Geoestatistics and Kriging Techiniques for Welfare Analysis of Chickens through Enthalpy Distribution in State of São Paulo, Brazil

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Abstract. *The current scenario shows a great challenge for animal farm production due to climate changes and their direct impact on quality and productivity levels. It is necessary to study about information standards of thermal comfort situations for animals, for this to be better understood by producers. The locations of rural buildings can be an evidence of the needs for an adequate choice of construction material or efficient cooling system. Researchers of rural buildings and ambient area use environmental physical parameters to characterize the situations to which animals are subjected. One of these parameters is enthalpy, which measures the amount of energy in a system, related with latent and sensible heat. This information allows microclimate thermal analysis of animal production systems. Thus, the present work aimed to assess geostatistical techniques concerning temperature and relative humidity and to calculate the enthalpy in 25 points of the State of Sao Paulo, Brazil, at meteorological stations in summer season. The points were used with ordinary kriging to establish a contiguous map listing all other prediction points through the chosen model. The results show on the maps regions of stress and comfort situations for poultry production between the first until the 6th week, with the areas of higher and lower risk for this production system. Thus, during the period of assessment, it was possible verify kriging maps related with the situation presented greater thermal comfort, suggesting special attention about the adoption of efficient management for poultry production.*

Keywords. *Thermal Comfort, Productivity, Thermorregulation, Enthalpy, Geoestatistcs*

Introduction

Many researchers have evaluated various methods for point interpolation of climate data, and it concluded the geostatistical methods have been rated superior over techniques such as inverse distance weighting, least-squares polynomial regression and others (Creutin & Obled, 1982; Tabios & Salas, 1985; Lebel *et al.*, 1987; Phillips *et al.*, 1992; Ishida & Kawashima, 1993; Goovaerts, 2000).

In Brazil, broilers chickens are almost entirely created in open installations, without environmental protection, and the producers did not testify properly the planning stages of construction. The locations of the farms may be an evidence of their needs in terms of structural adequacy or even need a cooling system efficient.

Thus, professionals in the area of environment and rural buildings should make use of physical parameters of the environment to characterize the microclimate, which the animals are subjected. One of these parameters is the enthalpy.

This physical variable measures the amount of energy in a system. The energy is latent and sensible heat, or dry and wet heat exchanges, these details allow an analysis of the thermal microclimate of the confinement systems. It knows that the environment in which the animals are subjected is very important to the process and the consequent thermoregulation factors. These reactions reflect states of comfort or thermal stress, which is the cause of health problems, behavior and welfare. The Brazilians researchers use the enthalpy as indicative to the quality of the thermal environment of animal production, as an index of thermal comfort for poultry, cattle and pigs.

The calculation of enthalpy is directly related to temperature and relative humidity. These two variables inform the conditions that favor or hinder the heat loss by animals in confinement, an important fact under situations of heat stress, present in tropical countries, such as Brazil. There are intervals of enthalpy values (Barbosa Filho et al., 2007) related to situations where the animals are in comfort, or in thermal stress, or even in situations of alert, when drastic attitude must be taken. There are also ranges that indicate the irreversibility of the system, thus the animals come to death.

This work aims analysis the spatial dependence of the medium enthalpy in areas relating to high density of poultry systems production. Information about temperature and humidity throughout the months of November, December, January and February were collected so that could be calculated the medium enthalpy in the state of Sao Paulo in these seasons.

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Material and Methods

The dataset belong to automatic weather stations of the São Paulo State. The variables collected were average temperature (T) and average air relative humidity (UR) to calculation of enthalpy by the equation used by Barbosa Filho et al. (2007):

$$H = 6{,}7 + 0{,}243 * T + \left\{ \frac{UR}{100} * 10^{\left(7{,}5*T / 237{,}7*T \right)} \right\} \tag{1}$$

Considering that T (° C) and RH (%) are temperature and relative humidity respectively. The value of the enthalpy (H) is given by kJ / kg of dry air. The dataset is from the National Institute of Meteorology (INMET) for automatic stations. Thus were collected temperature and humidity to calculate the medium enthalpy by each month, November, December, January and February, and in each locality. This information is related with 25 meteorological stations in the state of Sao Paulo.

It can be evidenced regions affected by critical values of enthalpy and which the information would be more relevant to the purpose of the work, related to areas close to poultry industries.

Geostatistics was used by verification about the possible spatial dependence between enthalpy values in each spatial coordinated. It was used a fixed geometry, that by definition is a collection of prior determined points. The random attribute in this case is the enthalpy, resulting from medium temperature and humidity during the months cited. Thus, this is a punctual analysis process of enthalpy in pre-established coordinates.

About geostatistical models, it is necessary a subjacent spatial model S(x) and its response Y_i. This random variable is presented as n-dimensional (Y_1. .. Y_n) (Diggle & Ribeiro Jr, 2006), and S(x) represents the all the values of Y(x). The statistical software used is the R version 2.3.1 (R Development Core Team, 2006) and package *GeoR* which allows the use of data and techniques for the geostatistical analysis. The dataset was transformed in *geodata* for effective reading by geoR package. This format shows a matrix that contains the x and y coordinates (*coords*) and the data of interest (*data*). The map of Sao Paulo state was put in coordinate systems in the same software.

Graphs are presented to spatial distribution analysis and the histogram was used to normality verification and symmetry of the data. The graphics relating to the data and coordinates show the tendency in relation to east-west and north-south orientation. The analysis of orientation tendency is a preliminary step and not always conclusive. Then, the use of semivariograms can help to understand the data behaviors, its degree of dissimilarity in terms of distance Euclidian through *variog* command.

The models was adjustment to the function of the semivariance by the likelihood maximization method, which estimates the Gaussian parameters in the model, such as Φ (1 / 3 of the variance with the curve semivariogram stabilized), σ^2 (variance) and ζ^2 (variance of the noise), by the function *likfit*. This process identifies the presence of spatial dependence of the variables in question. The models are constructed in order to represent the behavior of the data analysis. This is a very important step which will determine the efficiency of the analysis as a whole. The method of interpolation, or kriging, estimate a value of unknown variable in regions not sampled.

Information of the model selected in the previous step is used to the effective prediction of regions not sampled. This results about the variances of points predicted is used to build a maps with certain gradient of colors that correspond to the predictions of medium enthalpy generated by the model adopted which refers to the spatial variation of points of analysis.

Results and Discussion

The study used the average values of temperature and humidity to calculate the maximum enthalpy, then it is possible to know the regions that can achieve the values which represent the stress or comfort conditions which the birds were submitted. The graphs below show the points of meteorological station in the São Paulo state (Figure 1).

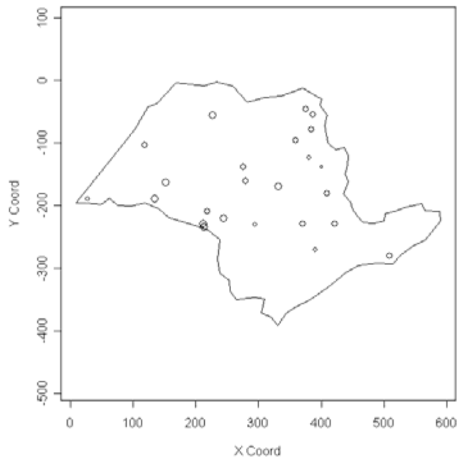

Figure 1. Points of meteorological station in the São Paulo State.

The graphs of trend are relating to the distribution of points and its histogram (Figure 2). There are low tendency of Y coordinates, the X coordinates show a slight tendency to the east-west orientation. These curves are referring to November month, the tendencies are the same compared with the December, January and February.

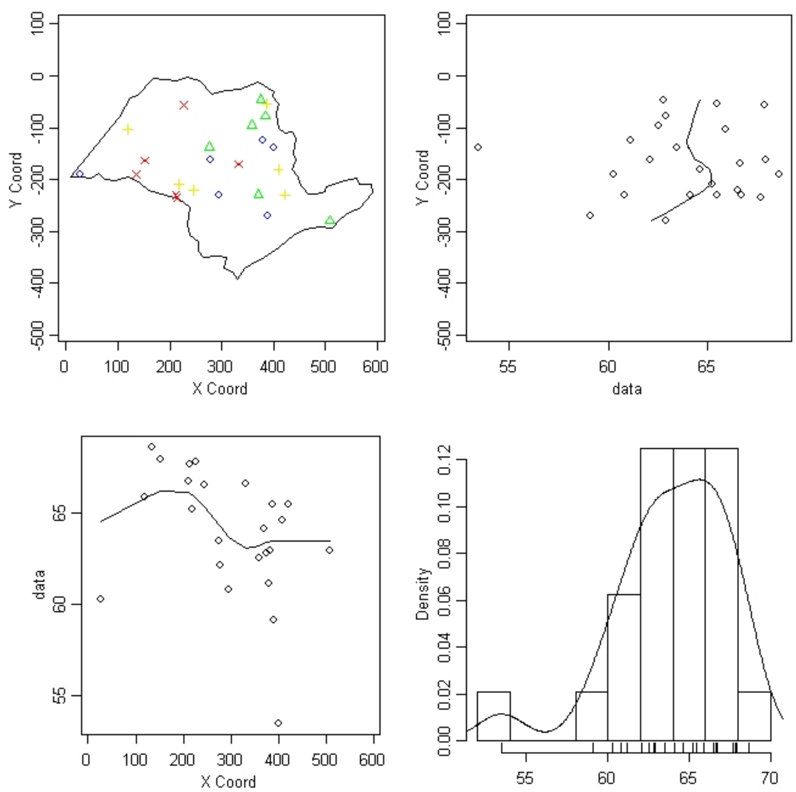

Figure 2. Trend analysis in the X and Y coordinates**.**

It was applied the Box-Cox transformation as a possible correction of skewness of the dataset, informed by the histogram in Figure 2. The graphic in the Figure 3 below shows that is not possible some improvements in skewness due to the value assigned to lambda (λ) to be close to the unit.

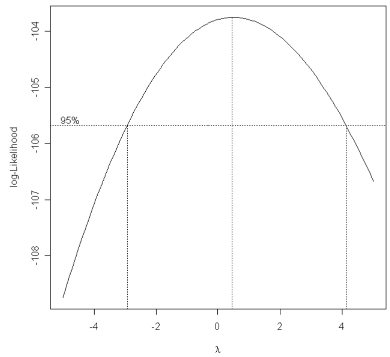

Figure 3. Projection of the parameter Box-Cox transformed.

The models were chosen properly to fit the data. Thus was used the command trend that defines a linear model in its covariates, in spite of the waste in graphics, according Diggle & Ribeiro Jr. (2006). Thus, the models used to predict the data in the process of kriging were:

1. Linear model of the first order, without effect of the east-west;
2. Quadratic model; and
3. Linear model of second order, without effect of north-south direction.

It is necessary to have stringent criteria to choose the appropriate model. Thus is employed the method of Likelihood Maximization method for the search of a model that be efficient to recognize the spatial dependences. It was calculated therefore the value of log L for each tested model. The figures for the Model 1, 2 and 3 are, respectively:

1. -61.44
2. -61.44
3. -63.24

The model 1 has been chosen because present the least amount of log L, explained by the fact to be a small space between the data. The prediction of the data is performed with the parameters already estimated by the models adopted at an earlier stage. But it is necessary to adopt a grid of points to be predicted and it is done in R with the command *expand. grid* that shows to program the limits and distances of the points being predicted in a certain area of interest.

After the adoption of a grid-based, the kriging is performed based on data informed by the model. Thus, it is necessary to build a map for analysis of the surface as illustrated in Figure 4.

The colors scale was adjusted to present consistent values of enthalpy with the situations determined by enthalpy tables (Barbosa Filho et al, 2007):

1. Thermal Comfort (54.7 to 62.9 kJ / kg dry air)
2. Alert (63.0 to 68.6 kJ / kg dry air)
3. Critical (68.7 to 75.8 kJ / kg dry air)
4. Letal (75.9 to 90.8 kJ / kg dry air)

The graphics above represent the enthalpy average monthly during the months of November 2007 to January 2008. The minimum and maximum values of enthalpy in November were, respectively, 53.45 and 68.62 kJ / kg dry air. The box-plot of November (Figure 5) shows that most of the data showed values within the range of 62.44 to 66.55 enthalpy kJ / kg, range characterized by state of alert for broiler chickens in the seventh week of creation (Barbosa et al., 2007).

In December, the enthalpy values were between 58.33 and 74.32 kJ/Kg. There were some regions that presented comfort situation but the most of the region was submitted to critical conditions. The box-plot (Figure 5) shows the range of data was between 69.07 and 71.67 kJ/kg. This represents a critical situation throughout most of the territory extension, showing in this month an injury to the thermal comfort provided by environment for broiler chickens.

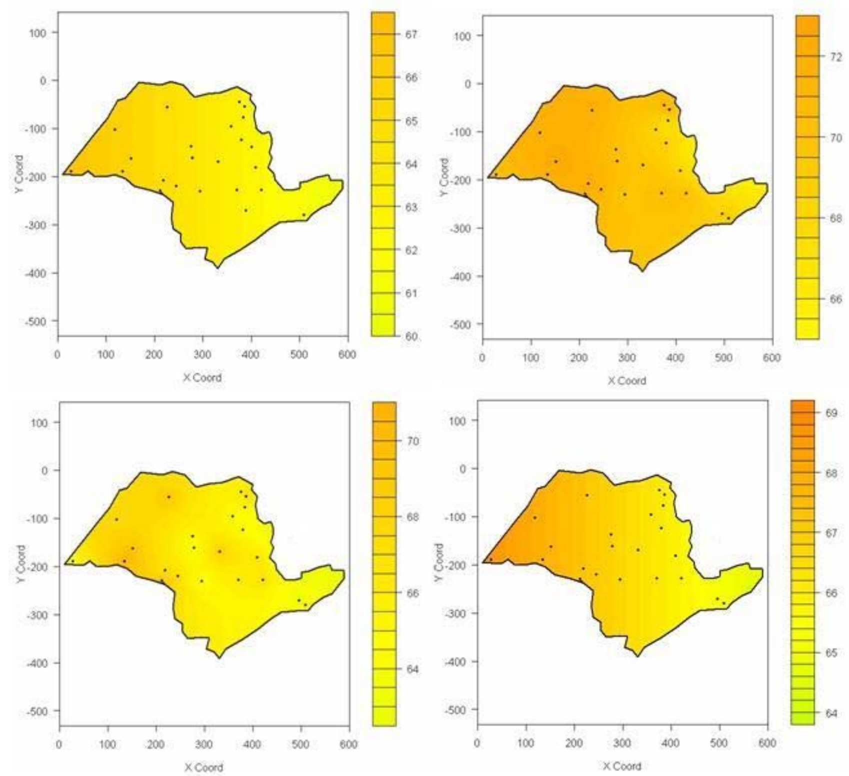

Figure 4. Maps with the regions predicted: November to February from the top to right.

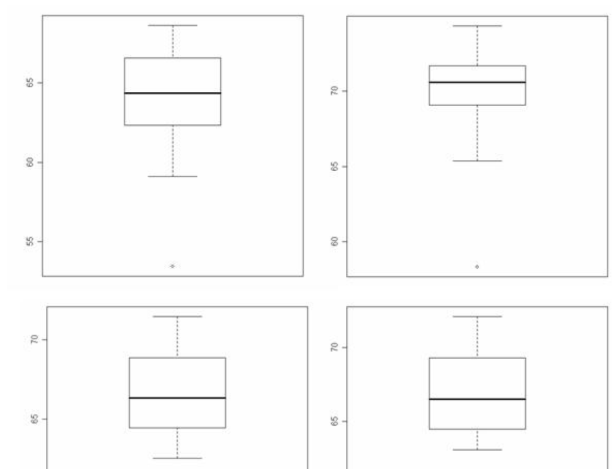
Figure 5. Box-plot for the months of November to February, from the top to right.

Referring to the January, it was found that the enthalpy values showed minimum and maximum values between 56.33 and 71.47 kJ/kg. The box-plot (Figure 5) shows that the amount of data is presented in the range 64.46 and .68.80 kJ/kg characterized by alert situation as well as the month of December, but with lower values.

Continuing with the same analysis, in February the minimum and maximum were 55.78 and 72.12 kJ/kg, which correspond with the comfort and critical situations, but considering the map (Figure 4), it was verified regions of higher enthalpy. The comfort region was linked to the meteorological stations that accused smaller values of average monthly temperature, but the most of territory was in alert and critical conditions. The values of box-plot (Figure 5) were between 64.55 and 69.32 kJ/kg.

In a previous analysis, the October (Figure 6) was examined for the comparison purpose with the situations above. It appears that the values of minimum and maximum were 58.20 and 70.12 kJ/kg respectively. The box-plot showed important values to characterize the standard range: 61.60 and 65.40 kJ/kg what is characterized by presence of comfort situation in the most part of the time.

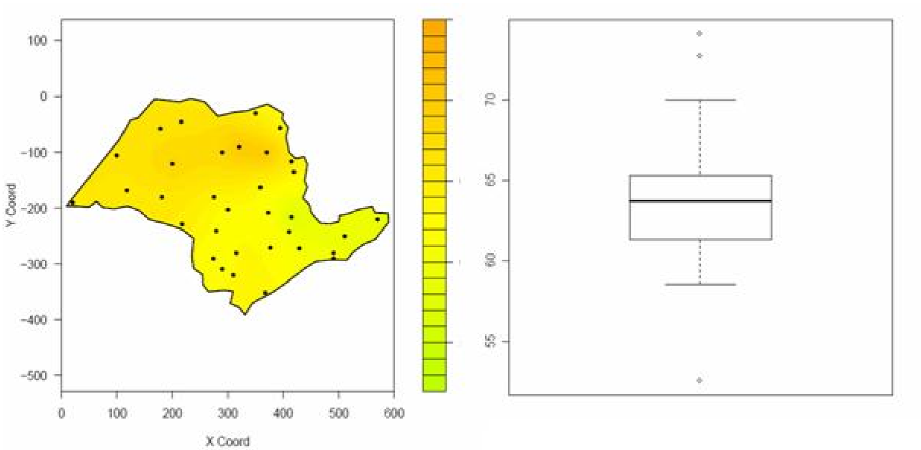

Figure 6. Map and box-plot to October (2007).

The map explains efficiently the situation occurring in the month of October. Due to climate change suffered over the centuries and thermal inversions in the winter, it is possible to find ranges of transitions between comfort and possible conditions of alert already in October.

The predicted values show that in the southern coastal and valley of Paraíba there is a prevalence of cases of thermal comfort (region slightly green in October). The region north of the state, where lie the cities of Ribeirao Preto, Sao Carlos, Sao Jose do Rio Preto among others, are known to have high averages of temperature and relative humidity, despite the high altitudes. The maps of November to January showed precisely this region, in terms of values relating to the range of emergency during these months. These values of enthalpy characterized a microclimate place that will result in losses for the producer unless it remains in constant attention to the management of its production system.

The other regions showed up in a position to alert and critical, which is not surprising for the fact that mainly in December show high values of average temperature and humidity. This framework tends to worsen due to changes of the system of rain that will increase with the arrival of summer. The increase of temperature and humidity will be crucial to that future analyses show maps with regions characterized by lethal situation, not present in these months.

According to the IPCC, in the twentieth century there was an increase of 0.65 ° C in average temperature. Overall this is more pronounced in the decade of 90th. In the near future could occur more radical changes, this is a warming between 1.5 ° C and 5.8 ° C in the average global temperature in 100 years, has Potentially almost the same intensity of change between the end of the ice age and current interglacial period.

It should be noted that the conditions November to February showed up almost entirely in situations of alert and criticized for the welfare of broiler chickens.

Conclusions

The results show on the maps regions of stress and comfort situations for poultry production between the first until the 6th week, with the areas of higher and lower risk for this production system. Thus, during the period of assessment, it was possible verify kriging maps related with the situation presented greater thermal comfort, suggesting special attention about the adoption of efficient managing for poultry production.

The kriging techniques were satisfactory as a geostatistical method, because they are based on the characteristics discussed earlier, but the care in terms of the period of analysis should be taken. Maps fortnightly studies in enthalpy during a given station can show in more detail the transitions that the period presents. This work is extremely important for a clearly illustration to the producer the situations in which they are and the regions where the productive sector is installed, and thus cooperate for the search of adequate management during periods of great concern. In brief, this study will link to information from mortality rates in specific regions to be validated the method of analysis and information for the producers of the state of São Paulo.

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