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# Spatio-Temporal Estimation of Soil Respiration for Indo-Gangetic Plain using Remote Sensing

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**Abstract-**Soil respiration, a process of $CO_2$ addition from terrestrial ecosystems to the atmosphere, is highly sensitive to temperature change. Various relations showing dependence of soil respiration on soil temperature has been established. It is possible to obtain land surface temperature (LST) from Remote Sensing. This remotely sensed LST can be used as a soil temperature to estimate soil respiration. Present study shows the use of remote sensing in quantification and up-scaling soil respiration to large scale through modeling. Best fitted model relating soil respiration with soil temperature was found using in-situ data collected over period of two years (May 2007 to April 2009) in a part of Indo-Gangetic plain followed by soil respiration estimation for Indo-Gangetic plain using remotely sensed MODIS derived LST. For this, various temperature dependent linear, power, exponential and logistic models of soil respiration were fitted on the field data (Monthly mean soil respiration - Monthly mean soil temperature) and analyzed using regression analysis. MODIS derived monthly mean LST were calibrated using field monthly mean soil temperature to obtain MODIS derived monthly mean soil temperature images. Modified Schlentner and Cleve model fitted well compared to other models whereas linear model also showed the good predictability. These best fitted models were applied on MODIS derived monthly mean soil temperature images of Indo-Gangetic plain to estimate the monthly mean soil respiration. Study showed that the soil respiration is positively correlated with soil temperature and remote sensing has potential to monitor soil respiration at local, regional and global scale.

**Index Terms:** Soil respiration, Temperature, Climate change, Model, Remote Sensing, Land surface temperature, Indo-Gangetic plain.

## 1. INTRODUCTION

Soil is the largest global pool of terrestrial carbon and is at least three times larger than the atmospheric carbon pool [1,2].Soil respiration, a critical process, defined as the production of carbon dioxide by microorganisms (hetrotrophic respiration) and plant roots, normally refers to the total carbon dioxide efflux at the soil surface. Soil respiration is considered as the second largest source of $CO_2$ efflux between terrestrial ecosystems and the atmosphere, and is a major pathway of global carbon cycling [3,4,5,6,7]. It plays a critical role in regulating atmospheric $CO_2$ concentration. Soil respiration is very sensitive to environmental changes such as temperature change. Soil temperature increase, amplifies the microbial and root activity thus raises the soil respiration rate [8,9,10,11]. Elevated rates of soil respiration could significantly impact the concentration of $CO_2$ in atmosphere with potential feedbacks to climate change [2,4,12,13,14,15]. With global warming, role of soil as carbon sink could change to a major carbon source [16,17,18,19]. So, as a key factor influencing soil $CO_2$ efflux, the temperature sensitivity of soil respiration has gained considerable attention of the research community. Different models have been developed and are being developed relating soil respiration with the soil temperature. Models such as exponential or Arrhenius equations, linear models, quadratic models, logistic models, and empirical models shows temperature dependence of soil respiration [11,20].

Many studies have been done around the globe to measure and understand soil respiration. But these measurements are local or site specific. To improve the precision of carbon budget estimation, soil respiration need to be measure at a regional and global scale [21,22]. Limited soil respiration global scale studies are present today but regional scale studies are even more limited due to difficulty in scaling local soil respiration to regional scale [23,24,25,26]. Due to difficulty in obtaining information on heterotrophic respiration from space, inability of remote sensing instrument to measure soil respiration on large scale and complexity involved in scaling local soil respiration to large scale [27,25,24], not much work has been done using remote sensing for its estimation. For large scales, temperature is more influencing factor than other environmental factors for soil respiration [28,29,30,31]. Since remote sensing is used to obtain land surface temperature (LST), this LST can substitute soil temperature to estimate soil respiration. Present study aims to model $CO_2$ emission rate versus temperature from known in-situ data collected over a part of study area and to scale up $CO_2$ emission rate to regional scale using remote sensing.

## 2. MATERIAL AND METHOD

### 2.1 *Study area characteristics and concerns*

Indo-Gangetic plain (21°32'20.56"N - 30°24'41.64"N and 77°05'40.39"E - 89°50'12.55"E) (Fig. 1), spread along river Ganga between Himalaya and Deccan plateau, In our study area it covers the states of Uttar Pradesh, Bihar, Jharkhand, West Bengal and is among the most fertile alluvial plain of the world. In this region, seasonal temperature varies widely with scorching summer from April to June, rainy season from July to September and cold winter from November to February. With wheat as the main crop in the west and rice in the east, it is the most intensively cultivated zone of India. Maize, Mustard, Barseem, Sorghum, Sugarcane, several pulses and vegetables are other important crops. Its agriculture production supports major population of South Asia [32]. Rapid population growth and reduction in resources has put stress on this region to support current as well as future demands. Agricultural soil is one of major source of greenhouse gases. Crop rotation system, irrigation, extensive use of fetilizers, burning of crop residue, conventional tillage practice and burning of diesel fuel practiced over decades in this region has lead to direct impact on greenhouse gases emission such as $CO_2$, $N_2O$ and $CH_4$ [33]. Though increased $CO_2$ concentration increases the crop yield but associated temperature rise and precipitation may result in overall production decline [32]. Long term experiments in this region has already shown decline in the productivity and is a cause of concern [33]. Global warming could lead increased soil respiration rates in this region. Higher soil respiration rates will further increase the $CO_2$ concentration in atmosphere and may result in overall productivity decline of this region. This decline productivity will affect the many million people of South Asia. So, in this climate change scenario, it becomes imperative to study and monitor soil respiration in Indo-Gangetic plain.

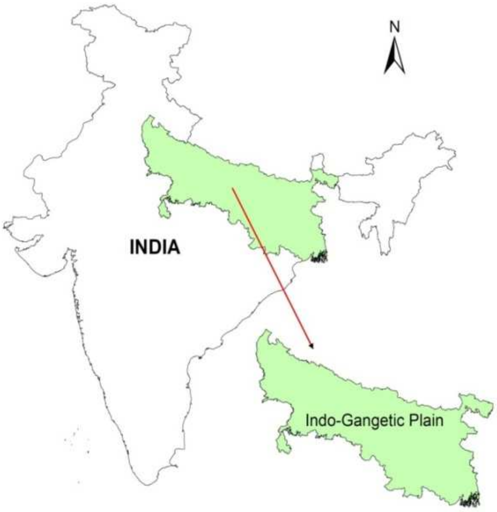

Fig. 1. Map showing Study Area – Indo-Gangetic Plain

### 2.2 *In-situ data collection*

Data for $CO_2$ emission rate (soil respiration) and soil temperature at 78 locations in different districts, viz., Saharanpur, Haridwar, Muzaffarnagar, Meerut, Bagpat and Ghaziabad of Uttar Pradesh from May 2007 till April 2009 was collected. Widely used closed chamber method was implemented to measure $CO_2$ emission rate. Measurements were made by PSP soil respiration system (EGM-4 $CO_2$ Analyser) which had an inbuilt soil temperature probe. Soil temperature measurements were made at 5 cm depth. Data collected was processed to obtain monthly mean $CO_2$ emission rate and monthly mean soil temperature. The final data had twenty five locations with monthly mean soil $CO_2$ emission rate (g $m^{-2}hr^{-1}$) and monthly mean soil temperature (˚C).

### 2.3 *Model selection*

The dependency of soil respiration ($CO_2$ emission rate) on the temperature was tested by using scatter plot between monthly mean soil respiration and monthly mean soil temperature. Five hundred fifty observations were used for analysis. The scatter plot showed the non-linear relationship between them that has also been seen in many previous studies. Ten models (Table 1) were tested on the data using the linear / Non-linear regression of SPSS

17(statistical software) with Marquardt-Levenberg algorithm that minimizes the sum of squares of differences between the dependent variable values in the equation models and the observed values to determine the parameters of the equation. The equations fitted are presented in Table 1.

### 2.4 *MODIS Land surface temperature (LST) data*

The MODIS Land surface temperature - MOD11A2 product, a global LST (8 day composite), 1km x 1km resolution, was used to extract MODIS-derived monthly mean LST (˚C) for each month from May 2007 to April 2009 for study area.

### 2.5 *Calibration of MODIS monthly mean LST data using field temperature data*

Using latitude and longitude value of twenty five locations, MODIS monthly mean LST values were extracted for each month from May 2007 till April 2009. The extracted MODIS monthly mean LST was then correlated with in-situ data of monthly mean soil temperature using linear regression analysis. The monthly mean soil temperature data were found to be linearly related to MODIS monthly mean LST (Fig. 2) with coefficient of determination ($R^2$) equals to 0.646. The equation obtained is given below:

*Monthly mean soil temperature = 0.789×MODIS monthly mean LST + 2.48*

The above obtained linear equation was then used to calibrate the MODIS monthly mean LST imagery.

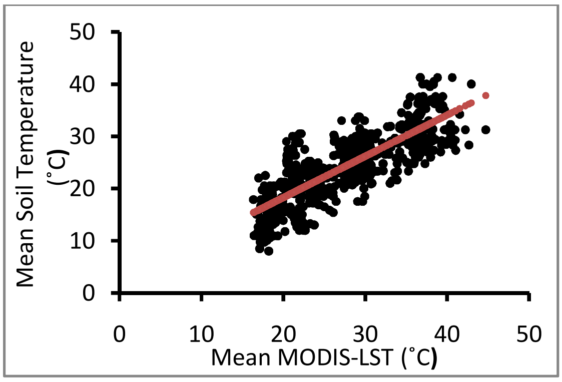

Fig. 2.Graph showing linear relationship between MODIS-derived LST and field data.

### 2.6 *Soil respiration for Indo-Gangetic plain*

Based on the statistical regression analysis obtained best suited equation was used to determine soil respiration of the Indo-Gangetic plain. Modified Schlentner & Cleve equation was finally selected to apply on the monthly mean soil temperature imageries to generate the monthly mean soil respiration imageries for each month. Mean of preceding year and succeeding year months were taken to generate monthly mean respiration images of Indo-Gangetic plain. Annual mean soil respiration image were also generated using annual mean temperature image which is generated by taking the mean of all monthly mean temperature images. In same manner linear model was also used to generate monthly mean and annual mean soil respiration images because of its simplicity and predictability. Monthly mean soil temperature for the month of May, June, July, August and September were ignored because of cloud cover. Sequential flow of methodology is depicted in Fig. 3.

## 3. RESULTS

### 3.1 *Best-fit Model*

Numerous models attempted in present study are depicted in Table 1. Individual model parameters have also been shown in the Table 1 for various models. Only two models linear and Modified Schlentner & Cleve model (1985) were chosen based on the $R^2$ value and root mean square (RMS) error value. The latter model showed highest value of $R^2$ value 0.425 and minimum RMS error 0.23131 gm-$^2$hr$^{-1}$. However because of simplicity and reasonably higher $R^2$ value 0.301 and lower RMS error 0.23484 gm$^{-2}$hr-1, linear model was also selected. Quadratic model showed inferiority to the other models. Models such as first order exponential given by Kucera & Kirkham (1971), Fang & Moncrief (2001), O'Connel (1990), Lloyd & Taylor (1994) and Jenkinson (1990) are better than quadratic and produced the almost same soil respiration predictability with nearly same coefficient of determination of regression ($R^2$ = 0.30). Scatter plots linear and Modified Schlentner & Cleve model fitted on data are shown in Fig. 4.

### 3.2 *Spatio-Temporal Variation of Mean Soil Respiration in Indo – Gangetic Plain*

Both models showed that $CO_2$ efflux from surfaces of Indo-Gangetic plain varies seasonally with lower $CO_2$ effluxes during winters and higher effluxes during summers. This seasonal variation can be depicted from spatial pattern of monthly mean soil respiration for Indo-Gangetic plain derived from Modified Schlentner & Cleve (1985) and Linear model are presented as follow in Fig. 5 and 6 respectively.

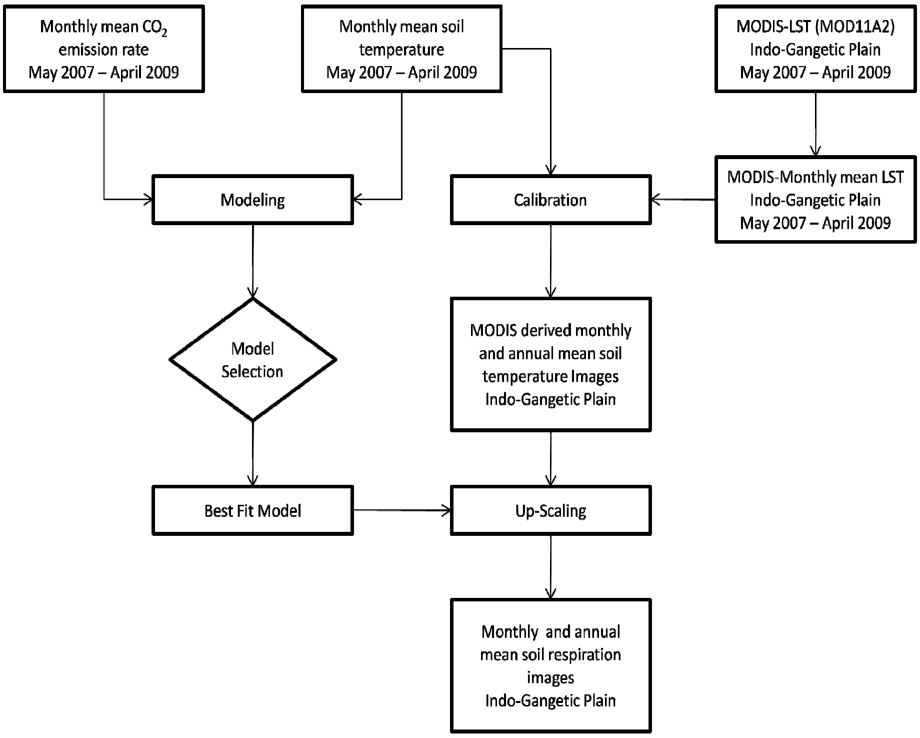

Fig. 3.Sequential flow of Methodology

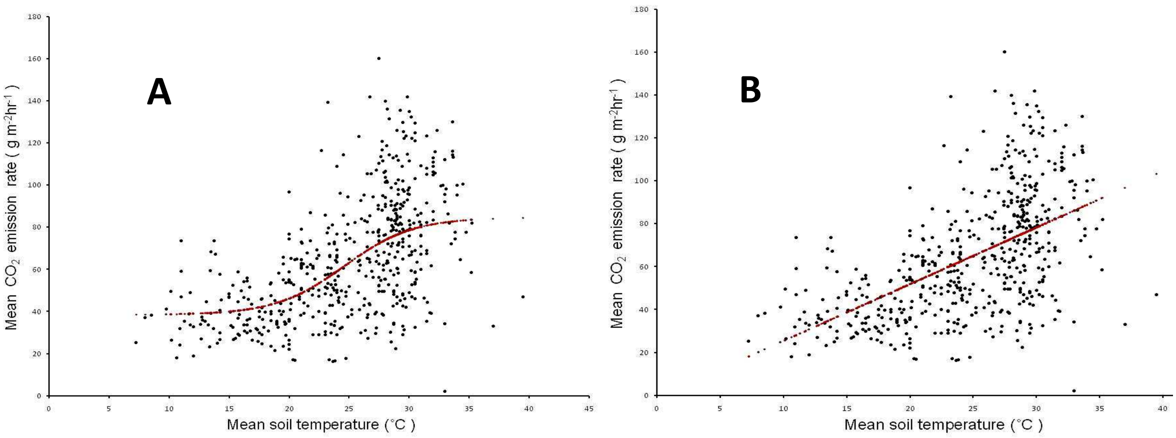

Fig. 4. (A) Fitted Modified Schlentner & Cleve model and (B) Fitted Linear Model

Table 1. Fitted models with estimated parameters, coefficient of determinations and the RMSE

| **Model** | **Fitted equation with estimated parameters** | **R$^2$** | **RMSE** |
|---|---|---|---|
| Linear | $Y = a + bT$ , a = -0.999 b = 2.461 | 0.301 | 0.23484 |
| Quadratic | $Y = aT^2$ , a = 0.093 | 0.16 | 0.25745 |
| Kucera&kirkham | $Y = a(T + 10)^b$ , a = 0.31 b = 1.5 | 0.304 | 0.23443 |
| Fang &Moncrief | $Y = a(T - T_{min})^b$ , a = 0.083 b = 1.786 Tmin= -16.418 | 0.304 | 0.23440 |
| First order exponential | $Y = ae^{bT}$ , a = 21.505 b = 0.043 | 0.30 | 0.23507 |
| O' Connel | $Y = ae^{bT+CT^2}$ , a = 10.524 b = 0.101 c = -0.001 | 0.308 | 0.24436 |
| Arrehnius | $Y = ae^{\frac{E\,(T-10)}{R(T+273.15)283.15}}$ , a = 34.162 E = 0.00000406 | 0.298 | 0.23541 |
| Lloyd &taylor | $Y = ae^{\frac{E\,(T-10)}{(T+273.15-T_O)(283.15-T_O)}}$ , a = 28.249 E = 0.07 T0 = 227.423 | 0.304 | 0.23434 |
| Jenkinson | $Y = \frac{d}{a+b^{-\frac{T-10}{10}}}$ , a = 0.258 b = 2.385 d = 34.261 | 0.307 | 0.23378 |
| Modified Schlentner& Cleve | $Y = \frac{d}{a+b^{-\frac{T-10}{10}}} + c$ , a = 0.006 b = 33.264 c = 38.436 d = 0.277 | 0.425 | 0.23131 |

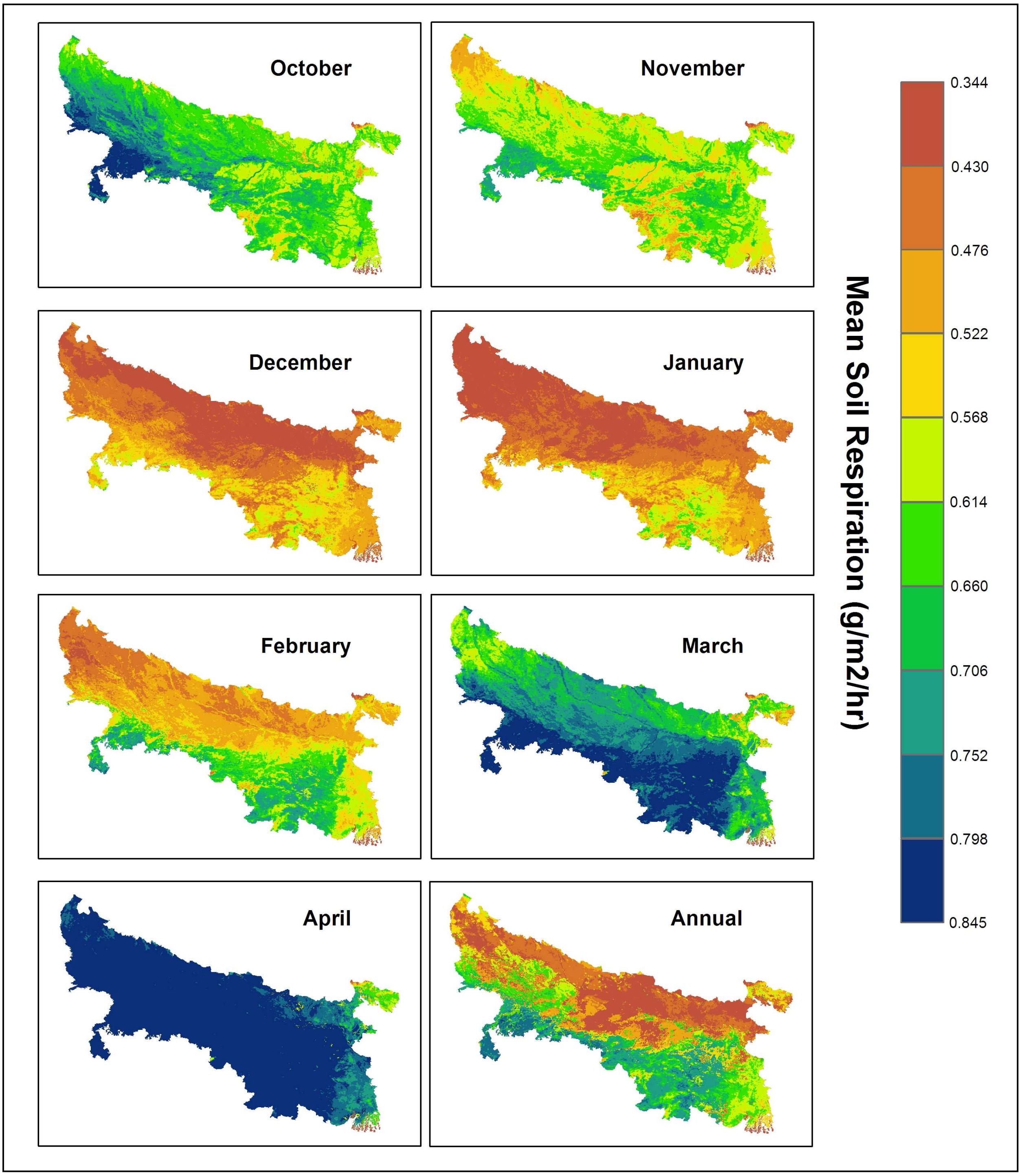

Fig. 5. Spatio-Temporal pattern of monthly and annual mean soil respiration for Indo-Gangetic plain using Modified Schlentner & Cleve Model

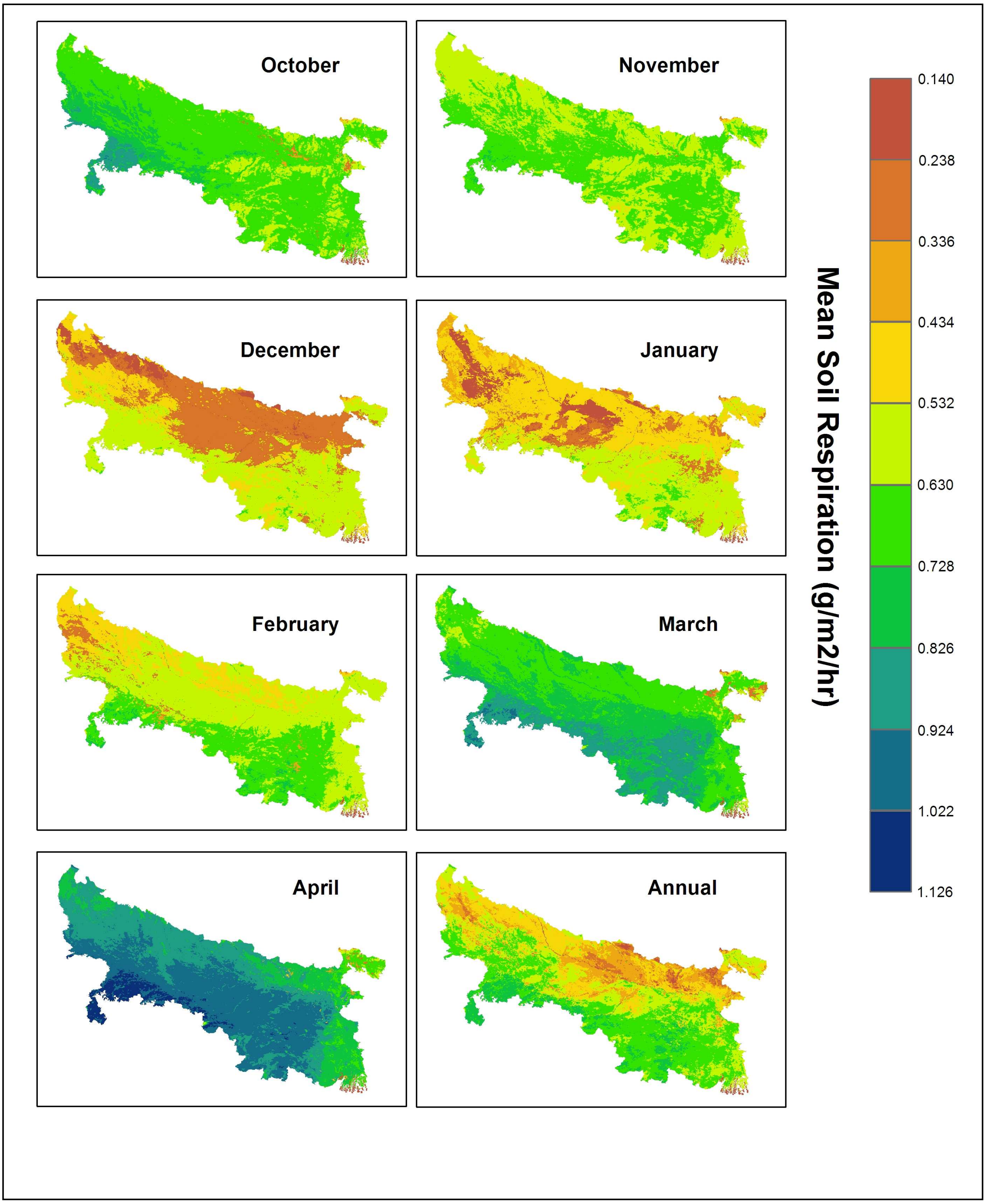

Fig. 6. Spatio-Temporal pattern of monthly and annual mean soil respiration for Indo-Gangetic plain using Linear Model

### 3.3 *Mean Soil Respiration*

It was found that monthly mean soil respiration predicted from Modified Schlentner & Cleve model (1985) was less than predicted by linear model with lesser deviations as well. Table 2 and Table3 shows the summary of the monthly mean soil respirations from January to December and for a year for Indo-Gangetic plain generated by Modified Schlentner & Cleve (1985) and linear model respectively.

Table 2. Summary of monthly mean soil respiration for January to December and for a Year by Schlentner& Cleve model

| **Month** | **Mean** ($g\ m^{-2}h^{-1}$) | **Stddev** ($g\ m^{-2}h^{-1}$) | **Coef. of variation** |
|---|---|---|---|
| January | 0.4651 | 0.0566 | 0.1216 |
| February | 0.5540 | 0.0865 | 0.1561 |
| March | 0.7336 | 0.0767 | 0.1045 |
| April | 0.8136 | 0.0551 | 0.0677 |
| October | 0.6635 | 0.0695 | 0.1047 |
| November | 0.6022 | 0.0523 | 0.0868 |
| December | 0.4702 | 0.0534 | 0.1135 |
| Annual | 0.5543 | 0.1233 | 0.2224 |

Table 3. Summary of monthly mean soil respiration for January to December and for a Year by Linear model

| **Month** | **Mean** ($g\ m^{-2}h^{-1}$) | **Stddev** ($g\ m^{-2}h^{-1}$) | **Coef. of variation** |
|---|---|---|---|
| January | 0.4717 | 0.1180 | 0.2501 |
| February | 0.5838 | 0.0888 | 0.1521 |
| March | 0.7444 | 0.0866 | 0.1163 |
| April | 0.8945 | 0.0996 | 0.1113 |
| October | 0.6770 | 0.0674 | 0.0995 |
| November | 0.6312 | 0.0376 | 0.0595 |
| December | 0.4350 | 0.1491 | 0.3427 |
| Annual | 0.5729 | 0.1254 | 0.2188 |

## 4. DISCUSSION

Soil respiration is highly dependent on temperature[7,11] and shows the seasonal pattern of higher values in hot season and lower values in cold season[3,34]. The relationship between soil respiration and temperature is nonlinear as observed in previous studies and temperature alone has been used to model the soil respiration. Soil temperature alone could explain the total variance of soil respiration, up to 40% of variance of soil respiration was explained by temperature alone with the help of the models used. The results of the present study are in agreement with that of the Peng et. al.[35], Jones and Cox[17] and Bond-Lamberty and Thomson[25], the reason could be that as the soil temperature and soil moisture correlated with each other, it is possible that relationship between soil respiration and soil temperature is confounded by soil moisture. Also contribution of other factors cannot be ruled out.

Remote sensing is the powerful technique and it provides a lot of information related to land, ocean and atmosphere. Using satellite based land surface temperature (LST), soil respiration for Indo-Gangetic plain was extrapolated to understand the spatial pattern of soil respiration over the Indo-Gangetic plain. The results are in agreement with that of Tamai [36], Fang and Moncreif [11] and Wang et al. [37]. Wang et al. [38] also reported that the model of Schlentner and Van Cleve showed minimum RMS error, we also found that this model showed minimum RMS error.

Most of the studies done on soil respirations are limited to small area and with global concern related with soil respiration it is mandatory to quantify it for larger areas. And hence, remote sensing could be a better technique to estimate the soil respiration over large areas.

## 5. CONCLUSION

Present study showed that the soil respiration is positively correlated with soil temperature. Remote sensing can be used effectively for quantification and up-scaling soil respiration at local, regional as well as at global scale. Present study will provide light to mitigate global warming and climate change. And more studies using the technique of remote sensing are needed in order to improve the estimation of soil respiration. With the introduction of soil moisture and biophysical parameter along with temperature better prediction is expected. Soil moisture derived from SMOS and MODIS water vapor products have the scope for further research with minimum uncertainty.

## 6. FUTURE SCOPE

Though soil temperature is the dominant influencing factor for the soil respiration, but there are other factors which can influence it. Most of the factors that influences soil respiration can be derived from remote sensing. Attempt has to be made to model including moisture and soil properties for large area. Provided other data sets like soil moisture content etc are available at high resolution, remote sensing can be used for better quantification of soil respiration.

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