Research Article

Delineation of Vulnerable Zones for YSB Attacks under Variable Temperatures Using Remote Sensing and GIS

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Abstract | The spatiotemporal changes in temperature are a main cause for a shift in crop phenology as well as failure of crop calendar. Yellow stem borer (YSB) is an insect pest of rice crop that may reduce rice yield about 20% due to the use of insecticide at inappropriate times and unsuitable locations following the crop calendar. The purpose of this research was to delineate the vulnerable zones for YSB attacks on rice crop using satellite thermal datasets. The area under investigation was 13700 km^2 area out of which 8627 km^2 was covered by rice plantations. Thermal datasets covered the area of 8627 km^2 comprising 10663 pixels which returned 10663 spatially distributed temperature values. Six, thermal datasets were obtained for the duration between (April 03-June 22) 2014, with a temporal window of 16 days to delineate YSB vulnerability from egg laying to pupa evolution stage. The results obtained highlight that 73% of the investigation area were venerable for a female YSB to lay 100-143 eggs on April 03, that increased up to 96% to lay 148-176 eggs on April 19, due to increase in temperature. On May 05, about 5377 km^2 area was found in egg hatching phase, on May 21, 1514 km^2 area was found in larva evolution phase and on June 22, 1725 km^2 area was found in pupa evolution phase. The results proved that satellite technology is an efficient and cost-effective tool to demarcate the vulnerable zones to YSB attacks and to take remedial measures accordingly.

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Introduction

About 3 billion people of the world are using rice (*Oryza sativa*) as regular food (Mosleh et al., 2016). Several efforts have been made to increase per acre productivity to fulfil the food demands of increasing population, but insect pest is the major yield limiting factor (Saxena et al., 2007). Insect Pests have become a challenge for agronomists due to their extensive activity. More than 20 types of insect pest directly affect the rice plant that results in severe loss of economy (Patkan M.D. et al., 1981). Probably temperature may be the most important environmental factor that influences the insect behaviour (N. Manikandan et al., 2013). Anthropogenic activities on a global scale are responsible for environmental changes, especially an increase in temperature (Harrison J. et al., 2006). The climatic changes affect the insect pest distribution, their population dynamics, intensity, abundance and feeding behaviour (Ayres J.S. et al., 2009). High temperature plays an important role in pest development (Pincebourde S. and Casas J., 2006). The insect pest development in cold temperature results in their dark body colour. Scirpophaga insertulus is known as a walker pest in rice growing zones of India (Chelliah A., Benthur J.S. et al., 1989) and southeast Asia (Banjaree et al., 1968; Patkan M.D. et al., 1968). The yellow stem borer is widely distributed and most destructive predominant specie in Bangladesh, Pakistan, Malaysia, Vietnam, Indonesia and Thailand. The YSB (*Scirpophaga incertulas*) lay eggs near the tip of the rice plant leaf. The minimum threshold temperature required for a female YSB to lay eggs, is 13° C. The number of eggs laid by YSB dramatically increases at higher temperature, for example the YSB lays 143 eggs at 28° C and 176 eggs at 36° C (N. Manikandan et al., 2013). Egg hatching occurs at 16° C or higher, but the optimum temperature for egg hatching is 21-33° C. The high temperature causes 3-4 days early development in the egg hatching process, for example YSB eggs take 8.5 days at 28° C and 5.5 days at 36° C for hatching (N. Manikandan et al., 2013). Larva of YSB dies above 35° C so hatching needs high temperature for development, but larval stage of YSB needs comparatively low temperatures. YSB larva crawls toward the top of the plant and stay there for short periods. Some larva falls into the water due to wind and swim due to an air layer around their bodies. They stay and feed on leaf sheath tissues and bore into the stem at the attachment point where leaf and stem are interconnected. A hole is created due to larval bore at this interconnection point that is covered by web that may be detected by the naked eye. Pupa stage of YSB development takes place into the stem where the moth is born and escaped (M.D. Patakh and Z.R. Khan; 1994).

The date of the YSB egg hatching process varies from year to year, depending upon local weather conditions. For example, in Logan, egg hatching of apple pest began in May, 15th 2005, May, 5th 2006 and April, 30th 2007. If apple growers use a crop calendar to spray on the fixed date, it may not be effective insecticide treatment every year (Marion S. et al., 2008), therefore it is important to examine, where and when the spray is needed.

The objective of this research was to use thermal datasets (a product of Landsat satellite series) to calculate the spatial distribution of temperature. It helped to delineate the regions, where pixel-based temperature values were favourable for YSB development in each stage (egg laying, egg hatching, larva and pupa evolution). It also helped to take in time remedy actions at more appropriate places regardless of crop calendar to save the rice crop from YSB attacks.

Study area

Our study area is a subset of the province, Punjab in Pakistan, mapped in Figure. 1 that consist of five major districts, including Lahore, Sheikhupura, Hafizabad, Nankana sahib and Gujranwala, with spatial extent of 31N to 32.5N latitude and 73 E to 75 E longitude. These districts are considered as the largest producer of rice. According to USGS, our study area is the subset of Landsat satellite patch with 149 paths No and 38 row No.

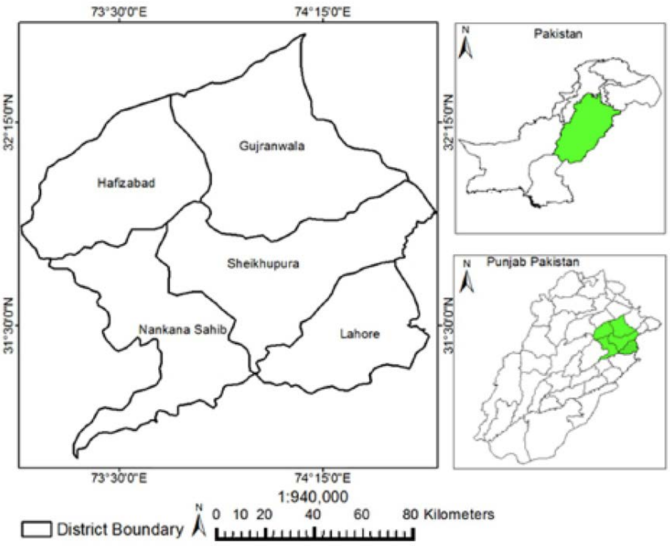

Figure 1: *Study Area.*

Materials and Methods

Continuous emission of oxides of Carbon and Nitrogen leads to global warming (Farooqi et al., 2005) which has become one of the greatest global challenges. Industrial revolution that occurred in 1700-1800s, contributed toward climate change (Shah et al., 2012) and influenced people and their lives in various sectors like health, agriculture, farming efficiency, physical comfort and the whole economic sector (Wigely, 1985; Folland, 1999). Climatic parameters like humidity, temperature, pressure and actual vapor pressure are considered to investigate climate change due to which an increase in global mean surface temperature was recorded with an increase of 0.6 °C in last century. If the same rate of change in temperature continuous, it would be an increase in global temperature 1.8 °C to 4 °C by the end of 21th century (Houghton et al., 1995). Houghton et al. (1995) also revealed that there is a shift in growing period of various crops due to increase in temperature. Global climate change model projected that Pakistan will face an increase in temperature of 1.3-1.5 °C in 2020s, 2.6-2.9 °C in 2050s and 3.6-4.5 °C in 2080s

(Bhutiyani, 2010). A period of 1950-2009 was rated as warmest time of the history (WMO, 2010) due to industrial revolution. Change in temperature has a direct impact on insect pest emergence and development therefore, it is significant to observe the pest behaviour at various temperatures.

The methodology used in this research is based on computation of pixel-based temperature values through thermal datasets as recorded by Landsat 8 thermal bands (10,11). These datasets were acquired for the complete rice cultivation period keeping in view the YSB emergence and growth stages. YSB follows an optimum temperature for existence beyond which she dies. The process to investigate all stages of YSB evolution were determined on temperature grounds because temperature has a profound impact on spatial variability of YSB population. We selected three sites to examine the population dynamic of YSB at spatial location (31.5 N, 73.6 E), (31.96 N, 74.27 E) and (32.08 N, 74.39 E). Light traps, mirrors along with humidity and temperature meters were also installed at these locations to determine the variability index in YSB population due to temperature. We computed pixels-based temperature values for various YSB development stages as listed is in table and applied linear regression to our findings to check temperature effects on YSB development.

The products of Landsat satellite series are extensively used in many remote sensing applications like urban sprawl assessment, agricultural yield estimation and appraisal of deforestation. Landsat 8 thermal datasets are commonly known as B10 and B11 which are freely available on the United States Geological Survey (USGS) website (https://earthexplorer.usgs.gov/), with a temporal window of 16 days. These datasets are comprised of 100*100 m boxes called pixels and each pixel preserves a unique number called digital no (DN).

The complete process of extraction of temperature values from thermal datasets is mentioned on the USGS official page. (http://landsat.usgs.gov/Landsat8_Using_Product.php).

To calculate pixel-based temperature values across the thermal datasets (B10, B11) DN is converted into irradiance using the following equations.

$$Irradiance\ B10 = 0.0003342 * B10 + 0.1 \quad (1)$$
$$Irradiance\ B11 = 0.0003342 * B11 + 0.1 \quad (2)$$

The value of 0.0003342 mentioned in both equations (**1**) and (**2**), is extracted from metadata (a file that preserves all the information about an image) of Landsat 8 image, however this value may be different for thermal datasets of other earth observing satellites.

To compute temperature values, following formula was applied on above calculated irradiance-based datasets.

$$TB10 = \{K_2 / Ln\,(\mathcal{E}\,K_1 / Irradiance\ B10 + 1)\} - 272.15 \quad (3)$$

$$TB11 = \{K_2 / Ln\,(\mathcal{E}\,K_1 / Irradiance\ B11 + 1)\} - 272.15 \quad (4)$$

In equations (**3**) and (**4**), K_1 and K_2 are the constants for thermal bands and their values are mentioned in the metadata of Landsat 8 which are;

K1 for B10 = 774.89; K1 for B11 = 480.89; K2 for B10 = 1321.08; K2 for B11 = 1201.14

Value of emissivity ($\mathcal{E}$) used in the equations (**3**) and (**4**) is 0.95. Final temperature against each pixel is computed by taking an average of both datasets T B10 and T B11.

$$T = (T\,B10 + T\,B11) / 2$$

Pixel based temperature values are computed using "Raster Calculator", an elegant tool embedded in Arc GIS 10.1.

Linear regression model is useful to investigate the relationship of one parameter with the other. In our case we applied linear regression to temperature and investigated its impact on various YSB development stages.

Results and Discussion

Egg laying of yellow stem borer started in the month of April that took 31-46 days for pupa emergence depending upon various temperatures experienced therefore six thermal datasets were acquired for the months from (April to July, 2014) to cover the complete life cycle of YSB. Table.1 describes the date of acquisition of thermal datasets (B10, B11) along with YSB growth stages.

The Figure 2 demonstrates the spatial distribution of temperature across the entire study area. The red color represents the built-up area showing highest temperature values due to the intense impact of anthropogenic activities. Blue color highlights the water body representing lowest temperature values and the green color is associated with the vegetative area. The color scheme was assigned to all datasets by investigating the YSB actions at various temperature values to take preventive measures in-time before YSB attacks. Pixel based temperature values were computed using algorithm described in methodology section. The urban areas act as "Urban heat islands" showing highest temperature values due to anthropogenic activities as compared to fields under vegetative practices. The areas with high temperature values were found vulnerable to YSB at any development stage therefore the regions adjacent to urban communities were found more porn to YSB attacks.

Table 1: *Thermal datasets acquisition dates for YSB stages.*

Sr. No	Date	Yellow stem borer stages
1	April 03, 2014	Egg laying stage
2	April 19, 2014	Egg laying stage
3	May 05, 2014	Egg hatching stage
4	May 21, 2014	Larva initiation stage
5	June 06, 2014	Larva initiation stage
6	June 22, 2014	Pupa stage

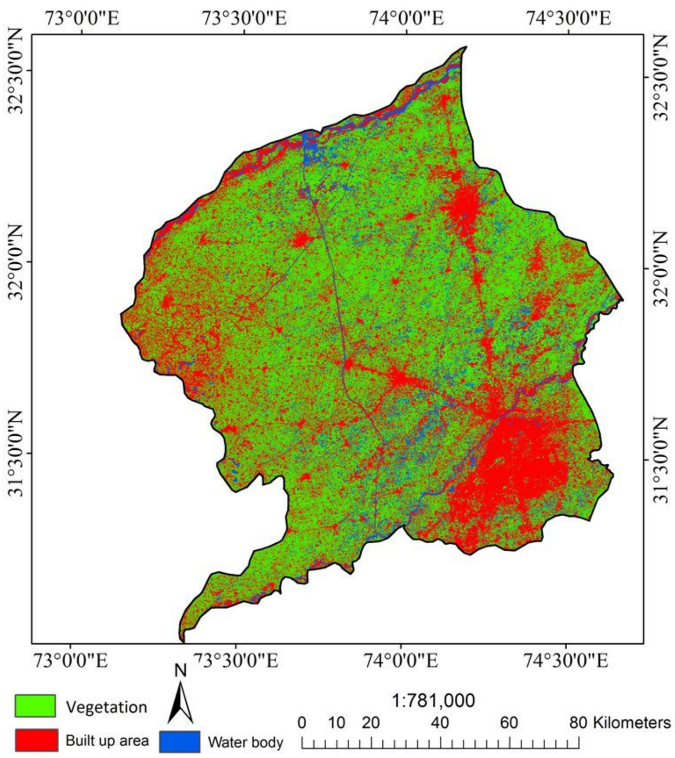

Figure 2: *Land use land cover.*

It was important to extract the vegetative area only to improve the results. So, we executed land use, land cover (LCLU) classification using supervised classification utility in Erdas imagine 14 to clip the required vegetative area. We verified the classification results through global positioning system (GPS) based ground survey.

Figure 3 demonstrates that the area under investigation is 13700 km^2 out of which 8627 km^2 area is covered by mixed vegetation. Same classification results were found by Raza et al. (2018).

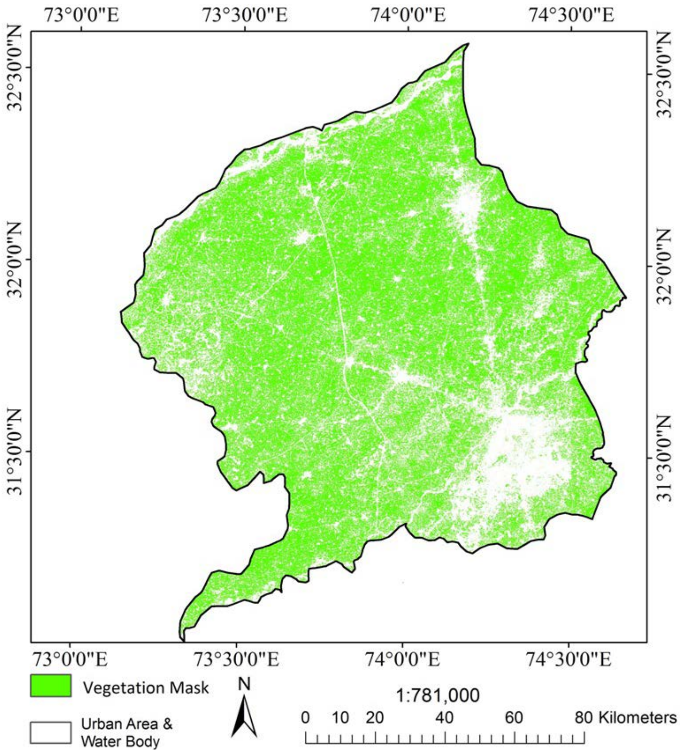

Figure 3: *Vegetation mask.*

We computed pixel-based temperature values for each thermal dataset described in Table 1 using the same technique discussed in the methodology section of this research. The vegetation mask drawn in Figure 3, was applied to each temperature dataset to subtract water body and the built-up area. The overlay utility tool in Arc GIS 10.1 was applied for subtraction process that returned the temperature values only for vegetative area.

Table 2 describes the impact of various temperature values on the development of YSB throughout the life history. It was devised by combining the views of local entomologists and the filed observations.

Egg laying stage

The Figure 4 is obtained using pixel-based temperature values using thermal dataset for the date April 03, 2014. It illustrates the spatial distribution of the egg laying ratio by a female YSB at various temperature values. The results showed that a female YSB

Table 2: *Development of various YSB stages (egg laying, egg hatching, larva and pupa evolution) at various temperature values.*

YSB Stes	Minimum Threshold	Maximum Threshold	Additional Detail	Life span (31-46) Days
Egg laying stage	13°C	37°C	YSB laid 80 eggs at 15-20°C YSB laid 100 eggs at 20-28°C YSB laid 143 eggs at 28-30°C YSB laid 148 eggs at 30-32°C YSB laid 168 eggs at 32-34°C YSB laid 176 eggs at 34-36°C	
Egg hatching stage	16°C	33°C	16°C -20°C is critical low temperature 20°C -32°C is optimum temperature 32°C -37°C is critical high temperature	6-7 days
Larva stage	10°C	29°C	10°C -23°C is critical low temperature 23°C -29°C is optimum temperature 29°C -35°C is critical high temperature 35°C > Larva death	16-27 days
Pupa stage	16°C	34°C	16°C -29°C is critical low temperature 29°C -35°C is optimum temperature 35°C -40°C is critical high temperature 40°C > Pupa dies.	9-12 days It emerges as a moth.

laid less than 80 eggs in 1595 km² area, 100 eggs in 2903 km² area, 143 eggs in 2720 km² area, 148 eggs in 1145 km² area, 168 eggs in 453 km² area and 173 eggs in 111 km² area.

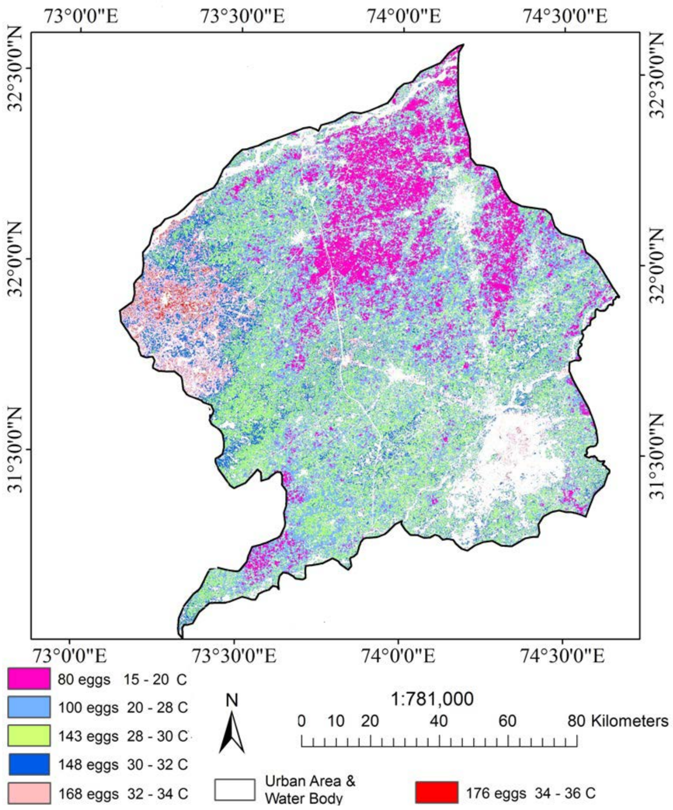

Figure 4: *April egg Distribution.*

The Figure 5 illustrates the egg distribution ratio laid by a female YSB at different temperature values for the date April 19, 2014. The results showed that a female YSB laid less than 80 eggs in 48 km² area, 100 eggs in 200 km² area, 143 eggs in 1122 km² area, 148 eggs in 2474 km² area, 168 eggs in 3064 km² area and 173 eggs in 2035 km² area. N. Manikandan et al., 2013 investigated the effect of elevated temperature on development time of YSB development and found the same results for egg laying stage.

The Figure 6 describes that the egg laying ratio by a female YSB increased on April 19, 2014 as compared to that was on April 03, 2014. Dotted black line in the Figure. 6 represents that 73% of our study area with temperature values between 20-30° C on April 03, 2014 was suitable for a female YSB to lay 100-143 eggs and the black line represents that 96% of our study area with temperature values between 30-36° C was suitable for a YSB female to lay 148-176 eggs on April 19, 2014. M.D. Patakh and Z.R. Khan, 1994 found that 23-33° C was good for a female YSB to lay 110-140 eggs, the egg laying ratio increased at higher temperature values.

Egg hatching stage

The thermal dataset for the date May 05, 2014 was used to evaluate the spatial distribution of the egg hatching ratio in Figure. 7 using the egg hatching rates defined in Table 2. Regions marked in Figure 7 with red color covering 3255 km², green is 5377 km²and blue is 331 km² areas, results in to harsh, optimum and delayed hatching process respectively. N. Manikandan et al., 2013 and M.D. Patakh and Z.R. Khan, 1994 found that temperature values between 28-33 °C were favourable for egg hatching stage.

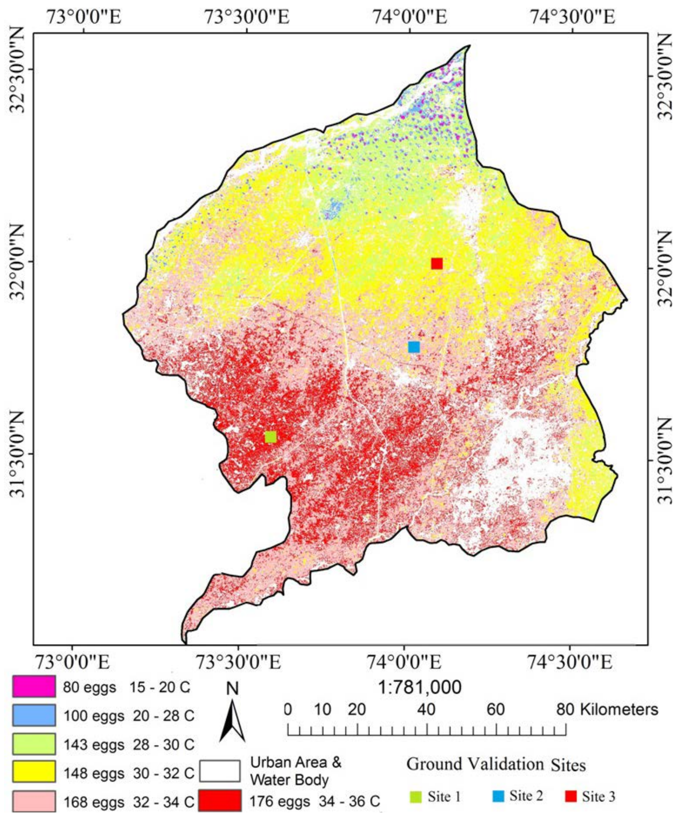

Figure 5: *April egg map.*

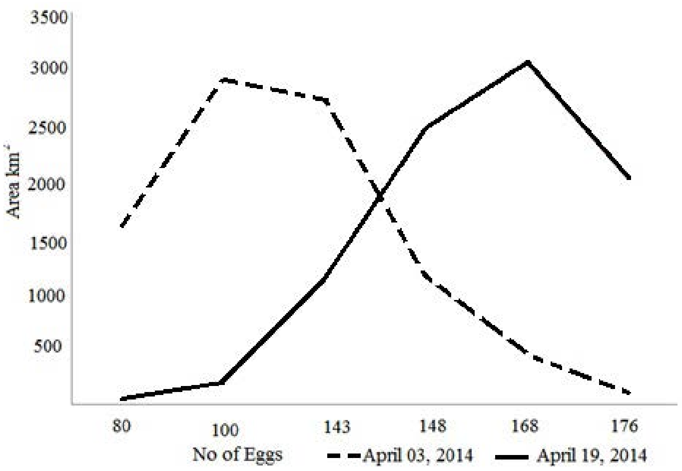

Figure 6: *Egg leaving comparision.*

Larva stage

Larva evolution took 16-27 days for full development, therefore we obtained two thermal datasets for the dates May 21, 2014 and June 06, 2014 to demarcate spatial distribution of larva evolution. The Figure 8 describes the spatial distribution rates of larva evolution on May 21,2014. The study area was distributed on larva evolutionary rates defined in Table 2. Regions marked in Figure. 8 with green colour covering 1514 km^2, blue colour is 4056 km2 and red is 3378 km2, resulted in optimum, critical high and lave death zones respectively. Dhaliwal G.S., Jindal V. et al., 2010 fond that a temperature range between 28-33 °C is optimum for larva evolution. Pradhan, S. ,1972 found that high temperature more than 35 °C were critical for larva emergence.

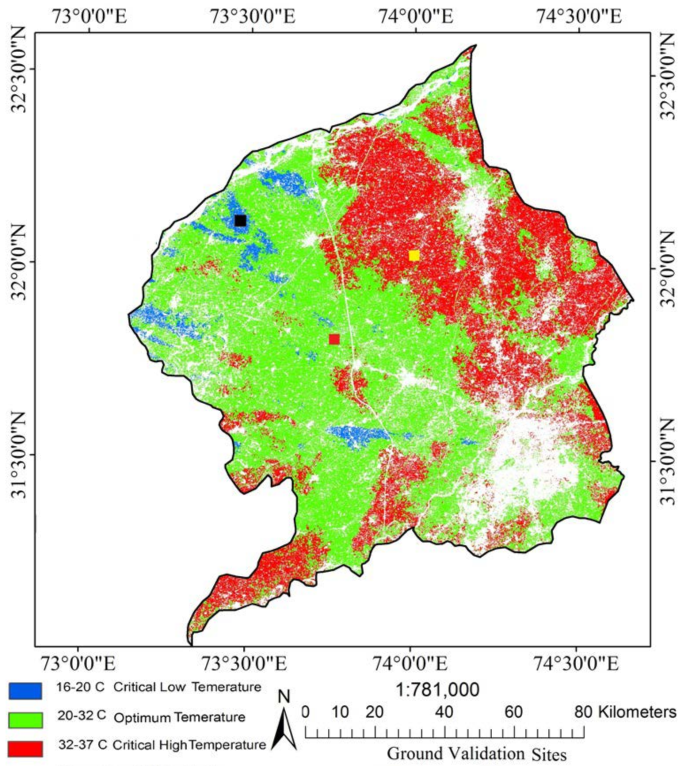

Figure 7: *May egg hatch map.*

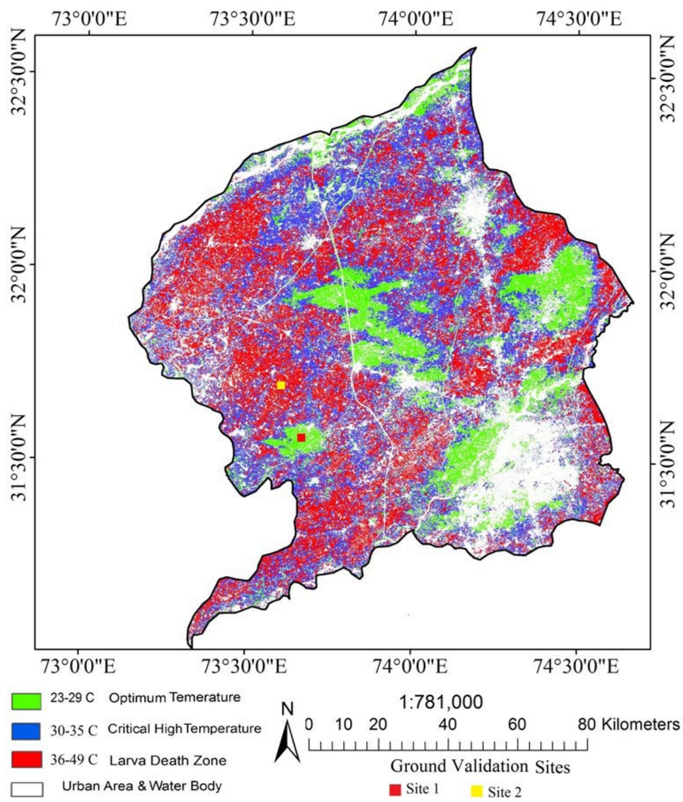

Figure 8: *May larva map.*

The thermal dataset for the date June 06, 2014 was used to demarcate the regions under larva development in Figure 9. About 1725 km^2 areas marked as suitable for larval evolution, 3756 km^2 with critical high temperature values and 3455 km^2 were the death zones for larval development of YSB.

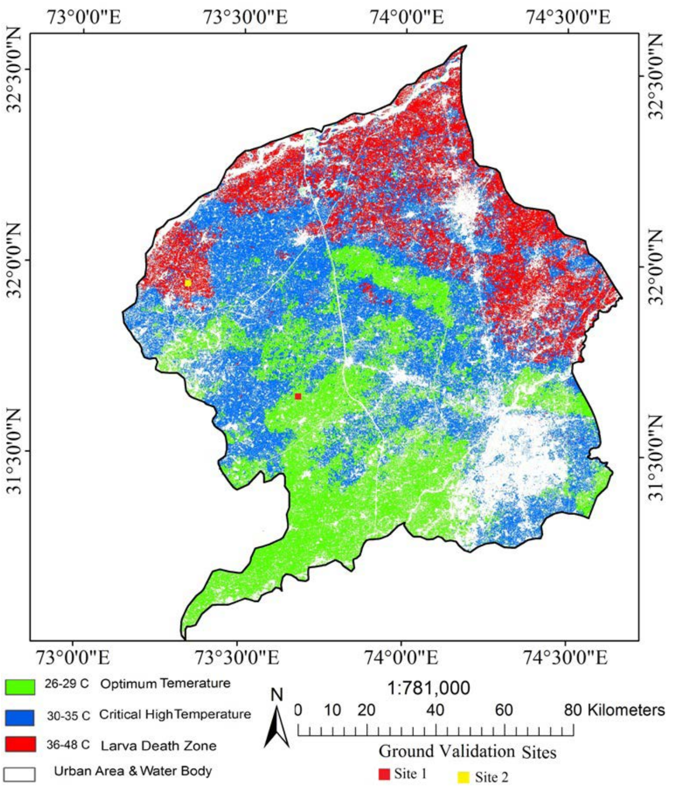

Figure 9: *June larva map.*

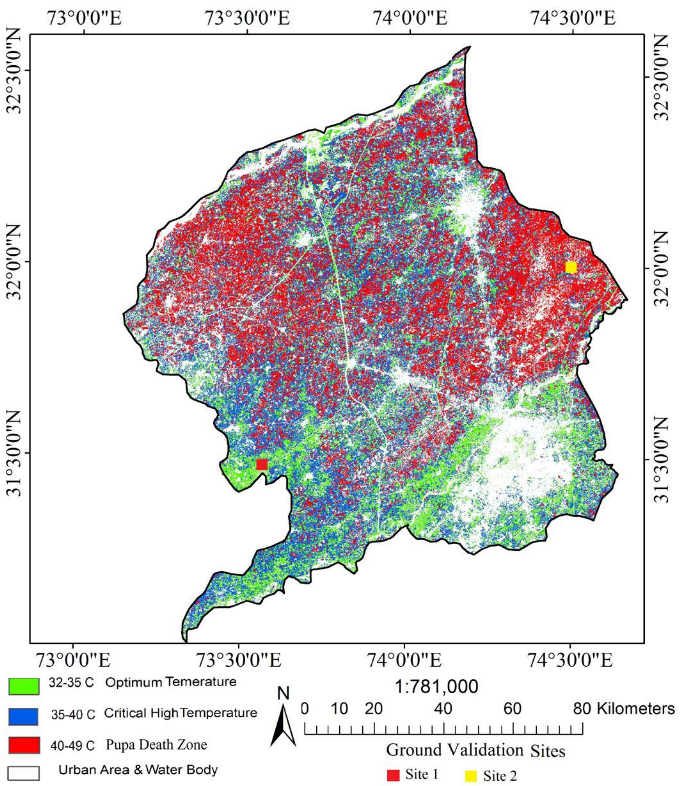

Figure 10: *June pupa.*

Pupa stage

Pupa stage of YSB is achieved normally at the end of June that takes about 9-12 days for full development. Therefore, we obtained thermal dataset for the date June 22, 2014 to check spatial distribution of pupal development in our study area.

The Figure 10 describes the spatial distribution of temperature and its impact on the pupa stage of YSB. Regions marked in Figure 10 with green colour covered 1725 km^2, blue colour 3725 km^2 and red colour 3455 km^2, resulted in optimum, critical high and pupa death zones respectively. N. Manikandan et al., 2013 found that a temperature range between 30-37 was optimum for pupa evaluation and all the temperature values high than this range cause a critical condition for pupa stage.

Industrial race to maintain a regional economy is the main reason for the shift in global climate change that influenced the crop calendars. Therefore, farmers do not rely on crop calendar to predict the exact time of spray to save the rice crop from YSB attacks.

Degree day method (DDM) is well known and widely used method to predict the intensity of YSB attacks. Using DDM, a daily mean temperature for a particular day is obtained from the local meteorological station. Maximum five temperature values are available for five districts in our study area, so the DDM is limited to an extent because five temperature values are not enough to predict YSB attacks precisely.

Thermal datasets (a product of Landsat satellite series) are powerful tools to generate pixel-based temperature values with a spatial resolution of 100 m. These datasets covered the entire study area by 10663 pixels, hence, we had 10663 temperature values. Thermal datasets are a salient tool to examine pixel-based temperature effect on YSB growth, that enabled us to predict the exact time of insecticide spray and to delineate the affected area where YSB attacks were expected on rice crop to take preventive measures in time.

Egg laying section of our research revealed that the areas with high temperature values were vulnerable to more concentrations of YSB eggs, therefore a female YSB laid more eggs on April 19, 2014 in comparison to April 03, 2014. We demarcated areas where the spray was needed to destroy the eggs.

About 5377 km^2 of our study area with temperature values between 20-32°C was ideal for initialization of the egg hatching process. The vulnerable sites with optimum temperatures for larva and pupa development were marked with green colour in Figure. 7, 8 and 9 that needed spray instantly. The areas marked with red colour in Figure 7, 8 and 9 were actually the death zones for larva and pupa, where temperature values were not favourable for their survival, therefore these areas were considered secured zone for rice crop.

Ground validation

We selected three sites which were vulnerable for a female YSB to lay eggs on April 19, 2014. These sites were marked as site 1 with spatial location (31.5 N, 73.6 E), lime box, site 2 with spatial location (31.96 N, 74.27 E), blue box and site 3 with spatial location (32.08 N, 74.39 E), red box respectively in Figure 5. Thermal datasets represented the presence of 176 eggs at site 1, 168 eggs at site 2 and 148 eggs at site 3 respectively. Hand held lens was used to count the number of eggs for each site by visiting physically in situ. The concentration of eggs was 173-176 at site 1, 161-165 at site 2 and 144-146 at site 3.

We selected three sites for field observations which were vulnerable for egg hatching process in Figure 7. These sites were marked as site 1 with spatial location (32.10 N, 74 E), yellow box, site 2 with spatial location (31.83 N, 73.75E), yellow box and site 3 with spatial location (32.21 N, 73.5 E), brown box respectively in Figure 7. Broken egg shells of YSB were observed at site 1 that represented the egg hatching stage was achieved in the red areas of the Figure 7. Temperature values were critically high at site 1 therefore hatching process was speedier than the other two sites. Site 2 was observed with partially hatched eggs, but site 3 with low temperature values, was observed in the eggs hatching process.

Larva evolving needs comparatively low temperatures for survival described in Table 2. We observed the larva evolution at two sites as site 1 with spatial location (31.57N, 73.62E), red box and site 2 with spatial location (31.68N, 73.53E), yellow box in Figure 8. The thermal dataset for the date May 21, 2014 represented site 1, as vulnerable and site 2, as safe for larva evolution. The site 1 was observed in larva evolution phase during the field visit while site 2 found safe because the temperature values were beyond the upper threshold limit at site 2 for larva survival. The same procedure was adopted for Figure 9. The ground observations were close to as determined by thermal datasets for the date June 06, 2014.

Pupa of YSB, normally emerges out from the rice plant stem during the night. We selected two sites with spatial location, (31.51 N, 73.53 E) as site 1 and (32.12 N, 74.08 E) as site 2. The thermal dataset for the date June 22, 2014 showed the site 1 vulnerable for YSB pupa evolution but the site 2 was found safe. We used the light trap to attract the attention of YSB pupa at night time at both sites. More than 100 of pupa were crawling toward the light at site 1 but there were only 3-10 pupa at site 2.

The main objective of the ground validation was to examine the reliability and efficiency of thermal datasets that proved to be approximately 95% in agreement.

Statistical findings

A regression analysis was applied to egg laying rates by a female YSB at various temperature values and found a relationship of $y = 6.4\,x - 56.16$ with a coefficient of determination of $R^2 = 0.9$ as mentioned in Figure 11. R^2 shows that 90% of egg laying stage is dependent upon temperature and also the temperature and egg laying is in direct relationship with each other. Optimum temperature values for egg hatching, larva and pupa evolution mentioned in Figure 7,8,9 and 10 were found good for YSB development. The temperature values other than optimum range cause critical condition for YSB emergence in egg hatching, larva and pupa evolution so there exist an inverse relationship.

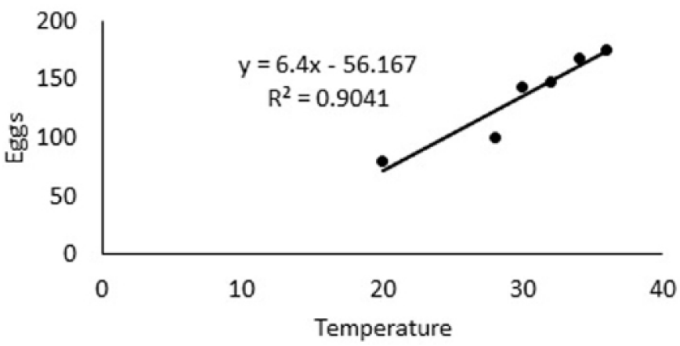

Figure 11: *Egg laying at various temp.*

Figure 11. Relationship between egg laid at various temperature values by a female YSB.

Conclusions

Thermal datasets are the products of Landsat 8 satellite series that proved very useful input for obtaining pixel-based temperature values to examine the activity of YSB spatiotemporally. Remotely sensed thermal datasets increased the spatial and temporal resolution that enabled us to investigate YSB vulnerability with a temporal window of 16 days. The Landsat 8 thermal bands (B10 and B11) are very handy input that provides pixel-based temperature values in a large area which in turn is difficult to cover physically otherwise. The Thermal datasets proved reliable due to their compatibility with field observations.

Author's Contribution

Syed Muhammad Hassan Raza: Involved in the complete organization of the manuscript that included acquisition of temperature datasets, data processing and data display in form of maps.
Syed Shehzad Hassan: Executed filed surveys for ground validation.
Syed Amer Mahmood: Arrranged fund to perform filed surveys, helped in write up of this manuscript, also involved in the complete organization of the manuscrip.
Veraldo Liesenberg: Overviewed the grammatical mistake and supervised the complete project virtually.

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