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Impact of Climate Changes on Cryosphere in Suru-Zanskar Valley, Kargil: Observed Trends, and Socio-Economic Relvance

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It is a great honor and privilege to deliver the Prof. A. B. Mukerji Memorial lecture at IIG conference, Kurkshetra, Haryana. I am extremely grateful to Professor A. B. Mukerji family members and IIG for having provided an opportunity to share my experience on Cryosphere sciences with young geographers. My association with Prof A. B. Mukerji dates back to 1965, when I joined the Department of Geography, Panjab University, Chandigarh, as M.A student. Since then I have had an privilege of knowing Prof. Mukerji intimately as a teacher, research supervisor for my Ph.D dissertation, and above all as human being. It was Professor Mukerji who initiated me in field of research and teaching in geography. Prof. Mukerji was one of the top five geographers of the country with sharpest minds and most prodigious output of his generation. A great researcher and above all a renowned scholar of international repute during last five decades. He had love for field work and discerning eye for details to dig out past and formulate hunches. He envisaged the importance of empiricism and modeling techniques in field of physical and cultural geography. I have a great admiration on his commitment to this society and the discipline of geography more so his humanity with youngsters. I can only offer him my salutation today.

Therefore, I have accepted to deliver and share data on cryosphere of Suru-Zanskar Valley of Kargil for the benefit of young geographers, consonance with theme of the conference.

1. Cryosphere is frozen part that includes all permanent glaciers, seasonal snow and permafrost grounds. They are important water banks or dynamic reservoir of water exchanging mass with part of global hydrological system.

2. Ladakh is mostly heavily cryospheric region outside the polar area as it houses nearly 50% cryospheric area of India confined to protracted zones of High Himalaya-Karakorum, Zanskar- Ladakh ranges that contain some of the world's highest peaks and largest glaciers outside the polar region. It contains nearly 5000 glaciers encompassing glacier area of 31871km² and total ice volume of 815.62³km including largest Saichen

The lecture delivered as "Prof. A. B. Mukharji memorial lecture" at Kurukshetra University, Kurikshetra.

glacier-72km length. It is important water shed of Upper Indus river and is largest productive highland-lowland system supporting large population.

3. Kargil region has nearly 1796 glaciers of various sizes include small niche glaciers to as large as Drung Drung glacier. Suru Zanskar valley has 268 glaciers encompassing area 1221.km². Here I report the statusof cryosphere Suru- Zans kar valley for nearly 50 years (1965-2013) on remotely sensed volumetric changes of 300 glaciers housed in zanskar and Drassof higher Himalaya-karokorum monitored by multi temporal satellite images of 2001 and 2013 for short term basis and Survey of India topographic sheets of 1965 on long term basis. All the satellite images were georef red. Glacier boundaries and permafrost areas were delineated using normalized difference snow index and TM Band ratio ¾.

- ❖ Over a record period of 28 years there has been small increase in annual mean temperature at Drass of – 0.226°c/ per decade (prior 1995) to 0.375 °c/ per decade after 1996, there has been significant increase mean temperature during the winter season particularly late winter and early summer.
- ❖ Analysis of mean monthly temperature (Max. & Min.) trend line for a period of 28 years, lack of fit of lower portion of data (1988-2000) to upper portion data (2001-2013), attribute to phase transition threshold. It indicate early winter cooler, late winter warmer humid and summer cool and wet during time series 2001, 2013 in comparison to cold winters (Nov.-March), mild late winter (March-May) and warm and dry summer during 1988-2000.
- ❖ The monitoring of snouts of 300 glaciers in Himalaya – Karakorum of Suru-Zanskar and Drass valley for period of 2001-2013 with the help of satellite imageries reveal 83% glaciers are stable in their position, whereas 54% glaciers have shown no change in area during the period 1965-2001 ,confirming the behavior of climate changes since the year 2001.Further revealed that late winter warming has lead to shifting of permafrost line to higher altitude
- ❖ The recent climatic changes during the late winter season/early summer have resulted in increasing trend in summer precipitation and warming of temperature have encouraged the farmers to switch over to wheat cultivation from barley cultivation, in areas where soil is conducive for it's growth.
- ❖ In the adjoining mountainous region, where crop production ahs least feasibility, live stock rearing is a natural alternative supported by more conducive sub- arid cold climate during the summer season.
- ❖ The favorable summer condition has resulted to increase in area under cereal crops and marginal increase in fodder crop. Nearly 35% increase in cultivated land devoted to wheat cultivation, 20.5% increase in pasture land, 13.45% increase in fodder crop area and marginal increase in grim crop.

1. Introduction

The cryosphere as the frozen part of the world include all permanent and seasonal snow and ice deposits on the land as well frozen ground (perma-frost).It is the second largest component of climate system after ocean with regard to mass and heat capacity. They are dynamic reservoirs of constantly exchanging mass with parts of global hydrological system, process by which glaciers, permafrost areas gain or lose snow and ice and establish a link between climate, glacier mass and glacier fluvial dynamics related directly to the behaviour of climate. Here, I report on cryosphere status over the past 50 years (1965-2013) on remotely- sensed volumetric changes of ice and snow in Suru-Zanskar valley, Higher Himalaya. Ladakh is a most heavily glaciated region outside the polar area as it houses nearly 50% glaciers of India confined to protracted zones of High Himalaya-Karakorum ,Zanskar- Ladakh ranges that contain some of the world's highest peaks and largest glaciers outside the polar region. It contains nearly 5000 glaciers encompassing glacier area of 31871km^2 and total ice volume of 815.62km^3. The region mainly influenced by the air mass of Westerly's particularly Western disturbances during the winter season that results in snow cover extent in higher reaches and glacier melt water production in lower reaches lead to development of a watershed of the Indus. The Indus contributes a lot to Agrarian as well in Industrial economy of North India by providing perennial irrigation as well generating hydroelectric power. Variability of climate and its impact on glacier mass balance been reported from Alps and Rocky (Fujila, 2008, Bitz, and Battisti,1999, Bowling 1977; Brinkman and Barry 1972). However, conflicting signal of change in climate, in terms of change in temperature, snowfall and snow extent is reported from West Himalaya (Yadav et al. 2004; Fowler and Archer 2006; Bhutiyani et al. 2007; Koul and Ganjoo 2009). The studies have investigated the role of meteorological parameters in governing the snow cover extent and it has been found that annual change in glacier mass balance are largely due to winter and spring time anomalies in accumulation which in turn are mainly due to anomalies in precipitation and temperature (Letreguilly 1988,Kaul,1988).

The recent publication by Intergovernmental Panel on Climate Change in Fourth and Fifth Assessment report generated lot of debate about the status of Himalayan Glaciers. The present study is to understand how in having high relative relief that is cause of perturbation in ambient temperature generating katabatic winds in glacier valley do affect the extent and terminus of glacier valley. Therefore, we assess regional differences in extent of glaciers and perm-frost areas in Kargil glacier valley, Higher Himalaya from remotely measured glacier snout changes and glacier area changes between 1965 and 2013 and detailed field truth collected during 2011-2014 to assess overall behaviour of glaciers in the valley. Further, our objective is to determine if the glaciers in this valley at present behave in steady state phase and relate the same to present day climatic and other topo-climatic factors generated by high relative relief.

2. Regional Setting

The Kargil region forms a vast mountainous region between the Great Himalaya Range in the South-southwest and Indus Valley in the north- east and occupies southern part of Ladakh. It has nearly 1796 glaciers, confined in Upper Indus basin, housed in Zaskar, Suru and Drass valley. Zanskar-Suru basin has thirty six sub-basins, out of which nineteen sub-basin are glaciered, housing nearly 768 glaciers encompassing an area of 1221.43km^{2} (17.44% of total area).

Suru-Zanskar sub basin is the Vth order basin of IVth order Indus and it extends between the Suru-Zanskar (close to Pensila-La) in the west to Padam in the east (fig 1: see page 19). Panzila-La is gateway to Zanskar valley, situated on road connecting Kargil, with Padam (head quarter of Zanskar). The Panzila-Padam road remains closed to vehicular traffic during winter season due to closure of Panzila-La pass as result of heavy snowfall. Zanskar valley is encircled by ridge crusts of higher peaks (3450-6270m) of Himalaya studded with large glaciers, namely Haptal, Yaranchu, Shimling, Mulung, Kanthang, Denya, Durungdrung and others and their ridges descend precipitously. The study region is a tri-armed valley system lying between Great Himalaya and Zanskar Mountain. The three arms radiate star like towards the west, north, and south to form wide central expanse where regions two principal drainages Suru and (Lugnug and Stod) meet to form the main Zanskar .The magnitude of high relief and overall steepness of slopes provide an overwhelming impression that region has distinct climatic condition between that of Central Asia and monsoon land of South Asia

The valley contains some of the highest and steepest mountain slopes. The relative relief of main valley is rarely less than 2500m; even the tributaries have elevation difference of 2000m in a horizontal distance of 2 to 4 km. Valley walls are covered with rills, gullies, and mud channels. Massive debris slopes covered with screed gradually merge with fans, low terraces, valley fills and channel gravels on the floor of the valley. Three glacio-fluvial terraces are differentiated in the Zanskar Valley along its mountain rim, their elevation ranges from 3300 to 3500m, 3500 to 3800m,and 4000 to 4200m. Physiographic ally, Suru-Zanskar is a region of great inequality, having Great Himalayan flank, Zanskar Upland Mountain, Mountain rim and rolling basin floor (Koul and Raina 2011)

Zanskar valley is represented by the rocks of Central Crystalline, Phe Formation and Purple Formation. Most of the south, southwest and west part of the valley is represented by Central Crystalline rocks consisting of crystalline schist, stratified migmatites, porphyritic granites, gneisses and feldspathic quartz-muscovite-biotite schist often garneferous. The rocks are intricately folded into flextures slips, recumbent and disharmonic folds.

Suru-Zanskar valley has a distinct climatic characteristic due to its location in the shadow zone of Great Himalaya having an aerodynamic link with the air mass of westerly air flow and westerly disturbances (originating from Mediterranean and Caspian ocean) moving aloft the Pamir Range. The air mass develops cold high air pressure at higher altitude that ultimately sinks to lower altitude giving rise to cold anticyclone leading to production of thermal gradient during winter season (October to May) that is responsible for anchoring southerly jet. The study region has cold sub arid type of climate. The winters are long chilly (mean minimum temperature -15°C to-35°C), lasting November to May. Summers are short (June to September) mild (temperature varies between - 8°C to 25°C) .Nearly 72% of its annual precipitation is received by Western Disturbances that is confined to November to May which sometimes prolongs to summers as well otherwise summers get scanty rains.

3. Methods

Most of the glaciers in Suru-Zanskar valley is located in remote and treacherous terrain that is inaccessible and not connected with motor able road. The monitoring of glaciers is difficult by direct field methods .Remote Sensing has advantage of giving synoptic view of the region on regular basis. The IRS-IC- LISS III (October, 2001 and 2013) data was provided for Suru basin by Space Application Centre (SAC) at pixel resolution of 23.5m for the detailed study. The base map of the area was prepared from Survey of India (SOI) 1965 topographic maps of the scale 1:50000. Only seven topographic sheets of Suru basin were available that covered 148 glaciers out of these 96 glaciers (>0.5km²) selected for detail study. All the satellite images were geo-referenced using SOI topographic maps. Images co-registered with each other resembled to same resolution. The glacier boundaries were delineated using topographic maps and the area was digitized using topographic Geographic Information system. The boundaries of glaciers delineated by visual interpretations and manual techniques using GIS False colour made from visible and near infra red satellite images could be used successfully to map various glacial features such as glacier boundary, accumulation area, ablation area, equilibrium line, moraines etc. The Normalised Difference Snow Index (NDSI) and TM band ratio has been used to demarcate glacier, periglacier, permafrost areas and also clean ice and debris ice along Ablation zone and Snout area of glacier. The streams emerging out of snout as well transverse crevasses developed near snout could be identified sharply in NDSI image. Shape file of the basin as well the glacier boundaries delineated from the satellite images was over lapped on topographic sheets and then it was digitized using Geographic Information System techniques. Bench mark glaciers like Kangrez and Machoi were monitored for long time fluctuation records. Thermal monitoring of permafrost and glacier areas was carried by opening pits by ice drill to monitor temperature at different depth by thermistors.

The location and sources of meteorological data used in this study chosen, for their proximity to glaciers length of their records. The climatologically network in Ladakh is biased by predominant location of stations at Leh. Kargil, and Drass on valley floor. To assess regionally representative trend, the meteorological data of Drass monitored by Indian Meteorology Department (IMD) and Snow and Avalanche Establishment (Government of India), using standard meteorological practices, is adopted as representative of the region. The data for record period of 28 years (1987-2013) is used to assess seasonal changes, if any in monthly mean maximum, mean minimum temperature and precipitation as tool to glacier stratigraphic system (Nov, Dec. previous year, and Jan to Oct. current year). Hence, under this system length of season and duration of “mass balance year of glacier year” varies. The mass balance year is divided in to winter (Nov-Mar) ,late winter (Mar-May), summer (Jun-Aug), late summer (Sep-Oct) and is used in this study to isolate the inter-seasonal signals. The monthly mean maximum, minimum temperature and snowfall been analyzed for each phase by fitting linear least square trend line (1988 - 2000 , 2001-2008, and 2008-2013) to assess the impact of temperature and precipitation on the health of glaciers. The significance of trend line is shown by probability value (P value) for significance level $\dot{\alpha}=0.05$.The value of R-square (R^2) from regression is used to show correlation coefficient between glacier fluctuation and external climatic variables like temperature and precipitation (Haeberli and Beniston 1998, Kulkarni et al.2002, Singh et al. 2005, Koul and Ganju 2010).

4. Results

Glaciers are sensitive to climate change. The overall growth or decay of glaciers depends on the temperature of the ambient climate largely and to input of mass in the form of solid precipitation to lesser extent. The studies carried in North America, show that some glaciated regions have positive correlation between temperature and snowfall and in some regions snowfall and temperature is negatively correlated (Bowling 1977, Brinkman and Barry 1972).

Station	Mean Min Temperature				Mean Max Temperature			
	Drass Min	Leh Min	Kargil Min	Srinagar Min	Drass Max	Leh Max	Kargil Max	Srinagar Max
Drass Min		0.739 (r), 0.000(p)	0.967(r), 0.000(p)	0.812(r), 0.000(p)				
Leh Min	0.739 (r), 0.000(p)		0.925(r), 0.003(p)	0.492(r), 0.000(p)				
Kargil Min	0.967(r), 0.000(p)	0.925(r), 0.003(p)						
Srinagar Min	0.812(r), 0.000(p)	0.492(r), 0.000(p)						
Drass Max						0.596(r), 0.041(p)	0.791(r), 0.209(p)	0.764(r), 0.231(p)
Leh Max					0.596(r), 0.041(p)		0.797(r), 0.203(p)	0.779(r), 0.435(p)
Kargil Max					0.791(r), 0.209(p)	0.797(r), 0.203(p)		
Srinagar Max					0.764(r), 0.231(p)	0.779(r), 0.435(p)		

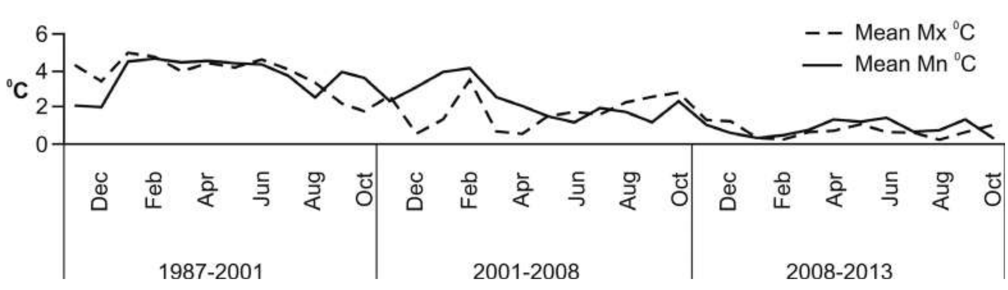
Correlation coefficient (r) and p-value of winter mean minimum temperature (Nov-May) numbers above table (Top left to bottom right) diagonal- and summer mean maximum temperature (June-Sept).

Therefore the changes of snow cover is uncertain and much depends on meteorological parameters which require in-depth investigations. It is often argued that variability in mass balance of maritime glaciers is dominated by winter season precipitation, while continental glaciers like in Kargil valley are most strongly influenced by change in temperature during summer season too (Walters and Meier 1989). Studies been investigated to assess the role of meteorological parameters in governing the snow cover extent and it has been found that annual change in glacier extent is due wintertime anomalies in accumulated snow and maximum temperature anomalies in summer (Letreguilly 1988). Investigations carried to study relationship between snowfall and temperature of Drass meteorological station as representative of Zanskar valley (aligned to Pamir air mass route), a record of 28 yrs to assess seasonal change, if any in mean maximum and mean minimum temperature along with precipitation.

4.1 Spatial correlation of temperature

To assess regionally representative trends, it is necessary to establish the extent to which seasonal variation in temperature particularly with regard to mean minimum and mean maximum are correlated across the Ladakh region. The correlation matrices of annual, seasonal, and monthly temperature between weather stations at Drass, Kargil, Leh and Srinagar .A summary of the results for the key period of accumulation (snow) on glaciers and ablation (melting of snow), divided between the mean minimum temperature during winter six months (Nov-May) and men maximum temperature summer months (Jun-Sept) is shown in the Table (Archer 2004). The spatial analysis reveal high best seasonal positive correlation coefficient between temperatures at Drass with other stations Kargil, Leh (Ladakh) and Srinaga (south of High Himalaya). The correlation in mean temperature is much higher during winter (0.8) than summer season (0.76). The high correlation in mean temperature between Drass with Kargil, Ladakh and Srinagar stations separated by considerable horizontal distances and intervening mountain barriers can be used to provide a regional picture of seasonal and year to variation in temperature.

Fig. 2. Drass Mean Maximum and Mean Minimum Temperature (STDEV) 1987-2013



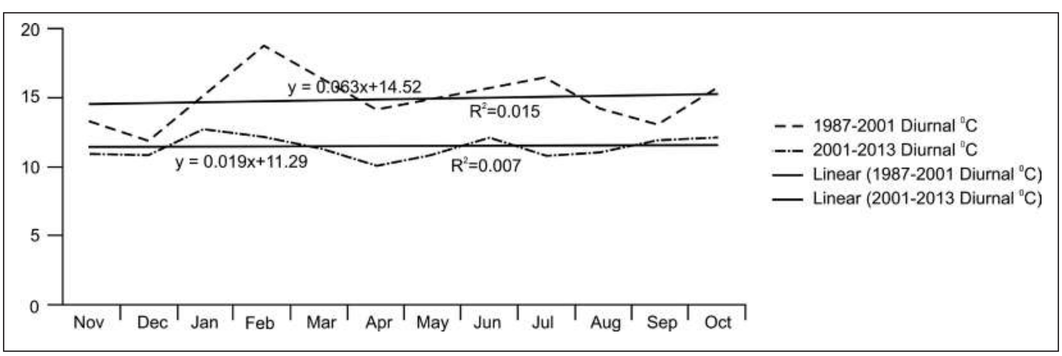
4.2. Analysis of temporal temperature change

Temperature time series at Drass Valley Station (1987-2013) been used to provide a regional picture of seasonal and year-to-year variation in temperature and glacier mass extent at higher altitude. Over a record period of 28 years, there has been a small increase in annual mean temperature at Drass of -0.226°c decade^{-1} prior to 1995°. However, since 1996 the rate of increase has accelerated to 0.375°c decade^{-1}. If individual month of season are further examined then large significant increase in mean temperature are seen during the winter season particularly November to June, a possible signal of seasonal shift of winter to June.

The mean monthly maximum summer temperature for time series 1987-2001, 2001-2008 and 2008-2013 is to provide a regional picture of seasonal and year-to-year variation in temperature (Fig.2). The mean monthly maximum summer temperature from June, July, August, and September is 16.2°C,20.8°C,17.7°C and 11.7°C, respectively for the years 1987 -2001,as compared to 20.6°C, 23.7°C, 23.6°C and 20.4°C for the years 2001-2008 and 14.9°C,17.22°C,15.17°C and 10.82°C for the years 2008-2013. During summer season, particularly, in July and August highest temperature ranged between 26.2 and 25.3°C in the years,2001-2008 and 1987-2001 respectively as compared to 12.1°C and 13.7°C during 2008-2013 respectively. The degree variation of standard deviation of mean maximum temperature during summer months ranged between 5.18-1.85°C, 3.6°C-0.911°C, and 1.3-0.22°C (Fig.2) during 1987-2001, 2001-2008 and 2008-2013, respectively indicating higher range of dispersion in maximum temperature during 1987-2001 in comparison to 2008-2013.

The mean minimum temperature during winter season (November, December, January, February, March, April, and May) ranged between -3.635°C to-22.45°C, -1°C to-19.33°C and -9.48°C to 1.02°C respectively for the time series 1987-2001,2001-2008 and 2008-2013 respectively, showing degree variation of standard deviation of 1.98-4.71°C,1.57-4.17°C and 0.28-1.39°C (Fig.2). The lowest minimum temperature during winter season recorded in January and February is -34°C and -27°C in 1989-2001and 2001-2008 respectively as compared to -13.4°C and -10.7°C during the time series 2008-2013.

Fig. 3 : Drass: Diurnal Temperature of Maximum and Minimum (1987-2013)

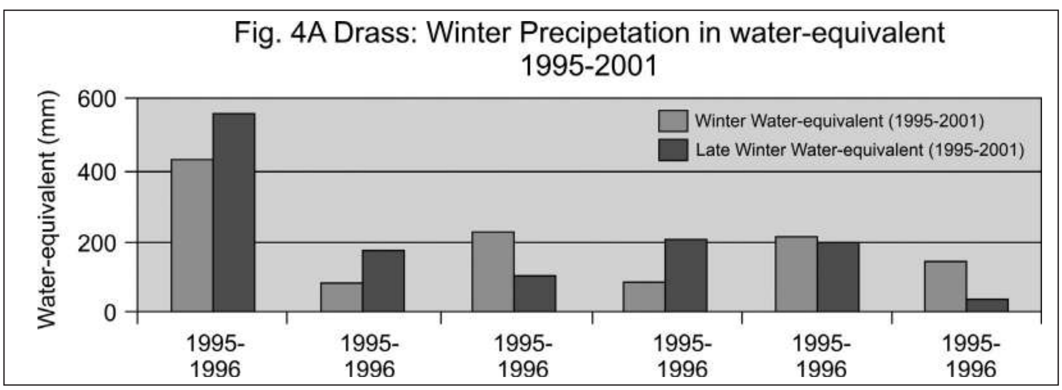


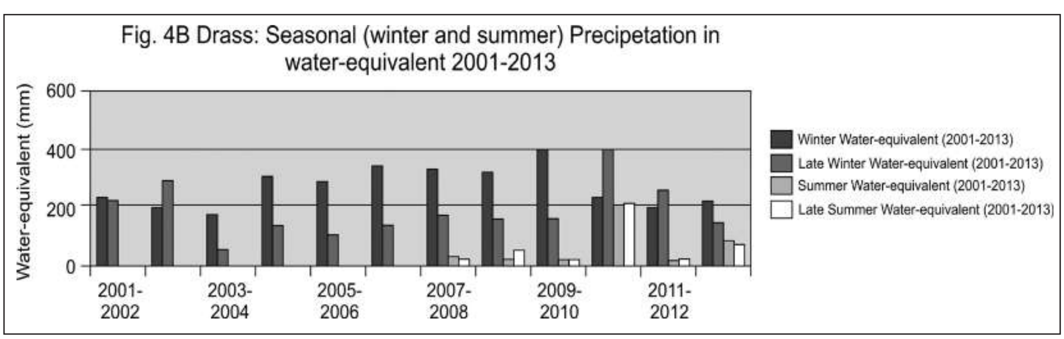
The monthly diurnal temperature range for winter and summer season (Fig 3) shows an increasing trend during 1987-2001 and 2001-2013 and the average winter diurnal is 14.9, 11.3°C, summer diurnal 14.98, and 11.576°C respectively for the time series. The highest diurnal range in 1987-2001 and 2001-2013 during winter is February 18.8°C and 12.8°C and in summer, July 16.48°C and 12.04°C respectively.

4.3. Precipitation

The analysis of daily precipitation from first fortnight of November 1995 to last fortnight of October 2001 varies from 984mm to 171.6mm in water equivalent in comparison 979.9mn to 219mm w.e.v. during years 2001-2013 (Fig.4A and 4B). Out of total precipitation, highest contribution(above 500mm w.e.v.) of snowfall is, 984mm (1995-96),979.5mm.(2010-11), 565mm,562mm,589.1mm.495mm and587.3mm w.e.v,(2007-2012), moderate, (300-450mm w.e.v.) of snowfall recorded during the seasonal years of 2001-2007and 2012-2014 and low snowfall of less than 300cm during 1991-95,1997-98,1999-2000, and 2000-2001, respectively revealing 1991 to 2001 a dry decade with exceptional anomaly of 1995-96.

The pattern in annual, seasonal and monthly mean snowfall investigated for the time series 1995-2001,show 196mm w.e.v of snow took place between months of November and March (winter) and 206.8mm w.e.v of snow between March and May(Late winter) suggesting that about 52% of snowfall took place in late part of winter. Similarly, during the period 2001-2007, 253.4mm of water equivalent of snowfall took place in winter season (November, December- previous year, and January-





February-current year) and 155.48mm w.e.v of snowfall of late winter (March-May) that amounts to 38%of total snowfall in late winter (Fig. 5 see page 20). During 2008-2013, 278mm w.e.v of snowfall in winter season,211.67mm w.e.v. of snowfall in late winter (March to May), and 100.71mm w.e.v.of precipitation in summer (June-September) suggesting that 37.5% snowfall took place late winter and 17% precipitation in summer season (Fig. 4).

4.4. Primary Impact of Climatic Change on Cryosphere:

The cryosphere is on one hand a very useful indicator to monitor changes in climate, on the other hand plays crucial in many climate processes that directly affect human societies. Thus plays a major role in various dimensions of climate system: it is affected if climate changes, but it owns changes in turn affect the climate system. Monitoring these changes therefore provides crucial knowledge about climate changes.

The trends in annual, seasonal and monthly mean temperature and precipitation(snow fall) were investigated of Drass station (Representative of Study region) for Suru-Zanskar glacier basin from 1988 to 2013.The records have been analyzed by fitting linear least square trend line to assess the behaviour of temperature and precipitation. The analysis reveals that mean maximum temperature (1987-2000) shows no change in trend line during winter as well late winter season, temperature in relation to late winter (March-May) showing increasing trend in temperature (Fig.6A). Similarly mean maximum temperature (2001-2013) trend line shows decreasing trend during summer (June-August) as well late summer (September-October) season, thereby indicating cooling, hence reducing degree - day melting of glaciers (Fig 6D). The trend line of mean minimum temperature however shows marginal change in its behaviour (Fig 6C).

The trends in diurnal temperature change shows increasing trend in 1987-2000 and 2001-2013 in summer as well winter that substantiate that late winter warming leading to sublimation of ice from glacier body triggering the influence of precipitation during summer 2005-2013.

Out of total precipitation, highest contribution (above 500mm w.e.v.) of snowfall is, 984mm (1995-96),979.5 mm. (2010-11), 565mm, 562mm, 589.1mm. 495mm and587.3mm w.e.v, (2007-2012), moderate ,(300-450mm w.e.v.) of snowfall recorded during the seasonal years of 2001-2007and 2012-2014 and low snowfall of less than 300cm during 1991-95,1997-98,1999-2000, and 2000-2001, respectively revealing 1991 to 2001 a dry decade with exceptional anomaly of 1995-96.

Analysis of rainfall records shows that study region experienced overall dry spells during the summer periods of 1995-2002. The rainfall scenario in summer period initiated a change in year 2002-03 latter as regular phenomenon since 2005-06. The total rainfall/snowfall record for the years 2011,2012,2013,2014 from June to September is 42.0, 56.2, 90.1, 146.1 mm in water equivalent respectively (Fig.5). Whereas the analysis of precipitation recorded at the glacier, base camp and at higher ablation zone in vicinity of equilibrium line reveal that rainfall occurs at lower elevation near glacier snout and snowfall at higher elevation in ablation and accumulation zones. Further heavy snowfall in later part of winter and summer holds considerable significance in terms of health of glacier and helps in consolidating ice, reducing ambient temperature and degree-day melting that results positive impact on glacier stability and growth.

The role of temperature and precipitation have been examined in governing glacier cover extent in Suru-Zanskar valley and found that negative correlation (-0.471,-0.145) between mean minimum temperature and snowfall in 1995-2000, in comparison to weak positive correlation (0.191) during winter season of 2000-2013 time series, is insignificant as per "P" test values (Table 1). The temperature and precipitation analysis and their trend shows an interesting shift of peak summers and winter season until late summer (August, September) and late winter (March to June), this shift has helped the overall health of glaciers and their stabilization process.

5. Cryosphere- Glacier Distributions

The Suru-Zanskar valley contains nearly 30% Cryosphere area in the form seasonal snow, glaciers and permafrost grounds, glaciers (18%) occupy the large surface area. Glacier inventory is prepared from the available Survey of India topographical sheets document 268 glaciers in Zanskar valley basin confined between altitudes 3600m to 6478m. Out of these, 131 glaciers are housed in Higher Himalaya and 137 glaciers in Zanskar Mountains. Out of the total 268 glaciers,98 glaciers >1km length, 90 glaciers1-2km, 56 glaciers 2-5km,15 glaciers 5-10km,5 glacier 10-15km,3 glaciers 10-20km and one Durung Drung 23km length. The large glaciers are confined in Higher Himalaya in the protracted valleys, medium size small glacier are sheltered cirques along the mountain flanks of Zanskar, and small niche type are located in depressions of avalanche slopes as hanging glaciers. The small glaciers have developed broad foot at valley terminus in comparison to large glaciers extending their snout to basin terminus indicating minor oscillations in current times. The glaciers are distributed more or less equally in all direction show preferred orientation to north (26glaciers), northeast (56glacier), northwest (44glaciers), south (40glaciers), southeast (5glaciers), southwest (32glaciers) and east-west (65glaciers).

5.1.1 Glacier Inventory

96 glaciers (area 1km^2 and above) selected as sample glaciers in Suru - Zanskar valley are for detailed comparative study. Fifty eight (60%) glaciers are in the range > 5km^2,19 glaciers (19.8%of total) are between 5km^2-15km^2, 8 (8.3%) glaciers are between15km^{2}and30km^2, 4 (4.2%) glaciers are between 30km^2-45km^2, 2 (2.1%) glaciers are between 45km^2 and 60km^{2}and 2 (2.1%) glaciers are greater than 60km^{2}area. The Durung Drung is the largest glacier in the basin, has area of 72.14km^2.This clearly suggests that Zanskars valley is occupied by glaciers of different dimensions preferably of small glaciers. The glaciers in Suru-Zanskar basin are distributed more or less equally in all directions and do show preferred orientation to north, northeast, and northwest (62%). A good number of glaciers are orientated in north east (21 nos) and north- west (19 no's), north (14 no's), east-west (22 no's), However, as per the satellite data of year 2001, the total number of glaciers has increased to 152 due

to fragmentation of large ones to smaller ones resulting in change in areal extent. The change in areal extent in glacier area has decreased from 855.27km² to783.06km² and 777.29km² during the period 1965, 2001, and 2013 respectively.

Satellite data have been used as base of comparison for their detail study, in order to assess the behaviour of the Suru-Zanskar glaciers during current times (2001-2013) and in the early past (1965-2001). In addition, to study causative factors responsible for changes in behaviour of glaciers in Zanskar valley.

5.1.2. Monitoring of Current Behaviour Glaciers (2001 and 2013)

To assess current behaviour of the glaciers the IRS-LISS-III images of 2001 and 2013 visually interpreted to demarcate the boundaries of 154 glaciers of Suru-Zanskar valley. The various digital image-processing techniques are applied to supplement it with ground truth data in satellite image of 2013 for accurate identification of snout position and to assess change in area of all the glaciers.

5.1.3 Steady State phase in glacier area and snout position

The study shows that 115 (75%) glaciers of different dimensions do not show any change in their area between the periods 2001 and 2013. Out of 115 glaciers, 79 glaciers are less than 5km², 18 glaciers 5km²-10km², 10 glaciers 10-20km², 3 glaciers 20-30km² and 4 glaciers 30-45km², and 1glacier 45-60km²area. The glaciers of these categories are distributed in more or less in all direction with large percentage (61.2%) is oriented north.

Interestingly ,the thirteen glacier ID No.56C-09,23,37,42,57,59, 76,81, 114,128,134,144,148,show gain in area by 10% and 80% respectively from 2001 to 2013, the snout of the glaciers are confined in northeast and north direction (Fig 2). **Overall 81% (128)** glaciers of Suru-Zanskar are currently either in steady state or in advancing mode, most of the glaciers are of larger dimensions (20-60km²).

The remaining 26 glaciers show change in area, length, as per satellite imageries of 2001 and 2013.The dominant are small dimensions (>5km²) and their orientation is

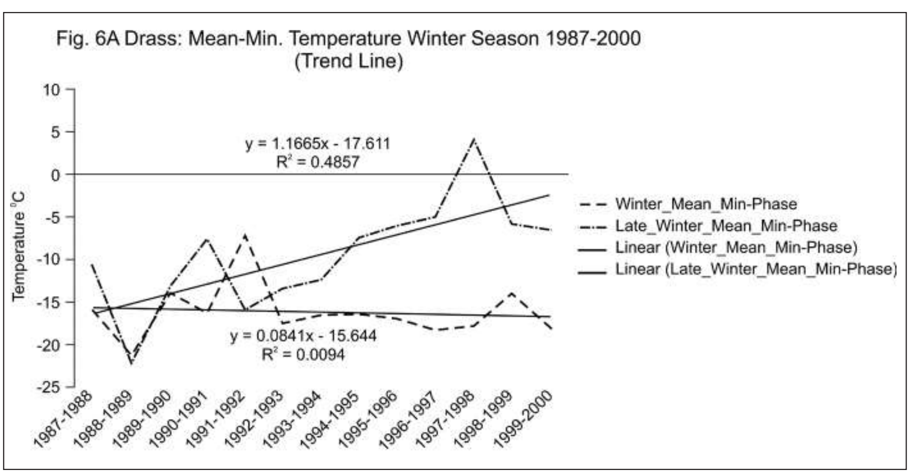


Fig. 6A Drass: Mean-Min. Temperature Winter Season 1987-2000 (Trend Line) in north east (55.5%), east-west, and north (31.75% each) .0ne glacier has lost more than 1km² area, three glaciers have loss more than 0. 5km-1km² area, 5 glaciers 0. 5km² -0.25km², 17 glaciers vacated less 0.20km² area.

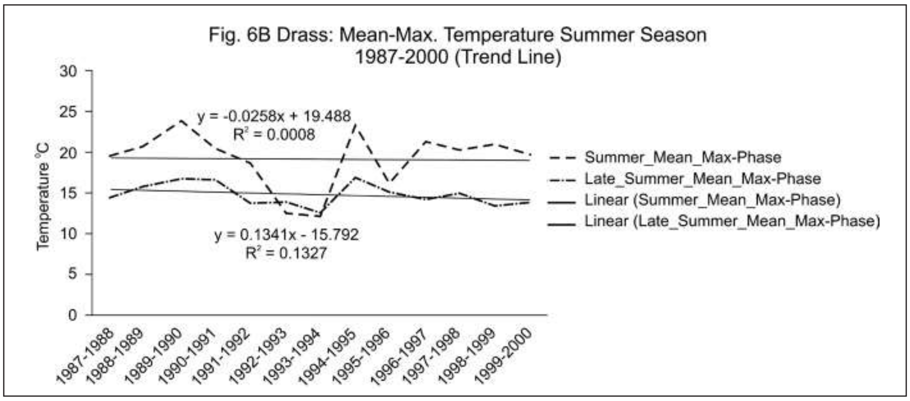
5.1.4 Long-Term Monitoring of Glaciers between 1965 and 2001 and 2001-2013

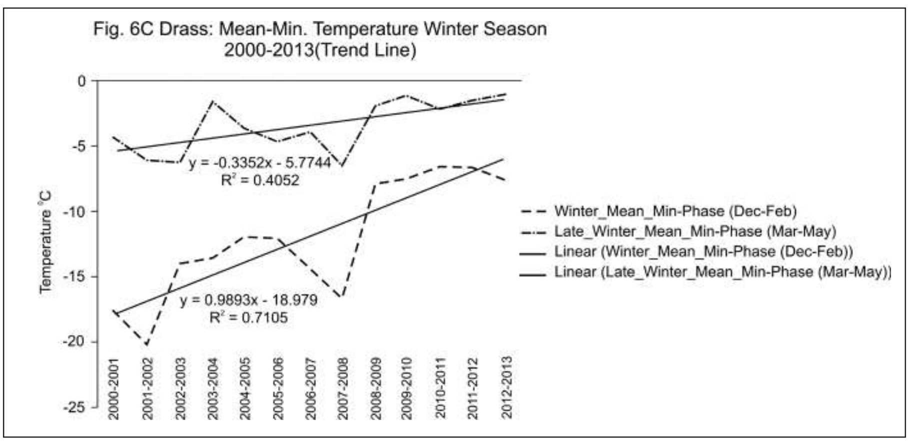
Ninty six glaciers of Zanskar valley identified for long-term monitoring for the period 1965 - 2001 and 2001-2013. In-homogeneity in glacier area,**48** glaciers (50% of sample glaciers) show no change in area since the year 1965, **three** glaciers experienced gain in area, 15 small (2-10km²) glaciers loss 17-50% of its area, 10 medium large size (10-30km²) glaciers lost 10-30% of glacier area and 11 large (31-72km²) glaciers lost 8-12.5% with exception of two glaciers (47-49km²) facing south-east vacating area lost 22-24% of its area, remaining glaciers lost marginal area during last 50 years period.

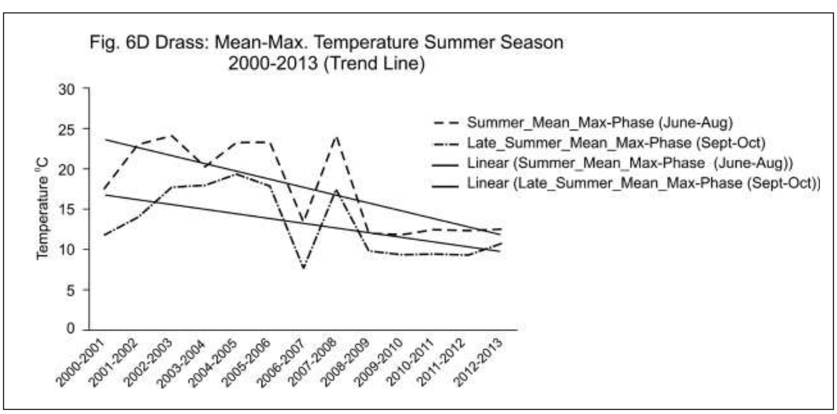
Due to in-homogeneity in glacier area and observation period, we evaluated the changes in glacier areas on yearly basis. Three glaciers vacated area at the average rate of 1,13,000 m²/yr, 12 glaciers experienced loss of 20,000m-70,000m ²/yr, 12 glaciers vacated 2500m ²-5000 m ²/yr and remaining glaciers lost 15m ²-1500 m ²/yr. The majority of large and medium large (numbering 19) loss large area due to climatic stress prior 2001 that resulted in fragmentation and retreat of their hanging glaciers from main glacier, and remaining of the large and medium size glaciers housed in protracted areas did not experience any change in area. Small and niche ones confined in higher altitude of Zankar were affected by solar radiation melting. The yearly change in area of each glacier ranges 0.12% to 1.56% of glacier area. TheDurun Drung glacier in Znskar valley, Kangriz glacier in Suru valley, Machoi glacier in Drass valley were under taken for study of secular movement of snout and the effect, if any, of inter-intra-annual seasonal variation on health of glacier. The glaciers does not show any change in position of snout since1902(Workman 1909), However, it is evident from the comparison of photographs of 1902 and2007 thickness at snout and ablation zone has certainly reduced in past one century but no retreat in position of snot.

5.2 Permafrost Distribution

Permafrost is thermally defined phenomenon describing ground or foot hills that remains at or below 0ºc at least two years, irrespective of presence of water or ice. Permafrost is influenced by climate, topography, and ground condition. The Zanskar region experiencing extreme cold arid climate and temperature during major part of the year is below freezing (-30ºC to -35ºC) leading to permafrost condition along glacier (ice) margin from snowline of Higher Himalaya flanks and Zanskar uplands to foot hills valley margins. The low temperature has lead to freezing of super saturated ice margins to permafrost conditions leading to production of ice wedges and rock glaciers on valley and solifluction is observed within basin slope and patterned ground with Pangolins in valley floor. This landscape category covered an area 249.58km² as per Survey of India topographic map (1965) and as per satellite data 2001 and 2013 and field survey observation, the area has shrunk to 187.54km² and 178.76km² respectively. Permafrost line has shifted from the altitude from 3420m altitude 3455m from 1965 to 2001 as annual decadently in temperature has shot up from - 0.226ºc to +0.371˚c decade. Further permafrost degradation at lower altitude has lowered active layer thickness 1-2m which is thawing in summer and refreezing in winter leading to warm permafrost conditions since year 2001 particularly from 2005-2006.Fragmentation of permafrost line observed between Panikhar (3317m) and Parkhachik (3634m) stations along aerial distance 20km.







6. Secondary Impacts of climate change on Cryosphere

6.1 Impact of climate change on valley slopes- Mass Movement

The most important impact of climate change during last fifteen years is gradual increase in mean maximum and mean minimum during late winters (April-June) and precipitation pattern has resulted in degradation of valley slopes resulting in slope failures and slope gullies. The mass movement areas are confined to parts of Higher Himalayan flanks and Zanskar uplands on the rocks phyllites, schist's and quartzite that are devoid of ice bodies. During winter season the snowfall on the bare slopes is sometimes drifted to interior areas otherwise subjected to extreme freezing due to very low temperature (-45˚C) for long duration of the winter (October-May). The freezing leads to large pressure and stress conditions on valley walls and solifluxion and navel fluxion in the inter mountain basin floor and valleys .It leads to the process of ground freezing resulting in formation of cracks and hummocks. During summer season thawing produces more water than retained and lateral plantation and frequent freezing develops thermo planation and frost thrusting along valley walls due to differential heaving. Along the valley walls there is mass wasting caused by super saturated permafrost frozen wall that moves down slopes and produces scree cones and rock glaciers. In the basin floor patterned ground is produced. The periglacial area covers 339.58km² leading to slides. Out of which scree covers an area 290.63km and debris slope(alluvial and mud slides) covers 68.95km² produced by heaving processes. In Zanskar uplands frost heaving is mostly confined to foot hill of the mountains along valley margins covering an area 68.95km² out of which 88% lies in Zanskar uplands having a slope of 32˚.In these areas ice wedge and solifluxion is observed up to depth of 3m between rocks and within thermokarst basins. The process of thawing in these areas leads mass movement process. During last ten years nearly 14% debris slopes have been stabilized by planting sapling of Willow and Popular trees. NGOs and J&K Forest Department have already initiated reclamations of large number of slopes in the vicinity of Padam by social forestry. Further check dams have been constructed in the upstream of Zanskar river to store water and canalise it to nearby lands for raising grasslands.

6.2. Impact of climate change on Land use

The mountainous country like Suru-Zanskar has adverse terrain and climatic condition that permits the human souls to have socio-economic settings in relatively low altitude in the vicinity of river to carry out agriculture practices. The land use practices therefore displays roughly corresponding to altitudinal zones. The altitude variation is explanatory variable of vegetation, and climate as latter is indicator of former. On the basis of above factors, the different land cover of the study region are: agriculture and settlement (45.65km), grassland and grazing land (24.47km),water bodies (394.08km-5.06%), glacier and peri-glacier activity (3020km-43.14%), rocky and barren (3715.8km-53.08%) (Koul et.al 2007). The existing land use area indicates that area under non available for cultivation has decreased from 1338.8 hectare (1980-81) to 1283.09 hectare(1990-91) and to 1276.01hectare(2013-2014);land under miscellaneous tree, crops and grooves from 683.63hectare (2001-2002) to 681.03hectare(2013-2014); fallow land area decreased from 232 hectares (2001-2002) decreased to 229.9hectare (2013-2014) and net area sown occupies 2399.7 hectares (2013-2014) as compared to 2345.45 hectares (2001-2002) (Raina and Koul 2011).The area under wheat, pea and vegetable cultivation has increased by 25% to30% and also yield per hectare has increased 30% during 2001 to 2013.

7. Disscusion and conclusion

Over a record period of 28 years, there has been a small increase in annual mean temperature at Drass of -0.426°c decade^{-1} prior to year 1995. However, since 1996 the rate of increase has accelerated to +0.275°c decade^{-1}.The analysis of mean monthly temperature (Maximum and Minimum) trend line for period 28 years, lack of fit of lower portion of data (1988-2000) to upper portion of data (2001-2013) hence it is attributed to phase transition threshold. It indicates that winter is cooler, late winter warm humid, and summer cool and wet during time series 2001-2013 in comparison to cold winters (November-March), mild late winter (March-May) and warm and dry summer during 1988-2000. Further, the decrease in mean maximum as well mean minimum temperature during 2004-2013 is associated with change with inter-decadently of Pacific Oscillation and with increase in El Nino/southern Oscillation events that resulted lower ablation season temperature particularly during summers of 2004-2014(Yasunari 1987) (Fig3 and Fig.4). This is further substantiated by decreasing trend in diurnal temperature during 2004-2013. These trends in weather conditions have undoubtedly leaded a favourable environment for decelerated retreat to the extent of no change in glacier area (115glaciers) during last thirteen years (2001-2013) Further remaining 13 glaciers show gain in area and 28 glaciers show marginal loss in area including bench mark glaciers like Kangriz glacier in the Suru valley, Durung Drung glacier in the Zanskar valley and Machoi glacier in the Drass basin where detail field study were conducted during 2005-2014.The Kangriz glacier, Machoi glacier and Drung Drung glacier do not show any change in the position of snout since 1888 (Oldham 188,Workman 1909, La Touche 1910).However,it is evident from the comparison of the early photographs of 1888,1902 and1910 and 2009-2013 that thickness of these glaciers at snout and ablation zone has certainly reduced in past one century but no retreat in position of the snout. Thus the documentary evidence collected through early photographs (1888-2010) for past one century confirm that the bench mark glaciers like Kangriz glacier, Durng Drung glacier, and Machoi glacier have undergone some changes in its volume but not in position of snout. The kangriz glacier is situated on Zanskar Fault similar to that of Drung Drung glacier, and reactivation fault in geologically younger times (Ganjoo 2009) has resulted in shift of path of glacier. It would premature to conclude if the change in volume is exclusively due to change in climate or due to neotectonic in the area. Further majority of the glaciers in Suru-Zanskar valley are currently (2001-2013) in stabilizing stage (83% glaciers) mode. Prior to the period 2001, the temperature was extremely low(-30ºc to-40˚c)during early winter, milder in late winter and warmer in summer and as such, the glaciers in study valley were under climatic stress leading to fragmentation of 19 glaciers and thawing of permafrost zone and fragmentation of permafrost line resulting in loss in permafrost area (Bahuguna,et al.2014,Bolch,et al 2008,Fujila,K.2008,Ye,et al,2006).

Due to climatic stress the permafrost line shifted from lower to higher altitude line resulting in vacating of large area at the margin of basin floor and mountain rim due to warmer trend in late winter and early summer maximum temperature. These changes have encouraged farmers to switch over wheat cultivation from barley cultivation, in areas where soil is conducive for its growth due to extensive use of mechanisation. Further in adjoining mountainous region where crop production has least feasibility, livestock rearing is the natural alternative supported by more conducive sub-arid climate during summer season. The substantial availability of green edible bio-mass has efficiently routed through live stock link food chain to meet entire demand for consumption for increased cattle population as well the pastoral products including demand of domestic fuel in the form of dung mass, as well the demand of butter, wool and meat.

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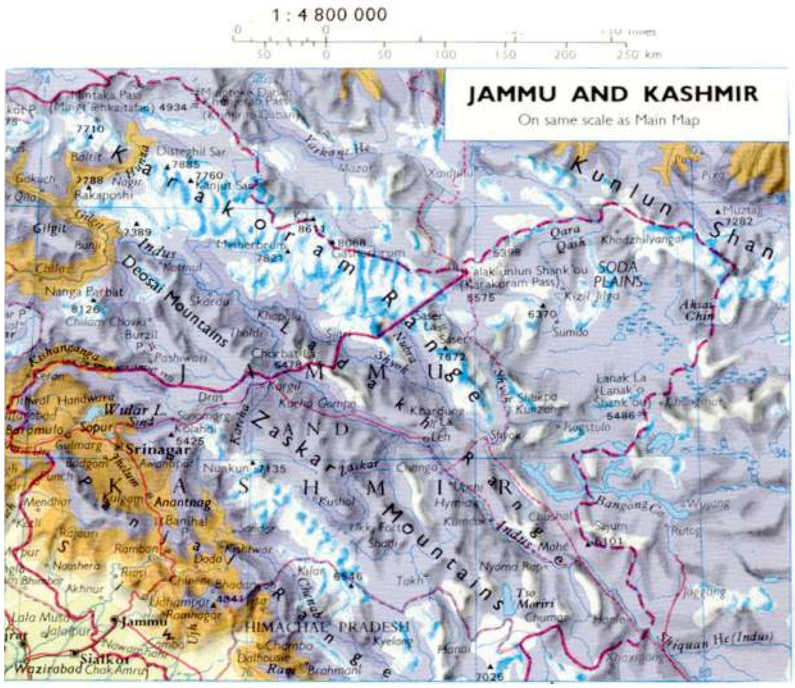

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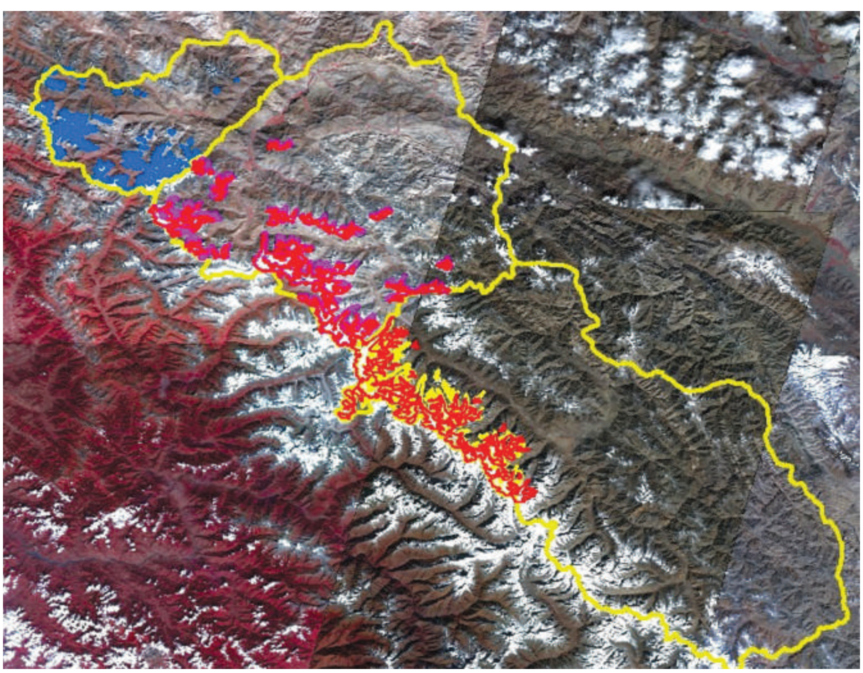

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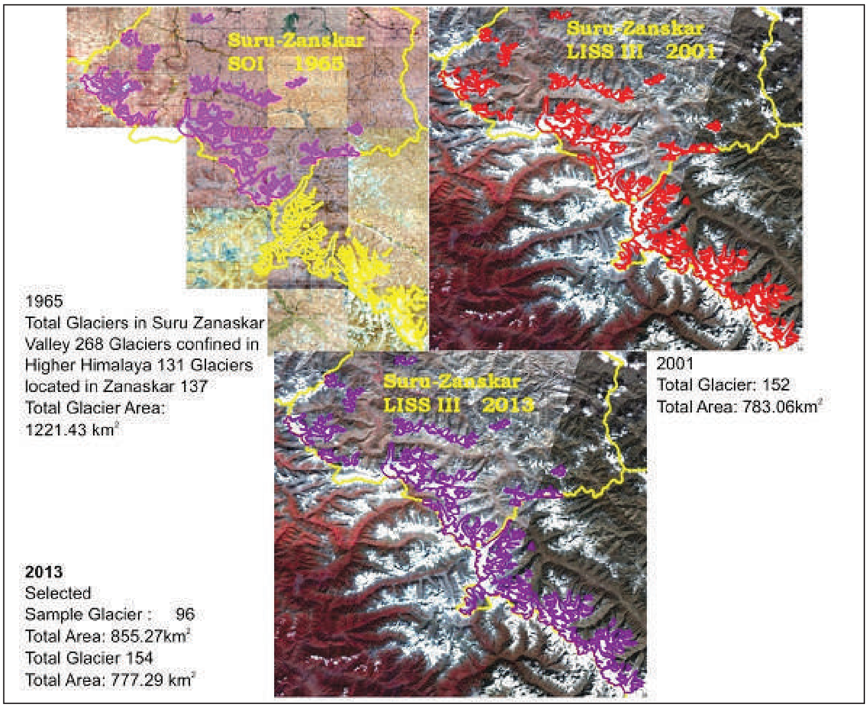


Fig 5: See page 10 for the text

Map 1: The slum located proximate to the mall, along E.M. Bypass and opposite to the planned Salt Lake City. (See page 26)

Plate 1: The slum gets overlooked by the towering gated residences along E.M. Bypass. (See page 26)

Map 2: The gated residence located adjoining the railway station. (See page 27)

Plate 2: The magnificence of the gated residence gets overshadowed by the disorder of the adjoining railway station. (See page 28)

Map 3: The slum located along Jadavpur railway station and within a ward (ward 104) that claims to be slum-free. (See page 28)

Plate 3: The material and/or non material segmentation of the slum near Jadavpur railway station. (See page 28)

Map 4: The elite old planned area of Golf Green arranged around a central park. (See page 29)

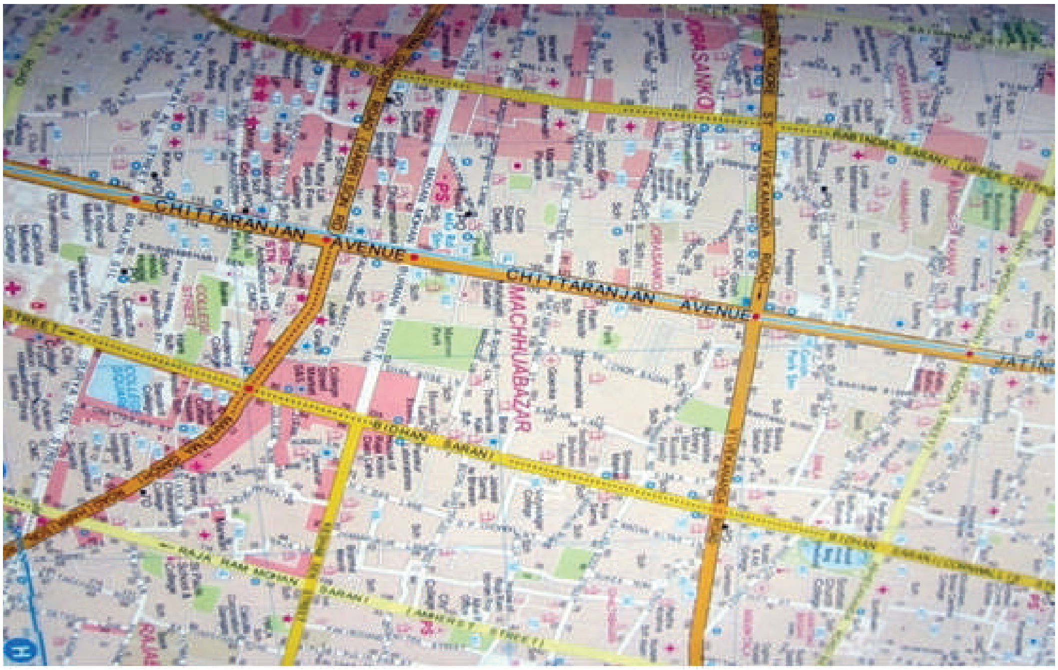
Plate 4: Golf Green located within a zone that is pleasant and actually slum-free and free from other so called nuisance as well. (See page 29)

Map 5: Park Circus: One of the Muslim dominated areas in Kolkata.
The red circles indicate mosques – an expression of religious impression on city spaces and an evidence of concentration of religion in particular city spaces. (See page 30)

Plate 5: Costumes: Another expression of culture and religion and the repetition of which confer images to city spaces. (See page 30)

Map 6: The Chinatown in Tangra is a distinct segment of the area dotted by mostly leather industries, Chinese restaurants and other expressions of the community's presence on city space. (See page 30)

Plate 6: The literally walled Chinatown in Tangra (See page 30)



Map 7: It is along most of these roads that resides Kolkata's homeless, especially along C.R. Avenue. (See page 31)

Plate 7: A pavement dwelling along C.R. Avenue in Kolkata. (See page 31)

Plate 8: The homeless along C.R. Avenue in Kolkata. (See page 31)