Influencing factors and GIS-based spatial interpolation for distribution of draught animals in Madhya Pradesh

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The study investigates the trend and spatial distribution of the draught animal population in Madhya Pradesh, situated at lat. 21.6°N to 26.30°N and long. 74°90′E to 82°48′E. Draught animals dominated around 20% (3 million hectares) of the net sown area of Madhya Pradesh, with power availability of more than 0.37 kW/ha. A 1% increase in tractor density reduces the draught animals by 0.89%, and a 1% increase in percentage forest area increases the draught animals by more than 0.5%. The spherical form of the semivariogram model with an estimate of nugget, sill and range as 0, 500 and 1.6 respectively, was used in kriging. The neighbour search radius and the minimum number of neighbours were taken as 3° and 20 respectively.

Keywords: Anisotropy, draught animal power, semivariogram, spatial interpolation.

IN the Indian economy, the agriculture sector showed a positive growth rate to the overall gross domestic product (GDP) amidst the COVID-19 pandemic, while other sectors declined during financial 2020–21 (ref. 1). The contribution of agriculture sector to GDP was around 20% during 2020–21 and was the maximum share in the last decade[2]. This highlights the importance of the agriculture sector in India from an economic point of view. Farm mechanization plays an important role in Indian agriculture.

Farm mechanization is the process that improves farm labour productivity through the use of agricultural machinery and implements. This process uses all forms of power sources and mechanical assistance, including simple hand tools, agricultural labourers, draught animals, and heavy machinery. While Indian agriculture has shown its strength globally, there are two important weaknesses observed in the last decade. The first is stagnant or slower productivity growth and the second is the shortage of agricultural workers. In 2001, the percentage of agricultural workers to the number of total workers was 58.2% and will drop to 25.7% by 2050 (ref. 3). Studies showed that the application of improved implements in farmers' fields could increase crop productivity by 30% and reduce the cost of cultivation by 20% (ref. 4).

Farm mechanization can play an important role in overcoming the shortage of the agricultural workforce. The importance of farm mechanization has been covered by many studies by several authors. A study quantified agricultural mechanization status for soybean-wheat cropping pattern for the Bhopal region of Madhya Pradesh[5]. It has been reported that the farm power availability in Madhya Pradesh is 1.80 kW/ha (ref. 6). Farm mechanization, to be more specific, tractorization, has reduced the dependence of Indian agriculture on draught animals in the past decades. The first livestock census in India was conducted in 1919–20. Since then, the census has been conducted once every five years. The total male cattle in India was 95.54 million in 1997, declining to 47.40 million in 2019 (livestock census). In Madhya Pradesh, the draught animal population was 10.40 million in 1997, and decreased by 62% (3.97 million) in 2019. At the national level, the oxen population dipped by 30% according to the livestock census of 2019. The total male cattle in India is 47.40 million (43.94 indigenous, 3.46 exotic cross breed) according to the livestock census of 2019. However, draught animals continue to be utilized in many regions of India due to small land holdings and hilly topography, where farm operations using a tractor are impossible. Many studies have been conducted on using draught animals in Indian agriculture. It has been reported that the energy for ploughing two-thirds of the cultivated area in India comes from animal power. It has also been estimated that at least 200 days of work in a year were necessary to obtain a break-even point considering the maintenance and hiring rate for draught animals[7]. According to research, despite farm mechanization, draught animals continue to be utilized on Indian farms due to small land holdings and highly undulated topography[8]. It has been reported that 60% of the total draft power used in agriculture comes from animal sources[9], and that a pair of bullocks could develop about one horsepower during agricultural operations. A study observed that draught animal power had been extensively used for crop production and transportation in Chandrapur, Nashik, Satara and Solapur districts of Maharashtra[10]. This paper deals with the assessment and spatial interpolation of draught animal density in Madhya Pradesh. The influencing factor of draught animals has been identified using a log–linear model; ordinary kriging has been used for spatial interpolation in the presence of anisotropic continuity.

District-wise temporal and cross-sectional data were obtained through survey and secondary sources with location (latitude and longitude) for all the 51 districts of Madhya Pradesh. District-wise secondary data of Madhya Pradesh on draught animals during 1995–2019 were obtained from the livestock census. The secondary data on land use classification were obtained from the department of farmers welfare and agricultural development, Madhya Pradesh. Data on forest areas was obtained from the forest survey of India, Ministry of Environment, Forest and Climate Change. Draught animal power (DAP) availability was estimated using the formula given below, considering the horsepower obtained from one bullock is equivalent to 0.50 hp (ref. 11).

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$$\mathrm{DAP}\left(\frac{\mathrm{kW}}{\mathrm{ha}}\right)=\frac{\text{Total number of bullocks}\times 0.5}{\text{Net sown area of village (ha)}}\times\frac{746}{1000}. \quad (1)$$

District-wise DAP has been evaluated for Madhya Pradesh, and districts were categorized into high, medium and low groups based on the 25th and 75th percentile.

Log-linear model has been used to identify the factors affecting the draught animal population in Madhya Pradesh. The dependent variable for this model was the district-wise number of draught animals per 100 ha of net sown area. The independent variables were selected based on partial R^2. The independent variables retained in the model were the number of tractors per 100 ha of net sown area, percentage of forest area and irrigated area (00'ha).

The spatial variability in draught animals was investigated using semivariogram and ordinary kriging (OK). Before fitting many forms of semivariogram, the trend was removed, and instead of the original variable, residuals were used in identifying forms of semivariogram to be used in kriging (spatial interpolation).

Ordinary kriging uses spatial autocorrelation of the variable under investigation. It consists of a semivariogram to express the spatial dependence in the form of autocorrelation. The semivariogram measures the persistence correlation as a function of distance. The range is the distance at which the spatial correlation exists; beyond that distance, spatial correlation vanishes. The sill corresponds to the maximum variability in the absence of spatial correlation. The kriging estimate $z^*(x_0)$ and error estimation of variance $\sigma_k^2(x_0)$ at any point x_0 were estimated as follows

$$z^*(x_0)=\sum_{i=1}^{n}\lambda_i z(x_i), \quad (2)$$

$$\sigma_k^2(x_0)=\mu+\sum_{i=1}^{n}\lambda_i\gamma(x_0-x_i), \quad (3)$$

where λ_i is the weights for corresponding x_i, μ the lag range constant and $\gamma(x_0-x_i)$ is the semivariogram value corresponding to the distance between x_0 and x_i (refs 12, 13).

Semivariogram is a basic tool to examine the spatial distribution of the variable under interest. A semivariogram is expressed as follows[14]

$$\gamma(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(h)}[z(x_i)-z(x_{i+h})]^2, \quad (4)$$

where $\gamma(h)$ is the semi variance, h the lag distance, z the variable under interest (draught animal density), $N(h)$ the number of pairs of locations separated by a lag distance h, $Z(x_i)$ and $Z(x_{i+h})$ are values of Z at positions x_i and x_{i+h} (ref. 15). The empirical semivariograms obtained from the data were fitted by theoretical semivariogram models to produce geostatistical parameters.

Isotropic continuity is a situation where the variance/semivariogram is independent of spatial direction. It was necessary to detect the presence of anisotropic in which semivariogram depends on the spatial direction. There are two types of anisotropic, geometric anisotropic and zonal anisotropic. In the case of geometric anisotropic, the semivariogram range varies in different directions and remains the same, whereas in the case of zonal anisotropic, sill depends on spatial direction.

The fitting of empirical semivariogram was performed, and the lag distance, maximum lag distance, and number of maximum lags were obtained. Further, the direction of anisotropy was detected considering the number of directions equals 12 with an angle tolerance of 22.5°. It was necessary to detect anisotropic continuity in which semivariogram depends on the spatial direction. In addition, range and sill (scale) were estimated in corresponding directions. Spherical form (Sph) of semivariogram has been applied as it is widely used in studies related to geographical locations. Ordinary kriging was performed for residuals of draught animals. Suitable neighbour search radius, minimum number of neighbours and structure of covariance model were used to predict grid points. The predicted values for residuals of draught animal density were further transformed into predicted draught animal density for each grid point using a fitted general linear model.

All statistical analyses were performed using SAS-9.3 (SAS Institute Inc., Cary, NC, USA). The REG procedure was used for fitting log–linear model. The GLM procedure was used to detect the dependence of draught animal density on latitude and longitude. The fitting of the empirical semivariogram was performed using PROC VARIOGRAM, and OK was performed using PROC KRIGE2D.

Draught animal density (number of draught animals/00'ha) was considered a dependent variable in the log–linear model and spatial interpolation. Draught animals have been used in Indian agriculture since pre-historic times. Even in the modern era of farm mechanization and use of internet of things (IOT) in agriculture, animal power is used in many regions with hilly topography, where farm operations cannot be done using tractors. Some farmers still use bullocks for intercultural operations in *kharif* crops like maize and soybean in plains where these operations cannot be performed using power-operated implements due to the wet condition of fields. During a survey in Sagar district of Madhya Pradesh, it was observed that farmers used bullocks for digging carrots and other farm operations in vegetable cultivation.

Locations of districts (latitude and longitude) were considered independent variables in the spatial interpolation of draught animal density. In the initial stage, district-wise data on percentage of forest area, irrigated area, small farmers below poverty line (BPL) and number of tractors/00'ha were considered as independent variables. The variables such as percentage of irrigated area, small farmers BPL were dropped from the log–linear model as these variables had less than 15% partial R^2 values.

Draught animal population has declined in Madhya Pradesh over the past few decades (Figure 1). The draught animal population decreased to 3.97 billion in 2019 from 10.40 billion in 1995, reporting a 166% decrease in draught animal population. District-wise data on draught animal population during 2012–2019 in Madhya Pradesh showed that though the draught animal population declined in many districts, there are some districts where draught animal population increased or remained almost constant, as shown in Figure 2. The districts like Mandla and Anupur showed an increase in draught animal population in 2019 compared to 2012, and the districts like Barwani, Sahdol and Jhabua showed no declining trend in draught animal population. The percentage change in draught animal population since 2012 is presented in Figure 2. Madhya Pradesh has 15.35 million hectares of net sown area, out of which around 20% is dominated by draught animals. This showed that draught animal population remained almost constant in the ten districts of Madhya Pradesh. These districts are located in hilly regions with more undulated land.

District-wise DAP has been evaluated for each district of Madhya Pradesh. Further, districts were categorized into high, medium and low groups based on the 25th and 75th percentile. The 25th and 75th percentile values were evaluated as 0.03 and 0.37 kW/ha respectively. The districts

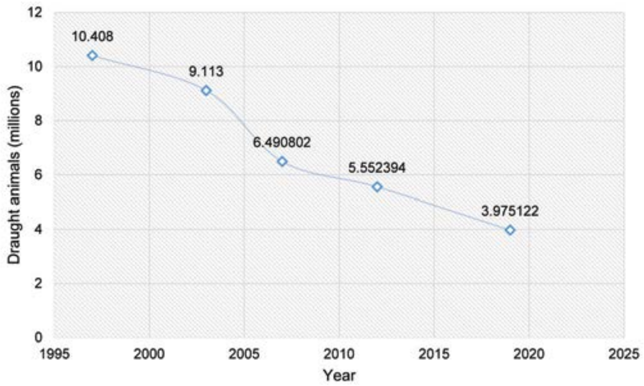

Figure 1. Scenario of draught animals in Madhya Pradesh.

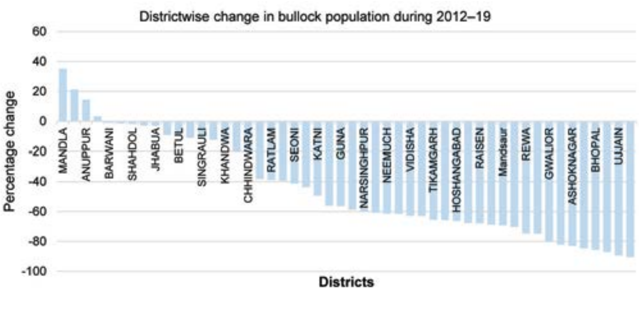

Figure 2. Percentage change in draught animal population.

with DAP of more than 0.37 kW/ha were grouped as high, 0.03 to 0.37 kW/ha as medium and less than 0.03 kW/ha as low. According to Manoj *et al.*[5], estimate of DAP for Bhopal region was 0.04 kW/ha, but now, DAP has declined to 0.008 kW/ha as per 2019 census data.

A log–linear model is utilized here to identify the factors affecting draught animal population in Madhya Pradesh, considering the district-wise number of draught animals per 100 ha of net sown area as dependent variable. The independent variables were selected based on partial R^2, and the variables retained in the model were number of tractors per 100 ha of net sown area, percentage of forest area, and irrigated area (00 ha). The R^2 and adjusted R^2 of the fitted model were 0.59 and 0.56 respectively, which showed that these three independent variables explained around 59% variations in draught animal population. The fitted model was highly significant (p value <0.0001). The error mean square (estimate of σ^2) was found to be 1.10 for the fitted model. All the parameter estimates were significant at 0.05% level of significance. The fitted model is given below with the standard error of the parameter estimates in parenthesis.

$$\ln(DA) = \underset{(1.38)}{4.24} - \underset{(0.21)}{0.891} \times \ln(TR) + \underset{(0.15)}{0.52} \times \ln(FA),$$

where ln denotes natural logarithm, *DA* the number of draught animals/100 ha, *TR* the number of tractors/100 ha and *FA* is the percentage of forest area.

The above equation showed that a 1% increase in tractor density reduces the draught animal density by 0.89%, and a 1% increase in percentage forest area increases the draught animal density by more than 0.5%. This showed that tractor density was a significant factor influencing the draught animal density in Madhya Pradesh, followed by forest area.

The spatial distribution of draught animals was investigated using semivariogram, and spatial prediction of draught animals was made using ordinary kriging. A scatter plot of draught animals (Figure 3) showed an increasing trend in draught animals toward the east direction. The spatial trend in draught animals has been removed using a second-order general linear model, and residuals obtained from this model were used in identifying the best-fit form of semivariogram. There was a significant effect of longitude and latitude on draught animal density as F value was found significant ($F_{4,46} = 22.52$) for the fitted general linear model. ANOVA table and estimates of parameters for the general linear model also indicated significant trends towards the east direction (p value <0.0001), while there was very little or no trend towards the north (p value >0.046). The empirical semivariogram has been constructed using residuals obtained from the general linear model.

The preliminary estimation of the empirical semivariogram was performed using PROC VARIOGRAM. The empirical semivariogram suggested a lag distance of 0.49°, a maximum lag distance of 9.81° and number of maximum lags of 5 (9.81/2), approximately for residuals of draught animal density. The direction of anisotropy has been detected considering the number of directions equals 12 with an angle tolerance of 22.5°. It was necessary to detect the presence of anisotropic. Maximum range was found in the direction of 75° north of east, and minimum range was observed in the direction of 15° north of west. The sill (scale) was almost constant in these two directions, providing evidence for geometric anisotropic continuity. The estimate of scale and range in the direction of 75° were 497.27 and 1.66 respectively (all were found significant at 0.05%). Similarly, estimates of scale and range in the direction of 165° were 470.72 and 1.19 (significant at 0.05%). Considering these estimates, the spherical form (Sph) of the semivariogram has been fitted as this form is widely used in studies related to geographical location. A plot of the fitted spherical form of semivariogram using weighted least square technique in both directions is shown in Figure 4.

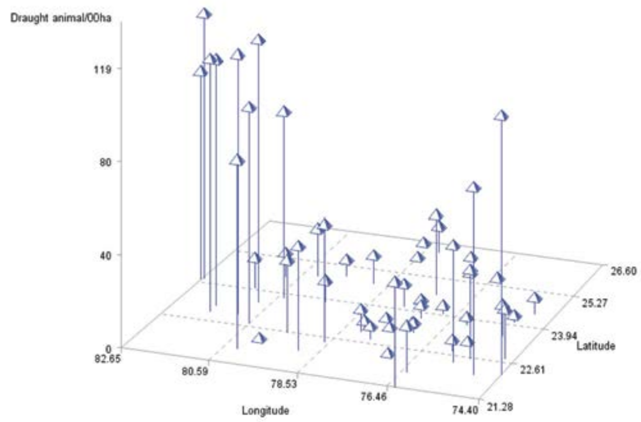

Figure 3. Spatial trend in draught animal density in Madhya Pradesh.

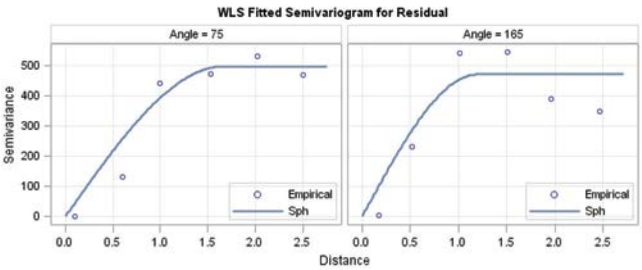

Figure 4. Fitted spherical form in two different directions.

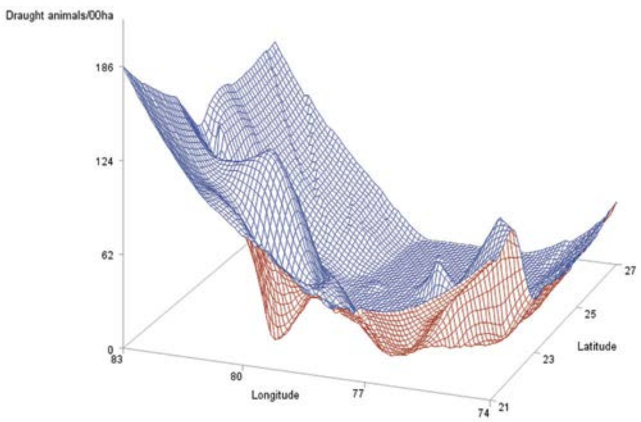

Figure 5. Spatial interpolation of draught animal density in Madhya Pradesh.

OK has been performed for residuals of draught animals obtained from a general linear model using PROC KRIGE2D. Neighbour search radius and the minimum number of neighbours were taken to be 3° and 20 respectively. The used structure of covariance model was (nugget = 0, sill = 500 and range = 1.6). The prediction grid points were 5571, and the actual points were 51. There were more than 55,425 villages in Madhya Pradesh; thus every predicted grid point represents almost 10 villages of Madhya Pradesh. The predicted values for residuals of draught animal density were further transformed to predicted draught animal density for each grid point using a fitted general linear model. The surface plot of spatial prediction for draught animal density at different grid locations has been shown in Figure 5. The spatial prediction of draught animal density can be made for any location within Madhya Pradesh for further use in research and policy interventions related to draught animals. The study may help in assessing the required number of bullock-operated implements based on the command area per pair of bullocks to perform farm operations on time. This will enhance input use efficiency and time-saving. Properly utilizing bullock power sources will reduce greenhouse gas emissions and lead to sustainable agriculture. The study will also enable policymakers to implement community-level biomethanation plants and promote natural farming. In addition, the study will be useful in small area estimation like estimating draught animal density and bullock-operated implements at the village/block level.

Draught animals dominated around 20% (3 million hectares) of net sown area of Madhya Pradesh. Of the 51 districts of Madhya Pradesh, 13 districts had draught animal power availability of more than 0.37 kW/ha. It was observed that 1% increase in tractor density could reduce draught animal density by 0.89%, and 1% increase in forest area can increase the draught animal density by more than 0.5%. The result showed a significantly increasing trend in draught animals towards the east direction (latitude) in Madhya Pradesh. Empirical measures of spatial continuity suggested a maximum range at 75° north of east and a minimum range at 15° north of west. The sill (scale) was almost constant in these two directions, suggesting a geometric anisotropic continuity. The estimate of scale and range in the direction of 75° were 497.27 and 1.66 respectively, and both were significant at 0.05%. In addition, estimates of scale (470.72) and range (1.19) were found significant in the direction of 165°. Spherical form of semivariogram has been fitted using ordinary kriging with neighbour search radius and minimum number of neighbours of 3° and 20 respectively. The parameter estimate for nugget, sill and range of spherical form of semivariogram used in spatial prediction was 0, 500 and 1.6 respectively. The draught animal density was predicted for 5571 grid points/spatial locations, and each location almost represents 10 villages of Madhya Pradesh.

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