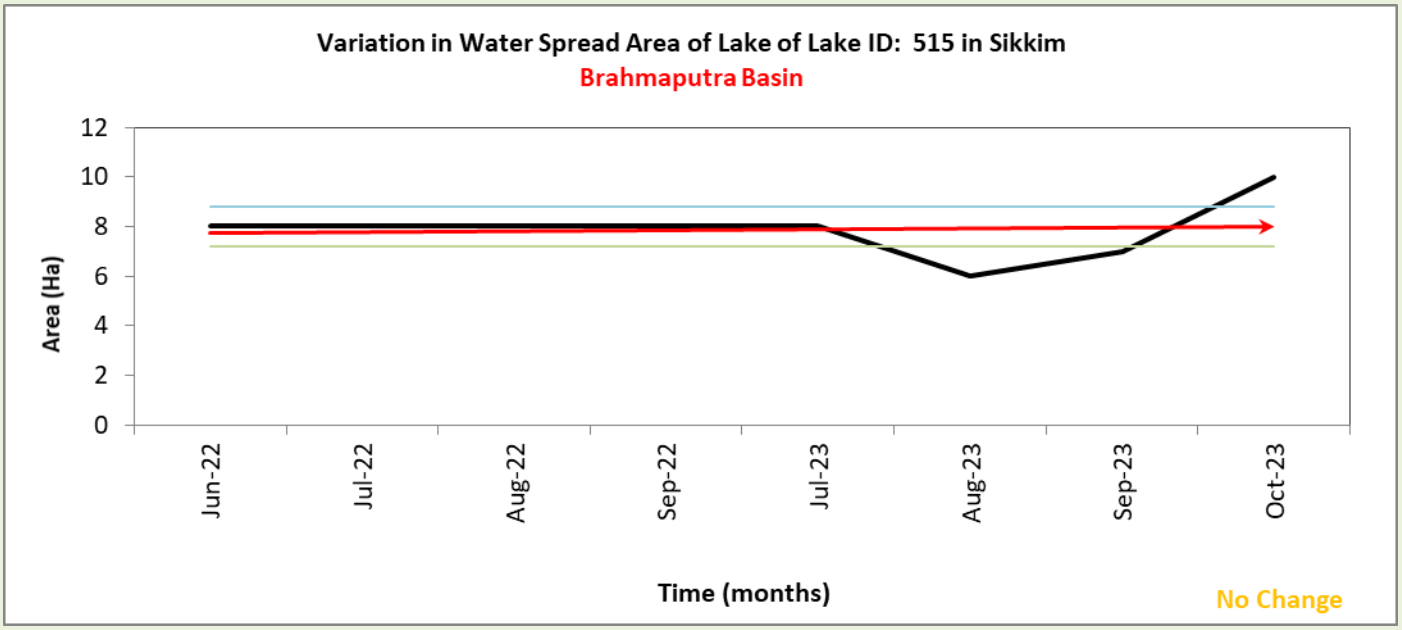


Figure 4.181(ii) Trend Analysis Plot ±20%

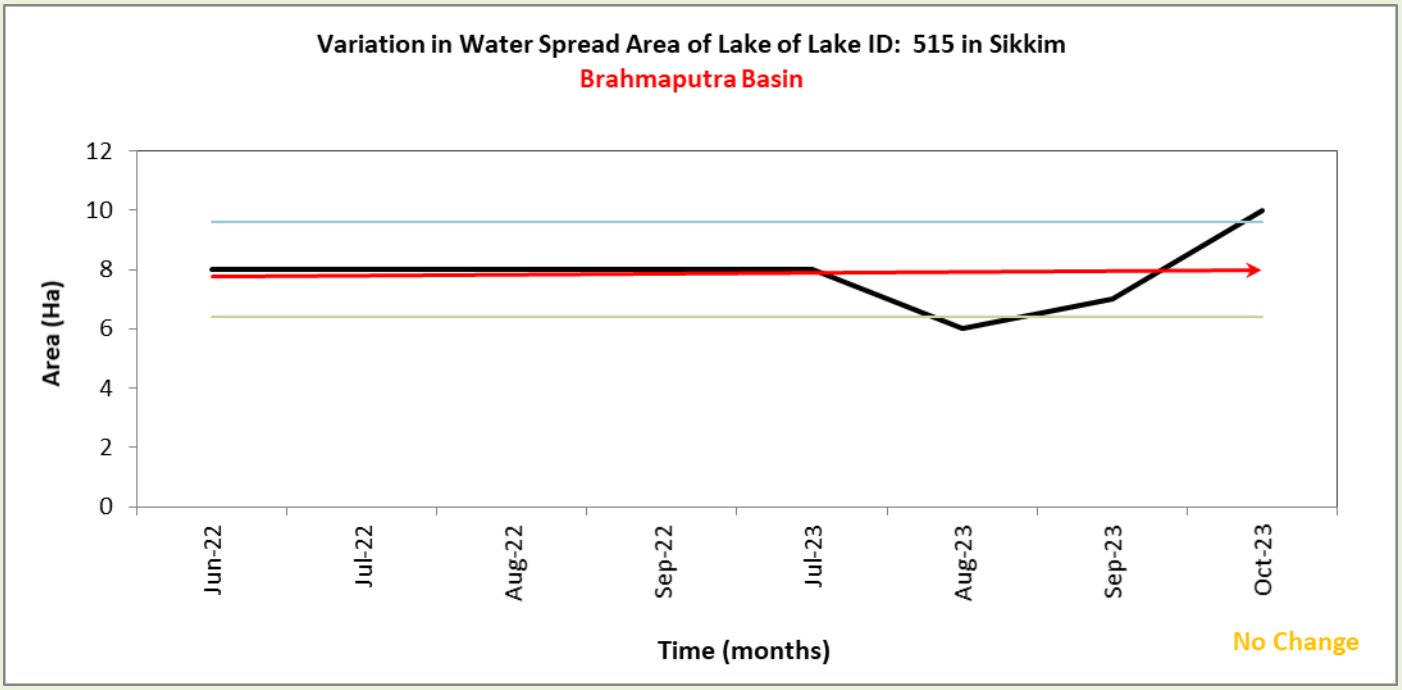


Figure 4.182(i) Trend Analysis Plot ±10%

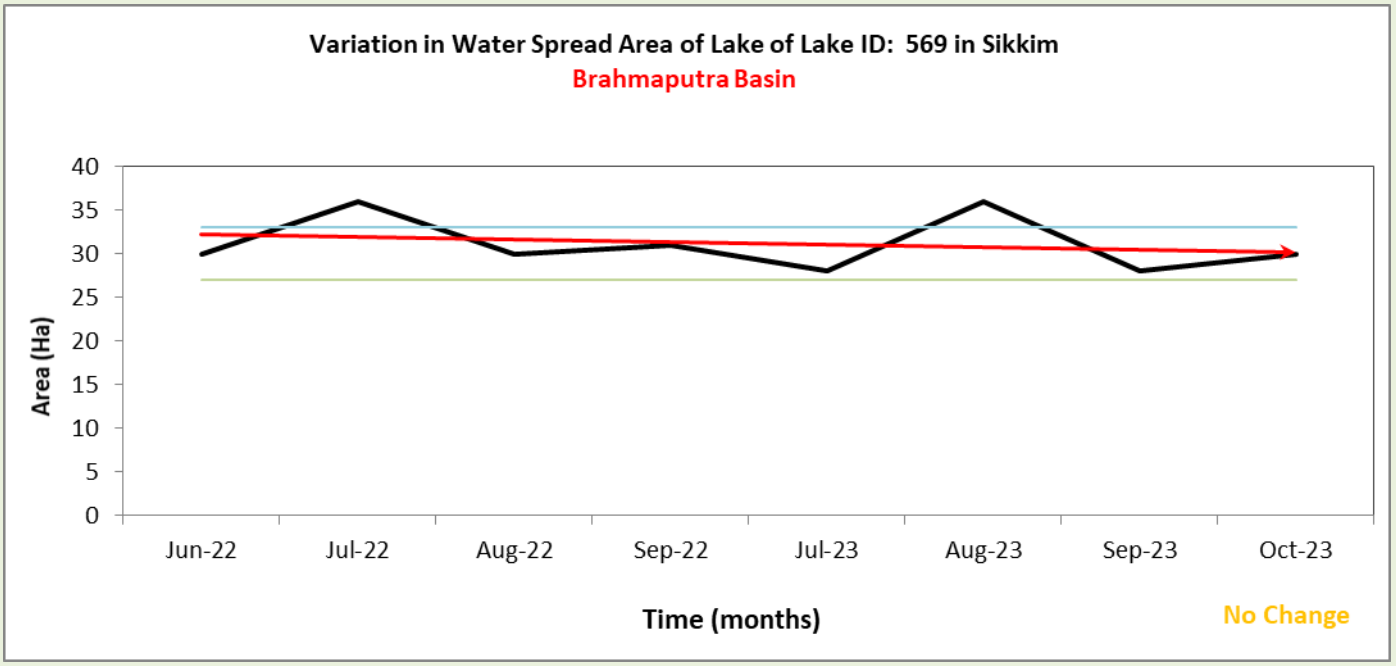


Figure 4.182(ii) Trend Analysis Plot ±20%

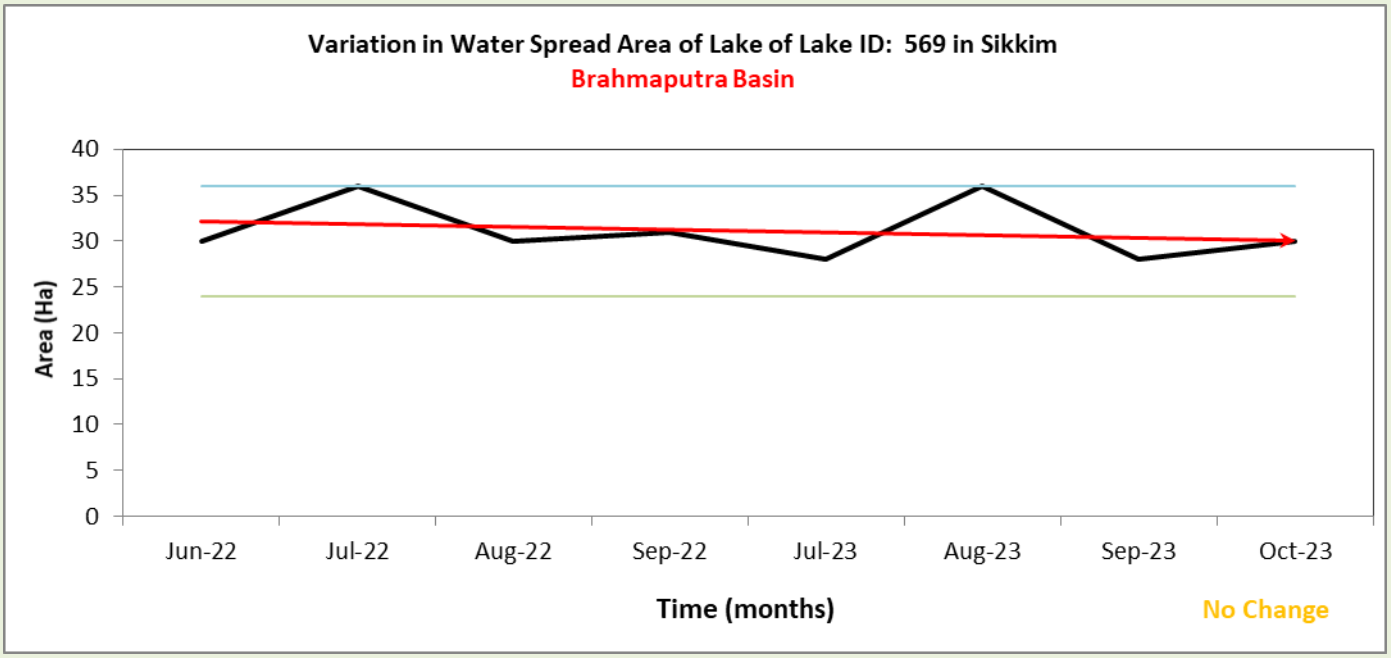


Figure 4.183(i) Trend Analysis Plot ±10%

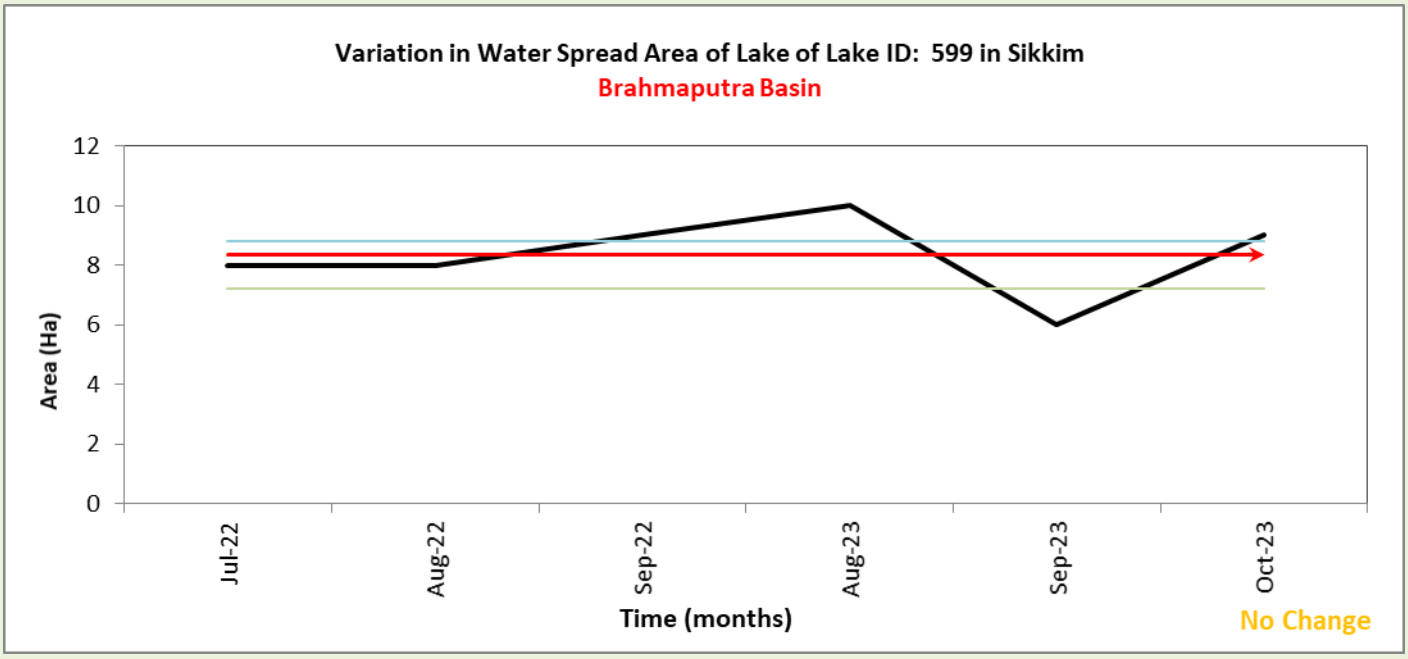


Figure 4.183(ii) Trend Analysis Plot ±20%

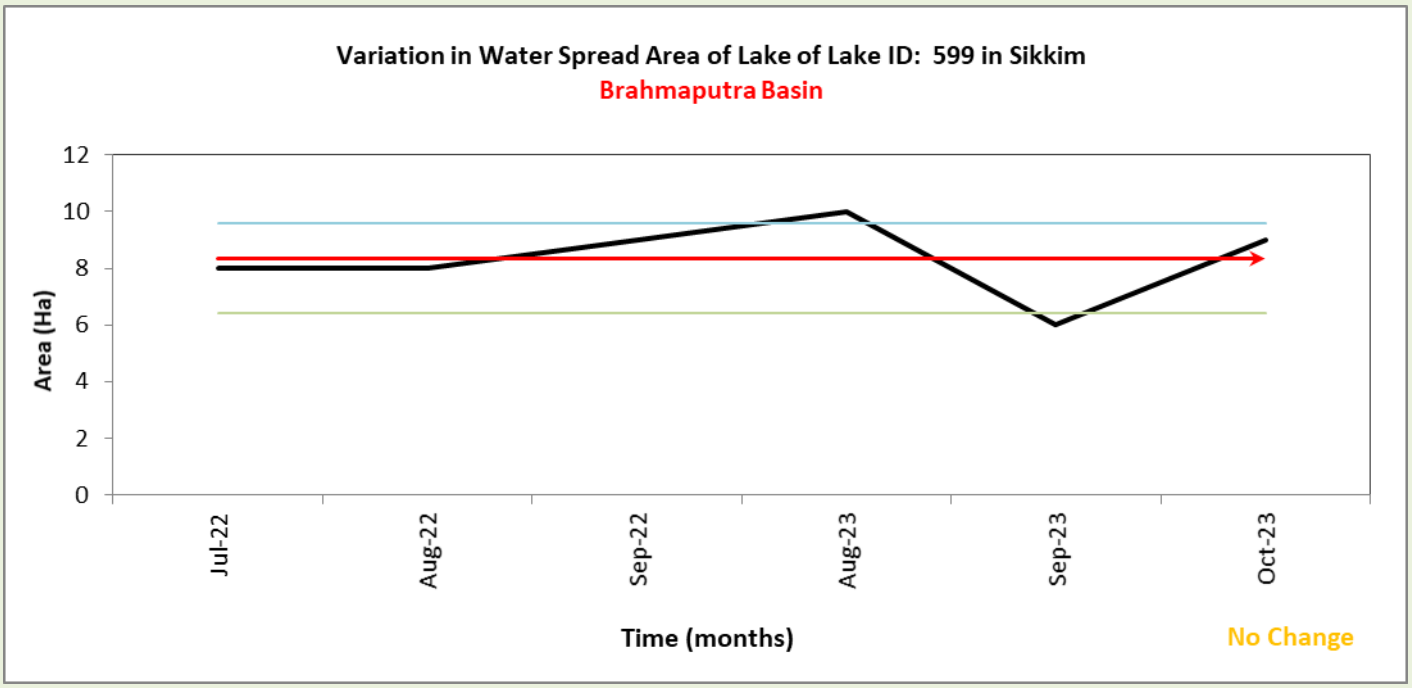


Figure 4.184(i) Trend Analysis Plot ±10%

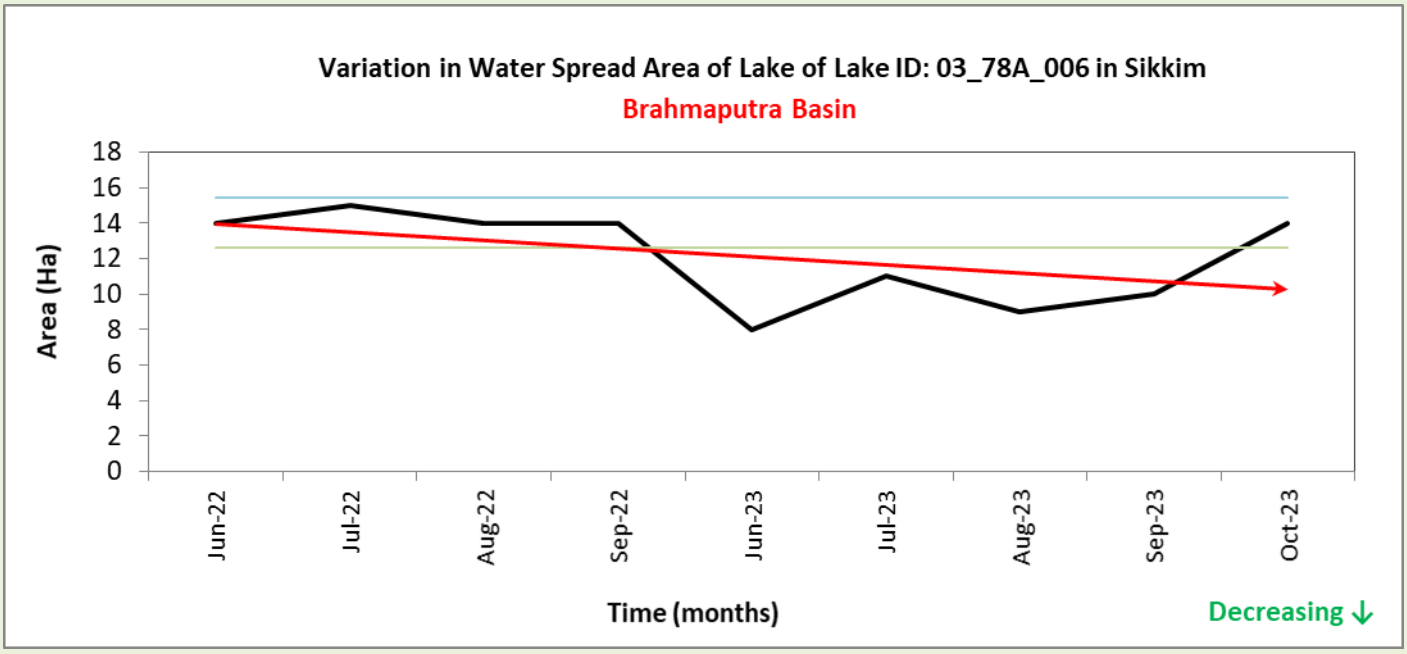


Figure 4.184(ii) Trend Analysis Plot ±20%

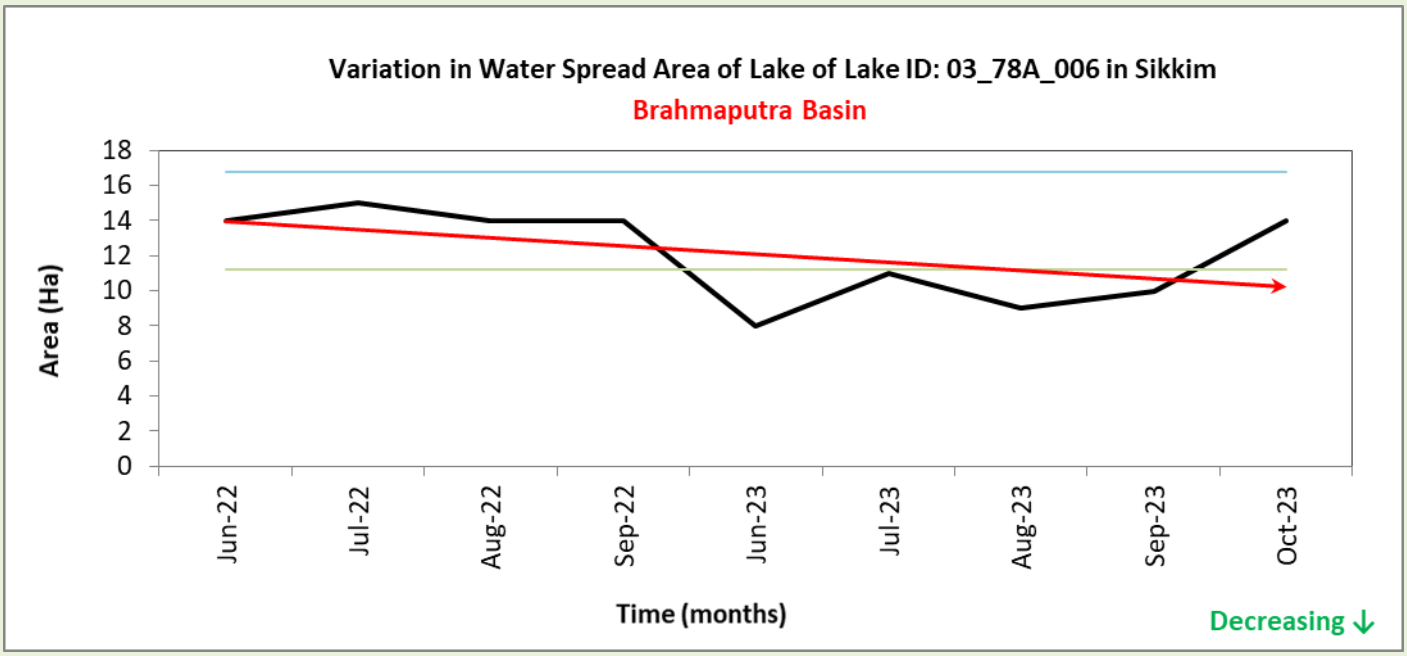


Figure 4.185(i) Trend Analysis Plot ±10%

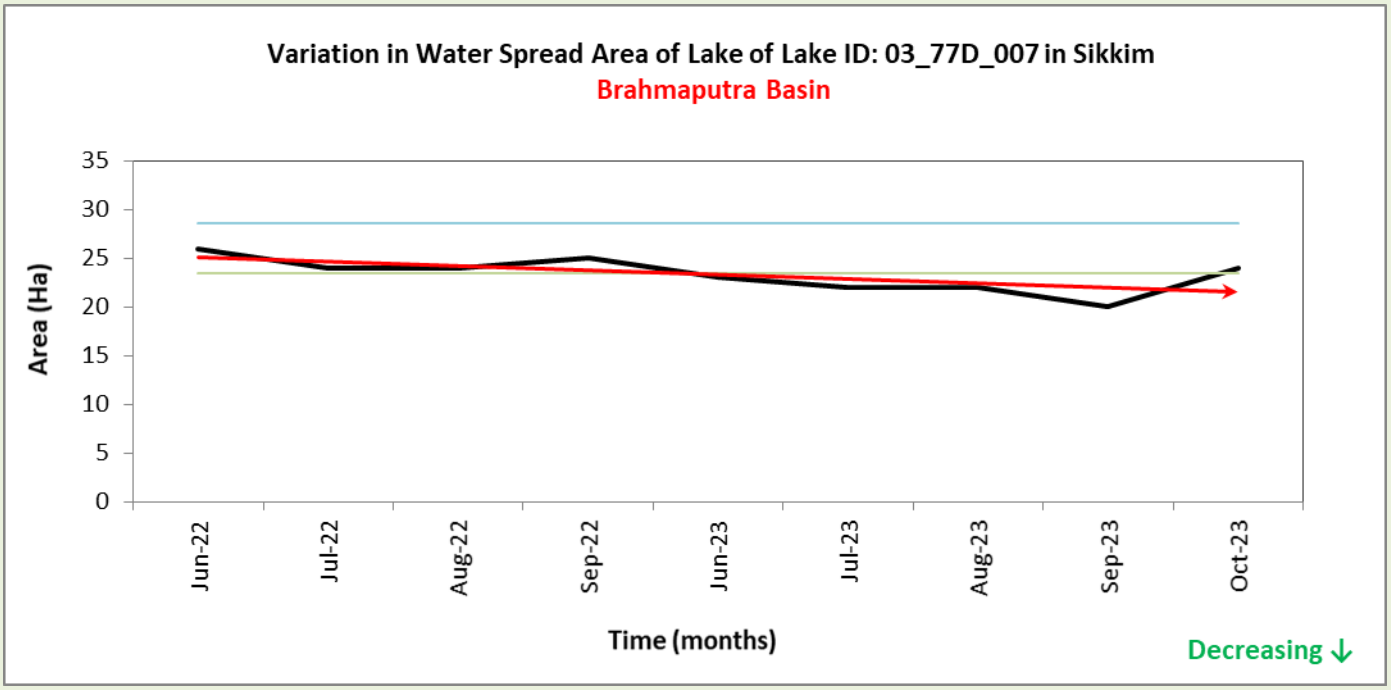


Figure 4.185(ii) Trend Analysis Plot ±20%

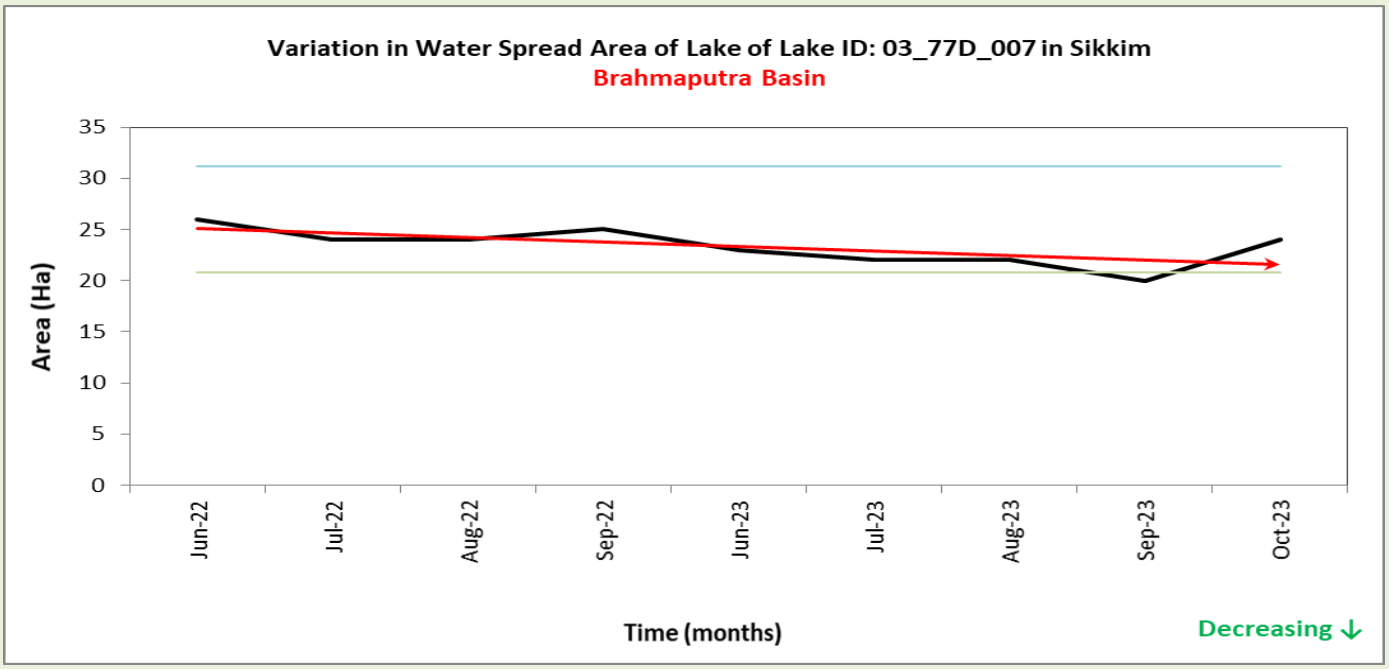


Figure 4.186(i) Trend Analysis Plot ±10%

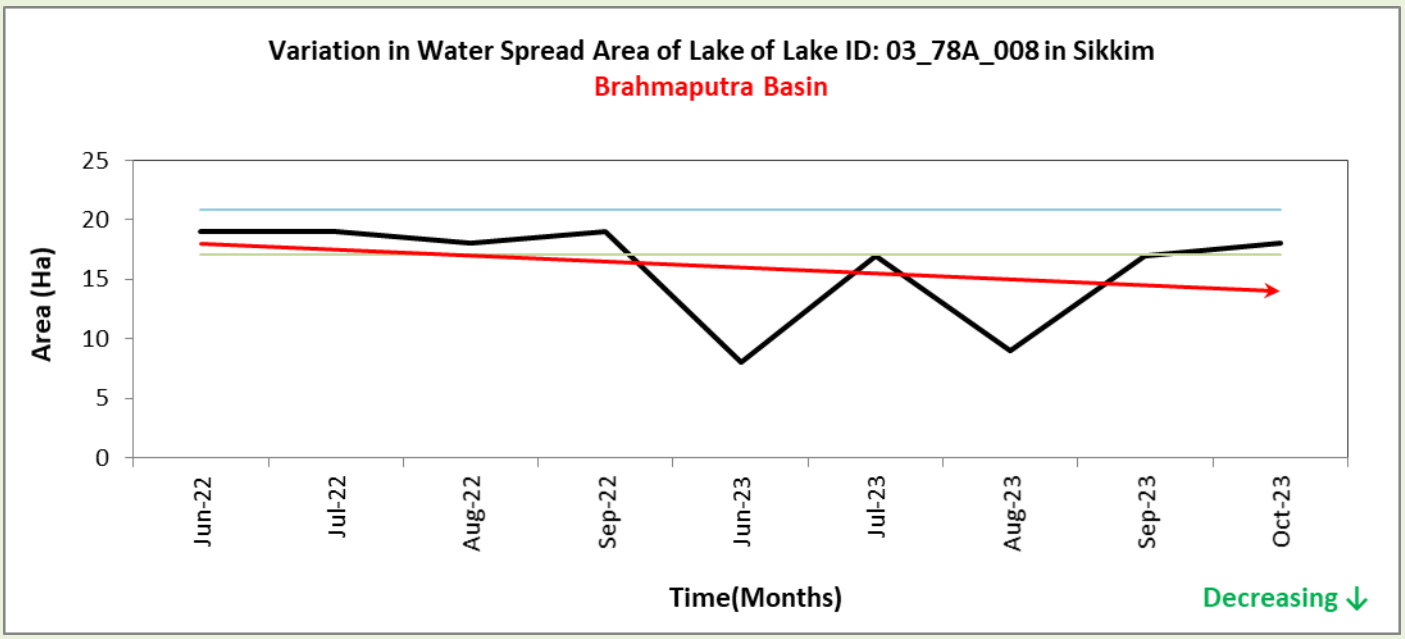


Figure 4.186(ii) Trend Analysis Plot ±20%

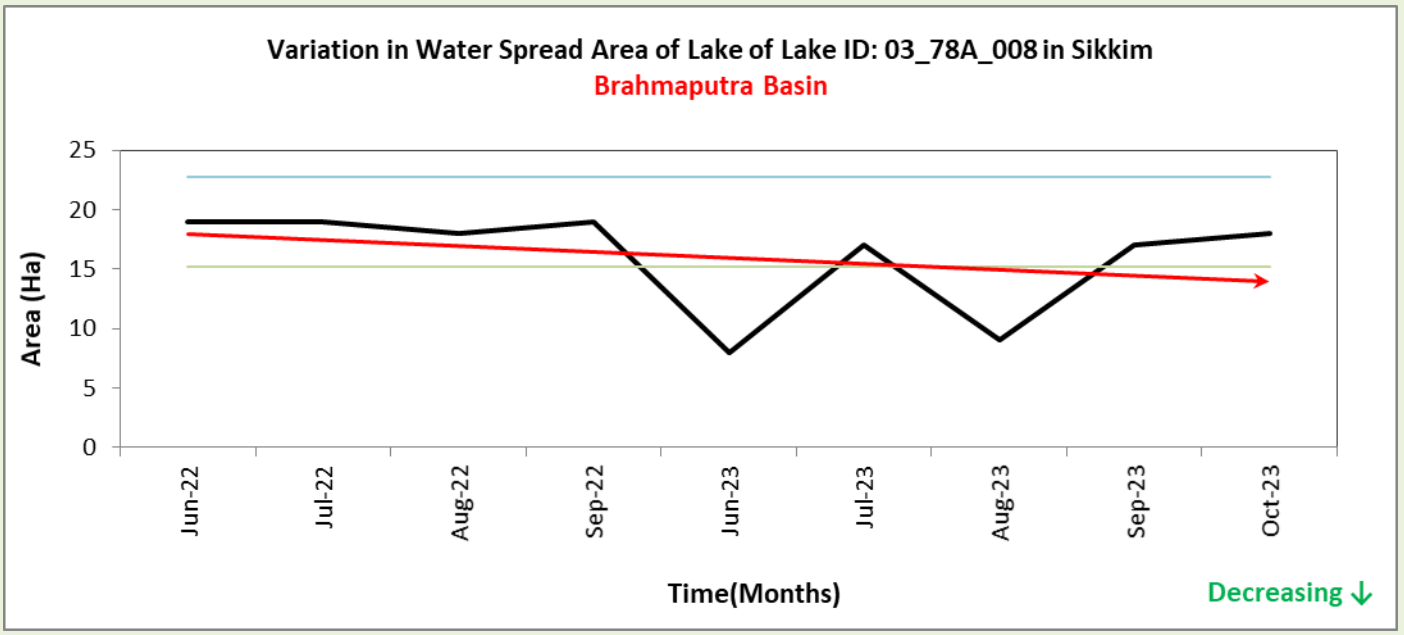


Figure 4.187(i) Trend Analysis Plot ±10%

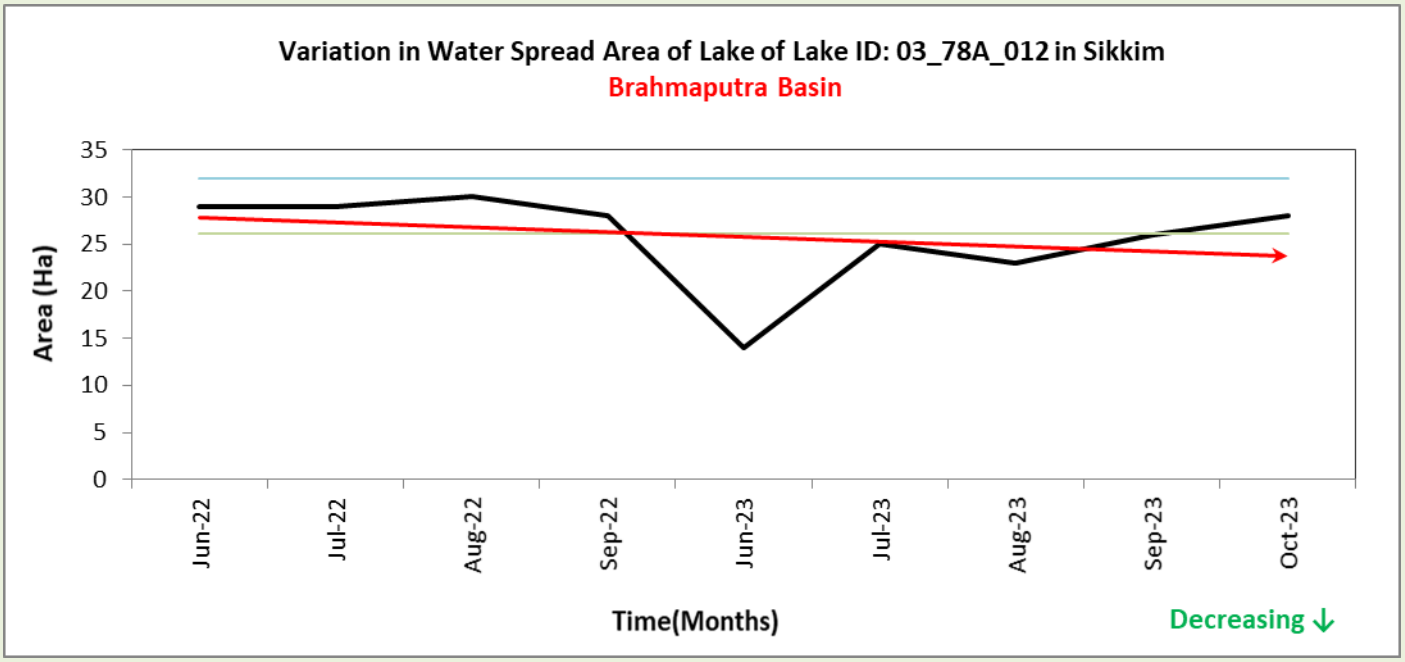


Figure 4.187(ii) Trend Analysis Plot ±20%

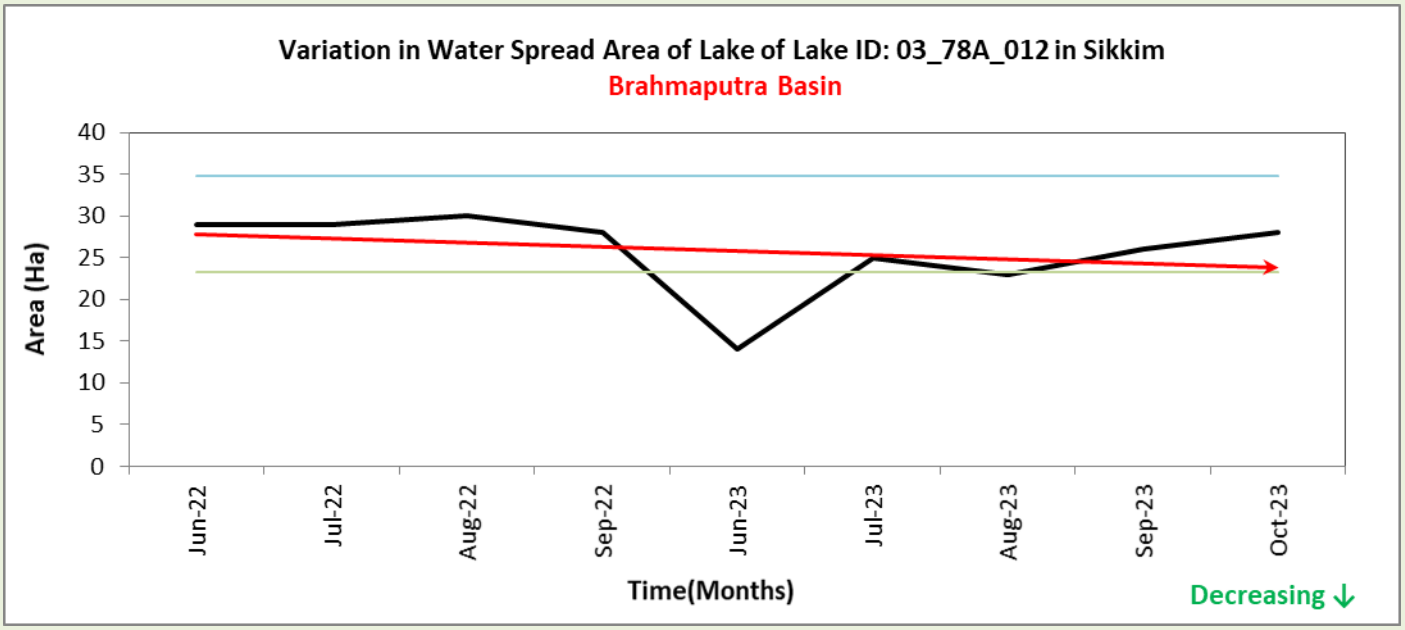


Figure 4.188(i) Trend Analysis Plot ±10%

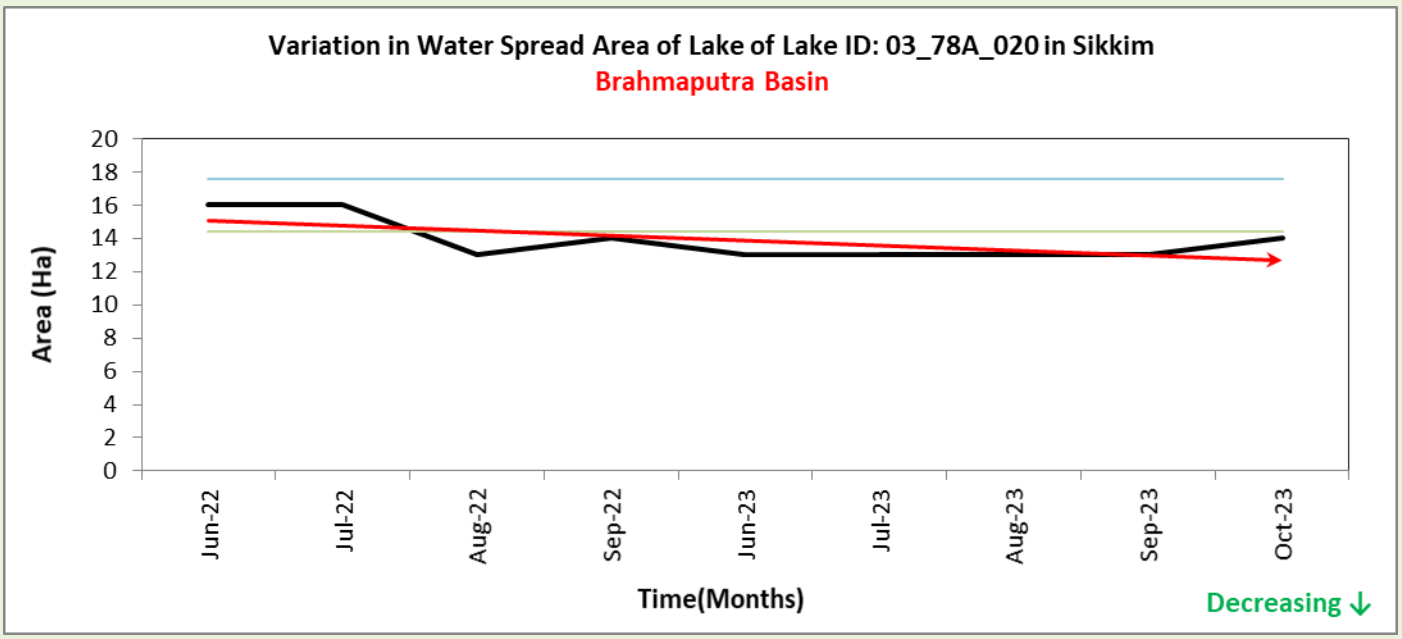


Figure 4.188(ii) Trend Analysis Plot ±20%

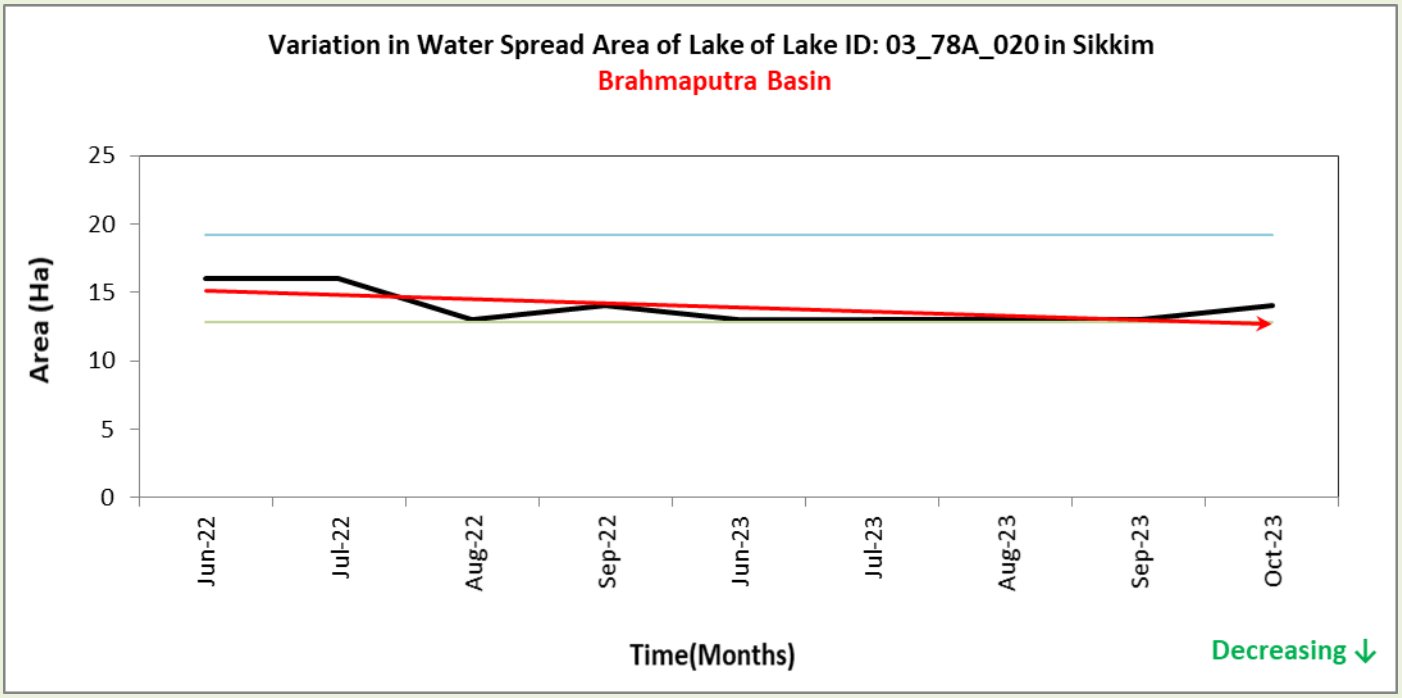


Figure 4.189(i) Trend Analysis Plot ±10%

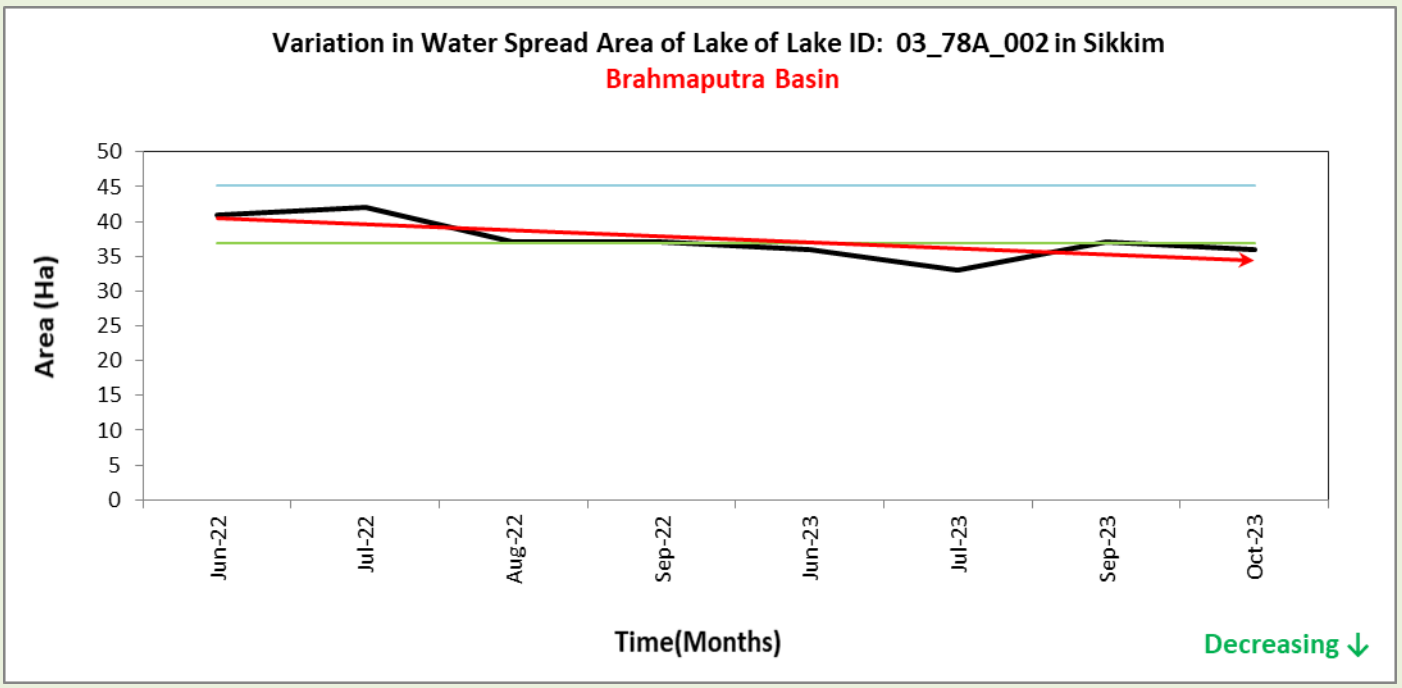


Figure 4.189(ii) Trend Analysis Plot ±20%

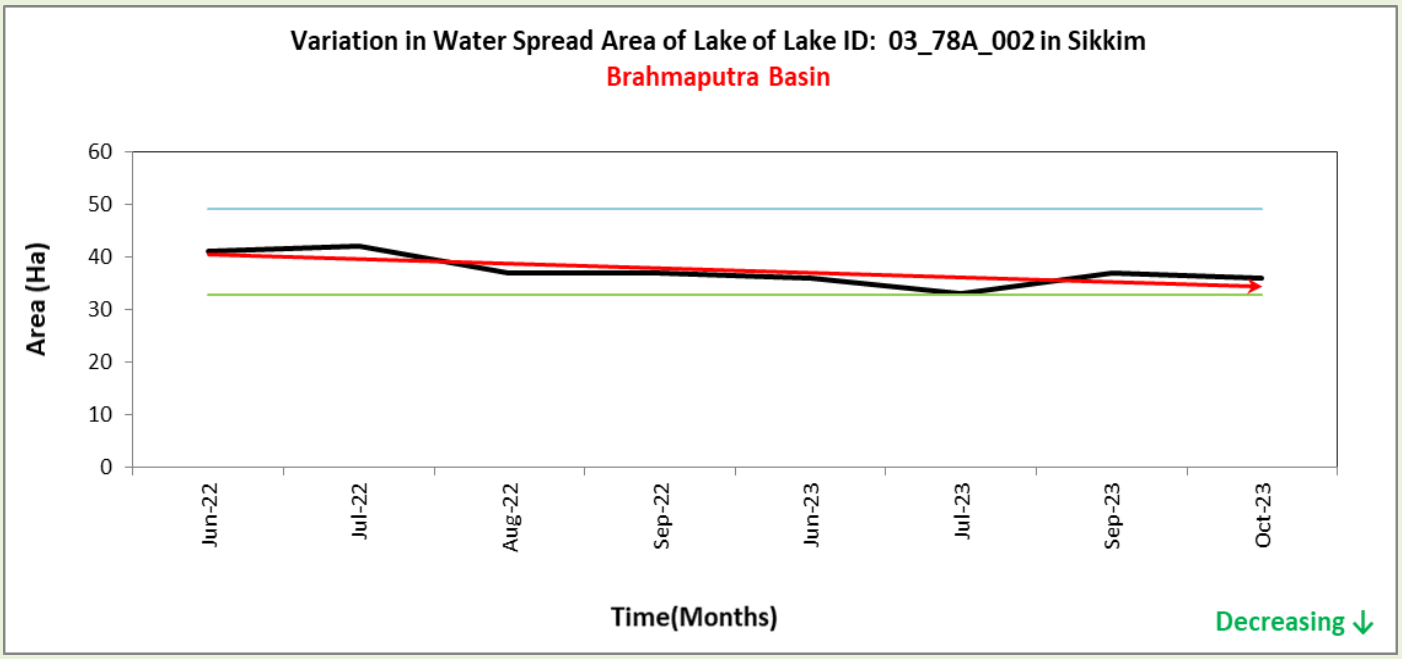


Figure 4.190(i) Trend Analysis Plot ±10%

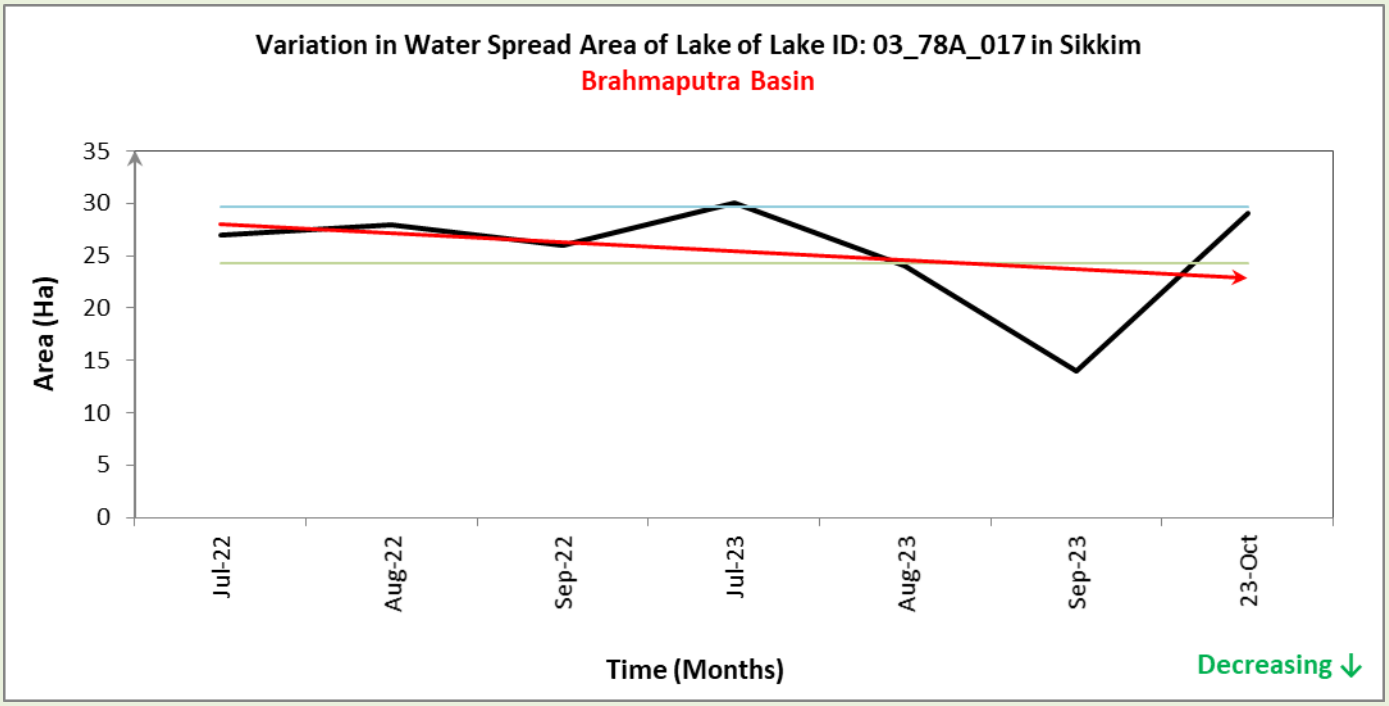


Figure 4.190(ii) Trend Analysis Plot ±20%

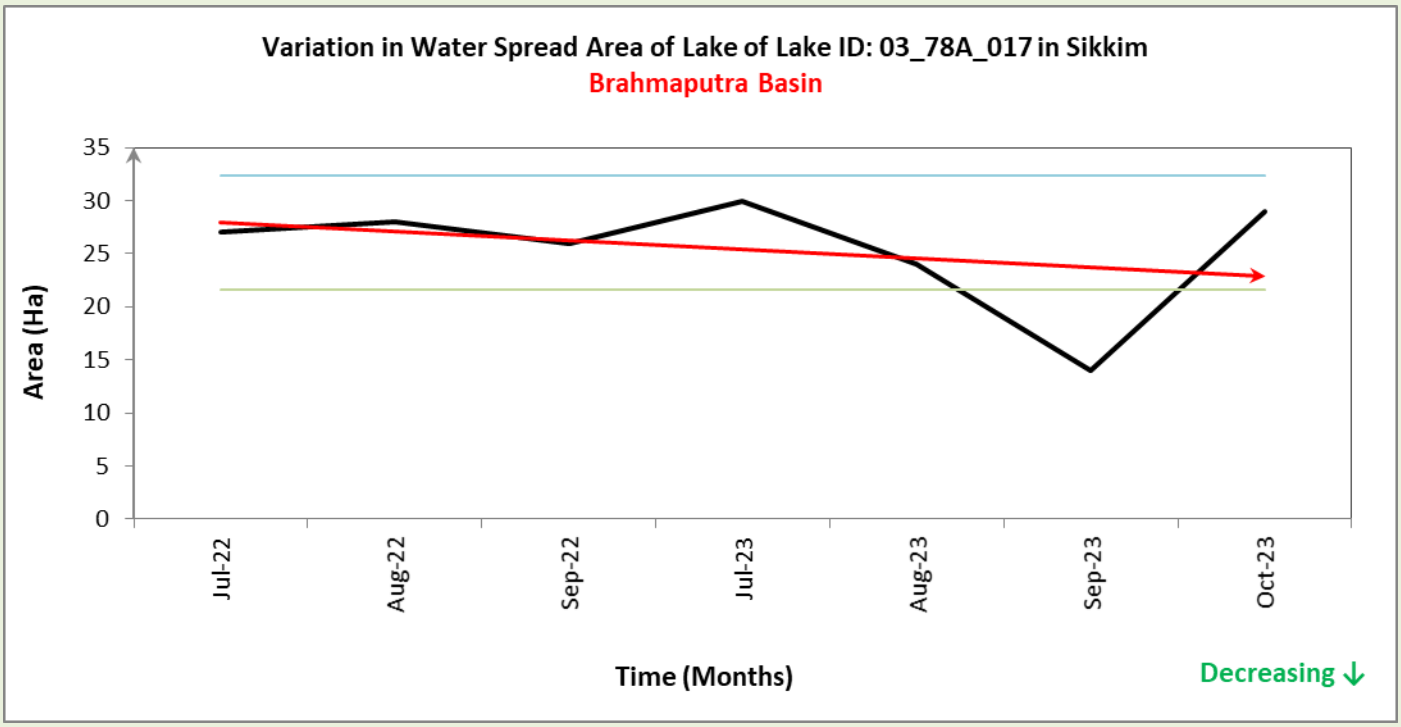


Figure 4.191(i) Trend Analysis Plot ±10%

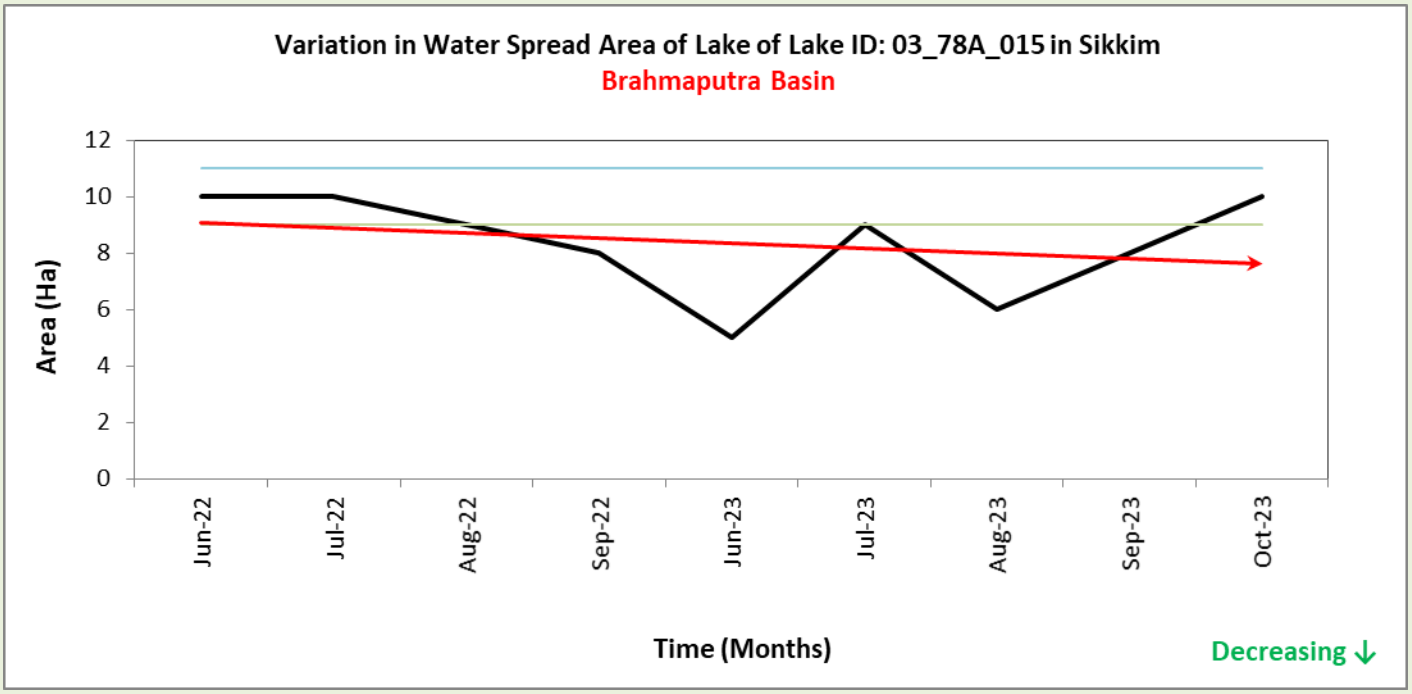


Figure 4.191(ii) Trend Analysis Plot ±20%

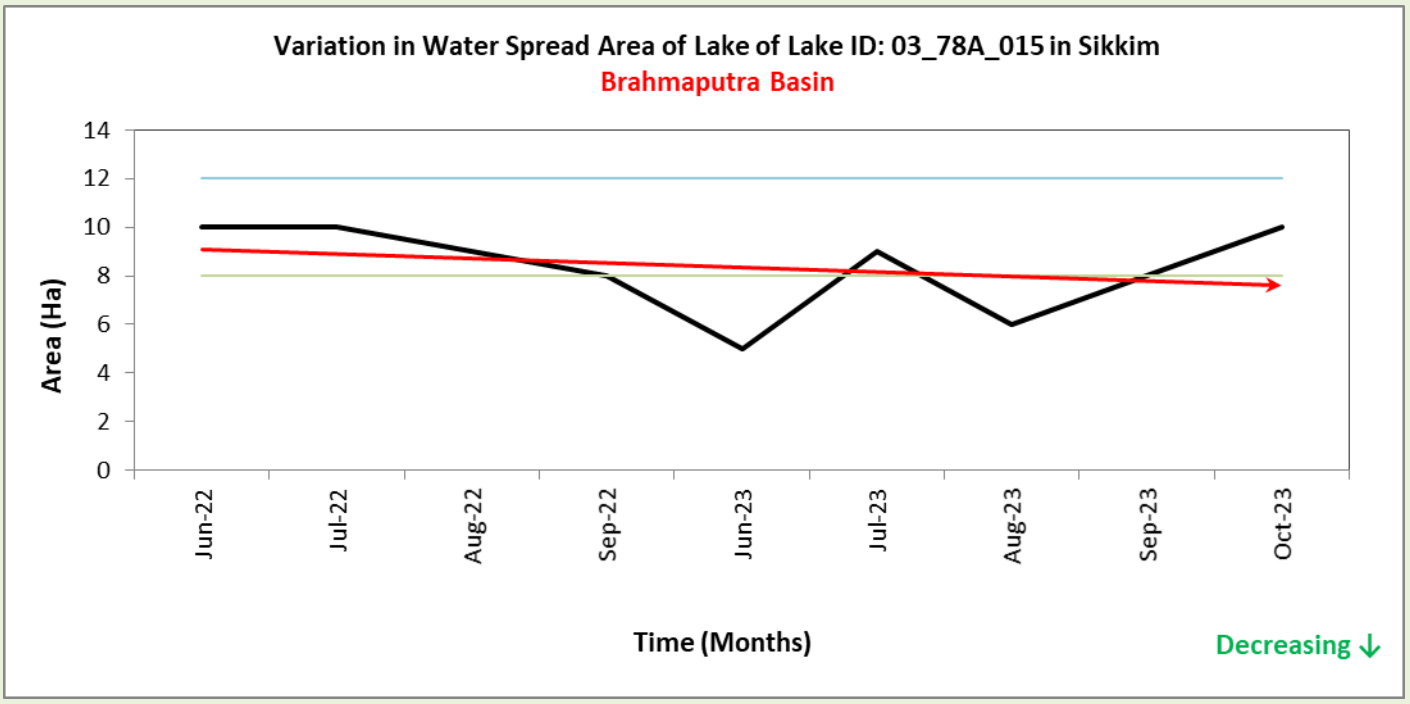


Figure 4.192(i) Trend Analysis Plot ±10%

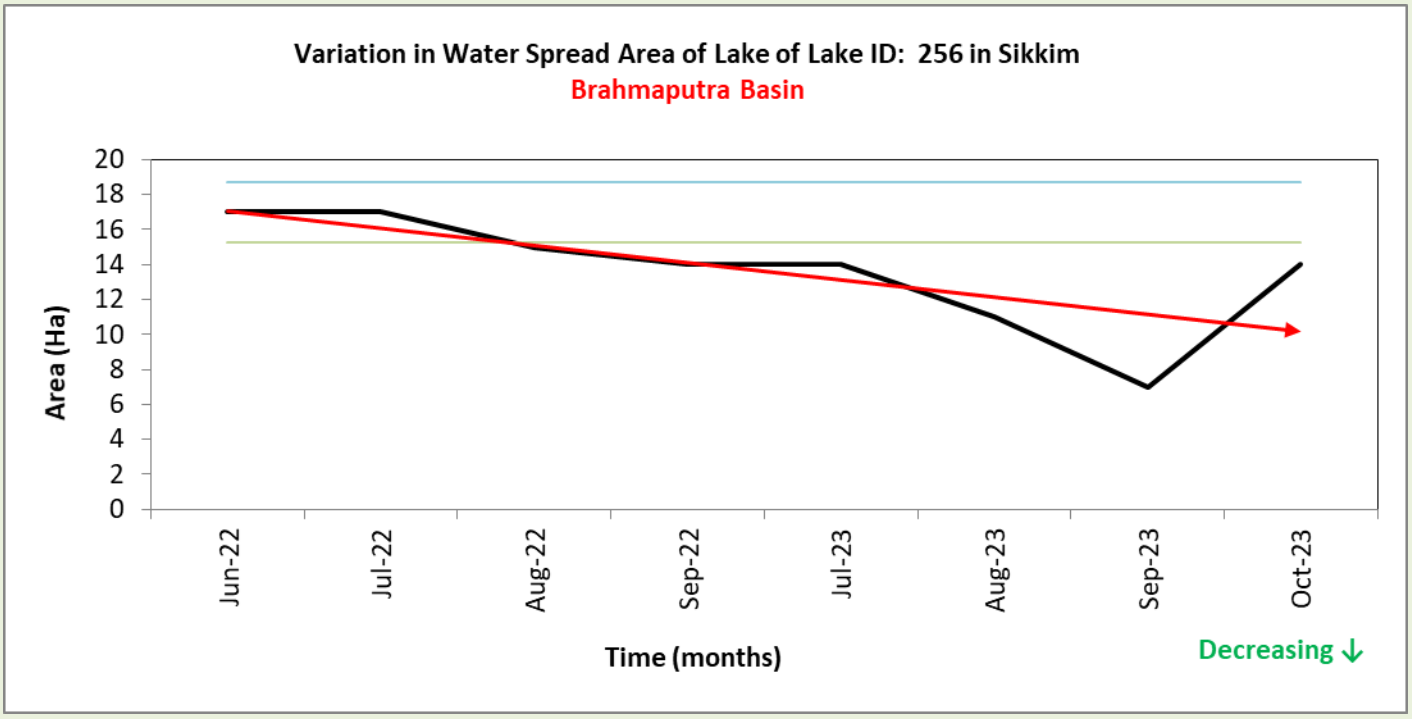


Figure 4.192(ii) Trend Analysis Plot ±20%

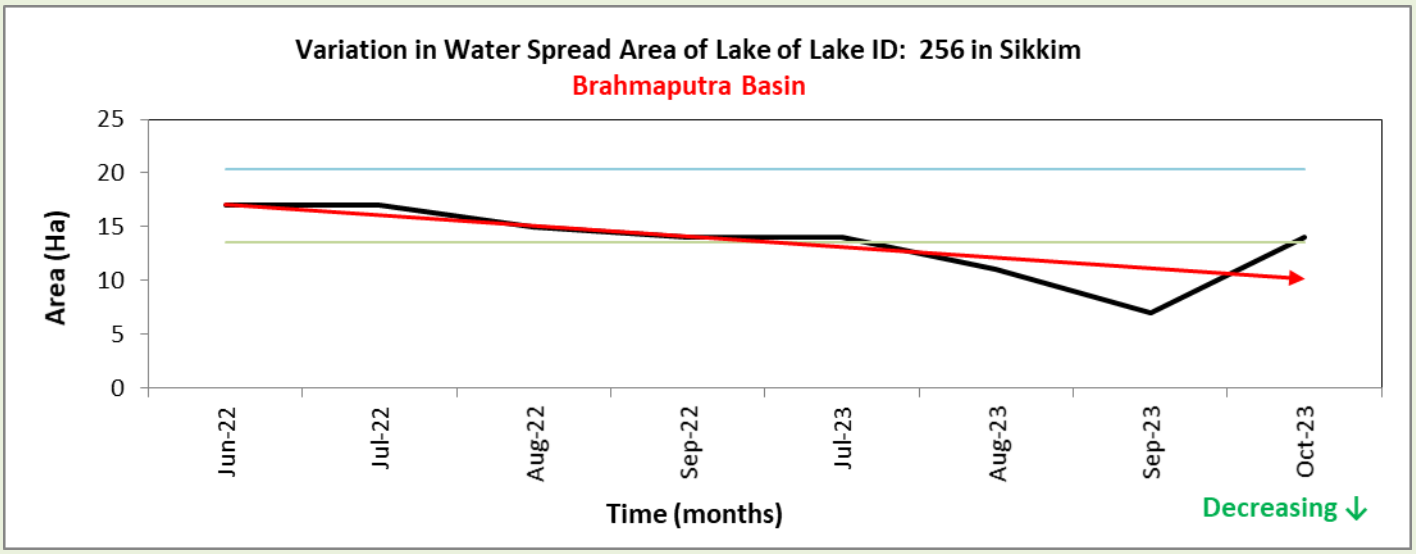


Figure 4.193(i) Trend Analysis Plot ±10%

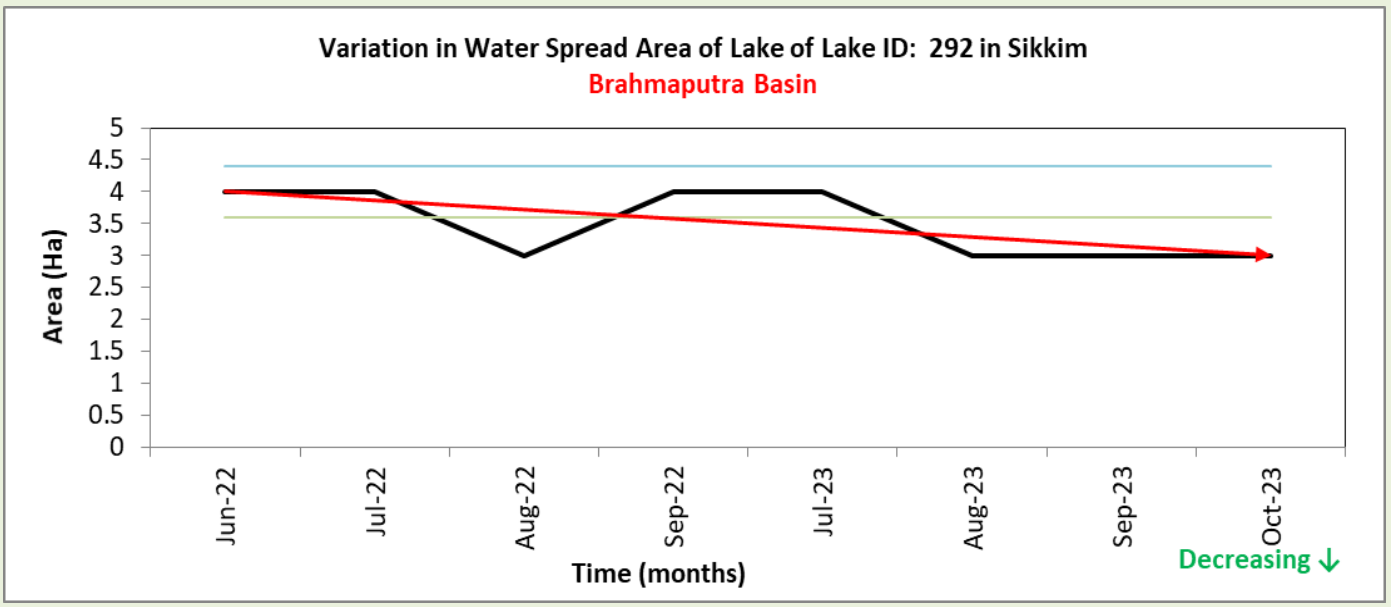


Figure 4.193(ii) Trend Analysis Plot ±20%

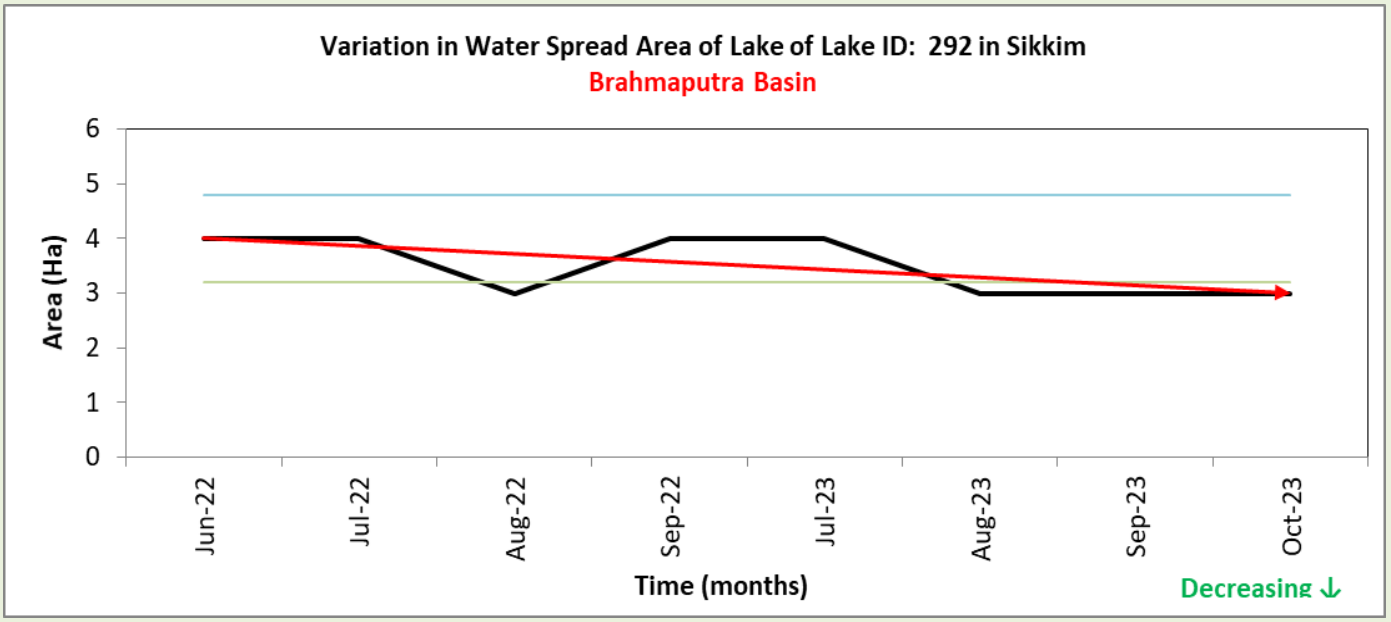


Figure 4.194(i) Trend Analysis Plot ±10%

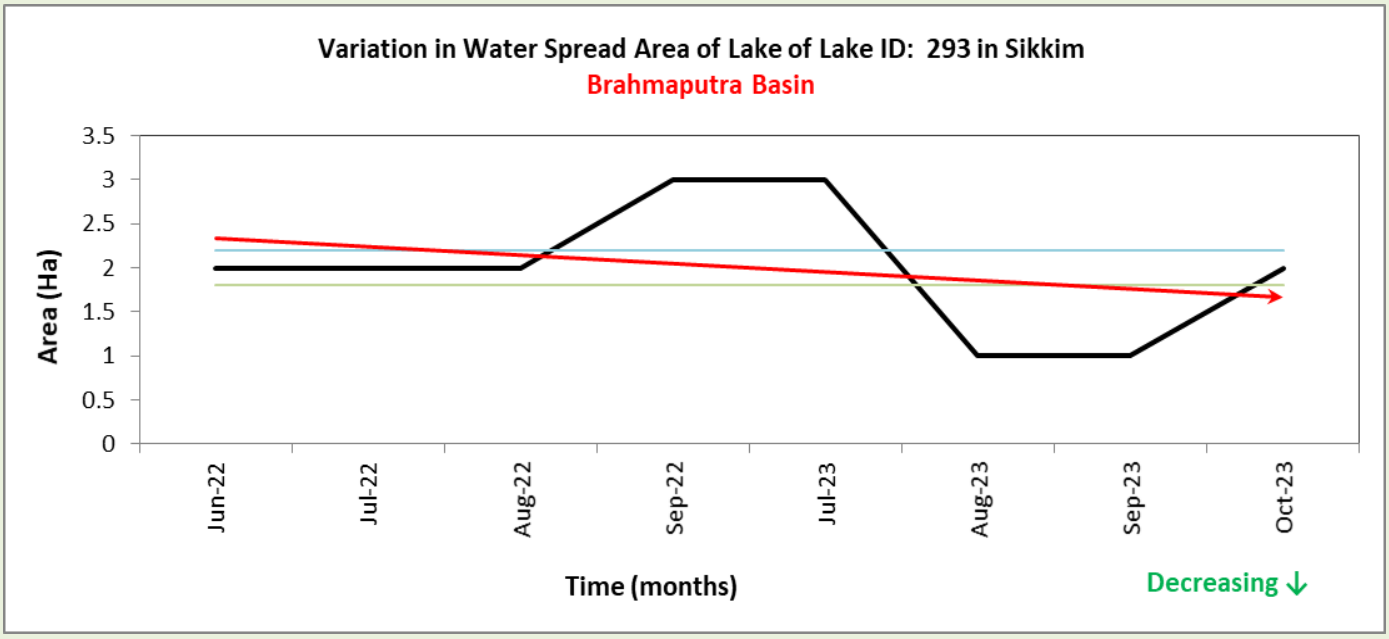


Figure 4.194(ii) Trend Analysis Plot ±20%

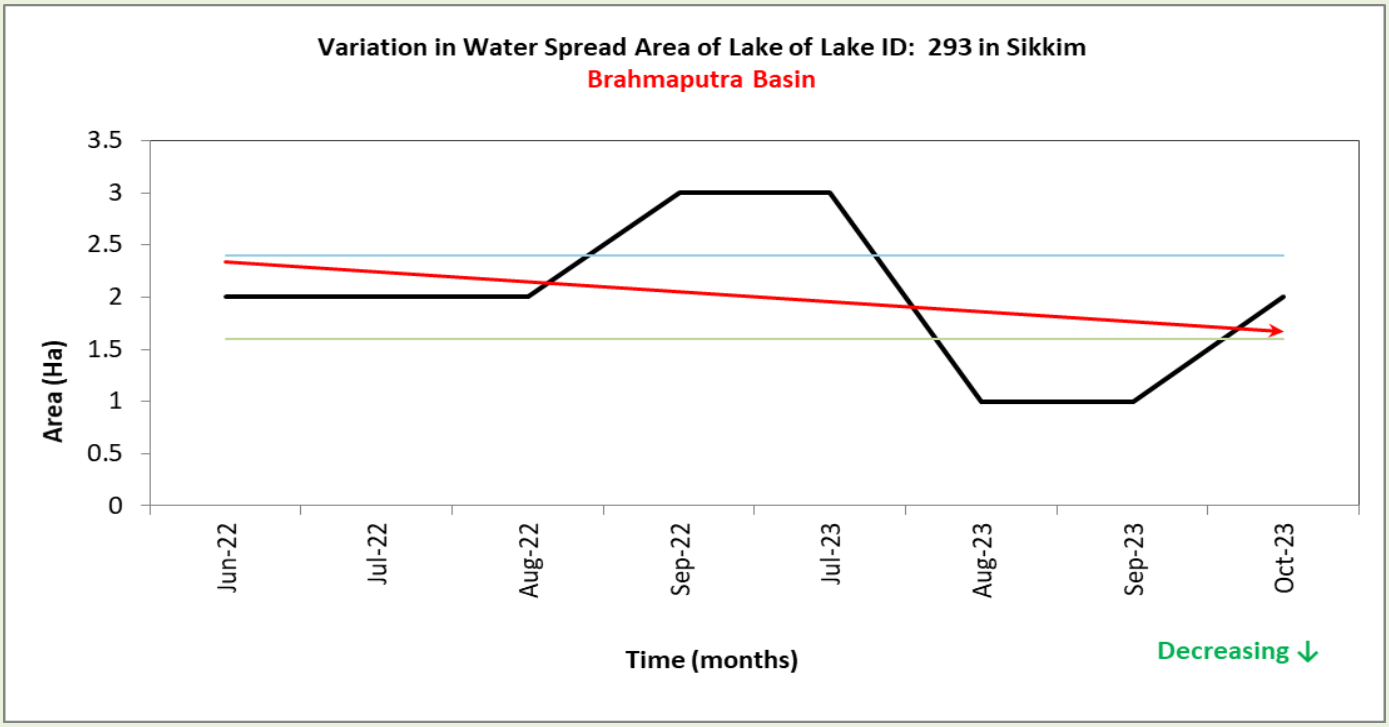


Figure 4.195(i) Trend Analysis Plot ±10%

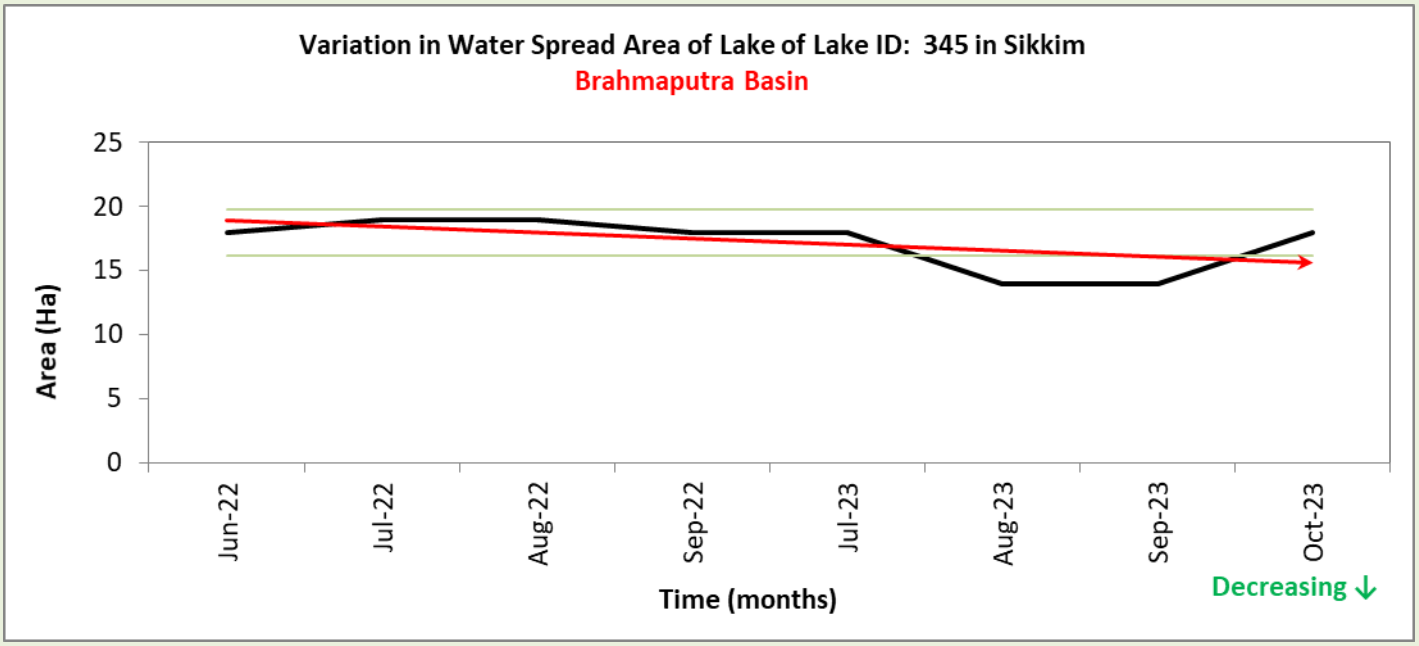
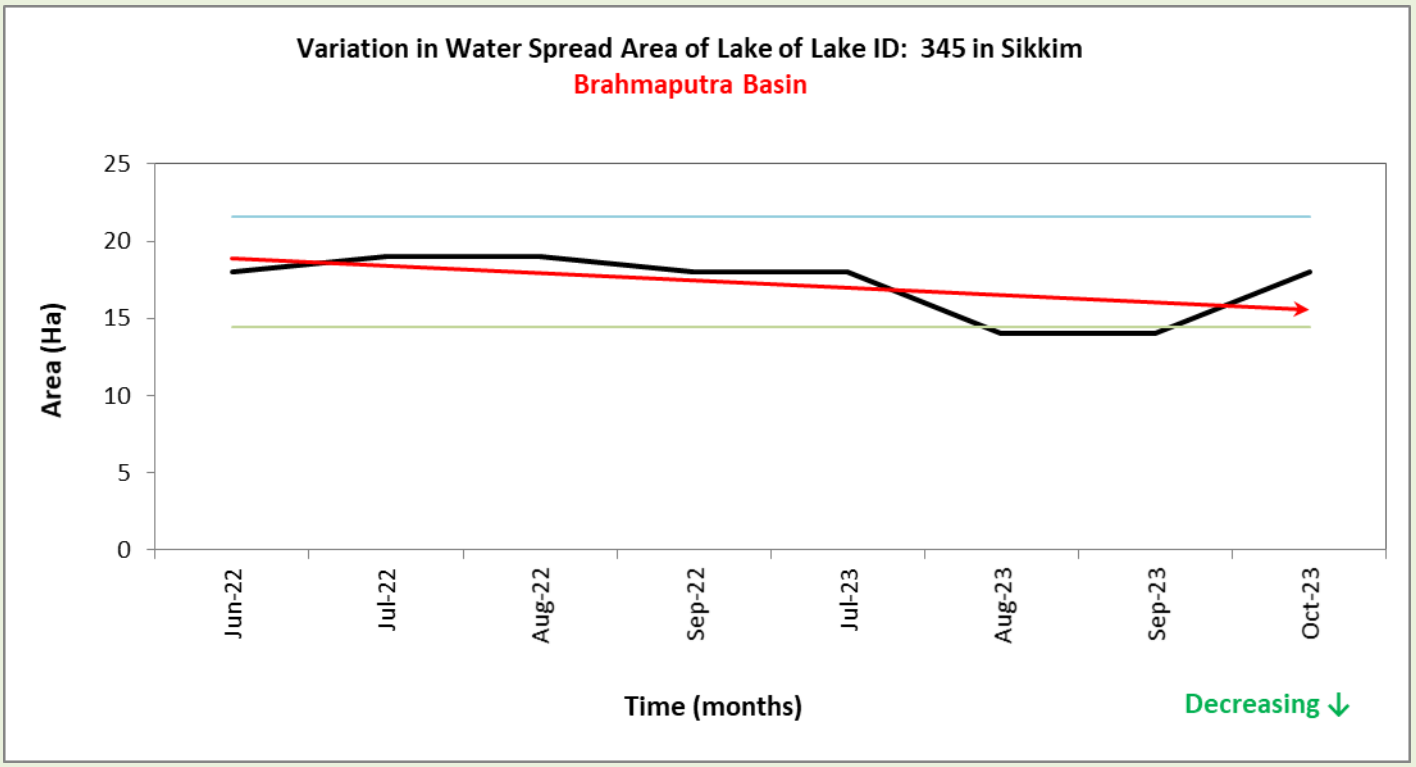


Figure 4.195(ii) Trend Analysis Plot ±20%



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 ±10%

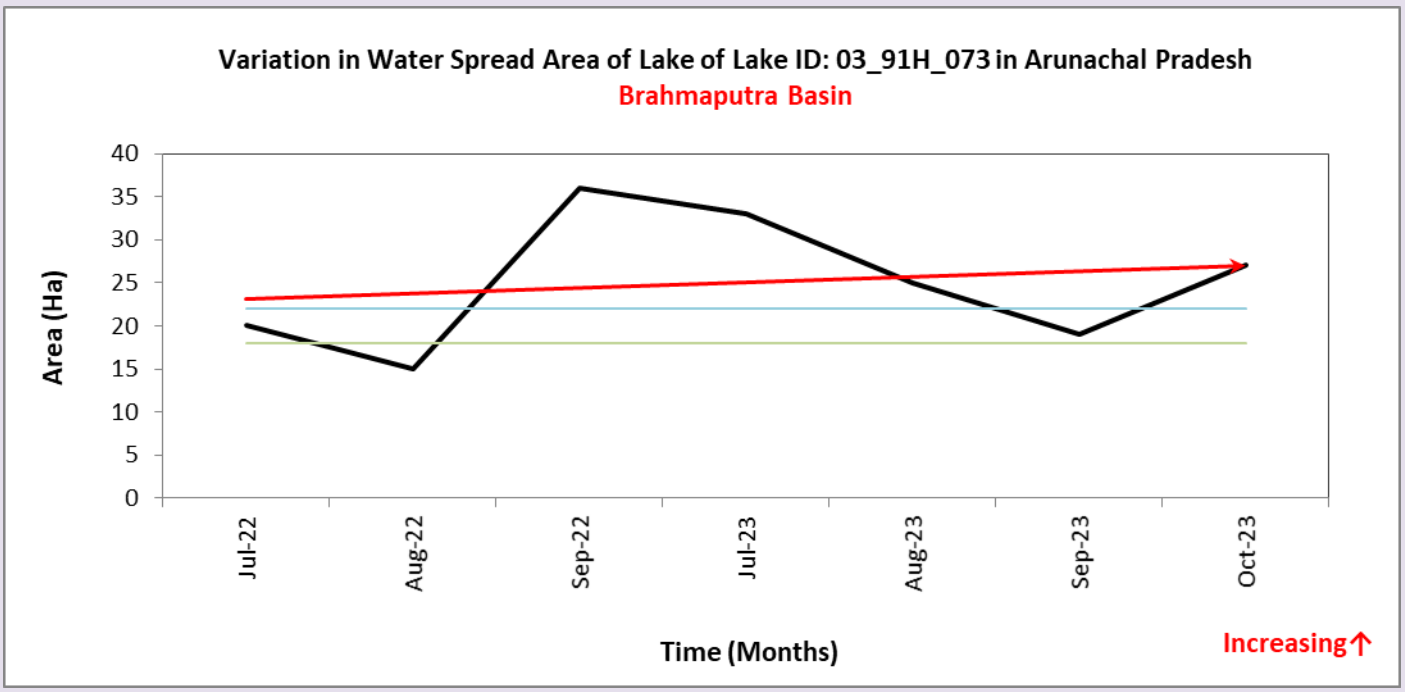


Figure 4.196(ii) Trend Analysis Plot ±20%

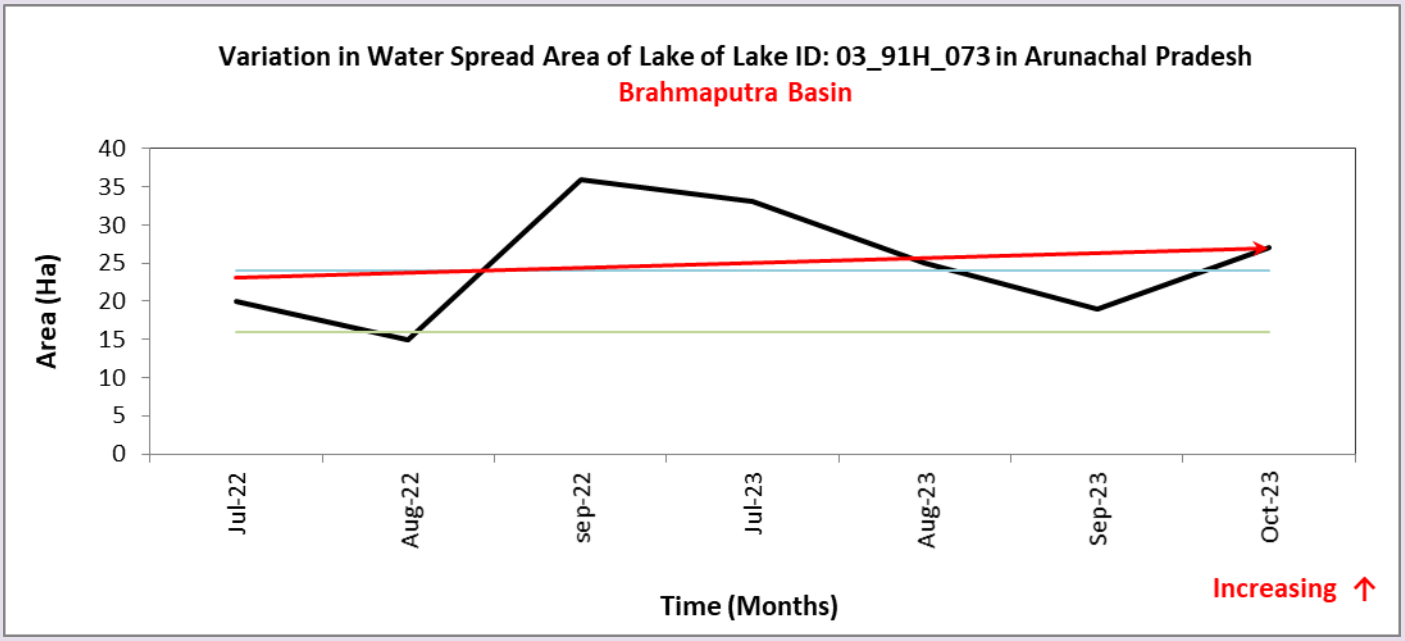


Figure 4.197(i) Trend Analysis Plot ±10%

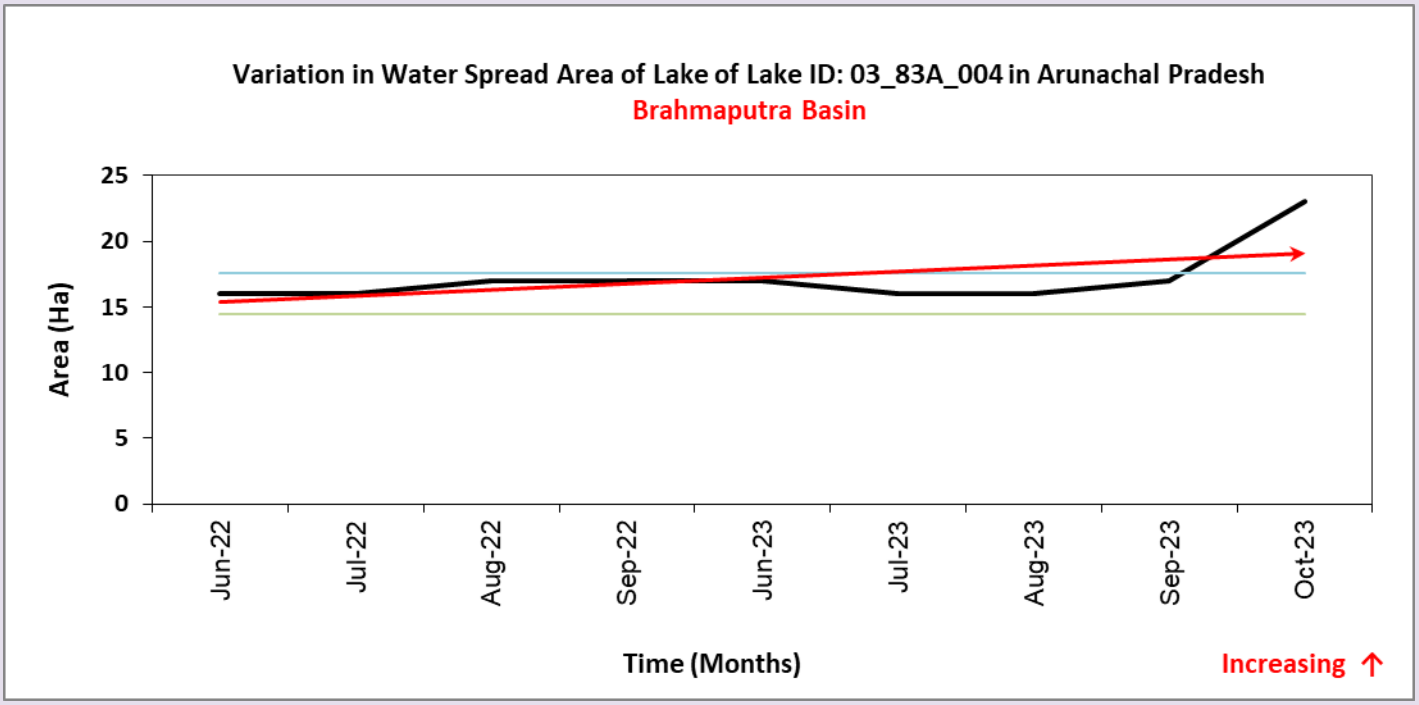


Figure 4.197(ii) Trend Analysis Plot ±20%

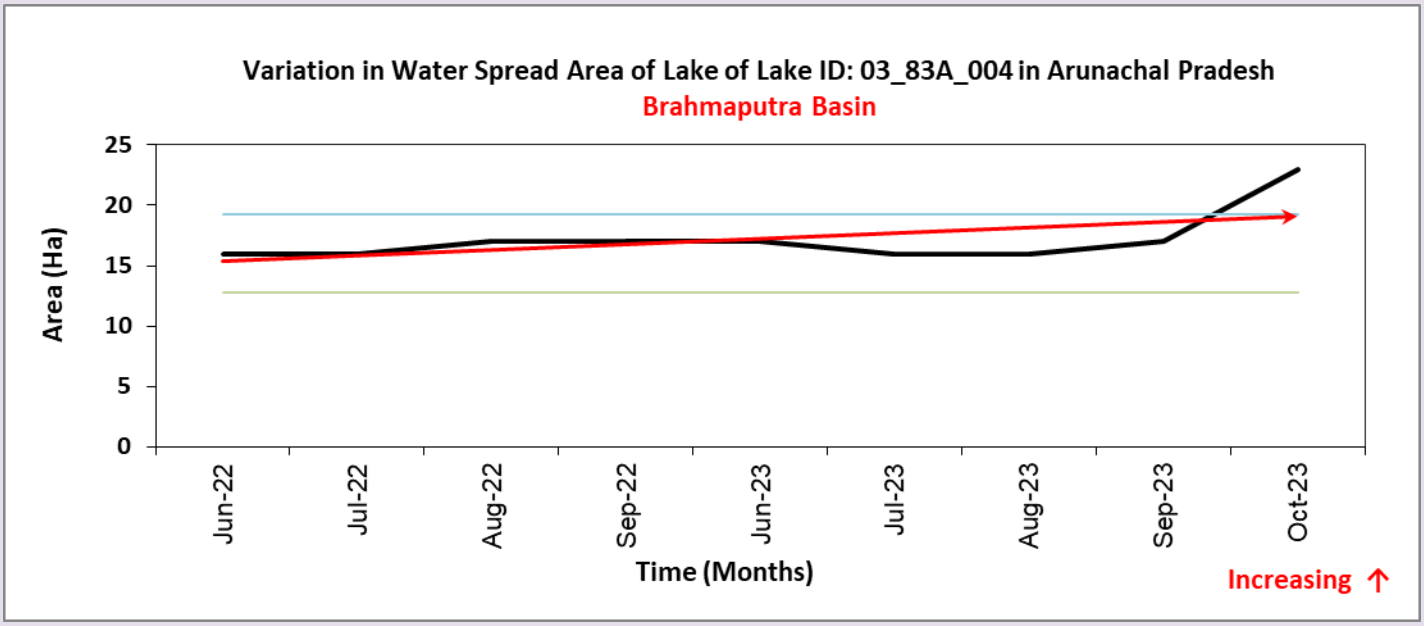


Figure 4.198(i) Trend Analysis Plot ±10%

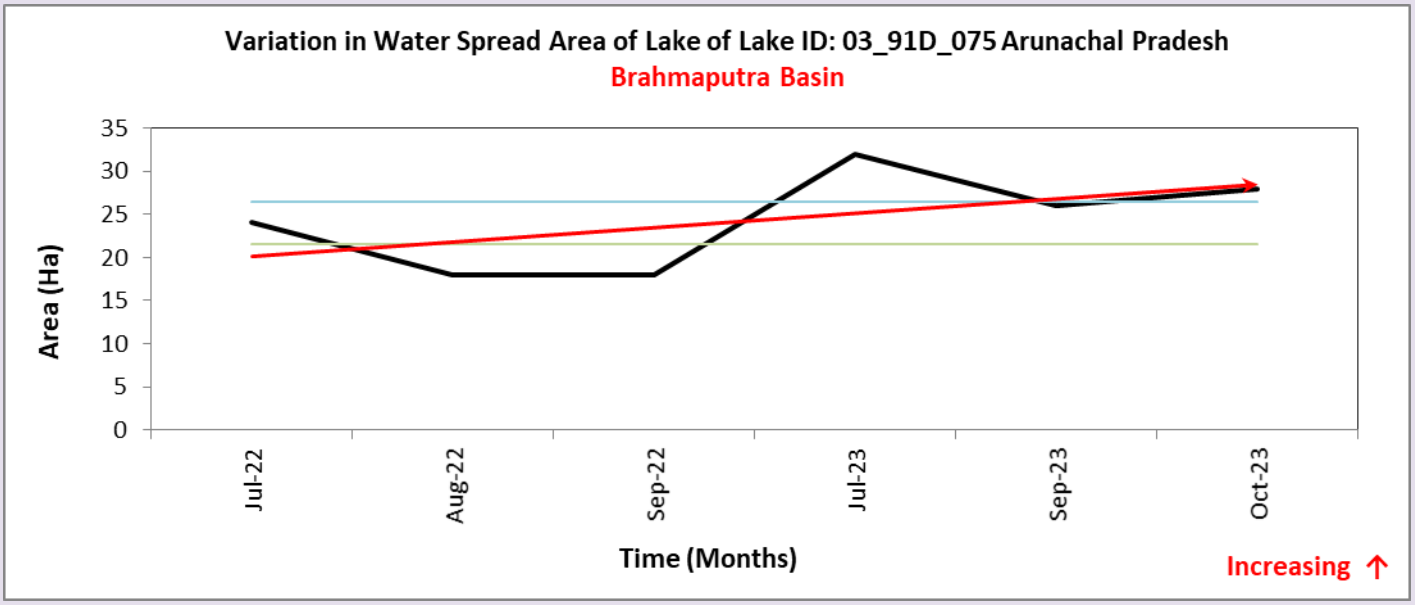


Figure 4.198(ii) Trend Analysis Plot ±20%

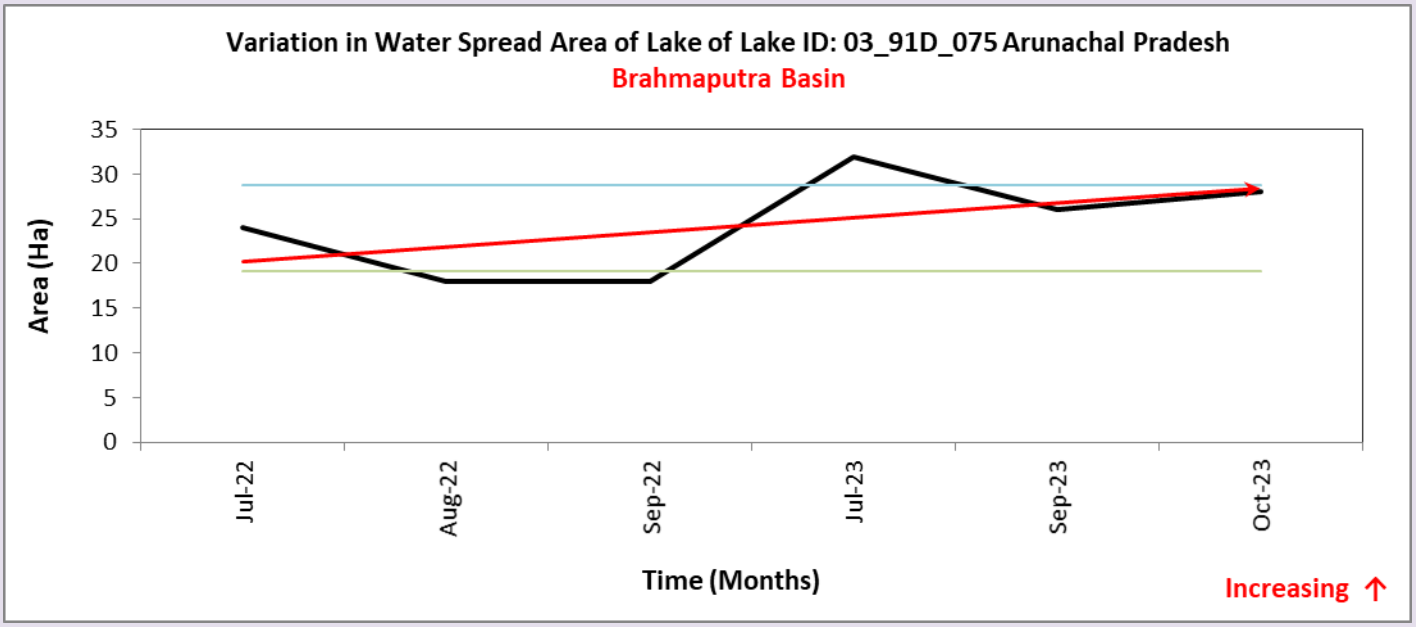


Figure 4.199(i) Trend Analysis Plot ±10%

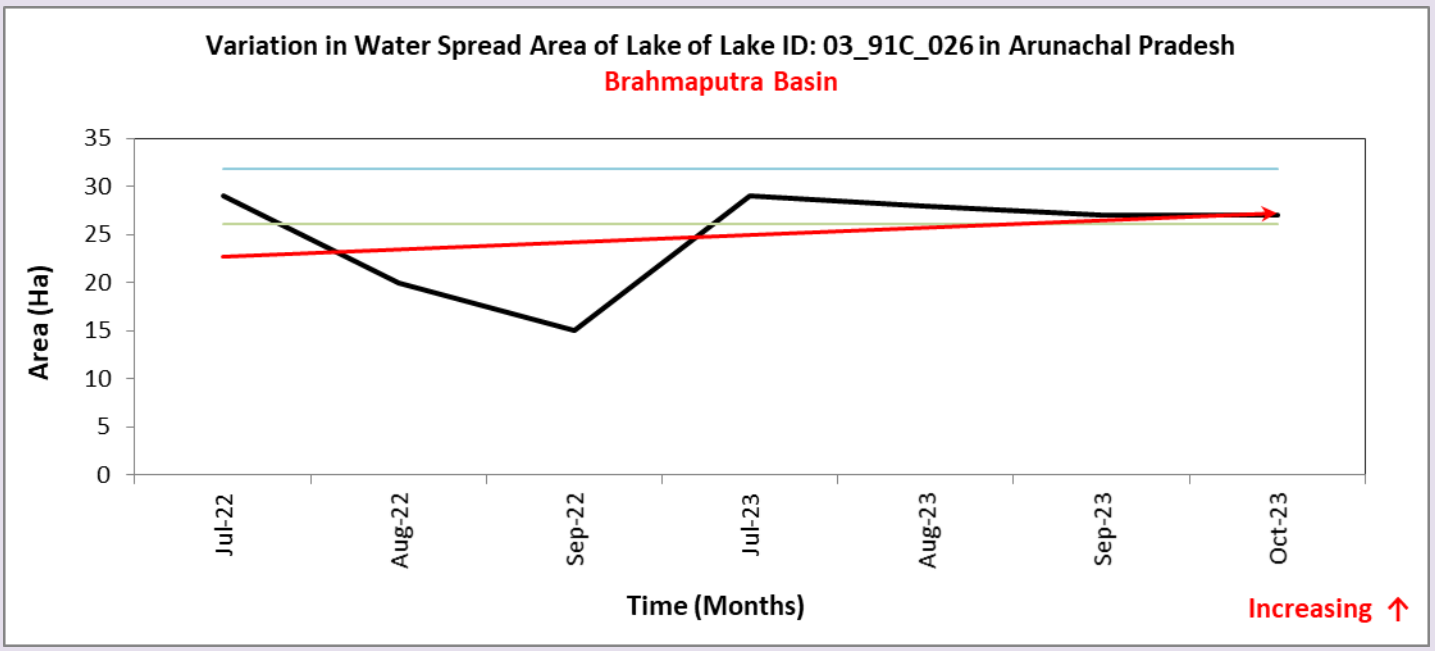


Figure 4.199(ii) Trend Analysis Plot ±20%

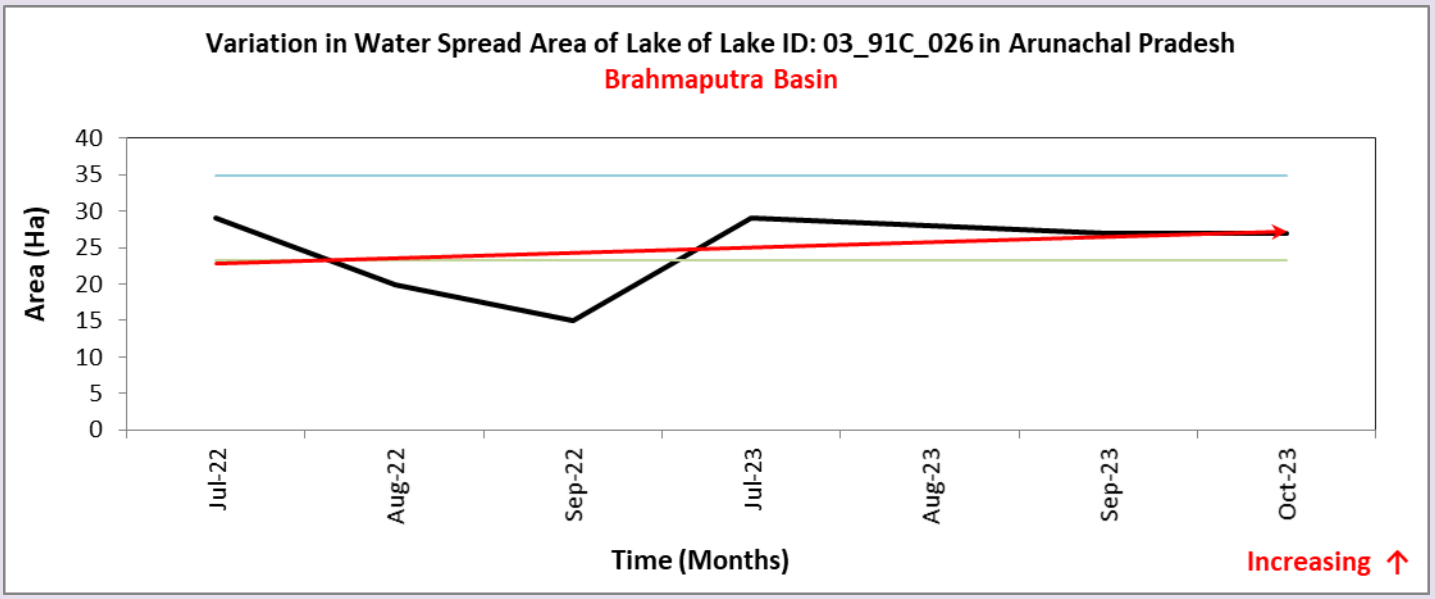


Figure 4.200(i) Trend Analysis Plot ±10%

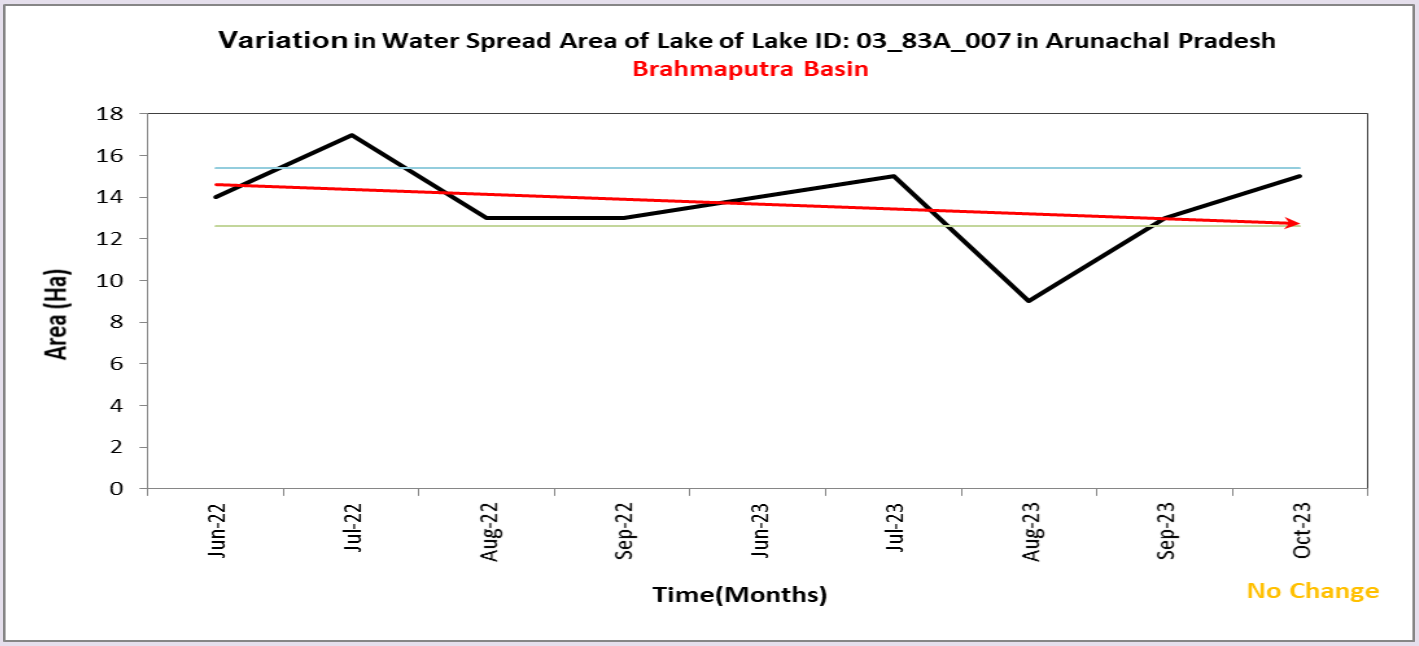


Figure 4.200(ii) Trend Analysis Plot ±20%

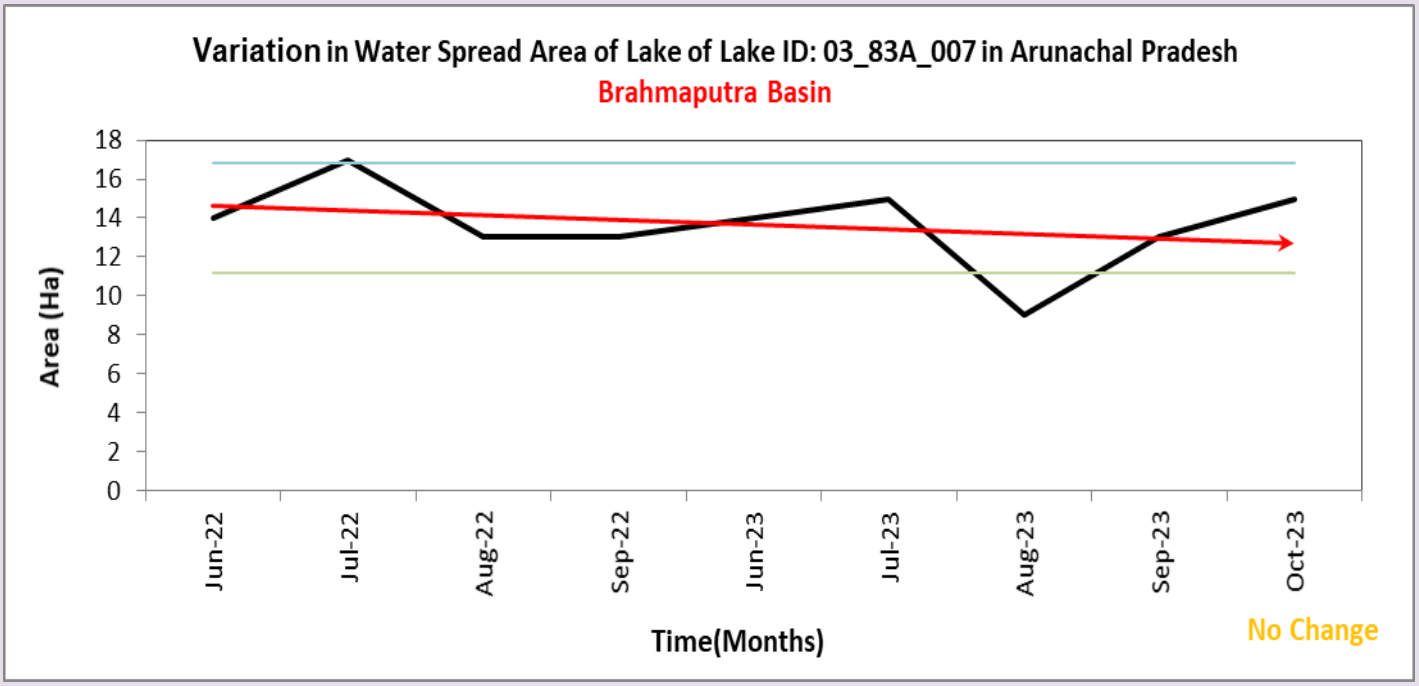


Figure 4.201(i) Trend Analysis Plot ±10%

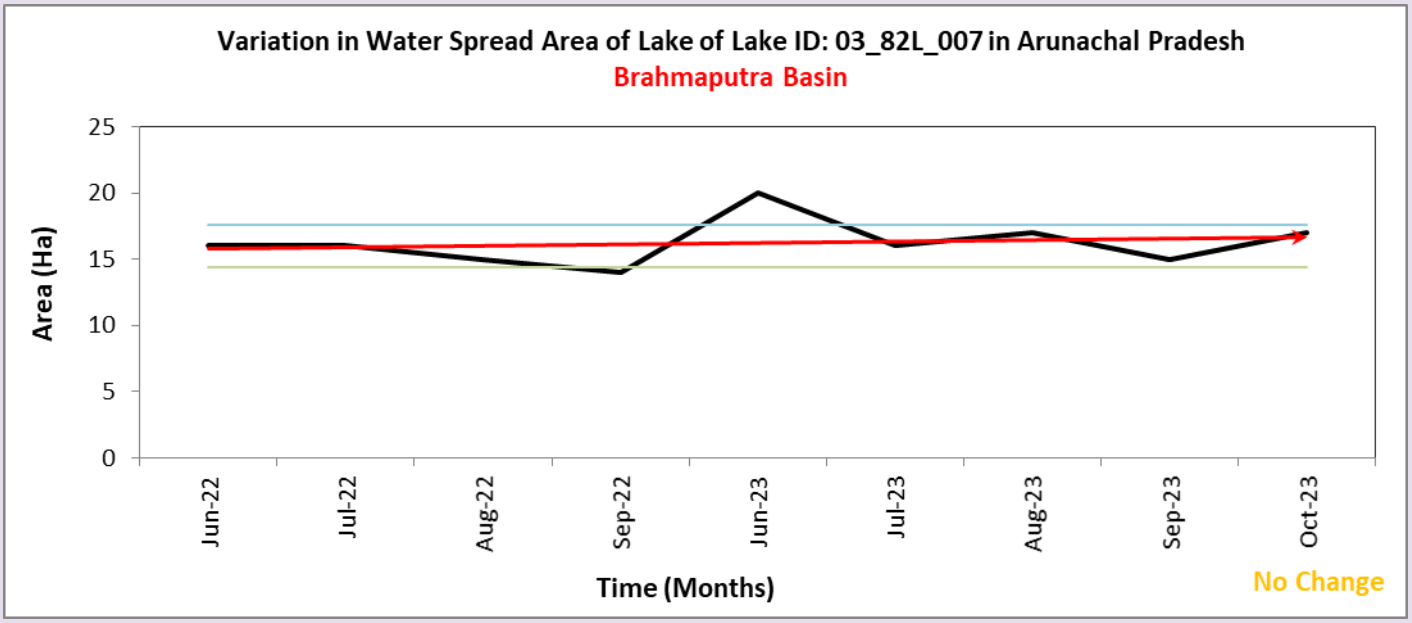


Figure 4.201(ii) Trend Analysis Plot ±20%

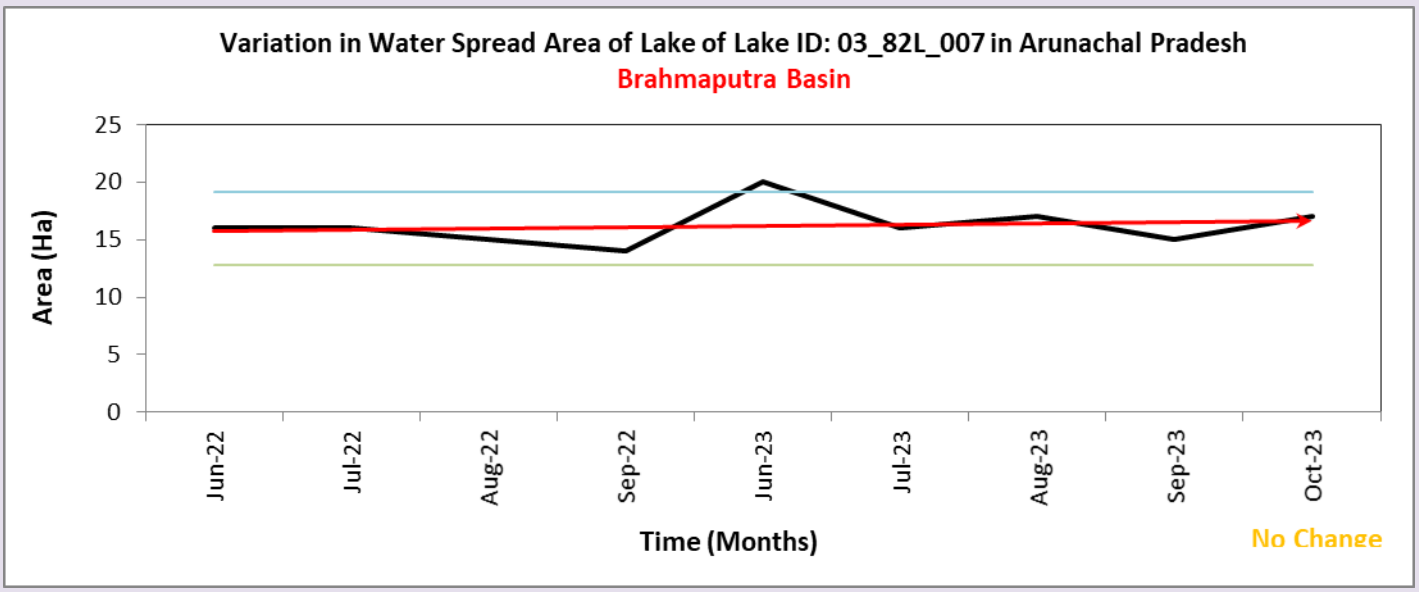


Figure 4.202(i) Trend Analysis Plot ±10%

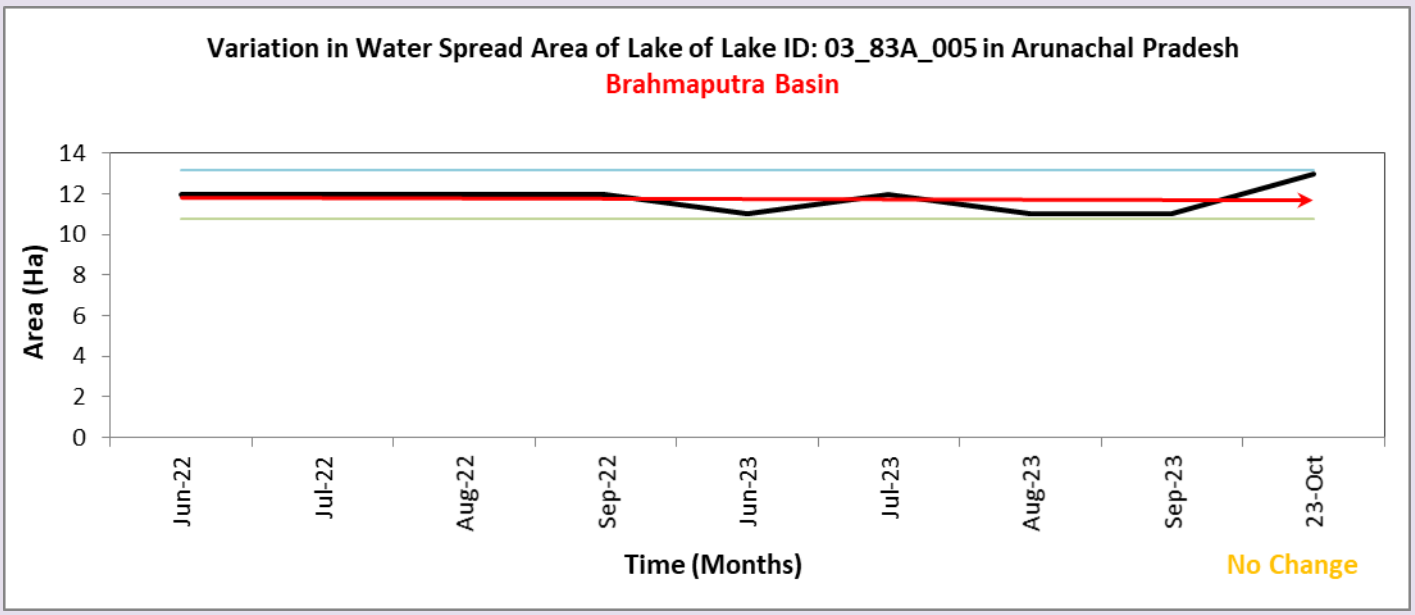


Figure 4.202(ii) Trend Analysis Plot ±20%

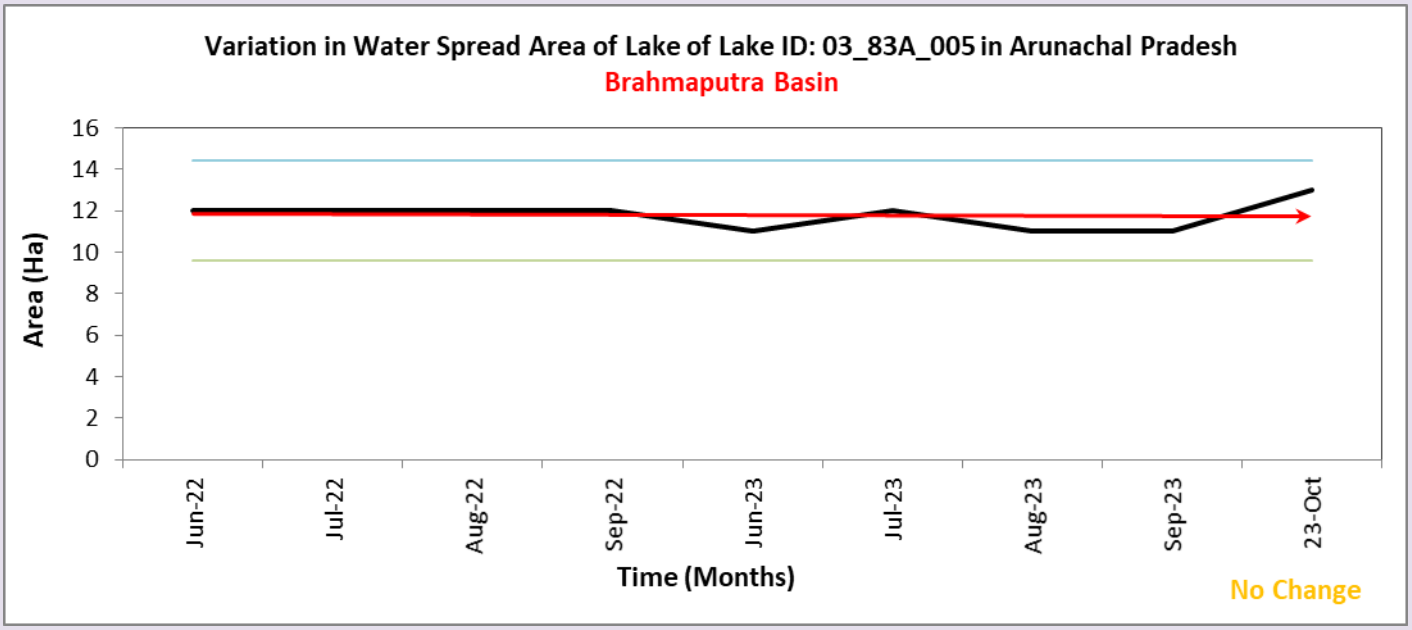


Figure 4.203(i) Trend Analysis Plot ±10%

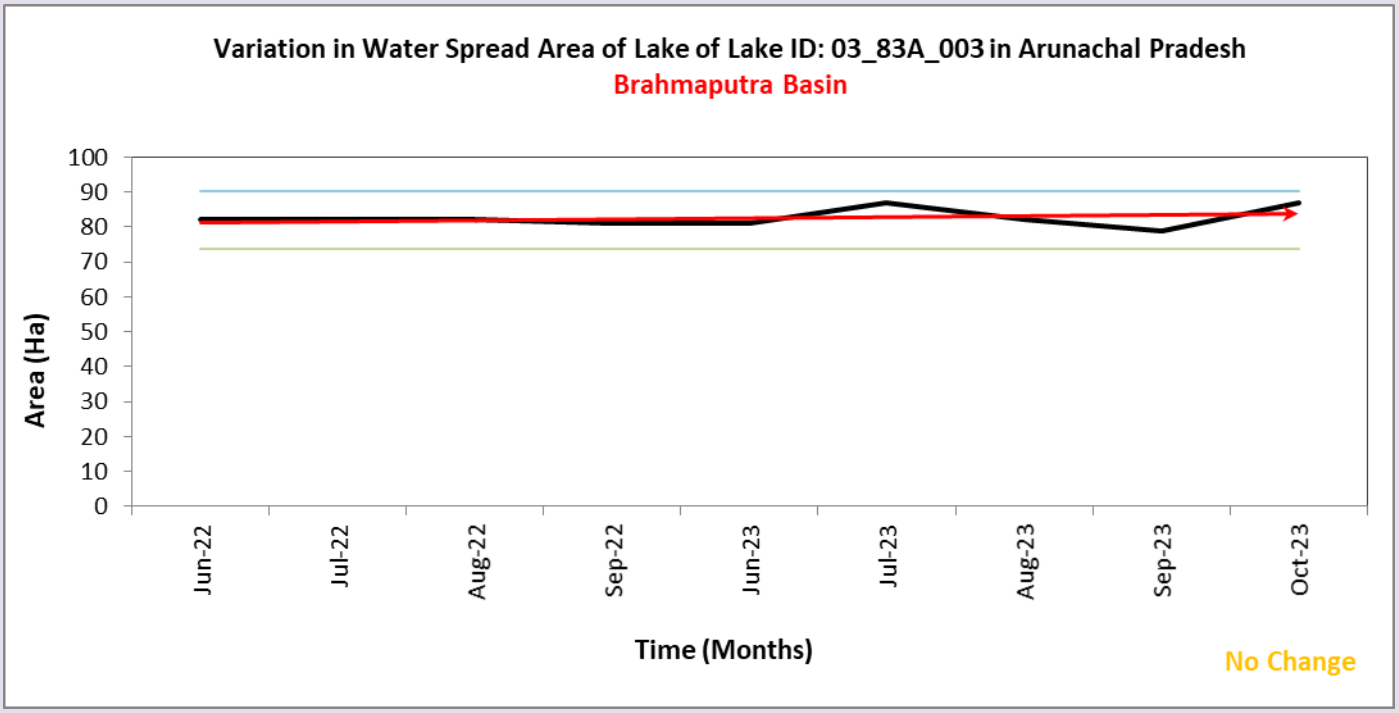


Figure 4.203(ii) Trend Analysis Plot ±20%

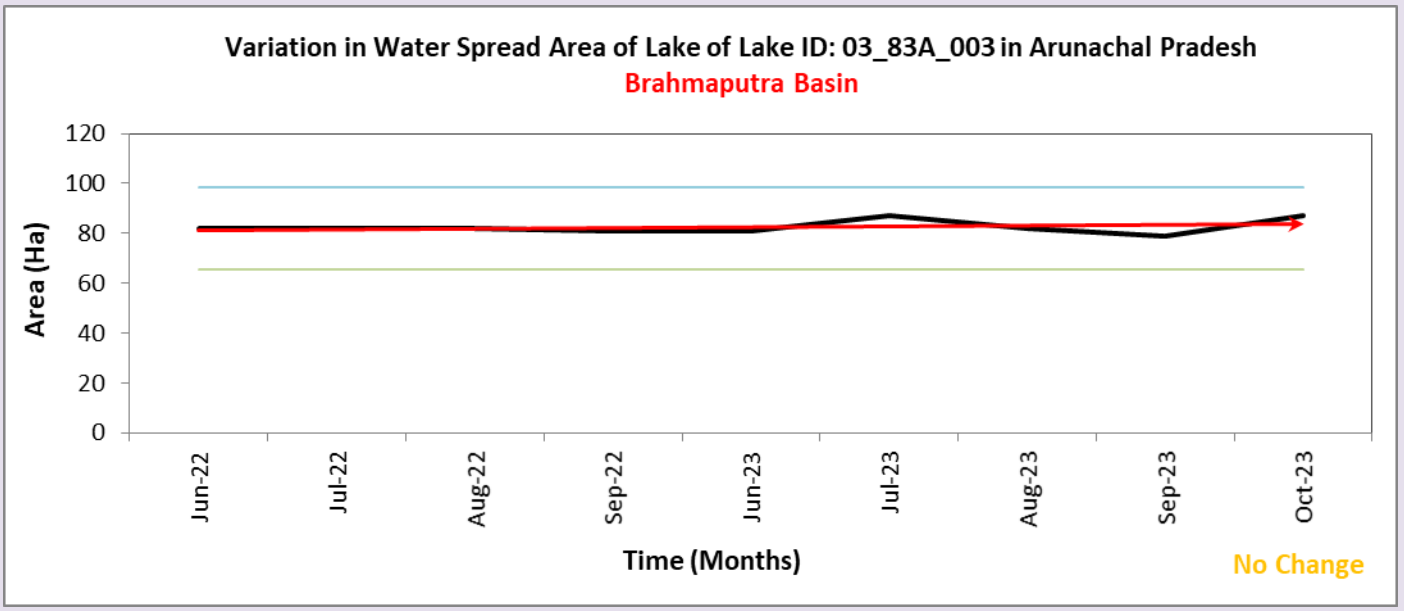


Figure 4.204(i) Trend Analysis Plot ±10%

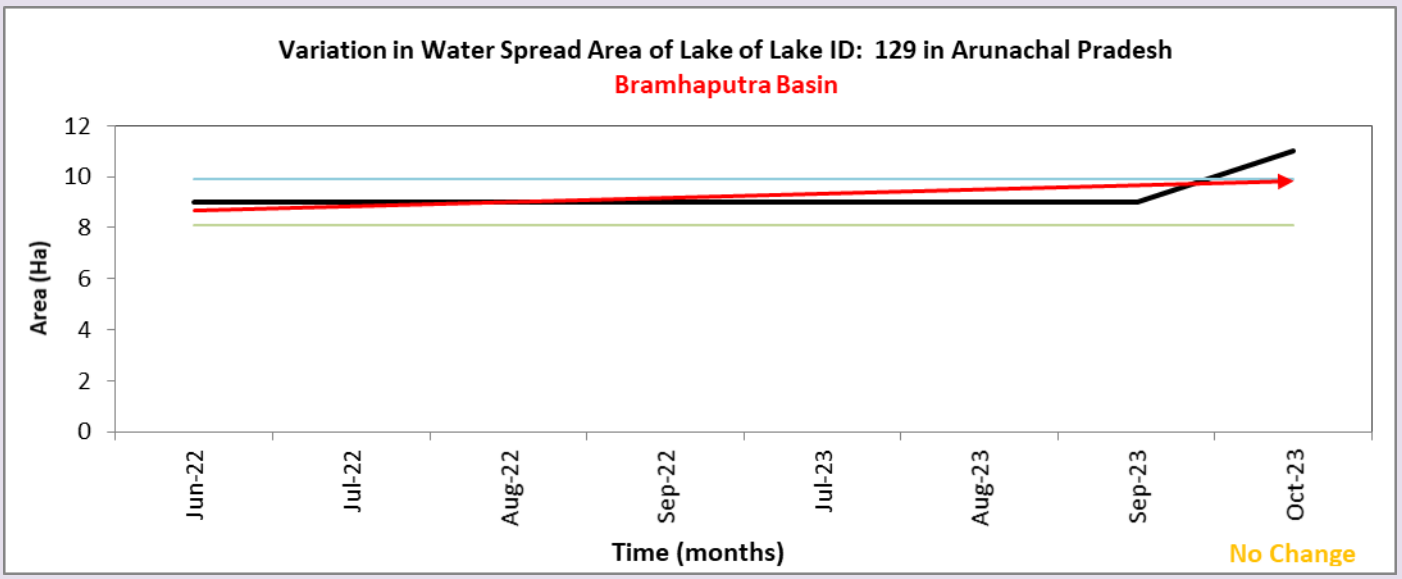
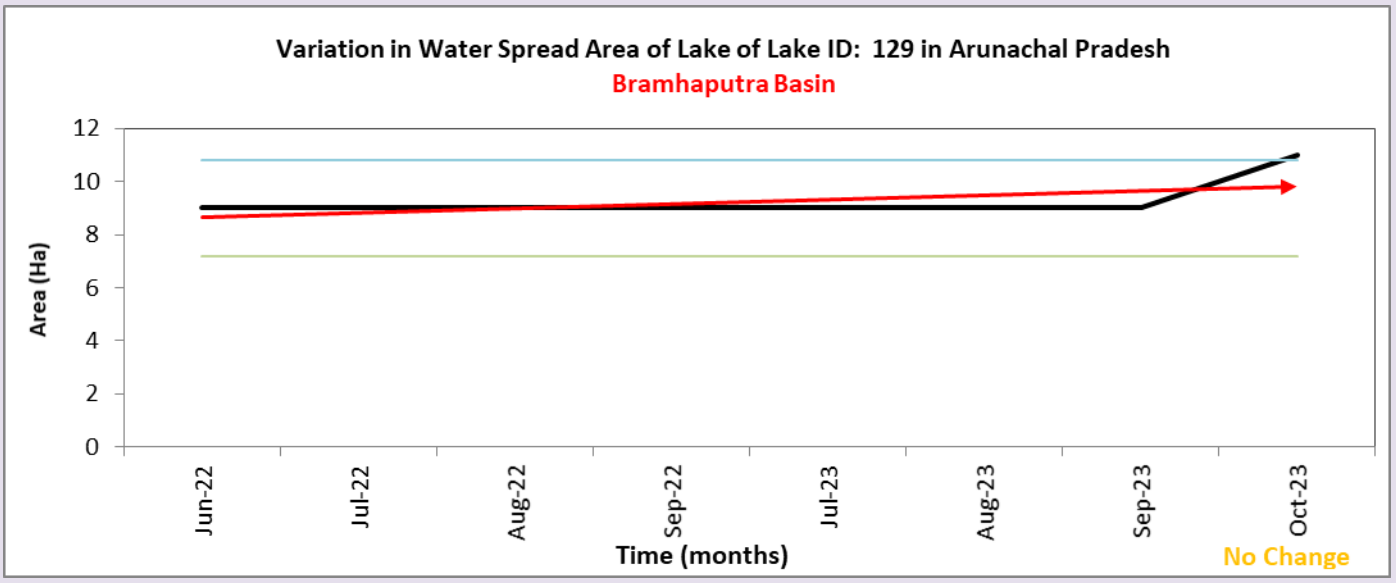


Figure 4.204(ii) Trend Analysis Plot ±20%



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

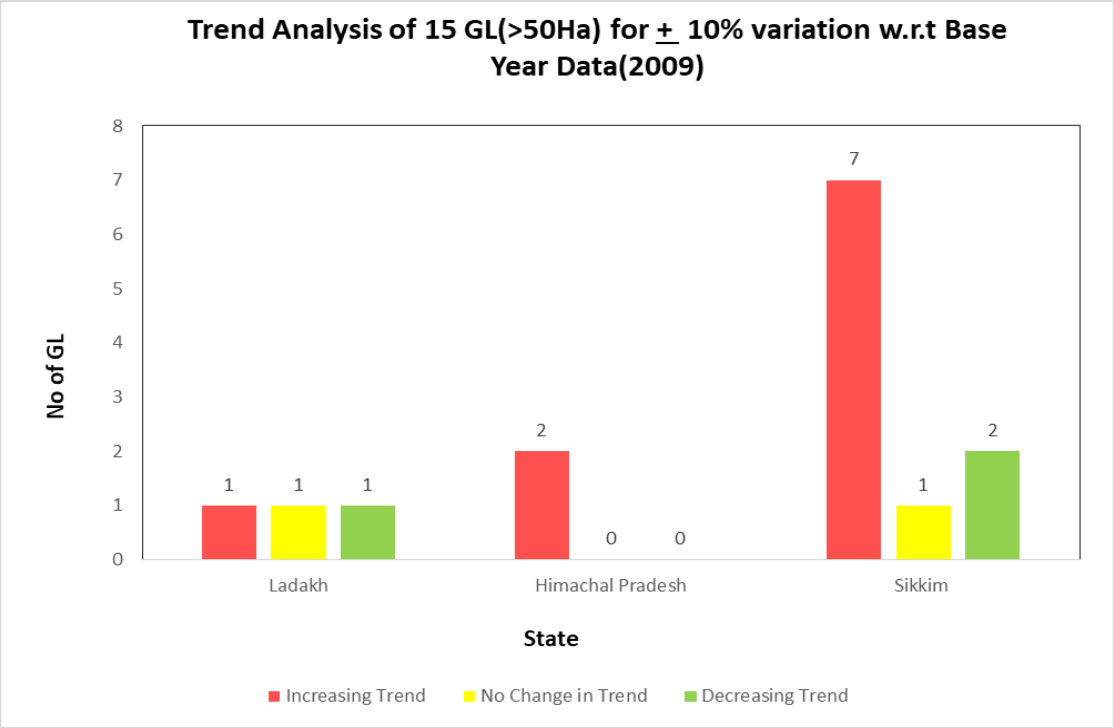


Figure 4.205(i): Trend Analysis carried out for Change in Waterspread area of 15 GL (>50 Ha) w.r.t. Base year Data 2009 for ±10% variation

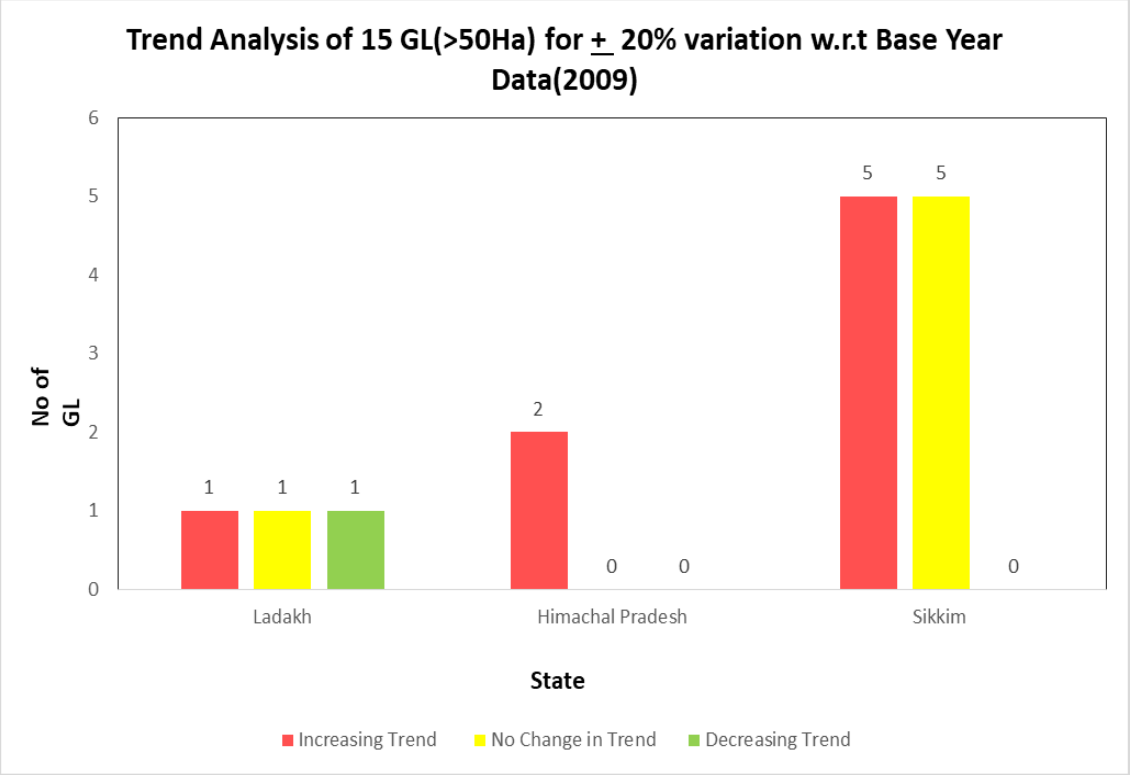


Figure 4.205(ii) Trend Analysis carried out for Change in Waterspread area of 15 GL (>50 Ha) w.r.t. Base year Data 2009 for ±20% variation

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

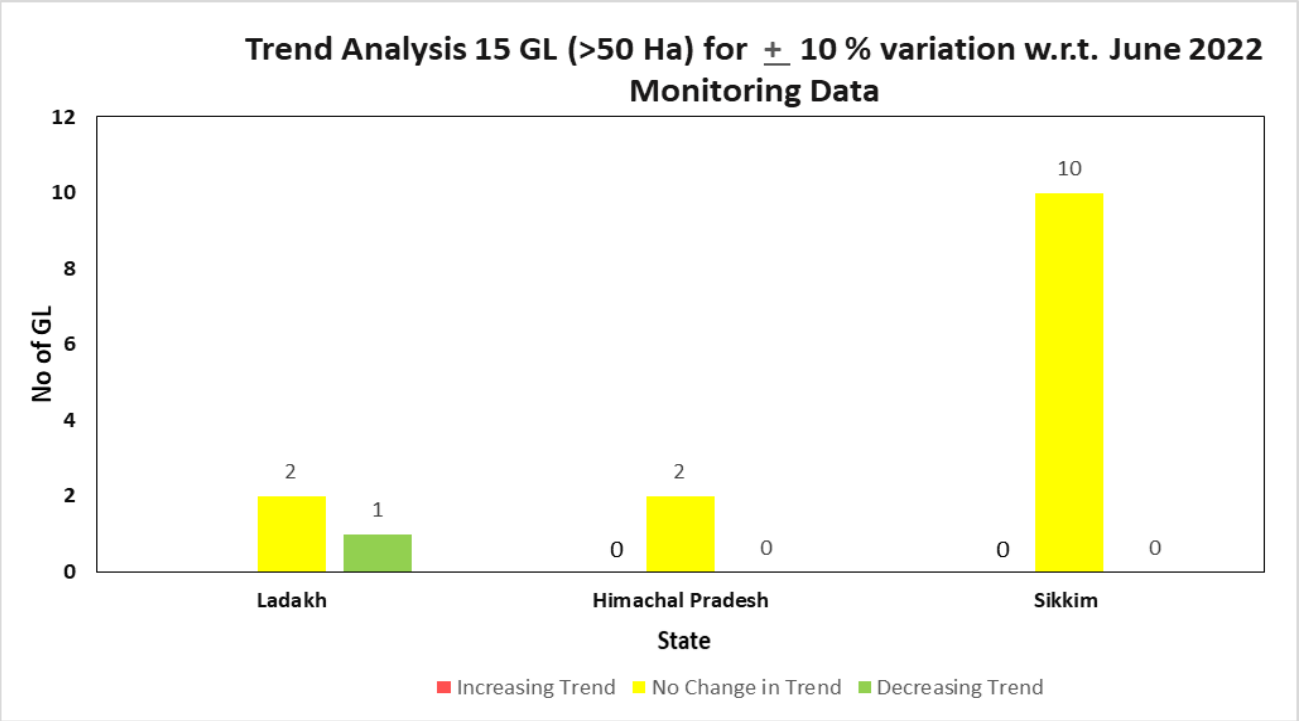


Figure 4.206(i): Trend Analysis carried out for Change in Waterspread area of 15 GL (>50 Ha) w.r.t. Base year Data 2022 for ±10%variation

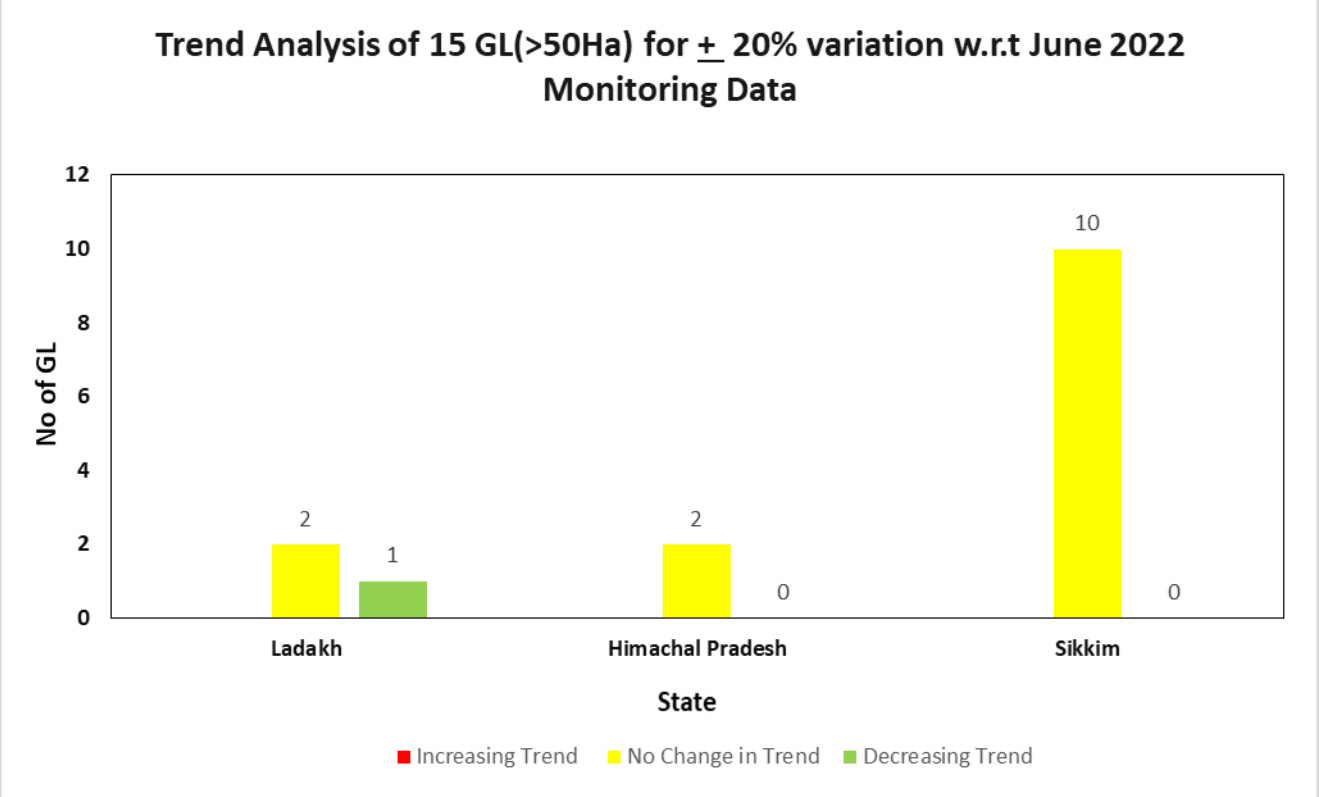


Figure 7.206(ii): Trend Analysis carried out for Change in Waterspread area of 15 GL (>50 Ha) w.r.t. Base year Data 2022 for ±20%variation

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

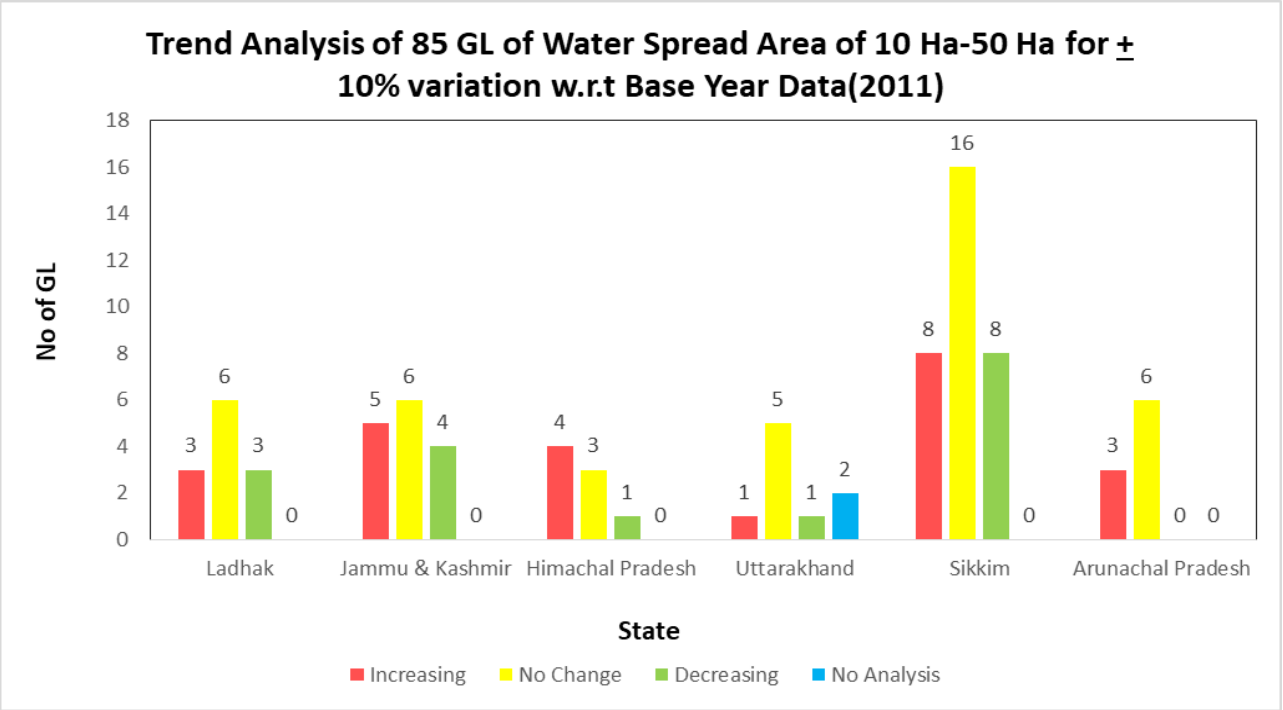


Figure **4.207(i)**: Trend Analysis carried out for Change in Waterspread area of 85 GL (10-50 Ha) w.r.t. Base year Data 2011 for ±10% variation

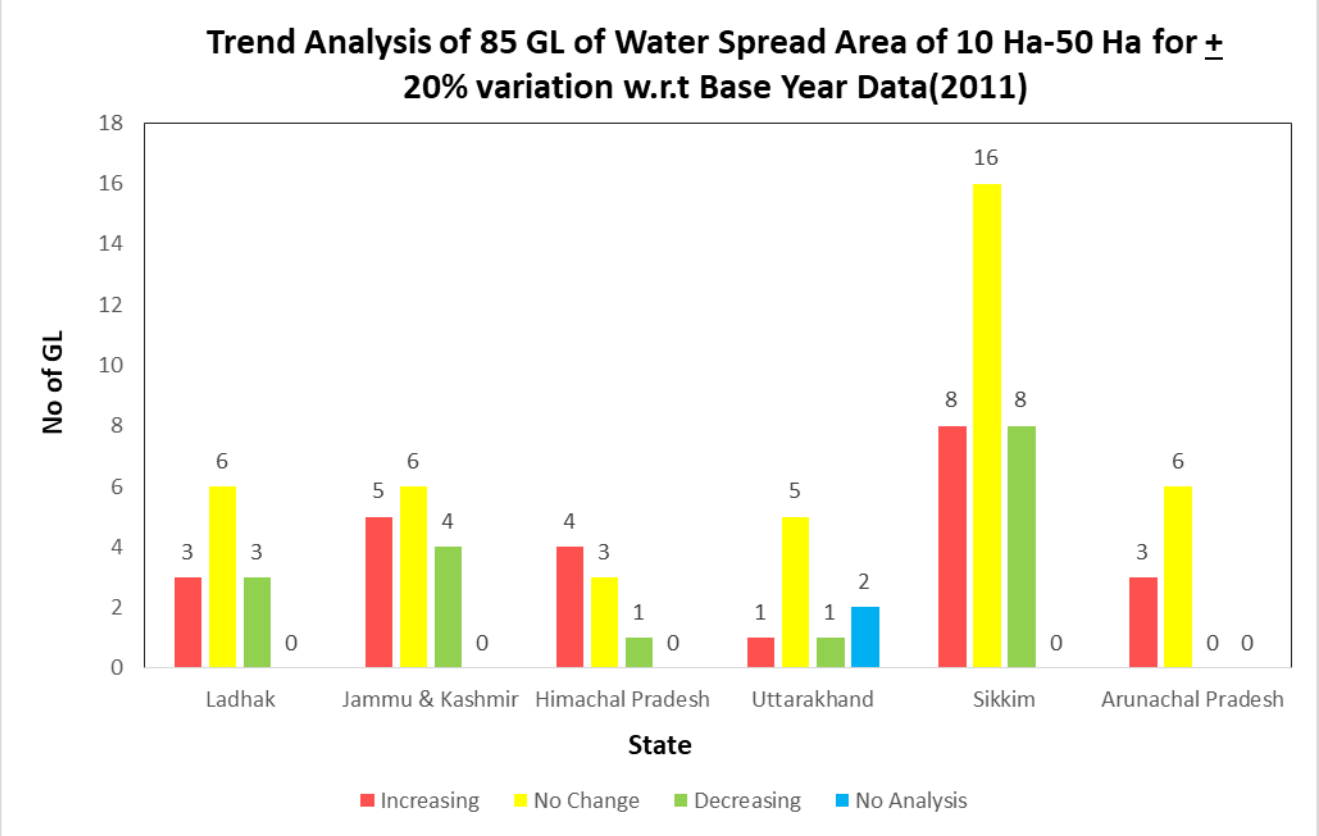


Figure **4.207(ii)**:: Trend Analysis carried out for Change in Waterspread area of 85 GL (10-50 Ha) w.r.t. Base year Data 2011 for ±20% variation

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

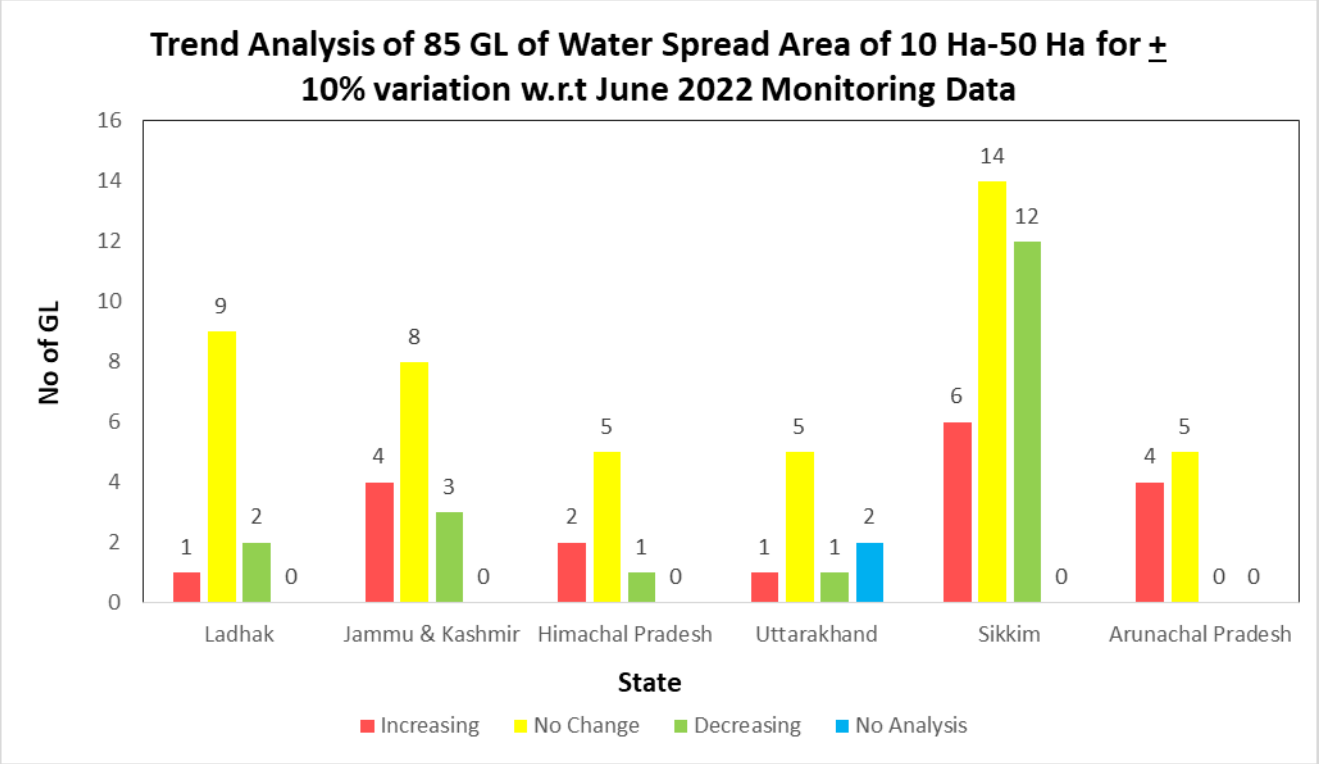


Figure **4.208(i)**: Trend Analysis carried out for Change in Waterspread area of 85 GL (10-50 Ha) w.r.t. Base year Data 2022 for ±10%variation

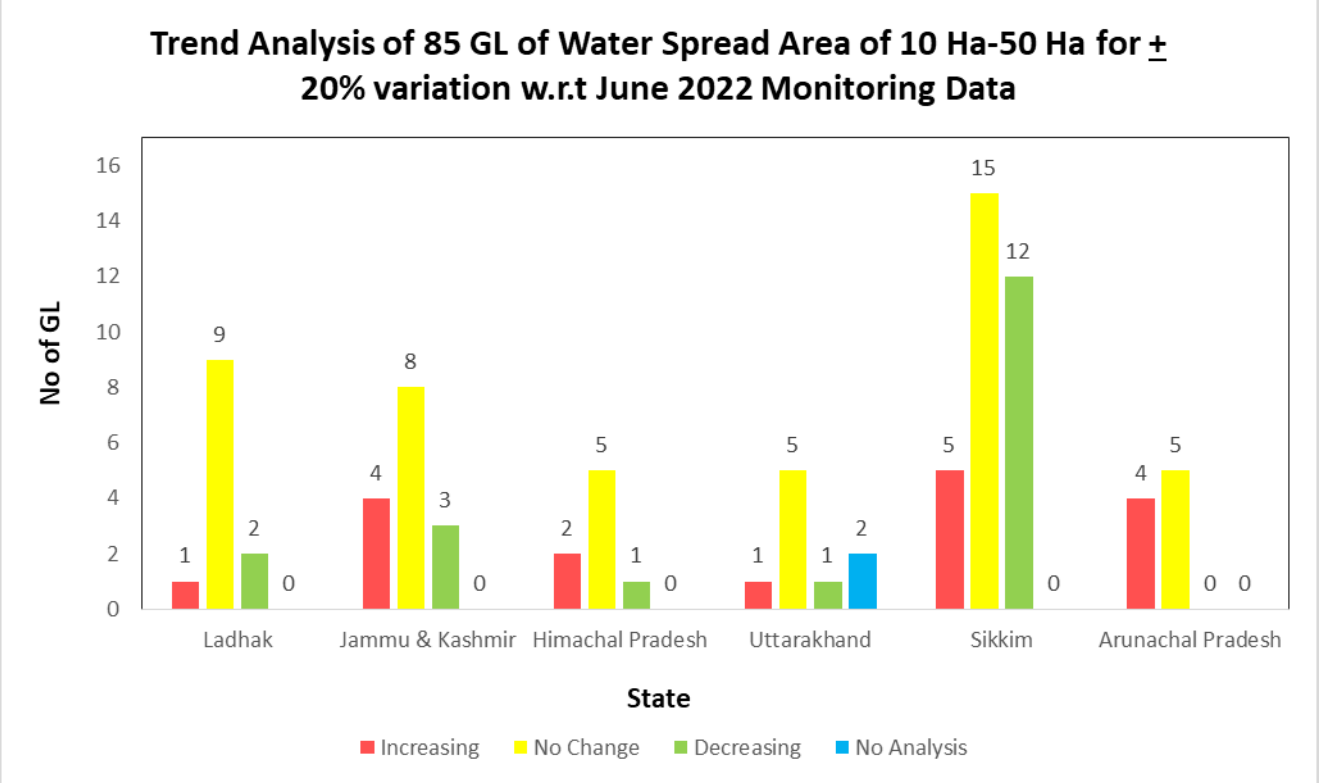


Figure **4.208(ii)**: Trend Analysis carried out for Change in Waterspread area of 85 GL (10-50 Ha) w.r.t. Base year Data 2022 for ±10%variation

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
Total	**10**	**8**

- 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
Total	**0**	**0**

- 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
Total	**24**	**24**

- The lakes showing increasing trend for **±10% is 18 Nos.** and **±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	
	± 10% Variation	± 20% Variation
Ladakh	1	1
Jammu & Kashmir	4	4
Himachal Pradesh	2	2
Uttarakhand	1	1
Sikkim	6	5
Arunachal Pradesh	4	4
Total	**18**	**17**

- 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
		±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**

- From the above table, it is observed that the number of increasing lakes under ±10% and ±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 1st and 2nd 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 ±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

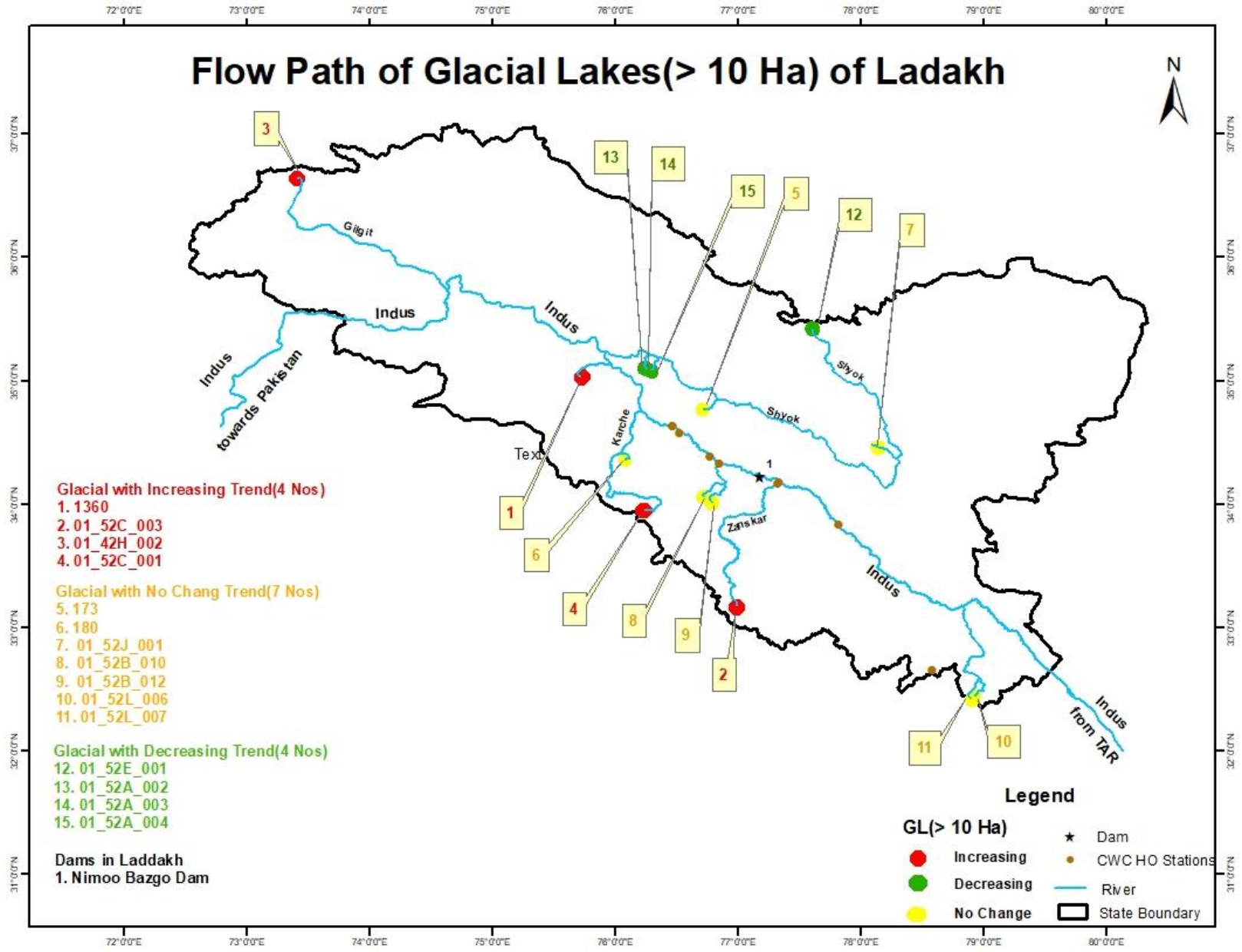
(ii) GLOF Dam Break Analysis

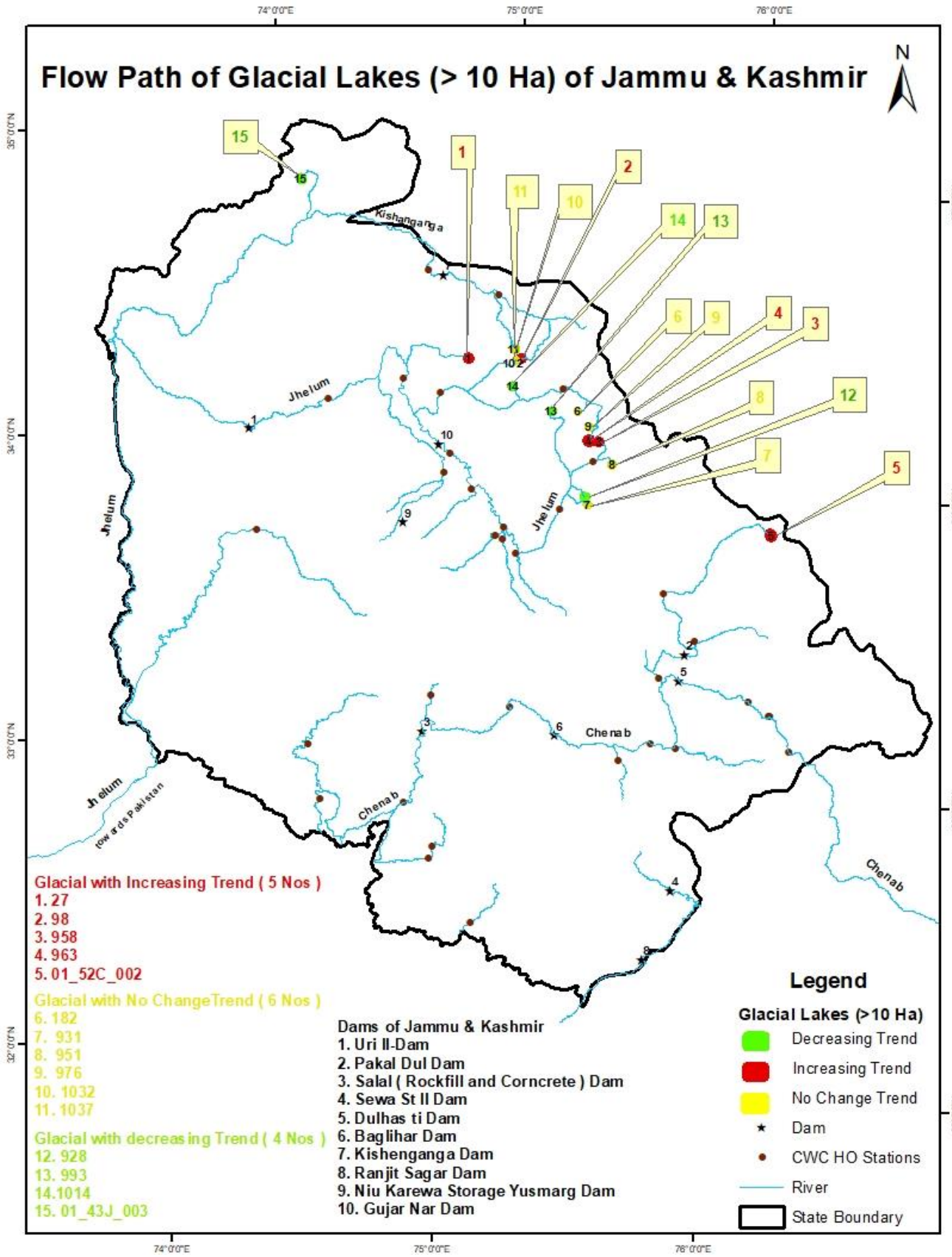
(iii) Risk assessment in the event of GLOF

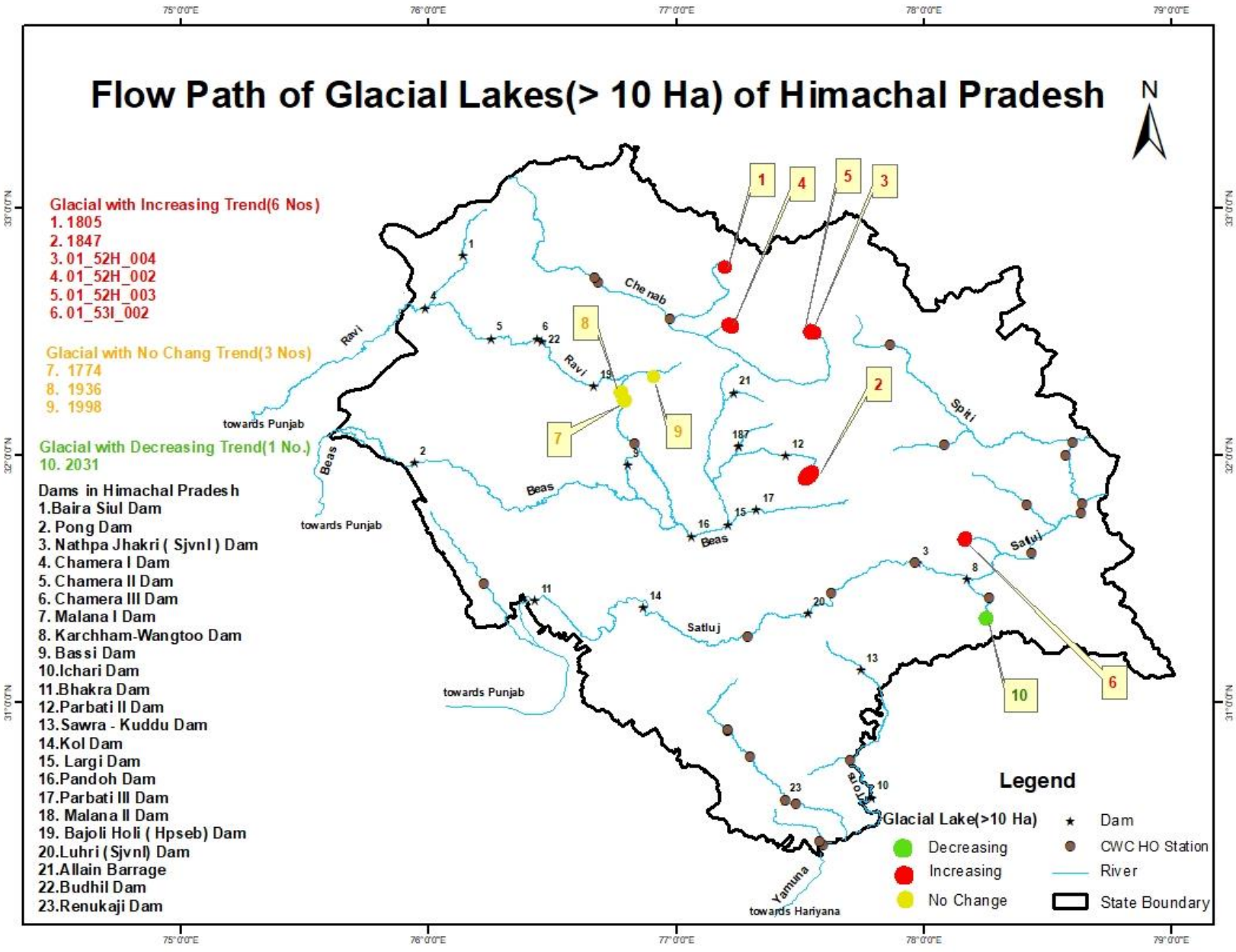
(iv) Installation of Early Warning System

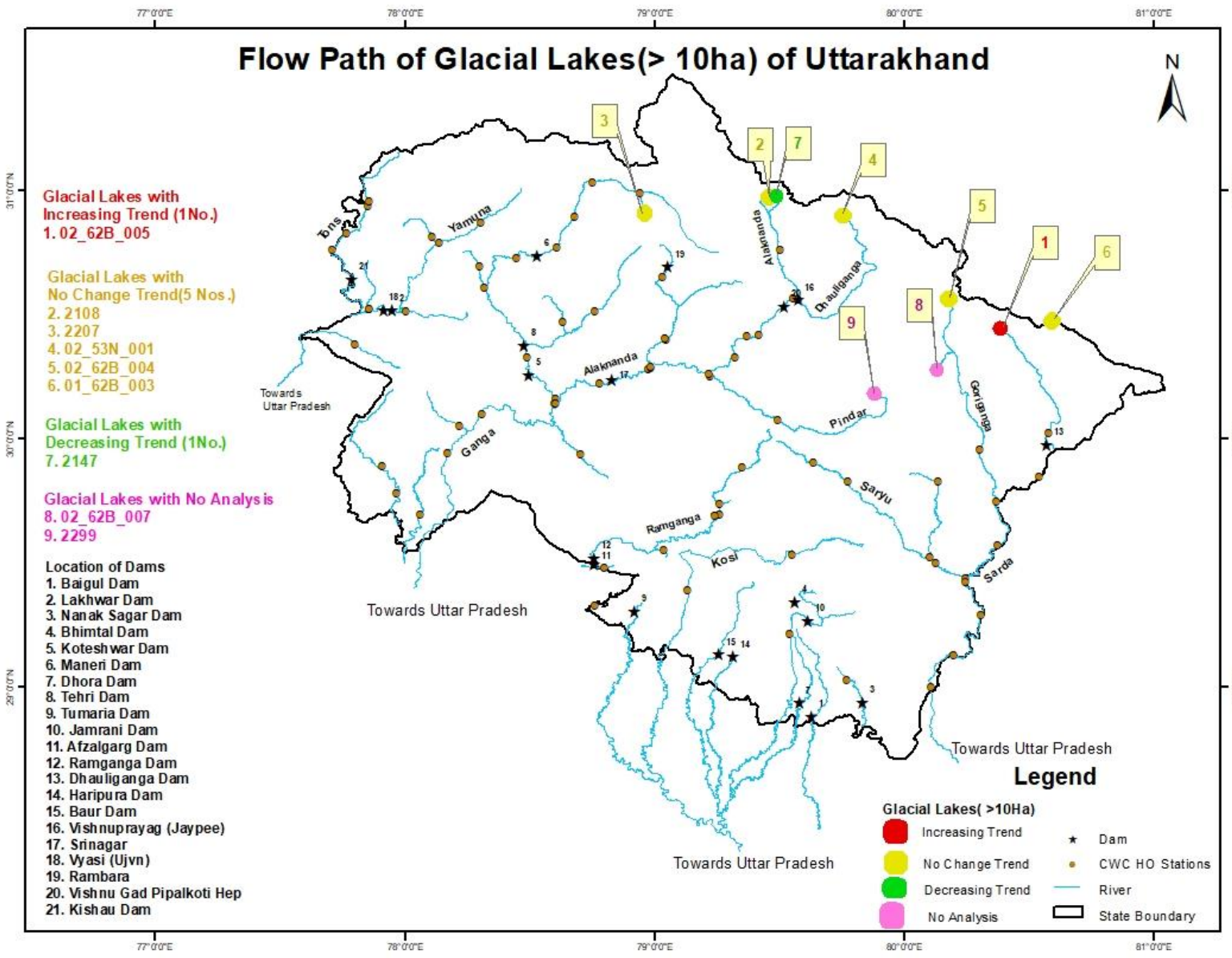
(v) Planning of Mitigation Measures

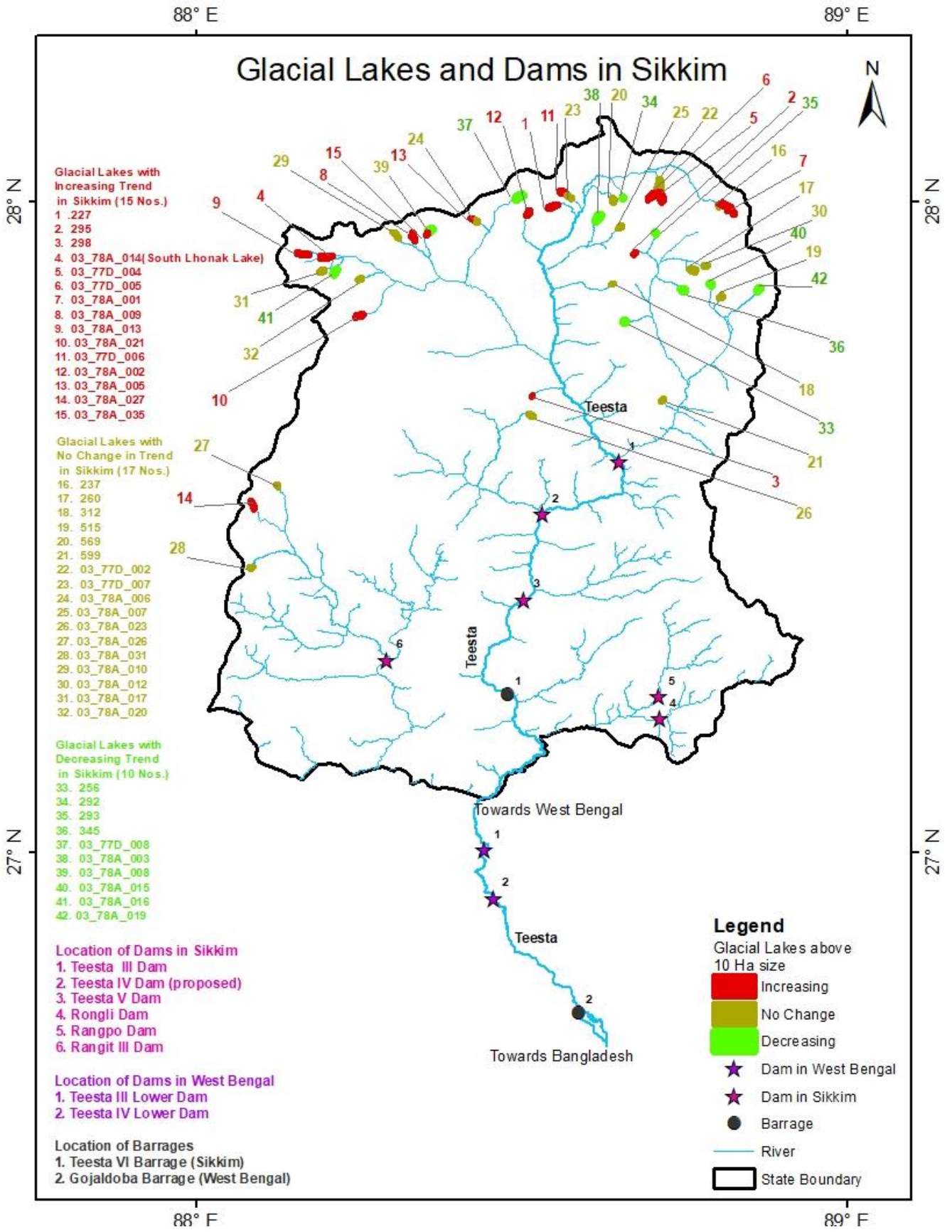
Further mapping of settlements, various infrastructures are in progress.

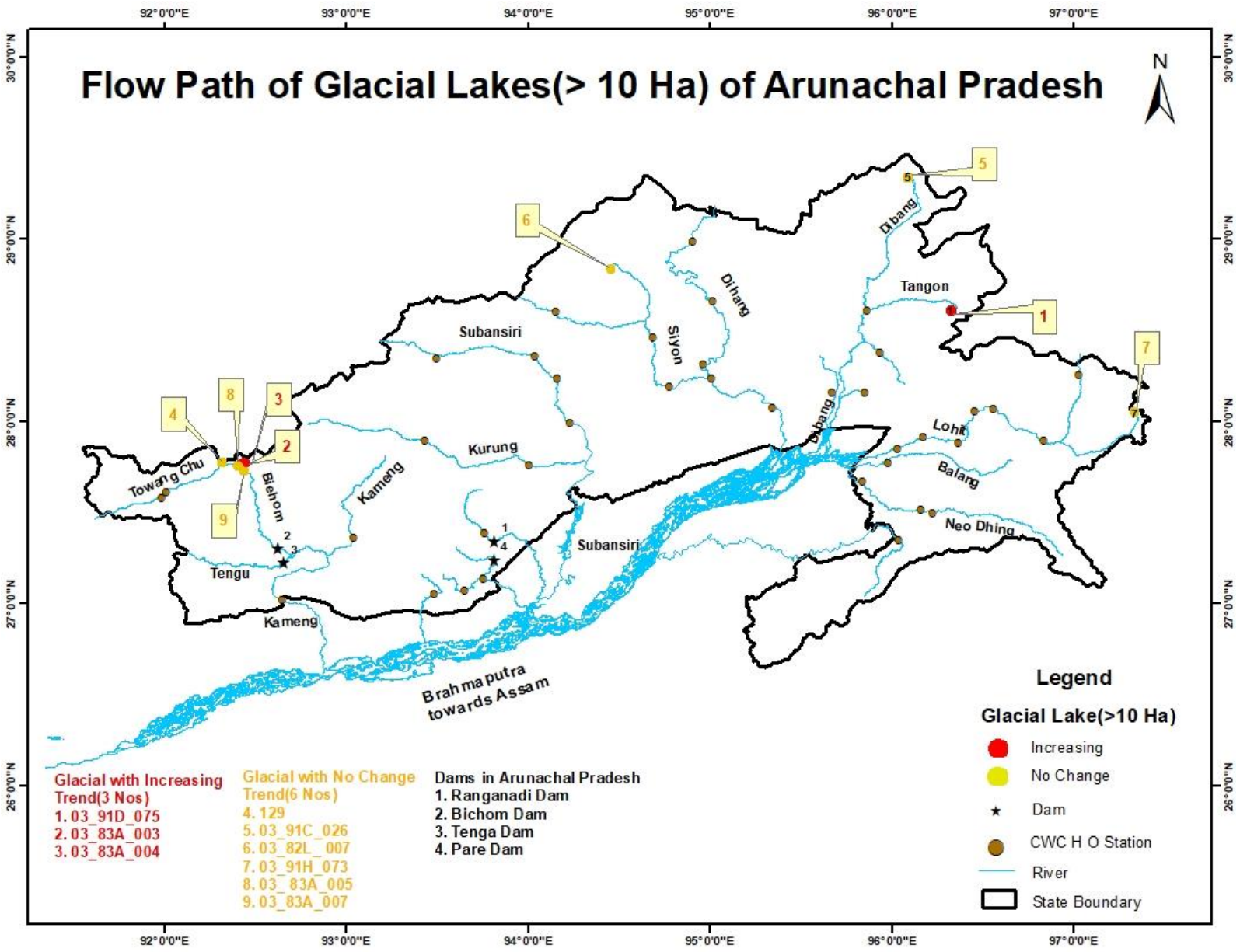

Flow Path of Glacial Lakes(> 10 Ha) of Ladakh
N
Gilgit
Indus
Indus towards Pakistan
Indus
Shyok
Shyok
Karche
Zanskar
Indus
Indus from TAR
Text
Glacial with Increasing Trend(4 Nos)
1. 1360
2. 01_52C_003
3. 01_42H_002
4. 01_52C_001
Glacial with No Chang Trend(7 Nos)
5. 173
6. 180
7. 01_52J_001
8. 01_52B_010
9. 01_52B_012
10. 01_52L_006
11. 01_52L_007
Glacial with Decreasing Trend(4 Nos)
12. 01_52E_001
13. 01_52A_002
14. 01_52A_003
15. 01_52A_004
Dams in Laddakh
1. Nimoo Bazgo Dam
Legend
GL(> 10 Ha)
Increasing
Decreasing
No Change
Dam
CWC HO Stations
River
State Boundary


Flow Path of Glacial Lakes (> 10 Ha) of Jammu & Kashmir
N
74°0'0"E
75°0'0"E
76°0'0"E
35°0'0"N
34°0'0"N
33°0'0"N
32°0'0"N
Kishanganga
Jhelum
Jhelum
Jhelum
towards Pakistan
Chenab
Chenab
Chenab
Glacial with Increasing Trend (5 Nos)
1. 27
2. 98
3. 958
4. 963
5. 01_52C_002
Glacial with No ChangeTrend (6 Nos)
6. 182
7. 931
8. 951
9. 976
10. 1032
11. 1037
Glacial with decreasing Trend (4 Nos)
12. 928
13. 993
14.1014
15. 01_43J_003
Dams of Jammu & Kashmir
1. Uri II-Dam
2. Pakal Dul Dam
3. Salal (Rockfill and Corncrete) Dam
4. Sewa St II Dam
5. Dulhas ti Dam
6. Baglihar Dam
7. Kishenganga Dam
8. Ranjit Sagar Dam
9. Niu Karewa Storage Yusmarg Dam
10. Gujar Nar Dam
Legend
Glacial Lakes (>10 Ha)
Decreasing Trend
Increasing Trend
No Change Trend
Dam
CWC HO Stations
River
State Boundary


Flow Path of Glacial Lakes(> 10 Ha) of Himachal Pradesh
N
Glacial with Increasing Trend(6 Nos)
1. 1805
2. 1847
3. 01_52H_004
4. 01_52H_002
5. 01_52H_003
6. 01_53I_002
Glacial with No Chang Trend(3 Nos)
7. 1774
8. 1936
9. 1998
Glacial with Decreasing Trend(1 No.)
10. 2031
Dams in Himachal Pradesh
1.Baira Siul Dam
2. Pong Dam
3. Nathpa Jhakri (Sjvnl) Dam
4. Chamera I Dam
5. Chamera II Dam
6. Chamera III Dam
7. Malana I Dam
8. Karchham-Wangtoo Dam
9. Bassi Dam
10.Ichari Dam
11.Bhakra Dam
12.Parbati II Dam
13.Sawra - Kuddu Dam
14.Kol Dam
15. Largi Dam
16.Pandoh Dam
17.Parbati III Dam
18. Malana II Dam
19. Bajoli Holi (Hpseb) Dam
20.Luhri (Sjvnl) Dam
21.Allain Barrage
22.Budhil Dam
23.Renukaji Dam
Chenab
Ravi
Beas
Satluj
Spiti
Yamuna
towards Punjab
towards Hariyana
Legend
Glacial Lake(>10 Ha)
Decreasing
Increasing
No Change
Dam
CWC HO Station
River
State Boundary
75°0'0"E
76°0'0"E
77°0'0"E
78°0'0"E
79°0'0"E
33°0'0"N
32°0'0"N
31°0'0"N


Flow Path of Glacial Lakes(> 10ha) of Uttarakhand
N
77°0'0"E
78°0'0"E
79°0'0"E
80°0'0"E
81°0'0"E
31°0'0"N
30°0'0"N
29°0'0"N
Glacial Lakes with Increasing Trend (1No.)
1. 02_62B_005
Glacial Lakes with No Change Trend(5 Nos.)
2. 2108
3. 2207
4. 02_53N_001
5. 02_62B_004
6. 01_62B_003
Glacial Lakes with Decreasing Trend (1No.)
7. 2147
Glacial Lakes with No Analysis
8. 02_62B_007
9. 2299
Location of Dams
1. Baigul Dam
2. Lakhwar Dam
3. Nanak Sagar Dam
4. Bhimtal Dam
5. Koteshwar Dam
6. Maneri Dam
7. Dhora Dam
8. Tehri Dam
9. Tumaria Dam
10. Jamrani Dam
11. Afzalgarg Dam
12. Ramganga Dam
13. Dhauliganga Dam
14. Haripura Dam
15. Baur Dam
16. Vishnuprayag (Jaypee)
17. Srinagar
18. Vyasi (Ujvn)
19. Rambara
20. Vishnu Gad Pipalkoti Hep
21. Kishau Dam
Towards Uttar Pradesh
Towards Uttar Pradesh
Towards Uttar Pradesh
Towards Uttar Pradesh
Yamuna
Tons
Alaknanda
Dhauliganga
Pindar
Gori Ganga
Ganga
Ramganga
Saryu
Kosi
Sarda
Legend
Glacial Lakes(>10Ha)
Increasing Trend
No Change Trend
Decreasing Trend
No Analysis
Dam
CWC HO Stations
River
State Boundary


Glacial Lakes and Dams in Sikkim
88° E
89° E
28° N
27° N
N
Glacial Lakes with Increasing Trend in Sikkim (15 Nos.)
1 .227
2. 295
3. 298
4. 03_78A_014(South Lhonak Lake)
5. 03_77D_004
6. 03_77D_005
7. 03_78A_001
8. 03_78A_009
9. 03_78A_013
10. 03_78A_021
11. 03_77D_006
12. 03_78A_002
13. 03_78A_005
14. 03_78A_027
15. 03_78A_035
Glacial Lakes with No Change in Trend in Sikkim (17 Nos.)
16. 237
17. 260
18. 312
19. 515
20. 569
21. 599
22. 03_77D_002
23. 03_77D_007
24. 03_78A_006
25. 03_78A_007
26. 03_78A_023
27. 03_78A_026
28. 03_78A_031
29. 03_78A_010
30. 03_78A_012
31. 03_78A_017
32. 03_78A_020
Glacial Lakes with Decreasing Trend in Sikkim (10 Nos.)
33. 256
34. 292
35. 293
36. 345
37. 03_77D_008
38. 03_78A_003
39. 03_78A_008
40. 03_78A_015
41. 03_78A_016
42. 03_78A_019
Location of Dams in Sikkim
1. Teesta III Dam
2. Teesta IV Dam (proposed)
3. Teesta V Dam
4. Rongli Dam
5. Rangpo Dam
6. Rangit III Dam
Location of Dams in West Bengal
1. Teesta III Lower Dam
2. Teesta IV Lower Dam
Location of Barrages
1. Teesta VI Barrage (Sikkim)
2. Gojaldoba Barrage (West Bengal)
Teesta
Towards West Bengal
Towards Bangladesh
Legend
Glacial Lakes above 10 Ha size
Increasing
No Change
Decreasing
Dam in West Bengal
Dam in Sikkim
Barrage
River
State Boundary


Flow Path of Glacial Lakes(> 10 Ha) of Arunachal Pradesh
N
92°0'0"E
93°0'0"E
94°0'0"E
95°0'0"E
96°0'0"E
97°0'0"E
30°0'0"N
29°0'0"N
28°0'0"N
27°0'0"N
26°0'0"N
Subansiri
Kurung
Kameng
Tengu
Towang Chu
Bichom
Siyon
Dihang
Dibang
Tangon
Lohit
Lohit
Balang
Neo Dhing
Brahmaputra towards Assam
Glacial with Increasing Trend(3 Nos)
1. 03_91D_075
2. 03_83A_003
3. 03_83A_004
Glacial with No Change Trend(6 Nos)
4. 129
5. 03_91C_026
6. 03_82L_007
7. 03_91H_073
8. 03_83A_005
9. 03_83A_007
Dams in Arunachal Pradesh
1. Ranganadi Dam
2. Bichom Dam
3. Tenga Dam
4. Pare Dam
Legend
Glacial Lake(>10 Ha)
Increasing
No Change
Dam
CWC H O Station
River
State Boundary

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