Artificial Neural Network Model for Prediction of Land Surface Temperature from Land Use/Cover Images

Article *in* International Journal of Advanced Trends in Computer Science and Engineering · January 2013

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Prediction of Land Surface Temperature from Land Use Land Cover Images using an Artificial Neural Network Model

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Abstract

Estimation of land surface temperature (LST) is important for urban climate studies particularly for the study of intensity of urban heat island and its spatial distribution. LST is primarily depends on the land use/land cover (LULC) of the area and changes with extent of urbanization. For LST retrieval, remote sensing satellite images of high resolution with thermal band are required which are scarce. This paper deals with the development of artificial neural network model for prediction of LST image from LULC image. The advantage of the model is that model requires only LULC image to get LST image. A feed forward back propagation network is developed with LM training algorithm. For training the model LULC image and LST image of 2001 was used. For testing the model LULC and LST image of 1990 was used. The model was found to give good results. The outputs of the model were converted in to images and presented.

Keywords*:* Land surface temperature, Remote sensing data, Land use/Land cover, Artificial neural network

1. INTRODUCTION

The urban air temperature is gradually rising in all cities in the world. One of the possible causes is the drastic reduction in the greenery area in cities. The distinguished climatic condition termed 'Urban Heat Island' (UHI) is developing in the rapidly urbanized cities. Understanding the distribution of Land Surface Temperature and its spatial variation will be helpful to decipher its mechanism and find out possible solution. The development of LST images requires Landsat imagery of high resolution with thermal band. The availability of Landsat imagery is limited. This paper deals with the development of an artificial neural network model for prediction of LST from land use land cover images which can be developed by a variety of satellite data available.

Several researchers used the Landsat imagery to develop land use/cover images as well as temperature images. K. C. Seto, C. E. Woodcock, C. Song, X. Huang, J. Lu And R. K. Kaufmann, have monitored the land-use change in the Pearl River Delta using Landsat TM.[1] J. Li and H.M. Zhao have studied the Urban Land Use and Land Cover Changes in Mississauga using Landsat TM images.[2], Land use land cover images were developed from Landsat imagery for Vijayawada city by K. Sundara Kumar, M. Harika, Sk. Aspiya Begum, S. Yamini, & K. Balakrishna.[3] Javed Mallik, Yogesh Kant and B.D.Bharath estimated land surface temperature over Delhi using Landsat-7 ETM+.[4] LST images were developed from Landsat data using ERDAS for Vijayawada city by K. Sundara Kumar, P. Udaya Bhaskar, K. Padmakumari.[5] K. Gobakis et al have developed an artificial neural network model to predict urban heat island based on experimental investigation.[6] Mehmet Şahin, B. Yiğit Yildiz, Ozan Şenkal & Vedat Peştemalci have developed a model using artificial neural network for the estimation of land surface temperature (LST) using meteorological and geographical data in Turkey.[7]

2. STUDY AREA AND DATA SOURCES

Vijayawada is a historical city situated at the geographical centre of Andhra Pradesh state in India on the banks of Krishna River with latitude $16^0 31^1$ N and longitude 80^0 39^1 E. Vijayawada city of Andhrapradesh is experiencing rapid urbanization that has resulted in remarkable UHI. Urban Heat Island is one of the upcoming urban climate related problems developing in the city.

For the present study Landsat images were procured from USGS website. The details of the imagery collected are given in Table.1.

Table 1: Details of Imagery procured from USGS

Sl.No	Date	Satellite/Sensor	No of Bands	Reference system/ Path/Row
1	10-11-1990	Landsat5/TM	7	WRS2/142/49
2	31-10-2001	Landsat7/ETM+	8	WRS2/142/49

3. METHODOLOGY

The present research work involves image processing of Landsat data and development of land use and land cover images. This was done by the unsupervised classification method using ERDAS Imagine software. Normalized Difference Vegetation Index (NDVI) image was developed from bands 2, 3 & 4 of Landsat images. Using the thermal band of Landsat image LST has been retrieved by using the model maker of ERDAS. The detailed procedure can be referred by the author’s research paper given in references 3 and 5.

DERIVATION OF NDVI

The Normalized Difference Vegetation Index (NDVI) is a measure of the amount and vigour of vegetation at the surface. The reason NDVI is related to vegetation is that healthy vegetation reflects very well in the near infrared part of the spectrum. The value is normalized to -1<=NDVI<=1 to partially account for differences in illumination and surface slope. The index is defined by equation 1.

$$\mathbf{NDVI} = \frac{(\boldsymbol{BAND}\ \mathbf{4} - \boldsymbol{BAND}\ \mathbf{3})}{(\boldsymbol{BAND}\ \mathbf{4} + \boldsymbol{BAND}\ \mathbf{3})} \quad (1)$$

RETRIEVAL OF LST

The digital number (DN) of thermal infrared band is converted in to spectral radiance (L_λ) using the equation supplied by the Landsat user’s hand book.

$$\mathbf{L}_\lambda = \left\{ \frac{\boldsymbol{LMAX} - \boldsymbol{LMIN}}{\boldsymbol{QCALMAX} - \boldsymbol{QCAL\ MIN}} \right\} * \boldsymbol{DN} - \mathbf{1} + \boldsymbol{L_{MIN}} \quad (2)$$

L_{MAX} = the spectral radiance that is scaled to *QCALMAX* in W/(m^2 * sr * µm)

L_{MIN} = the spectral radiance that is scaled to *QCALMIN* in W/(m^2 * sr * µm)

QCALMAX = the maximum quantized calibrated pixel value (corresponding to L_{MAX}) in DN = 255

QCALMIN = the minimum quantized calibrated pixel value (corresponding to L_{MIN}) in DN = 1

L_{MAX} and L_{MIN} are obtained from the Meta data file available with the image and are 15.303, 1.2378 for Landsat5 /TM and 12.65, 3.2 for Landsat7 /ETM+ respectively. The effective at-sensor brightness temperature (T_B) also known as black body temperature is obtained from the spectral radiance using Plank’s inverse function.

$$\mathbf{T_B} = \frac{\boldsymbol{K2}}{\boldsymbol{In}\left(\mathbf{1} + \frac{\boldsymbol{K1}}{\boldsymbol{L\lambda}}\right)} \ \textbf{(Unit: Kelvin)} \quad (3)$$

The calibration constants K1 and K2 obtained from Landsat data user's manual are 607.76, 1260.56 for Landsat5 /TM and 666.09, 1282.71 for Landsat7/ETM+. An Emissivity image is developed using the classified image and the NDVI image by giving emissivity values for different types of land cover. Emissivity values are given as 0.90 for built-up land, 0.96 for bare soil, 0.98 for vegetation, 0.99 for thick vegetation. The resulting emissivity image is used to develop land surface temperature image. The surface emissivity image based on NDVI classes is used to retrieve the final Land Surface Temperature.

$$\textbf{LST} = \frac{T_B}{1+(\lambda+T_B/\rho)*In\epsilon} \quad \textbf{(Unit: Kelvin)} \qquad (4)$$

where, λ is the wavelength of the emitted radiance which is equal to 11.5μm. ρ = h.c/σ, σ = Stefan Boltzmann's constant which is equal to 5.67 x 10-8 Wm-2 K -4, h = Plank's constant(6.626 x 10 -34 J Sec), c = velocity of light (2.998 x 108 m/sec) and ε is spectral emissivity. For all the calculations at pixel level of the image, models were developed using Spatial Modeller module of ERDAS Imagine 9.1.

ARTIFICIAL NEURAL NETWORK MODEL

A feed forward back propagation artificial neural network model with LM training algorithm has been developed in MATLAB with LULC, NDVI, Latitude and Longitude as input parameters and LST as output Parameter. The model architecture was shown in Fig.1.

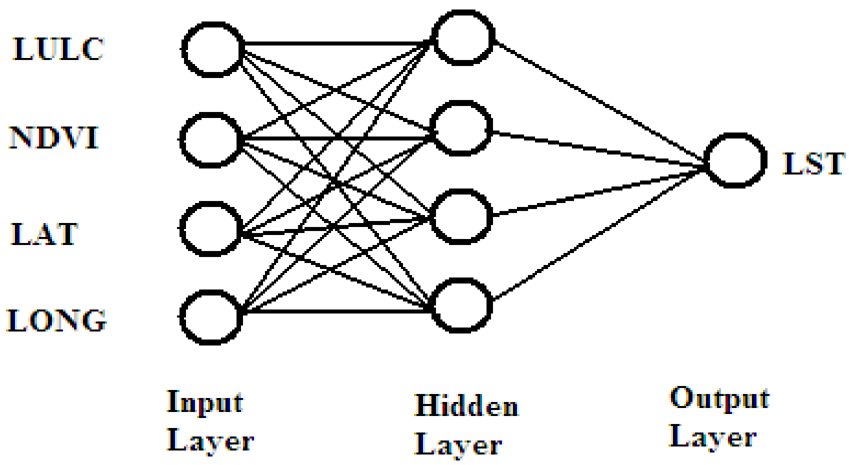
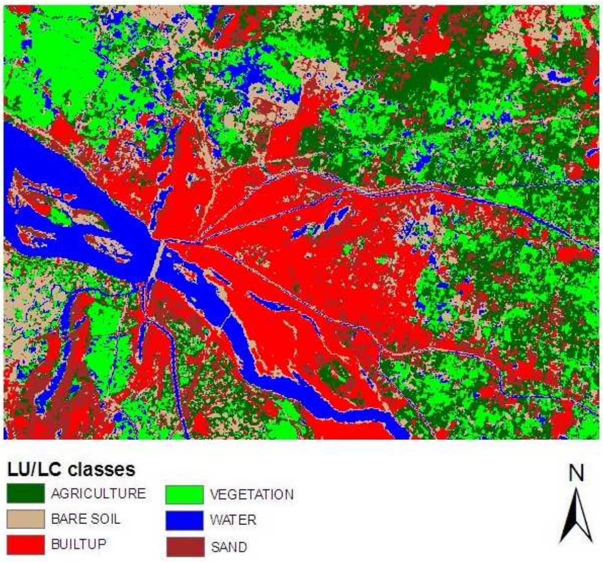


Fig 1: ANN model architecture

Using the pixel values the image data has been converted in to discrete data in Arc GIS for use in the model. For training the model LULC and LST images of 2001 are used. For testing the model LULC and LST images of 1990 are used. The values of latitude and longitude of pixels were obtained by using a model in Arc GIS. The output of the ANN model obtained from MATLAB which is in the form of discrete data is converted in to image format using Arc GIS.

4. RESULTS AND DISCUSSION

The LULC and NDVI images developed from Landsat data using ERDAS are given in Fig.2 to 5



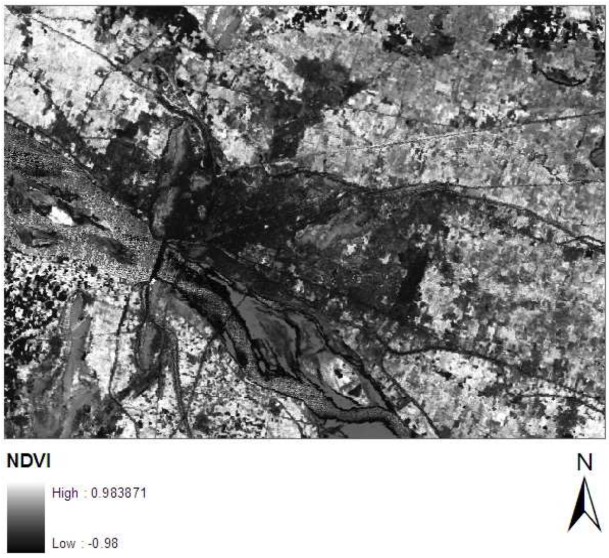


Fig.2 LU/LC image for 1990

Fig.3 NDVI image for 1990

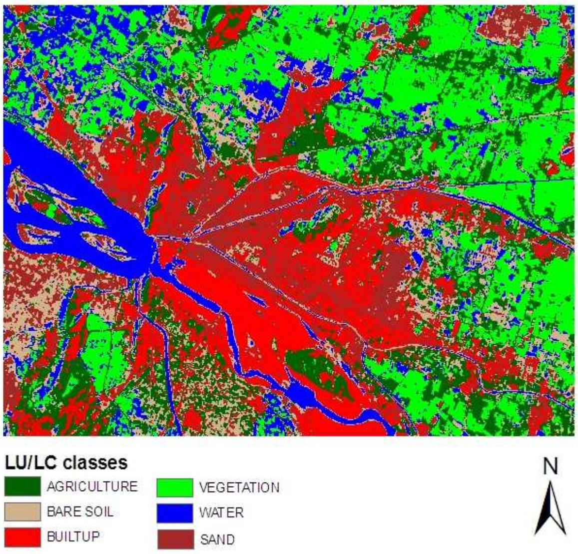


Fig.4 LU/LC image for 2001

Fig.5 NDVI image for 2001

The LST images developed by Landsat data using ERDAS imagine software and corresponding LST images obtained from the ANN model are presented in the Figures 6 to 9.

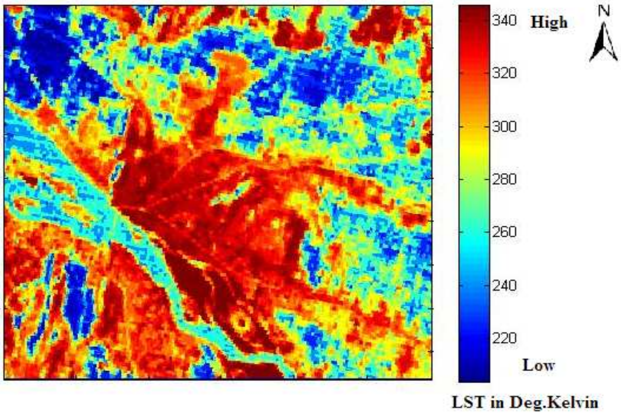


Fig.6 LST image for 2001 from Landsat data

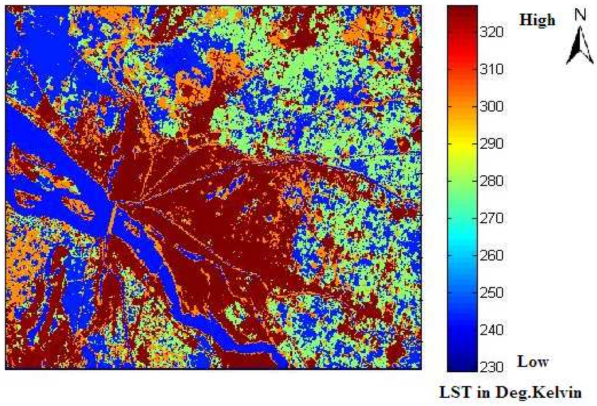


Fig.7 LST image for 2001from ANN model

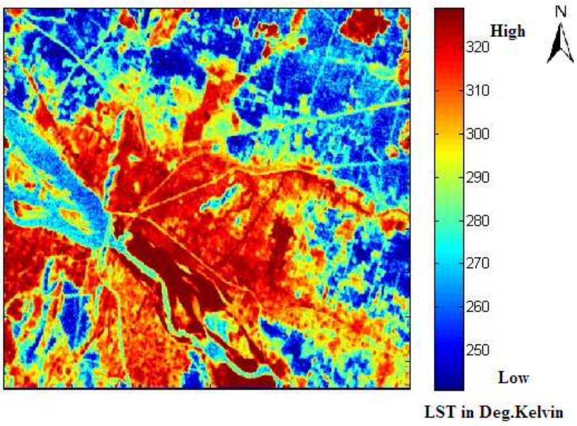


Fig.8 LST image for 1990 from Landsat data

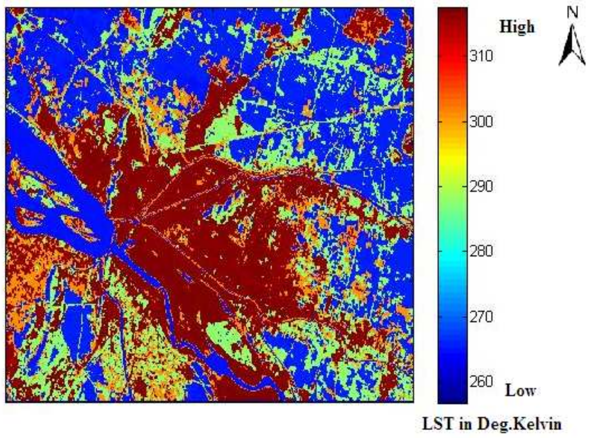


Fig.9 LST image for 1990from ANN model

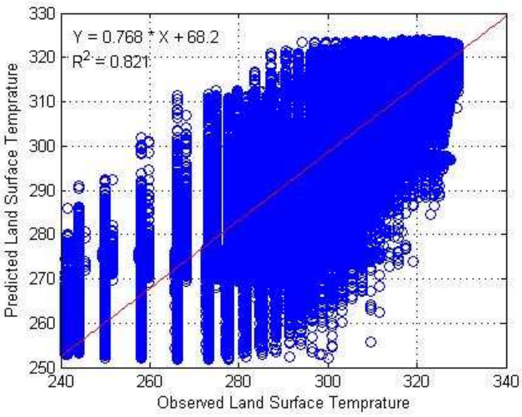


Fig.10 Scatter plot for the year 2001

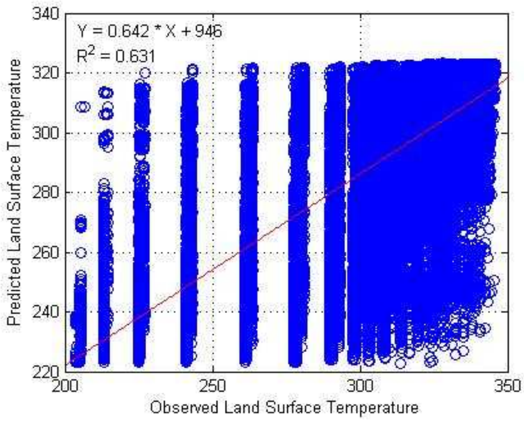


Fig.11 Scatter plot for the year 1990

The scatter plots for the observed and predicted LST were given in Figures 10 and 11 for the years 2001 and 1990 respectively. The variation of the observed or estimated and predicted data of LST through ANN model for the year 2001 and 1990 were shown in the Figures 12 to 15 for a randomly selected column and row in the output data set.

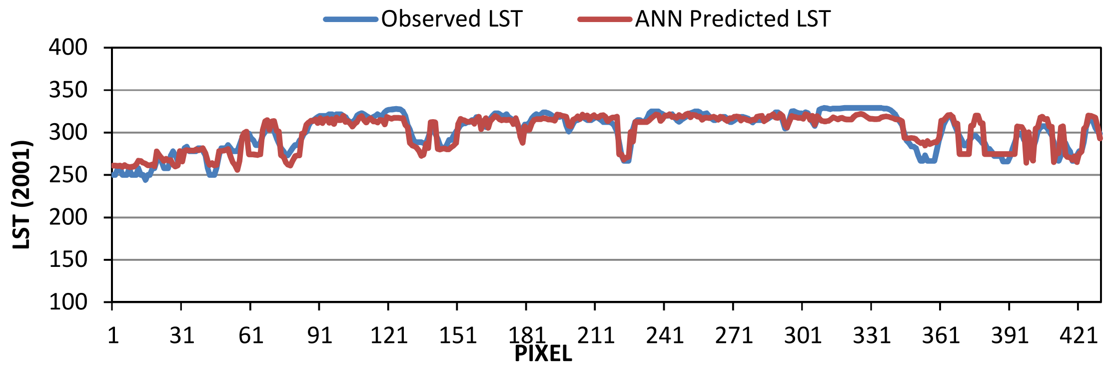


Fig.12: Variation of the observed and predicted data for a columnof LST for the year 2001

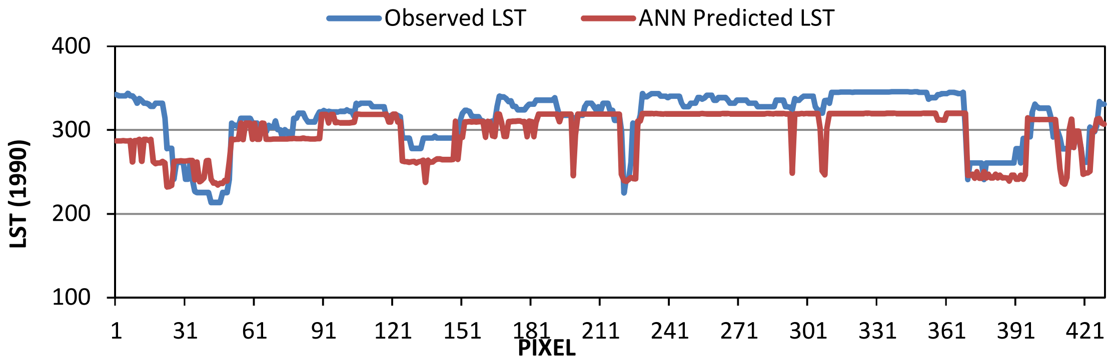


Fig.13: Variation of the observed and predicted data for a column of LST for the year 1990

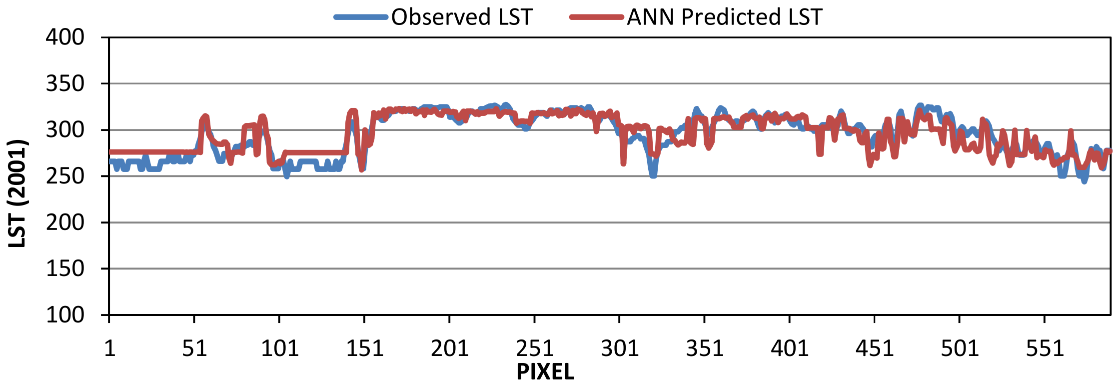


Fig.14: Variation of the observed and predicted data for a row of LST for the year 2001

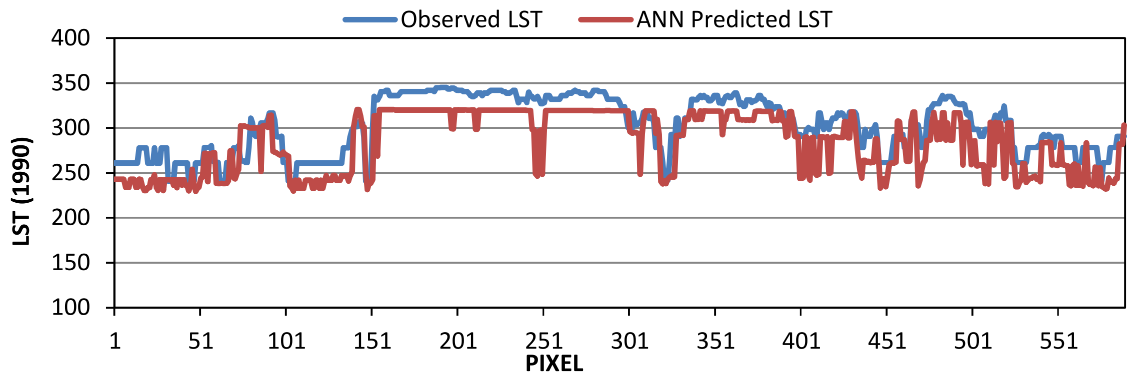


Fig.15: Variation of the observed and predicted data for a row of LST for the year 1990

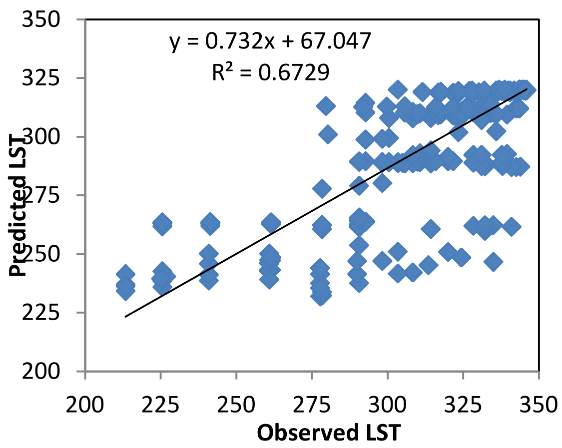


Fig.16: Scatter plot for a column for 1990

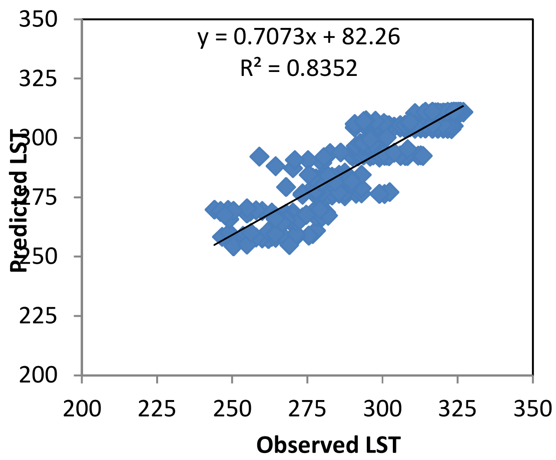


Fig.17: Scatter plot for a column for 2001

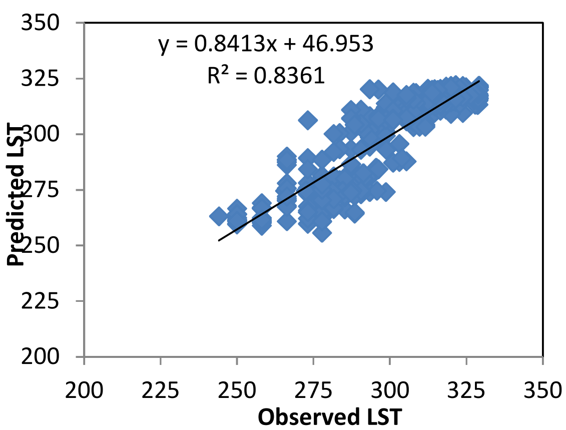


Fig.18: Scatter plot for a row for 1990

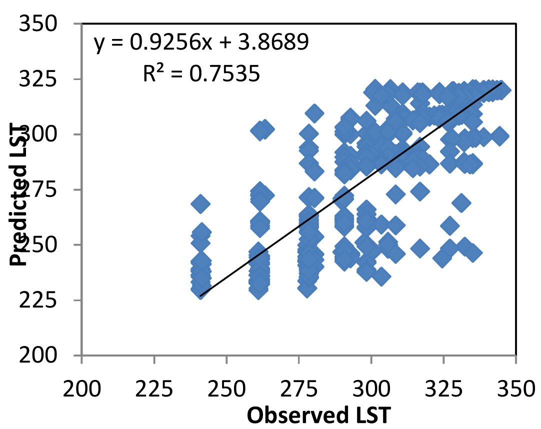


Fig.19: Scatter plot for a row for 2001

The scatter plots for the observed and predicted LST data for the year 2001 and 1990 for a randomly selected column and row are given in the Figures 16 to 19. From the above graphs and the scatter plots it is clear that the model is able to predict with good accuracy. The goodness of fit statistics is presented in the Following Table.2.

Table. 2: Goodness-of-fit statistics for the observed and predicted LST

MODEL	E_{NS}	RMSE	R^2	MAE
Training year 2001	81.621	10.756	0.821	8.552
Testing year 1990	57.889	21.489	0.631	18.137

R^2 : Coefficient of determination, RMSE : root mean square error .

MAE : Mean absolute error , E_{NS} : Model Efficiency

5. CONCLUSION

The distinguished climatic condition termed 'Urban Heat Island' (UHI) is developing in the rapidly urbanized cities. Vijayawada city of Andhrapradesh is experiencing rapid urbanization that has resulted in remarkable UHI. Understanding the distribution of Land Surface Temperature (LST) and its spatial variation will be helpful to decipher its mechanism and find out possible solution. Retrieval of LST from satellite imagery is tedious and also availability of remote sensing data with thermal band with high resolution is scarce. Hence with the development of a model using the artificial neural network the LST can be predicted easily from LULC images. By inputting the model with a variety of data the model can be trained in a better way. From the output of the model it was clear that the ANN model predicts very well with good accuracy. The randomly selected column and row data of the LST image were compared and studied with the help of scatter plots, and found that the predicted LST values are very close to the observed values. The goodness of fit statistics shows that R^2 value for the years 2001(training), 1990(testing) are 0.821, and 0.631 respectively. The model can also be used to predict future LST with LULC images and will be helpful to monitor urban heat island development in cities.

6. REFERENCES

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