Int J Appl Earth Obs Geoinformation 66 (2018) 37–45

Contents lists available at ScienceDirect

Int J Appl Earth Obs Geoinformation

journal homepage: www.elsevier.com/locate/jag

Research Paper

GlobeLand30 shows little cropland area loss but greater fragmentation in China

Qiangyi Yu[a,b,*,1], Qiong Hu[a,1], Jasper van Vliet[b], Peter H. Verburg[b,c], Wenbin Wu[a,*]

[a] Key Laboratory of Agricultural Remote Sensing (AGRIRS), Ministry of Agriculture/Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, China
[b] Environmental Geography Group, Institute for Environmental Studies (IVM), Vrije Universiteit Amsterdam, Amsterdam 1081HV, The Netherlands
[c] Swiss Federal Institute for Forest, Snow and Landscape (WSL), Birmensdorf, Switzerland

ARTICLE INFO

Keywords:
Land use change
Fragmentation
Characterization
Gross change
Cropland protection
GlobeLand30

ABSTRACT

Understanding of cropland dynamics in a large geographical extent is mostly based on observations of area change, while the changes in landscape pattern are hardly assessed. The total amount of cropland in China has remained relatively stable in recent years, which might suggest there was little change. In this analysis, we combine the number of cropland patches (NP) with the total cropland area (TA) for a more comprehensive characterization of cropland change in China. We use GlobeLand30–a global land cover dataset with a 30 m resolution for the years 2000 and 2010–and characterize changes in TA and NP for each county as increase, stable, or decrease. This characterization shows that 703 out of 2420 counties experienced both cropland loss and increased fragmentation. The predominant cropland loss in these areas, especially in the North China Plain, is converted to artificial land. Another 212 are characterized by the opposite developments: an increase in cropland and decreased fragmentation. These counties, are mainly characterized by a conversion of forest areas and grassland areas. It suggests that the cropland conservation policy in China effectively protected the total cropland area in overall, but the consequences in terms of fragmentation might be underestimated. Counties with no obvious change in both indicators, measuring 279 counties, are mainly located in the Southeast. Our results are further compared with local level case studies: the fair consistency indicates alternatives of applying GlobeLand30 for analyzing landscape changes across scales and for cross-site comparisons.

1. Introduction

Cropland is vital for human as a producer of food, fuel, fibers, and many other ecosystem services. It is the largest use of land on the planet and it is one of the most important land cover types for society (Foley et al., 2011). Cropland is also an essential research topic for land system studies (Verburg et al., 2013) and landscape studies (Merriam, 1988), where the spatial-temporal characteristics of cropland has been assessed from local level to global level. Land system science mainly focuses on the area of cropland cover, and the existing analyses include area expansion and conversion (Döös, 2002; Tyler et al., 2015), abandonment (Schierhorn et al., 2013), displacement (Meyfroidt et al., 2010; van Vliet et al., 2017), and potential availability (Lambin et al., 2013; Eitelberg et al., 2015). Recently, more attention is given to the spatial structure of croplands in terms of farm size (Samberg et al., 2016), field size (Fritz et al., 2015) or the level of fragmentation of cropland area with other land use types (van der Zanden et al., 2013). Usually, cropland area change is often considered in the context of climate change, food security, and sustainability at a macro level (Verburg et al., 2015), while fragmentation is frequently connected with detailed placed-based ecological and social processes at a micro level, e.g. distribution, movement, and persistence of species (Forman and Godron, 1986; Turner, 1989).

In China, the spatial-temporal characteristics of cropland and their consequences, among other land cover types, have gained much attention from scientists and policy-makers. This is because Chinese cropland plays an essential role as the “rice bowl” for the country, which currently feeds 22% of the world population with only 7% of the planet's cropland resources (Ryan and Flavin, 1995). Especially since the late 1990s, the challenge to provide national food security has been amplified along with China’s unprecedented economy growth. A national level land cover mapping work suggests a net cropland loss of

---

[*] Corresponding authors at: Key Laboratory of Agricultural Remote Sensing (AGRIRS), Ministry of Agriculture/Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, China.

E-mail addresses: yuqiangyi@caas.cn, q.y.yu@vu.nl (Q. Yu), wuwenbin@caas.cn (W. Wu).

[1] Co-first author of this work.

https://doi.org/10.1016/j.jag.2017.11.002
Received 14 July 2017; Received in revised form 25 October 2017; Accepted 11 November 2017
0303-2434/

0.69 million ha from year 2000 to 2005 (Liu et al., 2010), then followed by a loss of 0.15 million ha from 2008 to 2010 (Zhang et al., 2014). Together, cropland has roughly decreased about 1.02 million ha in the first decade of the 21th century (Liu et al., 2014a). Such an area loss is believed to have large impacts on food security (Shi et al., 2013; Kong, 2014; He et al., 2017) and on other ecosystem services (Lü et al., 2012; Liu et al., 2012; Wu et al., 2013; Peng et al., 2017a). However, those assessments only included area change, without considering changes in

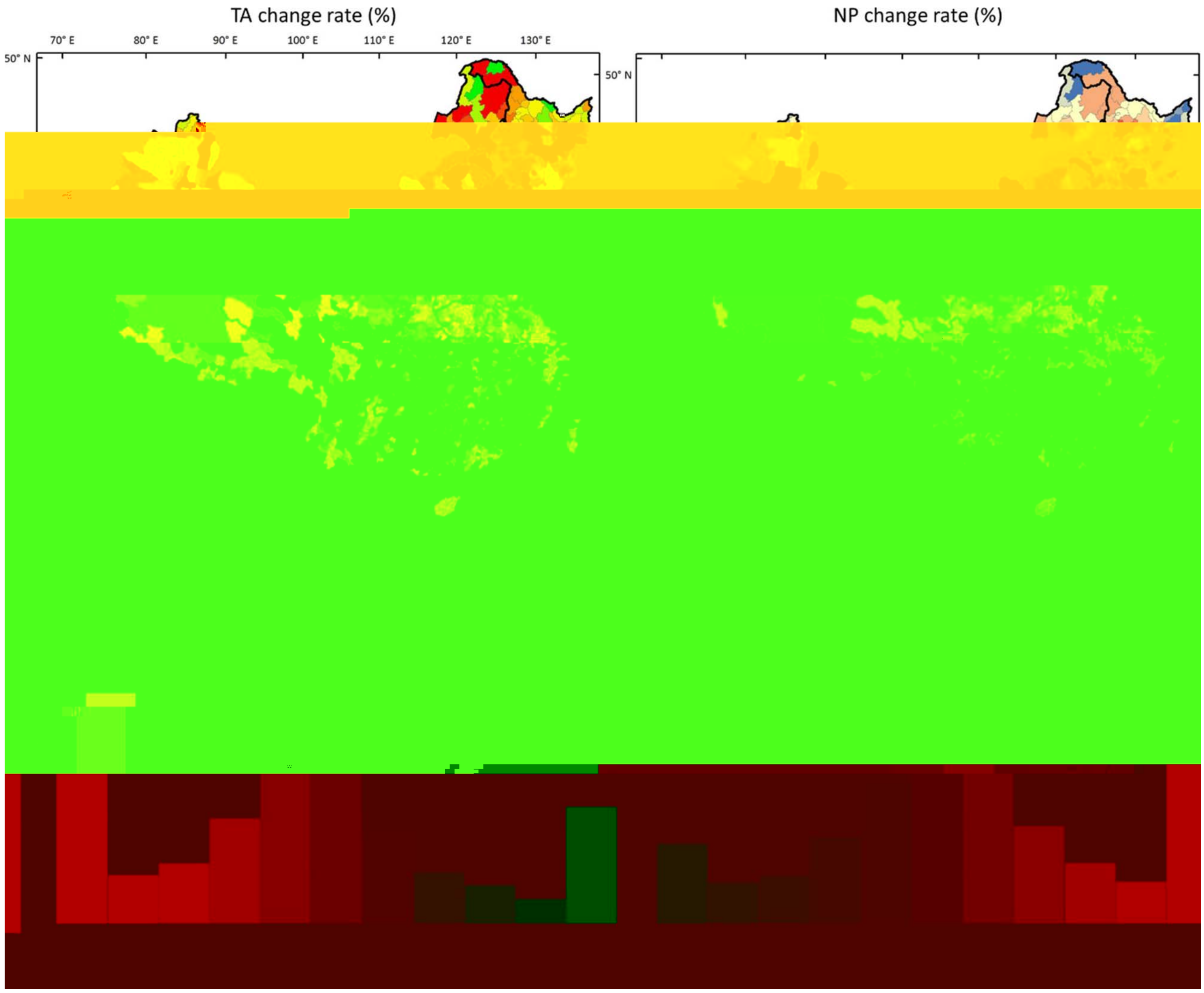

Fig. 2. Characterization of cropland change in China at a county level. The histograms of TA change rate and NP change rate are displayed in lower-left and lower-right, respectively. The spatial distributions of TA change rate and NP change rate are displayed in upper-left and upper-right, respectively. Colors in the maps correspond with the histograms, and intervals are set following the Freedman-Diaconis rule (see Section 2.2).

conversion matrices for cropland at the county level basis, quantifying the gain and loss of cropland area from/to the other land cover types. Specifically, we assess what land cover type is the largest contributor to the observed cropland change. For example, in a county that is characterized by a net cropland loss in combination with cropland fragmentation, we look for the land cover type that makes the largest gross contribution to the observed cropland loss. We further adopt such a gross area conversion as the manifestation of cropland change to the identified characterizations in terms of both TA and NP.

3. Results

3.1. Observed cropland change

The distributions of TA changes and NP changes across counties are presented in the lower part of Fig. 2. These figures show that about 25% of the total counties remain stable for either TA or NP, and that the number of counties decrease with increasing amount of change. Fig. 2 also shows that a decrease in TA predominates across counties, while an increase in NP prevails. The locations of TA changes and NP changes are illustrated in the upper part of Fig. 2. It shows that most counties located in Northern and Central China experienced a net loss in cropland, including Inner Mongolia, Hebei, Henan, Shanxi, Shaanxi, Shandong. Counties with higher NP changes are also located in the North China Plain (Hebei, Henan, Shanxi, Shandong, and the northern part of Anhui and Jiangsu), in addition to the vast territory of Inner Mongolia and Xinjiang. The spatial patterns of TA and NP in the year 2000 and 2010 are displayed in the Supplementary Information (SI).

Following the bin width estimated from the histogram-based approach, nine combinations of cropland change can be found, as presented in Section 2.2. The indicator-combining analysis suggests that the counties with TA loss and NP increase predominate in China, as 703 out of 2420 are characterized accordingly (Fig. 3). This figure further shows that cropland loss is frequently accompanied with fragmentation in China between 2000 and 2010.

Counties with TA loss and NP increase – the largest group across the whole country – are mainly located in the North China Plain, the Lower Yangtze River Basin, as well as Liaoning, Hainan, central Inner Mongolia, north Zhejiang, east Yunnan, west Guangdong. Counties with TA loss and NP decrease – the second largest group observed (313 out of 2420) – are mainly located in the South (Hunan, Yunan, and Guangxi), east Shandong, and north Jiangsu. Counties with no change in TA and NP, measuring 279 counties, are mainly located in the Southeast (Jiangsu and Fujian). Other types of cropland change are distributed more scattered throughout the country (Fig. 3).

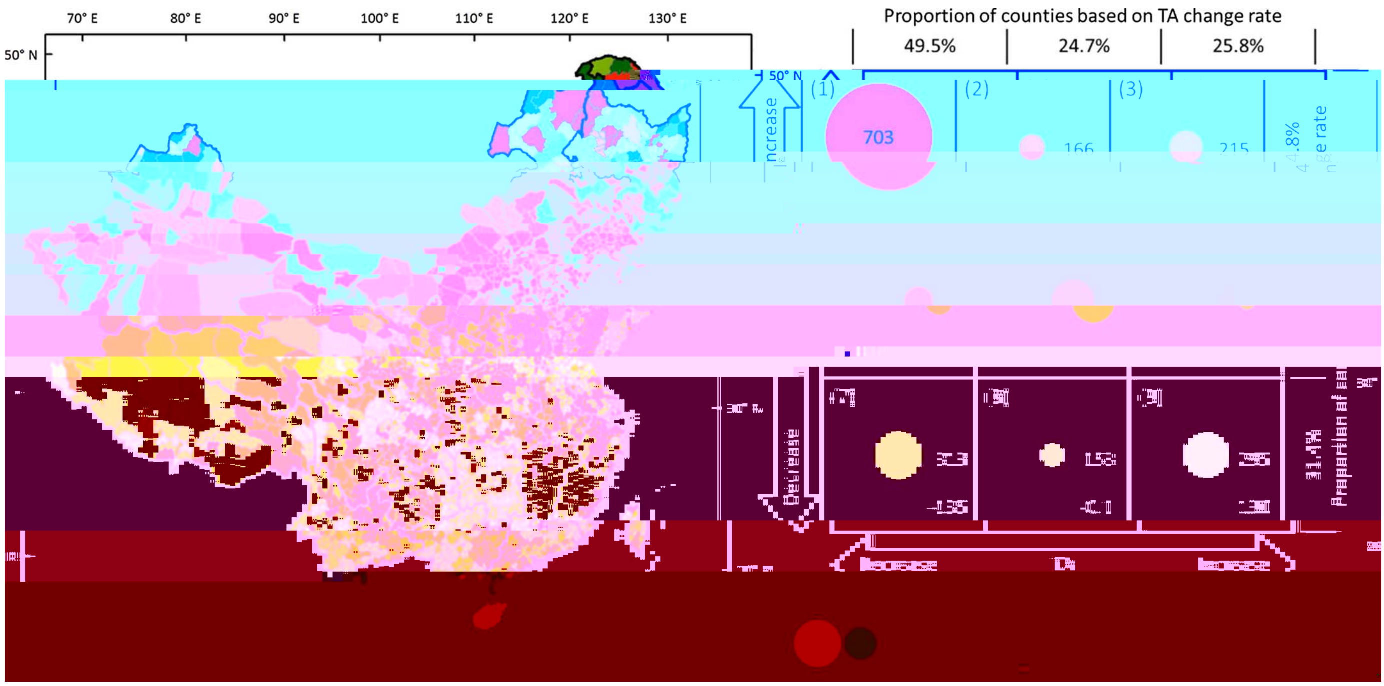

Fig. 3. Characterization of cropland change in China combining TA change rate and NP change rate. The left map presents the spatial distribution at the county-level basis, while the right figure illustrates the legend of the map as well as the statistics of the characterization results.

3.2. Manifestations of cropland change

There is much more gross change in cropland than net change, as we found a 10.5 million ha gross decrease and an 8.6 million ha gross increase between 2000 and 2010, yielding a 1.9 million ha net cropland loss. In other words, net change only accounts for 9.9% of the total gross change in cropland. The conversion matrix also indicates that cropland change is mainly related to changes in forest, grassland, water, and artificial land at the national level (Fig. 4). Fig. 5 illustrates the largest contributor of gross cropland change, in which only counties with change in both TA and NP are selected for the illustration (see Fig. 3, the corner groups).

Fig. 5 shows some clear relations between cropland change and it's manifestations: Fig. 5(1) shows that cropland fragmentation is mainly associated with artificial land development in the North China Plain, with grassland occupation in part of Inner Mongolia, Liaoning and Yunnan, and with forest occupation in Hainan province. Fig. 5(7) shows that a larger cropland loss to artificial land in parts of the North China Plain as well as southern China might yield cropland concentration, but the pattern is more scattered. It also shows that cropland loss in the West is mainly associated with increased forest and grassland. The right figures both show that a net increase in cropland is mainly related to a conversion of forest and grassland. The reclamation on grassland would more likely yield an overall cropland fragmentation in the West (Fig. 5(3)). The clearance of forests might also lead to fragmentation in some places (Fig. 5(3)), while it is related to cropland concentration elsewhere, especially in the south (Fig. 5(9)).

4. Discussion

4.1. Bridging the gap of cropland change studies across disciplines and scales

Different ways of measuring cropland change have been used across the literature. Net area changes of cropland, as well as other land uses, are used most often. Such a simple indicator has been used, for

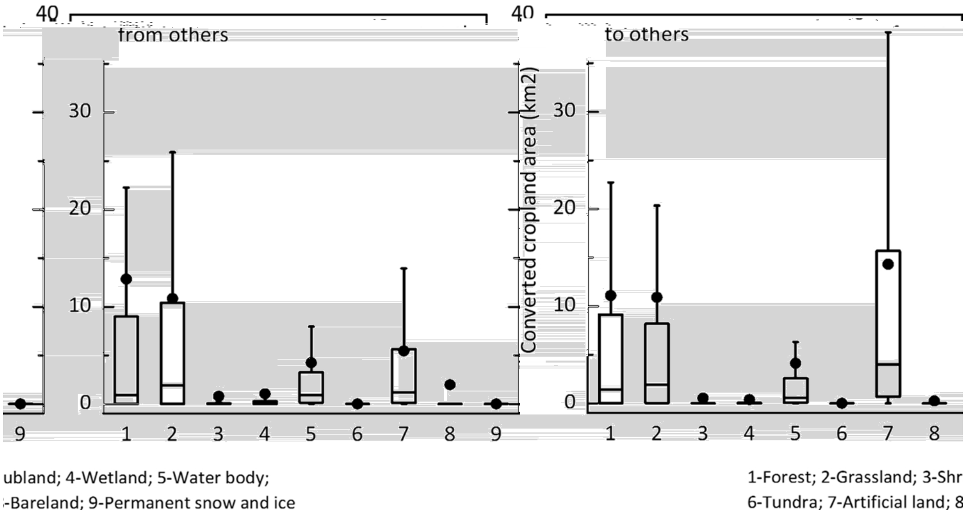

Fig. 4. Landscape conversions representing cropland loss (left) and gain (right) to/from other land cover types. The figure is plotted based on county level values. The boxes indicate the 25%–75% percentile, the winkles indicate the 5%–95% percentile, the lines with in the boxes indicate the median, and the dots indicate the average values of each land cover type. The values out of the 5%–95% percentile scope might not be presented in the figures.

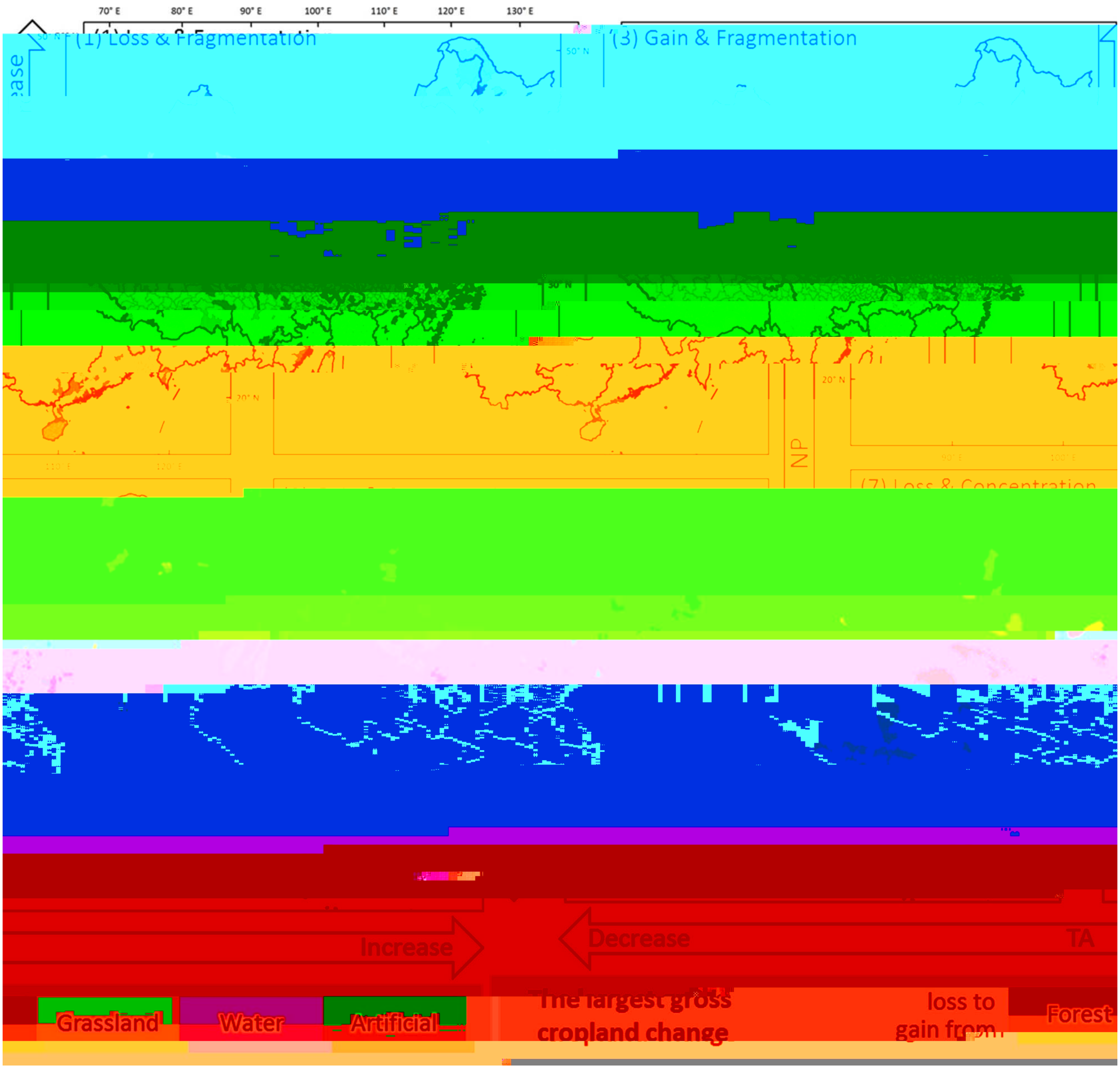

Fig. 5. Manifestations of cropland change, characterized by the largest gross change to the identified characterizations in terms of both total area and number of patches. Different colors indicate different land covers converted from or to cropland. Darker colors indicate gross cropland loss while lighter colors mean gross cropland gain. Only the counties with change in both TA and NP are displayed (see Figs. 1 and 3).

example, in economic models to indicate the resource capacity of agricultural sector (Schmitz et al., 2014), and in earth system models to measure the land use impacts on global climate (Deng et al., 2013). Recent work by Fuchs et al. (2015) and Pongratz et al. (2014) has shown the importance for accounting for gross changes of land use rather than only focusing on net change. However, there are few studies that, across larger spatial scales, assess the spatial structure of cropland. Even the mosaic representation of land systems are typically based on land cover compositions (including the fraction of cropland), rather than the landscape pattern (van Vliet et al., 2017). In our study, we have combined these different indices of change in studying cropland change in China, and we confirmed the hypothesis that more gross changes might only result in a limited net change, but it is associated with a much larger change in landscape pattern.

Cropland fragmentation is context-, and scale-dependent. For example, the physical, social, and operational fragmentation have been conceptualized for different research disciplines, which focused on non-contiguous land parcels, scattered and downsized ownership, and mismatch between different scale of holdings and recourse accessibilities respectively (King and Burton, 1982; Sabates-Wheeler, 2002). The measurements are different from each other as well. For example, the physical fragmentation is mostly presented in a spatially explicit way based on fine resolution remotely-sensed images (Baldi et al., 2006; Su et al., 2014; Cheng et al., 2015). While socioeconomic data such as census and cadaster are frequently used for describing ownership fragmentation, e.g. using per capital cropland as an indicator (Tan et al., 2006; Deininger et al., 2012). Although the physical, social, and operational fragmentation might be related to each other, there are few studies that combine these aspects together, due to the lack of a human-land integrated observing system (Yu et al., 2017). Complicating factor is the high scale-dependence of fragmentation because “landscape” is not a geographically precise unit of measurement (Meentemeyer and Box, 1987). Therefore, cropland fragmentation can be understood at pixel, plots/households, village, and district levels, which are

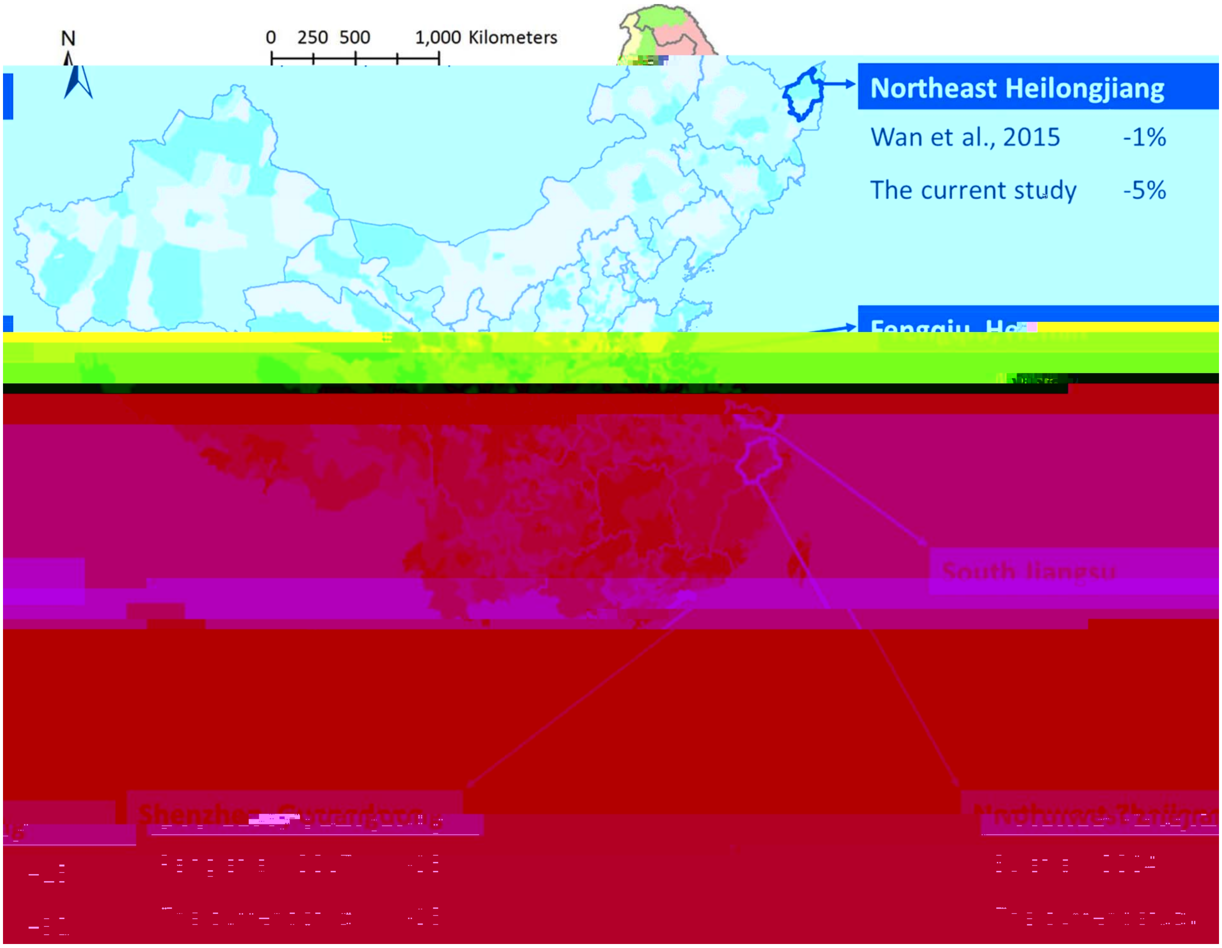

Fig. 6. Comparison of NP change rate with five relevant local scale case studies (highlighted out in tables); and spatial distribution of the classification of mean patch size change at the county-level basis, with thresholds set according to the histogram-based approach (see Section 2.2).

underpinned by different processes and would have different consequences on crop production, biodiversity and biomass (Müller and Munroe, 2008).

Our study bridges the gaps of cropland change studies cross disciplines and scales. First, its purpose fits land system science that is to observe and explain the changes of cropland cover, while an extra landscape indicator is used in addition to the widely-used indicator (i.e. total area) for improving the characterization, and the net area changes are disentangled to larger gross area changes for better manifesting the characterization. Second, unlike the traditional socioeconomic studies, our study explores the physical fragmentation at the land cover level. Therefore, the applied data and the meaning behind are totally different from those ownership fragmentation studies. A comparison using the current results as proxy against other fragmentation studies would thus be interesting. Third, in contrast to existing studies which have preliminarily examined cropland fragmentation at small scales, e.g. Peng et al. (2017b), Fan and Ding (2016), Wan et al. (2015), Cheng et al. (2015) and Su et al. (2014), we provide a national level overview. Fig. 6 shows the comparison of NP change rate with these five relevant case studies. It suggests that the global datasets are fairly consistent with local case studies and thus allow capturing the detailed landscape characteristics, and cross country/region comparisons as well. Moreover, most of the existing studies investigated the landscape indices independently, our study characterizes cropland change in both terms of area and structure. It is believed that integrating landscape characteristics would deepen our understanding of the geographies of agricultural land use change (Wadduwage et al., 2017).

4.2. Implications and limitations

We measure cropland fragmentation as an aspect of land change processes complementary to the well-documented area change, and reveal how changes in land cover and landscape pattern interact with each other. Our results suggest a strong trend of cropland fragmentation associated with a relatively small area loss. These findings are partly supported by the smaller scales studies, e.g. Cheng et al. (2015) and Su et al. (2014). The predominant trend of cropland loss and fragmentation lead to a decreased mean patch size in many counties across China (Fig. 6), and the average county level mean cropland patch size decreased by 28.1%, against to a sharp increase of mean patch size of urban land, see Fang et al. (2016).

We find that the expansion of artificial land is the most significant contributor for both cropland loss and fragmentation (Fig. 5(1)) in the flat and productive North China Plain, indicating the current urbanization process may take place at the cost of cropland, and further fragment the concentrated cropland patches into smaller pieces. This is in correspondence with the existing studies that show that urban land is often taken from primary cropland (Xu et al., 2016), and that the fragmentation due to urbanization might be further accelerated by peri-urbanization (van Vliet et al., 2017), i.e. the landscape interface between town and country where cropland and artificial land are interwoven. On the other hand, the net cropland increase is mainly related to conversion of grassland and forest in the Northeast, Northwest and South. This suggests that the national level cropland “increasing vs. decreasing balance” policy inevitably makes infringements into the more conserved ecosystems, in order to balance the noticeable cropland loss in the more fertile regions. While it should also be noted that some counties in the West and South China have witnessed cropland loss associated with forest and grassland regrowth, and cropland becomes more concentrated overall (Fig. 5(7)). This suggests that the ecological restoration programs (known as “Grain for Green”) might have successfully converted the marginal cropland, thus decreased the number of cropland patches (Wang et al., 2017). However, it should be noted that while our analysis established clear relations, it does not reveal the causal mechanisms underlying these relations. Such analysis would require an assessment of biophysical and socioeconomic conditions in the processes of cropland fragmentation cross scales, e.g. in those hotspot areas.

Our study adopts NP for measuring the changes in landscape pattern. A large number of other indices have been developed to measure landscape fragmentation, including patch density, cohesion index, splitting index, effective mesh size, normalized landscape shape index, perimeter area ratio distribution and aggregation index, etc., in addition to TA and NP, see Jaeger (2000), Li and Wu (2004), and Uuemaa et al. (2009). However, comparisons show that different landscape metrics are often strongly correlated (Riitters et al., 1995; Peng et al., 2010; Plexida et al., 2014), justifying a selection rather than an inclusion of all metrics for the assessment of cropland changes. Hence, while NP might not cover all aspects of fragmentation, we believe it is a meaningful indicator for such a large-scale analysis, especially when it is used along with TA: one controls the total amount, the other reflects the discreteness. Adding additional metrics wouldast,n,

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jag.2017.11.002.

References

Baldi, G., Guerschman, J.P., Paruelo, J.M., 2006. Characterizing fragmentation in temperate South America grasslands. Agric. Ecosyst. Environ. 116, 197–208.

Chen, J., Ban, Y., Li, S., 2014. China: open access to Earth land-cover map. Nature 514 434-434.

Chen, J., Chen, J., Liao, A., Cao, X., Chen, L., Chen, X., He, C., Han, G., Peng, S., Lu, M., Zhang, W., Tong, X., Mills, J., 2015. Global land cover mapping at 30 m resolution: a POK-based operational approach. ISPRS J. Photogramm. Remote Sens. 103, 7–27.

Cheng, L., Xia, N., Jiang, P., Zhong, L., Pian, Y., Duan, Y., Huang, Q., Li, M., 2015. Analysis of farmland fragmentation in China modernization demonstration zone since reform and openness: a case study of south Jiangsu province. Sci. Rep. 5, 11797.

Döös, B.R., 2002. Population growth and loss of arable land. Global Environ. Change 12, 303–311.

Deininger, K., Savastano, S., Carletto, C., 2012. Land fragmentation, cropland abandonment, and land market operation in Albania. World Dev. 40, 2108–2122.

Deng, X., Zhao, C., Yan, H., 2013. Systematic modeling of impacts of land use and land cover changes on regional climate: a review. Adv. Meteorol. 2013, 11.

Dewan, A.M., Yamaguchi, Y., Ziaur Rahman, M., 2012. Dynamics of land use/cover changes and the analysis of landscape fragmentation in Dhaka metropolitan, Bangladesh. GeoJournal 77, 315–330.

Eitelberg, D.A., van Vliet, J., Verburg, P.H., 2015. A review of global potentially available cropland estimates and their consequences for model-based assessments. Glob. Change Biol. 21, 1236–1248.

Fan, Q., Ding, S., 2016. Landscape pattern changes at a county scale: a case study in Fengqiu, Henan province, China from 1990 to 2013. CATENA 137, 152–160.

Fang, C., Li, G., Wang, S., 2016. Changing and differentiated urban landscape in China: spatiotemporal patterns and driving forces. Environ. Sci. Technol. 50, 2217–2227.

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O/'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockstrom, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D.P.M., 2011. Solutions for a cultivated planet. Nature 478, 337–342.

Forman, R.T.T., Godron, M., 1986. Landscape Ecology. John Wiley & Sons, New York.

Freedman, D., Diaconis, P., 1981. On the histogram as a density estimator: l2 theory. Probab. Theory Relat. Fields 57, 453–476.

Fritz, S., See, L., McCallum, I., You, L., Bun, A., Moltchanova, E., Duerauer, M., Albrecht, F., Schill, C., Perger, C., Havlik, P., Mosnier, A., Thornton, P., Wood-Sichra, U., Herrero, M., Becker-Reshef, I., Justice, C., Hansen, M., Gong, P., Abdel Aziz, S., Cipriani, A., Cumani, R., Cecchi, G., Conchedda, G., Ferreira, S., Gomez, A., Haffani, M., Kayitakire, F., Malanding, J., Mueller, R., Newby, T., Nonguierma, A., Olusegun, A., Ortner, S., Rajak, D.R., Rocha, J., Schepaschenko, D., Schepaschenko, M., Terekhov, A., Tiangwa, A., Vancutsem, C., Vintrou, E., Wenbin, W., van der Velde, M., Dunwoody, A., Kraxner, F., Obersteiner, M., 2015. Mapping global cropland and field size. Glob. Change Biol. 21, 1980–1992.

Fuchs, R., Herold, M., Verburg, P.H., Clevers, J.G.P.W., Eberle, J., 2015. Gross changes in reconstructions of historic land cover/use for Europe between 1900 and 2010. Glob. Change Biol. 21, 299–313.

Han, G., Chen, J., He, C., Li, S., Wu, H., Liao, A., Peng, S., 2015. A web-based system for supporting global land cover data production. ISPRS J. Photogramm. Remote Sens. 103, 66–80.

He, C., Liu, Z., Xu, M., Ma, Q., Dou, Y., 2017. Urban expansion brought stress to food security in China: evidence from decreased cropland net primary productivity. Sci. Total Environ. 576, 660–670.

Huang, Q., Li, M., Chen, Z., Li, F., 2011. Land consolidation: an approach for sustainable development in rural China. AMBIO 40, 93–95.

Jaeger, J.A.G., 2000. Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation. Landsc. Ecol. 15, 115–130.

King, R., Burton, S., 1982. Land fragmentation: notes on a fundamental rural spatial problem. Prog. Geogr. 6, 475–494.

Kong, X., 2014. China must protect high-quality arable land. Nature 506, 7.

Lü, Y., Fu, B., Feng, X., Zeng, Y., Liu, Y., Chang, R., Sun, G., Wu, B., 2012. A policy-driven large scale ecological restoration: quantifying ecosystem services changes in the loess plateau of China. PLoS One 7, e31782.

Lambin, E.F., Gibbs, H.K., Ferreira, L., Grau, R., Mayaux, P., Meyfroidt, P., Morton, D.C., Rudel, T.K., Gasparri, I., Munger, J., 2013. Estimating the world's potentially available cropland using a bottom-up approach. Glob. Environ. Change 23, 892–901.

Li, H., Wu, J., 2004. Use and misuse of landscape indices. Landsc. Ecol. 19, 389–399.

Li, Y., Liu, Y., Long, H., Cui, W., 2014. Community-based rural residential land consolidation and allocation can help to revitalize hollowed villages in traditional agricultural areas of China: evidence from Dancheng county, Henan province. Land Use Policy 39, 188–198.

Liu, J., Liu, M., Tian, H., Zhuang, D., Zhang, Z., Zhang, W., Tang, X., Deng, X., 2005. Spatial and temporal patterns of China's cropland during 1990–2000: an analysis based on Landsat TM data. Remote Sens. Environ. 98, 442–456.

Liu, J., Zhang, Z., Xu, X., Kuang, W., Zhou, W., Zhang, S., Li, R., Yan, C., Yu, D., Wu, S., Jiang, N., 2010. Spatial patterns and driving forces of land use change in China during the early 21st century. J. Geogr. Sci. 20, 483–494.

Liu, Y., Li, J., Zhang, H., 2012. An ecosystem service valuation of land use change in Taiyuan city, China. Ecol. Modell. 225, 127–132.

Liu, J., Kuang, W., Zhang, Z., Xu, X., Qin, Y., Ning, J., Zhou, W., Zhang, S., Li, R., Yan, C., Wu, S., Shi, X., Jiang, N., Yu, D., Pan, X., Chi, W., 2014a. Spatiotemporal characteristics, patterns, and causes of land-use changes in China since the late 1980. J. Geogr. Sci. 24, 195–210.

Liu, Y., Fang, F., Li, Y., 2014b. Key issues of land use in China and implications for policy making. Land Use Policy 40, 6–12.

Liu, Z., Müller, M., Rommel, J., Feng, S., 2016. Community-based agricultural land consolidation and local elites: survey evidence from China. J. Rural Stud. 47, 449–458.

Long, H., Li, Y., Liu, Y., Woods, M., Zou, J., 2012. Accelerated restructuring in rural China fueled by ‘increasing vs. decreasing balance’ land-use policy for dealing with hollowed villages. Land Use Policy 29, 11–22.

Müller, D., Munroe, D.K., 2008. Changing rural landscapes in Albania: cropland abandonment and forest clearing in the postsocialist transition. Ann. Assoc. Am. Geogr. 98, 855–876.

McGarigal, K., Marks, B.J., 1995. FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure.

Meentemeyer, V., Box, E.O., 1987. Scale effects in landscape studies. In: Turner, M.G. (Ed.), Landscape Heterogeneity and Disturbance. Springer New York, New York, NY, pp. 15–34.

Merriam, G., 1988. Landscape dynamics in farmland. Trends Ecol. Evol. 3, 16–20.

Meyfroidt, P., Rudel, T.K., Lambin, E.F., 2010. Forest transitions, trade, and the global displacement of land use. Proc. Natl. Acad. Sci. U. S. A. 107, 20917–20922.

Nagendra, H., Munroe, D.K., Southworth, J., 2004. From pattern to process: landscape fragmentation and the analysis of land use/land cover change. Agric. Ecosyst. Environ. 101, 111–115.

Peng, J., Wang, Y., Zhang, Y., Wu, J., Li, W., Li, Y., 2010. Evaluating the effectiveness of landscape metrics in quantifying spatial patterns. Ecol. Indic. 10, 217–223.

Peng, J., Liu, Y., Liu, Z., Yang, Y., 2017a. Mapping spatial non-stationarity of human-natural factors associated with agricultural landscape multifunctionality in Beijing–Tianjin–Hebei region, China. Agric. Ecosyst. Environ. 246, 221–233.

Peng, J., Zhao, M., Guo, X., Pan, Y., Liu, Y., 2017b. Spatial-temporal dynamics and associated driving forces of urban ecological land: a case study in Shenzhen city, China. Habitat Int. 60, 81–90.

Plexida, S.G., Sfougaris, A.I., Ispikoudis, I.P., Papanastasis, V.P., 2014. Selecting landscape metrics as indicators of spatial heterogeneity—a comparison among Greek landscapes. Int. J. Appl. Earth Obs. Geoinf. 26, 26–35.

Pongratz, J., Reick, C.H., Houghton, R.A., House, J.I., 2014. Terminology as a key uncertainty in net land use and land cover change carbon flux estimates. Earth Syst. Dynam. 5, 177–195.

Pontius, R.G., Shusas, E., McEachern, M., 2004. Detecting important categorical land changes while accounting for persistence. Agric. Ecosyst. Environ. 101, 251–268.

Riitters, K.H., O'Neill, R.V., Hunsaker, C.T., Wickham, J.D., Yankee, D.H., Timmins, S.P., Jones, K.B., Jackson, B.L., 1995. A factor analysis of landscape pattern and structure metrics. Landsc. Ecol. 10, 23–39.

Ryan, M., Flavin, C., 1995. Facing China's limits. In: Brown, L.R. (Ed.), State of the World 1995: A Worldwatch Institute Report on Progress Toward a Sustainable Society. W.W. Norton, New York, pp. 113–131.

Sabates-Wheeler, R., 2002. Consolidation initiatives after land reform: responses to multiple dimensions of land fragmentation in Eastern European agriculture. J. Int. Dev. 14, 1005–1018.

Samberg, L.H., Gerber, J.S., Ramankutty, N., Herrero, M., West, P.C., 2016. Subnational distribution of average farm size and smallholder contributions to global food production. Environ. Res. Lett. 11, 124010.

Schierhorn, F., Müller, D., Beringer, T., Prishchepov, A.V., Kuemmerle, T., Balmann, A., 2013. Post-Soviet cropland abandonment and carbon sequestration in European Russia, Ukraine, and Belarus. Glob. Biogeochem. Cycles 27, 1175–1185.

Schmitz, C., van Meijl, H., Kyle, P., Nelson, G.C., Fujimori, S., Gurgel, A., Havlik, P., Heyhoe, E., d'Croz, D.M., Popp, A., Sands, R., Tabeau, A., van der Mensbrugghe, D., von Lampe, M., Wise, M., Blanc, E., Hasegawa, T., Kavallari, A., Valin, H., 2014. Land-use change trajectories up to 2050: insights from a global agro-economic model comparison. Agric. Econ. 45, 69–84.

Shi, W., Tao, F., Liu, J., 2013. Changes in quantity and quality of cropland and the implications for grain production in the Huang-Huai-Hai Plain of China. Food Sec. 5, 69–82.

Su, S., Hu Y. n. Luo, F., Mai, G., Wang, Y., 2014. Farmland fragmentation due to anthropogenic activity in rapidly developing region. Agric. Syst. 131, 87–93.

Tan, S., Heerink, N., Qu, F., 2006. Land fragmentation and its driving forces in China. Land Use Policy 23, 272–285.

Tang, X., Pan, Y., Liu, Y., 2017. Analysis and demonstration of investment implementation model and paths for China's cultivated land consolidation. Appl. Geogr. 82, 24–34.

Taylor, P.D., Fahrig, L., Henein, K., Merriam, G., 1993. Connectivity is a vital element of landscape structure. Oikos 68, 571–573.

Turner, M.G., 1989. Landscape ecology – the effect of pattern on process. Annu. Rev. Ecol. Syst. 20, 171–197.

Tyler, J.L., Salmon, J.M., Holly, K.G., 2015. Cropland expansion outpaces agricultural and biofuel policies in the United States. Environ. Res. Lett. 10, 044003.

Uuemaa, E., Antrop, M., Roosaare, J., Marja, R., Mander, U., 2009. Landscape metrics and indices: an overview of their use in landscape research. Living Rev. Landsc. Res. 3, 1–28.

van der Zanden, E.H., Verburg, P.H., Mücher, C.A., 2013. Modelling the spatial distribution of linear landscape elements in Europe. Ecol. Indic. 27, 125–136.

van Vliet, J., de Groot, H.L.F., Rietveld, P., Verburg, P.H., 2015. Manifestations and underlying drivers of agricultural land use change in Europe. Landsc. Urban Plann. 133, 24–36.

van Vliet, J., Eitelberg, D.A., Verburg, P.H., 2017. A global analysis of land take in cropland areas and production displacement from urbanization. Glob. Environ. Change 43, 107–115.

Verburg, P.H., Mertz, O., Erb, K.-H., Haberl, H., Wu, W., 2013. Land system change and food security: towards multi-scale land system solutions. Curr. Opin. Environ. Sustain. 5, 494–502.

Verburg, P.H., Crossman, N., Ellis, E.C., Heinimann, A., Hostert, P., Mertz, O., Nagendra, H., Sikor, T., Erb, K.-H., Golubiewski, N., Grau, R., Grove, M., Konaté, S., Meyfroidt, P., Parker, D.C., Chowdhury, R.R., Shibata, H., Thomson, A., Zhen, L., 2015. Land system science and sustainable development of the earth system: a global land project perspective. Anthropocene 12, 29–41.

Wadduwage, S., Millington, A., Crossman, N.D., Sandhu, H., 2017. Agricultural land fragmentation at urban fringes: an application of urban-to-rural gradient analysis in Adelaide. Land 6, 28.

Wan, L., Zhang, Y., Zhang, X., Qi, S., Na, X., 2015. Comparison of land use/land cover change and landscape patterns in Honghe National Nature Reserve and the surrounding Jiansanjiang region, China. Ecol. Indic. 51, 205–214.

Wang, J., Peng, J., Zhao, M., Liu, Y., Chen, Y., 2017. Significant trade-off for the impact of grain-for-green programme on ecosystem services in north-western Yunnan, China. Sci. Total Environ. 574, 57–64.

Wu, K., Ye, X., Qi, Z., Zhang, H., 2013. Impacts of land use/land cover change and socioeconomic development on regional ecosystem services: the case of fast-growing Hangzhou metropolitan area, China. Cities 31, 276–284.

Wu, W., Yu, Q., Verburg, P.H., You, L., Yang, P., Tang, H., 2014. How could agricultural land systems contribute to raise food production under global change? J. Integr. Agric. 13, 1432–1442.

Xu, M., He, C., Liu, Z., Dou, Y., 2016. How did urban land expand in China between 1992 and 2015? A multi-scale landscape analysis. PLoS One 11, e0154839.

Yu, Q., Shi, Y., Tang, H., Yang, P., Xie, A., Liu, B., Wu, W., 2017. eFarm: a tool for better observing agricultural land systems. Sensors 17, 453.

Zhang, Z., Wang, X., Zhao, X., Liu, B., Yi, L., Zuo, L., Wen, Q., Liu, F., Xu, J., Hu, S., 2014. A 2010 update of national land use/cover database of China at 1:100000 scale using medium spatial resolution satellite images. Remote Sens. Environ. 149, 142–154.