AN ANALYSIS OF PAST THREE DECADE WEATHER PHENOMENON IN THE MID-HILLS OF SIKKIM AND STRATEGIES FOR MITIGATING POSSIBLE IMPACT OF CLIMATE CHANGE ON AGRICULTURE

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ABSTRACT

The weather data of 30 years (1981 to 2010) recorded at Tadong meteorological station located in the mid-hill location of Sikkim was analyzed. The average annual rainfall of 30 years at Tadong was 3097.78 mm, spread over in 156.90 rainy days/year. In the past 30 years, the number of rainy days has increased at the rate of 0.5 days per decade and mean annual rainfall has increased at the rate of 41.46 mm per decade. However, if weather data of last two decades (1991-2000 to 2001-10) alone was taken into account, the number of rainy days as well as the annual rainfall at Tadong has decreased at the rate of 0.72 days/year and 17.77 mm/year, respectively. The mean minimum, mean maximum and average temperature at Tadong was 13.99 ^{o}C, 23.29 ^{o}C and 18.64 ^{o}C, respectively. The difference between mean minimum and mean maximum temperature across months was 9.30±1.35 ^{o}C. The mean maximum temperature did not exhibit any significant departure from long term average but the mean minimum temperature have increased 1.95 ^{o}C in 30 years from 1981-2010 (or 0.06 ^{o}C increase/year). Further, the rate of increase in the mean minimum temperature between the decade 1991-2000 to 2001-10 was greater *i.e.* 0.81 ^{o}C/decade or 0.08 ^{o}C increase/year. The year 1986, 1988, 1989, 2006 and 2009 had experienced low precipitation (< 2751.62 mm) hence classified as drought years. The years 1990, 1995, 1996 and 2003 received high rainfall *i.e.* ≥ 3443.94 mm (μ 3097.78+σ 346.16 mm) hence classified as abnormal year. The remaining 21 years *i.e.* 1981, 1982, 1983, 1984, 1985, 1987, 1991, 1992, 1993, 1994, 1997, 1998, 1999, 2000, 2001, 2002, 2004, 2005, 2007, 2008 and 2010 were normal years. The mean minimum, maximum and average relative humidity (RH) at Tadong was 51.91%, 86.04% and 70.98%, respectively. The difference between the mean maximum and mean minimum RH was 30.13%. The mean duration of sunshine hours was 3.66 hrs/day. The duration of sunshine was low (<15 hours/week) from 18th July to 5th August. Climate change is a global phenomenon. An understanding of the past weather phenomenon at the regional or local level would help researchers and planners to predict the possible impact of global warming on agriculture sector and also to plan measures to reduce the ill effects of warming. Some of the measures to reduce warming are discussed in this article.

KEYWORDS: *Global warming, Rainy days, Annual rainfall, Mean minimum temperature, Mean maximum temperature, Average temperature, Relative humidity*

Maize crop is vulnerable to hailstorms during its initial growing period

Plate 1: Submerged paddy field applied with Nitrogenous fertilizers is the source of CH_4 and N_2O emission. However, in Sikkim paddy is cultivated in terraced field under organic condition. Hence the rate of CH_4 and N_2O emission is relatively low

Change is a feature of earth's climate, but faster rate of change due to increased human interference is a great concern to all. According to a report of the Intergovernmental Panel on Climate Change (IPCC 2007a), the average rise in surface temperature in the past 100 years (1906 to 2005) was 0.74°C but the rate of warming in the last part of 50 years (1956-2005) was little higher (0.13°C/decade) than the rate of warming in the first part of 50 years (0.07 °C/decade). Global warming refers to continuing rise in the average temperature of the Earth's atmosphere. Several factors or processes external to the climate system such as radiative forcing, volcanic eruption, changes in solar luminosity, and variations in Earth's orbit around sun influences climate. They are called external forcing. However, researchers and planners call attention on the *radiative forcing*, which denotes changes in atmospheric gas compositions mainly due to increased concentration of green house gases. Greenhouse gases (GHG) are the gases in the atmosphere that absorb and emits radiation within the thermal infrared range. The higher concentration of GHG and their absorption and emission property leads to what is known as 'greenhouse effect'. The major GHG are water vapour, carbon dioxide (CO_2), methane (CH_4), ozone (O_3), nitrous oxide (N_2O) and other pollutants. The readers may note that the major gases of atmosphere such as nitrogen (N_2), oxygen (O_2) and argon (Ar), are not GHG since they are transparent (not absorbent) to infrared radiation.

The earth receives energy from the solar radiation predominately in the visible part of the spectrum (380-750 nm) and in the form of short wavelengths and some in nearby-visible part of the spectrum (*i.e.* UV and IR). Roughly 1/3rd of the solar energy that reaches the top of atmosphere is reflected directly back to space and the remaining 2/3rd is absorbed by the earth surface (IPCC 2007b). To maintain its thermal equilibrium, the earth radiates some amount of absorbed energy back into atmosphere and space. As earth is colder than the sun, it radiates back in longer wavelengths (400-1000 nm), primarily in the infrared part of the spectrum (Mitchell 1989). At these wavelengths, GHG were largely transparent to the incoming short wave solar radiation but more absorbent to the outgoing long wave infrared radiation. As a result, each layer of atmosphere with GHG absorbs some of the heat radiated upwards from earth surface or lower layers of atmosphere. But, again to maintain its own thermal equilibrium, the GHG, re-radiates the absorbed heat in all directions, both upwards and downwards. The upwards transmission of heat has got no significant effects on outer space but the downward emission of heat causes more warmthness on the earth surface. The process by which thermal radiation from the earth surface is absorbed by the atmospheric GHG and then re-radiated in all directions resulting in warming of lower atmosphere (troposphere and stratosphere) and earth surface was termed as '*greenhouse effect'* by Joseph Fourier, in 1824, due its analogy to the similar effect in real greenhouses. Naturally occurring amounts of GHG have a mean warming effect of about 33 °C (59 °F) on earth surface (Wikipedia 2011). However, increasing human population, industrialization, motorization and combustion of fossil fuels have increased the amount of greenhouse gases in the atmosphere, resulting in increased radiative forcing from GHG *i.e.* increased amount of heat absorption and re-radiation, and increased warmthness on the earth surface. This is a global concern today. The increase in the level of CO_2 (36%) and CH_4 (148%) in the post-industrialization era (since 1750) amply exemplify the above fact.

Factors such as deforestation, intensive agriculture and animal husbandry do contribute to the release of GHG into atmosphere, thereby degrading stratospheric ozone and increasing biologically harmful UV radiation to reach the earth's surface. Deforestation affects carbon reuptake resulting in increased concentrations of CO_2 in the atmosphere; enteric fermentation in cattle, microbial decomposition of manure and cultivation of crops like paddy in submerged soil release CH_4 into the atmosphere. Excess application of nitrogenous fertilizers leads to leaching and release of N_2O into the atmosphere. According to IPCC report (2007) world agricultural practices accounts for 54% of methane emissions, 80% of N_2O emissions, and 90% CO_2 emissions. Land clearing method prevailing in the North Eastern Region of India such as *Jhum* or shifting cultivation and *bun* or slash and burn system directly releases GHG and particulate matter such as soot into the air by burning biomass. Intensive agriculture with excess use of nitrogenous fertilizers along with intensive animal husbandry followed in States like Punjab and Haryana, rice cultivation in submerged / waterlogged soils followed in States like West Bengal, Assam, Bihar etc releases CH_4 and N_2O into the atmosphere. Fortunately, these practices are either less or absent in Sikkim. Nonetheless, as warming is a global phenomenon it has impact on Sikkim too. Considering the fragile location of Sikkim in the Eastern Himalaya, its altitudinal variation (270-8580 m amsl) and its ecosystems, it is necessary to analyze the past weather phenomenon of Sikkim, so as to prepare an action plan at local level for mitigating any adverse effects arising out of changes in the climate.

MATERIALS AND METHODS

The daily weather data such as minimum and maximum temperature, minimum and maximum relative humidity, rainfall, evaporation, humidity, and duration of sunshine recorded from 1981 to 2010 at the meteorological observatory located in the campus of ICAR Research Complex for North Eastern Hill Region, Sikkim Centre, Tadong was taken for this study. The observatory is located at 1350 m above the mean sea level (msl) and represents the mid-hill location (climate) of Sikkim.

1. RESULTS AND DISCUSSION

1.1 Rainy days: From the rainfall data of three decades (1981-2010), the mean weekly, monthly and yearly rainy days have been estimated. A day is considered as rainy day when it received rainfall ≥2.5 mm. At Tadong, on an average 156.90 days in a year have received rainfall equal to or greater than 2.5 mm which was slightly lesser than the number of rainy days at Gangtok (163.6 days). Almost all the months have received rainfall (Fig 1), however, the period from April to September have experienced >15 days rainfall per month. The highest number of rainy days were found during July (26.53 days) followed by August (24.70 days), June (23.23 days), May (19.90 days), September (19.47 days) and April (15.67 days). The number of rainy days were few during March (8.87 days), October (8.03 days), February (4.57 days), Jan (2.27 days), November (2.13 days) and December (1.53 days). Out of 30 years, the highest rainy days (181 days) were observed during 2003 with total annual rainfall of 3740.60 mm whereas, the year 2009 had the lowest rainy days (128 days) with annual rainfall of 2458.86 mm. The rainfall data have showed that in the past three decades, the number of rainy days have increased at the rate of 8.7 days/decade from 1981-90 (decade mean=153.5 days/year) to 1990-2000 (decade mean=162.2 days) but decreased at the rate of 7.2 days/decade for the period from 1991-2000 to 2001-10 (decade mean=155 days). To be precise, the decline was more conspicuous after 2005. In 2005, the number of rainy days was 157 which matched well with the long-term average rainy days of past 30 years (156.90 days) but it decreased to 141 days in 2006, slightly went up to 146 days during 2007, in 2008 it again increased nearer to long term average (157 days) but afterwards it decreased sharply (128 days in 2009). Again in 2010 it showed a U-turn *i.e.* increased to 165 days. The pattern of rainy days also indicates a three year cycle of increase followed by decrease. Therefore, the rainy days forecast for 2011-2013 could well show an upward trend of between 165 to 169 days at 75-80% probability level.

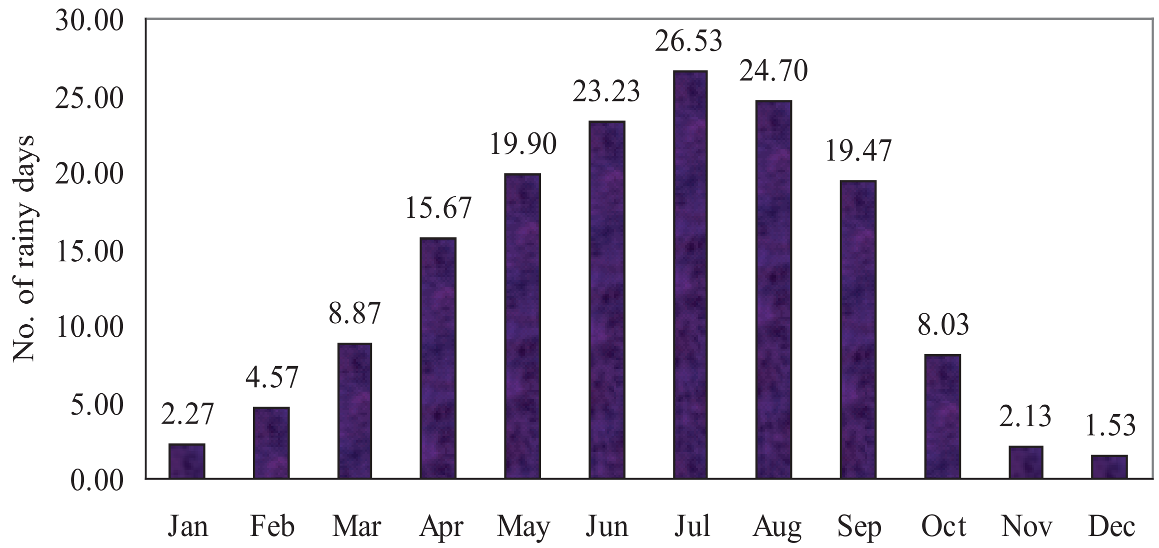

Fig. 1: Month-wise average number of rainy days at Tadong (mid-hills of Sikkim) from 1981-2010

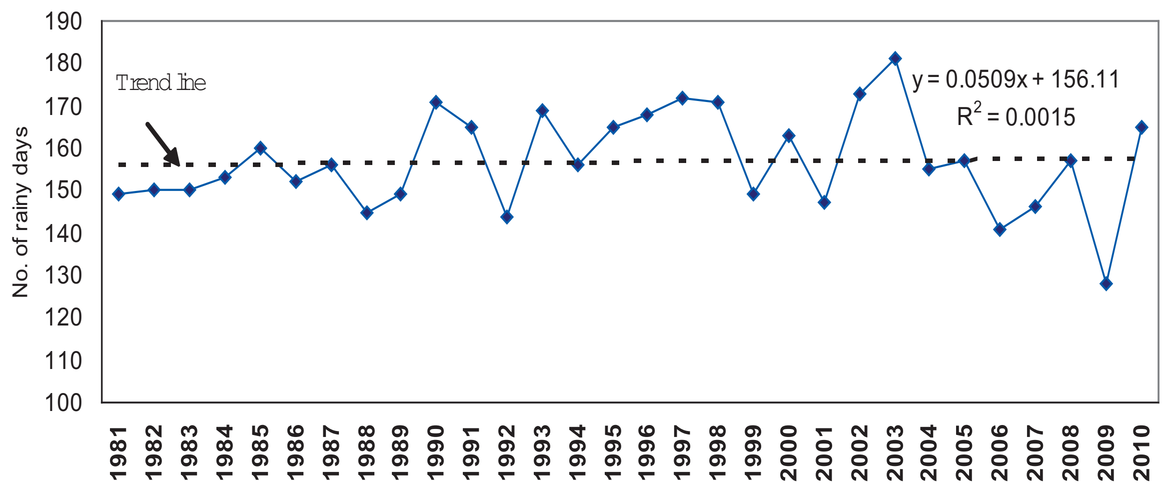

Fig. 2: Graph depicting the year-wise average number of rainy days at Tadong from 1981 to 2010

1.2 Weekly rainfall: The average annual rainfall of 30 years at Tadong was 3097.78 mm. The weekly rainfall data showed that 30 out of 52 weeks have received rainfall >20 mm and 20 weeks have received rainfall <20 mm. If the average crop water demand is considered as 3 mm rainfall/day, then 20 weeks may fall under deficit weeks. Twenty third week of the year coinciding with 4th to 10th June has experienced the highest rainfall of 134.40 mm/week whereas, the 48th week corresponding to 26th November to 2nd December has experienced the minimum rainfall of 1.21 mm/week. Singh (2001) reported the suitability of log normal distribution function for predicting the annual maximum rainfall at Tadong. The same was used in the present study. The weekly rainfall corresponding to their probabilities were calculated by Weibull's formula and plotted on log-normal probability paper. After plotting, the line of best fit has been drawn through these points and expected rainfall amounts at 10% to 90% probabilities has been calculated (data not shown). It was found that at 80 per cent probability, appreciable amount of rain water would be available from 17th week till the end of 37th week *i.e.* from 23rd April to till 16th September. Therefore, farmers may begin nursery preparation for paddy, finger millet etc from 17th week onwards. The maximum one day rainfall of 209 mm with 25 years recurrence interval is expected to occur around Tadong. This value may be used for design of soil conservation structures in the mid-hills. The maximum one day rainfall of 231 mm and 254 mm is expected to occur with 50 years and 100 years recurrence interval respectively. These values may also be used for design of large water storage structures.

1.3 Monthly rainfall: Thirty years of monthly rainfall data at Tadong since 1981 has revealed that the maximum rainfall has occurred during the month of July (537.44 mm/month) followed by June (533.03 mm), August (492.05 mm), May (451.56 mm), September (391.79 mm), April (291.69 mm), October (149.71 mm) and March (118.27 mm). On the other hand, December has experienced the lowest rainfall (19.66 mm) followed by January (23.21 mm), November (31.15 mm) and February (58.23 mm). From the data, it can be seen that the dry spells would occur from November to February and therefore, irrigation facilities must be augmented during this period for raising winter season crops such as mustard, cabbage, cauliflower, radish, wheat, etc; life saving irrigation should also be augmented for cattle and perennial/ plantation crops like citrus and large cardamom.

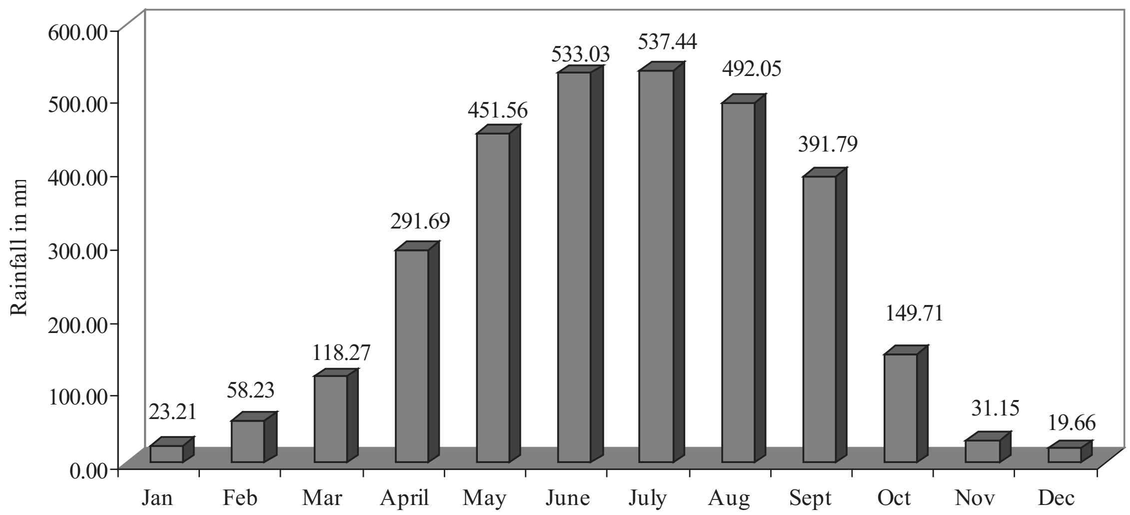

Fig. 3: Average monthly rainfall at Tadong during the period 1981 to 2010

The expected monthly rainfall at different probability levels has been worked out using Weibull's formula (Table 1). Maize is a major cereal crop of Sikkim sown during February. The actual rainfall during the month of February in the past 30 year was 58.2 mm/day spread over in 4.57 days. The expected rainfall during February in the forthcoming years would also be somewhere between 3.2 cm and 29 mm at 30% and 80% probability which is insufficient for field preparation and maize germination. Therefore, maize sowing can be delayed till the 2nd fortnight of February. Once pre-monsoon showers have occurred after 15th February, farmers may take up maize sowing without risk because sufficient precipitation would occur in the subsequent weeks/month. The month April, May, June, July, August and September are expected to receive rainfall from 180-610 mm. It is therefore, advisable to begin kharif season agricultural activities from April onwards so that minimum of two crops can be taken up utilizing rain water. Crops like baby corn, maize, urd, beans, finger millet and paddy are the suitable crops during this period. The month of May is expected to receive minimum rainfall of atleast 190 mm/month at 80% probability level and in the subsequent three months plenty of rainfall (375-610 mm/month) is expected to occur. Thus, farmers may initiate nursery activities for paddy during May itself, puddling and transplanting can be taken up at the end of May. The high rainfall is advantageous for crops like paddy and large cardamom but detrimental to crops like ginger. High precipitation coupled with high humidity and low sunshine hours is expected during monsoon period. This would increase the spread of ginger soft rot. Therefore, adequate drainage around ginger field combined with prophylactic spray of fungicide (if organic ginger, use only biocontrol agents) may be resorted.

Table 1: Monthly expected rainfall (mm) at different levels of probability and its impact on agricultural activities

Month	Monthly expected rainfall (mm) at probability			Impact on agricultural activities / Remarks
	30%	50%	80%	
January	29	12.3	3.2	The occurrence of rainfall would be low at all probabilities. As a result, late moisture stress may happen to rabi crops, large cardamom and mandarin which in-turn would hasten maturity of crops like mustard or affect the yield of late maturing varieties. Water sources from natural spring would also be reduced. So, life saving irrigation has to be provided for safeguarding crops and animals.
February	55	26.8	8	It is the ideal time for sowing maize. Although the expected rainfall at the start of February (at 80% probability) is insufficient for field preparation and maize germination, once pre-monsoon showers have occurred, farmers may take up maize sowing because in the subsequent weeks /month good precipitation is expected.
March	130	96	60	
April	320	260	180	
May	500	408	190	Sufficient rainfall will be available at all probability levels; hence farmers may initiate nursery activities for paddy.
June	610	500	375	Rainfall is sufficient for paddy transplanting.
July	580	522	440	Heavy rainfall is expected to occur during this period; Farmers are advised to drain excess water from the field particularly in ginger field; due to high humidity, stored food grains may spoil quickly. They have to be safeguarded against fungal attack /spoilage.
August	540	478	390	
September	380	310	120	
October	180	123	68	It is ideal time for sowing rabi season (winter) crops like mustard, wheat, cabbage, cauliflower, peas, etc. The expected rainfall is sufficient at all probabilities for starting nursery / sowing activities. Sometime excess rainfall would also happen which may delay field preparation. Therefore, if there is cessation of rainfall for one week, farmers may take advantage of the cessation period for ploughing their field.
November	87	48	18	The expected rainfall is insufficient at 50% and 80% probability. Crops need supplementary irrigation from sources other than rain water.
December	19	6.7	1.5	

In general, rabi season agricultural activities commence after the cessation of heavy rainfall. It coincides with the month of October. The actual rainfall during the month of October in the past 30 years was 149.71 cm. The expected rainfall during October is somewhere between 68 cm and 120 mm at 30% and 80% risk level. This rainfall is sufficient enough to begin field preparation and sowing of winter season crops. However, the later part of winter season experiences soil moisture stress. The stress situation begins at the start of December. The month of December is expected to receive very low rainfall, from a mere 1.55 mm at 80% probability level to 19 mm at 30% probability level. The rainfall expected in the subsequent month (January) is also very low (3.2-29 mm/month) at different risk level. As a result late moisture stress could be visualized on seasonal crops like mustard, cole vegetables as well as perennial crops like large cardamom and mandarin. The high maximum temperature and longer duration of sunshine during January-February may hasten maturity of crops like mustard or affect the yield of late maturing varieties. Water sources from natural springs would also be reduced. Hence, life saving irrigation has to be arranged for crops and animals.

1.4 Seasonal rainfall: A year has been divided into three seasons *i.e.* pre-monsoon, monsoon and post-monsoon based on the spread of rainfall. In Sikkim, the pre-monsoon season spreads over March to June, monsoon season from July to October and post-monsoon season from November to February. The average rainfall for 30 years during the monsoon period was 1570.99 mm, equal to 50.71% of the total rainfall. The pre-monsoon period also receives good amount of rainfall *i.e.*1394.54 mm or 45.02% of the total precipitation. Conversely, the post-monsoon period was a dry period receiving only 132.25 mm rainfall, equal to 4.27% of the total rainfall. Using the seasonal and yearly rainfall data, the probability analysis for seasonal and annual rainfall has been carried out. The expected rainfall at different probability levels is shown in Table 2. The estimated pre-monsoon season rainfall at 70% probability level *i.e.* leaving only 30% at risk, was 1230 mm, which is sufficient for taking pre-monsoon crops like maize and beans. Similarly, the estimated monsoon season rainfall at 70% probability level was 1500 mm, which is also sufficient for taking water-loving crops like paddy. However, the post-monsoon rainfall (67.5 mm) as well as annual rainfall (2800 mm) at 70% probability is far-below the 30 years average rainfall for the season or year and therefore, irrigation facilities have to be improved especially during the post-monsoon period so as to tap the yield potential of winter season crops like mustard, cole vegetables, wheat etc.

Table 2: Expected seasonal and annual rainfall (mm) at different levels of probability

Season / Year	**Average rainfall (mm) from 1983-09**	**Expected rainfall (mm) at probability**				
		10%	**30%**	**50%**	**70%**	**90%**
Pre-monsoon (Mar-Jun)	1394.54 (45%)	1750	1500	1350	1230	1000
Monsoon (Jul-Oct)	1570.99 (51%)	1820	1700	1600	1500	1320
Post-monsoon (Nov-Feb)	132.25 (4%)	240	150	95	67.5	40
Annual	**3047.34**	**3400**	**3100**	**3000**	**2800**	**2550**

1.5 Annual rainfall: The average annual rainfall from 1981 to 2010 at Tadong was 3097.78 mm which is roughly three times higher than the all India average rainfall (11182.8 mm) of the period 1901-2003 (Guhathakurta and Rajeevan 2006). The year 2003 has witnessed the highest rainfall of 3740.60 mm which was 23% higher than the 30 years average followed by 1996, the second highest rainfall year (3711.49 mm or 22% higher than the normal). Conversely, the year 2009 had received the lowest rainfall (2458.86 mm or -19% departure from the normal) followed by the year 1986 (2490.10 mm or 18% less rainfall). It appear that the annual rainfall at the mid-hills of Sikkim follows 2-3 year cyclic pattern *i.e.* 2 to 3 years of high rainfall (than the normal) followed by 2 to 3 years of low rainfall and therefore, a trend line drawn using the moving average of 3 consecutive years well matches with the actual rainfall (Fig 4). A perusal of decade-wise mean rainfall since 1981 to 2010 have revealed that the mean rainfall has increased at the rate of 30.21 mm/year for the decade from 1981-90 (decade mean=2955.64 mm/year) to 1990-2000 (decade mean=3257.65 mm) but decreased at the rate of 12.44 mm/annum for the decade from 1991-2000 to 2000-10 (decade mean=3080.02 mm). If the whole period from 1981-90 to 2001-10 is taken into account then the number of rainy days is increasing at the rate of 0.05 day/year and the amount of rainfall is also increasing at the rate of 4.15 mm/year. But if the mean annual rainy days and annual rainfall is compared between the decade 1991-2000 *versus* 2001-10, the decrease in the number of rainy days at the rate of 0.065 day/year and quantity of precipitation at the rate of 17.77 mm/year was discernible, which is matter of concern for all.

1.6 Index of wetness: The annual index of wetness was calculated for 30 years by dividing the actual rainfall of a year by the average rainfall of 30 years. The values were plotted in the graph and shown in Fig 5. The index of wetness gives an idea about years with high precipitation (if the values are >1) and years with low precipitation (if the values are <1). The year, 2009 received the lowest rainfall of 2548.86 mm and thus, it has

Rural households are increasingly shifting to multi-occupational and multi-locational strategies for income generation

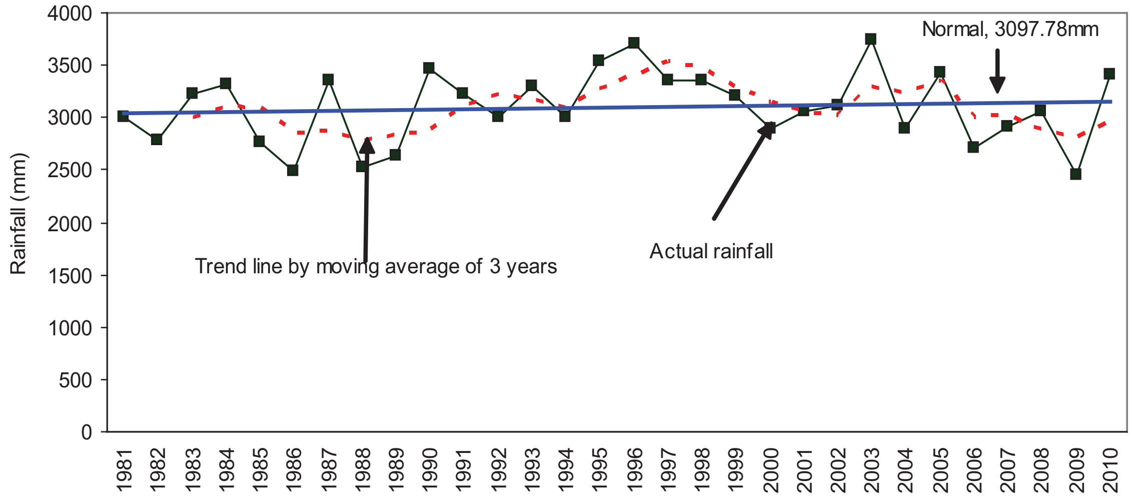

Fig. 4: The trend in annual rainfall at Tadong for the period from 1981-2010

the lowest value of index of wetness (0.79) whereas the year 2003 was the highest rainfall year, hence the index of wetness was 1.21. Out of the 30 years, the index of wetness was >1.00 for 15 years *viz.*, 2002, 1999, 1983, 1991, 1993, 1984, 1998, 1997, 1987, 2010, 2005, 1990, 1995, 1996 and 2003 (shown in the increasing order of rainfall) whereas, the index of wetness was <1.00 in another 15 years *viz.*, 2009, 1986, 1988, 1989, 2006, 1985, 1982, 2000, 2004, 2007, 1992, 1981, 1994, 2001 and 2008 (shown in the increasing order of rainfall). In other words, 50% of the period from 1981 to 2010 has experienced rainfall greater than the normal and 50% of the year received rainfall lesser than the normal. Wider negative departure from the normal (low rainfall years) happened during 2009, 1986 and 1988 and wider positive departure (very high rainfall years) happened during 2003 and 1996. This is again an issue of concern. The excess rainfall years might have witnessed more runoff leading to more soil erosion and landslide whereas, the low rainfall years might have affected the water availability to rabi crops resulting in lower yields.

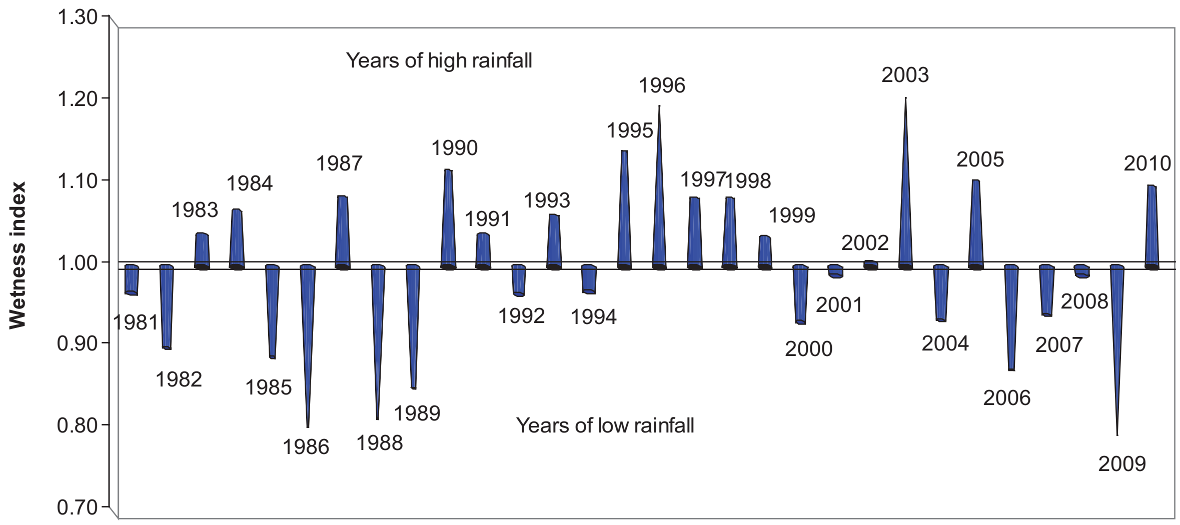

Fig. 5: Index of wetness at the mid-hills of Sikkim over a period of three decades (1981-2010)

1.7 Normal, abnormal and drought months: According to Sharma *et al.* (1979) any month receiving precipitation in-between 50 to 200% of the average monthly rainfall is a normal month; an abnormal month in one which receives precipitation more than twice the average monthly rainfall and any month receiving precipitation <50% of the average monthly rainfall is the drought month. Any year receiving rainfall between mean (μ) ± standard deviation (σ) is the normal year. Any year receiving rainfall less than or equal to μ-σ is called drought year whereas, any year receiving rainfall more than or equal to μ+σ is called abnormal year. On the basis of the above definition, the rainfall for a month to be a drought, abnormal or normal with the long term average rainfall of 1981 to 2010 was calculated and was plotted in a chart (Fig 6). It can be seen from the Fig 6 that about 265 months (73.61% of the total months) during the period were normal months; 21 months or 5.83% of total months were abnormal months and 74 months or 20.56% of the total months were of drought months. During the period of past 30 years, drought has occurred in the months of October, November, December, January, February and March. In 17 out of 30 years, December was the drought month, followed by November (15 out of 30 years), February (11 out of 30 years), October and January (10 out of 30 years). Similarly, the abnormal month (excess rainfall than the normal) also happened to be in the months October, November and December (4 each out of 30 years). Any year which has received rainfall ≤ 2751.62 mm (μ 3097.78-σ 346.16 mm) was a drought year. Accordingly, the year 1986, 1988, 1989, 2006 and 2009 which had precipitation < 2751.62 mm were classified as drought years for Tadong. Any year that has received rainfall ≥ 3443.94 mm (μ 3097.78+σ 346.16 mm) were ought to be an abnormal year, therefore the years 1990, 1995, 1996 and 2003 were considered as abnormal years. Years receiving rainfall between 2751.62 and 3443.94 mm were the normal years. Therefore, the remaining 21 years (70% of the total years) *i.e.* 1981, 1982, 1983, 1984, 1985, 1987, 1991, 1992, 1993, 1994, 1997, 1998, 1999, 2000, 2001, 2002, 2004, 2005, 2007, 2008 and 2010 were the normal years.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1981	N	D	D	N	N	N	N	N	N	D	N	D	NY
1982	D	N	D	N	N	N	N	N	N	D	N	AN	NY
1983	N	N	N	N	N	N	N	N	N	D	D	N	NY
1984	N	D	N	N	N	N	N	N	N	N	D	N	NY
1985	N	N	N	N	N	N	N	N	N	N	AN	N	NY
1986	D	D	N	N	N	N	N	N	N	N	D	N	DY
1987	D	N	N	N	N	N	N	N	N	N	D	D	NY
1988	D	N	N	N	N	D	N	N	N	D	D	N	DY
1989	N	N	N	D	N	N	N	N	N	D	AN	D	DY
1990	N	N	N	N	N	N	N	N	N	D	D	D	AN-Y
1991	AN	D	D	N	N	N	N	N	N	D	D	N	NY
1992	N	N	D	N	N	N	N	N	N	N	D	N	NY
1993	N	N	N	N	N	N	N	N	N	N	N	D	NY
1994	N	N	N	N	N	N	N	N	N	AN	N	D	NY
1995	N	N	D	N	N	N	N	N	N	D	AN	AN	AN-Y
1996	AN	N	N	N	AN	N	N	N	N	AN	D	D	AN-Y
1997	N	N	N	N	N	N	N	N	N	N	D	AN	NY
1998	D	N	N	N	N	AN	N	N	N	N	D	D	NY
1999	N	D	D	N	N	N	N	N	N	AN	N	D	NY
2000	N	D	N	N	N	N	N	N	N	N	AN	D	NY
2001	AN	AN	AN	N	N	N	N	N	D	N	N	D	NY
2002	N	D	N	N	N	N	N	N	N	N	D	N	NY
2003	N	AN	N	N	N	N	N	N	N	AN	D	AN	AN-Y
2004	N	N	N	N	N	N	N	N	N	N	N	D	NY
2005	N	N	N	N	N	N	N	N	N	N	D	D	NY
2006	D	N	N	N	N	N	N	N	N	D	N	D	DY
2007	D	D	D	N	N	N	N	N	N	N	N	D	NY
2008	D	D	N	N	D	N	N	N	N	D	N	N	NY
2009	D	D	N	N	N	N	N	N	N	N	D	D	DY
2010	D	D	AN	N	N	N	N	N	N	N	N	D	NY

D Drought month or year **N** Normal month or year **AN** Abnormal month or year

Fig. 6: Chart showing year-wise drought, normal and abnormal months at Tadong

2. Air Temperature: The mean minimum, maximum and average temperature at Tadong over a period of 30 years was 13.99 ºC, 23.29 ºC and 18.64 ºC, respectively. The temperature from 1st week to 13th week was below long-term average. At 14th week (2-8th April) the average temperature (18.45 ºC) nears to the long term average, and then rises gradually (Fig 7). From 25th week to 34th week, coinciding with 2nd July to 26th August, the temperature remains high around 23±1 ºC. Then it starts declining and touches just below average (17.54 ºC) at 44th week (29th October 4th November). The 32nd week has experienced the maximum temperature of 23.50 ºC. In terms of monthly average, the mean minimum temperature during January was 6.92 ºC and the mean maximum temperature was 16.49 ºC (Fig 7). The minimum as well as the maximum temperature rise upward and reach the peak during July (Tmin=19.52 ºC, Tmax=26.53 ºC and Tmean =23.03 ºC) and August (Tmin=19.38 ºC , Tmax=26.84 ºC and Tmean =23.11 ºC). During August, the mean minimum temperature was 19.38 ºC and the mean maximum temperature was 26.84 ºC. After August, temperature decreases and during December, the mean minimum and maximum temperature reaches to 8.34 ºC and 18.32 ºC, respectively. During

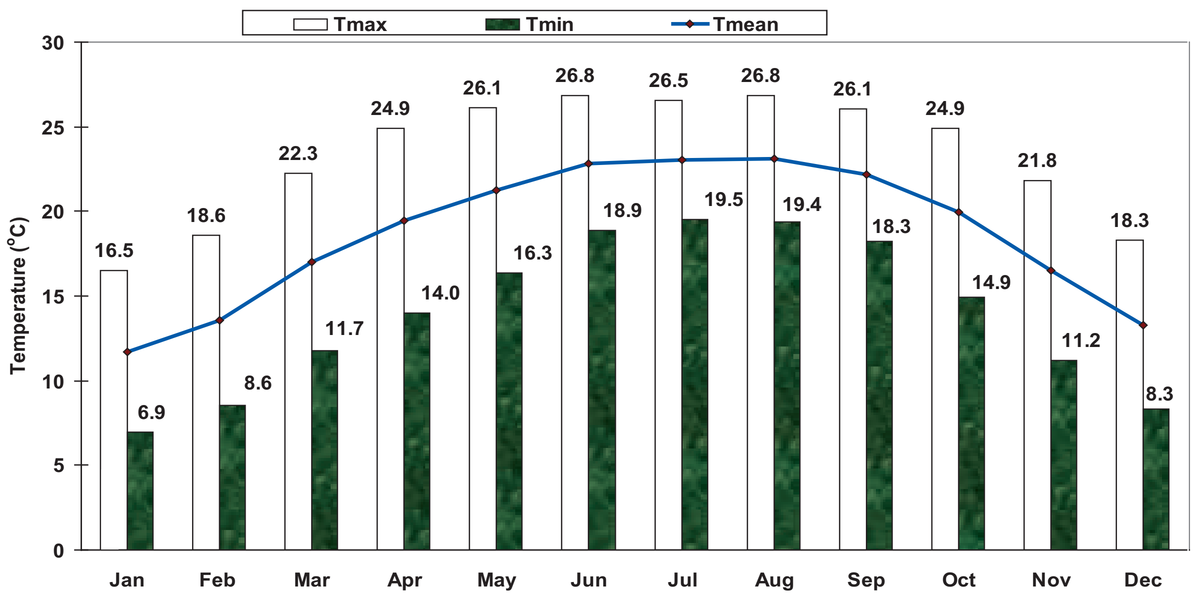

Fig. 7: Minimum, maximum and average temperature at Tadong for the period 1981 to 2010

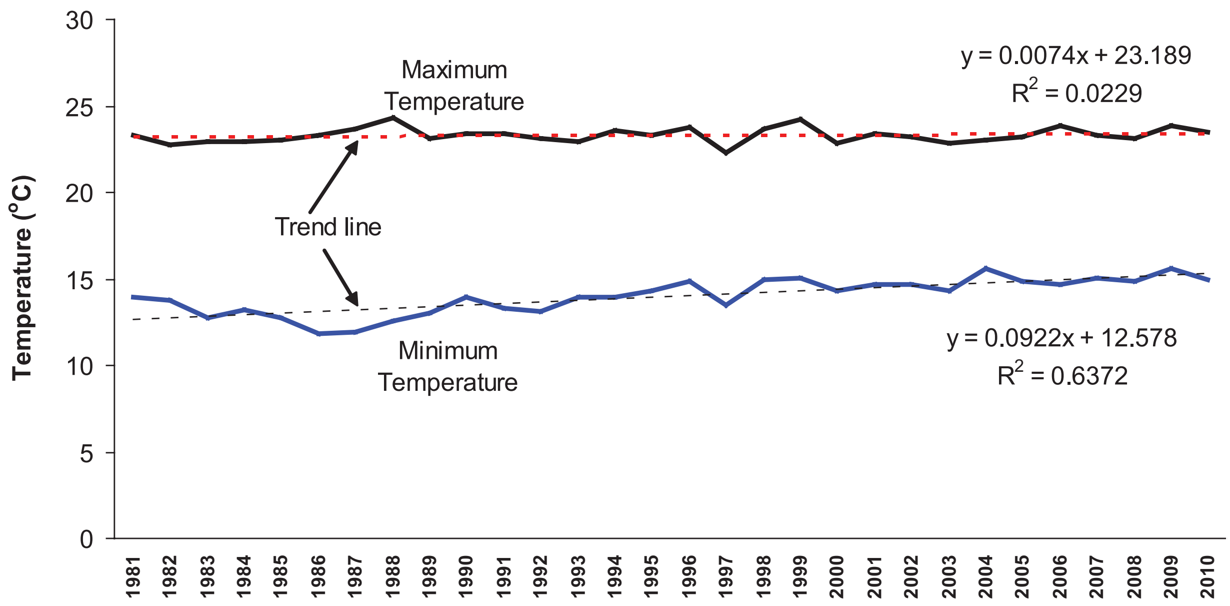

Fig. 8: The trend in minimum and maximum temperature at Tadong for 30 years

winter months (Dec-Feb) the minimum temperature fluctuates around 6.92-11.21°C. Maize seed requires above 8 °C for germination. During January the minimum temperature is 6.92 °C which rises to 8.55 °C during the second fortnight of February. Therefore, farmers are advised to sow maize after a shower and if the minimum temperature rises to 8 °C.

During the past 30 years, the difference between the minimum and maximum temperature across months was 9.30±1.35 °C; the difference was narrow (7-8 °C) during rainy season (June-September) but wider (9.5-11 °C) at two points of time *i.e.* just before and just after winter (during March-April and during October-November). The narrow difference between the minimum and the mean maximum temperature during June, July, August and September could be attributed to rise in the minimum temperature. In the past 30 years, the highest annual average temperature was recorded in 2009 (19.71 °C) and then in 1999 (19.61 °C), while the lowest annual average temperature was recorded during 1986 (17.57 °C) and then in 1987 (17.80 °C).

The index of hotness was calculated by dividing the actual mean temperature of a year by the average mean temperature of 30 years. The results are presented in the graphical form (Fig 9). The index gives an idea about the years of high temperature (if the values are >1) and years of low temperature (if the values are <1). Out of the 30 years, 17 years (2009, 1999, 1996, 2004, 1998, 2006, 2010 and 2007) were the high hotness year while 13 years were low hotness year (1986, 1987, 1983, 1997, 1985, 1984, 1989 and 1982).

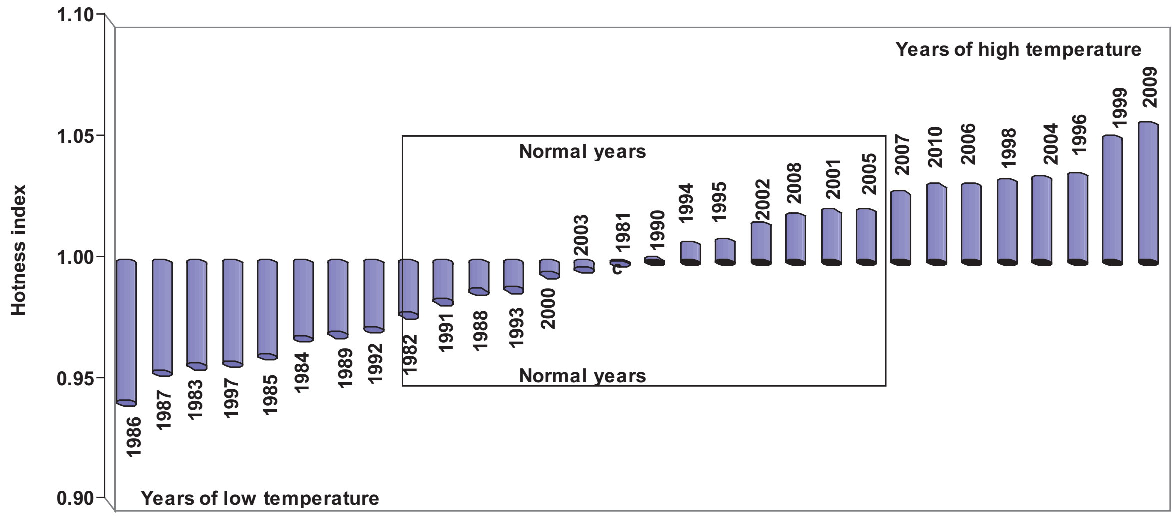

Fig 9. Index of hotness in the mid-hills of Sikkim over a period of three decades

3. Relative humidity (RH): The mean minimum, maximum and average RH for the period 1981-2010 was found to be 51.91%, 86.04% and 70.98%, respectively. Generally, the difference between maximum and minimum RH in the past 30 years was 30.13%. The difference was narrower (18.96-23.05%) during the monsoon period (June to Sept) and wider (31.48-38.85%) during winter to early spring (Oct-Mar). From 17th week onwards (23-29th April) the average RH (70.24%) rises to above average, reaching the peak at 28th week or 9-15th July (82.34%) and then declining gradually (Fig 10). The RH went down below average at 42nd week (69.51%) coinciding with 15-21st September. During winter months, particularly from November to February, the RH was lower (average RH =64.85-65.93%) and the lowest RH (60.57%) in a year was recorded during the 51st meteorological week coinciding with 17-23rd December. The period from May to October was the high humid period at Tadong. During this period, the minimum RH was >50% and the maximum RH was >85%. This high humidity may favour pathogenic and storage fungi to grow and spread faster. Therefore, any stored seeds and food grains get spoiled easily. Further, the spread of blast disease of rice and leaf spot in pulses would also be faster during this period. Hence, adequate precautionary measures need to be taken to prevent spoilage.

The annual average relative humidity in the past 30 years in the mid-hills of Sikkim has dwindled between 67.96% and 74.73% with a mean of 70.98% (Fig 11). The year 1992 has experienced the lowest relative humidity (67.96%) whereas the year 1996 has experienced the highest RH (74.73%). However, from 2000 to 2009 wider variation in the values of average RH could be noticed.

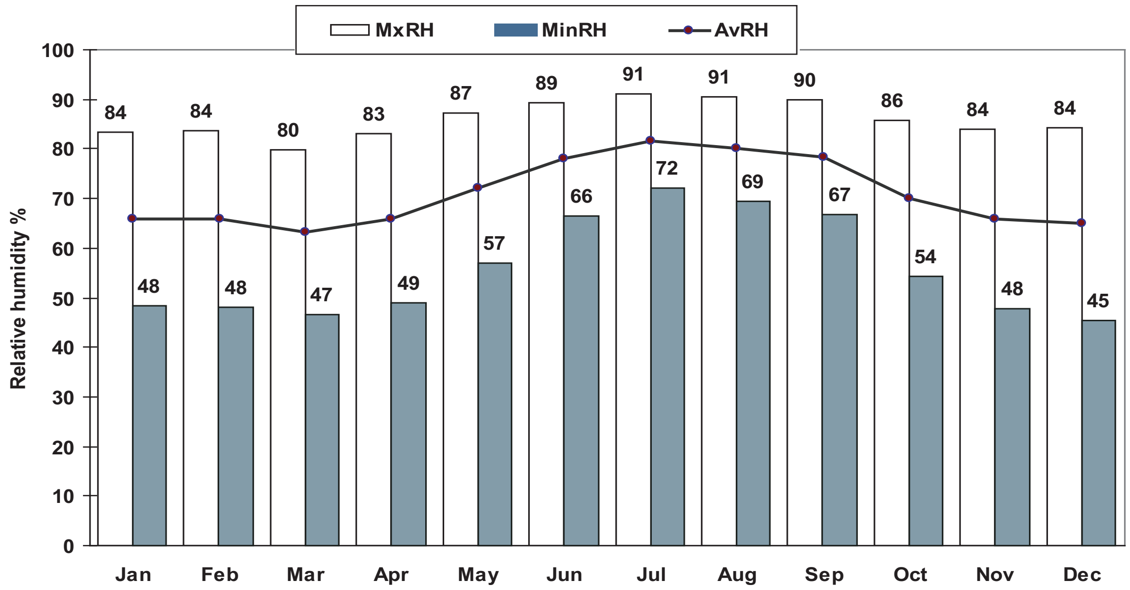

Fig. 10: Average monthly mean, maximum and average RH at Tadong from 1981 to 2010

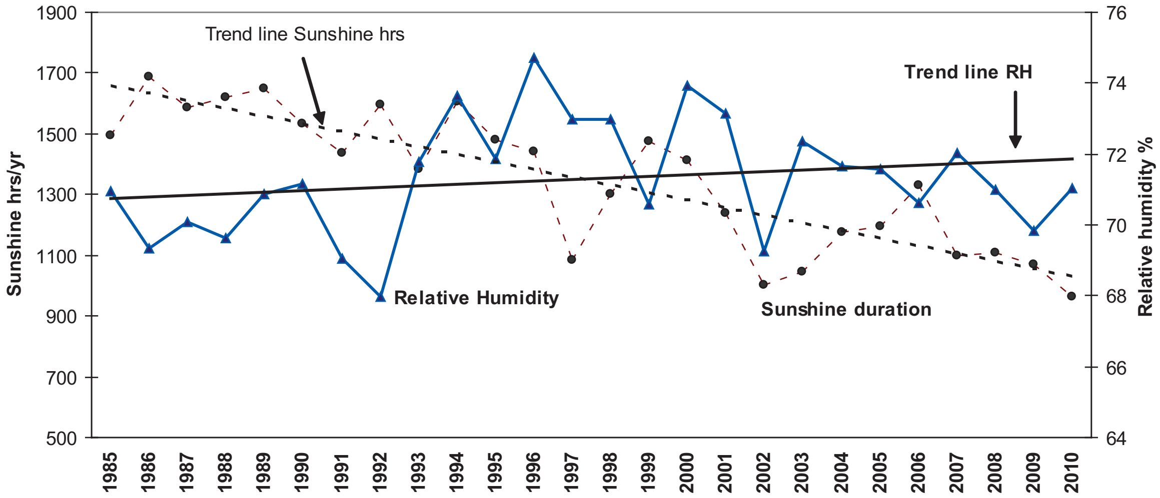

Fig. 11: Trend in annual average relative humidity and sunshine hours at Tadong (Sikkim)

4. Sunshine hours: The daily, weekly, monthly and yearly duration of sunshine at Tadong for the period from 1981 to 2010, excluding the year 1983 and 1984, was analyzed. The mean duration of sunshine hours was worked out to be 3.66 hrs/day or 25.71 hrs/week or 111.41 hrs/month or 1336.93 hrs/year. The duration of sunshine was low (<15 hours/week) from 25th-33rd week coinciding with 18th July to 5th August (Fig 12). During this period the temperature was high (23±1^{o}C), RH was also on the higher side (80±2%) and precipitation was at the maximum (125±5 mm/week). The rest of the weeks have experienced sunshine hours of more than 15 hours per week. The week-wise and month-wise data of sunshine hours at Tadong over the past three decades shows a clear bi-modal curve. That is, the bi-month October-November and again the bi-month April-May have received longer duration of sunshine (33-36 hrs/week). More specifically, the 43rd week (22-28 October) has experienced the longest sunshine hours of 44 hrs/week. During this week, the average temperature was 18.75˚C and weekly evaporation was 16.00 mm. Months falling in-between these bi-mode such as June, July and August experience lesser duration of sunshine. The trend analysis reveals a decreasing trend of sunshine duration since 1988 at the rate of 16.51 hours per year or 0.04 hrs/day.

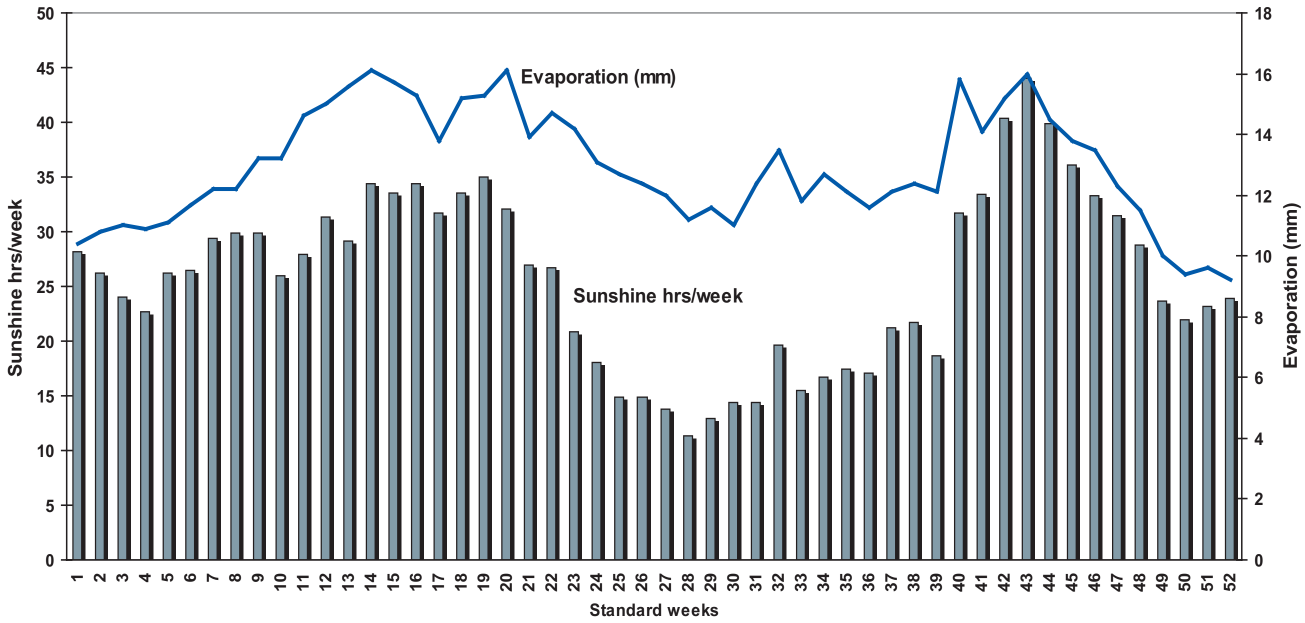

Fig. 12: Average weekly sunshine hours and evaporation at Tadong from 1981 to 2010

5. Evaporation: The 30 years data on evaporation at Tadong shows that the 14th week (2-8th April) and 20th week (14-20th May) have experienced the highest evaporation of 16.1 mm (Fig 12) followed by 43rd week coinciding with 22-28th October (16.0 mm). The 52nd week (24-31st December) has experienced the lowest evaporation of 9.2 mm. Month-wise, the highest evaporation has taken place during the month of October (68.11 mm) followed by May (67.52 mm), April (66.12 mm) and March (64.98 mm). The lowest evaporation was recorded in December (42.15 mm) followed by January (48.15 mm) and February (48.18 mm). June-Sept were the normal months with average monthly evaporation of 54-56 mm. This data will be useful while making irrigation planning. The average total annual evaporation was 679.15 mm as against the normal rainfall of 3097.78 mm. The year 2008 has experienced the maximum evaporation of 1275.10 mm followed by the year, 2007 (1243.30 mm). On the other hand, the year 1996 and 1995 have experienced the lowest evaporation of 210.5 mm and 222 mm. The yearly cumulative evaporation shows a rising trend from 1997 (248.30 mm) to 2009 (1173.10 mm) but it declined to 864.90 mm during 2010.

6. Changes in weather parameters in the mid-hills (Tadong) of Sikkim

***6.1 Rainy days and rainfall**:* During the period from 1981 to 2010, the number of rainy days in the mid hills has increased at the rate of 0.5 days per decade and the annual rainfall has increased at the rate of 41.46 mm per decade (See data given in Annexure I). The increase in the annual rainfall in the nearby location to Tadong (*i.e.* Gangtok) at the rate of 49.6 mm/decade from 1957-2005 was reported by Seetharam (2008). However, if weather data of last 2 decades (1991-2000 to 2001-10) alone is taken into account, the number of rainy days as well as the annual rainfall in the mid hills of Sikkim has declined at the rate of 0.72 days/year and 17.77 mm/year, respectively. The deficit in the number of rainy days could be attributed to fewer rainy days during February (0.21 day/year) and September (0.35 day/year). However, in the last decade (2001-10), the month April has experienced more rainy days (0.5 day/year) as compared to the previous decade (1991-2000). With respect to annual average rainfall over the last decade (2001-2010), the month of April has received more rainfall (9.93 mm/year) as compared to the quantity of rainfall during April in the previous decade (1991-2000). On the other hand, deficit rainfall was found during May-September. The North Eastern Hill Region of India as a whole receives plenty of rainfall and agriculture is fully dependent on rainfall. Therefore, both the distribution of rainfall across months and the total rainfall in a year are important. In this context, the decreasing trend of rainy days and rainfall is a concern. The results of various simulation models on global climate change reveal that though there may not be a major departure in the quantity of annual rainfall received but the number of rainy days would come down or the distribution will be uneven hence the drought period would prolong or intensity of drought and flood would become severe (Ramesh and Goswami 2007). In the past 30 years, in the whole of Sikkim, the year 1990, 1995, 1996 and 2003 have experienced high rainfall (>3462.60-3740.60 mm/year or 12-21% higher rainfall than 30 year average). There were 18 very high rainfall days (>124.4 mm/day) (http://www.imdsikkim.gov.in/). They were 25.04.1981 (134 mm/day), 07.05.1982 (182 mm), 20.10.1987 (155 mm), 29.09.1988 (127 mm), 17.05.1992 (166 mm), 05.06.1993 (145 mm), 04.10.1996 (201 mm), 09.06.1997 (224 mm), 12.06.1998 (166 mm), 13.06.1998 (139 mm), 12.10.2001 (130 mm), 06.06.2002 (188 mm), 03.06.2002 (132 mm), 12.04.2004 (133 mm), 25.09.2005 (141 mm), 27.04.2007 (132 mm), 23.05.2007 (158 mm) and 27.06.2007 (134 mm). The increase in precipitation would probably result in greater risks of soil erosion, soil fertility reduction etc. We have had unprecedented long spell of dryness in Sikkim witnessed during 1986, 1988, 1989, 2006 and 2009. These years have received 13-21% lower rainfall (2458.86-2707.70 mm/year) than the average of 30 years. This deficit rainfall have caused adverse effects on the economy of Sikkim, drinking water supply, irrigation to rabi crops, vegetable, orange etc. It is estimated that 60% of State's large cardamom production was lost during these dry spells. During the past few years, it was observed that the number of effective rainy days during winter (Nov-Dec) and early spring (Jan-Feb) are getting reduced thereby causing moisture stress to rabi crops. In light of above, it is suggested to have proper water conservation measures in the mid - hills of Sikkim, as it not only provides life-saving irrigation to winter crops but also water to animals.

6.2 Temperature*:* The average annual maximum temperature since 1981-2010 did not show any significant increase or decrease during the past 30 years which is a good sign of environment stability (Fig 8). Whereas, the average annual minimum temperature have increased 1.95 ^{o}C in the past 30 years from 1981-2010 (or 0.06 ^{o}C increase/year) which is a matter of concern. Further, the rate of increase in the mean minimum temperature during 1991-2000 to 2001-10 was greater *i.e.* 0.81 ^{o}C/decade or 0.08 ^{o}C increase/year. Earlier study by Singh (1999) has also indicated the increasing trend of minimum temperature at the rate of 2 ^{0}C at Tadong from 1986 to 1997. After analyzing the weather data of Gangtok from 1957-2005, Seetharam (2008) reported very marginal decrease in the mean maximum temperature (-0.003 ^{o}C /decade) but 0.2 ^{o}C increase /decade in the mean minimum temperature. The present study is a further confirmation of the increasing minimum temperature in the mid hills of Sikkim. Further probing of data of month-wise minimum temperature from 1981-2010 has revealed that the increase in minimum temperature was high during March (0.09 ^{o}C increase/year) and April (0.05 ^{o}C increase/year) and again during October (0.04^{o}C increase/year), November (0.07^{o}C increase/year) and December (0.06 ^{o}C increase/year). Increasing minimum temperature during October and November may affect germination of rabi crops like wheat and barley. Various prediction models on global warming indicate that the global surface temperature, by the year 2030, would increase somewhere between 1.5 ^{o}C and 4.5 ^{o}C with an average of 3 ^{o}C (WHO 1990 and IPCC 1990). This increase would be most marked in the high latitudes as well as in high altitudes. Small changes in temperature in the high altitude belt would affect drinking water supply and plant growth. Therefore, meteorological observatories may be set up at the high altitudes of Sikkim so as to monitor changes in weather elements as well as to enable precautionary measures.

6.3 Relative humidity: A glimpse of three decade (1981-2010) data on relative humidity at Tadong has revealed that annual average RH has increased at the rate of 0.22% per year for the decade from 1981-90 (decade mean=69.73%) to 1991-2000 (decade mean=71.95%) but decreased at the rate of 0.071% per year during 1991-2000 to 200-10 (decade mean=71.24%). Nevertheless, if the whole period (1981-90 to 2001-2010) is taken into account then the increase in annual average RH at the rate of 0.05% per year is discernible, which is a quite normal weather trend.

Due to acute scarcity of water, agricultural fields are often kept barren during winter

Frequent road blocks due to fragile topography and heavy downpours during monsoons
disrupts the marketing linkages for farmers

7. Expected impact of climate change on agriculture

7.1 Impact on indigenous crops : Both short and long-term variations in climate will continue to be the important determinants in influencing agricultural and livestock rearing activities in Sikkim. Sikkim has five agro-climatic zones/crop production systems. The temperate and high altitude zones are vulnerable to temporal shifts in climate. High altitude beans, apple, many wild edible fruits, cold water fishes, etc which are adopted to temperate zone may not yield or be productive if the threshold temperature is not met. It may affect the food and nutritional security of people inhabiting this zone. Crop adaptability to an environment is the result of genotype x environment interaction. Hence, the effect of climate change would vary with crop and variety in a given environment. Even in the absence of severe quantitative effects on agriculture, climatic variations are likely to reduce the number of crops or variety to be cultivated in a given region. This would also affect the dietary spectrum. At present, however, little is known about possible changes in temperature and annual rainfall in the temperate zone of Sikkim except a study by Sumi (1994) on the rainfall variation along Teesta valley.

Plate 2: Maize and large cardamom, are likely to be affected by changes in climate. The indigenous multiple cob bearing *"Murali makkai"* requires high altitude / cool climate for the expression of multiple cob. Pollination and seedset in large cardamom depends on the activities of insects and weather. Temporal and spatial changes in weather would affect the yield of these crops

7.2 *Impact of UV radiation on crop productivity*: Rice and maize are the major crops in Sikkim. Prediction models on global warming indicate that the UV radiation, mainly UV-B, is expected to increase by 20-25% by the year 2050, although it would vary with latitude (IPCC 1990). Studies on the likely effects of global climate change on rice production have indicated that UV-B radiation damages leaf tissues in rice seedlings (Dai *et al*. 1997). Leaves become stunted, stomata collapse and photosynthesis decreases. Some rice varieties appear to be better than others to withstand the adverse effects of UV radiation. In addition, UV-B may change the tolerance of crop to diseases (Farrow *et al*. 1989), although there is no evidence as yet. In other words, disease frequency may not increase by UV-B, but the effects of disease on plant growth are enhanced by UV-B radiation.

7.3 *Impact of higher CO_2 concentration on crop productivity*: The concentration of atmospheric CO_2 at present is 380 ppm. Although increase in atmospheric CO_2 stimulates plant growth and yield in C_3 plants like rice and wheat, the beneficial effects on rice growth would be limited up to 500 ppm (Baker *et al*. 1992). Experts predict that atmospheric CO_2 will surpass 650 ppm before the end of 21st century (http://www.neogenesisindia.com/open.html). Furthermore, the benefits of increased CO_2 would be lost if temperature rises. This is because increased temperature shorten the period over which rice grows. The prediction model suggests that few Asian countries would benefit due to increased CO_2 concentration, while some countries would lose their rice production. Overall, Asian rice production may decline by about 4% in the climate of the next century (Cruz *et al*. 2007). The North Eastern Region (NER) of India as a whole does not have sufficient scientific data in this regard. Hence, studies may be initiated to predict possible losses in rice productivity in the whole of North Eastern Region if- i) UV-B radiation continues to increase, ii) change in CO_2 concentration in NE region and iii) whether plant breeders can prevent those yield losses by developing new varieties that tolerate UV radiation and CO_2 concentration.

7.3 *Impact of extreme climatic events*: It is also foreseen that due to global warming the occurrence of extreme climatic events like heat waves, monsoons, droughts etc would have a more profound impact than the overall average changes. In this context, the occurrence of hailstorm and fog in Sikkim deserve special mention. Hail is a form of solid precipitation which consists of balls or irregular lumps of ice, that are individually called hail stones. Hail has a diameter of 5 mm (0.20") or more. Any thunderstorm which produces hail that reaches the ground is known as a hailstorm. In Sikkim on an average 4.2 days in year receive hailstorm. The hailstorm occurs along with pre-monsoon/summer shower during February (0.5 day), March (1 day/month), April (1.7 days) and May (0.5 days). At least two strong hailstorms are expected in the mid-hill climate somewhere between March to April, which have detrimental effects on pre-kharif maize sown during February. A small temporal and spatial shift in hailstorm pattern would leads to negative consequences in maize productivity even if the overall change in average temperature is small. Fog is the suspended collection of water droplets or ice crystals near the Earth's surface. Upslope fog (hill fog) and valley fog are found in Sikkim especially when relative humidity rises to very high level. Fogs not only impair visibility but also reduce light interception by plants. Prolonged foggy condition could cause physiological injury to crop or affect photosynthetic activities as reported by Takemoto *et al*. (1988) and Mildenbergera *et al*. (2009). Sumi and Gupta (1994) have studied the fog in relation to elevation and topographical features at two locations in Sikkim but detailed studies on the effect of hailstorm and fog on the productivity of agricultural crops of Sikkim is lacking. If appropriate model is available to predict the occurrence of hailstorm in Sikkim, then the sowing time of maize can be adjusted so that the vulnerable stage of maize crop coinciding with hailstorm could be averted.

Plate 3: The occurrence of hailstorm is a regular weather feature in Sikkim. Hailstorm coupled with heavy wind cause severe damage to maize crop as is seen in the photograph taken during 2008 at Tadong

7.4 *Impact of climate change on water availability for winter crops*: Over the years, there has been a reduction in the quantity of water available for irrigation in many parts of the country. This is happening in Sikkim as well. The season-wise rainfall data of past 30 years recorded at Tadong shows decrease in both number of rainy days and quantity of rainfall during monsoon season as well as in winter (post monsoon) season. However, the rate of decrease during winter was comparatively higher than during monsoon season. The number of rainy days has decreased at the rate of 4.50 days/30 years (0.15 day/year) during winter, whereas the decrease was higher during monsoon period *i.e.* 8.10 days/30 years (0.27 day/year). The average seasonal rainfall has decreased at the rate of 53.43 mm/30 years (1.78 mm/year) during winter, whereas the decrease was higher during monsoon period *i.e.* 139.01 mm/30 years (4.63 mm/year). Although the decrease of rainy days and rainfall was much higher during monsoon period than winter, due to continuous rain the decrease was not felt and *vice versa* in winter. In Sikkim, winter is generally dryer but the decreasing rainy days and rainfall during the past 30 years has made people to feel it further. Earlier report by Seetharam (2008) has revealed decreasing trend of winter rainfall at Gangtok at the rate of 0.7 mm per 10 year from 1957 to 2005.

Table 3: Decade-wise and season-wise changes in rainfall pattern at Tadong (Sikkim)

Season / Rainfall details	Pre-monsoon (Mar-Jun)	Monsoon (Jul-Oct)	Winter (Nov-Feb)
Rainy days			
Mean 1981-1990	64.60	77.30	11.60
Mean 1991-2000	66.50	83.50	12.20
Mean 2001-2010	71.90	75.40	7.70
Decade-wise increase / decrease in rainy days			
1981-1990 to 1991-2000	1.90	6.20	0.60
1991-2000 to 2001-2010	7.30	-1.90	-3.90
1981-1990 to 2001-2010	5.40	-8.10	-4.50
Rainfall (mm)			
Mean 1981-1990	1344.93	1491.80	118.91
Mean 1991-2000	1411.97	1680.09	165.64
Mean 2001-2010	1426.73	1541.07	112.21
Decade-wise increase / decrease in rainfall (mm) days			
1981-1990 to 1991-2000	67.04	188.29	46.73
1991-2000 to 2001-2010	81.81	49.27	-6.70
1981-1990 to 2001-2010	14.76	-139.01	-53.43

There are many natural springs (*dharas*) and streams (*jhoras*) in Sikkim. People have been collecting water from these natural springs and streams for drinking and to provide irrigation to winter crops. But we have been observing in the mid hills that in the past few years these natural springs are becoming seasonal with reduced discharge. Drying of natural springs has been observed in the mid-hills of Sikkim. Measures to reduce surface runoff and increase percolation would help to address this concern. Under the MGNREGA-Dhara Vikas initiative, revival of these springs has been initiated by taking up artificial groundwater recharge.

Plate 4: Natural spring

7.5 *Impact on plant and animal health*: Global warming may have deleterious effects on human, animal, fish and plant health (WHO 1990). It is expected that infant mortality from diarrheal diseases, malnutrition, under nutrition, risk of skin cancer, susceptibility of cardiovascular system to heat, vector-borne parasites and pathogens would increase. But the magnitude of it may vary with region. Changing climatic condition would also result in new spectrum of plant pathogens and pests that have a major effect on food production. Increase in temperature, rainfall, coupled with high humidity may reduce the wet season, promote fungal growth and aflatoxin may increase. All these would affect the drying, storage and processing of farm produce and also would probably result in increased food contamination, the consumption of which would affect the health of man and animals. Insect vectors may become more virulent. Weeds become more competitive under increased atmospheric CO_2 as most of them are C_3 plants.

Plate 5: Hybrid tomato farming in green houses is providing additional incomes to rural households

8. Strategies for reducing climate change or mitigating its ill effects on agriculture

8.1 *Reducing methane emission*: Methane is viewed 21 times more potent GHG than CO_2. Livestock and livestock-related activities and deforestation account for 35-40% of global methane emission. Enteric fermentation from ruminant animals contributes around 15% of the global methane source (Smith *et al*. 2007). About 80 million tonnes of methane enter into atmosphere every year from ruminants and by 2030, it is expected to rise to 128 million tonnes. From an animal nutritional perspective, CH_4 production represents energy loss. There is a need to feed concentrates rather than forage and finding out suitable pasture or fodder which contributes less CH_4 emission. On the latter aspect, the ICAR Sikkim Centre has initiated research work. Rice cultivation is a big source of atmospheric methane, possibly the biggest of man-made CH_4 sources (contributes about 13% of CH_4 emissions or 50-100 million tonnes of CH_4 /year). The warm waterlogged soil of rice provides ideal conditions for methanogenesis. Though some of the methane produced is usually oxidized by methanotrophs in the shallow overlying water, the vast majority is released into the atmosphere (Yan *et al*. 2003). Through an integrated approach in irrigation and fertilizer application substantial reductions in CH_4 emission can be brought out.. Many rice varieties can be grown under much drier conditions than those traditionally employed, with substantial reductions on methane emission without any loss in yield. In China, there is a shift in rice farming practices from submergence to dry paddy which was proved to reduce CH_4 emission without affecting rice yields (Bin 2008). This is because draining excess water stimulates rice root development, and also accelerates decomposition of organic matter in the soil to produce more inorganic nitrogen. This method as well as the SRI method of rice cultivation can be promoted in Sikkim. Additionally, there is the potential for improved varieties of rice. Finally, the addition of compounds such as Ammonium Sulphate, which favour the activity of other microbial groups over that of the methanogens, has proved successful under some conditions.

8.2 *Carbon sequestration*: As living organisms carry out respiration or as organisms die and decompose, the carbon compounds are broken down and add CO_2 to the atmosphere. The CO_2 is used by plants for photosynthesis, and the cycle keeps going. When trees die and decompose, CO_2 is released. This is a part of normal carbon cycle. When trees are cut down and used for fuel, the CO_2 is also released. The rate at which CO_2 is being released into the atmosphere is increasing as a result of increasing use of trees for fuel, building construction, making furniture etc. Carbon sequestration is a process of removing atmospheric CO_2 either through a biological process (*e.g.* plants and trees) or through a geological process (*e.g.* storage of CO_2 in underground reservoirs). Terrestrial carbon sequestration is the process through which CO_2 from the atmosphere is absorbed by trees, plants and crops through photosynthesis, and stored as carbon in biomass (tree trunks, branches, foliage and roots) and soils. The term "sinks" is also used to refer to forests, crop lands, and grazing lands and their ability to sequester carbon. Agriculture and forestry activities can therefore, be modified in such a way to sequester more CO_2 from the atmosphere than carbon releases, thereby a carbon sink would be created over a period of time (Smith *et al*. 2007). Some of the recommended measures that sequester carbon and/or reduce emissions of other GHG are given below.

1. *Forest activities:* Conserve forest cover and promote planting trees in household and forest lands.
2. *Riparian buffers:* Grasses or trees can be planted along the rivers, streams and terrace risers, wastelands to prevent soil erosion and nutrient run-off into waterways.
3. *Conservation tillage:* Any tillage and planting system in which 30% or more of the crop residue remains in the soil after ploughing is called conservation tillage (*e.g.* zero till, minimum till, mulch till etc). This disturbs the soil less, and therefore allows soil conservation and soil carbon to accumulate.
4. *Bio-fuel substitution:* By growing oilseed trees and *Jatropha* in forest and waste land.

8.3. *Organic agriculture:* Some of the ill effects of chemical based intensive agriculture could be minimized if synthetic chemicals are avoided (LaSalle and Hepperly 2011). Organic farming is one such option. Organic agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved. The State of Sikkim has been declared as Organic State. Therefore, the agriculture policy of the State in itself is a step towards reducing global warming. The importance and, in some cases, the major problems associated with organic fertilizers, deserve special mention. Manure produced by cattle is being used as organic fertilizer. However, application of large quantity of Farm Yard Manure (FYM would cause environmental degradation due to excess run-off during monsoon season (spoil water quality of rivers or lakes) and infiltration (may spoil ground water/spring water) besides volatilization of ammonia which adds to acidification of land and water. Therefore, to prevent leaching of nutrients and acidification the following measures are recommended.

1. *Manure management:* Methane and other gases are produced when manure is managed under anaerobic conditions typically associated with liquid or slurry manure-management systems. Methane reduction and other environmental benefits can be achieved by utilizing a variety of technologies and processes including aeration processes as well as by using the optimum quantity of FYM.
2. Raise pulse crops after monsoon season.
3. As far as possible, keep the soil covered with vegetation. This inhibits build-up of soluble nitrogen by absorbing mineralized nitrogen and preventing leaching during monsoon period.
4. Optimize other cultivation techniques such as weed, pest and disease control, liming, balanced mineral fertilizers permissible under organic farming.

CONCLUSION

Making agriculture sustainable is a great challenge. Sustainability implies that agriculture not only secures a sustained food supply, but that its environmental, socio-economic and human health impacts are recognized and accounted for within the national development plan**.** Agriculture exists within a symbiosis of land and water. Therefore, appropriate steps must be taken to ensure that agricultural activities do not adversely affect soil and water quality so that subsequent uses of land and water for different purposes are not impaired. The suggested measures are, i) prevention of soil runoff and sedimentation, ii) proper disposal of sewage and household waste, iii) minimize the adverse effects from agricultural chemicals by adopting integrated pest and disease management. Public awareness should be created on “the causes and impacts” of climate change. Training programmes prepared especially on how best an individual can help in reducing emission of GHGs and educational programmes at school and college levels on climate change would help a lot. Policies in transport sector should aim at reducing GHG emission.

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Common Red Apollo (*Parnassius epaphus*) in Lhonak valley, North Sikkim. Detailed biodiversity studies will help us to better understand the impacts of climate change on flora and fauna

Photo Courtesy: Sandeep Tambe

Annexure 1: Three decade weather parameters recorded at Tadong (Sikkim) during 1981-2010

Year	Rainy days	Rainfall (mm/yr)	T-min. (^{O}C)	T-max. (^{O}C)	T-mean (^{O}C)	RH-min. (%)	RH-max. (%)	RH mean (%)	Sunshine hrs/yr	Evaporation (mm/yr)
1981	149	2998.10	13.97	23.31	18.64	53.34	83.82	68.58	1274.70	664.17
1982	150	2791.20	13.76	22.73	18.24	51.46	87.11	69.28	1144.20	644.53
1983	150	3219.80	12.75	22.95	17.85	50.33	85.67	68.00		744.80
1984	153	3310.50	13.23	22.89	18.06	52.58	86.18	69.38		685.50
1985	160	2756.70	12.78	23.07	17.93	53.94	87.99	70.97	1494.90	677.80
1986	152	2490.10	11.84	23.29	17.57	51.47	87.25	69.36	1689.60	651.30
1987	156	3363.70	11.91	23.69	17.80	55.44	84.73	70.09	1585.00	683.10
1988	145	2522.90	12.58	24.28	18.43	54.45	84.83	69.64	1619.90	658.50
1989	149	2640.80	13.05	23.13	18.09	62.96	78.76	70.86	1650.30	492.10
1990	171	3462.60	13.93	23.40	18.67	60.98	81.33	71.15	1534.20	398.80
1981-90 Mean	**153.5**	**2955.64**	**12.98**	**23.27**	**18.13**	**54.69**	**84.77**	**69.73**	**1499.10**	**630.06**
1991	165	3220.10	13.30	23.39	18.35	54.14	83.98	69.06	1434.90	302.90
1992	144	2996.80	13.13	23.13	18.13	45.75	90.17	67.96	1596.20	324.90
1993	169	3294.00	13.92	22.96	18.44	53.93	89.67	71.80	1384.80	291.00
1994	156	3003.90	13.98	23.61	18.79	64.53	82.78	73.65	1606.00	292.90
1995	165	3537.85	14.30	23.32	18.81	59.68	84.05	71.86	1478.30	222.00
1996	168	3711.49	14.85	23.79	19.32	63.55	85.92	74.73	1442.60	210.50
1997	172	3357.30	13.45	22.28	17.87	57.26	88.69	72.98	1085.30	248.30
1998	171	3356.30	14.91	23.63	19.27	55.91	90.07	72.99	1301.30	501.50
1999	149	3210.30	15.02	24.20	19.61	53.78	87.38	70.58	1472.80	673.20
2000	163	2888.90	14.28	22.83	18.55	60.34	87.54	73.94	1410.60	709.50

Continued.....

Year	Rainy days	Rainfall (mm/yr)	T-min. (^{O}C)	T-max. (^{O}C)	T-mean (^{O}C)	RH-min. (%)	RH-max. (%)	RH mean (%)	Sunshine hrs/yr	Evaporation (mm/yr)
1991-00 Mean	**162.2**	**3257.69**	**14.11**	**23.31**	**18.71**	**56.89**	**87.02**	**71.95**	**1421.28**	**377.67**
2001	147	3065.59	14.67	23.40	19.04	61.55	84.74	73.14	1240.63	735.80
2002	173	3115.23	14.66	23.21	18.94	52.12	86.36	69.24	1000.12	1007.00
2003	181	3740.60	14.33	22.85	18.59	57.61	87.14	72.37	1043.25	1058.30
2004	155	2897.90	15.56	23.03	19.29	56.86	86.42	71.64	1175.02	867.90
2005	157	3424.20	14.90	23.18	19.04	56.47	86.63	71.55	1197.16	1054.10
2006	141	2707.70	14.67	23.81	19.24	55.81	85.46	70.64	1331.26	1017.60
2007	146	2918.30	15.04	23.31	19.17	56.75	87.28	72.01	1099.07	1243.30
2008	157	3066.80	14.90	23.12	19.01	55.03	86.92	70.97	1109.16	1275.10
2009	128	2458.86	15.58	23.83	19.71	53.94	85.75	69.85	1068.83	1173.10
2010	165	3405.00	14.96	23.50	19.23	55.48	86.58	71.03	963.96	864.90
2001-10 Mean	**155.0**	**3080.02**	**14.93**	**23.32**	**19.12**	**56.16**	**86.33**	**71.24**	**1122.85**	**1029.71**
Grand mean	**156.9**	**3097.78**	**14.01**	**23.30**	**18.65**	**55.91**	**86.04**	**70.98**	**1336.93**	**679.15**
Minimum	128.0	2458.86	11.84	22.28	17.57	45.75	78.76	67.96	963.96	210.50
Maximum	181.0	3740.60	15.58	24.28	19.71	64.53	90.17	74.73	1689.60	1275.10
SD	11.6	346.16	1.02	0.43	0.58	4.19	2.44	1.77	220.64	312.46
CV %	7.41	11.17	7.26	1.85	3.11	7.49	2.84	2.49	16.50	46.01
Decade-wise increase or decrease										
1981-90 to 1991-00	**+8.70**	**+302.05**	**+1.13**	**+0.04**	**+0.59**	**+2.19**	**+2.26**	**+2.22**	**-77.82**	**-252.39**
1991-00 to 2001-10	**-7.20**	**-177.68**	**+0.81**	**+0.01**	**+0.41**	**-0.72**	**-0.70**	**-0.71**	**-298.43**	**652.04**
1981-90 to 2001-10	**+1.50**	**+124.38**	**+1.95**	**+0.05**	**+1.00**	**+1.47**	**+1.56**	**+1.51**	**-376.25**	**399.65**

T- Temperature, **RH-** Relative Humidity, **SD-** Standard Deviation, **CV-** Coefficient of Variation

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Inter-cropping of ginger with mandarin orange: many horticulture crops are facing increased impacts of pests, pathogens and moisture stress due to climate change

Ecosystems perceived as intact and preserved like the Rathong chu valley in West Sikkim, are now coming under growing threat from climate change impacts
Photo Courtesy: Sandeep Tambe

Dying Himalayan springs and streams will adversely affect water security especially during the dry season