the district level. There was significant improvement in the estimators by the use of auxiliary information through calibration estimation technique for estimation of rice yield. In Bareilly district, there was maximum improvement in %CV of the calibration ratio-type estimator ($\bar{y}_{\text{cal}}$) over the simple HT estimator ($\bar{y}_{\text{HT}}$) for estimation of paddy yield when the sampling design under consideration was two-stage equal probability without replacement sampling design at each stage of selection. Further, the yield estimates of wheat crop varied from 3797.89 to 4686.76 kg/ha in case of HT estimator, whereas it varied from 3601.40 to 5136.72 kg/ha in case of the proposed calibration ratio-type estimator. The %CV varied from 2.49 to 3.42 in case of the HT estimator and it varied from 0.43 to 0.90 in case of the proposed calibration ratio-type estimator. So for estimation of wheat yield in the above-mentioned districts of UP, it can be seen that calibration ratio-type estimator of crop yield performs better that the usual HT estimator with respect to improvement in %CV under two-stage equal probability without replacement sampling design.

It can be concluded that for estimation of crop yield, the proposed estimator is more efficient than the HT estimator with respect to %CV under two-stage equal probability without replacement sampling design. Further, it can be concluded that no prior assumptions are made about the assisting model for formation of estimators with the help of auxillary informations, calibration estimation technique can be treated as a better alternative.

1. Deville, J. C. and Särndal, C. E., Calibration estimators in survey sampling. *J. Am. Stat. Assoc.*, 1992, **87**, 376–382.
2. Théberge, A., Extension of calibration estimators in survey sampling. *J. Am. Stat. Assoc.*, 1999, **94**, 635–644; http://dx.doi.org/10.1080/01621459.1999.10474157.
3. Horvitz, D. G. and Thompson, D. J., A generalization of sampling without replacement from a finite universe. *J. Am. Stat. Assoc.*, 1952, **47**, 663–685.
4. Cassel, C. M., Särndal, C. E. and Wretman, J. H., Some results on generalized difference estimation and generalized regression estimation for finite population. *Biometrica*, 1976, **63**, 615–620.
5. Singh, S., Survey statisticians celebrate Golden Jubilee Year – 2003 of the linear regression estimator. *Metrika*, 2006, **63**, 1–18.
6. Estevao, V. M. and Särndal, C. E., A new perspective on calibration estimators. In Joint Statistical Meeting – Section on Survey Research Methods, 2003, pp. 1346–1356.
7. Farrell, P. J. and Singh, S., Penalized chi square distancefunction in survey sampling. In Proceedings of Joint Statistical Meeting, New York (Available on CD), 2002, vol. 15.
8. Farrell, P. J. and Singh, S., Model-assisted higher order calibration of estimators of variance. *Aust. New Zealand J. Stat.*, 2005, **47**(3), 375–383.
9. Kott, P. S., An overview of calibration weighting. *Joint Statistical Meeting – Section of Survey Methods*, 2003, pp. 2241–2252.
10. Montanari, G. E. and Ranalli, G., Nonparametric model calibration estimation in survey sampling. *J. Am. Stat. Assoc.*, 2005, **100**(472), 1429–1442.
11. Singh, S., *Advanced Sampling Theory with Applications: How Michael 'Selected' Amy*, Kluwer Academic Publisher, The Netherlands, 2003, vols 1 & 2, pp. 1–1247.
12. Singh, S., Golden and Silver Jubilee Year – 2003 of the linear regression estimators. Presented at the Joint Statistical Meeting, Toronto (available on the CD), 2004, pp. 4382–4389.
13. Wu, C. and Sitter, R. R., A model-calibration approach to using complete auxiliary information from survey data. *J. Am. Stat. Assoc.*, 2001, **96**, 185–193.
14. Aditya, K., Sud, U. C., Chandra, H. and Biswas, A., Calibration based regression type estimator of the population total under two stage sampling design. *J. Indian Soc. Agric. Stat.*, 2016, **70**(1), 19–24.
15. Aditya, K. and Sud, U. C., Higher order calibration estimators under two stage sampling. In *Statistics and Informatics in Agricultural Research*, Excel India Publication, New Delhi, 2015.
16. Cochran, W. G., *Sampling Techniques*, John Wiley & Sons, New York, 1977, 3rd edn.
17. Särndal, C. E., Swensson, B. and Wretman, J., *Model-Assisted Survey Sampling*, Springer-Verlag, New York, 1992.

Received 27 May 2016; revised accepted 22 December 2016

doi: 10.18520/cs/v112/i09/1927-1931

Estimation of carrying capacity of livestock farm based on maximum phosphorus load of farmland and GIS spatial analysis technology

Bojie Yan[1], Jingjie Yan[2] and Wenjiao Shi[3,*]

[1]Department of Geography, Minjiang University, Fuzhou, 350108, China
[2]College of Telecommunications and Information Engineering, Nanjing University of Posts and Telecommunications, Nanjing 210003, China
[3]Key Laboratory of Land Surface Pattern and Simulation, Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China

To avoid the environmental pollution caused by livestock manure and provide rational layout of livestock farm, we estimated the livestock manure phosphorus load by the excretion coefficient method and have developed a livestock manure nutrient distribution model. The livestock manure phosphorus was distributed to farmlands using this model and spatial analysis technology. The carrying capacity of livestock farms was calculated based on the maximum livestock manure phosphorus carrying capacity of farmlands and expressed in pig for the Shangjie town, China. The results showed that the maximum, minimum, average and total livestock manure phosphorus carrying capacity of farmlands was about 55.97, 0.74, 12.21 and 13,382.90 kg respectively, and the total load of

*For correspondence. (e-mail: shiwj@lreis.ac.cn)

2854.79 kg manure phosphorus from livestock farms surpassed the carrying capacity of farmlands in Shangjie town in 2011. The results also demonstrated that the maximum, minimum, average and the total carrying capacity of livestock farms was respectively, 792, 10, 157 and 9128 pigs. Most of the livestock farms in the town had carrying capacity of less than 300 pigs and only six farms had carrying capacity of livestock more than 500 pigs. The results could provide decision support for the spatial layout of livestock farms, controlling environmental pollution caused by livestock manure.

Keywords: Carrying capacity, farmlands, livestock manure, phosphorus load.

THE livestock industry has developed rapidly, generating massive livestock manure, that has then resulted in many environmental problems. On the other hand, livestock manure could help improve soil fertility as it is rich in nutrients like nitrogen, phosphorus and potassium. However, studies have shown that the transportation distance of livestock manure is limited from livestock farm to farmland and livestock manure was mostly applied to farmlands located near the livestock farms[1–3]. Although livestock manure is an important source of organic nutrients, the unsafe use of manure nutrients has a negative impact on sustainable development of agriculture[4].

Once the amount of livestock manure applied surpasses the carrying capacity of a farmland, it would cause various environmental issues[5,6]. In order to minimize these environmental issues and promote sustainable development of livestock farms, the density of livestock needs to be controlled according to the carrying capacity of livestock in certain regions[7,8]. So it is important to estimate the carrying capacity of regional livestock farms intuitively and scientifically.

At present, many countries and regions have made various regulations of the maximum livestock density based on nutrient budget of farmland, such as 2.0 AU (Animal unit)/hm^2 in the European Union, and 3.5–4.5 AU/hm^2 in Germany, etc.[9,10]. A series of studies have focused on the carrying capability of livestock in different regions[11,12]. Thapa and Pandel[13] studied the carrying capability of livestock in Nepal's Shyangja district and evaluated the number of existing livestock according to livestock carrying capacity of the land. Depending on geographical information technology and remote sensing technology, Yu *et al.*[14] estimated herbage yield and the maximum carrying capacity of livestock of alpine grassland in Golog Prefecture, Qinghai, China. Moreover, the grazing capacity of livestock in the grasslands of Tibet was studied based on carrying capacity of livestock of grasslands[15]. According to the theory of farmland nutrient balance, Gerber *et al.*[16] estimated the space density of livestock and poultry. Wu *et al.*[17] made comparative analysis on carrying capacity of livestock and load index of farmlands in Yucheng city of Shandong and TaoYuan county of China's Hunan Province. Hao *et al.*[18] studied the carrying capacity of livestock based on the configuration of farmland area. The farmland areas and types also affect farmland nutrient requirements[19]. Therefore, if the carrying capacity of livestock manure of farmlands is estimated by distributing livestock manure to the farmlands equally, it would result in error and not reflect the actual carrying capacity of livestock manure of farmlands.

The estimation of carrying capacity of livestock and poultry adopted in the above-mentioned studies, considered only an average distribution of the total amount of livestock manure in an administrative area. A few studies had considered the space position of livestock farm, which livestock manure phosphorus surpassed the carrying capacity of farmlands nearby[11,19].

The objectives of the present study are: (i) to estimate the livestock manure phosphorus by the excretion coefficient method and establish livestock manure nutrient distribution model; (ii) to distribute livestock manure phosphorus to farmlands using the livestock manure nutrient distribution model and spatial analysis technology; (iii) to estimate livestock manure phosphorus load of farmlands and also their surplus nutrient of livestock manure phosphorus load and (iv) to calculate and display the carrying capacity of livestock farms visually using geographic information system (GIS) technology.

Shangjie town is located in the western suburbs of Fuzhou, Fujian Province, China with approximately 157 sq. km and 7.74 thousand residents. It is characterized by subtropical monsoon climate, with annual mean temperature of 21°C and annual mean precipitation rainfall of 2152.6 mm.

In order to estimate the carrying capacity of the regional livestock farm, the basic data were acquired and processed as follows. The digital distribution map of basic geospatial data, including administrative, road, water, land use and farmland, was generated from the QuickBird remote sensing image with 0.61 m resolution, and administrative map of Shangjie town in 2011 using ArcGIS9.3 software and ENVI5.0 software. Furthermore, a 1096 farmlands were selected from the digital distribution maps and classified into four types: cultivated land, vegetable land, garden land and facility agriculture land (plastic house, greenhouse, etc.) based on survey data and statistical data. Also, 58 livestock farms were chosen using global positioning system (GPS) technology and field investigations in Shangjie town. Other information such as the amount and type of livestock and poultry, culture cycle, etc. was generated from statistic data and investigations.

The manure nutrient load of a livestock farm was estimated by the excretion coefficient method. The excretion coefficient and nutrient content coefficient (Table 1) were obtained from the published literature, either within or outside the country, and from observations made in the study area[20–22]. The livestock manure nutrient load was calculated as follows[23,24]

$$M = \sum_{j=1}^{m} (\mathrm{Num}_j \times D_j \times R_j), \tag{1}$$

where M is the livestock manure nutrient from livestock farms (kg), Num_j the amount of livestock, D_j the feeding cycle of livestock (d), R_j is the daily excretion coefficients (kg/d).

In order to accurately estimate the carrying capacity of regional livestock farms, the livestock manure nutrient requirement in a certain region needs to be distributed. Thus, based on earlier reports[24,25], we adopted factors like the distance between livestock farms and farmlands, farmland area, type and fertility, which influence the application of livestock manure to the farmlands, and established the manure nutrient distribution model. We also adopted the Delphi method and analytic hierarchy process (AHP) to assign weights to the factors influencing the livestock manure nutrient distribution (Table 2). The formulae used are as follows[24,25]

$$Y = \sum_{i=1}^{m} \left(\left(\frac{\lambda_1}{d_i \sum_{i=1}^{n} (1/d_i)} + \frac{\lambda_2 s_i}{\sum_{i=1}^{n} s_i} + \lambda_3 b_j + \frac{\lambda_4}{c_i \sum_{i=1}^{n} (1/c_i)} \right) \times M_i \right), \tag{2}$$

where Y is the total amount of livestock manure nutrient requirement of the farmland (kg), M_i the total amount of livestock manure from each livestock farms (kg), d_i is the distance between the livestock farms and farmlands (km), s_i the farmland area (hm^2), b_j the farmland type, c_i the farmland fertility, λ_2 the weight of distance influencing livestock manure nutrient distribution, λ_2 the weight of farmland area influencing livestock manure nutrient distribution, λ_3 the weight of farmland type influencing livestock manure nutrient distribution, λ_4 the weight of farmland fertility influencing livestock manure nutrient distribution, n the number of farmlands within the economic hauling distance between livestock farms and farmlands, m the number of livestock farms for spreading on the farmlands.

$$d_i \le D_{\max}. \tag{3}$$

where $D_{\max}$ is the break-even hauling distance of transporting livestock manure to farmlands (km).

To minimize pollution caused by livestock farms, the amount of livestock manure nutrient is not allowed to surpass the carrying capacity of the farmlands. Therefore, the following condition should be satisfied

$$Y \times g/S \le F_{\mathrm{MAX}}, \tag{4}$$

where F_{MAX} is the maximum livestock manure nutrient load (kg/hm^2), S the farmland area (hm^2) and g is the loss coefficient of livestock manure nutrient (%).

The calculation of the carrying capacity of livestock farms was done as follows

$$X_{\mathrm{Num}} = C_{\mathrm{nutrient}} / (D_j \times R_j \times g), \tag{5}$$

where X_{Num} is the moderate scale of livestock farms, C_{nutrient} the livestock manure nutrient that could be disposed by farmlands nearby (kg), D_j the culture cycle of livestock, R_j the daily excretion coefficients (kg · d^{-1}) and g is the loss coefficient of livestock manure nutrient (%).

From the perspective of sustainable development of livestock farms, it is best to apply livestock manure as organic fertilizer to the farmlands. However, nitrogen and phosphorus load is of greater concern when applying livestock manure to the farmlands, because overloaded

Table 1. Excretion coefficients, phosphorus content and equivalent conversion coefficient in different livestock[20,22–24]

Livestock type	Feeding cycle (d)	Excretion coefficients (kg · d^{-1})	Phosphorus content (g · d^{-1})
Pig	199	3.58	2.45
Cow	365	46.84	38.47
Draft cattle	365	21.90	12.48
Beef cattle	300	23.71	19.85
Sheep	365	0.87	0.46
Horse	365	5.9	1.60
Donkey/mule	365	5.0	1.60
Rabbits	180	0.15	0.24
Layers	210	0.15	0.51
Duck	180	0.13	0.30
Goose	180	0.19	0.22
Broiler chicken	55	0.22	0.29

Table 2. Weights assigned to the factors influencing livestock manure nutrient distribution model

	T1	T2	T3	T4	Weight
T1	1	1/2	1/2	1/3	0.121
T2	2	1	1/2	1/2	0.193
T3	2	2	1	1/2	0.269
T4	3	2	2	1	0.417

T1, Slope of farmland; T2, distance between animal manure source and farmland; T3, farmland type; T4, fertility of farmland.

nitrogen will leak into groundwater as nitrate form of nitrogen and overloaded phosphorus will cause eutrophication of surface water[26,27]. Several surveys have indicated that water-soluble phosphorus easily causes serious environment problems[28,29]. Therefore, to avoid the potential environment pollution, phosphorus is taken as nutrient standard for application of livestock manure in this study.

Considering phosphorus loss with ratio of 16% in the process of applying livestock manure to the farmlands[1,30] and combining with excretion coefficient, nutrient content coefficient of manure and culture cycle of livestock and poultry (Table 1), livestock manure nutrient was estimated according to eq. (1) for Shangjie town, Minhou county for the period 2011. The results showed that the total amount of livestock manure phosphorus from the farms was 16,237.69 kg. On this basis, the livestock manure phosphorus was distributed to 1096 farmlands in Shangjie town according to the livestock manure nutrient distribution model and a program compiled in C# and SuperMap software. Figure 1 presents results of distributing livestock manure phosphorus to farmlands.

The maximum, minimum, average, and total livestock manure phosphorus of farmlands was 55.97, 0.74, 12.21 and 13,382.90 kg respectively. The average, minimum and maximum livestock manure phosphorus load of the farmlands was 25.63, 5.49 and 34.99 kg/hm^2 respectively. The maximum livestock manure phosphorus load of farmlands was less than the Europe Standard of 35.00 kg/hm^2 (refs 31, 32), which indicated that the manure nutrient distribution was reasonable and could help to prevent the potential pollution caused by livestock manure.

The results of distributing livestock manure phosphorus to farmlands showed that there was 2854.79 kg difference of livestock manure phosphorus in livestock farms and farmlands. This is because the livestock manure from farms had surpassed the carrying capacity of farmlands in Shangjie town in 2011. Therefore, to avoid the environment problems caused by the extra livestock manure phosphorus, remedial measures such as reducing phosphorus content of livestock manure before being applied to farmlands or controlling the farm scale of livestock farms according to carrying capacity of the farmlands should be taken up.

In view of the sustainable development of livestock farms, the best way is to control the carrying capacity of livestock farms. For this, the spatial distribution of livestock farms that are producing extra livestock manure, surpassing the carrying capacity of the farmlands nearby, has been plotted and displayed using spatial analysis technology. The amount of surplus phosphorus from each livestock farm (Figure 2) was also calculated based on the livestock manure nutrient distribution.

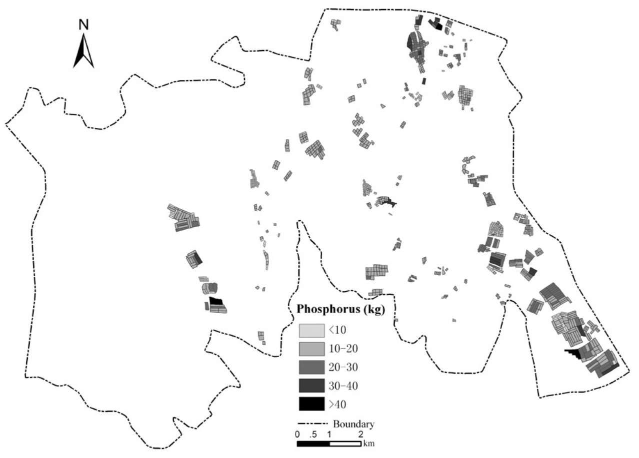

Figure 1. Results of distributing livestock manure phosphorus to farmlands in Shangjie town, China.

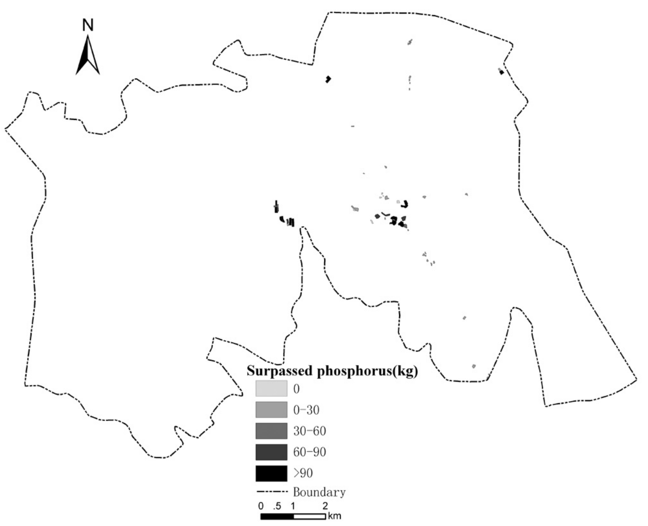

Figure 2. Surpassed phosphorus of each livestock farm in Shangjie town.

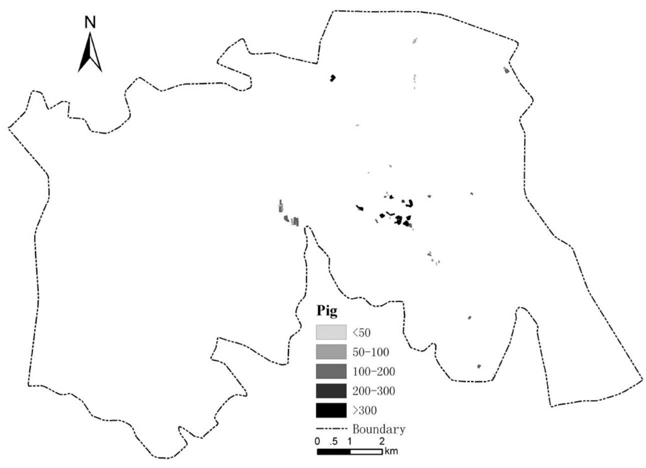

Figure 3. Result of estimating carrying capacity of livestock farms as pig.

The results showed that there were 51 livestock farms with livestock manure supply surpassing the carrying capacity of nearby farmlands. Only seven livestock farms had manure supply that could be safely disposed in the nearby farmlands. From statistical analysis, the maximum, minimum and average livestock manure phosphorus from the farms was calculated as 259.57, 0.03 and 49.22 kg respectively.

The amount of livestock manure which could be disposed in the nearby farmlands from 51 livestock farms was calculated by subtracting surplus manure phosphorus from the original amount of livestock manure. The carrying capacity of these 51 livestock farms was worked out using the excretion coefficient, nutrient content coefficient of livestock manure and culture cycle of livestock and poultry (eq. (4)). In order to display the carrying capacity of livestock farms uniformly, pig equivalent conversion coefficient was adopted instead of other livestock types (Table 1). Figure 3 shows the results of carrying capacity of livestock farms in Shangjie town obtained using pig equivalent conversion and GIS spatial analysis technology.

The maximum, minimum, average and total carrying capacity of livestock farms was 792, 10, 157 and 9128 pigs respectively. Livestock farms with carrying capacity less than 300 pigs accounted for 82.76% of total livestock farms in Shangjie town. Only six livestock farms with carrying capacity of 500 pigs were considered as small industrial livestock industry in China. Furthermore, the carrying capacity of livestock farms would increase if the manure from the farms could be disposed by other means instead of applying to farmlands.

This study has estimated the livestock manure phosphorus load from each farm by using the excretion coefficient method, and manure phosphorus was distributed to farmlands in Shangjie town by livestock manure nutrient distribution model. The results showed that the maximum, minimum, average and total livestock manure phosphorus carrying capacity of farmlands was 55.97, 0.74, 12.21 and 13,382.90 kg respectively. The results also demonstrated that the maximum livestock manure phosphorus load of the farmlands was 34.99 kg/hm^2, less than the European Standard of 35.00 kg/hm^2. Using this model we could distribute the livestock manure to farmlands uniformly. However, the total load of 2854.79 kg livestock manure phosphorus produced from livestock farms in Shangjie town surpassed the carrying capacity of the farmlands in 2011. Hence, the carrying capacity of livestock farms was calculated based on the maximum livestock manure phosphorus load of farmlands and expressed in pig. The results demonstrated that the maximum, minimum, average and total carrying capacity of livestock farms was 792, 10, 157 and 9128 pigs respectively. Also 82.7% of livestock farms had carrying capacity less than 300 pigs and only six livestock farms had carrying capacity more than 500 pigs.

1. Kellogg, R. L., Lander, C. H., Moffitt, D. C. and Gollehon, N., Manure nutrients relative to the capacity of cropland and pastureland to assimilate nutrients: spatial and temporal trends for the united states. In Proceedings of the Water Environment Federation, 2000, pp. 18–157.
2. Araji, A. A., Abdo, Z. O. and Joyce, P., Efficient use of animal manure on cropland economic analysis. *Bioresour. Technol.*, 2001, **79**, 179–191.
3. Bartelt, K. D. and Bland, W. L., Theoretical analysis of manure transport distance as a function of herd size and landscape fragmentation. *J. Soil Water Conserv.*, 2007, **62**(5), 345–352.
4. Ouyang, W., Hao, F., Wei, X. and Huang, H., Spatial and temporal trend of Chinese manure nutrient pollution and assimilation capacity of cropland and grassland. *Environ. Sci. Pollut. R*, 2013, **20**(7), 5036–5046.
5. Ulén, B., Bechmann, M., Fölster, J., Jarvie, H. P. and Tunney, H., Agriculture as a phosphorus source for eutrophication in the northwest European countries, Norway, Sweden, United Kingdom and Ireland: a review. *Soil Use Manage*, 2007, **23**(S1), 5–15.
6. Oenema, O., Oudendag, D. and Velthof, G. L., Nutrient losses from manure management in the European Union. *Livest. Sci.*, 2007, **112**(2007), 261–272.
7. Tammingan, S., Pollution due to nutrient losses and its control in European animal production. *Livest. Prod. Sci.*, 2003, **84**(2), 101–111.
8. Chen, B. X., Liu, J. Z., Wu, Y. B., Li, Y. S. and Peng, X. Z., Analysis of livestock manure carrying capacity of farmland soil and environmental capacity for livestock cultivation in Hainan province. *Acta Ecol. Anim. Domastic.*, 2012, **33**(6), 78–84.
9. Schroder, J. J., Scholefield, D., Cabral, F. and Hofman, G., The effects of nutrient losses from agriculture on ground and surface water quality: the position of science in developing indicators for regulation. *Environ. Sci. Policy*, 2004, **7**(1), 15–23.
10. Song, J. H., Regional livestock quota system under environmental capacity in Korea. *J. Rural Dev.*, 2005, **28**, 65–84.
11. Hou, L. K., Qiu, H. G., Chui, Y. W. and Wang, X. G., Research on environmental pollution and spatial layout of livestock sector. *Chin. Pop. Sci. Resour. Environ.*, 2011, **21**(12), 65–69.
12. Yang, Q., Tian, H., Li, X., Ren, W., Zhang, B., Zhang, X. and Wolf, J., Spatiotemporal patterns of livestock manure nutrient production in the conterminous United States from 1930 to 2012. *Sci. Total Environ.*, 2016, **541**(4), 1592–1602.
13. Thapa, G. B. and Paudel, G. S., Evaluation of the livestock carrying capacity of land resources in the Hills of Nepal based on total digestive nutrient analysis. *Agric. Ecosyst. Environ.*, 2000, **78**(99), 223–235.
14. Yu, L., Zhou, L., Liu, W. and Zhou, H. K., Using remote sensing and GIS technologies to estimate grass yield and livestock carrying capacity of alpine grasslands in Golog Prefecture, China. *Pedosphere,* 2010, **20**(3), 342–351.
15. Zhao, W., Shen, W. S., Liu, B., Li, N. F. and Wang, T., Carrying capacity of grasslands and its spatiotemporal change in Tibet, China. *Chin. Sci. Bull.*, 2015, **60**(21), 2014–2028.
16. Gerber, P., Chilonda, P., Franceschini, G. and Menzi, H., Geographical determinants and environmental implications of livestock production intensification in Asia. *Bioresour. Technol.*, 2005, **96**(2), 263–276.
17. Wu, L. F., Ouyang, Z. and Xie, X. L., Carrying capacity of livestock in cropland of two typical regions dominated by agriculture in China. *J. Nat. Resour.*, 2013, **28**(1), 104–113.
18. Hao, X. Y., Tang, X. M., Pan, Y. C., Liu, Y., Ren, Y. M., Zhang, Y. P. and Qiu, H., Optimization and implementation of livestock and poultry breeding configuration: taking land consolidation project in Yaoshan and Gaoyupu towns of Shunping county, Hebei Province as study case. *Acta Sci. Nat. Univ. Pekin.*, 2015, **51**(5), 923–929.

19. Peng, L. and Yu, B., Numerical study of regional environmental carrying capacity for livestock and poultry farming based on planting-breeding balance. *J. Environ. Sci*., 2013, **25**(9), 1882–1889.
20. *State Environmental Protection Administration, Investigation and Control Counter Measures of Pollution Situation of Livestock and Poultry Breeding Industry in China*, China Environmental Science Press, Beijing, 2002, pp. 14–103.
21. Peng, L. and Wang, D., Estimation of annual quantity of total excretion from livestock and poultry in Chongqing municipality. *Trans. Chin. Soc. Agric. Eng*., 2004, **20**(1), 288–292.
22. Yan, B. J. and Pan, Y. C., Estimation of nitrogen pollution load of farmland from livestock manure in China based on grid. *Bull. Soil Water Conserv*., 2015, **35**(5), 133–137.
23. Yan, B. J., Zhao, C. J., Pan, Y. C. and Wang, Y., Estimation of the amount of livestock manure and its environmental influence of large-scaled culture based on spatial information. *China Environ. Sci*., 2009, **29**(7), 733–737.
24. Yan, B. J., Zhao, C. J., Pan, Y. C., Yan, J. J. and Guo, X., Estimation of livestock manure nitrogen load and pollution risk evaluation of farmland in Daxing District. *Environ. Sci*., 2010, **31**(2), 437–443.
25. Yan, B. J. and Pan, Y. C., Research on characterization method of statistical data of scale raising farms. *T. Chin. Soc. Agric. Mach*., 2014, **45**(11), 154–158.
26. Vu, D. T., Tang, C. and Armstrong, R. D., Changes and availability of P fractions following 65 years of P application to a calcareous soil in a Mediterranean climate. *Plant Soil*, 2008, **304**(1–2), 21–33.
27. Wang, J. J., Zhang, H., Schroder, J. L., Udeigwe, T. K., Zhang, Z., Dodla, S. K. and Stietiya, M. H., Reducing potential leaching of phosphorus, heavy metals, and fecal coliform from animal wastes using bauxite residues. *Water Air Soil Pollut*., 2011, **214**(1–4), 241–252.
28. Israel, D. W., Osmond, D. L. and Roberts, L. C., Potential impacts of implementation of the phosphorus loss assessment tool (PLANT) on the poultry industry in North Carolina: case studies. *J. Soil Water Conserv*., 2007, **62**(1), 48–54.
29. Sørensen, P. and RubÆk, G. H., Leaching of nitrate and phosphorus after autumn and spring application of separated solid animal manures to winter wheat. *Soil Use Manage*, 2012, **28**(1), 1–11.
30. Li, W., Li, Y. X., Zhang, F. S., Lin, C. Y., Xiong. X. and Zhang, Z., The spatial and temporal distribution features of animal production in three northeast provinces and the impacts of manure nutrients on the local environment. *J. Agro-Environ. Sci*., 2007, **26**(6), 2350–2357.
31. Oenema, O., Liere, L. V., Plette, S., Prins, T., Zeijts, H. V. and Schoumans, O., Environmental effects of manure policy options in the Netherlands. *Water Sci. Technol*., 2004, **49**(3), 101–108.
32. Geng, W., Hu, L., Cui, J. Y., Bu, M. D. and Zhang, B. B., Biogas energy potential for livestock manure and gross control of animal feeding in region level of China. *Trans. Chin. Soc. Agric. Eng*., 2013, **29**(1), 171–179.

ACKNOWLEDGEMENTS. This research was partly supported by the National Natural Science Foundation of China under Grant nos 61501249 and 41601601, the Natural Science Foundation of Fujian Province under Grant nos 2016J01713 and 2016J01194, the Natural Science Foundation for Jiangsu Higher Education Institutions under Grant no. 15KJB510022, and the Natural Science Foundation of Jiangsu Province for Youth under Grant No. BK20150855.

Received 21 June 2016; revised accepted 28 November 2016

doi: 10.18520/cs/v112/i09/1931-1936

Characterization and comparative physico-chemical studies of Manahshila (traditionally used arsenic mineral) and the corresponding polymorphs of realgar (As_4S_4)

Vinamra Sharma[1,*], Amiya K. Samal[2], Anand K. Chaudhary[1] and Rajesh K. Srivastava[2]

[1]Department of Rasa Shastra, Faculty of Ayurveda, Institute of Medical Sciences, and
[2]Centre of Advanced Study in Geology, Institute of Science, Banaras Hindu University, Varanasi 221 005, India

This communication presents characterization and comparison of the physico-chemical properties of different varieties of Manahshila with the corresponding polymorphs of realgar. Three varieties of Manahshila have been described in Ayurveda, viz. Shyamangi, Kanavirak and Khandakhya; the last two are acceptable therapeutically. Khandakhya contains high percentage of arsenic than Kanavirak. In this study, both samples of Manahshila have been collected. Their physical and chemical properties have been correlated with the polymorphs of realgar. XRD study classifies Kanavirak as alacranite and Khandakhya as realgar. EDXA study confirms 51.33% and 68.14% of arsenic in alacranite and realgar samples respectively. This work correlates the ancient description of Manahshila with contemporary mineralogical classification (polymorphs) of mineral realgar.

Keywords: Alacranite, Manahshila, physico-chemical studies, polymorphs of realgar, mineralogical classification.

REALGAR (red arsenic – an arsenic-containing mineral drug) has long been used in traditional Indian medicines for the treatment of diseases of respiratory and digestive systems, skin diseases, psychological disorders and certain eye disorders[1–3]. Recently, it has been demonstrated that it is clinically effective for the treatment of patients with refractory or relapsed acute promyelocytic leukaemia (APL) and other hematopoietic malignancies[4–6]; this has given rise to an upsurge of research on its oldest to newest forms. Generally, inorganic realgar is highly toxic and carcinogenic[7,8]; however, Ayurveda has emphasized that a strong poison may be converted into a safe and potent therapeutic drug by applying specific pharmaceutical processes as described in the Ayurvedic literature (e.g. shodhana, marana, etc.)[9]. The drug Manahshila, one of the arsenicals, has been identified as realgar due to its similar chemical and physical properties. Ayurveda has advocated proper method of shodhana (purification and detoxification from the unwanted elements by intervention

*For correspondence. (e-mail: dr.vinamrasharma@gmail.com)