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GlobeLand30 maps show four times larger gross than net land change from 2000 to 2010 in Asia

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ABSTRACT

This article uses the GlobeLand30 maps of land cover to characterize the difference between years 2000 and 2010 in Asia. Methods of Intensity Analysis and Difference Components dissect the transition matrix for nine categories: Barren, Grass, Cultivated, Forest, Shrub, Water, Artificial, Wetland and Ice. Results show that Barren, Grass, Cultivated, and Forest each account for more than 21% of Asia at both 2000 and 2010, while transitions among those four categories account for more than half of the temporal difference. Nearly ten percent of Asia shows overall temporal difference, which is the sum of three components: quantity, exchange and shift. Quantity accounts for less than a quarter of the temporal difference, while exchange accounts for three quarters of the temporal difference. The largest quantity components at the category level are a net gain of Barren and net losses of Grass and Shrub. Shrub demonstrates the most intensive loss and gain relative to a category's size. The largest and most intensive transitions to Barren are from Grass and Shrub. The largest and most intensive transition to Artificial is from Cultivated. Error information is not available for GlobeLand30 concerning 2000 or temporal change, but a confusion matrix is available for the global extent at 2010. This article applies methods to interpret the difference between two time points when a confusion matrix is available for only the latter time point. If the 2010 global confusion matrix reflects errors in Asia, then such errors could help to explain some of the gross gain of Barren and the counter-intuitive loss of Artificial. If the GlobeLand30 data indicate true change, then gross change in Asia is 4.4 times larger than net change.

1. Introduction

Land change affects a wide spectrum of issues such as biodiversity, climate, economy, and health (Foley et al., 2005). Zhao et al. (2006) report that "Asia is one of the priority regions with respect to studies related to the global environment, land use and climate change. One of the main reasons for concern is the dramatic transformations in land use that have occurred". Several studies have investigated land change in parts of Asia (Fox and Vogler, 2005; Chen et al., 2013; Shafizadeh-Moghadam and Helbich, 2013; Galletti et al., 2016; Minaei and Kainz, 2016). The purpose of our article is to assess land change for all of Asia using data that have become recently available.

Numerous datasets monitor land change with various spatial and temporal resolutions. Grekousis et al. (2015) compared the characteristics, limitations, and uncertainties of 23 global and 41 regional land cover products. Their study showed that the finest spatial resolution datasets at the global extent are FROM-GLC (Yu et al., 2014) and GlobeLand30 (Chen et al., 2015). The Chinese National Administration of Surveying, Mapping, and Geoinformation created GlobeLand30 and made it available for free. GlobeLand30 shows land cover at the years 2000 and 2010.

Chen et al. (2015) report that GlobeLand30 has an overall accuracy of 79.3% area-weighted and 80.3% unweighted at the year 2010 and no accuracy assessment at 2000. The same article states "the overall accuracy presented in GlobeLand30 in the year of 2010 is better than 80%" and "From such results, it might be concluded that GlobeLand30 is a reliable product for a number of various applications." Their article does not specify whether temporal change detection might be one of those applications. A researcher must consider a particular application to decide whether data that have unknown error at 2000 and 20% error at 2010 are reliable for the particular application. If the percentage error at 2000 and/or 2010 is greater than the percentage difference

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between the maps at 2000 and 2010, then one naturally wonders whether the data are reliable to estimate change between 2000 and 2010. GlobeLand30's 20% error at 2010 does not necessarily imply that the GlobeLand30 is unreliable for the analysis of change from 2000 to 2010, because error at individual time points does not imply error of change between the time points. If a pixel has the same type of classification error at both time points, then the pixel could show persistence of the wrong category, but would still show absence of change correctly. Furthermore, one should consider the research question with respect to the components of error. The quantity component reflects the sizes of the categories and ignores the allocation of the categories. A classification has zero quantity error when the size of commission error for a category in some pixels is identical to the size of omission error for the same category in other pixels. Thus quantity error might be negligible even when overall error is substantial.

Furthermore, researchers should consider the components of error with respect to the components of temporal change. The quantity component of change measures net changes in the sizes of the categories between the time points. Other components of change measure changes that derive from simultaneous gross loss of a category in some locations and an identical size of gross gain of the same category in other locations, which combine to form zero net change. For example, Jokar Arsanjani (2018) used GlobeLand30 to estimate changes in the quantity of each category, and did not estimate the additional components that contribute to gross change. If the quantity components of error in GlobeLand30 were negligible, then the approach by Jokar Arsanjani (2018) would be appropriate to estimate quantity change, even when the maps at both time points have substantial total error. However, a measurement of only quantity change can miss most of the gross change.

To understand gross change, Aldwaik and Pontius, (2012) introduced Intensity Analysis, which dissects a time interval's transition matrix to compute sizes and intensities of gross change, losses, gains and transitions. Intensity Analysis has three levels. First is the interval level, which measures overall gross change during the time interval. Second is the category level, which measures the size and intensity of the gross loss and gross gain of each category. Third is the transition level, which measures the size and intensity of how each individual category transitions from other categories. To complement Intensity Analysis, Pontius and Santacruz (2014) introduced Difference Components, which separates gross difference into three components: quantity, exchange and shift. The quantity component measures the net difference in the size of the categories. The exchange component measures the difference when the transition from category i to category j at some locations occurs simultaneously with the same size of transition from category j to category i at other locations. The shift component is gross difference minus the quantity and exchange components. Exchange and Shift contribute to gross change but not to quantity change. Pontius (2019) showed how to compute the intensities of the three components.

This article illustrates how to apply methods to interpret temporal difference between two time points for the situation when a confusion matrix is available for only the latter time point, which is a common situation when using remotely sensed data to characterize change over long time intervals. Our specific objective is to apply Intensity Analysis and Difference Components to the GlobeLand30 maps to quantify the sizes, intensities and components of difference between 2000 and 2010 in Asia. We apply the two methods to analyze also GlobeLand30's confusion matrix at 2010 in order to see how map errors could influence the interpretation of temporal differences.

2. Materials and methods

2.1. Materials

Fig. 1 shows the spatial extent for our definition of Asia, stratified into five regions. Northwest Asia consists of Kazakhstan, Uzbekistan, Tajikistan, Turkmenistan and Kyrgyzstan. East Asia consists of Mainland China, Hong Kong, Macau, North Korea, South Korea, Japan, Taiwan, and Mongolia. South Asia consists of Afghanistan, Pakistan, India, Maldives, Sri Lanka, Nepal, Bhutan, and Bangladesh. Southeast Asia consists of Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, The Philippines, Singapore, Thailand, Timor-Leste, and Vietnam. West Asia consists of Armenia, Azerbaijan, Bahrain, Georgia, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, Turkey, United Arab Emirates, and Yemen. Our study excludes Russia because Russia is a Eurasian country. The boundary of countries was downloaded from thematicmapping.org. East accounts for 37% of Asia, West for 20%, South for 16%, Southeast for 15% and Northwest for 13%.

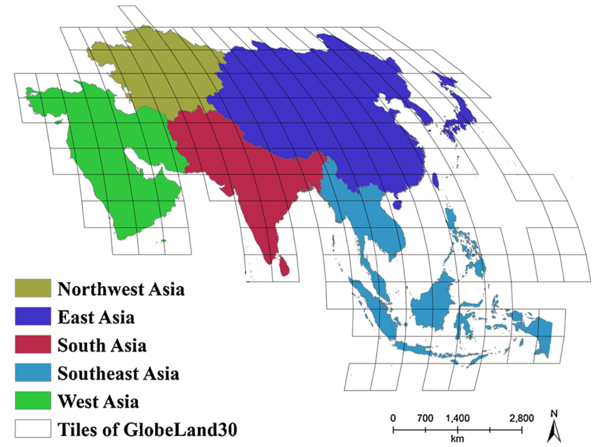

Fig. 1. Study area superimposed on tiles of GlobeLand30.

We extracted land cover data from GlobeLand30, which is based on Landsat imagery processed by a hybrid pixel and object-based method. Each time point is composed of 187 tiles that were downloaded from www.globallandcover.com. The GlobeLand30 tiles are available in the Universal Transverse Mercator projection, which is not an equal area projection. We mosaicked the tiles and reprojected them to the Mollweide projection, which is an equal-area projection. ArcGIS model builder computed the transition matrices, then a program in R confirmed the results. The creators of GlobeLand30 collected 154,070 reference samples to assess accuracy at 2010. We analyzed their confusion matrix at 2010, which is available from National Geomatics Center of China (2014). Table 1 defines the categories (Chen et al., 2017). Fig. 2 shows nine land categories at 2000 and 2010, along with the categories' losses and gains during 2000–2010.

2.2. Methods

A map overlay of 2000 on 2010 yields the transition matrix in Table 2. This matrix serves as the input for the equations. The first step is to convert Table 2 from thousand square kilometers to percentage of the spatial extent, by dividing by 30,928 then multiplying by 100%. The equations then analyze the resulting areas in term of percentage of the spatial extent. We analyze also a transition matrix identical in format to Table 2 for each of the five regions. Pontius (2019) gives the derivation of Eqs. (1)–(14). Lowercase i and lowercase j are indices that denote specific categories. Uppercase J is the number of categories, which equals nine for Asia. Eq. (1) expresses change for category j as the sum of the category's gross gain and gross loss. Eq. (2) gives the quantity component for category j, which is the absolute value of net change for category j. The quantity component measures the change in the size of category j, while the exchange and shift components do not reflect changes in the size of category j. Eq. (3) expresses the exchange component for category j. Exchange occurs for category j when the area

Table 1
Definitions of land categories.

Category	GlobLand30 Description
Barren	Vegetation cover less than 10% consisting of deserts, sandy fields, bare rocks, saline and alkaline lands.
Grass	Natural grass with greater than 10% cover.
Cultivated	Agriculture, horticulture and gardens covering paddy fields, irrigated and dry farmlands, vegetable and fruit gardens.
Forest	Trees with greater than 30% vegetation cover including deciduous and coniferous forests, and sparse woodlands with 10 - 30% cover.
Shrub	Shrub with greater than 30% cover containing deciduous and evergreen shrub, and desert steppe with greater than 10% cover.
Water	Water bodies surrounded by land including rivers, lakes, reservoirs and fish ponds.
Artificial	Lands altered by human activities comprising a full range of habitation, industrial and mining areas, transportation facilities and interior urban green zones and water bodies.
Wetland	Wetland plants and water bodies covering inland marshes, lake marshes, river floodplain wetlands, forest/shrub wetlands, peat bogs, mangroves and salt marshes.
Ice	Ice and Snow

of transition from category *i* to *j* is paired with an equal area of transition from *j* to *i* for $i \neq j$. Eq. (4) expresses shift for category *j* as the remainder when the quantity and exchange components are subtracted from the gross change. Eqs. (5)–(7) compute components for change overall in Asia as the sum of the components for category *j* divided by two. Division by two is necessary because each change involves two categories, i.e. the losing category and the gaining category. Eq. (8) expresses change overall as the sum of its three components. Eqs. (9)–(11) express the intensity of each of the three components of change overall. The three intensities in Eqs. (9)–(11) sum to one.

$$Change_j = Gain_j + Loss_j \quad (1)$$

$$Quantity_j = |Gain_j - Loss_j| \quad (2)$$

$$Exchange_j = 2\left\{\left[\sum_{i=1}^{J} MINIMUM\,(Transition_{ij},\ Transition_{ji})\right] - Persistence_j\right\} \quad (3)$$

$$Shift_j = Change_j - Quantity_j - Exchange_j \quad (4)$$

$$Quantity\ Overall = \sum_{j=1}^{J} Quantity_j/2 \quad (5)$$

$$Exchange\ Overall = \sum_{j=1}^{J} Exchange_j/2 \quad (6)$$

$$Shift\ Overall = \sum_{j=1}^{J} Shift_j/2 \quad (7)$$

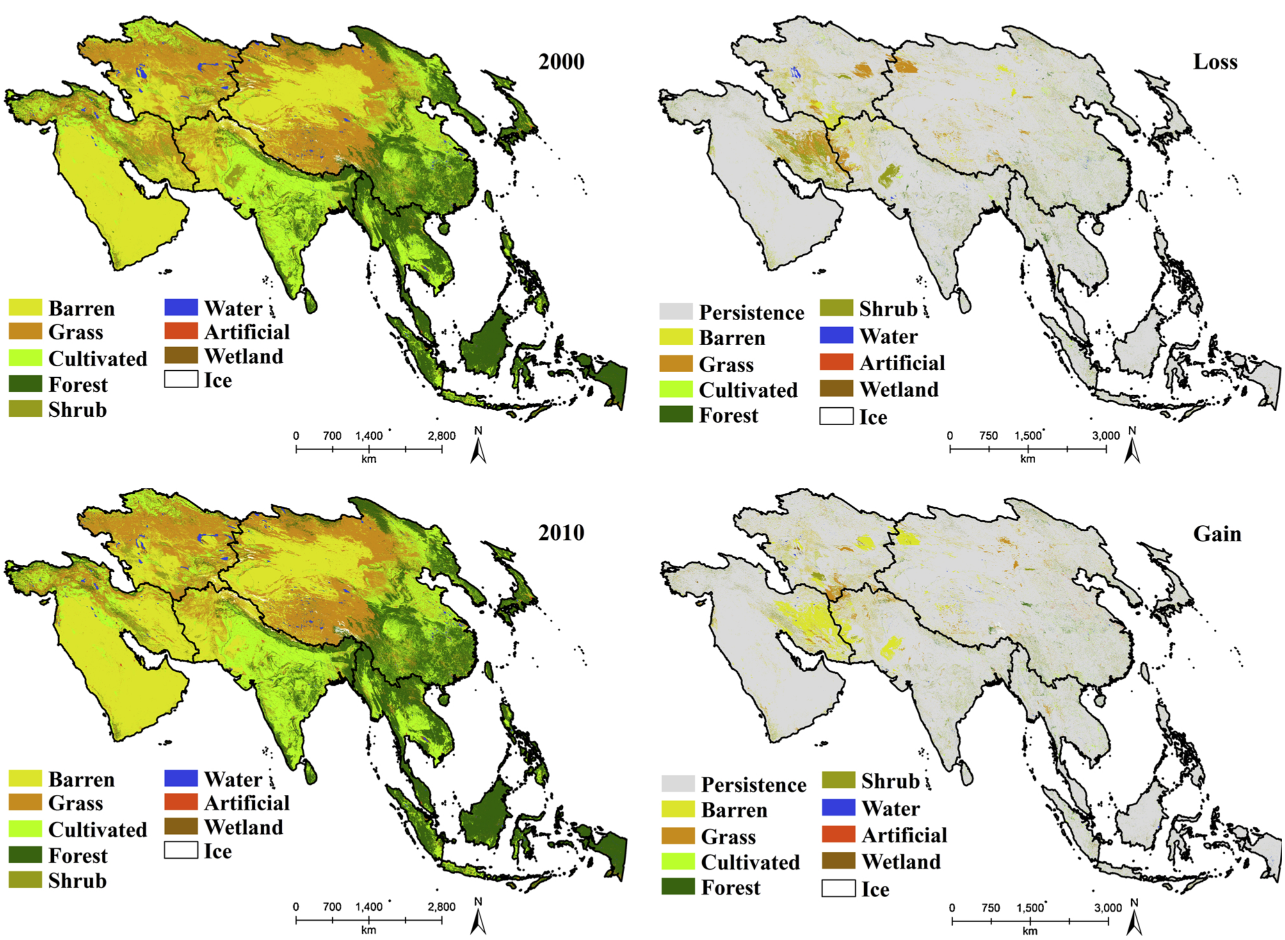

Fig. 2. Land categories of Asia at 2000 and 2010, along with persistence, loss and gain.

Table 2
Transition matrix in thousand square kilometers.

		2010										
		Barren	Grass	Cultivated	Forest	Shrub	Water	Artificial	Wetland	Ice	Total	Loss
2000	Barren	7,317	356	22	9	93	14	3	4	5	7,822	506
	Grass	726	6,403	87	218	78	14	8	13	16	7,563	1,161
	Cultivated	10	87	6,641	82	5	25	60	4	0	6,914	273
	Forest	11	229	101	6,239	39	10	4	5	1	6,638	399
	Shrub	363	92	8	32	365	2	1	1	0	863	499
	Water	18	15	26	10	1	339	2	14	0	425	86
	Artificial	1	3	32	2	0	1	320	0	0	360	40
	Wetland	6	13	6	5	1	16	0	127	0	172	46
	Ice	5	11	0	1	0	0	0	0	152	170	18
	Total	8,458	7,210	6,923	6,598	583	420	396	167	174	30,928	3027
	Gain	1,141	807	282	359	218	81	76	40	22	3027	

$$\textit{Change Overall} = \textit{Quantity Overall} + \textit{Exchange Overall} + \textit{Shift Overall} \quad (8)$$

$$\textit{Quantity Overall Intensity} = \textit{Quantity Overall}/\textit{Change Overall} \quad (9)$$

$$\textit{Exchange Overall Intensity} = \textit{Exchange Overall}/\textit{Change Overall} \quad (10)$$

$$\textit{Shift Overall Intensity} = \textit{Shift Overall}/\textit{Change Overall} \quad (11)$$

Eqs. (12)–(16) are for the category level. Eqs. (12)–(14) give the three component intensities for each category j by taking the size of the component divided by the size of the change. Eqs. (12)–(14) sum to one for each category j. Eqs. (15)–(18) are for Intensity Analysis of a single time interval (Pontius et al., 2013). Eq. (15) expresses the loss intensity for category i as the area of loss divided by the area of category i at the initial time, i.e. 2000. Eq. (16) expresses the gain intensity for category j as the area of gain divided by the area of category j at the final time, i.e. 2010.

$$\textit{Quantity Intensity}_j = \textit{Quantity}_j/\textit{Change}_j \quad (12)$$

$$\textit{Exchange Intensity}_j = \textit{Exchange}_j/\textit{Change}_j \quad (13)$$

$$\textit{Shift Intensity}_j = \textit{Shift}_j/\textit{Change}_j \quad (14)$$

$$\textit{Loss Intensity}_i = \textit{Loss}_i/(\textit{Loss}_i + \textit{Persistence}_i) \quad (15)$$

$$\textit{Gain Intensity}_j = \textit{Gain}_j/(\textit{Gain}_j + \textit{Persistence}_j) \quad (16)$$

Eqs. (17)–(18) are for Intensity Analysis at the transition level. Eq. (17) gives the intensity for the transition from category i to j by computing the area of transition divided by the area of category i at the initial time. Eq. (18) is the uniform transition intensity for the gain of category j, which is the area of the gain of j divided by the area that is not j at the initial time.

$$\textit{Transition Intensity}_{ij} = \textit{Transition}_{ij}/(\textit{Loss}_i + \textit{Persistence}_i) \quad (17)$$

$$\textit{Uniform Transition}_j = \textit{Gain}_j/[(\textit{Spatial Extent}) - (\textit{Loss}_j + \textit{Persistence}_j)] \quad (18)$$

Eqs. (1)–(16) analyze also the confusion matrix at 2010 for GlobeLand30 of global coverage excluding tundra. The confusion matrix has the same layout as Table 2, but the confusion matrix gives the number of validation observations as opposed to the size of areas. The confusion matrix is analogous to Table 2, where loss of i is commission error of i, gain of j is omission error of j, and persistence of j is agreement of j.

Lastly, we apply Eqs. (13) and (16) from Aldwaik and Pontius (2013) to assess whether the errors at the latter time point of a time interval can account for the deviation between change overall and each gain intensity. Enaruvbe and Pontius (2015) explain in detail the logic of those calculations.

3. Results

3.1. Interval level

Fig. 3a shows the results of Eqs. (5)–(8) applied to each of the five regions and to Asia overall. The Asia overall line in Fig. 3a indicates that the maps show difference between 2000 and 2010 for 9.8% of Asia's area. The stacked bars in Fig. 3a for Northwest, South and West extend beyond the line for Asia overall, which indicates that each of those three regions shows temporal difference with a higher percentage of its area than Asia overall. Fig. 3b shows the results of Eqs. (9)–(11) applied to each of the five regions and to Asia overall. The intensity of the quantity component for Asia is 22.6%, thus its reciprocal implies that gross difference is 4.4 times larger than quantity difference overall in Asia. The quantity component for the West and South regions extend beyond the Quantity line for Asia in Fig. 3b, which indicates that those

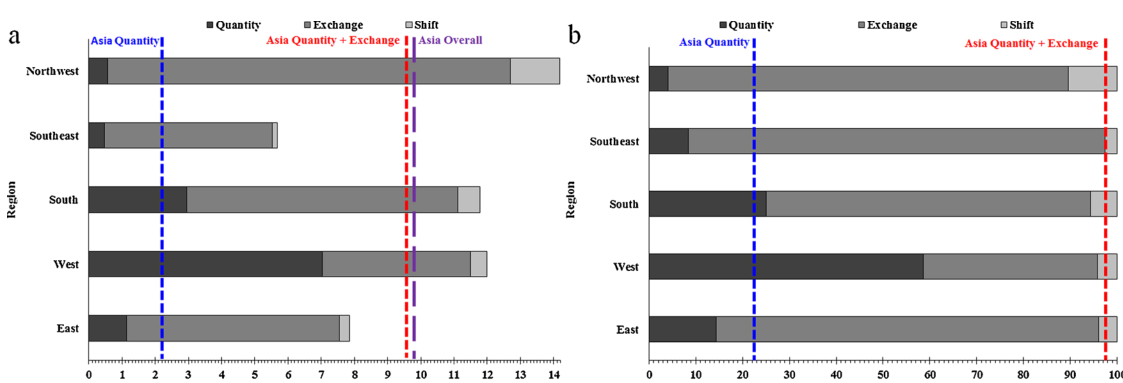

Fig. 3. Temporal difference by region for (a) percentage of region and (b) percentage of change. Dashed lines show components for Asia.

two regions experienced quantity difference more intensively than Asia overall. The Exchange component accounts for three-quarters of the temporal difference in Asia, which Fig. 3b shows as the distance between the two vertical dashed lines. Exchange is the most intensive component for all regions except the West.

3.2. Category level

Fig. 4a shows for each category the size of gain, persistence and loss as a percentage of Asia. The union of Persistence and Loss is the percentage at 2000. The union of Gain and Persistence is the percentage at 2010. Barren, Grass, Cultivated and Forest each account for more than 21% of Asia at both time points. Grass has the largest loss while Barren has the largest gain. Fig. 4b shows the results from Eqs. (15)–(16) concerning intensity as a percentage of each category's size. The vertical line indicates that 9.8% of Asia's area shows change during 2000–2010. If a bar stops before the line, then the category's loss or gain is dormant, meaning less intensive than in Asia overall. If a bar exceeds the line, then the category's loss or gain is active meaning more intensive than in Asia overall. Shrub is the most intensively active category for both loss and gain. Cultivated and Forest are the only categories that are dormant for both loss and gain. The large sizes of Cultivated and Forest in the denominators of their intensities produce their small intensities. Barren's gain is active while Grass' loss and gain are active, in spite of the large sizes in the denominators of their intensities.

Fig. 5a shows the results from Eqs. (2)–(4) as a percentage of Asia. Grass experiences the largest change, which is the result of its large gain combined with its even larger loss. Thus, Grass experiences net loss, as the letter L denotes in its quantity component. Barren experiences the second largest change, which is the result of its large loss combined with its even larger gain. Thus, Barren experiences net gain, as the letter G denotes in its quantity component. Fig. 5b shows the results from Eqs. (12)–(14) as a percentage of each category's change. Barren, Shrub and Artificial are the only categories that have a quantity component that is more intensive than the quantity intensity for Asia overall. For every category, exchange is the largest and most intensive among the three components. Cultivated has the most intensive shift component, as Cultivated transitions to Artificial more than Artificial transitions to Cultivated, while Forest transitions to Cultivated more than Cultivated transitions to Forest.

Table 3 shows the size of exchanges between pairs of categories in Table 1. The exchange between category i and j is two times the minimum of the sizes of the transition from i to j and the transition from j to i. The largest exchange is between Barren and Grass. This exchange is equal to the sum of 356 thousand square kilometers of transition from Barren to Grass shown in Table 2 and another 356 thousand square kilometers of transition from Grass to Barren. A counterintuitive exchange is between Cultivated and Artificial, which reflects an understandable transition from Cultivated to Artificial accompanied elsewhere by counterintuitive transition from Artificial to Cultivated. The sum of all exchanges constitutes 2,265 of the 3,027 square kilometers of change overall in Asia.

3.3. Transition level

Fig. 6 gives results from Eqs. (17)–(18) for gain of Barren, Grass, Cultivated and Artificial. If a losing category's bar is less than the uniform line, then the gaining category avoids the losing category. If a losing category's bar is greater than the uniform line, then the gaining category targets the losing category. The gain of Barren targets Shrub more intensively than any other category. The gain of Grass also targets Shrub most intensively. The gain of Cultivated targets Artificial and Water most intensively, which is counterintuitive. The gain of Artificial targets Cultivated and Water most intensively. Fig. 7 shows the

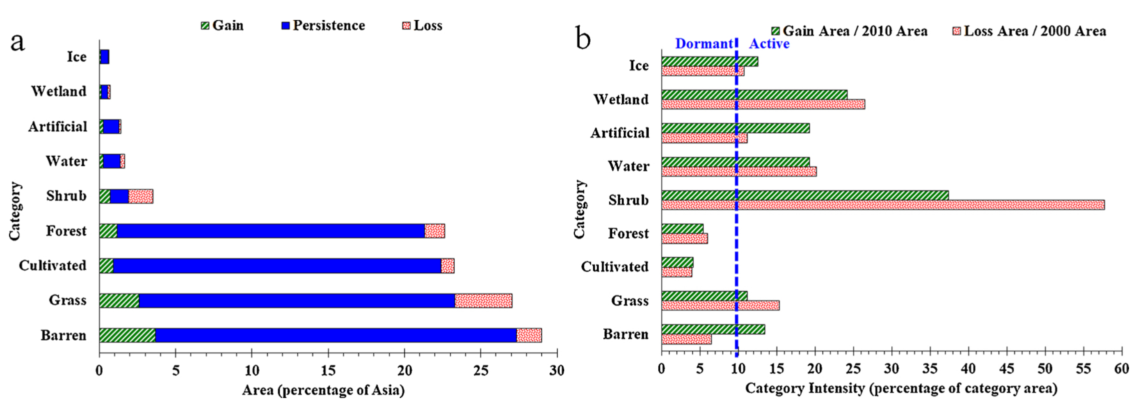

Fig. 4. Category level losses and gains for (a) size and (b) intensity. Dashed line indicates intensity of change overall as a percentage of Asia.

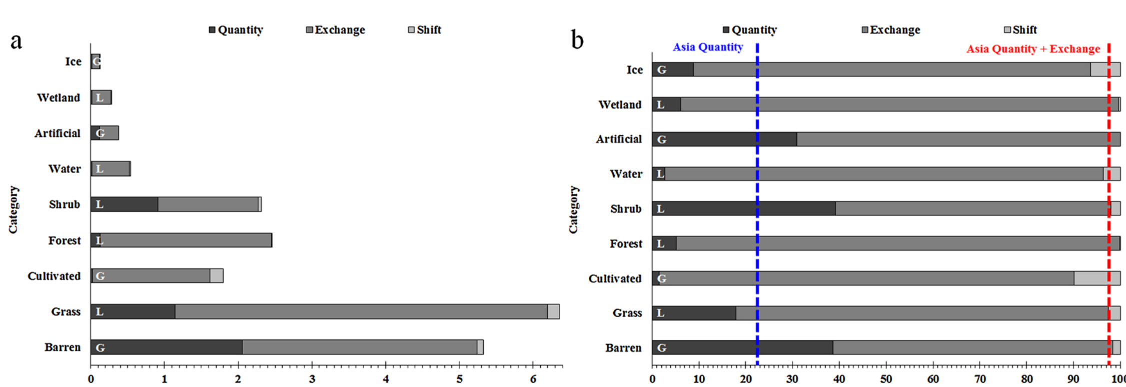

Fig. 5. Category level components of change for (a) size and (b) intensity. L denotes that loss is greater than gain, and G denotes that gain is greater than loss. Dashed lines show components for Asia.

Table 3
Exchanges during 2000–2010 in thousand square kilometers.

	Barren	Grass	Cultivated	Forest	Shrub	Water	Artificial	Wetland	Ice
Barren									
Grass	712								
Cultivated	20	174							
Forest	18	436	165						
Shrub	186	157	11	64					
Water	27	29	49	20	2				
Artificial	2	6	65	5	0	2			
Wetland	9	25	8	9	1	27	0		
Ice	9	23	0	1	1	0	0	0	

transitions to Barren and Grass. The largest transition to Barren is from Grass, while the most intensive transition to Barren is from Shrub. The largest transition to Grass is from Barren, while the most intensive transition to Grass is from Shrub.

3.4. Error analysis

Fig. 8 describes the GlobeLand30 confusion matrix at 2010 for the entire globe. The union of Omission and Agreement in Fig. 8a is the number of observations in the Reference information for each category. The union of Commission and Agreement is the number of observations in GlobeLand30 for each category. If commission error is larger than omission error for a category, then GlobeLand30 overestimates the size of that category, as Barren, Grass and Shrub illustrate. If commission error is smaller than omission error for a category, then GlobeLand30 underestimates the size of that category, as Forest and Artificial illustrate. Fig. 8b shows that omission or commission error intensity is greater than 22% for six of the nine categories. The vertical dashed line shows that the publically available confusion matrix for GlobeLand30 indicates 16.5% overall error, which is less than the often quoted 20% error (Chen et al., 2015). The 16.5% error is the sum of its components: 2.5% quantity, 12.5% exchange and 1.5% shift. Fig. 9a shows the size of the components by category as a percentage of the validation observations. The quantity overall line in Fig. 9b shows that quantity error constitutes 15% of overall error. The quantity component accounts for less than half of each category's error, for all categories except Artificial and Ice. Thus, if the goal is to estimate the quantity of each category, then most of the error is irrelevant in the majority of the categories, because a category's commission error cancels with its omission error.

Methods of Aldwaik and Pontius (2013) test whether the category level errors at 2010 can account for the deviation between the overall intensity line and each gain intensity in Fig. 4. Results show that the 23% commission error of Grass at 2010 could possibly explain why the gain of Grass appears active. The category level errors in GlobeLand30 at 2010 are sufficiently small that they do not fully explain the deviation between overall change intensity and gain intensities for the other eight categories. This suggests that the dormant or active status of the gain intensities in Fig. 4 are meaningful for all the categories except Grass.

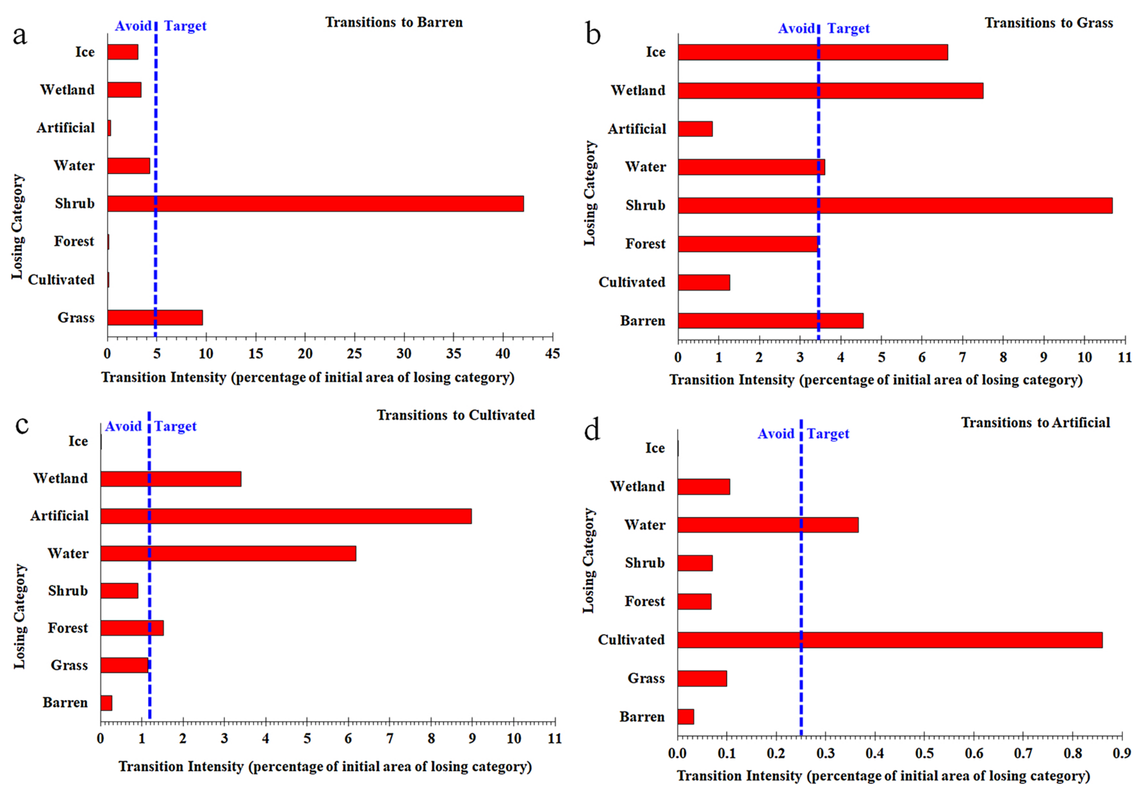

Fig. 6. Transition intensities for gains of (a) Barren, (b) Grass, (c) Cultivated and (d) Artificial. The dashed lines show uniform transition intensity from Eq. (18).

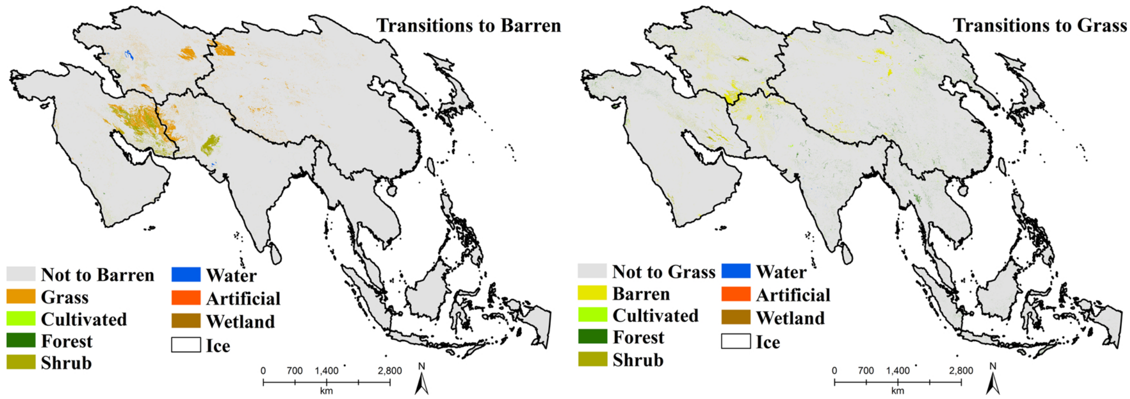

Fig. 7. Categories that transitioned to Barren and to Grass.

4. Discussion

4.1. Major findings

The largest quantity component of change among all the categories is for Barren, which shows net gain. Meanwhile, the global confusion matrix indicates that GlobeLand30 overestimates the size of Barren at 2010. The methods of Aldwaik and Pontius (2013) indicate that the commission of Barren at 2010 is insufficient to account fully for Barren's gain being active, which supports evidence for Barren's intensive gain. GlobeLand30 shows Barren expansion predominantly in Iran and to a lesser degree in northwest China and East Kazakhstan. Minaei et al. (2018) reported that 99% of the Barren expansion in Iran was due to loss of Shrub and Grass according to GlobeLand30, as our Fig. 7 shows. The nature of the transitions are in line with Amiraslani and Dragovich (2011), who consider Grass and Shrub as two important factors in desertification. Climatic conditions such as drought are likely to have contributed to Barren's gain in Central Asia (Guo et al., 2018), South Asia (Aadhar and Mishra (2017) and Southwest Asia (Barlow et al., 2015).

Grass and Shrub show the largest net losses. Meanwhile, GlobeLand30 overestimates the size of Grass and Shrub at 2010. If the quantity errors for the categories at 2000 are smaller than the quantity errors for the corresponding categories at 2010, then the apparent losses of Grass and Shrub might be actually larger than what GlobeLand30 indicates.

Cultivated loses nearly as much as it gains in Asia according to the GlobeLand30 maps. Meanwhile, GlobeLand30 overestimates the size of Cultivated at 2010. Therefore, it is not clear whether Cultivated has experienced any real net gain in Asia. The largest transitions to

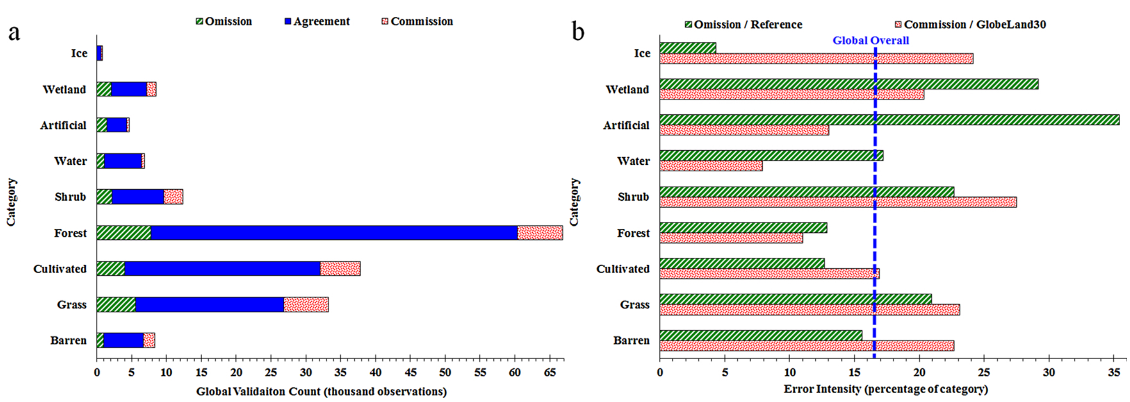

Fig. 8. Category level errors for (a) size and (b) intensity. Dashed line is error overall as a percentage of global validation observations.

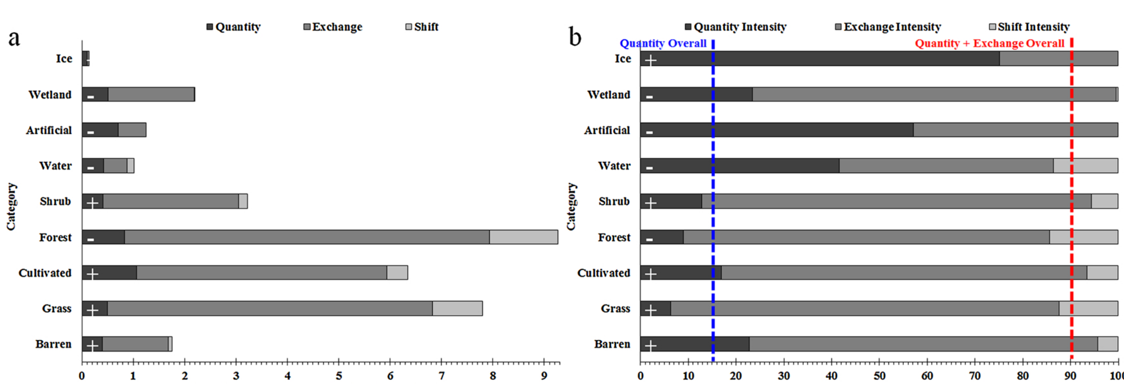

Fig. 9. Category level components of error at 2010 for (a) size and (b) intensity. The + symbol denotes that GlobeLand30 overestimates size of category, and the - symbol denotes that GlobeLand30 underestimates size of category. Dashed lines show component intensities overall for the globe.

Cultivated in Asia are from Forest and Grass. The most intensive transitions to Cultivated are from Artificial and Water, which is counterintuitive.

The GlobeLand30 data show simultaneous loss and gain of Artificial. Error analysis shows that GlobeLand30 underestimates the size of Artificial at 2010. Therefore, error might account for some of Artificial's apparent loss, especially Artificial's transition to Cultivated. Other data also shows counterintuitive transition from Artificial to Cultivated (Huang et al., 2018). Over 60% of the irrigated croplands globally are near urban areas (Thebo et al., 2014). The apparent loss of Artificial might be due to confusion between Artificial and Cultivated when those two categories are spatially intermingled.

4.2. Next steps

Our article illustrates an approach to interpret the temporal difference during a time interval, when information concerning error consists of a confusion matrix at only the latter time point. It would have been more helpful to have the spatially-explicit raw data concerning the geographic coordinates of the validation points, along with each point's reference category and map category. Researchers have not had access to such validation data, so they performed redundant tedious work to focus on their particular spatial extents. Sun et al. (2016) reported 54% error for central Asia, while studies for eight other regions ranged from 10% to 23% error for GlobeLand30 (Chen et al. (2017). Estoque et al. (2018) found that GlobeLand30 was least accurate among eight datasets for the forest category in the Philippines. It is not clear whether the variation in these reported errors reflects the variation in spatial extents or inconsistencies in evaluation criteria, such as judgements concerning reference points that are ambiguous. If maps creators would make georeferenced validation data available, then the research community could avoid such problems and could benefit from the creator's valuable validation information.

The available information for GlobeLand30 is a confusion matrix, which indicates that percentage error globally at 2010 is substantially larger than percentage change in Asia during 2000–2010. However, the quantity components are more similar; specifically the quantity component of error is 2.5% of the validation observations, while the quantity component of temporal difference is 2.2% of Asia. In any case, error assessments at individual time points are insufficient to understand errors of change. The next most helpful step would be to assess errors of temporal change following the advice of Olofsson et al. (2014) and van Oort (2007).

5. Conclusions

The methods of Intensity Analysis and Difference Components helped to interpret the difference between 2000 and 2010 in Asia with respect to the global error at 2010. The GlobeLand30 maps show the difference between 2000 and 2010 is 9.8% of Asia. Grass experienced the largest loss while Barren experienced the largest gain. The largest transitions were from Grass and Shrub to Barren. Shrub experienced the most intensive loss and gain relative to the size of the category. Artificial's gross loss was more than half of its gross gain. Errors in the data might help to explain Artificial's counterintuitive gross loss, some of Barren's net gain, and possibly additional temporal differences. GlobeLand30 has no error assessment at 2000 and the publically-available global confusion matrix at 2010 shows error for 16.5% of the validation observations. The quantity component of error at 2010 and of temporal difference during 2000–2010 are both approximately 2%. Error at individual time points does not necessarily indicate error of change between the time points. Therefore, the research community needs freely-available georeferenced data for an error assessment of change. If the differences between 2000 and 2010 indicate real land change, then Asia experienced 4.4 times larger gross change than net change.

Declarations of interest

None.

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