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Estimation of Surface Temperature Using Satellite Data in Sutlej Basin,

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Abstract

snow cover area and temperatures measured in Sutlej basin are used for snow melt runoff. In the study surface temperature is estimated using Poissons split window algorithm. The Land Surface Temperature (LST) obtained using National Oceanic Atmospheric Administrator (NOAA/AVHRR) thermal band data is compared with field measured air temperatures. Deviation between the LST obtained from (NOAA/AVHRR) data and field air temperature is generally within +/- 6o. The deviation between the LST obtained from Moderate Resolution Imaging Spectroradiometer (MODIS/AQUA) data and field air temperature is within +/- 7o. The deviation between LST derived from NOAA/AVHRR data and that of MODIS data is within +/- 5o. Correlation analysis has been made and using the regression equation, the LST has been computed at Jubbal station. A high correlation between field air temperature and LST from NOAA data (R2=0.813) and LST from MODIS data (R2=0.783) was verified. Comparison of actual air temperature with computed air temperature shows that the deviation is within +/- 5o. In view of the reasons for possible deviation as explained in earlier section, the results are acceptable and can be employed

Keywords:

Snow cover area, LST, SnST, Regression

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1. Introduction

The Himalaya is the youngest mountain which is developed by continent collision between the northward moving Indian plate and the Eurasian plate during 50-60million years ago (Majumdar, T. J. 2002). The Himalaya is 2500km long mountain ranges from west to east comprised of 30 mountains rising more than 7300 meters and includes the highest mountain peak (8848m) of the Everest. Sutlej River in Western Himalayas contributes a major extent of inflows into Bhakra reservoir in Himachal Pradesh, India (Paul, P. R,et al., 1994). The snow cover accumulated in winter months melts in lean summer months which are vital during the period of high demand for water and power (Reuben Paul P. Et al., 1994). The snow cover varies year to year (Siva Sankar. E, 1993). The snow that melts during summer months provides substantial runoff during lean period for hydro-electric power generations as well as irrigation and drinking water supplies. The terrain being hazardous and inaccessible across high altitudes and across international borders (YUICHIRO OKU et al., 2003), the remote sensed satellite data provides the most appropriate and valuable information. In addition to snow cover area, the snow surface temperature is important to address the energy input to the snowpack for melting (Samantha Ka Man Poon, 2004). The air temperatures are measured in the field at a few stations within the Sutlej basin. The temperature measured at these limited stations does not completely explain the horizontal and vertical spatial variability within the basin. It is therefore being experimented in NRSC, to estimate the Land Surface Temperature (LST) / Snow Surface Temperature (SnST) using thermal band satellite data and compare with field measured air temperatures so that the technique can be used operationally in the ongoing project.

2. Study Area and Data Used

Sutlej river basin in Western Himalayas is the study area. The river Sutlej is one of the main tributaries of Indus and has its origin near Manasarovar and Rakas lakes in Tibetan plateau at an elevation of about 4,500 m (approx.)(Reuben Paul P, et al., 1994). It is stretched about 47,000 Sq. Km. in area. The Sutlej basin is geographically located between 30 o 00' N, 76 00' E and 33 o 00', 82 o 00' E. Characteristics of the basin and inaccessibility of the major part of it make remote sensing application ideal for hydrologists to monitor the snow cover information of the region and assess the resulting water resource (Rama Moorthi, 1991). Geographically, the mountain ranges extend throughout the basin with altitudes ranging from about 2200 m to 7000 m above mean sea level (Majumdar, T. J., 2002). The most important factors controlling the climate and weather types in the Himalayas are altitude and aspect . Snow is the least during August. Fresh snowfall starts at the end of September and continues till the end of March (Dorothy K, et al., 1985). During summer months namely, April – May – June, vast amount of snow melt results in heavy runoffs in snow field rivers such as Sutlej (Siva Sankar.E, 1993). The study area is as shown in Fig.2.1. For the snow temperature and snow cover mapping, the satellite data from AVHRR sensor onboard NOAA satellite resolution is 1.1km and MODIS resolution is 1.1km and field temperature have been used to calculate LST and snow surface temperature (E.L.Muzylev, et al., 2007). NOAA/AVHRR Images imaging at about 13:30 Hrs. local time and MODIS image obtained 10:30 Hours local time are used in this study.

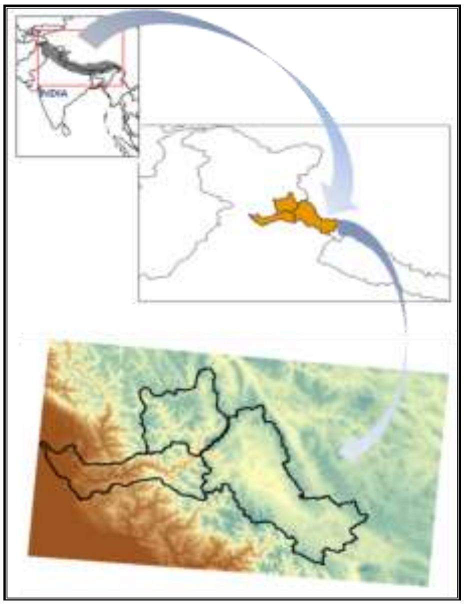


Fig.2.1: Location map of the study area (Sutlej basin)

3. Methodology

Snow cover in Sutlej basin was mapped using ERDAS/Imagine digital image processing software. The digital analysis steps can be classified into I) Pre-processing II) Classification III) Post (statistic) -classification processing IV) Estimation of Land Surface Temperature (LST) and snow Surface Temperature (SnST) from NOAA/AVHRR data. The data processing steps were done with digital image processing techniques using Erdas Imagine s/w. The details of the methodology to compute snow cover area, LST and SnST illumination index are explained in the following flow chart is as shown in the Fig.3.1.

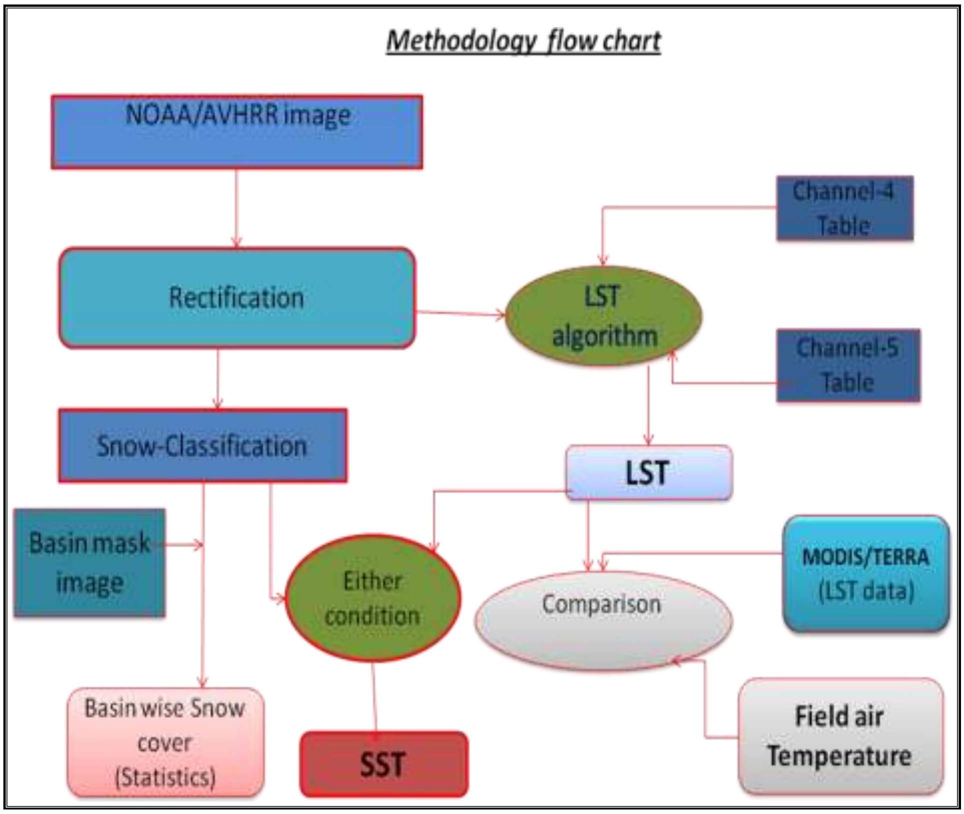
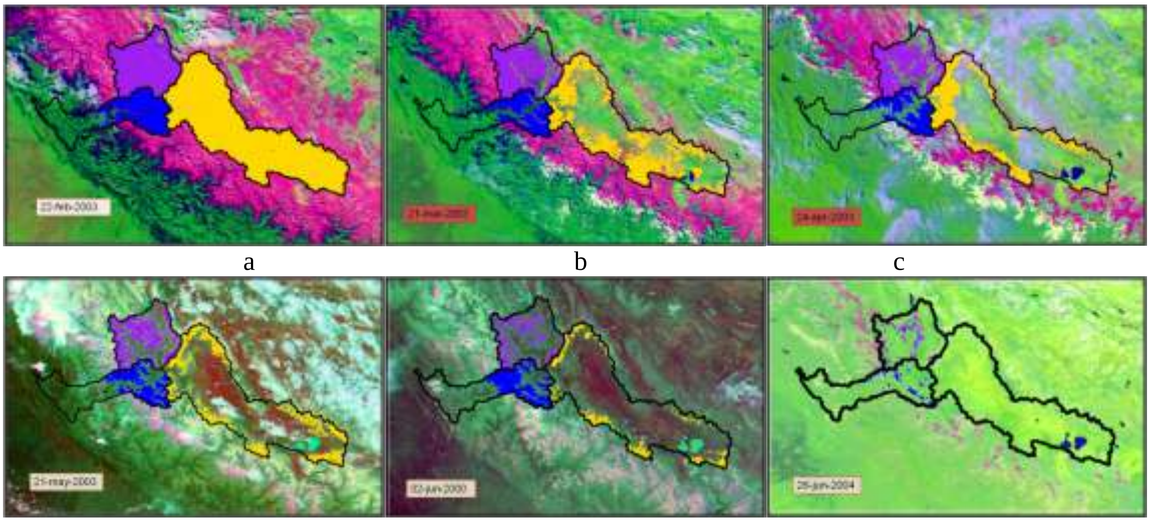


Fig.3.1: Methodology flow chart.

3.1. Snow Cover Area map

Classified image is used to extract the snow cover portion of Sutlej basin using the Sutlej basin mask image. Snow cover area Statistics in the Sutlej basin are computed by generating a matrix using classified image and reference basin mask. The snow cover area within the basin is expressed as percentage of total basin area denoting snow cover area available in the basin as on that date. Thus, the snow cover area values have been computed for all the images. The classified images are shown in the Fig.3. 2. The classified snow image is compared with basin mask image to compute the snow cover area within the basin.



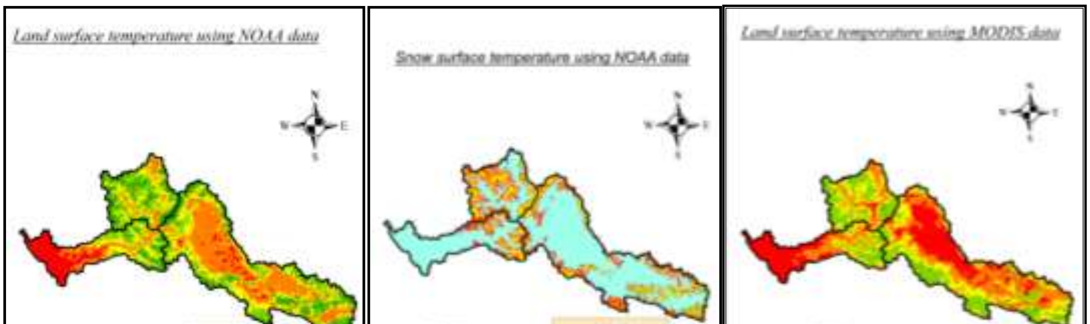
d e f

Fig.3.2: Snow cover area decreased monthly wise of Sutlej basin on (a) 22 Feb, (b) 21st Mar, (c) 24th Apr, (d) 21st May, (e) 02 Jun and (f) 26th Jun in 2003 year

geometrically corrected (E.L.Muzylev, et al., 2007). A split window algorithm for estimating land surface temperature from NOAA satellite as resolution 1.1km, (ZhengmingWana et al., 2002) split window algorithm to determine LST and SnST values. This algorithm requires as input values of surface radiation in AVHRR channels 4 and 5 from look up table, operating in 10.5-11.3µm and 11.5-12.5µm respectively for surface temperature monitoring (E.L.Muzylev, et, et al., 2007). Remote sensing of LST can be formulated as follows table3.1. LST and SnST read from these images are in degree Kelvin (oK) as 8 bit continuous data in LCC projection.

Table 3.1: LST &SnST Algorithm

NOAA-14/ AVHRR	$T45 = T4 + 1.8 (T4 – T5) + 48(1- ε)-75Δ ε$. where : T45 – Surface temperature calculated using split-window algorithm (channels: 4 & 5); T4, T5 – radiant temperature obtained from 4 & 5 channels, respectively. ε =1(Emissivity) Δε= (ε4 - ε5)= Approximately zero



MODIS data is downloaded from the https:// wist.echo.nasa.gov/ ~wist/ api/ imswelcome/.The MOD11A1 image daily LST products are in resolution 1.1km as 16 bit continuous data with scale factor of MODIS LST is 0.02 in sinusoidal projection (HomaKheyrollah Pour,2011). These MODIS LST images were re projected into Lambert Conformal Conic (LCC), WGS84 Then the re-project image is subset with the Sutlej basin boundary so as to obtain the area of interest as shown in the Fig.3.6. The LST of the ground surface is obtained by multiplying with 0.02. The LST image and snow cover image are compared with Boolean algebra functions to derive Snow Surface temperature (SnST) of the snow existing within the basin. The NOAA and MODIS LST &SnST degree Kelvin (oK) data was converted into degree Celsius (oC).

4. Analysis and Results

4.1. Snow Cover Area calculation

The satellite data during the period February to June months of the years 2000, 2001, 2002, 2003 and 2004 have been used in this study since the snow cover depletion and the resultant snow melt runoff is predominant in this period considering the data availability and suitability. The Sub basin wise snow cover area statistics were computed. The snow cover area existing on different dates in Sutlej basin is shown in Table 4.1.

Table 4.1: Snow covers area in Sutlej basin

S.No	Date	*Snow cover area in Sutlej basin (Area in Square km)*				*Total SCA (% of total basin area)*
		Spiti *(10087)*	***Tibet*** *(29970)*	***Lower-sutlej*** *(11418)*	***Total area*** *(51475)*	
1	22-Feb-03	9834	29949	5361	45144	88
2	22-Feb-04	9446	17693	4388	31527	61
3	11-Mar-03	8735	22236	4746	35717	69
4	21-Mar-03	7133	13962	4113	25209	49
5	31-Mar-03	9428	21448	5052	35928	70
6	15-Mar-04	7030	6837	3450	17317	34
7	01-Mar-04	9084	13707	4247	27039	53
8	07-Apr-03	8678	13091	3992	25761	50
9	24-Apr-03	6921	9325	4108	20354	40
10	04-Apr-01	6347	25283	3275	34906	68
11	06-Apr-01	8601	18123	4574	31298	61
12	05-Apr-02	5367	18392	3202	26961	52
13	14-May-03	6648	11642	4677	22966	45
14	16-May-03	5877	9262	3041	18180	35
15	21-May-03	5514	7232	3788	16534	32
16	10-May-04	4290	2996	2829	10115	20
17	23-May-01	3902	8452	3650	16004	31
18	24-May-01	4151	7184	3837	15172	29
19	06-May-04	6158	7159	3696	17013	33
20	29-May-04	4016	3684	2175	9874	19
21	02-Jun-00	3423	4062	3926	11411	22

The Tibet portion of Sutlej basin is approximately 60% of the total basin area. The snow cover in Tibet region depletes early in summer months whereas the snow cover in Spiti and Lower Sutlej regions depletes slowly and continue till the end of June month. The snow cover area approaches maximum possible value in the month of February and the depletion starts in the month of March depending on the prevailing temperature conditions. The maximum SCA (within the dataset used in this study) observed from satellite data is 88% recorded on 22 Feb 2003. The SCA is approximately 20% of basin area by the end of May in general. The year to year variation in SCA is very significant.

4.2. Comparison of LST Derived from NOAA / AVHRR, MODIS and Field Air Temperature

A statistical analysis was carried out between the LST derived from NOAA-AVHRR, MODIS LST maps and air temperature measured in the field to determine the relationship and mutual comparison. The field temperature data measured at Kalpa, Rakchham, Rampur and Jubbal stations in the Sutlej and neighbouring Yamuna basins have been used in this study. For comparison, to account for some location errors, a 3x3 window is considered and LST values have been read for 9 pixels at the location corresponding to the field temperature station. The average of these 9 values has been considered to represent the location of temperature station. The NOAA/AVHRR derived LST is compared with Field measured air temperatures. Similarly the MODIS LST map derived values have been compared with field measured air temperatures. Finally, the LST derived from NOAA/AVHRR and MODIS are mutually compared.

The LST values derived from NOAA/AVHRR data at different locations corresponding to the field temperature gauge stations have been compared as shown in Table 4.2. The maximum air temperature recorded in field is considered for comparison. The NOAA/AVHRR satellite overpass is at about 1300 Hrs local time and pixel resolution 1.1km and the maximum field air temperature is recorded as per the 24 Hour cycle. The satellite overpass time of MODIS/TERRA is at about 1030 Hrs local time and pixel resolution 1.1km.

The comparison of LST derived and field air temperature need to be done with some cautions. Significant deviations are possible in view of the following reasons.

1. Location coordinates of field temperature gauge stations may not be accurate.
2. In view of the spatial resolution of NOAA/AVHRR and MODIS being 1Km., whereas the field temperature station being a point, the variability within the pixel is not fully explained and comparison may be slightly inaccurate.
3. Time of satellite overpass, time of recording the maximum temperature in the field may be different.
4. Geometric rectification errors may contribute little bit error.
5. The LST corresponds to the surface whereas the field measured air temperature corresponds to a point in air at about 1m. Above the ground.

Table 4.2: Comparison of NOAA, MODIS and field temperatures

Date	NOAA	MODIS	Field	NOAA - MODIS	NOAA-Field	MODIS-Field
	Degree Celsius **C°**					
01-Mar-04	2	7	2	-5	0	5
01-Mar-04	7	2	8	5	-1	-6
11-Mar-03	6	6	9	0	-3	-3
11-Mar-03	28	24	20	4	8	4

Date	NOAA	MODIS	Field	NOAA - MODIS	NOAA-Field	MODIS-Field
	Degree Celsius **C°**					
11-Mar-03	3	-1	5	4	-2	-6
19-Mar-04	29	27	30	2	-1	-3
19-Mar-04	14	12	18	2	-4	-6
21-Mar-03	7	4	8	3	-1	-4
21-Mar-03	13	15	16	-2	-3	-1
21-Mar-03	30	30	30	0	0	0
26-Mar-00	29	29	30	0	-1	-1
26-Mar-00	15	11	16	4	-1	-5
31-Mar-03	24	19	23	5	1	-4
31-Mar-03	11	7	11	4	0	-4
31-Mar-03	5	9	10	-4	-5	-1
31-Mar-03	4	1	5	3	-1	-4
02-Apr-00	33	31	32	2	1	-1
02-Apr-00	14	15	18	-1	-4	-3
06-Apr-01	20	18	17	2	3	1
06-Apr-00	20	25	19	-5	1	6
06-Apr-00	6	9	14	-3	-8	-5
06-Apr-01	9	9	14	0	-5	-5
07-Apr-03	31	26	30	5	1	-4
07-Apr-03	12	12	14	0	-2	-2
07-Apr-03	20	16	18	4	2	-2
07-Apr-03	13	15	18	-2	-5	-3
24-Apr-03	20	15	17	5	3	-2
24-Apr-03	30	31	26	-1	4	5
30-Apr-00	35	36	33	-1	2	3
30-Apr-00	21	26	21	-5	0	5
06-May-04	20	19	20	1	0	-1
06-May-04	35	32	34	3	1	-2
06-May-04	29	21	25	8	4	-4
10-May-04	27	31	25	-4	2	6
10-May-04	36	38	33	-2	3	5
10-May-04	17	16	11	1	6	5
10-May-04	18	22	22	-4	-4	0
14-May-03	18	20	21	-2	-3	-1
14-May-03	18	24	21	-6	-3	3
14-May-03	39	36	33	3	6	3
14-May-03	11	17	17	-6	-6	0
16-May-03	35	37	36	-2	-1	1
16-May-03	17	22	17	-5	0	5
16-May-03	22	23	20	-1	2	3
16-May-03	24	25	20	-1	4	5
21-May-03	22	21	26	1	-4	-5
21-May-03	46	44	41	2	5	3
23-May-01	22	24	24	-2	-2	0
23-May-01	25	27	32	-2	-7	-5
29-May-04	24	19	21	5	3	-2
29-May-04	34	30	35	4	-1	-5
02-Jun-00	25	28	23	-3	2	5
02-Jun-00	34	39	33	-5	1	6
29-Jun-04	35	38	32	-3	3	6
29-Jun-04	24	26	24	-2	0	2
29-Jun-04	35	39	38	-4	-3	1

6. The deviation between the LST obtained from NOAA/AVHRR data and field air temperature is generally within +/- 6o. The deviation between the LST obtained from MODIS data and field air temperature is generally within +/- 7o. The deviation between LST derived from NOAA/AVHRR data and that of MODIS data is generally within +/- 5o as

shown in the figure 4.1. In view of the above cited reasons the deviations may still be acceptable.

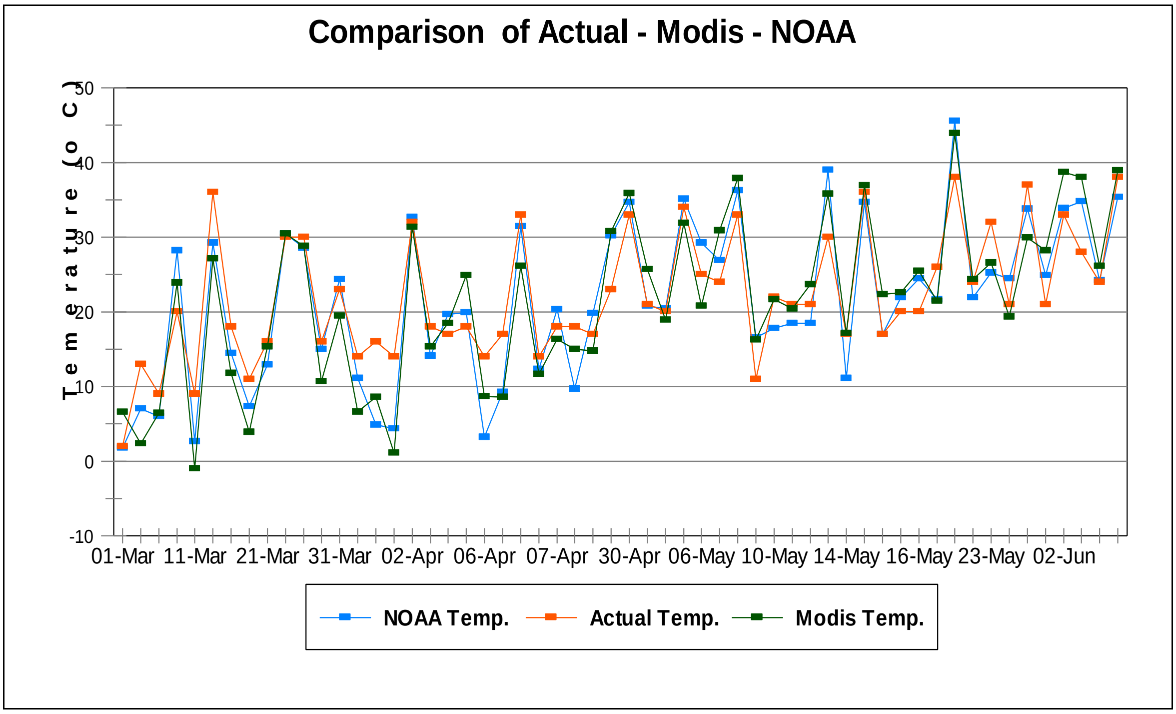


Fig .4.1: Inter-comparison of LST derived from NOAA, MODIS and field air temperatures

4.3. Statistical Analysis and Verification

Correlation analysis has been made between the LST derived from NOAA/AVHRR data and field air temperature and calculated the bias and standard deviation of the regression. Constant(c), X Coefficient, R Square and Std Err of Coefficient values computed in the regression analysis with input values of MODIS and actual temperature of Kalpa, Rakchham, Rampur Stations. The above regression equation values of constant, X coefficient values are used in Jubbal station to calculate values of computing field temperature. The field air temperature is considered as dependent variable and NOAA/AVHRR LST is considered as independent variable. The values of Constant(c), X Coefficient, R2 and Std Err of Coefficient.

$\mathbf{T_c = 1.139 \times T_n - 3.878}$ Where

T_n –NOAA or MODIS temperature.

T_c – Field temperature

Table 4.3: Comparison of computed and actual air temperature at Jubbal

DATE	NOAA LST C°	Field temperature C°	Computed air temperature using NOAA	Deviation C°
01-Mar-04	20	13	19	7
11-Mar-03	8	8	5	0
19-Mar-04	24	22	24	2
21-Mar-03	25	16	25	9
31-Mar-03	18	11	17	7
02-Apr-00	17	20	16	-3
07-Apr-03	25	16	24	9
06-May-04	30	20	31	10
10-May-04	30	22	30	8
14-May-03	19	24	18	-5
16-May-03	26	21	26	5
21-May-03	35	25	36	10
23-May-01	21	21	20	0
02-Jun-00	23	24	22	-1
29-Jun-04	37	23	39	14

The above regression equation has been verified by estimating the air temperature at Jubbal station. The LST value at Jubbal has been derived from NOAA/AVHRR data and air temperature has been computed. The computed air temperature is then compared with actual measured air temperature at Jubbal as shown in Table 4.3.

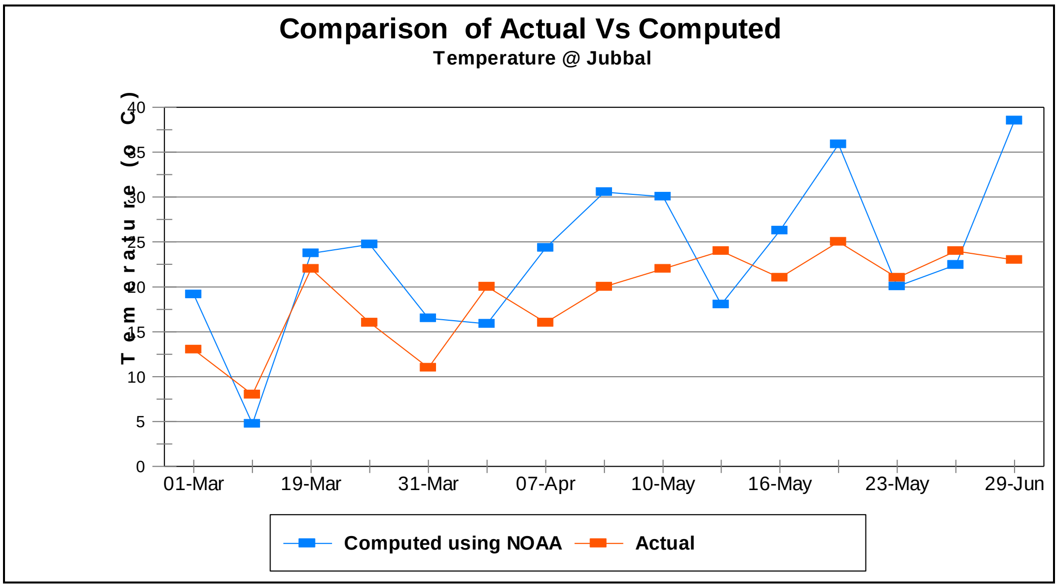


Fig 4.5: comparison in between actual and computed using NOAA temperature

The comparison of actual air temperature with computed air temperature shows that the deviation is within +/- 5o as shown in the figure4.5. Result of computing MODIS temperature values as shown in the table 4.5.

Table 4.5: Jubbal station temperature and computing values of NOAA and field

DATE	MODIS temperature C°	Field temperature C°	MODIS - field temperature Compare C°	Computed using MODIS
01-Mar-04	15	13	2	13
11-Mar-03	13	8	5	11
19-Mar-04	20	22	-2	19
21-Mar-03	21	16	5	20
31-Mar-03	15	11	4	14
02-Apr-00	22	20	2	22
07-Apr-03	22	16	6	21
06-May-04	25	20	5	25
10-May-04	26	22	4	26
14-May-03	23	24	-1	22
16-May-03	25	21	4	25
21-May-03	34	25	9	34
23-May-01	22	21	1	21
02-Jun-00	28	24	4	28
29-Jun-04	33	23	10	34

The comparison of actual air temperature with computed air temperature using MODIS temperature shows that the deviation is within +/- 5^o as shown in the figure4.6.

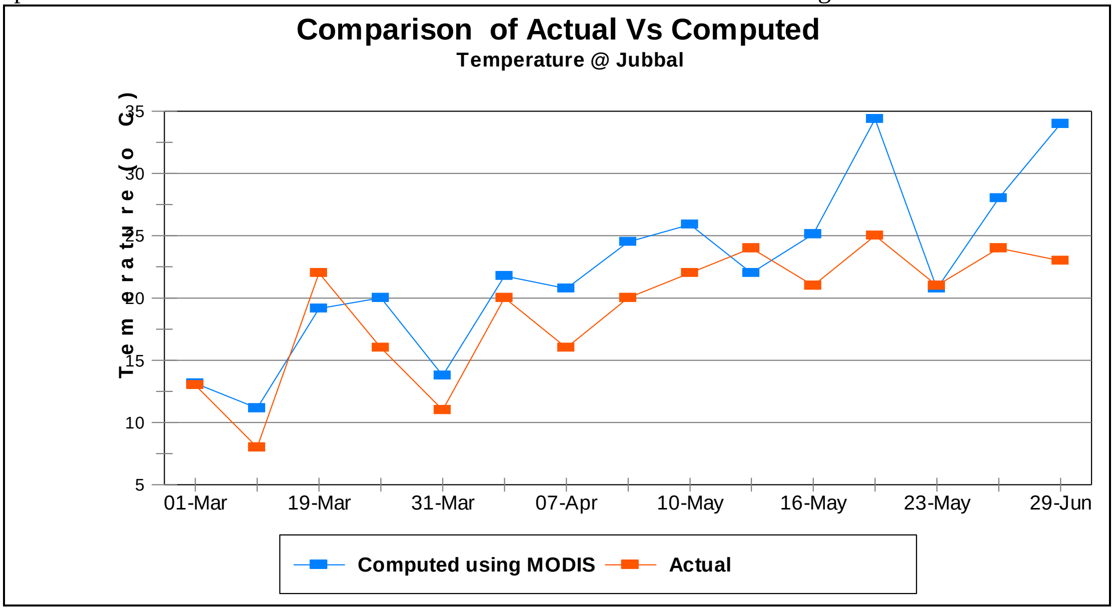


Fig.4.6: comparison in between actual and computed using MODIS temperature

Results were compared with ground temperature data, resulting in high correlation factors, indicating that the estimated surface temperature is a good match to observed value. Thus it may be concluded that, the LST estimated from satellite data can be used in snow melt runoff modeling as an alternative in absence of ground measured temperature data.

5. Conclusions

In snowmelt runoff studies, energy input to the snowpack is an important component. Generally, ground measured temperature used as an alternative indicator of energy input. In rugged terrain such as the Himalayas, meteorological stations collecting ground temperature data are sparsely located and the observations, being point data, are not representative of the whole terrain. In addition, the ground temperature is measured manually and hence it is susceptible to errors. In such conditions, LST maps prepared from satellite images are an attractive alternative. This approach can also be used for estimation of seasonal variation in LST. The NOAA-AVHRR images and MODIS LST maps are economical and suitable. In addition, these datasets are available for near real time, providing a further advantage. There is research potential for the use of LST data in snowmelt runoff computations. The conclusions of the present study are summarized hereunder. The Land Surface Temperature (LST) computed in the study area from NOAA/AVHRR satellite data using Split window are useful for Himalayan basin in absence of well distributed field measurements of air temperatures. The LST explains the spatial variability over the entire basin whereas the field air temperature measurements at a few stations indicate local weather conditions. In addition, since the field stations are generally located at lower altitudes, generally below 4000m in Sutlej basin, do not explain the variability in the vertical plane as the snow melt is predominantly from elevations above 4500m. Thus utility of LST in snow melt runoff modeling more relevant and appropriate to account for spatial and temporal variability. The LST derived from satellite data is comparable with field measured air temperatures. The estimated LST values and Field air temperature have a general difference of about 5o. However, the factors such as, time of satellite overpass, possible inaccuracies in exact locations of field stations and coarse spatial resolution of satellite data are responsible for some deviations in the actual measured and estimated temperatures. The LST derived from NOAA/AVHRR and MODIS data are in coherence. The study described in the paper shows encouraging results and can be employed

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2. Study Area

The Study area exposes an upto date record of the widely varied vegetation of Nallamalais. The slopes of Nallamalais shape a piece of the Eastern Ghats in Andhra Pradesh, India, arranged in the middle of $15^0$20'- $16^0$30'N and 78^0 30'- 80^0 10' E. It convers 5 regions of Adnrha Pradesh, they are Kurnool, Chitoor, Cuddapah, Nellore, Prakasham. The stones are of Kurnool and Cuddapah arrangements. The vegetation is comprehensively isolated into timberland, meadow and hydrophytic classes. Under timberland vegetation, three wide writes were perceived i.e. southern dry blended deciduous, South Indian soggy deciduous and scour. They fall under 778 genera and 144 families, drawing out the class species proportion to 1:2. The predominant families are Poaceae (178 taxa), Asteraceae, Cyperaceae, Papilionaceae,andEuphorbiaceae. Nine edaphic vegetation composes were seen in the investigation region. Its biodiversity was under investigated [3]. Figure 1 represents the study area Nallamala Forest.

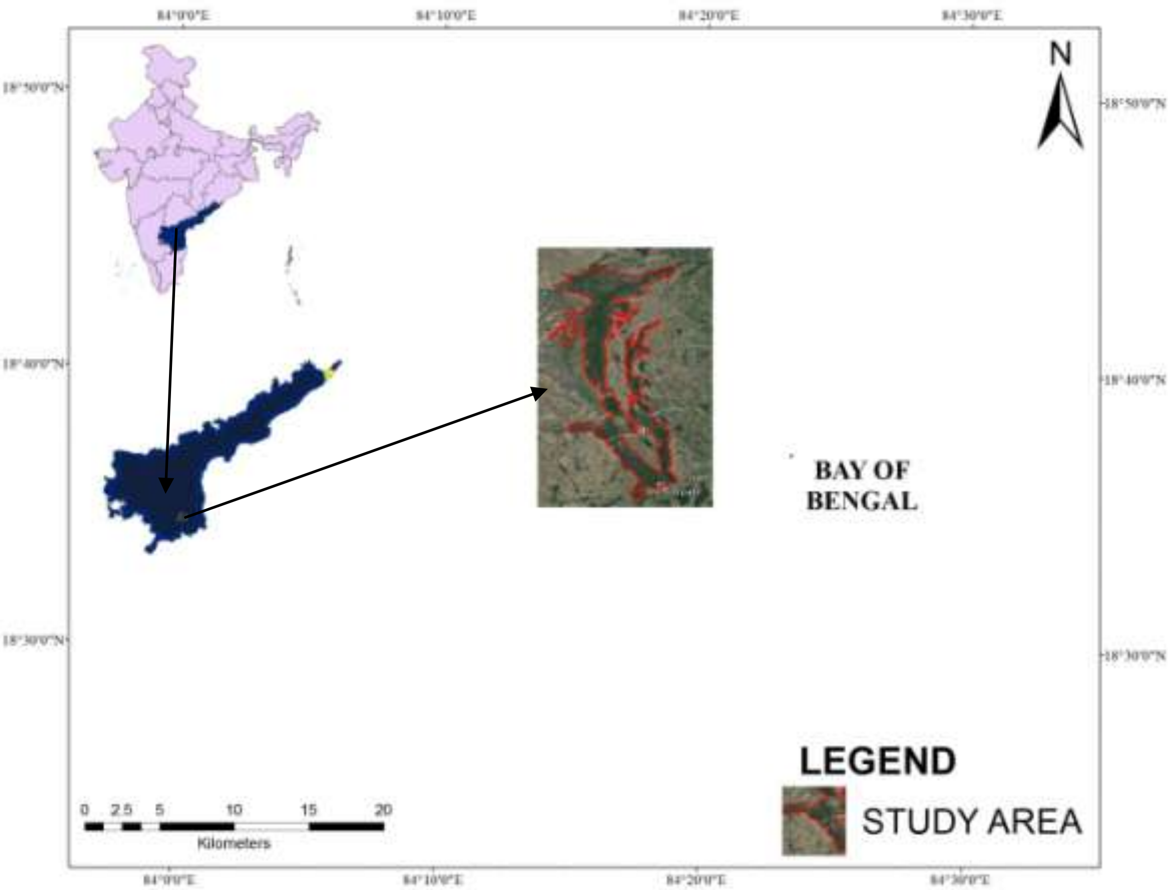

Figure-1: Stduy area, Nallamala Forest, Andhra Pradesh

3. Suitable Conditions for the Red Sandal Wood Crop

Sandalwood does best in places with bunches of sun, direct precipitation, and genuinely dry climate for part of the year. They lean toward a temperature scope of 12°-30° C (53°-86° F). The yearly precipitation ought to be in the scope of 850-1200 millimeters (33-47 inches).In terms of elevation, they can deal with anything in the vicinity of 360 and 1350 meters (1181-4429 feet), yet favor direct heights of in the vicinity of 600 and 1050 meters (1968-3444 feet).

Stay away from any dirt that has encountered water logging, which sandalwood does not tolerate. If you are planting in a sandy soil, ensure the water doesn't deplete too rapidly. Sandalwood lean towards red ferruginous soil. Sandalwood can likewise be planted in sandy soils, red earth soils, and vertisols. Vertisol is a sort of mud rich dark soil that agreements drastically in dry climate, making profound mud-breaks. The dirt pH ought to be in the vicinity of 6.0 and 7.5. Sandalwood endures rough ground and gravelly soil [4].

Sandalwood can just flourish on the off chance that it develops nearby another plant that produces settled nitrogen, a kind of characteristic compost. The sandalwood tree associates its root framework to that of the host tree keeping in mind the end goal to get the supplements it needs. In a perfect world, you should plant your sandalwood beside an officially settled host species, for example, extensive wattles (acacia trees) or casuarinas (a variety of tropical evergreens, including ironwoods and sheoaks).

4. Impact of Smugglers on Red Sandal Wood in Nallamalla Forest

Red sanders carrying, which was to the tune of Rs 3,300 crores in 2011-14, was decreased to about Rs 100 centers this year because of start of a few measures, including setting up of team of woods, police and income authorities to check pirating exercises. Upwards of 496 bootleggers, including nine worldwide runners, were captured by the police this year, as per a discharge issued by the state Information and Public Relations office [5][6].

5. Conclusion

The Red sandal wood is one of the precious crops of the Southern Andhra Pradesh. It is one of the sources of income of government of Andhra Pradesh. Unfortunately the forest assets of Andhra Pradesh are reducing day by day in the name of smuggling.

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