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Full Length Research Paper

Impact of climatic change on agro-ecological zones of the Suru-Zanskar valley, Ladakh (Jammu and Kashmir), India

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An attempt was made to divide the Suru-Zanskar Valley of Ladakh division into agro-ecological zones in order to have an understanding of the cropping system that may be suitably adopted in such a high altitude region. For delineation of the Suru-Zanskar valley into agro-ecological zones bio-physical attributes of land such as elevation, climate, moisture adequacy index, soil texture, soil temperature, soil water holding capacity, slope, vegetation and agricultural productivity have been taken into consideration. The agricultural productivity of the valley has been worked out according to Bhatia's (1967) productivity method and moisture adequacy index has been estimated on the basis of Subrmmanyam's (1963) model. The land use zone map has been superimposed on moisture adequacy index, soil texture and soil temperature, soil water holding capacity, slope, vegetation and agricultural productivity zones to carve out different agro-ecological boundaries. The five agro-ecological zones were obtained.

Key words: Agro-ecology, Suru-Zanskar, climatic water balance, moisture index.

INTRODUCTION

Mountain ecosystems of the world in general and India in particular face a grim reality of geopolitical, biophysical and socio economic marginality. More than 10% of the world's population inhabit mountains. Agriculture, horticulture and animal husbandry are the mainstay of 60 to 70% of the population in the mountains despite very small irrigated area (Bhagat et al., 2006a). Mountain characteristics are distinguishable from those of the plains and so are the agricultural lands. Over centuries, farmers in high altitude areas have evolved the farming systems and the strategies that are compatible with the specific resource features of the mountain ecosystems. Nevertheless, they are often confronted with unequal economic terms and conditions dictated by the larger economies of the plains, in addition to the several problems associated with their own system. As a result, they are tamed by poverty and food insecurity that persist despite a unique natural resource base and very high degree of biodiversity in the mountains.

Inaccessibility, fragility, diversity, niche and human adaptation mechanisms are the specificities or characteristics of the mountains (Jodha, 1990). Fragility, marginality and inaccessibility are the negative attributes of the mountains. These specificities impose restrictions on resource extraction/ arvest rates and limitation on many development opportunities in the mountains. High altitude agriculture often does not withstand biotic pressure beyond a certain limit and are able to support limited population often to the extent of subsistence. Self containment is one of the most valuable features of the high altitude farming system. The agricultural land is relatively more fragile and requires replenishment of nutrients lost through crop production. This loss of nutrients from the topsoil is compensated through animal residues. Traditional mountain agriculture is truly a solar powered ecosystem in which the kinetic energy received from sunlight is stored as organic molecules by green plants, which in turn, is used for plant growth and maintenance. Relying on renewable sources of energy (inexhaustible sunlight, crop residues, human and animal

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muscle power and microbial decomposition processes in the soil) the mountain farming system is controlled by ecological principles. The performance of the mountain farming system will be influenced enormously by the measure of diversity stocked in various components. The conditions for rich bio-diversity are created by micro climatic variability that exhibits varying degrees of diversity in mountainous farming system even within a short distance. Varying site factors like altitude, slope direction, temperature, humidity, rainfall, availability of irrigation and distance from the snowline or plains are the driving force for the diversification of agriculture into various farming situations.

The agro-ecological study is based on the combination of two words: agriculture and ecology. Weather affects the agricultural activity because climatological factors play a great role in the growth and development of plants. Among the various climatic factors, precipitation is one of the significant attributes in the agricultural sector which reduces the physiological drought and therefore accelerates the growth rate of plants. On the other hand, the study of climatic water balance provides information about the water requirements of the crops. Thus, an understanding of the interaction of the climatic conditions with biological processes of the plant is necessary for scientific farming which is based on plant cropping pattern and improved soil and water management practices (Subramaniam, 1990). The heterogeneity in the micro-climatic resources of India, necessitate studies on micro-regional characterization of agro-climate, which could be an essential pre-requisite to exploit the natural resources to meet the demands of staggering increases in population (Subramaniam, 1989). Agro-ecological studies in India were made by a number of scientists on the basis of analysis of individual attributes namely, physiography, climate, soil, crop and agricultural regions (Murthy and Pandy, 1978; Panabokke, 1979; Subramaniam and Rao, 1989; Chowdhary and Mandal, 1989; Basu and Chanda, 1989). Panabokke classified the agro-ecological zones of South and Southeast Asia, taking rainfall and soil as criteria. Subramanian classified agro-ecological zones of Prakasam and Nellore districts of Andhra Pradesh on the basis of moisture adequacy values and soil in which the moisture regimes were superimposed on a soil map.

In the Ladakh Province of the Jammu and Kashmir State, no such study has been carried out, despite the mountainous topography and harsh climatic characteristics. The scientists have concentrated heavily on the extra-Himalayan areas for the obvious reason of being far more easily accessible than the Himalayas- forever uncertain and seemingly treacherous. The present study attempts to describe agro-ecological aspects of the Suru-Zanskar Valley. A major concern of the study is to focus upon the soil geomorphology by investigating morphological, chemical and temperature characteristics of the soils; from under-cultivated, cultivated and uncultivated areas located at different altitude levels and also measures the thermal conditions and water holding capacity to assess their agriculture potentialities. The other major objective is to study the climatic water balance and its different components.

STUDY AREA

Suru- Zanskar Valley forms a vast mountainous region between the Great Himalaya Range in the southwest and Indus Valley in the north east and occupies the southern part of the Ladakh Himalaya. Geo-tectonically, it represents the North West extension of the world famous Spiti basin. The Zanskar valley lies between 32° 52' 30" N to 33° 52' 30" N latitudes and 76° 14' 5" E to 77° 32' 4" E longitude covering an area of 7000 km². Its largest length is 116 km and its mean length is 90 km and its mean breadth is 89 km (Figure 1). The Zanskar Valley is encircled by ridge crusts of higher peaks and ridges descend precipitously. Zanskar, the youngest mountain range of north-west Himalaya has a dramatic landscape with snow, glaciers, surging river system with a limited tract of alluvial floor and verdant upland that are judiciously cultivated by agrarian peasantry. The study region is a trio-armed valley system lying between the Great Himalaya Range and Zanskar Mountain: the three arms radiate star-like towards the west, north, and south with a wide central expanse where the region's two principle drainage (Doda River and Lungnak River) meet to form the main Zanskar River. It is surrounded by Pensi-la pass and Durung Drung Glacier in north west, Haptal, Shimiling, Yaranchu glaciers, Umasi-la pass (5342 m) and Hagshu-la pass (4975 m) west and south west, Yara-la (5697 m) in the east and Baralacha-la (4650 m) in the southeast, Perfi-la (4444 m), Namche-la (4460 m) and Charchar-la (5830 m) in the north. In the west, Umasi-la pass along the Great Himalaya and connects the Zanskar Valley with Paddar Valley of Kishtwar. The pass is through a huge ice field of Haptal glacier. Kang-la (5468 m) which remains open from June to September connects the study region with Himachal Pradesh. The interior of the North West part of Zanskar has a concentration of high lofty mountain ridges along with huge glacier basins that run almost parallel to the course of the river.

The magnitude of relief and overall steepness of slopes provides an overwhelming impression that the region has distinct climatic conditions between that of Central Asia and monsoonal land of South Asia. It has a distinct climatic characteristic as it is confined to the shadow zone of the Great Himalaya, having aerodynamic link with Pamir ranges. The region has cold desert type of climate with long (7 months) cold chilly winters and, short (4 months) mild summers. During winter season, the temperature drops to -30°C that leads to freezing of Sura-Zanskar River and the frozen river is used by local people

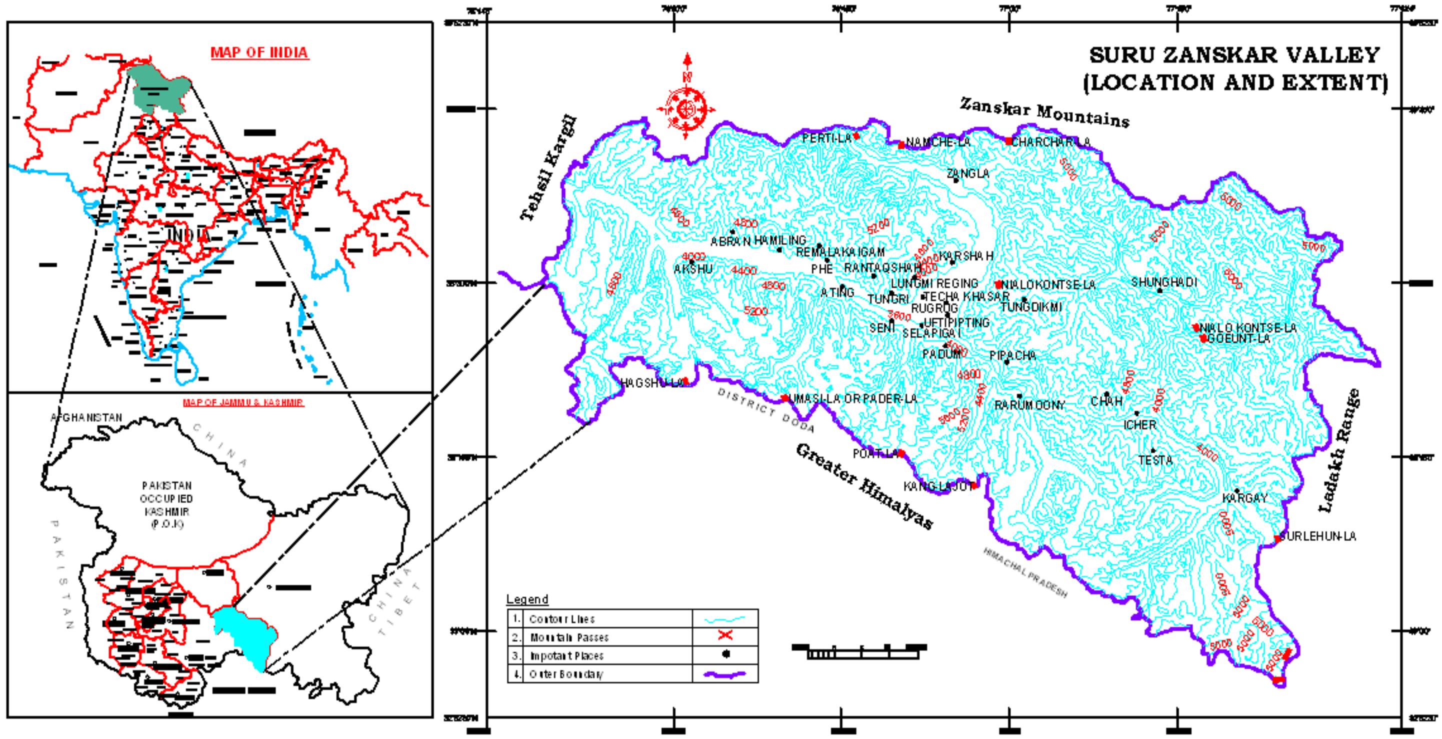


Figure 1. Suru-zanskar valley (location and extent extracted from survey of India toposheets).

as a main pedestrian route to Leh (Ladakh). This route is locally called Chadar route. The study region has a very limited area (1.5% of the area) under agriculture activity confined in the river basins and along the river terraces whereas the maximum area of the region is either barren (53.08%) or covered under glacier and peri-glacier activity (43.14%). The region has sparse vegetation comprising of few herbs and shrubs in higher altitude in the vicinity of permafrost areas. In the lower reaches, there are meadows and pasture lands adapted to moderate heat and the basin floor supports the cultivation of Wheat, Grim (Barley), Peas, Fodder, and vegetables. Per hectare yield of these crops is not satisfactory due to adverse climatic conditions and traditional farming techniques.

MATERIALS AND METHODS

The basic approach was to have a comparative analysis of agriculture and climate of Suru Zanskar Valley. Since the agriculture includes the crop agriculture system, animal husbandry, forestry and fisheries that can be defined as one system and climate the other. If these systems are treated independently, this would lead to an approach which is too fragmentary. As such, climate in turn affects the agriculture. As it has been considered that there has been a climatic change in view of that there should be change in agriculture system too as both are independent. The study involved the traditional field work to generate data on changing geomorphology, pedology, climate /weather, and agriculture land use practices and its effect on agriculture production of the region. The studies were planned to augment the understanding of the dynamics of climatic characteristic on land use planning. The detail mapping of the 7000 km^2 of the area was conducted on 1:50,000 scales accompanied by systematic sampling. The results are based upon extensive field observation and intensive laboratory work. The data collected from the field has been interpreted to derive the conclusion on pedo-geomorphological evaluation of the region pertaining to glacio-fluvial, glacial action related to arid and semiarid environment. The collection of soil samples has been made from cultivated as well as uncultivated areas. Their morphological characters were described according to the procedures given in soil sample manuals and agriculture handbook USDA (Kellogy, 1961) followed by analysing their chemical properties. The soil temperature and water holding capacity was measured by soil temperature probe and Keen box respectively.

For a comparative study, the climatic (1987 to 2006) and agriculture (1980 to 2006) data of different time periods have been incorporated for more comprehensive and solid investigation. The Suru-Zanzkar valley has no meteorological station, however the climatic/weather data generated by meteorological observatory located at Drass by Indian meteorological department, New Delhi (crow fly distance of 30 km from study region), and manual observatory set up by Jammu university research team at Durung Drung Glacier (4200 m altitude) are taken representative of the region as the stations are located en route to the air mass link with Pamir pass. The climatic water balance and its different components, like actual transpiration, soil moisture utilization and recharge have been evaluated by applying Thornthwaite's 'book keeping' procedure based on annual values of humidity and aridity indices (Thonthwaite, 1948). The moisture adequacy index of the soil was estimated on the basis of Subrahmanyam's method, based

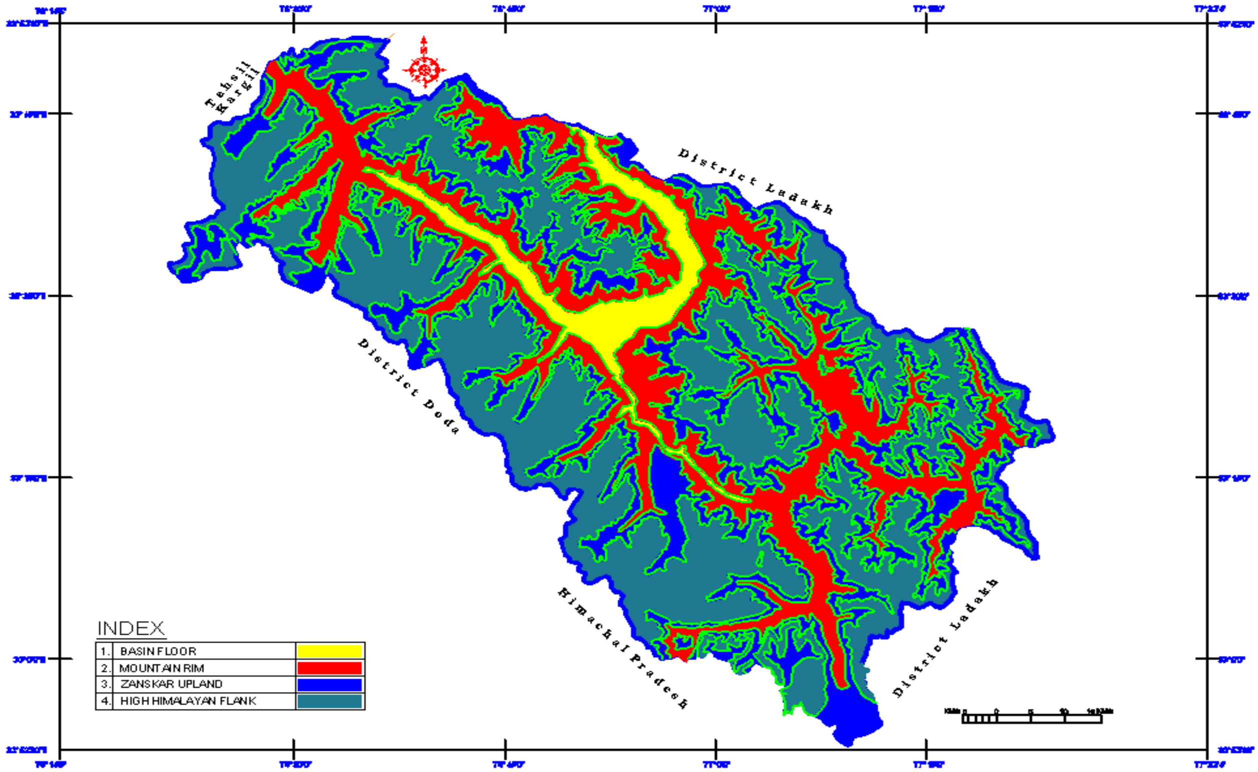


Figure 2. Suru-zanskar valley (physiographic divisions).

on annual values of actual evapo-transpiration and potential evapo-transpiration (Subrahmanyam, 1963) The studies pertaining to land use cropping pattern and crop production have been executed at village level basis. The agriculture productivity was worked out according to Bhatias' method based on percentage output of crops (Bhatias, 1967).

RESULTS

Physiographic characteristics

The Suru-Zanskar Valley is primarily a mountainous country griddled by high Himalayan ranges and Zanskar upland. The valley extends between the altitudinal range of 3500 and 6478 m and is drained by two major tributaries of Zanskar River, namely, Doda River and Lungnak River. Zanskar River flows northeast to join Indus River near Leh. The Zanskar valley is studded with eleven major glaciers, namely Durung Drung, Haptal, Haskira, Kange, Hagshu, Sumcha, Lechan, Denya, Mulang, Yaranchu, and Gompi covering an area of 1221.43 km sq. There is abundant evidence that Zanskar valley has been filled with enormous glacier system which extended deep into Stod- Lungnuk and Zanskar gorge to south-east Zanskar. The repeated rapid advances of large, steep gradient, tributary glaciers, to the main valley floor have considerably influenced slope by creating complex irregular terrain of moraines up to 70 m high with slopes as much as 55°. The relative relief of the main valley is rarely less than 2500 m, even tributaries have an elevation difference of 2000 m in horizontal distance of 2 to 4 km.

Valley walls are covered with rills, gullies and mud channels, massive debris slopes covered with scree that gradually merge with fans, low terraces, valley fills and channel gravels. Three glacio-fluvial terraces are differentiated in the Zanskar Valley along its mountain rim. Their elevation ranges from 3300 to 3800 m, 3800 to 4400 m, and 4400 to 5000 m. The first terrace zone has most of the population concentration. The second one usually forms the grazing grounds during the summer months and provides temporary shelter to the people and their cattle. The last one has also been developed as grazing grounds during the last couple of years due to favourable changes in summer weather conditions. Physiographically, Suru-Zanskar is a region of great inequality, having Great Himalayan flank, Zanskar upland (mountains), mountain rim and rolling basin floor displaying a steep rise in elevation, following the regional grain of west Himalaya (Figure 2). Literally, every aspect of natural condition is affected by these vast altitude differences. The altitude differences are fashioned in linear pattern due to the interaction between different geological and climatic processes resulting in evolving different ecological zones.

Table 1. Temperature (mean maximum/ minimum) and precipitation at Drass (1995-2006) and Durung Drung glacier valley (2005-2009).

Months	Temperature/precipitation of Drass (altitude 3066 m)			Temperature/Precipitation Durung Drung glacier valley (altitude 4162 m)		
	Mean maximum (°C)	Mean minimum (°C)	Precipitation (water equivalent) (mm)	Mean maximum (°C)	Mean minimum (°C)	Precipitation (mm)
January	-5.4	-21.3	707.9			
February	-2.4	-20.17	944.5			
March	2.66	-13.96	1137.9			
April	7.57	-7.53	782			
May	11.26	-2.39	69.1(40.6)*			
June	20.94	1.58	(7.85)*	16.94	-0.64	(10.02)*
July	23.68	7.54	(12.65)*	18.23	1.32	(14.56)*
August	23.36	8.13	(10.52)*	16.21	1.31	(13.17)*
September	19.74	3.54	(25.9)*	12.89	-3.19	(37.16)*
October	13.61	-6.04	(2.75)*	7.96	-7.8	(49.01)*
November	6.40	-8.41	259.9			
December	0.87	-13.5	414.8			

( )* Rainfall. Source: Indian meteorological department New Delhi and University of Jammu.

Meteorological observations

Suru-Zanskar valley has distinct climatic characteristics owing to its location in a higher altitude and it being encircled by high lofty mountains. The environment condition in the region is similar to that of Drass and Durung Drung Glacier valley, as both are located on lee side of high altitude passes and lies far away from the effect of the South West Indian Monsoon. The climatic conditions of the region are mainly influenced by air mass developed by Western Disturbances at Mediterranean and Caspian Seas. The study region has semi-arid to cold arid type of climate and nearly 90% annual precipitation is in the form of snowfall in winters and spring and only 10% in the form of rainfall during summers confined in the basin floor, mountain rim of the region and in the form of dry snow in higher- up regions.

Temperature

The records of different parameters particularly, temperature (Maximum, Minimum) and precipitation (Rainfall, Snowfall) are useful factors for agricultural activity particularly to accelerate productivity. The mean maximum summer temperature at Drass (3066 m) from June, July, August and September is 20.9, 23.7, 23.3 and 19.8°C. July is the hottest month with mean maximum temperature reaching up to 29°C. The mean minimum temperature during the winter season (October to April) ranged between -6.04 to -21.3°C. The meteorological data of Drass for record length of 20 years (1987 to 2006) and for Durung Drung Glacier basin for a length of five years (2005 to 2009) are useful to assess seasonal change if any, in mean maximum and minimum temperature, -6.6 to -21.3°C for a record length of twenty years (1987 to 2006). January is the coldest month when monthly temperature dips appreciably as low as -45°C (1989). The wide range of fluctuation in winter temperature is primarily caused by western disturbances which invade the region during the winter season (October to April).The summers are influenced by Westerlies. The mean maximum temperature varies from 18.23 to 7.96°C during summer season at Durung Drung glacier valley and mean minimum ranges between 1.32 and -7.8°C (Table 1), which shows that mean range of temperature in glacier valley (42,00 m altitude) is lower by 3.7°C due to lapse rate. The average diurnal temperature range of temperature during summer season is 18.1°C and the winter season is 16.4°C. The highest diurnal range is in June (18.26°C) and in February (17.7°C).

Precipitation

Suru-Zanskar valley receives snowfall during winter season due to western disturbances and rainfall during summer season. Most of the precipitation in higher reaches is received in the form of snowfall both during summer and winter season. The study region received precipitation (during years 1987 to 2006) on an average 239 cm per year. The highest precipitation (above 400 cm) was recorded during years of 1995 to 1996, 2001 to 2002, 2002 to 2003, 2003 to 2004, 2004 to 2005; the moderate precipitation (above 300 cm) recorded during the yeas 1997 to 1998, 1998 to 1999, and 2005 to 2006 out of which contribution of summer rainfall was only 10 to 20% of total precipitation. The rainfall pattern from May to September for years 1995 to 2006 was 40.6, 7.85, 12.65, 10.52, and 25.9 mm at Drass and at Durung Drung basin it was 10.02, 14.56, 13.2, 37.1, and 49.01 mm during May to September (2005 to 2009) respectively. (Table 1, Figure 5). The pattern of precipitation (snowfall and rainfall) changes from south east to North West of the region, as the North West part is in proximity to Panzila pass en-route to air mass link to Pamirs. Snowfall ranges between 2.05 to 6.84 m at Padum and 7.25 to 12 m at Durung Drung glacier valley.

Soils

The different soil samples collected from the different locations of the study area ranging in altitudes of 3340 to 4500 m were analysed for textural class, soil temperature and soil water holding capacity. On the basis of particle size analysis, the soils of the study area were identified as Sandy loam, Sandy clay loam, Sandy Skeletal, Sandy sand, Stony sand and Fragmental stone textures. The sandy loam and sandy clay loam texture classes are predominantly in valley bottom and rim land zone where cultivation of cereal crops and vegetables are practised. These soils comprise fine sand (58%), silt (20%), clay (15%) and rest coarse fraction. The soils of these types are confined in majority of villages, whereas in 15% of villages sandy loam texture soils are found. The soils have very low organic matter (1.56%), moderate to low fertility status particularly with regard to Phosphorous (11.7 to 16 kg/ha), Potassium (130 to 155 kg/ha) and Nitrogen (130 to 230 kg/ha) content. The capacity to reserve large quantity of water depends upon the texture of the soil. The water holding capacity of the soils of the study region ranges from 13.28 to 16.72, which has been grouped as low (below 15%) and high (above 15%). The high water holding capacity soils are found in Remalakigam, Rantaqahah, Tungri, Techakhsrar, Lungmireging, Karsha, Sani, Padum, Zangla, Pipcha, Rarumony, Khargay, and Tungdikmi villages. The lowest water holding capacity has been found in soils of Akshu, Abran, Hamaling, Ating, Salapiagia ,Rugrug, Uftipipting, Phe, Chah, Icher, Testa and Shumshady villages of the study region.

The soil temperature of the study region ranges are defined according to mean seasonal (summer) soil temperature in a control section (10 to 50 cm depth). Average root zone temperature of freezing characterise the peri-gelic soil temperature regime where permafrost is common. Low soil temperature and short growing season results in low biomass production. The temperature regimes, with their mean summer seasonal temperature in root zone ranges from +12 to -2°C observed between altitudes 3340 to 4500 m. It has been categorised as Isomesic (8 to 12°C), Isocryic (5 to 8°C), Cryic (0 to 5°C) and Perigelic (0 to -2°C) (Baier et al., 1975; Simonson, 1962). At lower altitudes below 3800 m, the soils of Iso-mesic temperature regime (8 to 12°C) are found. They allow growing of Wheat, Grim, Peas, and Vegetable crops. The soils of Iso-cryic (5 to 8°C) temperature regime develop meadows in the region up to an altitude of 4000 m. Cryic soils (0 to 5°C) have been observed in high alpine pasture lands between the altitudes 4000 to 4200 m. Soils having peri-gelic (0 to -2°C) temperature regime are unfit to support any kind of plant growth and are found in the zone of glacier and peri-glacier environment above the altitude of 4200 m.

Moisture index and moisture adequacy index

Water balance is an important parameter to assess the potentialities of the soil for cultivation of crop. It is related to the water holding capacity of the soil and has been estimated according to Thornthwaite moisture index, and Subramanium moisture adequacy index from the annual values of the precipitation records of the stations of Drass and Durung Drung Basin. These indices are based upon the annual values of humidity and aridity index worked from evapo-transpiration and potential evapo-transpiration. The moisture indices of the study region are 51.25 (Thornthwaites) and 0.95 (Subramanium). The results indicate that the region is suitable for crop cultivation.

Agricultural productivity

Agriculture in India has witnessed a gradual transformation from subsistence farming of early fifties to the present intensive agriculture, especially in better-endowed regions where basic infrastructure essential for realising potential of improved technologies in farmers field were created along with favourable government policies. In the mountainous region like Zanskar, agriculture is the mainstay of the people. 95% of the population are engaged in this activity through sedentary cultivation and pastoral animal rearing. Agricultural implements used by farmers are crude and primitive. Zho, a hybrid between yak and cow is deployed in drawing the small plough. The subsistent farming is still practised because of unfavourable climatic condition and highly fragile mountain ecosystem. The agriculture season some times gets delayed due to accumulation of snow in fields in great depths, particularly in lower altitudes (basin region) due to avalanching in spring season results in late sowing of seeds. To clear the snow from fields and to melt the snow, the farmers spread stored soil that enhances albedo by absorbing warmth from the sun. The region supports the cultivation of selected crops like wheat, Grim (barley) Pea, fodder and Vegetable that grow in a short period. The per hectare output of these crops have increased recently due to the development of hybrid variety of seeds that grow in a short period under harsh climatic conditions with assured water supply. The agricultural productivity of a region depends on the fertility and water holding capacity of the soil, intensity of rainfall, depth of water table, and method of cultivation and irrigation facilities. Of all the important factors playing crucial role in productivity, lack of irrigation is the significant factor and among physical factors affecting crop production, amount of rainfall is the most important one.

The pioneer work on agricultural productivity was initiated by Thompson (1926) followed by Ganguli (1938), Kendall (1939), Loomis and Barton (1961) and Horring (1964) in India as well as in the world on the basis of gross output of crops, productivity coefficients, crop yield index, and multi-relationship approach between input and outputs. Bhatias (1967) productivity method has been used, which is more scientific and is also an improved version of Kandels (1939) ranking coefficient technique. In this model the percentage yield of crop has been adopted instead of yield ranking of individual crop. The productivity index of the study region ranges from 50.44 in Tungrithigan village to 102.98 in Rugrug (Table 2). On the basis of productivity index the twenty five villages of the study area were divided into high (above 100), medium (90 to 100) and low (below 90) categories (Figure 3).

(a) High productivity index: The high productivity index has been observed in the villages of Rugrug, Padum Uftipipting, Sumshadi, Sani, Zangla, Tungdikim, Salapia, Karsha, and Testa. The high productivity in the aforementioned villages is mainly due to improving irrigation system, fertile soil, use of chemical fertilizers, and use of modern inputs and availability of low level land.

(b) Moderate productivity index: The moderate productivity index has been found in Remalakiagam, Rarumony, Kargikh, Techakhasar, Hamiling, Lungimireging, Abran, Phe, and Rantaqusha agrarian villages of the study region. The moderate productivity is mainly due to limited irrigation facilities, small size of holdings and unfavourable climate for the cultivation of Wheat, Grim, Peas and vegetables.

(c) Low productivity index: The low productivity index has been displayed by the villages of the study region namely Ating, Pipcha, Icher, Akshoo, Chah, and Tungithigan. The low productivity is largely due to lack of assured water supply, undulating topography and use of traditional farming techniques.

DISCUSSION

The entire valley of Suru-Zanskar being predominantly mountainous in nature, having climatic condition very harsh and the ecology of the region permitted the man to settle down and carry out simple farming in few suitable pockets which had specific features like relatively low altitude, gentle slopes, adequate soil cover and availability of water for irrigation. Therefore, all the agricultural activities are confined to river valleys during the summer season and the growing season extends for about four months only in a year. The agricultural practices displays marked spatial variations that roughly correspond to elevation ranging between 3500 and 6478 m, there is obviously considerable generalisation in constructing the zone. The utilization of land for cultivation and other land uses (forest and grassland) depends on physiographic conditions particularly terrain, climate, vegetation and slope which themselves are functionally related to altitude zones.

During the last 15 years, the agricultural practices have changed along the villages connected with the roads where mechanization and scientific methods have been introduced in agriculture by using tractors, threshers, fertilizers and hybrid variety of seeds suited to cold arid climate by the farmers. Due to these changes the total cropping area has increased to 2369.45 ha, particularly the areas under wheat, pea and vegetables (25 to 30%) cultivation and also yield per hectare has increased by 30%. The marginal change in weather condition has been noticed particularly with regard to the summer season. The trends in seasonal temperature (period 1987 to 2006) and rainfall pattern (period 1994 to 2006) were investigated. The records were analysed by fitting least square trend line to assess behaviour during different time periods. The analysis reveals that mean maximum as well mean minimum temperature is showing an increasing trend thereby indicating warming during months June to September (Figure 4A to P). The increase in temperature during June to September has resulted in the high Himalayan terrain (exposed valley

Table 2. Agricultural productivity of different agricultural villages of Suru- Zanskar valley.

Villages	Y.W (Y)	A.W (C)	Index	Y.G (Y)	A.G (C)	Index	Y.P (Y)	A.P (C)	Index	Y.F (Y)	A.F (C)	Index	Y.V (Y)	A.V (C)	Index	Bhatia
Rugrug	10	7.02	105.3	11	8	91.0	9.5	19.09	105.56	16.5	106.36	103	9.5	3.93	105.56	102.98
Padum	10	43	105.3	12	77	100	9.5	31.04	105.56	16.5.	64.11	103	9.5	4	105.56	102.84
Uftipibting	10	29.93	105.3	12	65.31	100	9.5	21	105.56	16.5	84.26	103	9.5	3.8	105.56	102.73
Shumshadi	10	20	105.3	10	3.93	83.3	9.5	13.02	105.56	15	3.56	93.8	9	1.14	100	102.16
Sani	10	28.09	105.3	12	29	100	9	4.04	100	16	13.52	100	9.5	3	105.56	102.12
Zangla	10	43	105.3	12	40	100	9.5	35	105.56	15	22	93.8	9.5	2	105.56	102.07
Tungdikim	10	37	105.3	12	56.02	100	9.5	21.03	105.56	16	45.6	100	9	1.5	100	101.93
Salapi	10	14.5	105.3	12	31.9	100	9.5	32	105.56	16	61.42	100	9.5	1.98	105.56	101.87
Karsha	10	28.9	105.3	12	31.4	100	9	15.02	100	16	50.01	100	9.5	2.27	105.56	101.29
Testa	9.5	4	100	12	39.93	100	9.5	18.5	105.6	16	34.97	100	9	2.5	100	101.04
Remalakiagam	9.5	18	100	12	40	100	9	10	100	16.5	21.68	103	9	1.02	100	100.75
Rarumoony	9.5	4.1	100	11	22.5	91.7	9	9	100	17	23.58	106	9	1.17	100	99.335
Kargay	8	1.07	0	12	39	100	8	0.04	0	16	41.64	100	9	1.53	100	98.667
Techa Khasar	10	20	105.3	11	27.6	91.7	9.5	15.7	105.56	15	14.59	93.8	9	1.56	100	98.38
Hamiling	9	9	94.74	10	10.5	83.3	9.5	9.5	105.56	16.5	25.27	103	8	0.98	88.889	98.163
Lungmireging	10	9.5	105.03	11	28.2	91.7	9	17	100	16	27.47	100	9	1.53	100	97.79
Abran	9.5	12.04	100	10	17.09	83.3	9.5	19	105.56	16	17.88	100	9	1.09	100	97.328
Phe	9	8	94.74	11	30	91.7	9	14.5	100	16	51.1	100	9	2.5	100	97.247
Rattaqshah	9.9	14	104.02	10	14.17	83.3	9	9.5	100	16	23.3	100	9	1.15	100	97.147
Ating	9.5	12.97	100	11	28.4	91.7	9	16.3	100	16	14.78	100	8	0.5	88.889	96.68
Pipcha	9.5	2.14	100	10	8.12	83.3	9	2.9	100	16	17.86	100	9.5	1.93	105.56	96.218
Icher	9.5	4.02	100	10	12	83.3	9	3	100	15.5	13.6	96.9	9	1.03	100	92.793
Akshu	9.5	3	100	10	23	83.3	8	9.5	88.889	16	14.5	100	9	1.25	100	90.461
Chea	9.5	5.15	100	10	16.12	83.3	8.5	2.07	0	16	19.31	100	8	0.7	88.889	88.848
Tungri	9.5	12.02	100	11	24	91.7	9	14	100	16.5	43.18	0	9	2	0	50.441

Y = Yield; C = crop, Y.W = yield wheat; Y.G = yield grim; Y.P = yield peas; Y.F = yield fodder; Y.V = yield vegetable; A.W = area wheat; A.G = area grim; A.P = area peas; A.F = area fodder; A.V = area vegetables.

walls and mountain peaks) to warm (3°C) more than free air as they are comprised of dark coloured migmites and granitic gneiss rocks. The high mountains cover nearly 1/3 of the total area of the region and houses large number glaciers encompassing 19.6% of the total area.

Therefore, these glaciers are source of moisture transfer through sublimation and coagulation and continuously release large quantities of latent heat into the atmosphere with rising column which maintains the powerful high pressure in upper stratum in the vicinity of the High Himalayan peaks. The increasing trend in rainfall (Figure 5) is responsible for changes in agricultural practices suitable for crop agriculture system in lower altitudes and also helped in growth of natural grasslands particularly Yarkandi variety in higher altitude. The favourable summer conditions thus

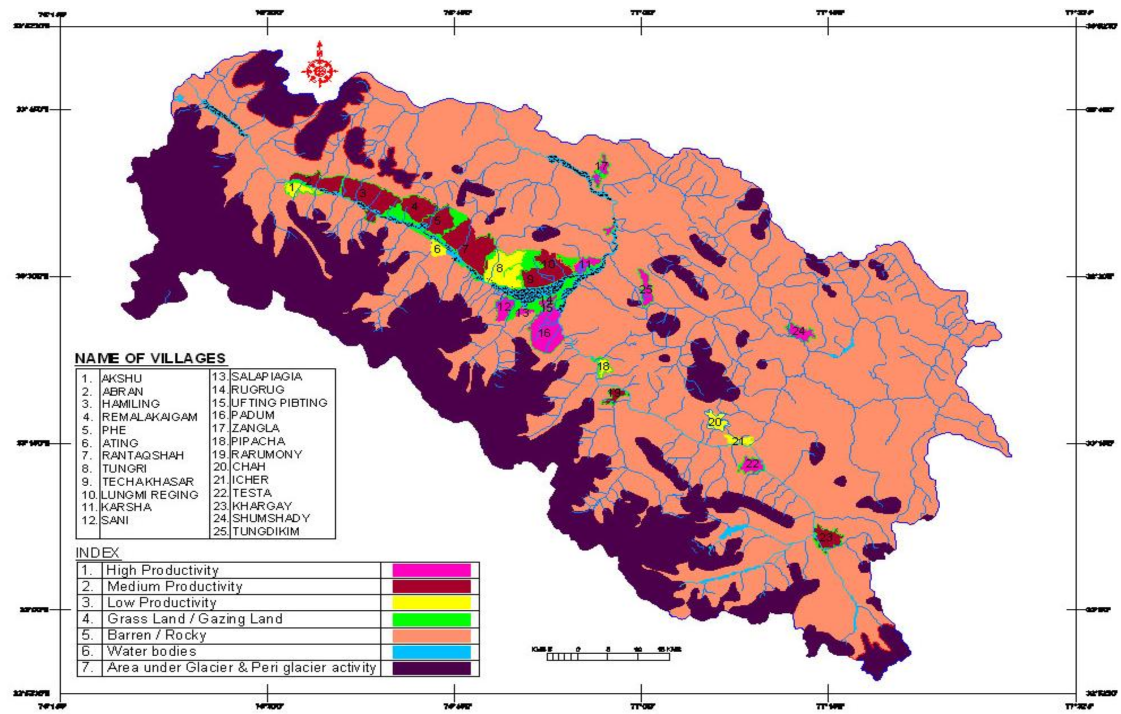


Figure 3. Suru-zanskar valley (agriculture productivity).

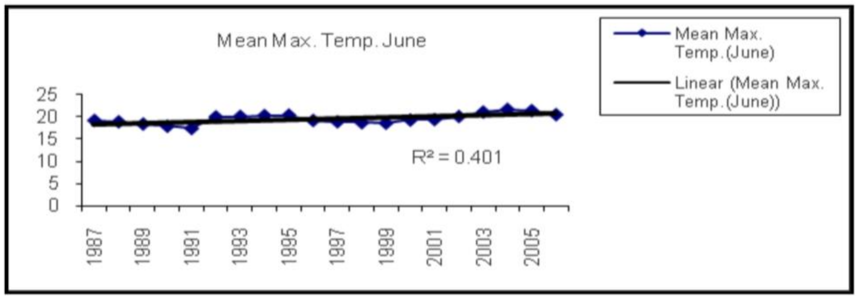
have resulted to increase in the area under cereal crop and marginal increase in fodder crops as well. About 35% of cultivated land is devoted to wheat cultivation, its cultivation has been extended to highly marginal areas such as pasture lands, where crop grows under sufficient moisture and ripens during summer warm temperature. There has been 20.5% increase in pasture land in higher alpine and meadow region due to warm moist climate and similarly there has been marginal reduction (13.45 %) in fodder cropped area in low land region. The increase in forage from grasses and shrubs has greatly helped to meet the entire demands of consumption for cattle population as well the pastoral products including the demand of the domestic fuel in the form of dung mass; as well as the demand of butter, wool and meat. The region is famous for Zanskari butter in the entire Ladakh region. The study conducted in the field to estimate per day average consumption of grass and average excreta released by animals (Cow, Yak, Dzo, Dozmo, Sheep and Goat) to find out the total production of dung from the total animal population (130716). The finding of the study reflects that the Zanskari cattle population generated 32631.52 tons of dung annually by consuming 205013.2 tons of forages from grasses and shrubs of the region. The estimation has been worked out on the modified version of Haidns biomass model (Table 3).

The agriculture practice is one of the most culture traits; entirely the product of geo-ecological setting as it reflects the manner and the extent of utilisation of vast resource base. The study region displays marked spatial variations with regard to agriculture practice that correspond to elevation ranging between 3500 and 6478 m. The entire valley has been divided into five major Agro-ecological zones by digitising different layers of data which pertains to physiography, slope, climate, soil type, soil moisture adequacy index, soil temperature and latter the composite ecological maps were superimposed on soil fertility, irrigation potential and agriculture productivity zones to carve out different agro-climatic boundaries of the zones a) Valley bottom isomesic, mixed cropping zone, b) Rim land isomesic, grim (barley) dominated cropping zone, c) Upland bushy isocryic, meadow zone, d) High alpine pasture cryic, scrubby zone, e) Great Himalaya perigelic, glacier and Peri-glacier zone; out of these, the land is used for cultivation and other uses in four zones only (Figure 6).

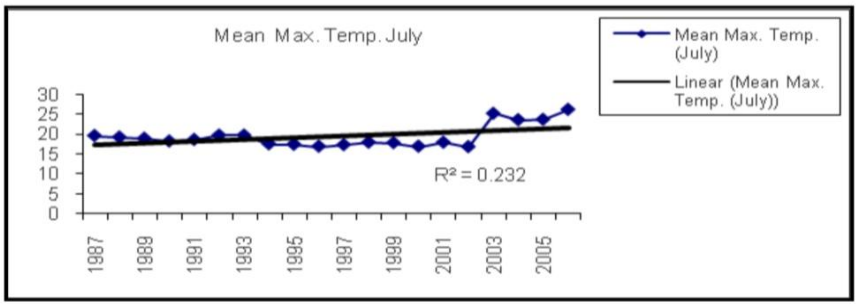
Valley bottom isomesic, mixed cropping zone

Low land zone covers a total area of 24.62 km² (0.35% of the total area). It extends between the altitudes of 3340 to 3600 m having a rolling plains topography with low land where strata are nearly horizontal because of veneer of fluvial deposits by large flood plains at the confluence of Lungnak and Doda River (at Padam village) and along the glacio fluvial terraces of Suru-Zanskar valley. The low lying plains commences from the base of two rivers: Stod River in the north to northwest and Lungnak River in the

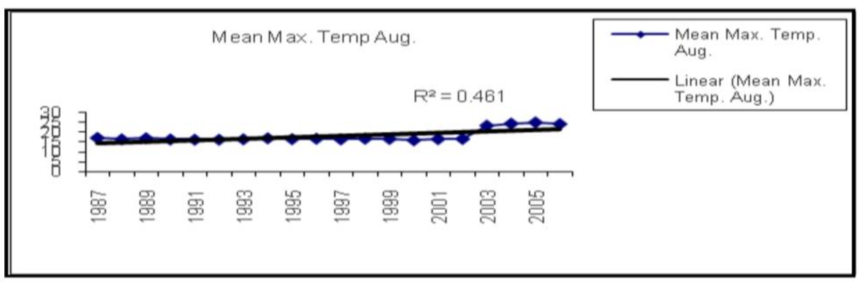
(A)


Mean Max. Temp. June
Mean Max. Temp.(June)
Linear (Mean Max. Temp.(June))
R² = 0.401

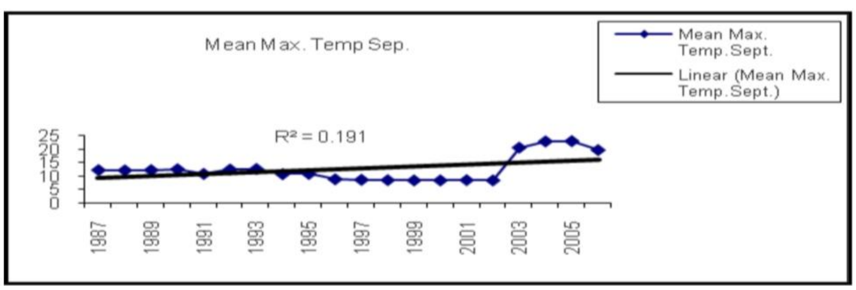
(B)


Mean Max. Temp. July
Mean Max. Temp. (July)
Linear (Mean Max. Temp. (July))
R² = 0.232

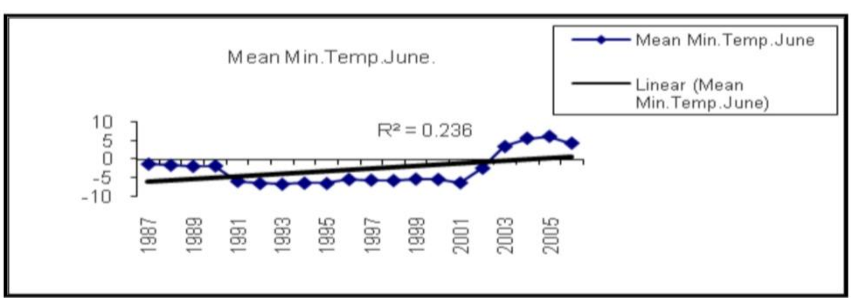
(C)


Mean Max. Temp Aug.
Mean Max. Temp. Aug.
Linear (Mean Max. Temp. Aug.)
R² = 0.461

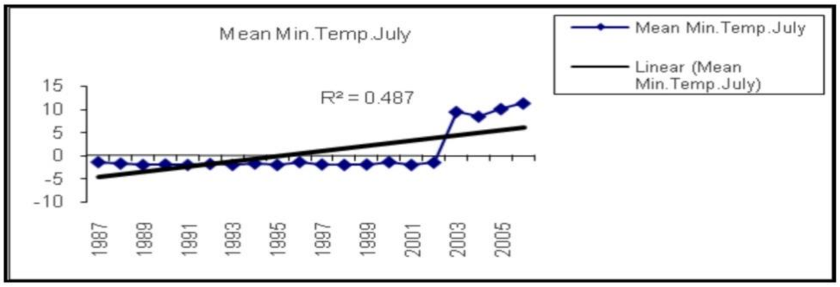
(D)


Mean Max. Temp Sep.
Mean Max. Temp.Sept.
Linear (Mean Max. Temp.Sept.)
R² = 0.191

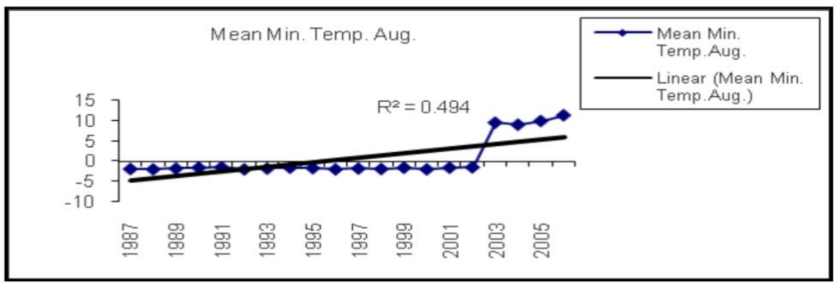
(E)


Mean Min.Temp.June.
Mean Min.Temp.June
Linear (Mean Min.Temp.June)
R² = 0.236

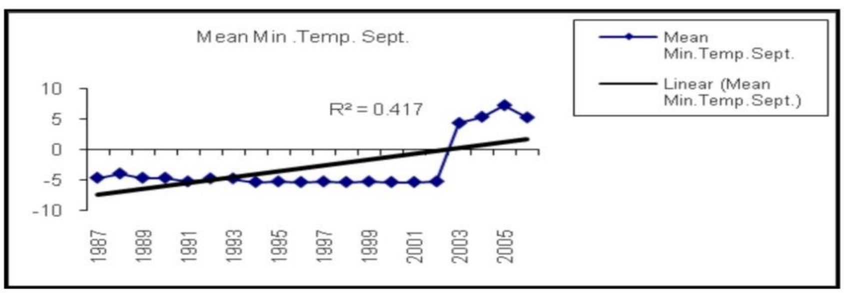
(F)


Mean Min.Temp.July
Mean Min.Temp.July
Linear (Mean Min.Temp.July)
R² = 0.487
15
10
5
0
-5
-10
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005

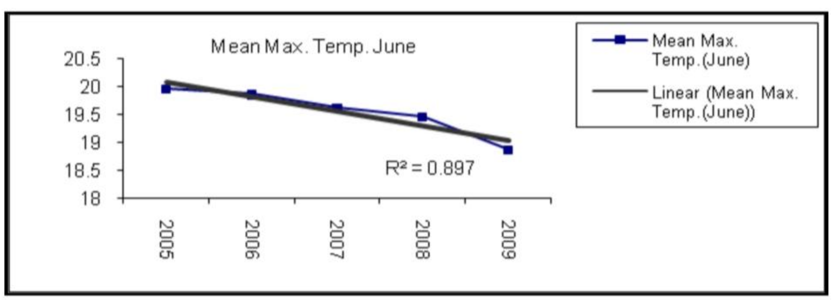
(G)


Mean Min. Temp. Aug.
Mean Min. Temp.Aug.
Linear (Mean Min. Temp.Aug.)
R² = 0.494
15
10
5
0
-5
-10
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005

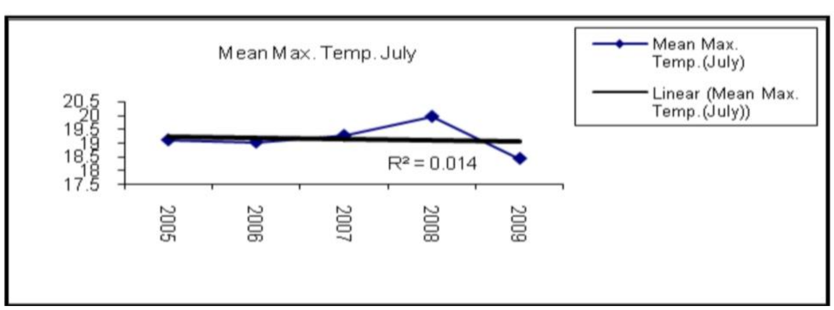
(H)


Mean Min .Temp. Sept.
Mean Min.Temp.Sept.
Linear (Mean Min.Temp.Sept.)
R² = 0.417
10
5
0
-5
-10
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005

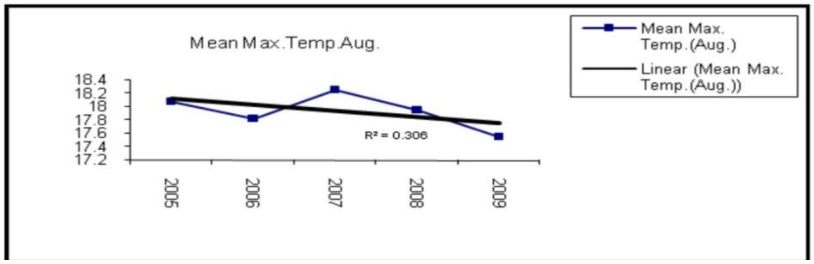
(I)


Mean Max. Temp. June
Mean Max. Temp.(June)
Linear (Mean Max. Temp.(June))
R² = 0.897
20.5
20
19.5
19
18.5
18
2005
2006
2007
2008
2009

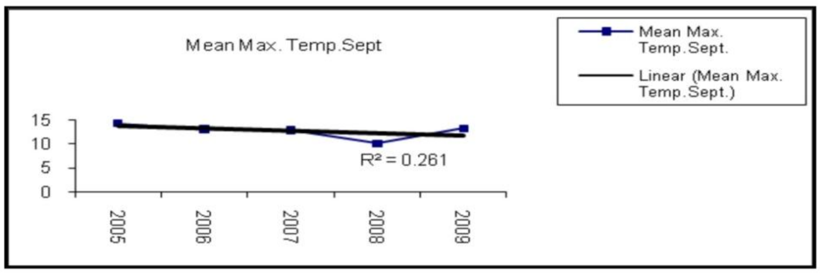
(J)


Mean Max. Temp. July
Mean Max. Temp.(July)
Linear (Mean Max. Temp.(July))
R² = 0.014
2005
2006
2007
2008
2009

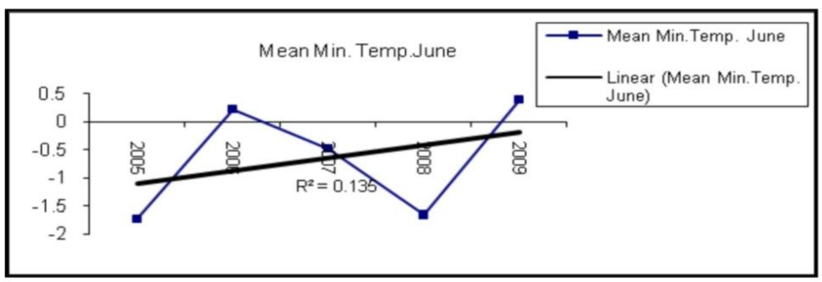
(K)


Mean Max.Temp.Aug.
Mean Max. Temp.(Aug.)
Linear (Mean Max. Temp.(Aug.))
18.4
18.2
18
17.8
17.6
17.4
17.2
R² = 0.306
2005
2006
2007
2008
2009

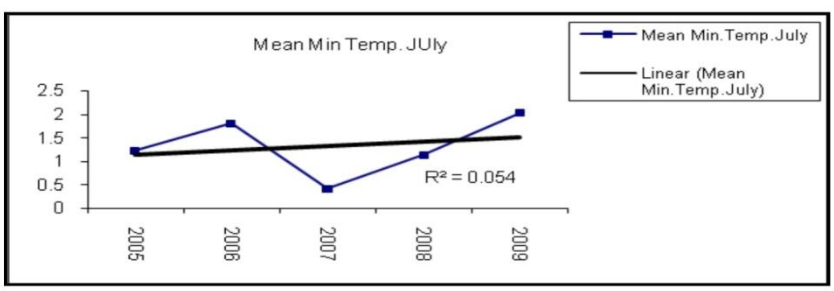
(L)


Mean Max. Temp.Sept
Mean Max. Temp.Sept.
Linear (Mean Max. Temp.Sept.)
15
10
5
0
R² = 0.261
2005
2006
2007
2008
2009

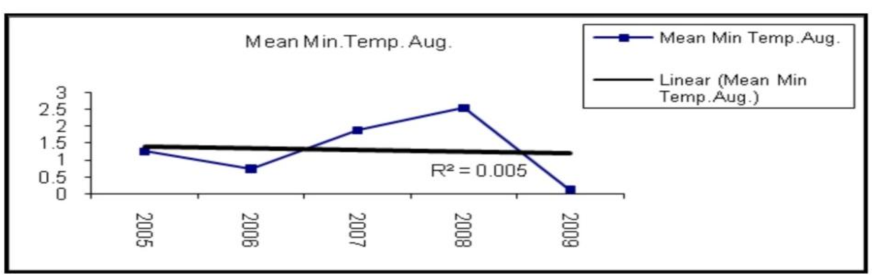
(M)


Mean Min. Temp.June
Mean Min.Temp. June
Linear (Mean Min.Temp. June)
0.5
0
-0.5
-1
-1.5
-2
R² = 0.135
2005
2009

(N)


Mean Min Temp. JUly
Mean Min.Temp.July
Linear (Mean Min.Temp.July)
2.5
2
1.5
1
0.5
0
R² = 0.054
2005
2006
2007
2008
2009

(O)


Mean Min.Temp. Aug.
Mean Min Temp.Aug.
Linear (Mean Min Temp.Aug.)
3
2.5
2
1.5
1
0.5
0
R² = 0.005
2005
2006
2007
2008
2009

(P)

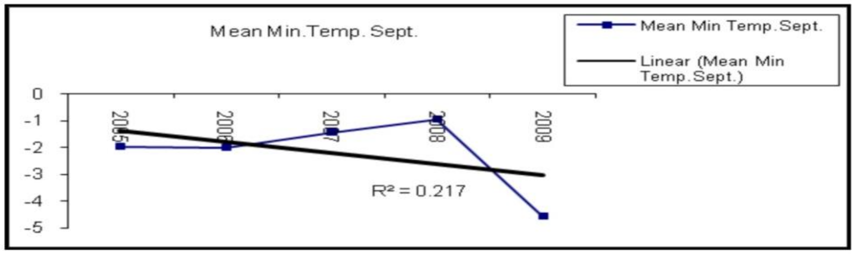


Figure 4. A to P trends in maximum and minimum temperature (A to H shows trends in maximum and minimum temperature of Drass (1987 to 2005) and I to P reflects trends in maximum and minimum temperature of Durung Durung Glacier valley 2005 to 2009).

east. The flood plain and terraces are fertile to support agriculture system. The soils of this zone are sandy clay loam having a maximum of moisture holding capacity (16.72%) and favourable soil temperature of 8 to 12°C that supports cultivation of Wheat, Grim, leguminous plants (Peas) and Vegetables. The region has a cold semiarid type of climate having short summer season of four months (June to September), long winter season of seven months (October to April) and May as transitional period. During summer period mean monthly maximum temperature ranges from 23.68 to 19.7°C. The summer precipitation is mainly in the form of rains (95 mm) and winter in the form of snow. The average amount of monthly precipitation varies between 21.4 to 100.6 mm. During the last 10 years, there has been an increasing trend in the behaviour of summer temperature as well as rainfall, that has led to changes in agriculture land use practices and also helped farmers to increase the production of cereal crops as well, the vegetables particularly wheat and pea. Due to favourable climatic conditions 25% of grim (barley) cultivated area has been switched over to wheat cultivation. The region has characteristic vegetation of Salix *Elegaus salix alba, Salix fragills, Populus euphratica, Populus candicans, Populus nigira* etc. A sizeable chunk of this zone is occupied by grasses on shallow soils which are unfit for cultivation. Grass species like *Cenchrus citiaris*, *Cenchrus setigerus* etc grow under willow and popular trees that prevent soil erosion and give cool and moist climate feeling during the summer season. The grass covered area in the zone is increasingly dispersed due to increase in the need for agricultural activity. The zone provides an important site for the growth of settlements at Padum, Sani, Salipia, Rugrug etc.

Rim land isomesic, grim dominated cropping zone

It extends between the altitudes of 3600 to 3800 m above mean sea level. Climate of this zone is cold semi arid characterized by severe cold dry winter and moderately hot summer. The temperature and moisture regimes of soil are isomesic and aridic. The high temperature and low humidity (20 to 40%) in this zone has resulted in water loss from the soil and plant surfaces. The soils of this zone are sandy loam to sandy clay loam with boulders. The high sand content in the soil is primarily derived from the scree slope due to action of weathering and mass movement processes. Further, these areas are subjected to severe wind action. The soils have high permeability and low water holding capacity (below 13.28%). The temperature of the soils of this zone ranges from 8 to 12°C. Most of the agriculture land in this zone is found along the stabilised alluvial fans. Farmers of this zone prefer to grow grim rather than wheat due to short growing season and cold arid climate. Further, grim tolerates soil salinity more than the wheat which explains the increased area under grim crop in the zone. Grass lands are observed on the slopes which are gentle towards the base and gradually steeper upwards. The dominant species of vegetation found in this zone are *Physochlina* spp, *Ephedra gerardina*, *Podophllum emodi*, *Dioscorea*, *Sussuria lappa* etc. The zone covers an area of 337.97 km² (4.82% of the total area). Settlements are found at Akshu, Abran, Hamiling Phe, Rantaqshah, Ating etc.

Upland bushy isocryic, Meadow zone

It extends between the altitudes of 3800 to 4000 m above sea level. This strip is an assemblage of glacial and glacio-fluvial soil derived from moraines, eskers and kame terraces. The continuum of landform is comprised of glacio fluvial sediments, grading from ice contact environments to distant outwash. The zone covers an area of 414.18 km² (5.91% of the total area). The dominant lithology of the zone is sandstone, shale,

Table 3. Suru-Zanskar Valley: average consumption of grasses/ bushes and excreta released by the livestock population.

S/N	Type of animals	Total livestock population (2001)	Average excreta released kgs/day/animal head in wet form	Average excreta released kgs/day/animal head in dry form	Total excreta Released in tones /day in dry form by Zanskari Cattle population	Total excreta Released in tones /year in dry form by Zanskari Cattle population	Per day consumption in Kgs/animal head	Total consumption of live stock population in tones per day	Total consumption in tones per year
1.	Cow	6594	5.5	1.76	11.60544	4235.986	16.5	108.80	39449.2
2.	Yak	1577	6.4	2.04	3.21708	1174.234	25.86	40.78	14884.7
3.	Dzo	1223	6.4	2.04	2.49492	910.6458	25.86	31.62	11541.3
4.	Dzomo	813	6.4	2..04	1.65852	605.35	25.86	21.02	7672.3
5.	Sheep	95,000	1.8	0.57	54.15	19764.75	2.87	272.65	99517.25
6.	Goat	24,000	1.8	0.57	13.68	4993.2	2.87	68.88	25141.2
7.	Other specific equines	1.509	5.4	1.72	2.59548	947.3502	12.36	18.65	6807.25
	Total	130716			89.40144	32631.515		562.4	205013.2

siltstone and granites. The climate of this zone is pleasantly warm and semi dry in summer though cold and very cold in winter. Isocryic soils (temperature 5 to 8°C) with poor physical conditions like sandy sand texture. The soils have higher rate of infiltration and percolation. The dominant grass species found in the zone are Red clover, alfa-alfa, Lucerne and Lentil. Red clover and Lucerne is doing well in the zone. Farmers prefer to rear livestock in this zone during the peak summer season. As a result of dry summers and heavy grazing pressure, the vegetation is sparse semi-desert steppe, the plants being mainly deep rooted tussock or semi-woody plants with un-palatable foliage. The region experiences rill erosion along the valley walls and sheet erosion in broad valley basins leading to the formation of large scree cone along the valley walls and undulated basin areas.

High alpine pasture cryic, scrubby zone

The zone extends between 4000 to 4200 m. It covers an area of 3909.23 km² (55.84% of the total area). This zone experiences harsh climate, dryness from extreme heat and cold and very low rainfall. The zone is composed of crystalline rocks like granites and gneisses and sedimentary formation like shale, sandstone and limestone. The slope of this zone is 32 to 40°. The cryic soils of this region are stony sands, shallow, severely eroded and are classified as Arctic "cryorthents". Sandy and gravely texture lead to low water holding capacity (WHC), low micro nutrient availability due to high concentration of $CaCO_3$, low organic matter and are prone to wind erosion. Soil temperature of this zone ranges from 0 to 5°C. In the zone, wild plants grow to a certain density. Here they produce, besides the nutritious grasses and herbs, a number of well known alpine flowers, such as Gentian Edelwei B or Padicularies. The zone is a home of famous Poppy (Genus Meconopsis) known as the romantic flower of the Himalayas. Hippophae scrub is the major woody component found in the zone which is used as material for roofing of houses. Large grazing grounds/pastures are found near the snout of the glaciers.

These grazing grounds / pastures are good seasonal grazing fields for the domestic livestock. During the post winter months or after melting of snow (Mid April to Mid June) the Zanskari farmers drive their livestock to these pastures where new new stocks of fresh grasses are grown spontaneously. The whole pasture land located in the zone is divided among villages and villagers graze their animals accordingly. In this way, a specific grazing field is grazed in the same season every

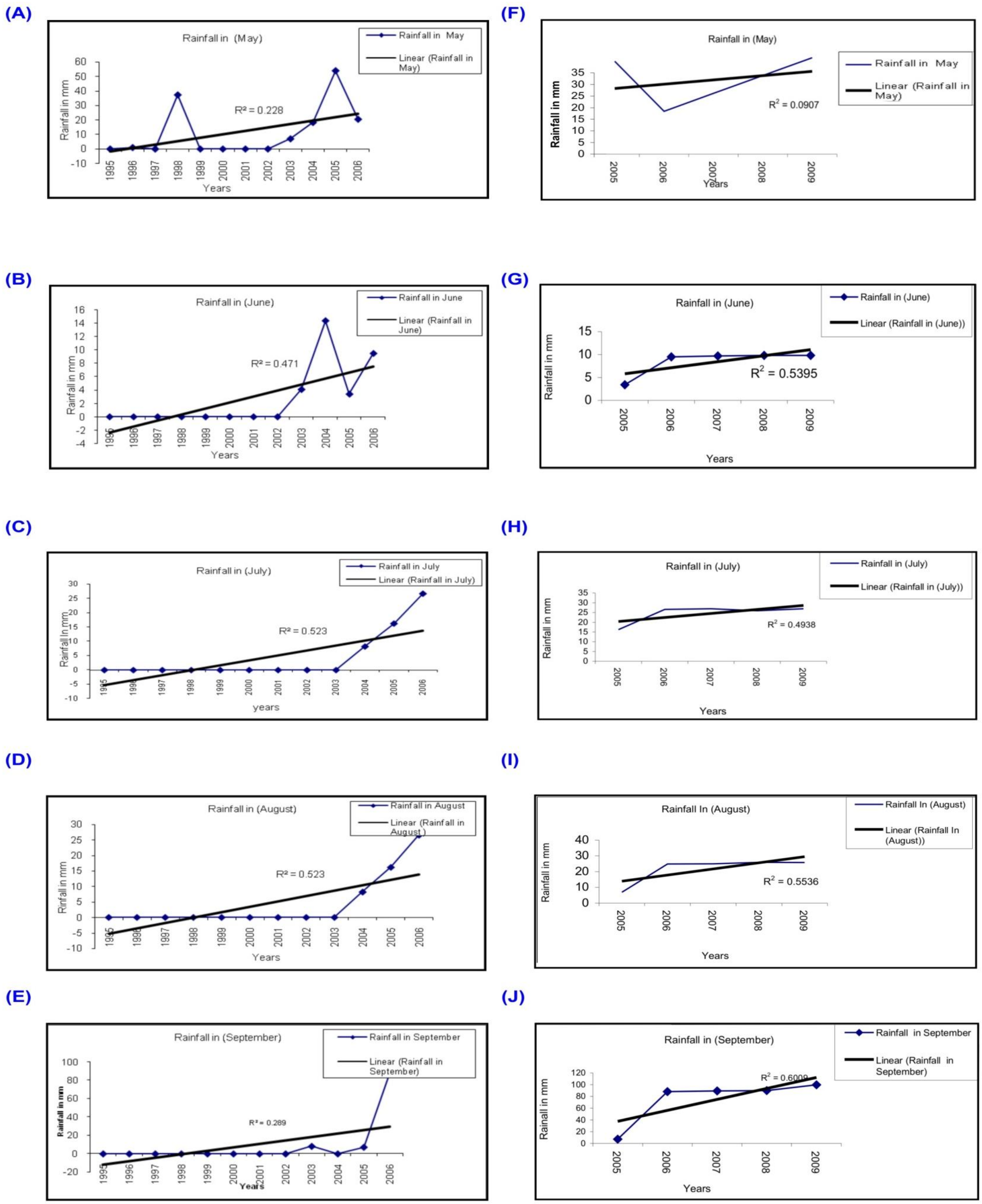


Figure 5. A to J Trends in rainfall (A to E shows trends in rainfall of Drass 1995-2006 and F to J reflects trends in rainfall of Durung during Glacier valley 2005 to 2009).

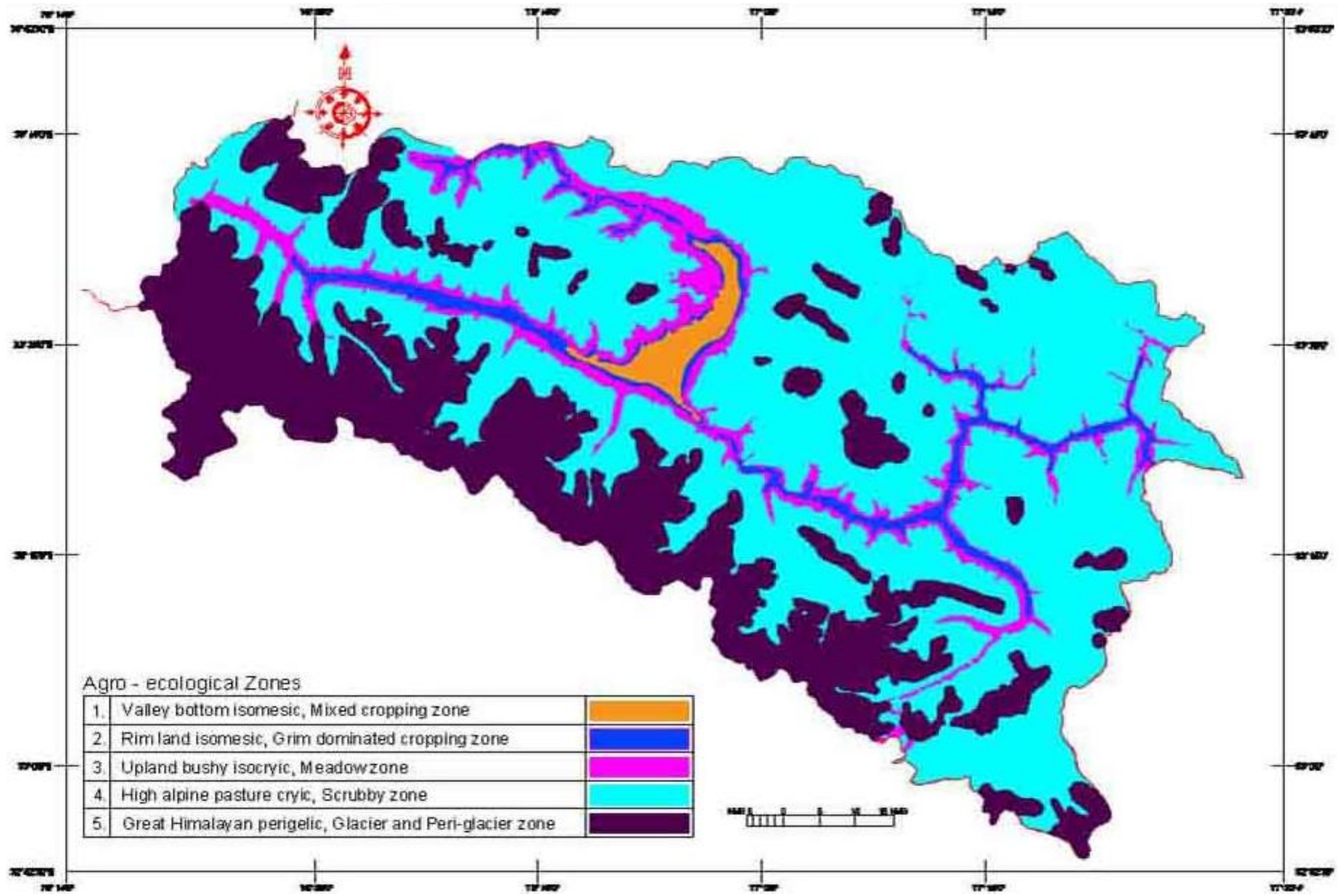


Figure 6. Suru-Zanskar valley (Agro-ecological zones).

year. This practice has caused depletion in the vegetative cover in higher mountain pasture lands. Some farmers send their women and children to watch the animals and establish temporary shelters (Doksa) at the pasture land. The big animal's like dzo, dzomo, yak etc do not require proper look and are left free to graze in the pastures. In general there is a seasonal movement of animals from each village to a series of high altitude camps. Sometimes due to shortage of fodder there is large migration of animal and some cattle from all over central Zanskar are sent to graze on the Pensi-la or in the Ralakun grazing fields, which results in overgrazing leading to ecological imbalance and slope failures. Various glacier and peri-glacier features are found throughout the zone.

Great Himalayan Perigelic, Glacier and Peri-glacial zone

The zone experiences high mountain climate in which practically all the precipitation is in the form of snow for more than nine months. It covers an area of 2314.78 km² (33.05% of the total area). The zone is covered with mountains of crystalline rocks. Large number of glaciers/ ice fields inhabits this zone with concentration in the south west part. Landforms of 40° and above 40° slope are found in the zone. Some of the large glaciers are Durung Drung, Haptal, Kange, Haggshu, Yaranchu, Nateo, Katkar, Tidu etc. The zone serves as main ice field divide of Zanskar and Kishtwar regions. The perigelic soils of this zone are primarily composed of moronic matter having un-assorted sediments ranging from clay to boulders. The zone is a house of some of the important mountain passes which connects the Zanskar region with other parts of the state. Overall, the zone is a store house of a large number of glaciers which contributes melted water to perennial rivers of the region, used to irrigate agricultural fields at lower altitudes.

Conclusion

Zanskar valley is one of the most active geomorphological environments on earth. It displays a greater degree of relief created by enormous glacier system, which extended into Zanskar gorge. The repeatedly rapid advance of large tributary glaciers to the main valley floor have considerably influenced the slope form by creating complex irregular terrain of moraine complexes produced by transfer of large volume of sediments to the main valley. The post glacier modification by peri-glacier weathering activity, fluvial and mass movement processes have lead to enormous accumulation of sediments in the form of glacio-fluvial terraces, alluvial and scree cones along the valley walls. Three glacio-fluvial terraces have been observed at different elevation ranging form 3500 to 4600 m.

The Zanskar valley can conveniently be divided into upper (Himalayan flank), Middle (Zanskar upland) and lower (mountain rim and Valley basin floor) reaches. The lower stretch of the valley comprises of alluvial plain girdled by river terraces produced by Doda River in north-northwest and Lungnak River in the east that confluence at Padum as Zanskar .Three glacial terraces have been differentiated at elevation range of 3550, 3700 and 4200 m.

The recent climatic change (during the last one decade) has been induced by marginal increase in mean monthly maximum temperature during the summer season (June to September). The increasing trend in maximum temperature has lead to sublimation of ice from glacier body resulting in increasing trend in summer precipitation. These changes have encouraged the farmers to switch over to wheat cultivation from barley cultivation, in areas were soil is conducive for its growth. Further in adjoining mountainous region where crop production has least feasibility, livestock rearing is the natural alternative supported by more conducive sub-arid cold climate during the summer season. The substantial availability of green edible bio-mass has efficiently routed through live stock link of food chain. In view of these changes, it is suggested that inter-disciplinary research on fodder and feed, including environment of bio-mass is urgently needed in this region.

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