International Journal of Applied Earth Observations and Geoinformation 102 (2021) 102431

Contents lists available at ScienceDirect

International Journal of Applied Earth Observations and Geoinformation

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

Developing a grid-based association rules mining approach to quantify the impacts of urbanization on the spatial extent of mangroves in China

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ARTICLE INFO

Keywords:
Mangrove
Urbanization
Association
Conservation
China

ABSTRACT

Being significant to the coastal sustainability, mangrove forests have decreased at an alarming rate over the past decades, under various pressures from both natural and anthropogenic forces, while urbanization has been widely recognized as one major factor for the dramatic areal mangrove loss. China has experienced rapid urbanization, particularly in coastal zones, which revealed negative impacts towards mangrove loss in previous literature. However, there is a lack of quantitative understanding between urbanization and mangroves loss at large spatial and temporal scales. Given its complexity at a large scale, the relationship between urbanization and mangroves changes remains under-explored, and satellite remote sensing provides a unique tool for addressing this imperative issue quantitatively. To this end, this study developed a grid-based association analysis (GBAA) method for quantifying and investigating the relationship between urbanization and mangroves changes using satellite-derived datasets in China during 1973–2015. Experimental results indicated that conservation policies in nature reserves have made significant contributions to mangrove conservation in China. The impact of urbanization on the spatial extent of mangrove forests weakened gradually outside nature reserves during 1973–2015, indicating that urbanization does not necessarily damage mangroves in recent decades. These findings provide important clues for understanding the relationship between urbanization and mangroves to support better and wiser policy-making for future mangrove conservation and urban management.

1. Introduction

Mangrove forests are a group of shrubs and trees that live in the coastal intertidal zones in the tropical and subtropical regions (Giri et al., 2011). Mangrove forests provide unique ecological environments that can protect the coastline against flood waves and Tsunamis, and filter pollutants from water. Mangrove forests are productive ecosystems that serve as breeding grounds for marine species, such as fish, shrimp, crabs, and other shellfish. They also provide fuel and building materials for local communities (Giri et al., 2008). However, the spatial extent of mangrove forests has decreased dramatically over the past decades at an alarming rate. The remaining mangrove forests are under pressure from both natural and anthropogenic forces (Alongi, 2002; Giri et al., 2008, 2011). The natural forces mainly include climate change, sea-level rise, and hydrological alterations, and so forth (Giri et al., 2011). The conversion of mangrove forests to agriculture, aquaculture and urban construction are major anthropogenic causes of deforestation. There has been an increasing interest in investigating urbanization's impacts on mangroves.

China has experienced rapid urbanization and industrialization during the last two decades. The urbanization process includes spatial urbanization, demographic urbanization, economic urbanization, and social urbanization (Zhao et al., 2016). Urbanization in China increased from 19.4% to 52.6% between 1980 and 2012 (Yang, 2013). The economic growth in the coastal region (only 13% of total land) contributed 60% of GDP (Ma et al., 2014). In coastal areas, land reclamation has

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https://doi.org/10.1016/j.jag.2021.102431
Received 18 March 2021; Received in revised form 15 June 2021; Accepted 30 June 2021
Available online 10 July 2021

become the primary approach to construct and extend built-up areas (Sengupta et al., 2019). Land reclamation due to rapid urbanization in China has led to the loss of ecosystem services value and coastal biodiversity, as well as ecological environment fragmentation (Duan et al., 2016). Thus, mangroves in China suffered from the high intensity of human disturbances during the urbanization process. The Chinese government began to attach importance to mangrove conservation and restoration and established nature reserves since the 1980s (Chen et al., 2009). Moreover, great efforts have also been made through replanting mangroves since the 1990s (Chen et al., 2009). Environmental awareness is also positively related to the level of urbanization and urban development. There is a complex interaction between urban and mangrove ecosystem during the urbanization and protection process.

Many researchers have studied the impact of urbanization on mangroves at an earlier stage using qualitative analysis. Artificial impervious surfaces can change the hydrological regimes and affect the nutrients dynamics and chemical pollutants, which will further influence the structure and function of coastal wetlands (Lee et al., 2006). It is challenging to conduct field work due to the mangrove's special living conditions at that time. As remote sensing technique has been widely applied in mangrove investigation, quantitative analysis of mangrove loss can be conducted by extracting land-use and land-cover changes from satellite imageries. Studies showed that large areas of mangrove forests and tidal flats were converted to other land use types, such as agriculture, aquaculture, and urban construction in the past (Jia et al., 2021; Thomas et al., 2017). Recently, some studies have explored the negative relationship between urban expansion and mangrove loss using statistical methods. For example, the correlation between mangrove loss and urban sprawl in Guangdong, China (Ai et al., 2019) and Mumbai, India (Vaz, 2014) were revealed using correlation analysis. Hayashi et al. (2019) conducted principal components analysis and revealed that the paved road network is the dominant driver of mangrove change, compared to other anthropogenic factors, such as population density, distance to urban centers and settlements. Furthermore, some researchers identified areas under high degrees of human disturbance by proposing a disturbance index (Ambastha et al., 2010) and Relative Integrated Anthropization Index (Samuel et al., 2019).

However, most previous studies on the relationship between urbanization and mangrove change were conducted at local scales with qualitative descriptions. A quantitative understanding of the impacts of urbanization on mangrove changes remains unclear from local, regional to global scales. Besides, in China, the Chinese government has made great efforts to establish protected areas and environmental protection policies since the 1970s. The effectiveness of these policies in conserving mangroves under the background of rapid urbanization is yet to be quantified and evaluated. In this respect, the association rules mining (ARM) technique will be applied in this study. ARM is a popular machine learning and data mining method for discovering correlations, associations, or patterns in an extensive database. Agrawal et al. (1993) first introduced ARM to analyze sales transactions and explore customer purchasing behaviour to target customers and improve customer service. Due to the advantage of dealing with non-numeric and categorical data, it has been widely applied to explore associations in many fields, such as medical diagnosis, bioinformatics, traffic crashes, hydrology, climate, urban study (Mennis and Liu, 2005; Xu et al., 2018; Zhong et al., 2019). Recently, some studies took advantage of satellite-based remote sensing datasets and converted them into categorical data by experiential knowledge and typical classification method, which transformed remote sensing products into valuable association knowledge (Ding et al., 2017; He et al., 2018; Rajasekar and Weng, 2009; Xue et al., 2017; Zhang et al., 2021; Zhao et al., 2019; Zhong et al., 2019). The ARM method can identify the frequent spatial patterns hidden in the remote sensing images and explore the relationship between them (Wang et al., 2020). In addition to identifying associations, ARM also has the potential to improve the accuracy of satellite image classification and interpretation (Wang et al., 2010; Zhou and Zhang, 2013).

Therefore, based on the long-term satellite observations of both urbanization and mangrove forests, this study aims to develop a new ARM-based approach to comprehensively explore the association between urbanization and mangrove changes, as well as to understand the effectiveness of conservation policy and nature reserves in China since the 1970s.

2. Study area and datasets

2.1. Study area

Mangrove forests in China are in tropical and subtropical coastal areas, spanning latitudes 18°12′ to 28°25′N and longitudes 108°01′ to 121°30′E. The study area is mainly located in the Southeast coastal regions, including the provinces of Zhejiang, Fujian, Guangdong, Hainan, Taiwan, and regions of Guangxi Zhuang Autonomous Region (referred as Guangxi), Hong Kong, and Macau, which have subtropical and tropical monsoon climates. Guangdong Province has the largest cover of mangroves, followed by Guangxi and Hainan Province. Mangroves in Zhejiang Province were transplanted from Fujian during the 1950s. More than 20 mangrove nature reserves were established in China since the 1970s. Fig. 1 shows the spatial distribution of total mangroves in China from 1973 to 2015 and the approximate location of 25 nature reserves. As shown in Table 1, the location and establishment time of 25 mangrove nature reserves at national, provincial, local levels were collected from China MangroveConservation Network (CMCN, www.china-mangrove.org), Zhang and Sui (2001), and Wang (2006), Chen et al. (2009).

2.2. Datasets

The datasets of mangrove forests in China were obtained from Jia et al.' study (2018), which present the spatial distribution of mangroves in 1973, 1990, 2000, and 2015. The datasets were interpreted from Landsat images, with overall accuracies 78%, 87%, 89%, 94% and kappa coefficients 0.71, 0.78, 0.85, 0.91, respectively. The Global Human Settlement Layer (GHSL) produced GHSL built-up datasets (Corbane et al., 2019) and GHSL population datasets (Freire et al., 2016), which is derived from Landsat image collections. The GHSL built-up datasets are at 30-m spatial resolution; GHSL population datasets are at 9 arcsec resolution, which depicts the number of residential population estimates per grid cell. Urbanization was characterized by analyzing the changes in built-up areas and population density collected from GHSL datasets.

GHSL datasets only provide multi-temporal build-up and population grids corresponding to epochs 1975, 1990, 2000 and 2015. Due to the unavailability of built-up dataset in 1973, as well as minor change (from 17.4% to 17.3%) in China's urbanization level from 1970 to 1975 (Chen et al., 2013), we assume that GHSL datasets in 1975 can be used to represent urbanization information in 1973 in this study.

GHSL datasets were generated at a global scale and have been widely applied in regional studies. In Fang et al.'s study (2021), an accuracy assessment of GHSL built-up products was conducted for 1990, 2000, 2015, by comparing the high-resolution remote sensing images from Google Earth. They indicated that the overall accuracy of built-up in China was 91.25% (1990), 89.45% (2000) and 91.05% (2014), respectively. Liu et al. (2020) conducted an accuracy assessment of GHSL built-up products over 20 cities in China. They suggested that GHSL built-up products are promising for depicting building density, but improvement still needed in dense urban areas. Mangrove forests live along the coastline, which mainly surrounded by a sparse urban environment. Accordingly, GHSL built-up datasets are applicable for depicting urban environment near mangrove forests in our study area. GHSL population datasets were developed based on GHSL built-up and GPWv4 population estimates. Therefore, GHSL population datasets were employed in this study to ensure data consistency.

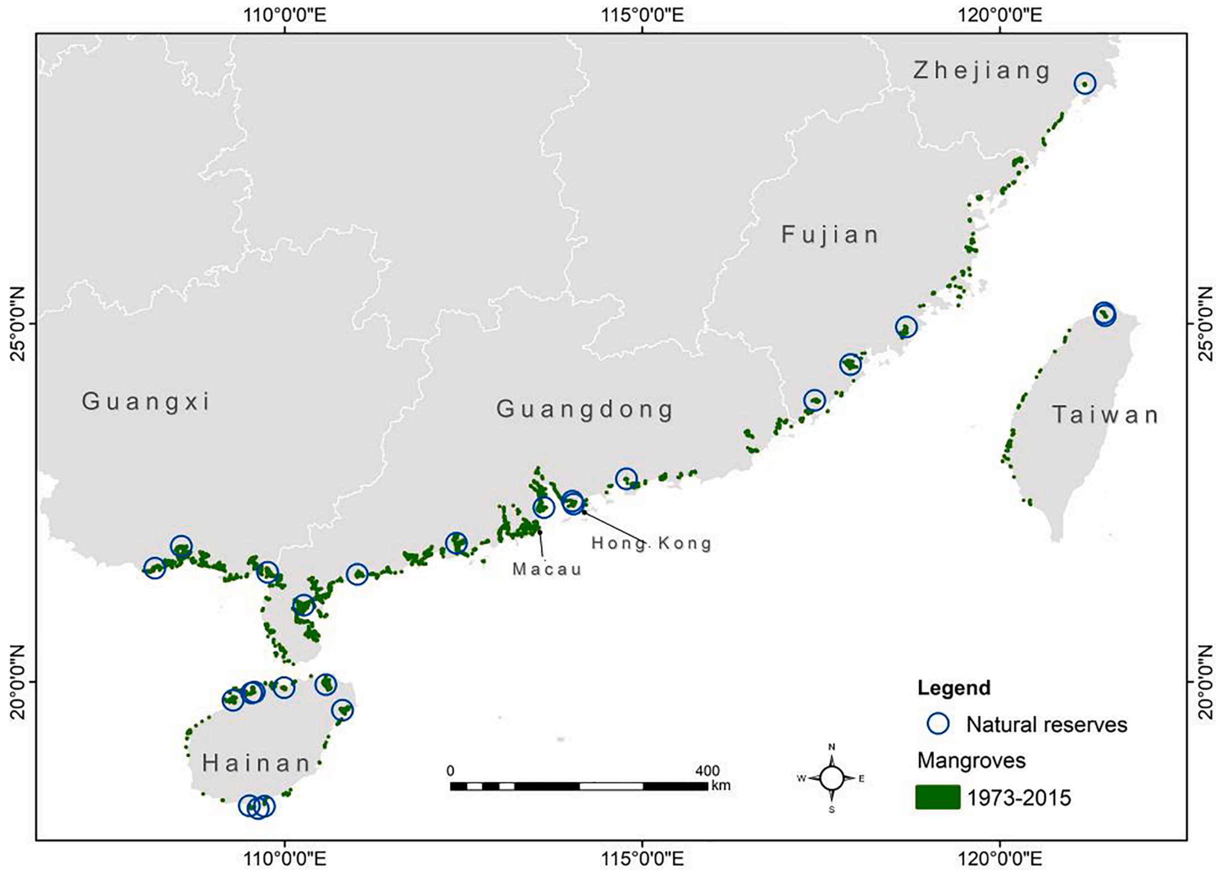

Fig. 1. The spatial distribution of total mangroves in China from 1973 to 2015. (The distribution of mangroves is shown at a coarser resolution for display purposes).

3. Methods

Previous analyses mainly used administrative or nature reserves boundaries as the spatial unit. In this study, we proposed a grid-based association analysis (GBAA) method to mine association rules, which use uniform sized grid cells as the basic geographical units of analysis. This method combined the grid-based spatial segmentation and association rules mining.

3.1. Grid-based spatial segmentation

The spatial extent of mangroves was segmented into several equally sized grid cells with a specific length. The grid size is generally determined by source datasets, application goals or expert experiences. The grid size must be suitable to capture the desired spatial variation of mangrove, built-up and population. It is significant to test the sensitivity of grid size to mining association rules and determine the optimal grid size. So, sensitivity analysis was performed to explore the grid scale effect and determine the optimal grid size, by comparing result variation at different grid sizes from 500 m to 5 km (with a 500 m interval). Then, the optimal grid size was chosen to demonstrate experimental results using the GBAA method.

The grid generation begins from the lower-left corner, following left-to-right and bottom-up sequencing. The extent of grid cells only includes square polygon that intersects mangrove distribution from 1973 to 2015. Each grid cell was assigned a sequential index starting from 1. As shown in Fig. 2, mangroves in the region of Dongzhai Harbor National Nature Reserve were used only for illustrating the grid cells generation and index labelling.

3.2. Association rules mining

Let $I = \{i_1, i_2, i_3, \cdots, i_n\}$ be a set of all items and $T = \{t_1, t_2, t_3, \cdots, t_m\}$ be a set of transactions in database, each transaction t contains a subset of the items in I. An association rule can be expressed as the form $X \rightarrow Y$, where X and Y are disjoint itemsets, i.e., $X \subseteq I, Y \subseteq I, X \cap Y = \varnothing$. X is called antecedent or If and Y is consequent or Then. In the market basket analysis, the rule $X \rightarrow Y$ indicates that people who buy itemset X are also likely to buy itemset Y. Consequent Y is an itemset that is found in combination with the antecedent X.

Support, Confidence, and Lift indicators were used to evaluate and measure the quality of rules. Support measures how frequently the itemset appears in the dataset and the significance or importance of an itemset. Mathematically, Support is the probability of co-occurrence of itemset X and Y. It can be calculated as follows (Eq. (1)).

$$Support(X \rightarrow Y) = P(X \cup Y) \; range : [0, 1] \quad (1)$$

Confidence is an estimate of the conditional probability of occurrence of the Y in a transaction under the condition that it also contains X, which is defined as follows (Eq. (2)).

$$Confidence(X \rightarrow Y) = \frac{Support(X \rightarrow Y)}{Support(X)} = \frac{P(X \cup Y)}{P(X)} \; range : [0, 1] \quad (2)$$

Lift is defined as the ratio of the observed joint probability of X and Y to the expected joint probability if they were statistically independent, which can be calculated as Eq. (3).

$$Lift(X \rightarrow Y) = \frac{Support(X \rightarrow Y)}{Support(X) \times Support(Y)} = \frac{P(X \cup Y)}{P(X)P(Y)} \; range : [0, \infty] \quad (3)$$

A Lift value greater than 1 means that the occurrence of X has increased the probability of the presence of Y. The rules with greater

Table 1
Summary of 25 mangrove nature reserves in China.

Nature Reserve	Location	Level	Year of establishment
Zhangjiang Estuary National Mangrove Nature Reserve	Fujian	National	1997
Jiulongjiang Estuary Mangrove Nature Reserve	Fujian	Provincial	1988
Wanhe Estuary Wetland Nature Reserve	Fujian	Provincial	2001
Futian Mangrove National Nature Reserve	Guangdong	National	1984
Zhanjiang Mangrove National Nature Reserve	Guangdong	National	1991
Qi'ao-Dangan Island Provincial Nature Reserve	Guangdong	Provincial	2000
Shuidong Bay Mangrove Nature Reserve	Guangdong	Local	1999
Huidong Mangrove Nature Reserve	Guangdong	Local	2000
Zhenhai Bay Mangrove Nature Reserve	Guangdong	Local	2000
Beilun Estuary National Nature Reserve	Guangxi	National	1990
Shankou Mangrove Nature Reserve	Guangxi	National	1990
Maowei Bay Mangrove Nature Reserve	Guangxi	Provincial	2005
Dongzhai Harbor National Nature Reserve	Hainan	National	1980
Qinglan Harbor Nature Reserve	Hainan	Provincial	1981
Xinying Harbor Mangrove Nature Reserve	Hainan	Local	1983
Huachang Bay Mangrove Nature Reserve	Hainan	Local	1983
Dongchang Mangrove Nature Reserve	Hainan	Local	1986
Caiqiao Mangrove Nature Reserve	Hainan	Local	1983
Tielu Harbor Mangrove Nature Reserve	Hainan	Local	1992
Qingmei Harbor Mangrove Nature Reserve	Hainan	Local	1989
Sanya Estuary Mangrove Nature Reserve	Hainan	Local	1990
Mai Po Nature Reserve	Hong Kong	National	1975
Tamsui River Mangrove Nature Reserve	Taiwan	Provincial	1986
Guandu Nature Reserve	Taiwan	Provincial	1986
Yueqing Ximen Island Marine Special Reserve	Zhejiang	Local	2005

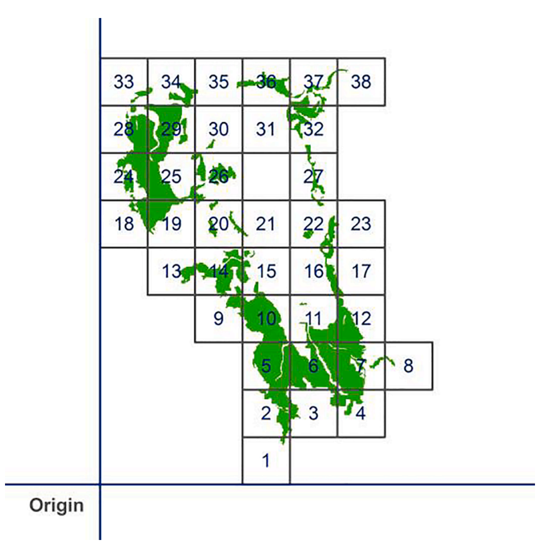

Fig. 2. Illustration of grid generation.

Support, Confidence and Lift values indicate stronger associations. If X and Y are independent, the Lift value will be 1. Apriori algorithm was originally proposed by Agrawal and Srikant (1994) to mine association rules among a set of items. Apriori algorithm is guided by a principle, that is, any subset of a frequent itemset must be frequent. The infrequent itemsets and their superset will be discarded to reduce the search space. Firstly, an iterative search is used to identify itemsets which Support value is larger than the minimum threshold (minSup). Then, all candidate rules which meet the confidence level (minConf) can be generated from frequent itemsets.

In this study, the association rule mining was conducted at grid scale. Each grid contains the attribution of outside or inside nature reserve, the changes in built-up areas and mangrove forests, and the population density for the final year of corresponding period. As the changes in built-up areas and mangrove forests, and the population density data are numeric, they were converted to categorical data type. As shown in Table 2, each indicator was classified into several categories, which regarded as items i in the association rule mining, a grid with the combination of different categories was considered as one transaction t. Each grid contains the following information: $t = \{NR, BUC, MC, PD\}$. The Apriori algorithm then identifies the association between mangrove changes (MC) and urbanization (BUC, PD) with/without protection (NR). For example, the rule $\{NR1, BUC0\} \rightarrow \{MC0\}$ is identified with the Support of 0.5, the Confidence of 0.7, and the Lift of 1.2. This rule suggested that if there is no built-up (BUC0) within or near nature reserves (NR1), it was likely that the mangroves stay stable (MC0) with minor changes. The Support of 0.5 means that the proportion of transactions that contains {NR1, MC0} and {MC0} is 0.5. The Confidence of 0.7 means that 70% of the transactions that contain {NR1, MC0} also contain {MC0}. Lift larger than 1 indicates that {NR1, MC0} has a positive influence on the occurrence of {MC0}. In this study, the threshold values for Support, Confidence and Lift were set as Support > 1%, Confidence > 30%, Lift > 1. Association rule mining was conducted for 1973–1990, 1990–2000, 2000–2015 three periods, respectively.

4. Results

4.1. Mangrove changes in China

As presented in Jia et al.' study (2018), a dramatic decrease of mangroves occurred from 1973 to 1990, after which the rate of decrease slow down gradually from 1990 to 2000. Then, there was a gradual rise from 2000, reaching 22419 ha in 2015. Overall, the areal extent of mangroves dropped from 488012 ha to 22419 ha over the period from 1973 to 2015.

As illustrated in Fig. 3, the intact mangrove cover between *t1* and *t2* is the area of overlap between mangrove cover in *t1* and *t2*, which is the geographic intersection set of M_{t1} and M_{t2}. The gained mangrove during a period can be expressed as the set of mangrove patches in *t2* but not in *t1*, which is the geographic complement set of intact in M_{t2}. The lost mangrove during a period is the set of mangrove patches in *t1* but not in

Table 2
Indicators and categories used in association rule mining.

Indicator	Abbreviation	Category	Definition
Nature reserve	NR	NR0	Outside nature reserve
		NR1	Inside/near nature reserve
Built-up areas change	BUC	BUC0	No built-up
		BUC1	Increase <10 ha
		BUC2	Increase ≥10 ha
Mangrove change	MC	MC0	Chang ± 10 ha
		MC1	Decrease ≥10 ha
		MC2	Increase ≥10 ha
Population density	PD	PD0	No people or <10 people/km^2
		PD1	≥10 people/km^2

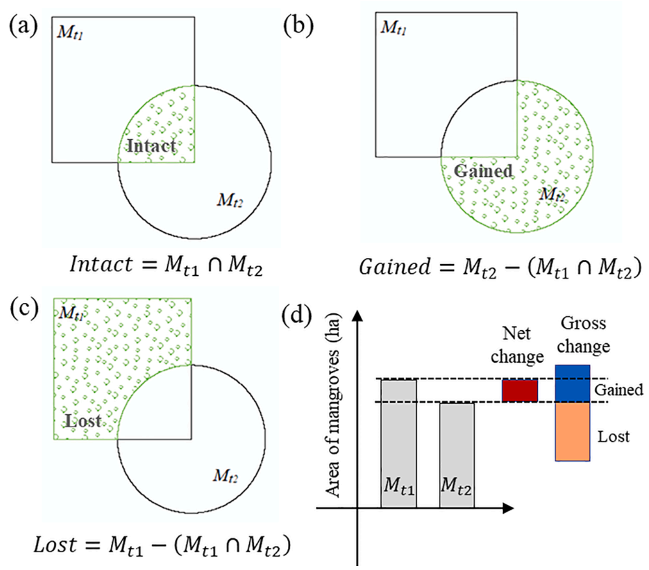

Fig. 3. Illustration of intact, gained, lost mangroves and net, gross change.

t2, which is the geographic complement set of intact in M_{t1}. Net change indicates the difference in total area of mangrove between two time steps. While gross change is the sum of all mangrove area gains and losses, providing the insights of dynamic changes in mangrove over time. The Fig. 3(d) referred to Fuchs et al.'s (2015) study.

The areal extent of gained, lost and intact mangroves over different periods in China were also shown in Fig. 4. Between 1973 and 2015, there was a total loss of 40434 ha of mangrove forests in China. The decrease in mangrove extent was offset by a gain of 14932 ha of new mangroves, resulting in a net change of 25501 ha and gross change of 55366 ha. There were also 7741 ha mangrove maintained from 1973 to 2015. Comparing the three periods, 1973–1990 period had the largest net loss, of 37618 ha, followed by 1990–2000 period with 13161 ha lost. The mangrove loss was much greater than the mangrove gain during 1973–1990 period. From 2000 to 2015, the area of mangrove gain exceeded mangrove loss, showing an increase trend of net change in mangrove extent.

4.2. Sensitivity analysis of grid size

The GBAA method was applied with different grid sizes to determine the impact of the variable under sensitivity analysis. The grid size is the only variable in the sensitivity analysis. As Lift is the indicator representing the degree of association of the generated rule, Lift values were used to compare the variations caused by grid size. Fig. 5 illustrates the distribution of Lift values of generated rules at different grid sizes conditions for three periods. For the 1973–1990 period, there are minor differences in the Lift values at different grid sizes. The Lift values were more sensitive to grid size during the other two periods. We calculated the mean values of Lift for three periods and the whole study period, as shown in Fig. 6. The highest mean values of Lift for both the second period and the whole study period were achieved at a 4 km grid size. Therefore, the grid size of 4 km was deemed optimal for exploring the association between urbanization and mangrove in China based on the GBAA method.

4.3. Grid-based urbanization and mangroves statistic

In this study, a total of 985 grids covering the spatial extent of mangrove forests from 1973 to 2015 were generated. Fig. 7 shows the distribution of mangroves and built-up areas in the regions of 6 national nature reserves in different time periods. The black grid cell has a side length of 4 km. In the region of Futian and Mai Po Nature Reserves, mangroves are distributed in the areas with high intensity of urbanization. Built-up areas have increased dramatically over the past decades. Other nature reserves are far from the dense urban areas. In the year between 1975 and 2015, the area of built-up increased significantly from 7682 km^2 to 13422 km^2 within the 10 km buffer of coastline in study area.

Table 3 summarize the result of grid-based statistic, all statistics were extracted based on grid cells. The count of grids cells covering the extent of mangrove forests were 768, 676, and 700 for 1973–1990, 1990–2000, and 2000–2015 period, respectively. Due to the different establishment year of nature reserves, the number of grids inside nature reserves were various for three period. There has been a decline in the maximum of

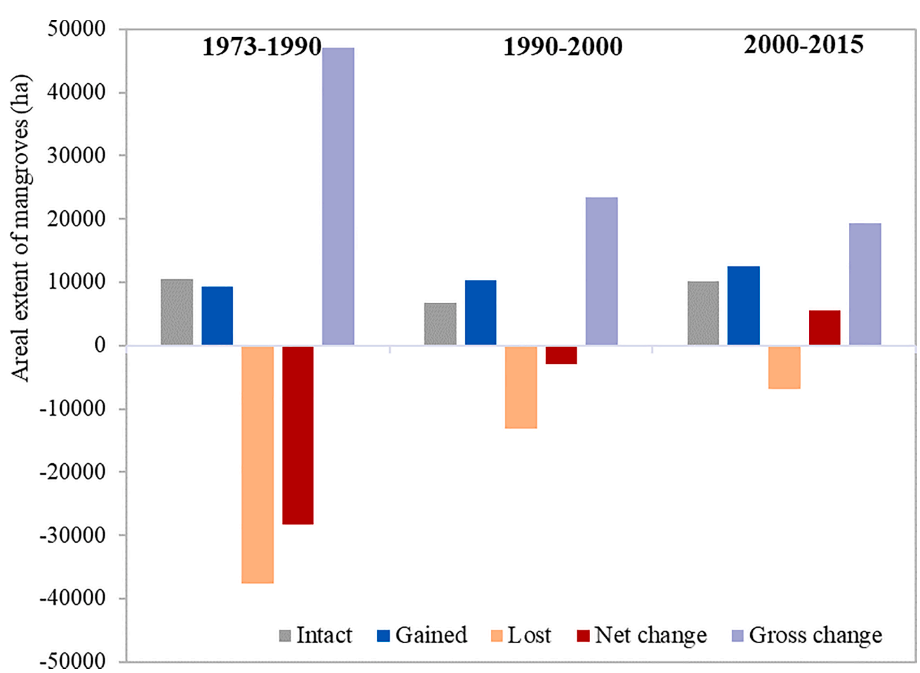

Fig. 4. Net changes and gross changes (gained, lost) in mangrove extent for different periods.

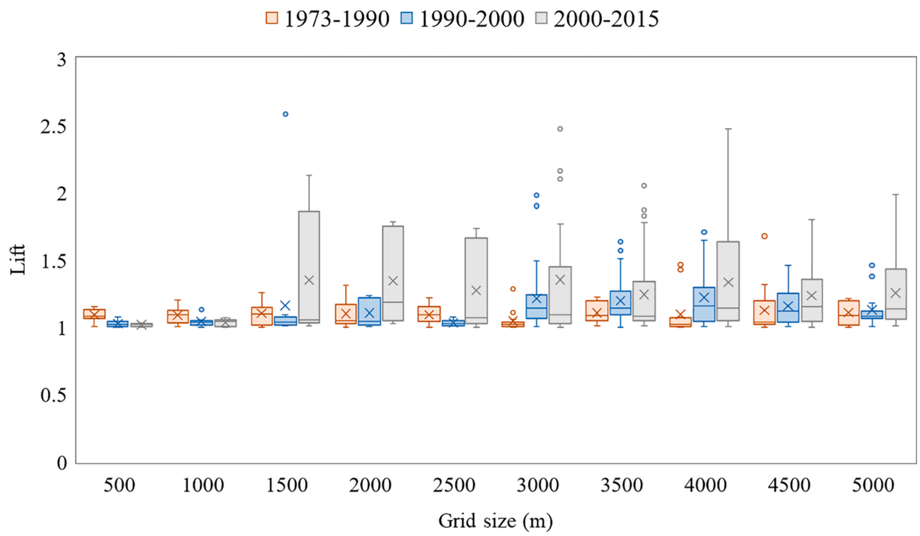

Fig. 5. Boxplot of Lift value with different grid sizes for three periods.

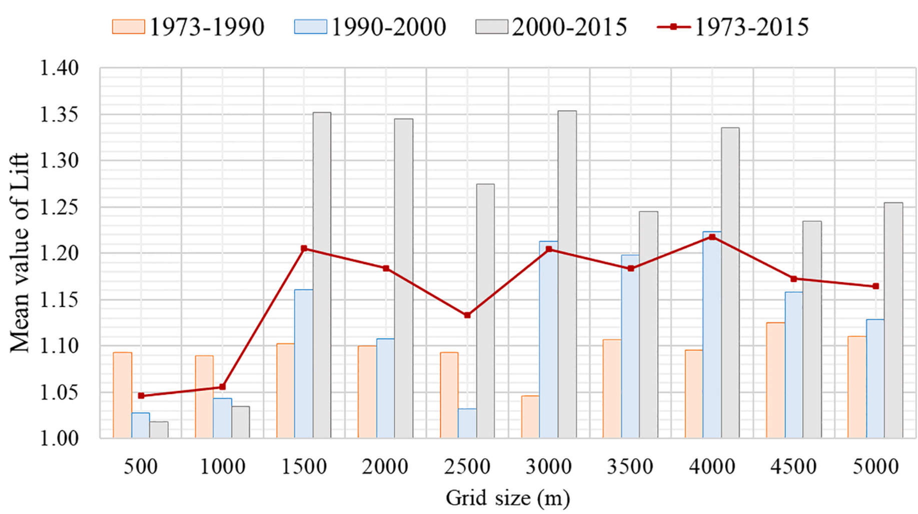

Fig. 6. Comparison of the mean value of Lift with different grid sizes for three periods.

mangrove decrease from −577.84 ha to −249.69 ha and a rise in the maximum of mangrove increase from 205.63 ha to 248.42 ha for three period. As a portion of mangroves are distributed in the regions far from urban areas, the minimums of built-up increase and population density are 0.

4.4. Association between urbanization and mangroves changes

Itemset with indicator larger than the minimum threshold were extracted as association rules through GBAA method. In total, 21, 31, and 24 association rules were generated for three periods, respectively. The generated rules were ranked by the Confidence value, to make the generated rules more readable, we reordered and removed some rules in the table. As shown in Table 4, 5, 6, Policy and Urbanization are antecedent, Mangroves is consequent. Fig. 8 illustrates scatter plots for visualization of all association rules, in which the x and y axis indicate Support and Confidence values, the colour represents the Lift values. Fig. 9 also shows the variation of three indicators for three period.

Selected association rules for 1973–1990 were shown in Table 4. For example, Rule #1{NR0, BUC1, PD1}→{MC1} indicates that outside nature reserves, if the built-up increased slightly (<10 ha) and population density in 1990 is larger than 10 people/km^2, it was likely that the mangrove forests decreased (>10 ha) during this period. Rule #20 shows the strong association between NR1 and MC0. The Support is around 1% due to the few numbers of nature reserves during this period. This rule indicates that mangrove changed slightly (MC0) inside or near nature reserves (NR0), even with large population density (PD1).

Meanwhile, a strong association between BUC1 and MC1 was observed from Rule #1, 3, 5. Based on these rules, it can be concluded that if the built-up increased slightly (<10 ha), mangrove reduction was more likely to occur outside nature reserves. Rule #10 {NR0}→{MC1} holds with the Support of 0.499, which is the largest Support value in the listed rules. It suggested that mangrove decrease outside nature reserves occurred in a relatively large proportion of grids in 1973–1990. It can be concluded that BUC0 and MC0 had a strong association, as shown in rule# 12, 16, 18. If there was no built-up area (BUC0) outside nature reserves (NR0), it was likely that the mangrove forests were relatively stable (MC0) during this period.

Selected association rules for 1990–2000 were listed in Table 5. Based on Rule# 16. 17, 23, 25, both mangrove decrease (MC1) and increase (MC2) were likely to occur within or near nature reserves. However, the association between NR1, BUC1 and MC2 is more significant with higher Lift values. If there was no built-up or built-up areas increased slightly, it was likely that the mangrove stayed stable outside nature reserves. The association between BUC1 and MC0 was also discovered based on Rule# 20, 22, indicating that mangrove reduction

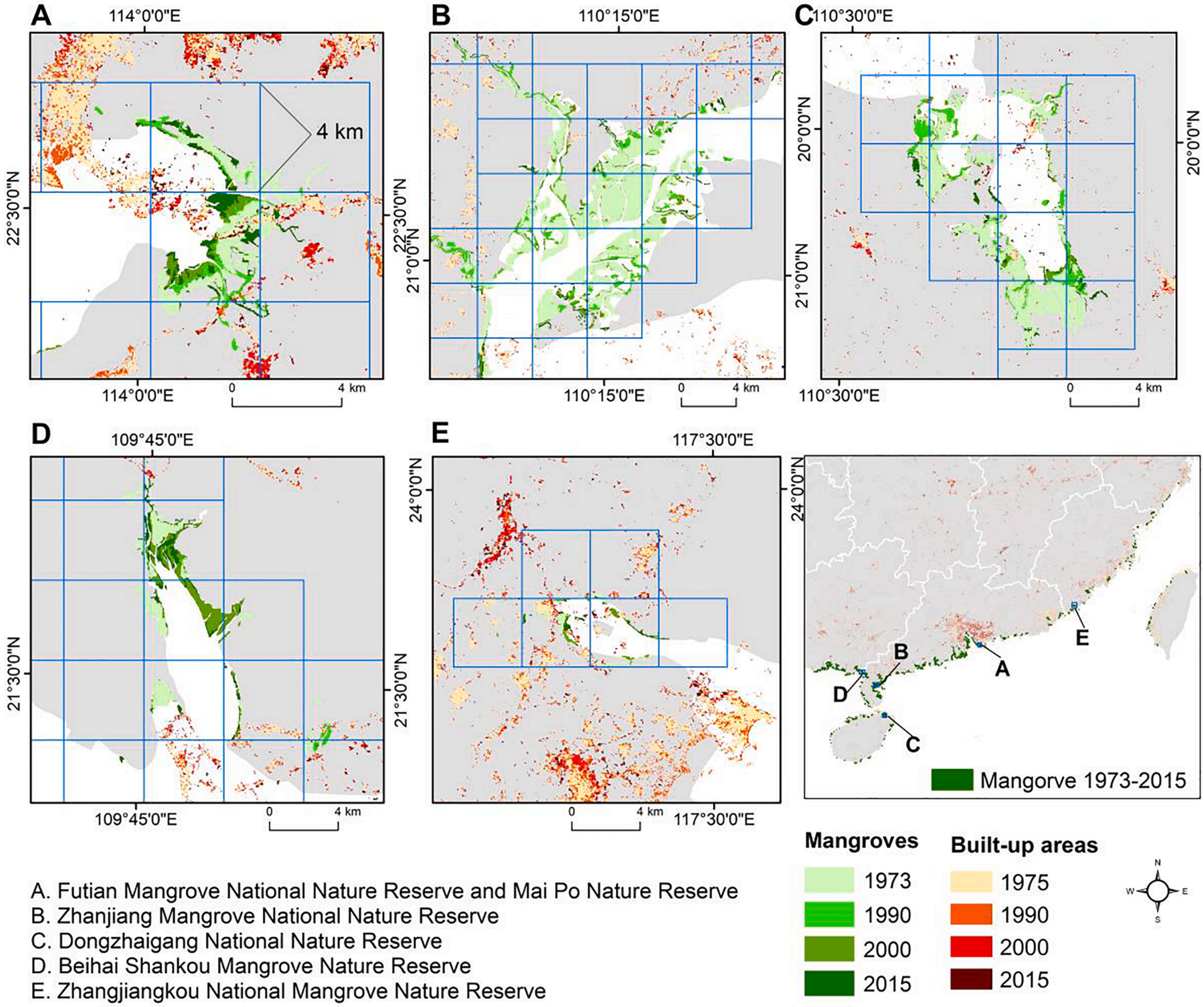

Fig. 7. Spatial distribution of mangroves and built-up areas in different periods.

Table 3
Grid-based urbanization and mangroves statistic.

		1973–1990	1990–2000	2000–2015
Total grid cells	Count	768	676	700
Inside nature reserves	Count	36	56	86
Mangroves change (ha)	Min	−577.84	−367.03	−249.69
	Max	205.63	181.76	248.42
	Mean	−36.76	−4.29	8.04
	STD	79.03	43.04	31.82
Built-up increase (ha)	Min	0	0	0
	Max	240.57	520.92	198.18
	Mean	7.96	14.17	9.79
	STD	23.77	40.65	22.81
Population density (people/ km^2)	Min	0	0	0
	Max	39355.95	54526.59	75834.02
	Mean	1568.03	2267.20	2447.30
	STD	3239.36	4767.81	5844.81

was more likely to occur outside nature reserves where it has experienced dramatic built-up expansion.

Selected association rules for 2000–2015 were shown in Table 6. Rule# 1 has the highest Confidence (0.765) and highest Lift value (2.478). Based on Rule# 1, 2, 13, 14, 15, 17, 18 with relatively high values of Confidence and Lift, no matter what urbanization pattern exists, mangroves were likely to increase within or near nature reserves during 2000–2015. Rule# 9 holds with the highest Support value of 0.517, and it indicates that the slight changes in mangroves were likely to occur outside nature reserves during this period. Based on Rule# 22, 23 with higher Lift values than Rule# 10, 11, it can be concluded that even there was significant built-up expansion, mangrove increase was more likely to occur outside nature reserves.

Only rules related to MC0 and MC1 were generated for the 1973–1990 period, consistent with the dramatic decrease in net change shown in Fig. 4. Moreover, only rules related to MC0 and MC2 generated for the 2000–2015 period, which is consistent with the increase in net change and minor mangrove loss. The apparent protective effect of nature reserves can be found from the association between NR1 and MC0 for the 1973–1990 period. However, a strong association between NR0 and MC0 was discovered both for both the 1990–2000 and 2000–2015 period, which indicated the slight changes of mangrove outside nature reserves. As indicated in Chen et al.'s study (2009), in addition to nature reserves established by the government, Chinese public recognized ecological values in the early 1990 s. Overall, mangroves inside nature reserves changed slightly during 1973–1990 and increased obviously during 2000–2015. For the mangroves outside nature reserves, the rules

Table 4
Association rules extraction for 1973–1990.

Rule ID	Policy	Urbanization	Mangroves	Support	Confidence	Lift
20	NR1	PD1	MC0	0.016	0.343	1.005
1	NR0	BUC1, PD1	MC1	0.132	0.561	1.075
3	NR0	BUC1	MC1	0.142	0.559	1.071
5	NR0	BUC1, PD0	MC1	0.010	0.533	1.021
7	NR0	PD1	MC1	0.466	0.533	1.020
9	NR0	BUC0, PD1	MC1	0.254	0.526	1.007
10	NR0	–	MC1	0.499	0.523	1.002
12	NR0	BUC0, PD0	MC0	0.025	0.500	1.466
14	NR0	PD0	MC0	0.035	0.450	1.319
16	NR0	BUC0	MC0	0.191	0.359	1.054
18	NR0	BUC0, PD1	MC0	0.167	0.345	1.011
21	NR0	–	MC0	0.326	0.342	1.001

Table 5
Association rules extraction for 1990–2000.

Rule ID	Policy	Urbanization	Mangroves	Support	Confidence	Lift
16	NR1	BUC1	MC1	0.018	0.462	1.545
17	NR1	BUC1, PD1	MC1	0.016	0.458	1.534
18	NR1	PD1	MC1	0.030	0.385	1.287
19	NR1	–	MC1	0.031	0.375	1.255
23	NR1	BUC1	MC2	0.013	0.346	1.708
25	NR1	BUC1, PD1	MC2	0.012	0.333	1.645
26	NR1	–	MC2	0.027	0.321	1.586
28	NR1	PD1	MC2	0.024	0.308	1.518
1	NR0	BUC1, PD0	MC0	0.016	0.733	1.471
4	NR0	PD0	MC0	0.044	0.600	1.204
5	NR0	BUC0, PD0	MC0	0.016	0.579	1.161
7	NR0	BUC0	MC0	0.194	0.555	1.113
8	NR0	BUC0, PD1	MC0	0.178	0.553	1.109
11	NR0	BUC1	MC0	0.164	0.521	1.045
12	NR0	–	MC0	0.473	0.516	1.035
13	NR0	PD1	MC0	0.429	0.509	1.021
14	NR0	BUC1, PD1	MC0	0.148	0.505	1.013
15	NR0	BUC2, PD0	MC0	0.012	0.500	1.003
20	NR0	BUC2, PD1	MC1	0.083	0.361	1.209
22	NR0	BUC2	MC1	0.089	0.351	1.174
31	NR0	PD1	MC1	0.253	0.300	1.004

Table 6
Association rules extraction for 2000–2015.

Rule ID	Policy	Urbanization	Mangroves	Support	Confidence	Lift
1	NR1	BUC0, PD1	MC2	0.019	0.765	2.478
2	NR1	BUC0	MC2	0.019	0.722	2.341
13	NR1	BUC2, PD1	MC2	0.019	0.565	1.832
14	NR1	BUC2	MC2	0.019	0.565	1.832
15	NR1	–	MC2	0.066	0.535	1.733
16	NR1	PD1	MC2	0.060	0.525	1.701
17	NR1	BUC1	MC2	0.029	0.444	1.440
18	NR1	BUC1, PD1	MC2	0.023	0.400	1.296
3	NR0	BUC1, PD0	MC0	0.011	0.667	1.181
4	NR0	BUC0, PD1	MC0	0.209	0.638	1.130
5	NR0	BUC0	MC0	0.223	0.632	1.119
8	NR0	PD1	MC0	0.489	0.592	1.049
9	NR0	–	MC0	0.517	0.590	1.045
10	NR0	BUC2, PD1	MC0	0.110	0.583	1.034
11	NR0	BUC2	MC0	0.113	0.572	1.014
22	NR0	BUC2	MC2	0.067	0.341	1.104
23	NR0	BUC2, PD1	MC2	0.061	0.326	1.056

showed a gradual weakening of impact of urbanization on mangroves as years goes by. We infer that the main reasons for these phenomena are the rising environmental awareness and declining human intervention during the urbanization process.

As presented in the rules for the 1973–1990 period, mangroves reduction was likely to occur where built-up areas increased. In this period, the impacts of urbanization on mangroves mainly manifested as the direct conversion of mangrove forests to urban construction. Tam and Wong (2002) stated that massive mangroves were converted to farmland in the 1970s; in the 1980s, mangrove mudflats were converted to ponds for aquaculture, including shrimps, fishes, and crabs; from the mid-1980s, urban construction and reclamation destroyed a large number of mangroves. Land reclamation has become the primary approach to conduct urban expansion in coastal regions.

Since the 1990s, China has made great efforts in mangrove conservation and reforestation (Chen et al., 2009). As a result, publics and local

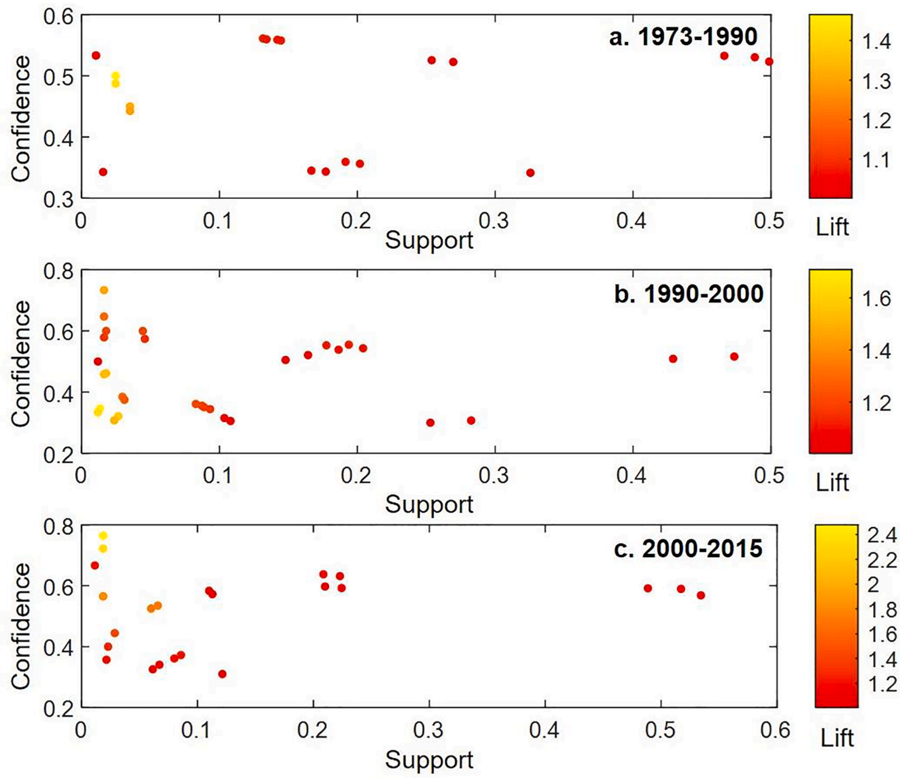

Fig. 8. Scatter plots of association indicators.

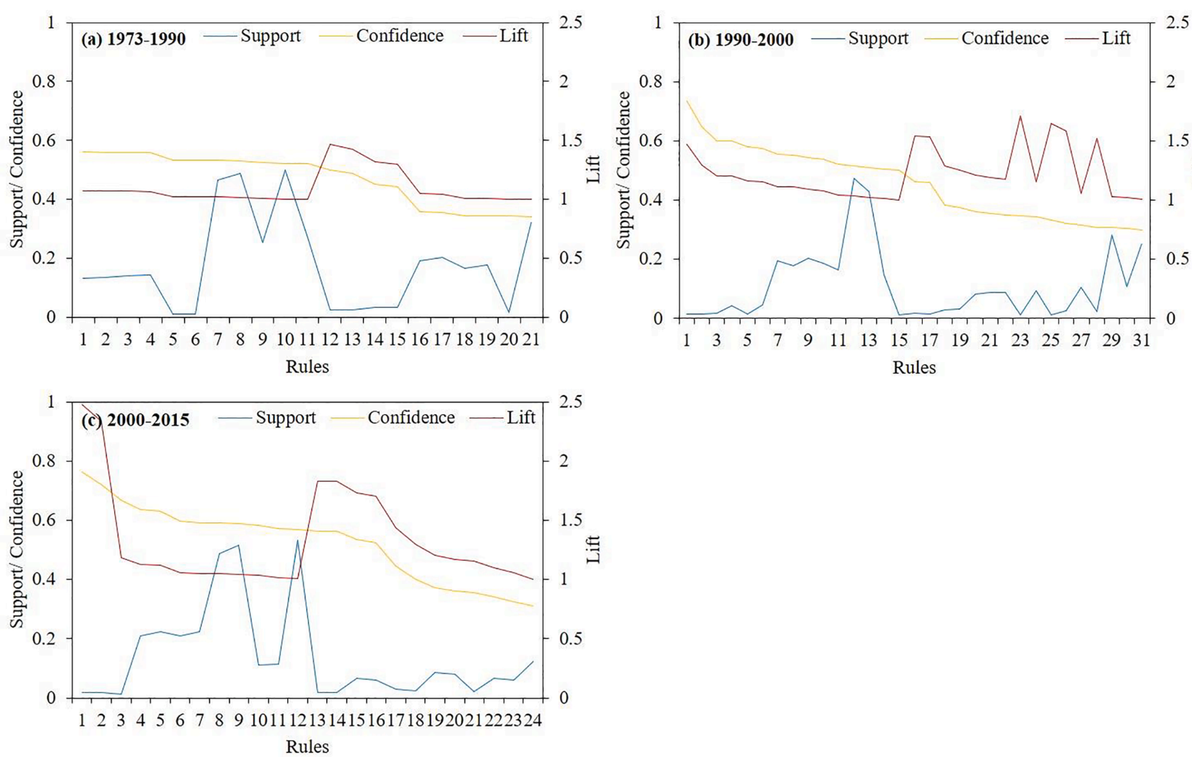

Fig. 9. Visualizations of association indicators.

communities realized the ecological and economic values of mangroves. From then, massive deforestation of mangrove is unlikely to recur. As presented in the rules for the last two period, mangroves changed slightly where even experienced built-up areas expansion. However, mangroves still being affected by wastewater charge, marine pollution, water transportation (Chen et al., 2009), which are related to the urbanization process to some extent. These phenomena may not directly cause the areal change of mangroves, but will threaten mangrove biodiversity and ecosystem functions.

5. Discussion

5.1. Reliability of the association rules

The GBAA method discovered several meaningful rules. One of the interest findings was that the correlation between urbanization and mangrove changes under the protection of nature reserves can be discovered. The results also proved the role and effectiveness of nature reserves and conservation policies. The data mining methods are inductive, not deductive, which are used to extract knowledge from observational datasets, not prove the pre-existing hypotheses (Mennis and Liu, 2005; Xu et al., 2018). Compared with conventional statistical methods, association mining method is able to employ categorical data. Thus, the characteristic of grid within nature reserve or not can be employed to analyze as an indicator. Although the optimal discretization of input numeric data remains to be confirmed, classification scheme in Table 2 was proved to be feasible. The areal changes of mangrove forests are the results of complex interaction among factors. GBAA method is capable of exploring the association among several indicator. Further research is needed to consider more possible factors on mangrove changes, such as sea level change and macro- climate change.

5.2. Urbanization and mangrove

Although previous studies revealed the negative relationship between urban expansion and mangrove loss. It is obvious that high level of urbanization and construction led to the conversion from wetland to residential, commercial, or industrial land in coastal regions and lead to pressure on mangrove ecosystem. However, the interaction and relationship between urbanization and mangrove system are complex and active. The human disturbances are reflected by the impacts on the structure and function of mangrove ecosystems, such as sediment loads and water quality (Lee et al, 2006). Influxes of sediment from urban construction provide harmful sediment to some mangrove species, and is also likely to accelerate new growth (Thomas et al., 2017). However, the sediment and nutrients from human activity, climate changes, and sea level rise may promote seaward or landward mangrove expansion (Alongi, 2018). Due to the increased environmental awareness and established conservation project during social urbanization process, massive deforestation of mangrove is unlikely to recur.

5.3. Uncertainty of the methodology

The datasets of mangrove and built-up areas distribution were extracted from satellite images. The accuracy of classification is affected by the spectral confusion in optical images among different land cover types, for example, the confusion between mangrove and mudflat, between impervious surface and bare soil (Lin et al., 2020). Another error source would be the length setting of grid cells. In our study, the length of 4 km depends on sensitivity analysis, which was proved to be feasible and effective. In this case, only the surrounding urban environment within 4 km grid cells were considered. Urban development within larger buffer zones may also affect mangrove growth. However, the optimal grid size is still uncertain. Due to the unavailability of the accurate locations and boundaries of nature reserves, the 3 km buffer zones of collected coordinate point of nature reserves were regarded as the extent of nature reserves in this study.

5.4. Limitation of the study

The impacts of urbanization on mangrove forests are complicated. Besides the spatial extent, a number of factors should be considered, including the species diversity, the community structures, carbon stock, and other aspects regarding the ecosystem services of the mangrove forests. From a geographic point of view, this study considers only the impacts of urbanization on the spatial changes of mangroves. In the future, more insightful studies are needed to provide a more comprehensive understanding of the impacts on mangroves from the human activities through urbanization process.

In this study, we consider the mangroves in whole China as the study object. Actually, due to the complex influence modes of urbanization on mangroves, local pattern of influences varies with multiple reasons. The areal changes of mangrove forests are the results of complex interaction among mangrove and urbanization-related factors. The impacts of urbanization on mangrove ecosystem at local scale will be explored in future studies.

6. Conclusions

In this study, the GBAA method was developed to explore the association between urbanization and mangrove changes in China, the role and effectiveness of conservation policy were also investigated. According to the discovered association rules, there are some findings for three periods: (1) For the 1973–1990 period, the conservation effort of nature reserves has been evaluated. Within the protected areas, the mangroves changed slightly. However, outside the nature reserves, mangrove reduction occurred where built-up increased slightly, and mangroves were stable where even no built-up area exists; (2) For the 1990–2000 period, in general, both mangrove decrease and increase were likely to occur within or near nature reserves. If there was no built-up area or built-up areas increased slightly, it was likely that the mangrove stayed stable outside nature reserves. Mangrove reduction was more likely to occur outside nature reserves where it has experienced dramatic built-up expansion; and (3) For the 2000–2015 period, mangroves increased dramatically within nature reserves no matter the degree of urbanization, which may be due to the implementation of mangrove conservation and restoration. Even in the region that experienced significant built-up expansion, mangrove increase was more likely to occur outside nature reserves; it may be due to the fact that people raised their awareness of protecting mangroves and wetlands.

Overall, it has been found that the conservation policy and establishment of nature reserves have made significant achievements in mangrove conservation and restoration. Moreover, the urbanization process has not significantly damaged mangroves in China. Outside nature reserves, the impact of urbanization on the spatial extent of mangrove forests weakened gradually during 1973–2015.

An advantage of the proposed GBAA method is that non-numeric data of conservation policy can be incorporated into quantitative analysis. The limitation of this method is that the obtained rules strongly depend on the accuracy of source datasets, grid size determination, indicator categorization. Although the optimal technical settings of methodology remain to be confirmed, the GBAA method exhibits good performance in exploring the associations. The results exemplify the effectiveness of nature reserves in mangrove conservation from 1973 to 2015 in China.

Funding source

This study was jointly supported by the Research Grants Council (RGC) of Hong Kong (HKU27602020, HKU14605917), the National Natural Science Foundation of China (42022061 and 42071390), and The University of Hong Kong (201909185015 and 202011159112).

CRediT authorship contribution statement

Shan Wei: Formal analysis, Visualization, Writing - original draft. **Yinyi Lin:** Data curation, Writing - review & editing. **Luoma Wan:** Validation, Writing - review & editing. **Guanghui Lin:** Writing - review & editing. **Yuanzhi Zhang:** Writing - review & editing. **Hongsheng**

Zhang: Conceptualization, Supervision, Funding acquisition, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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