Development of a Muga disease early warning system – a mobile-based service for seri farmers

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Flacherie is a major bacterial disease causing >40% loss during Muga summer crops. For finding the root causes of the diseases, relationships were established between rearing and production data corresponding to land use/land cover, land surface temperature and meteorological parameters. Adverse affects were found in farms associated with anthropogenic activities, in contrast to forest cover which shows a negative trend. Muga disease early warning system, a mobile-based application and dashboard has been developed to predict rate of flacherie infestation at least 5–10 days in advance, for proper precautionary measures by the farmers to avoid disease outbreak and crop loss.

Keywords: Crop loss, early warning system, flacherie disease, mobile-based service, Muga silkworm, remote sensing.

MUGA silkworm, *Antheraea assamensis* Helfer is endemic to North East India because of its unique climatic conditions which fulfil the silkworm's ecological requirements in its natural adobe[1]. These insects produce glittering golden silk in the form of cocoon and feed on the leaves of their host plants. Muga silkworms feed primarily on two host plants, viz. Som (*Persia bombycina*) and Soalu (*Litsaea monotetala*), which are abundant in NE part of India. Out of 9241 ha muga plantation in North East India, Assam alone has 6755 ha (ref. 2). Muga silkworms are outdoor-loving and cannot be reared inside because of their wild characteristics. Since Muga silkworms are being reared outdoors, variations in weather parameters such as temperature and humidity are constraints to heavy loss due to diseases[3,4]. Due to the outdoor rearing of Muga silkworms, outbreak of various diseases viz., flacherie, pebrine and muscardine are the major constraints encountered in the Muga silk industry[5,6]. Among these, flacherie caused by bacteria occurs most in summer crops, thereby causing the death of considerable number of larvae which ultimately affects cocoon production and productivity. Even after providing good quality foliage during rearing, in every crop about 14–40% loss normally occurs due to the incidence of such diseases[6]. Maximum flacherie occurrence in Muga was observed in Aherua crop (65–87% crop loss) followed by 33% loss in late Bhodia crop in Narayannagar and Lakhimpur; 13.97% loss in Bhodia crop in Tura, 34.8% loss in Aherua crop in Hahim[5].

Among the abiotic factors, temperature plays a major role in the growth and productivity of silkworms[7,8]. The incidence of flacherie disease is mainly due to sudden fluctuation in temperature (high humidity and high temperature) coupled with poor-quality food. The disease prevails in almost all seasons, but is relatively high in summer (Bhodia and Aherua crops; these terms are local words, Assamese used to refer to particular Muga rearing season)[3]. The emerging geospatial techniques have become practical approaches to solve real-life problems by serving as a tool for collection, distribution, storage, analysis, processing and presentation of geographical information. Their application into sericulture can play a significant role, particularly improving the production and quality of silk and also monitoring its rearing environment. Geospatial technology has been used extensively to evaluate land, water resources and climatic requirements for identifying potential areas for sericulture development that includes growing silkworm food plants and rearing silkworms[9–11].

The present study has been carried out to evaluate the landscape and meteorological parameters of Muga rearing farms for selected Muga silkworm disease, namely flacherie using geospatial techniques. The main aim is to identify various landscape and climatic parameters crucial for disease incidence towards the development of a mobile-based forewarning application for early warning systems on flacherie disease infestation. This will help the farmer take proper precautionary measures and the stakeholders to avoid disease outbreak at least a few days in advance.

Study area

Five different Muga rearing farms were selected, three in Assam (Jagduar, State Sericulture Farm, Jorhat; Regional Sericulture Research Station (RSRS), Central Silk Board

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(CSB), Boko, Kamrup; and Research Extension Centre, CSB, Lakhimpur) and two in Meghalaya (Muga Silkworm Seed Organization (MSSO) P-3 Unit, Nongpoh from Ri-bhoi district and MSSO P-4 Unit, tura from West Garo hill district), which reported high flacherie disease incidence and low production rate (Figure 1). These rearing farms are located in the urban areas, unlike the natural environment, as Muga silkworms are wild in nature.

Methodology

Land use/land cover (LULC) map of selected Muga farms was prepared using LANDSAT-8 satellite data of different years employing a standard classification approach[12]. Change detection of LULC along 3 km buffer from the farm location and corresponding land surface temperature maps were prepared. Corresponding rearing and meteorological data were collected from the respective farms. Geospatial database was generated by using meteorological and rearing data for overlay analysis to determine whether disease incidence and productivity are correlated to meteorological conditions. The meteorological parameters such as temperature and humidity have been mainly considered in the study, as these silkworms are highly sensitive to their environment. Statistical relationships were established to find a correlation between disease incidence and productivity with climatic parameters by taking an average of minimum temperature, maximum temperature, minimum humidity and maximum humidity on 30, 15, 10 and 5 days prior to silkworm harvesting. Figure 2 shows the detailed methodology for the study.

A mobile-based forewarning application called 'Muga disease early warning system' (MDEWS) has been developed based on ten years of historical and three years real-time meteorological as well as disease incidence data.

Results and discussion

Relation between land use/land cover and disease infestation

LULC map of the selected five farms was prepared taking 3 km buffer from each farm location. The major LULC within the 3 km buffer of Lakhimpur Muga farm was built-up, built-up/tree-clad followed by agricultural fallow land, water body and factory. Whereas RSRS Boko farm covered mostly agricultural land followed by built-up areas, forest, low-lying areas, barren land and water bodies. Similarly major LULC classes of Jogduar farm consisted of agricultural land, followed by settlement and tree-clad areas. On the other hand, major LULC classes of MSSO, Nongpoh, Ri Bhoi district were open forest followed by dense forest, agricultural fallow, built-up, water body and barren land. The major LULC classes of MSSO, Tura were built-up/tree-clad, followed by urban settlements, open forest, dense forest, water bodies and patches of shifting cultivation (Figure 3).

Correlation matrix of LULC was computed taking the major LU classes of four consecutive years for all farms falling into the buffer zones of the study areas (Figure 4) and parallel dataset corresponding to flacherie disease infestation (Figure 5).

The results explain positive and negative correlation with different LULC. In case of agricultural field, it increases near the Muga rearing farm. Disease incidence is found highly correlated, resulting in low productivity. It is evident that Muga silkworms must be reared in a natural healthy environment and are adversely affected by the slightest change in their environment. Therefore anthropogenic activities near Muga farms such as roads, built-up areas and settlement may likely affect the fragile nature of the silkworms. Most of the farms in the present study are near or surrounded by towns and roads (National

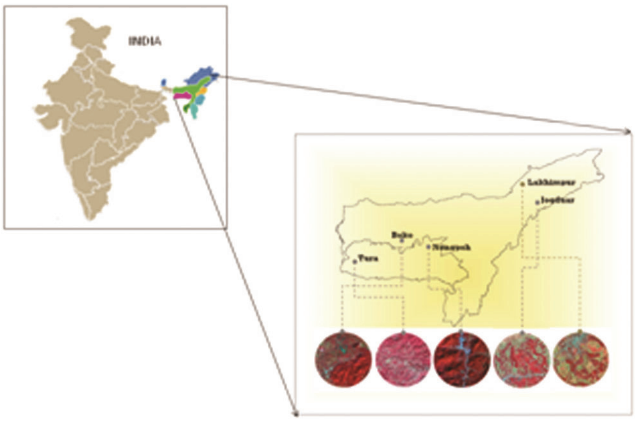

Figure 1. Location of study area.

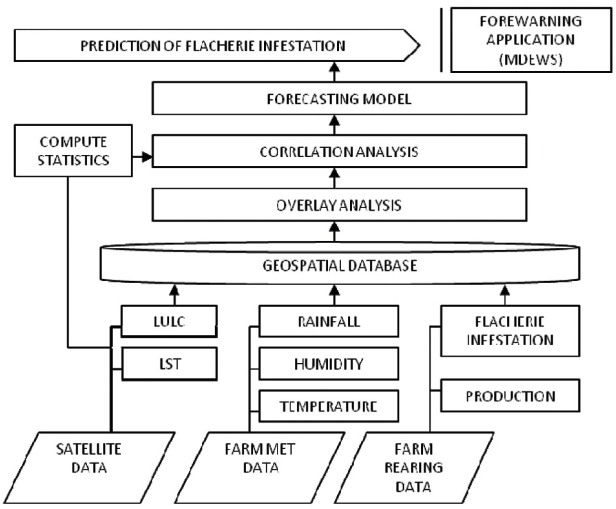

Figure 2. Methodology flow chart.

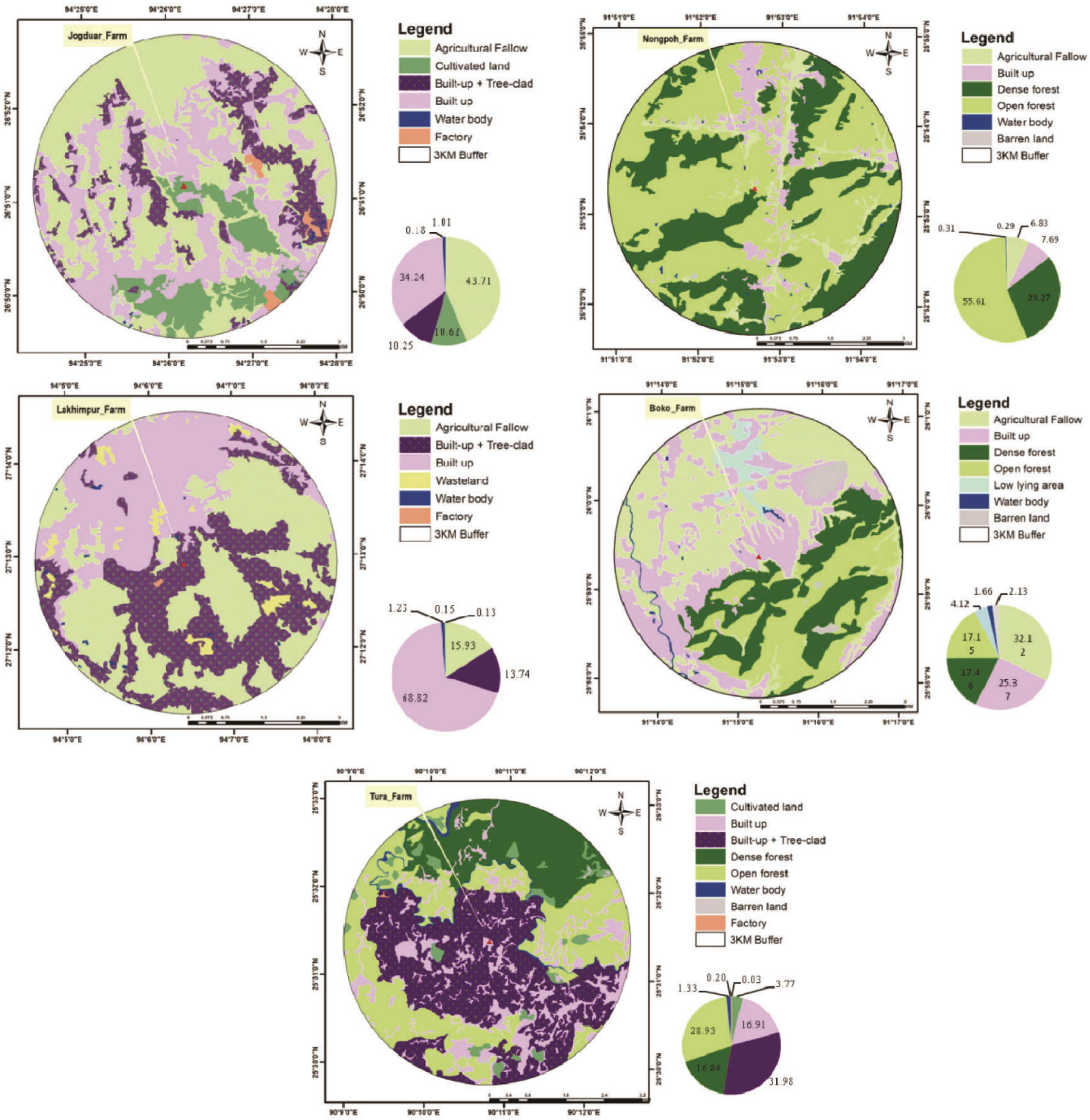

Figure 3. Land cover map of five selected Muga silkworm rearing farms.

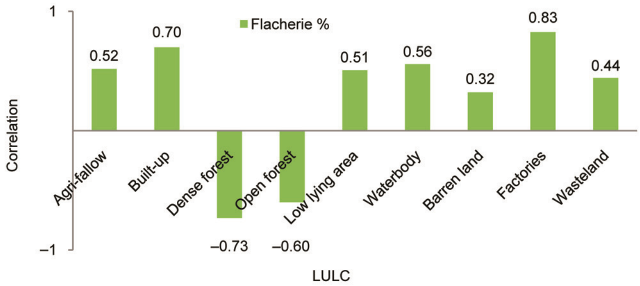

Figure 4. Correlation between land use land cover (LULC) and percentage of flacherie disease infestation.

Highways). Adequate tree cover is essential for a sustainable environment. Hence urban areas are found mostly associated with tree-clad areas. Considering tree-clad and built-up areas together as urban indicators, it was found that areas surrounding the farms in Lakhimpur with 80%, Jogduar with 45% and Tura with 49% are under intense anthropogenic activities. This makes these two farms more prone to the incidence of microbial diseases such as flacherie. On the other hand, the percentage of anthropogenic activities near Nongpoh and Boko is as low as 7 and 25 respectively. Tura farm is also located near a sub-urban area, but there is balance in its LULC patterns that occupy equal area under forest cover. The presence of forest cover shows a striking feature with the production and disease incidence occurrence, indicating a negative trend. This negative trend explains that greater the area surrounding a Muga farm is under forest cover, a negative trend in disease is observed. Among the study locations Nongpoh, Boko and Tura have large areas under forest cover within the buffer zone of the farm, corresponding to more than 85%, 34% and 44% respectively.

Low-lying areas are often associated with water bodies. Rearing farms near rivers and water bodies located at an elevation below 90 m near Brahmaputra basin are highly susceptible to floods. Water bodies also accumulate more heat during the day and farms falling under the buffer zone of such areas show high humidity in the hot and humid tropics. In the study locations, Lakhimpur and Jogduar farms were found to be hot and humid during summer, whereas in monsoon these farms experienced floods due to heavy rainfall. This could be the reason that river, water bodies and low-lying areas show a positive relationship with disease incidence and low productivity. Factories and mills are found within the buffer zone of the farm locations. Thus a significant positive relation is found between factories and disease incidence. This implies that higher the land cover concentrates of factories and mills near Muga farm, higher is the percentage of disease incidence. Lakhimpur, Jogduar and Tura have several factories and mills within the 3 km buffer zone of the farm area. Wasteland and barren land, which are categorized as unused or unproductive land, are usually under low maintenance. Thus, such LULC is not suitable around Muga rearing farms.

Relation between land surface temperature and disease infestation

The land surface temperature (LST) map was computed by taking 3 km buffer area from the centre of the farms in order to observe the variation in surface temperature, and its interconnected effect on production and disease in Muga silkworms. The land surface maps were generated from Landsat-5 and Landsat-8 taking an average of dataset of three consecutive years (Figure 6).

Figure 7 shows the correlation between LST and flacherie disease infestation of Muga silkworms. A negative relationship was found between flacherie incidence and LST less than or equal to 24°C. This implies that surface temperature ranging from 15°C to 25°C is ideal for the rearing of Muga silkworms. Further, it was found that the surface temperature and LULC are interrelated. LST was higher in the areas having high anthropogenic activities than areas less altered by human activities. It is evident from this study that locations such as Lakhimpur, Jogduar and Tura shows high LST than those of Boko and Nongpoh. The reason for this is that Lakhimpur, Jogduar and Tura have a greater percentage of land under anthropogenic activities such as settlement, built-up, tree-clad, roads and other infrastructure. The surface temperature in these areas is found to be as high as 25–29°C, which is in contrast with the parameter that has been found optimum for Muga silkworm rearing, i.e. ranging between 15°C and 25°C. It is worth mentioning that Tura despite being a forest-surplus region, LST is found to be high as the average annual highest temperature of Tura remains 31°C. Also the forest has degraded due to prolonged intensive shifting cultivation practice in these areas[13]. On the other hand, LST of Boko and Nongpoh was found most suitable for the rearing of Muga silkworms. This is because LULC around these farms is less affected by anthropogenic activities.

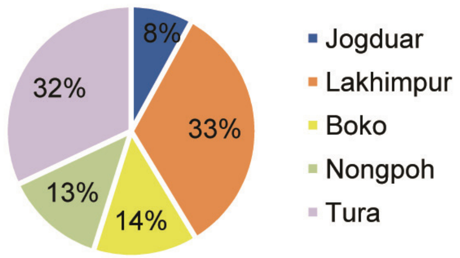

Figure 5. Farm flacherie disease infestation (%).

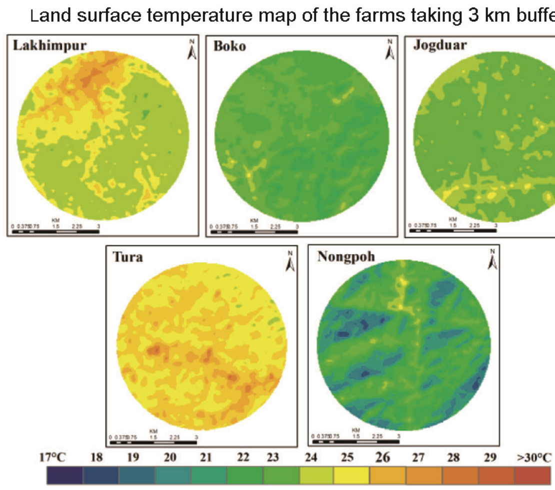

Figure 6. Comparative land surface temperature around Muga rearing farms.

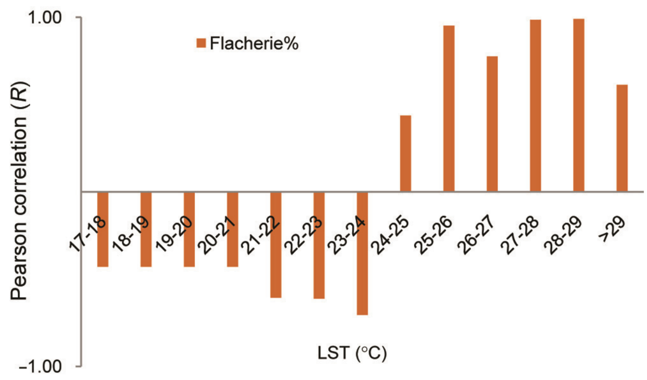

Figure 7. Correlation between land surface temperature (LST) and percentage of flacherie disease infestation.

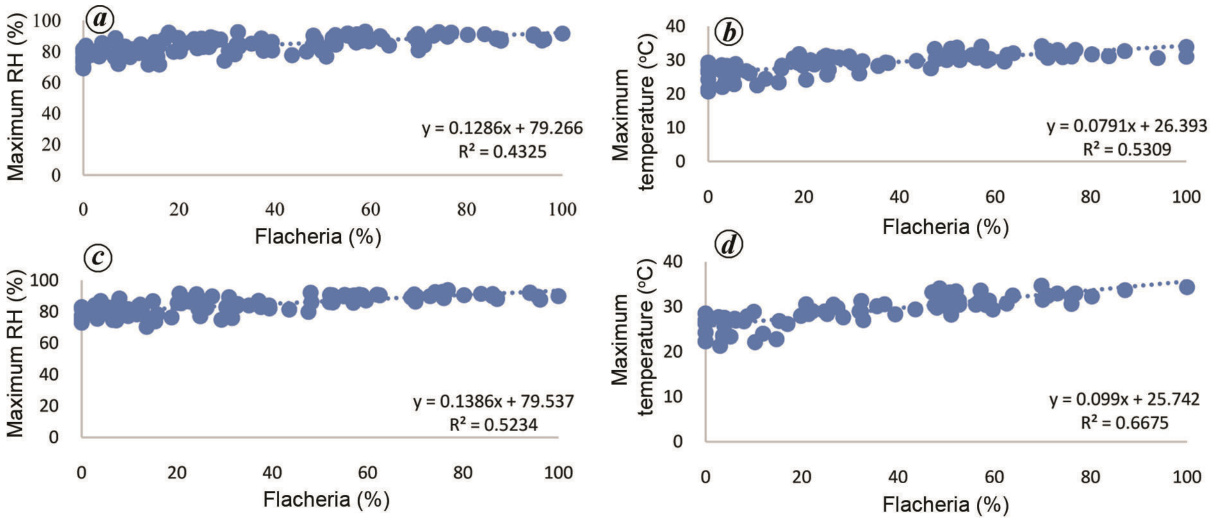

Figure 8. Relationship of falcherie incidence with various meteorological parameters. ***a***, With maximum humidity before 10 days of harvest. ***b***, With maximum temperature before 10 days of harvest. ***c***, With flacherie and maximum humidity before 5 days of harvest. ***d***, With maximum temperature before 5 days of harvest.

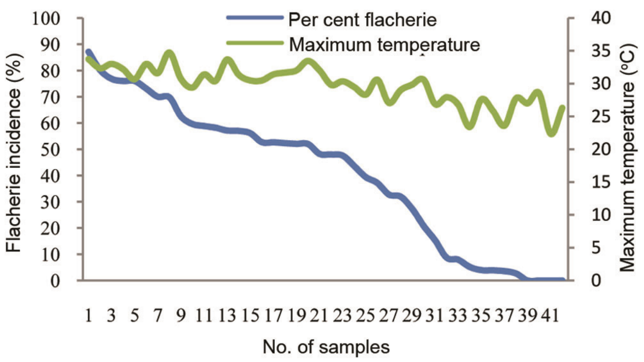

Figure 9. Flacherie disease associated with maximum temperature.

Relation between meteorological parameters and disease infestation

The meteorological parameters such as humidity, temperature, and rainfall were analysed taking ten-year datasets of each farm. The average of each meteorological parameter was taken prior to 15 days of brushing period till the date of harvest. For the analysis, we organized the meteorological parameters such as minimum and maximum temperature and humidity in the sequence of 15, 10 and 5 days prior to harvest. Harvesting of the mature silkworm is the final stage after that the worms go for spinning.

It was found that flacherie disease incidence was associated with a change in weather parameters (Figure 8). Relative humidity of more than 80% and temperature above 30°C were found to be associated with severe disease incidence (Figure 8). The optimum temperature and relative humidity range was 24–25°C and 75–80% respectively. For commercial crops, minimum temperature requirement was 16–20°C.

It was observed that when temperature and humidity exceeded the threshold limit, there was flacherie disease infestation in the rearing field (Figure 9). The disease infection is more certain when optimum range is exceeded specially 15 days prior to harvest when the larva is in their third to fifth instar. Similar results were reported that during silkworm rearing, high temperature adversely affects biological activity and concurrent physiological reactions[14] and that the silkworms were more sensitive in the fourth and fifth stages[15,16].

During the period when larva are in their third to fifth instar, the rise in temperature and humidity beyond the threshold gives rise to the inevitable disease incidence of flacherie. Among the five farms Boko, Lakhimpur and Jogduar were found to be the more prone to flacherie disease as the average temperature in these farms was above 27°C and average relative humidity above 85%. On the other hand, farms of Meghalaya were less prone to flacherie disease.

Multiple regression analysis was carried out to predict flacherie from 15 days average maximum temperature (maxT) and maximum humidity (maxRH) data before 10 days of harvest. These variables significantly predicted flacherie with $R^2 = 0.623$, $P < 0.01$. This model can explain approximately 62% of the variability in flacherie incidence due to these two variables, as shown in eq. (1).

$$\text{Flacherie\%} = -290.449 + 1.892\ \text{maxRH} + 5.725\ \text{maxT}. \quad (1)$$

Average maximum temperature and maximum humidity of 15 days before five days of harvest statistically significantly predicted flacherie with $R^2 = 0.776$, $P < 0.01$ (Figure 10). Both the variables added statistically significantly to the prediction, $P < 0.05$. This model can explain approximately

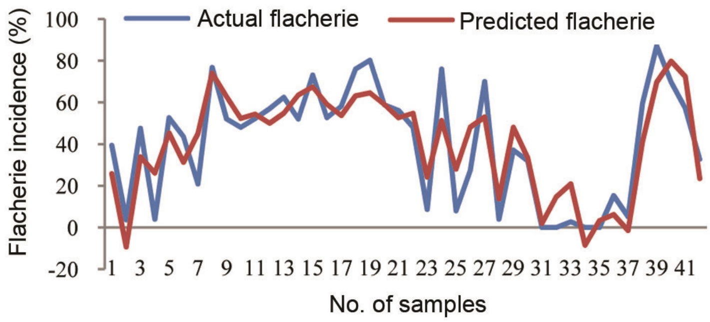

Figure 10. Prediction of flacherie infestation from 15 days average of maximum temperature and maximum humidity data before 5 days of harvest.

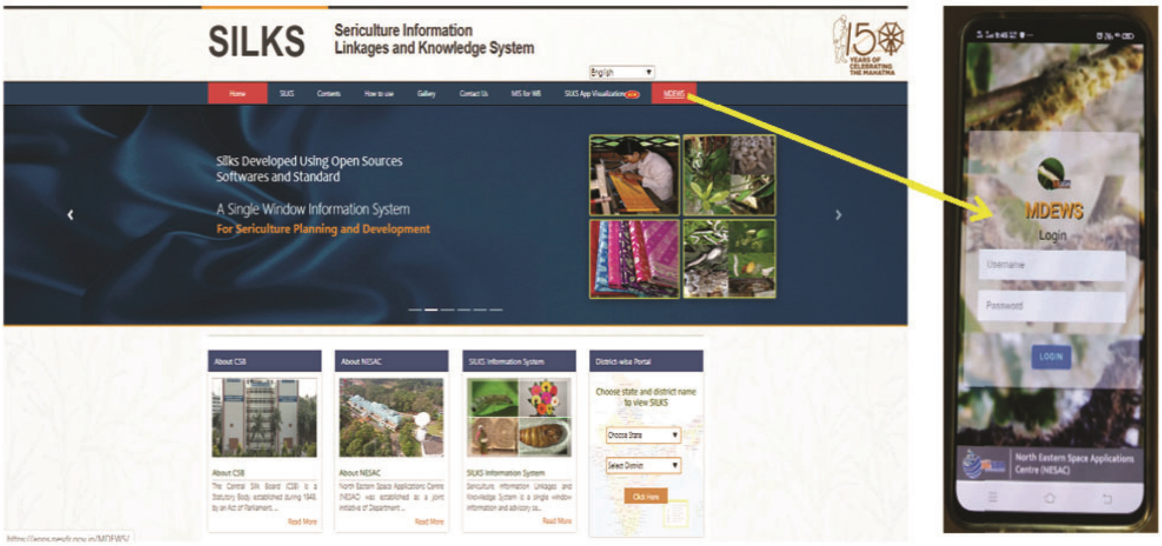

Figure 11. SILKS webportal (http://silks.csb.gov.in) showing MDEWS mobile application.

78% of the variance in flacherie incidence due to these two variables, as shown in eq. (2).

$$\text{Flacherie\%} = -287.709 + 1.766\ \text{maxRH} + 5.948\ \text{maxT}, \quad (2)$$

We have developed mobile-based forewarning application called 'Muga disease early warning system' (MDEWS) was integrating a forecasting model for early warning of flacherie disease incidence (percentage) of Muga silkworm both 5 and 10 days before harvesting. The users need to incorporate 15 days daily maximum temperature and maximum humidity data before 5 and 10 days of harvesting to obtain a prediction of flacherie infestation percentage. An Excel sheet with required meteorological data can also be uploaded for a prediction of flacherie infestation percentage. MDEWS has been developed initially to collect data and validate the model by authorized users. It is linked with sericulture information linkages and knowledge system (SILKS) portal for wider use by farmers as well as different stakeholders of the sericulture industry (Figure 11). SILKS is a single-window, ICT-based information and advisory services system for farmers, sericulture extension workers, administrators and planners working in the field of sericulture development. The portal is available in public domain (http://silks.csb.gov.in). MDEWS has certain limitations, e.g. the meteorological data are site-specific while precise data are required for accurate warning. The portal can predict flacherie disease incidence prior to 5 and 10 days of harvest. The portal gives prediction of flacherie prior to 5 days and 10 days of harvest, however the portal will give more accurate result than the prediction prior to 10 days of harvest.

Conclusion

Anthropogenic activities near silkworm rearing farms are highly undesirable. It is also anticipated that agricultural practice near Muga rearing farms may impact physiological growth and development of silkworms. It is observed that in spite of anthropogenic activities, farms having more than 30% forest cover within 3 km buffer areas are suitable for Muga silkworm rearing with regard to flacherie incidence, as there is a balance in LST among these regions. Correlation of flacherie disease incidence with LST is found to be positive wherever surface brightness exceeds the optimal temperature of 24°C, i.e. with rise in temperature, disease incidence and low productivity are recorded.

The optimum temperature and humidity required for Muga silkworm rearing are 15–25°C and 75–85% respectively. Beyond these conditions, Muga silkworms are prone to flacherie disease. It is found that fluctuation in temperature and humidity adversely affects silkworm rearing. Fifteen days average of maximum temperature and maximum relative humidity during the rearing season can be effectively used to predict flacherie infestation at 5–10 days prior to harvest coinciding with fourth and fifth instar stages of silkworm respectively. The Muga silkworm rearing farmers should take precautionary measures to avoid disease outbreak during the period when the temperature exceeds 30°C and relative humidity exceeds 80% for a few consecutive days.

The recommendations and the model developed show the potential of geospatial technology for farm-level planning and management. MDEWS will help Muga farmers take precautionary measures to avoid crop loss due to microbial diseases. More obligations can be met by linking seri advisory given by expert groups of different institution into the SILKS portal for wider use by farmers as well as different stakeholders of the sericulture industry in the states. Although pollution is one of the significant factors associated with anthropogenic effects on silkworms, it has not been dealt with in the present study due to time constraint.

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