UNIVERSITY OF DELHI
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REGISTRAR

	55.	Dr. Seema Mehra Parihar, Associate Professor Dr. Satya Prakash Tripathi, Associate Professor Dr. Vandana Sarin Walia, Associate Professor	Kirori Mal College	Geography Mathematics Statistics

The Principal,
Kirori Mal College,
University Enclave,
Delhi-110007.

Subject: - Innovation Projects from Colleges, University of Delhi.

Dear Sir/Madam,

The scheme "Innovation Projects from Colleges" announced through a circular issued on January 23, 2012 attracted a large number of applications. You would be glad to know that the Innovation Project from your college, titled **"Mapping the Spatial Topology of two sub- glacier basins of NW Himalayan for multi class change detection using MODIS, Landsat and IRS data"** has been selected for support. You have been allotted Project Code No. **KMC – 105** and this may be referred to in all correspondence/reports on the subject.

The Hon'ble Vice Chancellor is pleased to release a grant of Rs. 5.0 Lakhs (Rupees Five Lakhs only) for the first phase which must begin immediately. The project duration is one year i.e. May 15, 2012 to May 14, 2013. Quarterly reports are to be submitted to the Dean Academics, University of Delhi through the mentor and the Principal of the College. A rigorous midterm review will be conducted by the University on the basis of which the second/final installment will be considered.

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The objective of the approved scheme for Innovation Projects is to encourage inter-disciplinary research inculcate research aptitude and skills and synergy among under-graduate students and faculty across the board. If the objective is not met and the project is not conducted according to the agreed guidelines, the second installment of the grant will not be released. The PI's will be responsible for following GFR & other government norms of expenditure.

The budget guidelines are as follows:

1.	Equipment / consumables	–	Rs. 3, 00,000/-
2.	Travel (i) local	–	Rs. 80,000/-
	(ii) Outside Delhi but within India	–	Rs. 1, 90,000/-
3.	Stipends	–	Rs. 1, 20,000/-
4.	Honorarium	–	Rs. 25,000/-
5.	Stationery / Printing	–	Rs. 1, 00,000/-
6.	Seminar/ final presentation	–	Rs. 85,000/-

- 50% amount in each of the above object heads is being released. Re-appropriation not exceeding 10% under each object head may be allowed in special circumstances by the College Principal under intimation to the Internal Audit Officer, University of Delhi.

Kindly acknowledge receipt of the letter and the grant.

With best wishes.

Yours sincerely,

REGISTRAR

Encl.: Cheque No. 360524 3/02/12 ₹ 45,00,000/-
(for Project Code No: KMC-101, KMC-102, KMC-103 KMC-104, KMC-105, KMC-106, KMC-107, KMC-108, KMC-109)

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MAPPING OF GLACIERS SENSITIVITY SPATIAL TOPOLOGY IN NORTH-WEST HIMALAYA USING SPATIAL MODELING

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ABSTRACT: The Study aimed to observe the changes in the glacier post "Himalayan-Tsunami" flood in Uttarakhand region during June 2013, which proved to be a catastrophe for the region, and its effect on Glacier Area Coverage, surrounding Vegetation cover classes and Surface Temperature.

In this study, for reliable mapping of the changes in Glacial region and its surrounding vegetation area, Remote Sensing data derived parameters like statistical measures of ground correlated spatial values NDSI(Normalized Difference Snow Index), changes in the land cover class area, temperatures variation during both Pre-Monsoon and Post-Monsoon (Summer and Winter Season) for more than one decade of data was analyzed. Spatial Modeling was used to semi-automate the process to get the desired output. Parallel analysis using surrounding pixels was used to determine various parameters NDVI (Normalized Difference Vegetation Index), NDVI-categorization for vegetation class. Land surface temperature is also undertaken for the study using temporal images for more than a decade.

Acquisition of Remote sensing data was done from the satellite sensors Landsat TM5 (Thematic Mapper 5) and ETM+ (Enhanced Thematic Mapper plus), MODIS (Moderate Resolution Imaging Spectroradiometer) Terra 11A1, Survey of India toposheet 1:50000 Scale for demarcation of AOI (Area of Interest), collection of ground control points using field survey. Atmospheric correction was applied on Raw Image Data to get normalized reflectance value after considering the correction for Solar Elevation and Solar Distance, and sensor energy calibration measures (LMax/LMin and Bais/Gain in reflectance value) was estimated. The indices NDSI was calculated using ratio of band Green and band SWIR for classifying snow bound areas. NDVI (Normalized Difference Vegetation Index) was calculated using ratio of band Red and band NIR for classifying forest classes using temporal data. ERDAS Spatial Modeler is used to semi-automate valued parameters to categories and create Snow-Ice map. MODIS Terra 11A1 monthly data for a decade was used to know land surface temperature and its sensitivity. Change detection was carried out using pre-monsoon and post-monsoon Landsat data for analysis on the basis of image classification, image difference and its region demarcation.
Sensitivity analysis observes the resultant changes occurred in terms of dimensions, temperature- statistic and land use and land cover on temporal datasets. In year 2013 post monsoon forest class decreased and same level of change was not observed during decade in snow- glacier region.

KEYWORDS: **Glacial Mapping, Spatial Modelling, Land Surface Temperature, Temperature changes at glaciers and forest class changes after *Himalayan-Tsunami* June2013 in Uttarakhand region.**

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1. INTRODUCTION: : Uttrakhand state, situated in Northern India is abode for the maximum part of North-western Himalayan range. The Great Himalayas considered to be sacred across various religions, contain many glaciers which are the birth place of various rivers such as Bhagirathi, Yamuna, etc. It has profoundly shaped the cultures and religions of South East Asia. The North-western part of The Himalayas is surrounded by Karakoram and Hindu Kush Ranges.

The flora and fauna of north-western part of the Himalayan Range vary with altitude, climate, rainfall, and type of soil. In order to identify the changes in forest classes, snow cover and glacier areas, an analysis was carried out during Pre-Monsoon (summer) and Post-Monsoon (winter) seasons for a period of 10 years. This analysis further assisted in providing an imperative understanding of changes in the Land Surface Temperature of the above mentioned region for the same duration of time.

During June 2013, Himalayan Flash floods in Uttarakhand, which happened to be the biggest catastrophe for the region, effected the surrounding vegetation cover class and surface temperature tremendously and adversely too. Its influence is exhibited by glaciers and snow cover also, in this region.

The figure I(a) below, shows the cloud over the North Indian region and figure I(b) i.e. Nasa's Tropical Rainfall Measuring Mission(TRMM) satellite image, shows estimated rainfall from 11 June 2013 till 17 June 2013.

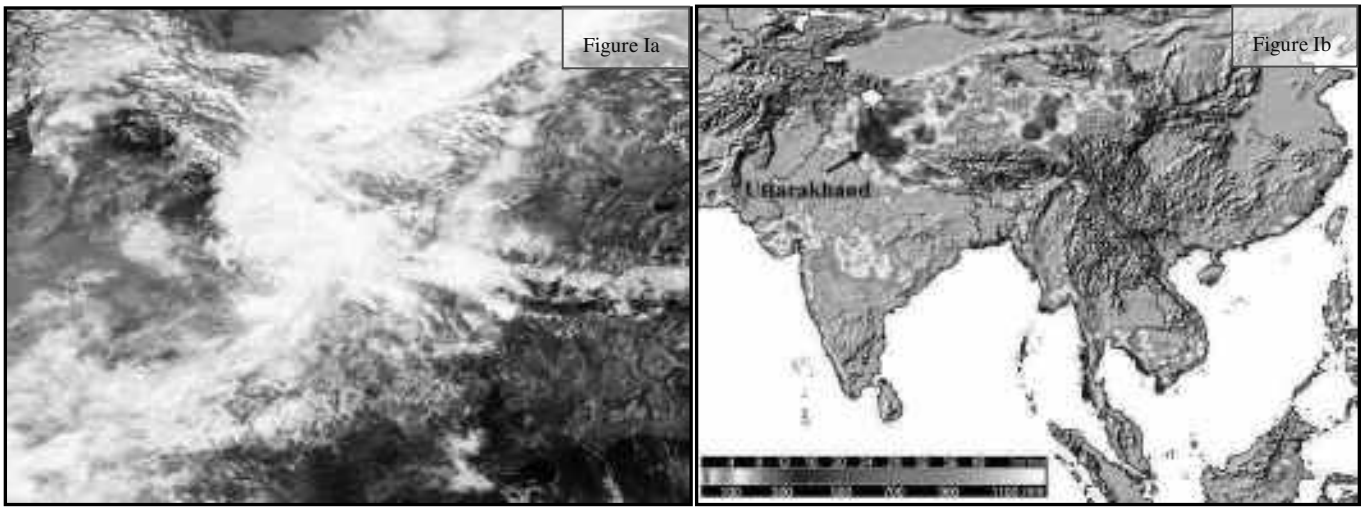


Figure I(a):NASA satellite imagery of Northern India on 17 June13.
Figure I(b): NASA Tropical Rainfall Measuring Mission, It shows estimated rainfall of seven days between 11-17June13. Image Credit: NASA

2. STUDY REGION: Study was undertaken over North-West Himalayan Glaciers Khatling which is located at an altitude of 3720m, Phatling glacier is at an altitude of 3722m.Surface temperature of Khatling and Phatling Glacier Minimum temperature is about -35 degree Celsius for both, Maximum temperature -12 and -9 degree Celsius was observed between during year 2001 to 2013. Study area consists both glaciers and 81*81 sq km of area upto tehri dam was taken as region. Area also falls into sub watersheds of Bhilangna River situated in Uttarakhand India at Latitude. 30.5^0 N and Longitude 79^0E. Bhilangana River is also a major stream of the drainage system which contributes to Bhagirathi River. Bhagirathi flows into the accumulation of Tehri dam for its renewable and recreational uses. It also gets its stream tributaries to Bal-Ganga at Ghansali point at an altitude of 970m. The Khatling and Phatling glaciers trek route passes along the Bhilangna River and its surrounding forests, nearest accessible road way point Ghuttu, which is approximately at a trekking distance of 6 Km and favorable timing to trek is only during the daytime.

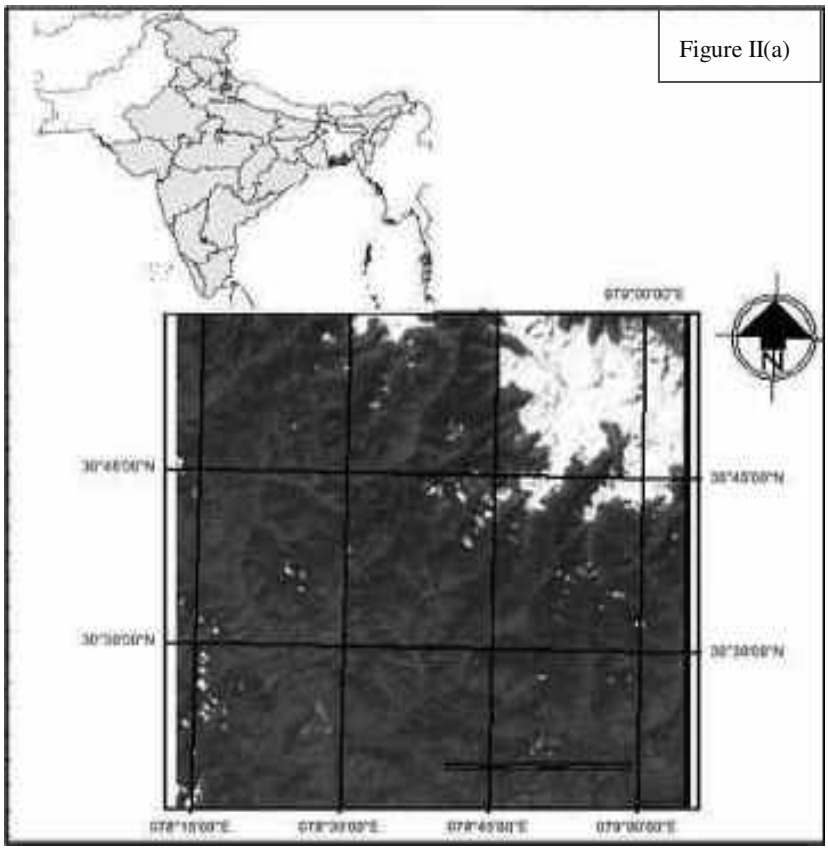


Figure II(a): Show location map of study region using Landsat image.

SNO	Data	Data Type	Temporal Period
1.	Landsat Images	Landsat TM5, Landsat ETM+, Landsat 8	Pre and Post Monsoon between 2002-2013
2.	MODIS	MODIS 11A1 Terra LST data	Jan2001 to Dec2013
3.	ASTER DEM	ASTER DEM 30 sq.m	
4.	Survey of India Topo-sheet	Traced Topo-sheet	Scale 1:50k
5.	GPS Receiver with WAAS	GPS Receiver Ground survey point	Validation and checking

Table I: Data Sources Used

3. METHODOLOGY: Topographical data of scale 1:50K from Survey of India map was used to trace and demarcate the area of interest for Glacier regions. It was also used to compare the changes in various temporal Landsat data of Pre-Monsoon and Post-Monsoon and MODIS Terra 11A1 monthly temporal data for land surface temperature calculation. Geo-correction of data was done by using ground surveyed control points and images in correlation with each other.

Geo-rectification was done as to co-register all the different satellite data (Landsat satellite data, in particular Landsat8, 7ETM+, TM5). Ortho-rectification was carried out on landsat data using Aster DEM. Landsat 7ETM+ data was found to contain noise in their bands, and the noise was removed using the verifiable gap filling technique using input of same season data and then the data was enhanced using Min-Max stretch technique under Erdas Imagine. Enhancement technique has also been applied onto the images to fill the gap and make the imagery seamless. Atmospheric correction was applied on raw image data to get reflectance value on the basis of Solar elevation, Solar distance, LMax/LMin and Bais/Gain reflectance value estimated (Markham and Barker, 1992).

Landsat Images were radiometrically corrected for conversion of DN to radiance using gain and offset information of sensor Meta data file supplied along with zipped file. Spatial modeler was used to run radiance model. Then Radiance value get converted to reflectance value using solar zenith and sun distance seasonal value available in Landsat user manual using spatial modeler. Reflectance value images used for analysis and sensitivity value calculation.

The MODIS 11A1 LST image product at .928km by .928km spatial resolution gridded in to integerized sinusoidal projection. A tile contain 1200 by 1200 grids with a swath of 1114 square-km. The SDS (Scientific Data Sets) in the MODIS product MOD11A1 product includes details of daily daytime 1km grid land surface temperature (LST_DAY_1KM), quality control of day time(QC_Day),Time of day time Land surface temperature observation(Day_View_Time), View Zenith angle of daytime land surface temperature (Day_View_Angle), Emissivity, Clear_day_coverage and scale factor, others. To convert Pixel DN reflectance to temperature used to convert LST_Day_1km scale value to temperature kelvin value.

Image analysis on Landsat Pre-processed images is used for calculating band indices on Pre-monsoon and Post-monsoon images. NDSI (Normalized Difference Snow Index) Dozier, 1989 Hall et.al. (1995) value was calculated using ratio of band Green and band SWIR. NDVI (Normalized Difference Vegetation Index) value was calculated using ratio value of band Red and band NIR, which is categorized to classify forest classes on temporal images. MODIS images h25v5 region was projected and processed for calculating day land surface temperature of glaciers.

Demarcation Area of interest for Glacier region was digitized using traced Topographic map scale 1:50k surveyed in decade 1980. Area calculated for glacier region and forest classes on temporal data is shown in form of graphs. MODIS data was used for surface temperature calculation to draw the changes in glacial temperature after the ill-fated flood during June 2013 in Uttarakhand region.

METHODOLOGY

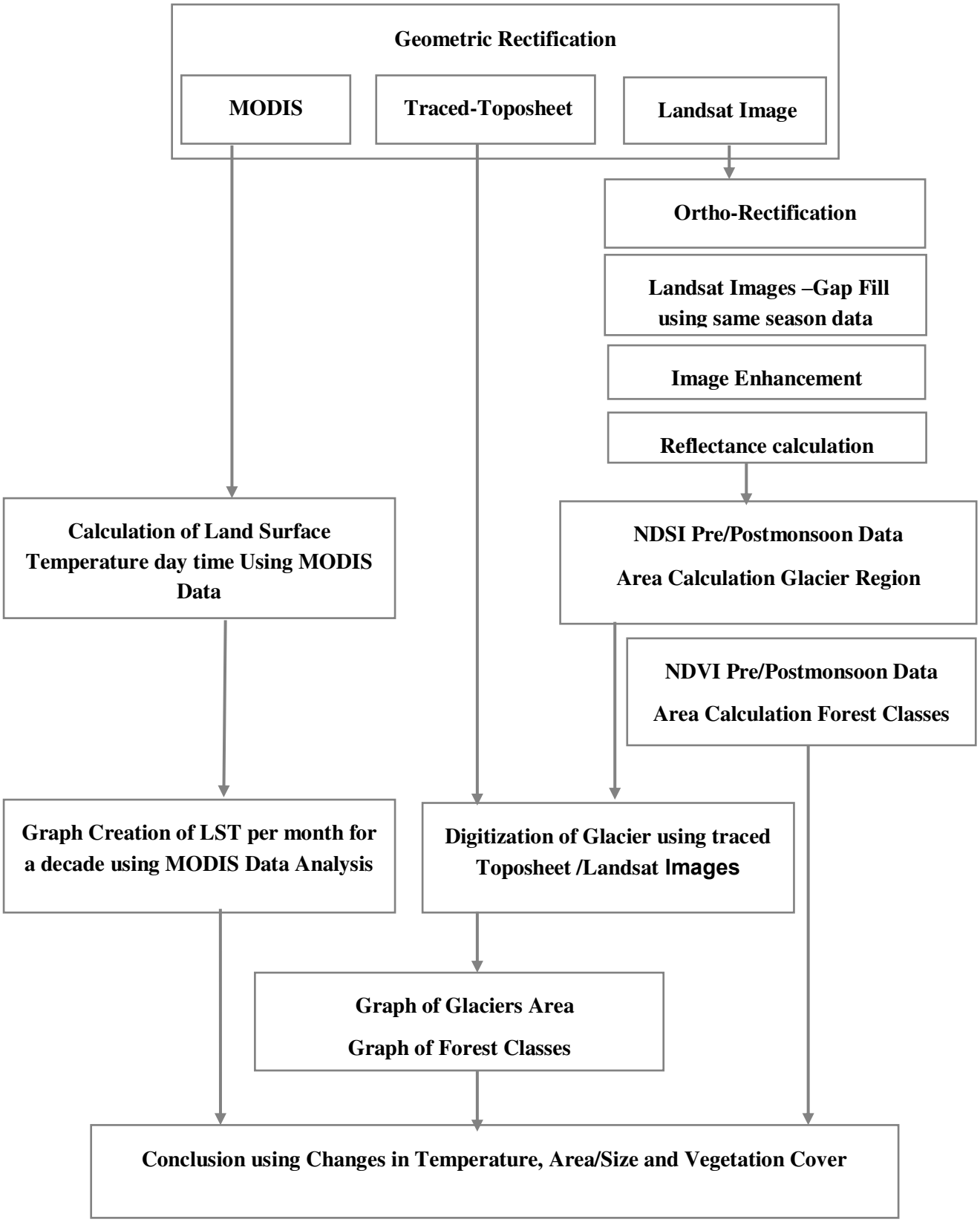


Figure III(a): MGSST

3.1 SPATIAL MODELLING: Spatial Modeling was used to automate the process of creating output using various temporal data sets.

SNO.	Data used at a time	Formula	Remarks
1.	Subset of Landsat Data	Either("Images")IF("Glaciers.shp"=True),Other wise =0	Subset Images.
2.	Landsat Images	NDSI=(Band(G)-Band(Swir))/ (Band(G)+Band(Swir))	Normalised Differential Snow Index
3.	NDSI Categorized output	Glacier =(NDSI>=0.4)	Glacier demarcation
4.	Landsat Images	NDVI=(Band(NIR)-Band(R))/ (Band(NIR)+Band(R))	Normalized Differential Vegetation Index
5.	NDVI Categorized output	Open Forest =(0.1-0.3), Forest=(>0.3)	Forest Classes

Table II: Spatial Modeler Formula and Data used

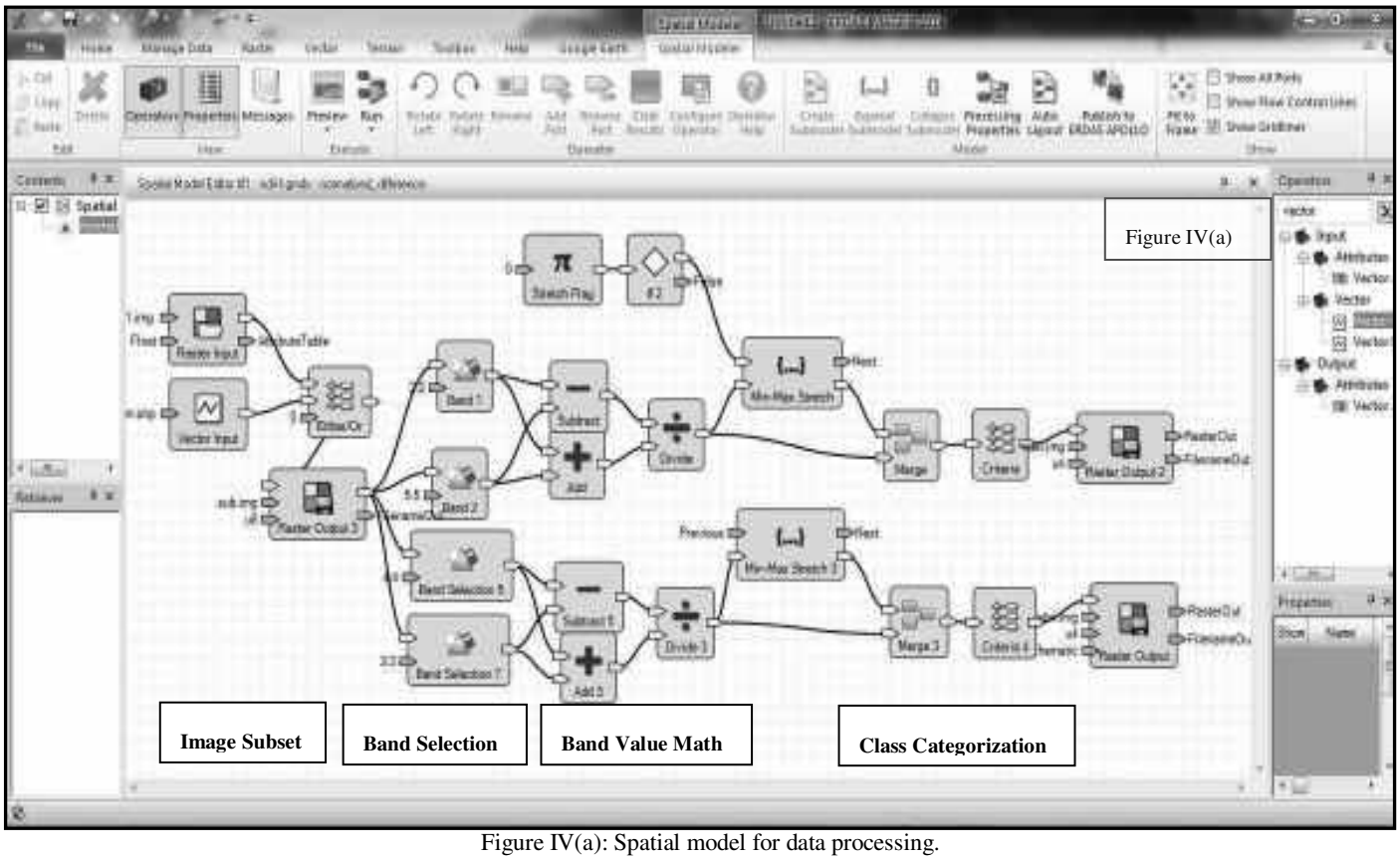


Figure IV(a): Spatial model for data processing.

4. RESULTS ANALYSIS: Space borne satellite data was acquired for more than a decadal year to derive the sensitive statistical values to understand trend of Land Surface Temperature using MODIS 11A1 of around thirteen years monthly-wise data between 2001 to 2013 and Landsat data used for thirteen years to derive forest classes using band indices NDVI categorized value and other band indices NDSI to derive categorized Glacier area.

MODIS image data for glacier studies are collected for temporal month-wise data, where the glacier region are covered with clouds have nil value for LST band then value it get averaged for Pre-Monsoon season values and Post-Monsoon season used to show in the graph depicted below to understand the correct trend of Land surface temperature.

Graph is created using MODIS 11A1 LST value and cloud covered season value gets used average Pre-Monsoon season and Post-Monsoon season value to average out nil value.

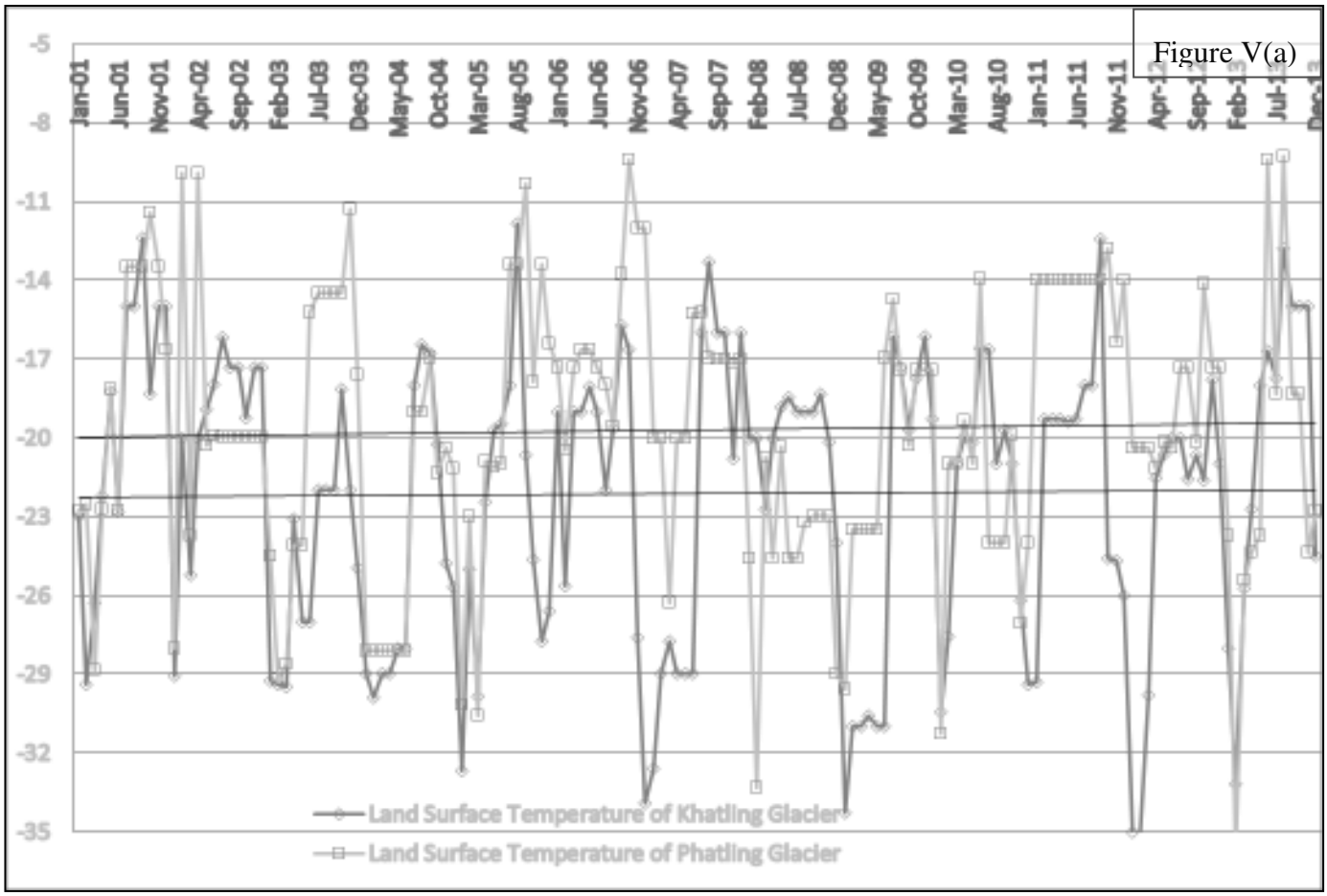


Figure V(a): Graph of MODIS 11A1 LST for Khatling and Phatling Glaciers temperature Celsius between Jan2001-Dec2013

Landsat images shown below for year 2013 date 26 May2013 and 16 July2013 and trace toposheet demarcated area of Khatling and Phatling glaciers shown as to know the changes in snout and area of glaciers.

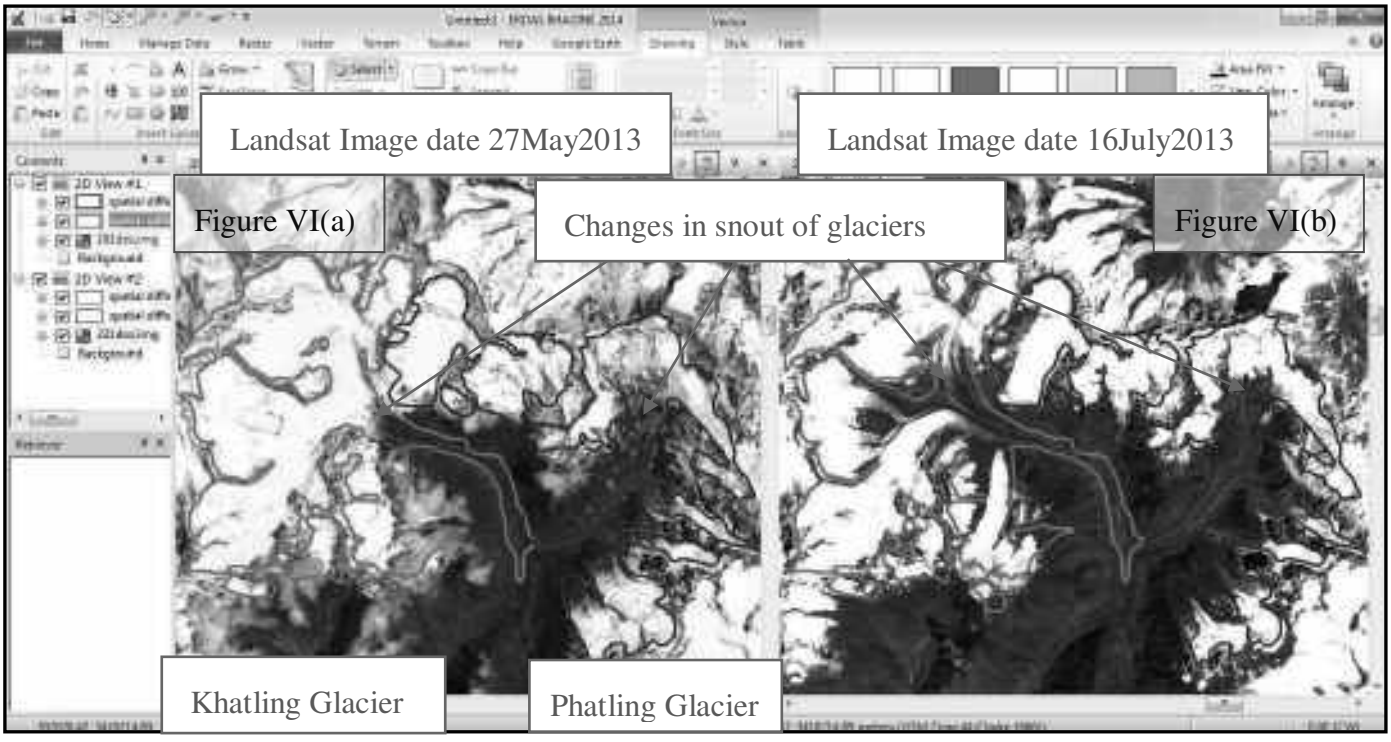
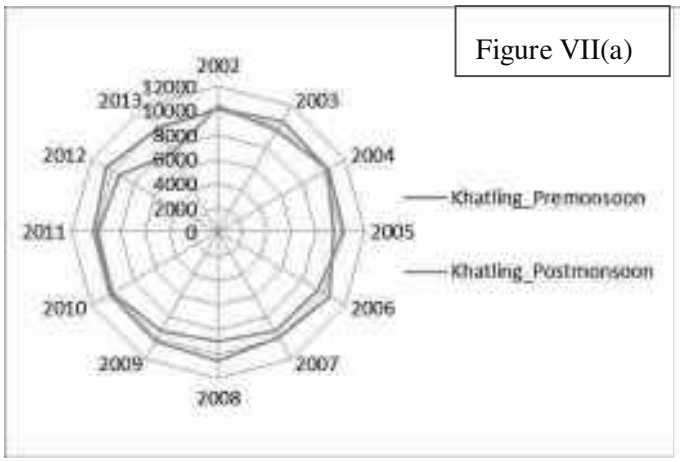


Figure VI(a)&VI(b): Snow Area change in Khatling and Phlatling Glaciers before image 27May2013 and after image 16July2013 Landsat image.

Figure VI: Landsat images band ratio NDSI images value above 0.4 considered as glaciers area and then checked at ground at few locations points using GPS (Ground Positioning System) receivers



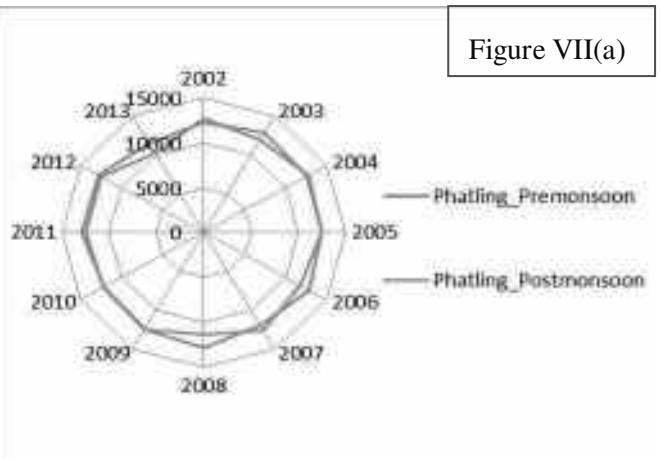


Figure VII(a): Glacier Cover Area season wise for Khatling Glacier in Hectare.
Figure VII(b): Glacier Cover Area season wise for Phatling Glacier in unit Hectare.

Another band Ratio NDVI categorized value between 01. to 0.3 was grouped into Open Forest class and value above 0.4 was grouped to be considered as Forest class.

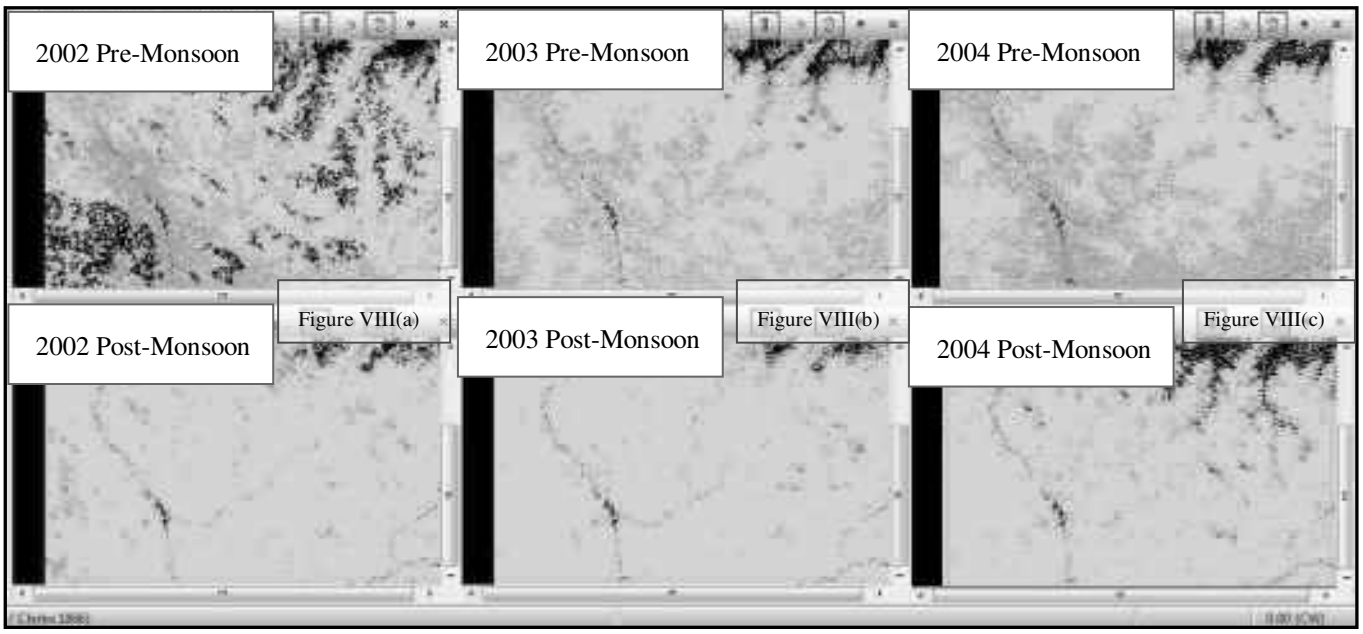


Figure VIII(a), VIII(b), VIII(c): showing forest class of Pre-Monsson and Post-Monsson of year 2002, 2003, 2004 respectively.

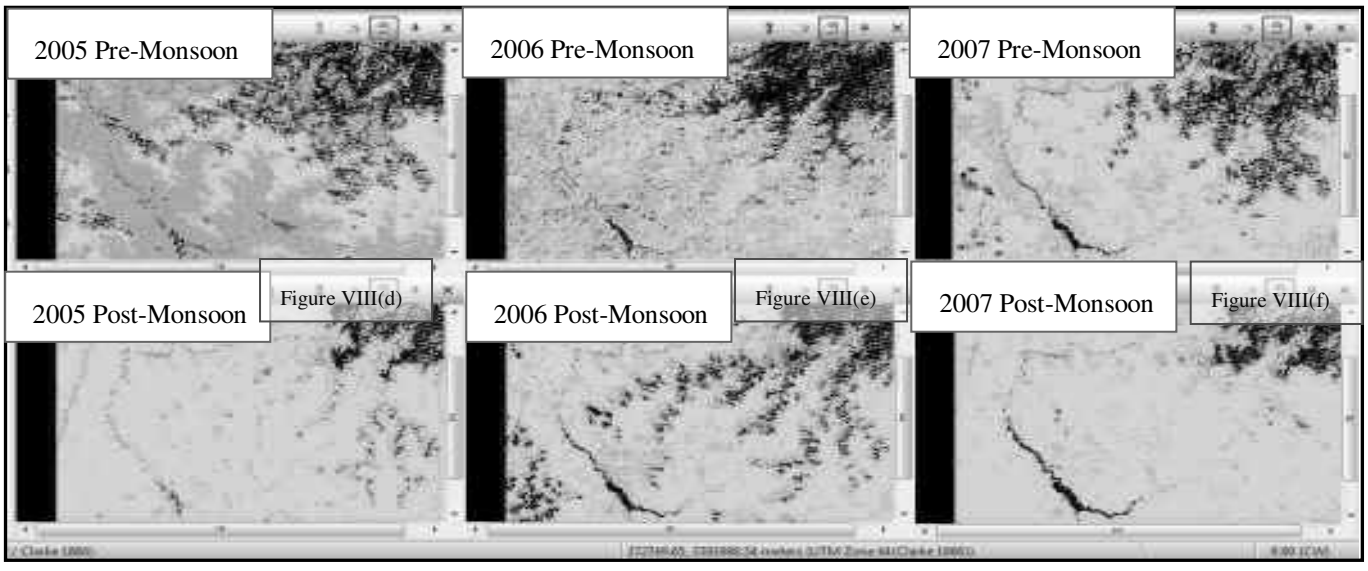


Figure VIII(d), VIII(e), VIII(f): showing forest class of Pre-Monsson and Post-Monsson of year 2005, 2006, 2007 respectively.

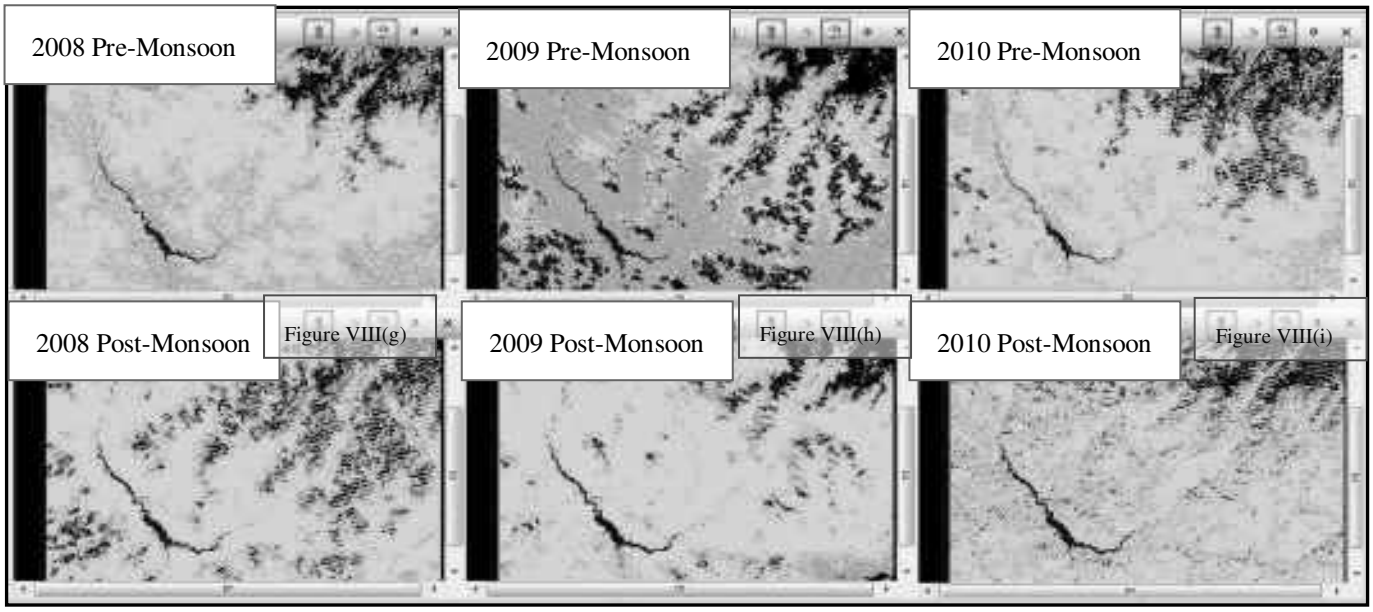


Figure VIII(g), VIII(h), VIII(i): showing forest class of Pre-Monsson and PostMonsson of year 2008, 2009, 2010 respectively.

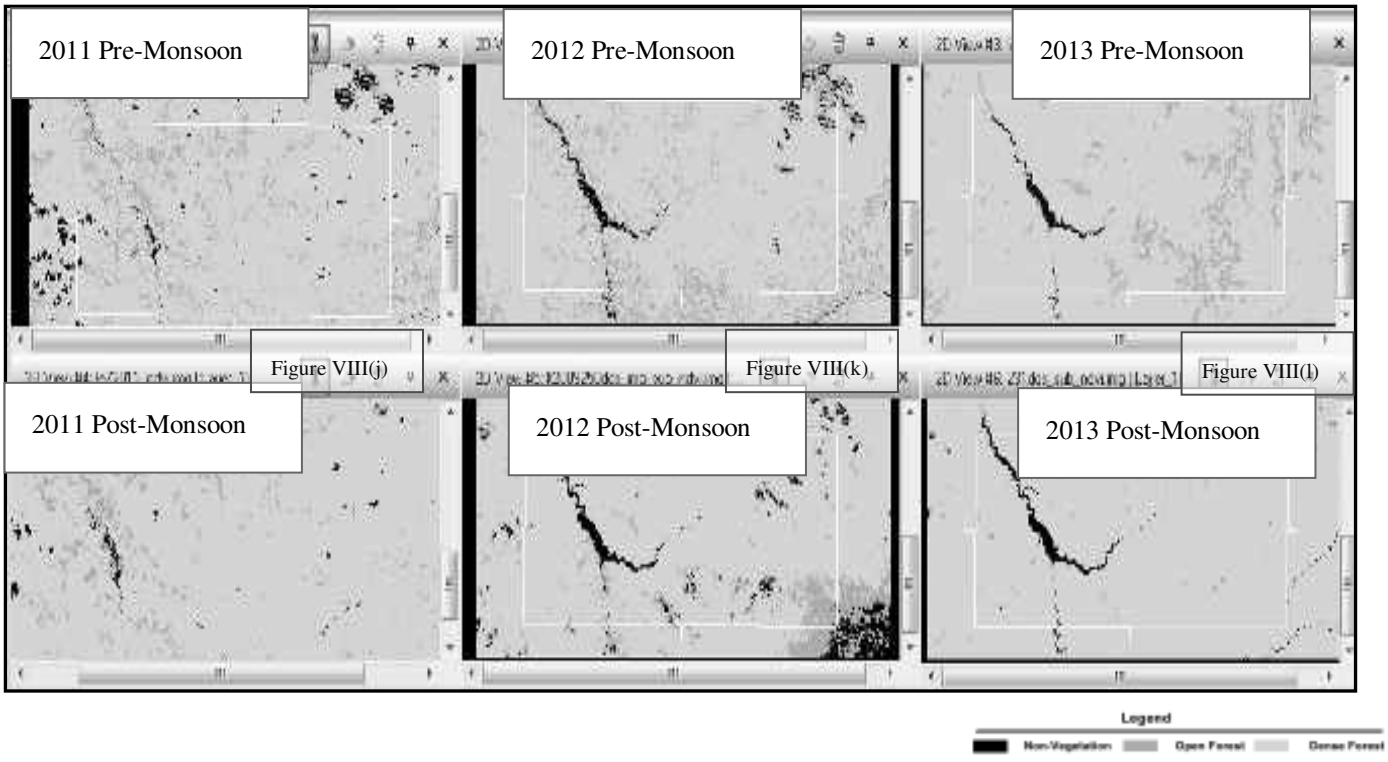


Figure VIII(j), VIII(k), VIII(l) showing forest class of Pre-Monsoon and Post-Monsoon of year 2011, 2012, 2013 respectively.

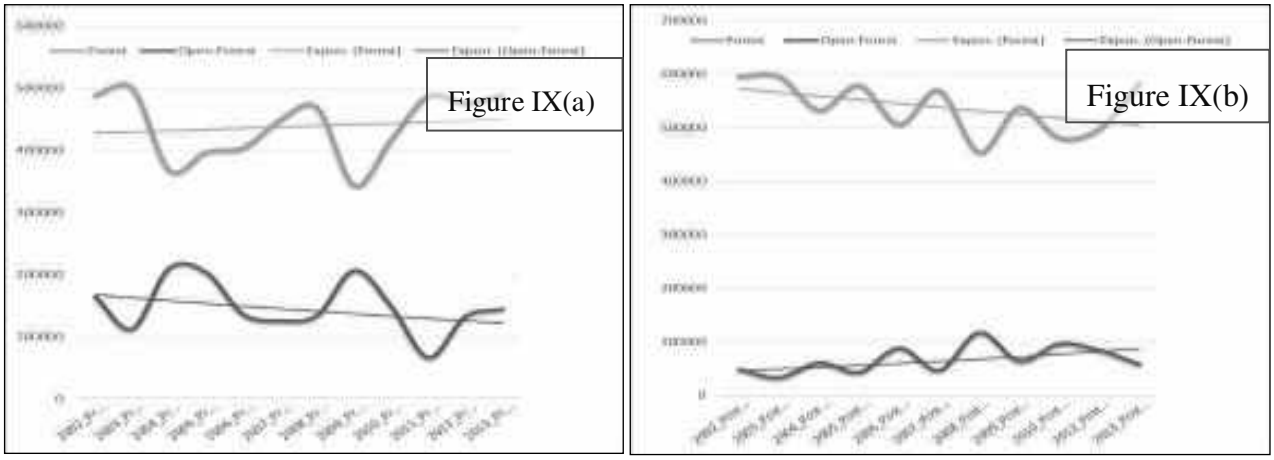


Figure IX(a), IX(b): Landsat NDVI value based Open Forest and Forest Classes for Pre-Monsoon and Post-Monsoon data y axis values in Hectares.

4.1 VALIDATION AND CROSS CHECKING OF DATA: The methodology adopted in this study and Spatial modeling results was tested for getting the output uniformly valued data which was validated by correlating with each other. All Landsat images are analyzed after image was converted from Raw DN value to calculated Reflectance value of Images, the reflectance image band ratio values used for analysis and class categorization. Landsat NDVI class categorized images of Pre-Monsoon and Post-Monsoon is used to get a comparison matrix for more than a decade for respective season values. Landsat NDSI Glacier class value was compared for both summer and winter season of respective seasonal values. Forest area get cross checked on the ground for year 2013 post monsoon season, forest trees are got uprooted due to landslides and due to heavy rainfall uprooted trees came into Tehri dam water reservoir area . Forest area get corrected form Tehri dam floating tree reservoir water area, then corrected new post monsoon forest cover get created as shown in figure V(b).

High-end GPS receivers dual channel with Wide Area Augmentation System (WAAS) enable were used for ground verification on Landsat data at reachable region through trekking near glaciers and vegetation areas.

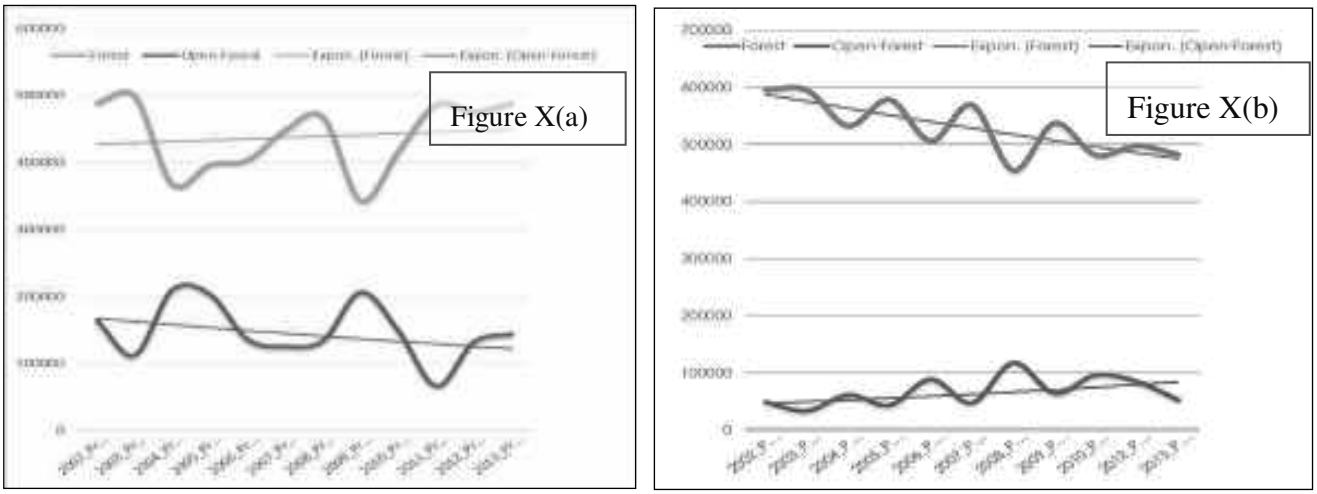


Figure X(a),X(b): Landsat NDVI value based Open Forest and Forest Classes for Pre-Monsoon and corrected Post-Monsoon data y axis values in Hectares.

5. CONCLUSIONS:

1. Result of Mapping of Vegetation area in the study region for Pre-Monsoon and Post-Monsoon data analysis of Landsat images temporal time period between 2002 - 2013.
   i. As using Pre-Monsoon and Post-Monsoon Forest class logarithmic exponential trend line created on the graph, which shows for Pre-Monsoon (data of months between April and May) open forest decrease and forest class in increasing trend. Post-Monsoon (data of months between August and September) Open forest area is on increasing trend and forest class area on to decreasing trend on logarithmic exponential trend scale, with reference to figure X(a),X(b).
   ii. Forest area during the period 2004 and 2009 year Pre-Monsoon season was converted to open forest and increase in open Forest area, all though Forest Area was decreased during the period as it was converting into open forest and density of vegetation get decreased, conclusion after comparing figures VIII(c),VIII(h) and X(a).
   iii. During period of year 2005 season Pre-Monsoon over all vegetation index was gets decreased.
   iv. Forest area during 2007 year Post-Monsoon season increased in forest class.
   v. As after analyzing Vegetation area cover during period of 2013 in Uttarakhand get ***"Himalayan-Tsunami"*** with heavy rainfall Pre-Monsoon (day 101), Pre-Monsoon (day 181) and Post-Monsoon (day 261) data observed that after Post-Monsoon forest cover was decreased, mainly into open forest area and total forest cover was decreased to its least area cover during 2002 -2013 year period (study taken on basis of canopy cover, derived result was also used for creating graph).
2. Land Surface temperature day time is determined using MODIS 11A1 Terra data of every month for fourteen year on glaciers Kathling and Phatling shown in figure X(a).
   i. As temperature was a Minimum mercury level during December to January month winter season and simultaneously Maximum mercury level June to September during summer season.
   ii. Trend analysis of temperature more over same and negative value hammered during at minimum mercury and during June and July 2013 both the glaciers have comparatively higher temperature.
   iii. While comparing the landsat data of temporal data it is observed approximately 18% of snow cover of glaciers Khatling and Phatling gets decreased in month of June 2013.

3. Overall impact on glaciers have small changes is demarcated of over period between 2001-2012 and in another year to year some advances, retreats are also observed. Study need to under taken for few decades to know environmental changes and its impact assessments.

ACKNOLWEDGEMENTS: We thank NASA/USGS Program.for providing ASTER DEM data and Landsat Image Data used in the paper at no cost. Dr.Harnam Singh, Dr S.P. Tripathi and Mr Rajdeep Choudhary are also acknowledged.

REFRENCES:

1. Albert, T.H., 2002, *Evaluation of remote sensing techniques for ice-area classification applied to the tropical Quelccaya ice cap, Peru.* Polar Geography, 26,210–226.
2. Adhikari, S. and Huybrechts, P., 2009, *Numerical mode ling of historical front variations and the 21st-century evolution of glacier AX010*, Nepal Himalaya; Annals of Glaciology, 50, 27-34
3. Arora, M., Goel, N. K. and Singh, P., 2005, *Evaluation of temperature trends over India*; Hydrological Sciences Journal 50, 81-93
4. Bhutiyani, M. R., Kale, V. S. and Pawar, N.J., 2007, *Long term trends in maximum, minimum and mean annual temperatures across the northwestern Himalaya during the twentieth century*; Climatic Change 85,159-177
5. Barry, R. G., 2002, *Mountain Climate change and cryosphere responses*: A review; World Mountain Symposium 2001
6. Bhambri, R. and Bolch, T., 2009, *Glacier mapping: a review with special reference to the Indian Himalayas. Progress in Physical Geography*, 33, 672–704.
7. Singh V. P., Haritashya, U. K. *Encyclopedia of Snow, Ice and Glaciers*
8. Fischer, L., Kääb, A., Huggel, C. and Noetzli, J., 2006, *Geology, glacier retreat and permafrost degradation as controlling factors of slope instabilities in a high-mountain rock wall: the Monte Rosa east face*. Natural Hazards and Earth System Sciences, 6, 761–772.
9. Gopal, S., Woodcock, C. E. & Strahler, A. H., 1999, *Fuzzy neural network classification of global land cover from a 1° AVHRR Data Set*. Remote Sens. Environ.67, 230–243.
10. Grubbs, F. E., 1969, *Procedures for detecting outlying observations in samples;* Technometric.11,13-14.
11. Grubbs, F. E., 1950, *Sample criteria for testing outlying observations*; Annals of Math. Statistics 21, 27-58
12. Hansen, J., Sato, M., Ruedy, R., Lo, K., David, W. L. and Martin, M. E., 2006, *Global temperature change*; PNAS103(39), 14288-14293
13. Hodges, R. J., Addo, S. and Birkinshaw, L., 2003, *Can observation of climate variables be used to predict the flight dispersal rates of Prostephanus truncates?;* Agricultural and Forest Entomology 5,123-135
14. Haboudane, D., Miller, J. R., Pattey, E., Zarco, T. P. J. & Strachan, I.B., 2004, *Hyperspectral vegetation indices and novel algorithms for predicting green LAI of crop canopies: modeling and validation in the context of precision agriculture*. Remote Sens. Environ.90, 337–352.
15. Kriegler, F.J., Malila, W.A., Nalepka, R.F., and Richardson, W., 1969, Preprocessing *transformations and their effects on multispectral recognition*. Proceedings of the Sixth International Symposium on Remote Sensing of Environment, 97-131.
16. Kulkarni, A.V., Bahuguna, I.M., Rathore, B.P., Singh, S.K., Randhawa, S.S., Kulkarni, A.V., Rathore, B.P., Mahajan, S. and Mathur, P., 2005, *Alarming retreat of Parbati glacier, Beas basin, Himachal Pradesh*. Current Science, 88, 1844–1849.
17. Kulkarni, A.V., Bahuguna, I.M., Rathore, B.P., Singh, S.K., Randhawa, S.S., Sood, R.K. and Dhar, S., 2007, *Glacial retreat in Himalaya using Indian remote sensing satellite data. Current Science*, 92, 69–74.
18. Philip, G. and Ravindran, K.V., 1998, *Glacial mapping using Landsat Thematic Mapper data: a case study in parts of Gangotri glacier, NW Himalayas*. Indian Journal of Remote Sensing, 26, 29–34.
19. Kulkarni, 2006, *Snow-and Glaciers-of-the-Himalayas* ISRO-SAC - 13th June
20. Shapiro, G. I., Aleynik, D. L. and Mee, L. D., 2010, *Long term trends in the sea surface temperature of the Black Sea*; Ocean Sci. 6, 491-501,
21. Sharma, K. P., Moore, B. and Vorosmarty, C.J., 2000, *Anthropogenic , climatic, and hydrologic trends in the Koshi Basin, Himalaya*; Climatic Change 47, 141-165
22. Sharma, U. K., Kajii, Y. and Akimoto, H., 2000, *Characterization of NMHCs in downtown urban center Kathmandu and rural site Nagarkot in Nepal.* Atmospheric Environment 34, 329-3307
23. Shrestha, A. B., Wake, C. P., Mayewski, P. A. and Dibb, J. E., 1999, *Maximum temperature trends in the Himalaya and its vicinity: An analysis based on temperature records from Nepal for the period 1971-94;* Journal of Climate 12, 2775-2786
24. Shrestha, A. B. and Aryal, R., 2010, *Climate Change in Nepal and its impact on Himalayan Glacier*; Reg Environ Change 10113-10174
25. Toutin, T., 2004, Review article: *geometric processing of remote sensing images: models, algorithms and methods*. International Journal of Remote Sensing, 25, 1893–1924.
26. User manual by *http://lpdaac.usgs.gov/products/modis_products_table/mod11a1* dated 01Jan2012.
27. Zevenberg, L.W. and Thorne, C.R., 1987, *Quantitative analysis of land surface topography*. Earth Surface Processes and Landforms, 12, 47–56.