

The Response Relationship between Land Use/Land Cover and Watershed Lagged Effect based on Different Time Scales—A Case Study in Central Guizhou of China*

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The response relationship between land use/land cover and watershed lagged effect based on different time scales--a case study in Central Guizhou of China*

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Abstract: As we all know, the drought occurrence indicates that there is no rainfall or little rainfall in a certain period. However, the no or little rainfall does not mean that the droughts must be occur, and the occurrence of droughts shows a certain lag in the different areas. This paper analyzes the characteristics of watershed lagged effects and human activities in Central Guizhou of China (CGC) by the Lagged Index (*LI*) and Landscape Index (*LI*) based on the land use data, rainfall and runoff data during the periods of 1971-2016. The results show that the influence difference of the same land use type on the lagged intensity was particularly significant ($P < 0.001$) in the different ages (1970s-2010s). Among them, it gradually increased for the impacts of the wood land, grass land and cultivated land on the lagged intensity with the increasing of ages, and reached the maximum in the 2000s, and reached the maximum in the 2000s, while it did not change significantly for the water land and construction land. The impact of land use type transfer on watershed lagged effects is particularly significant ($P < 0.001$). Among them, it gradually increases for the wood land transfer with the prolongation of lagged periods, and reaches the maximum for the construction land transfer in the lag-1 period (X_{t-1}), and is not significant for the rest type transfer. The impact differences of the principal components (*Zs*) on watershed lagged effects are particularly significant for the morphological characteristics of land use types in different lagged periods ($X_{t-0}-X_{t-3}$), and different ages (1970s-2010s), as well as the different time scales (1-12 months). Among them, it is the largest for the impact of grass land and water land on watershed lagged intensity, and gradually increases with the increasing of time scales (the maximum in the 9-month scale), followed by the wood land and cultivated land with the maximum in the 9- and 6- month scales, respectively. And it is the smallest for the construction land, and gradually increases with the increasing of time scales (the maximum in the 9-month scale).

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26 **Key words:** Lagged effect; Watershed water storage; Human activities; Karst drainage basin.

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29 **1. Introduction**

30 As we all know, the drought occurrence indicates that there is no rainfall or very little rainfall in a certain period,
31 while it does not mean that the drought must be occur without rainfall or little rainfall in some periods. There is a
32 certain lag for the occurrence of droughts in different regions, and its lag time and intensity are greatly affected by
33 watershed water-stored capacity. Therefore, the drought is more influence by the watershed water storage (soil, aquifer,
34 lake, river) whether than by the rainfall deficit. It means that drought may occur in high flow seasons (van Loon, 2013).
35 Hence the study on driving mechanism of watershed lagged effects will contribute to the monitoring and prediction of
36 Karst drought.

37 There are the double aquifer media and double water system structures on the surface and underground in Karst
38 drainage basins where it has the *sieve* and *threshold* effects on the atmospheric precipitation, which will affect the
39 watershed runoff recharge, and show the special hydrological effects. For example, compared with the non-Kart basins,
40 the peak runoff modulus, low flow modulus and Coefficient of Variation (C_v) in Karst basins tend to a similar and stable
41 value with the increasing of basin spatial scales (Liang et al., 1995 & 1997) . The different spatial scales of Karst
42 basins and different spatial coupling of landform types will have great differences on the impact of flood peak effects.
43 The studies show that it is represented the positive proportional relationship between the flood peak and basin area in
44 the non-Kart basins, and a special relationship in the medium and small Karst basins (Liang, et al., 1998) . In the Karst
45 areas, lithology is an important component of basin underlying media, and its lithologic type and structure will control
46 the development of the landform and water system, promote the formation of watershed water-stored spaces and affect
47 the watershed water-stored capacity (he et al., 2015). For example, the higher the limestone proportion is, the smaller
48 the low flow modulus is, and the higher the dolomite proportion is, the larger the low flow modulus is. The higher the

49 proportion of peak-cluster depression is, the smaller the low flow modulus is, and the larger the proportion of Feng Lin
50 plain (basin) is, the higher the low flow modulus is (Wang et al., 2002) . In terms of the relationship between the
51 structure and function of soil systems, He et al., (2013a & 2013b) analyzed the influences of a single factor,
52 multi-factor coupling of soil single factor, as well as the soil multi-factor coupling on the watershed water-stored
53 capacity, and revealed the driving mechanism of watershed water-stored capacity to hydrological droughts. They found
54 that the order of the influences of soil four factors on hydrological droughts is Soil Relative Roughness ($R=0.968$)>Soil
55 Relative Coverage ($R=0.56$)>Soil Relative Humidity ($R=0.558$)>Soil Type ($R=0.464$). Similarly, hydrology drought is
56 more influenced by the patch density and maximum patch distributions of land use types than by the patch edge and
57 shape distributions. The larger the patch fractal dimension index of land types, the smaller the impact of land use type
58 distributions on hydrological droughts (He et al., 2014).

59 In summary, there are many types of media (lithology, soil, vegetation and land use, etc.), impure texture and
60 complex structure in Karst drainage basin. Such as different sizes of dissolution gaps and holes and pipes, formed under
61 the differential erosion or dissolution effects of soluble water, will provide the spaces and places for the atmospheric
62 precipitation lagged flow on the surface and underground. And it results in the basins having a certain water-stored
63 capacity (He et al., 2013a, 2013b ,2014 & 2015), as well as the different hydrological responses to climate changes in
64 the different time scales (López-Moreno et al.,2013). For instance, to explore the propagation process from the
65 meteorological to hydrological drought, Li et al., (2020a) quantified the meteorological drought, hydrological drought,
66 agricultural drought and vegetation drought by the drought indices, such as the Standardized Precipitation Index (*SPI*),
67 Standardized Runoff Index (*SRI*), Standardized Streamflow Index (*SSI*) and Vegetation Health Index (*VHI*).It is found
68 that the propagation time is within one month from meteorological to hydrological drought, within two months from
69 hydrological to soil moisture, and between two to three months from hydrological to vegetation drought. The lag
70 response time of agricultural drought to meteorological drought and hydrological drought to agricultural drought has
71 obvious seasonal characteristics with the spring and winter longer, autumn and summer shorter (Li et al., 2020b).

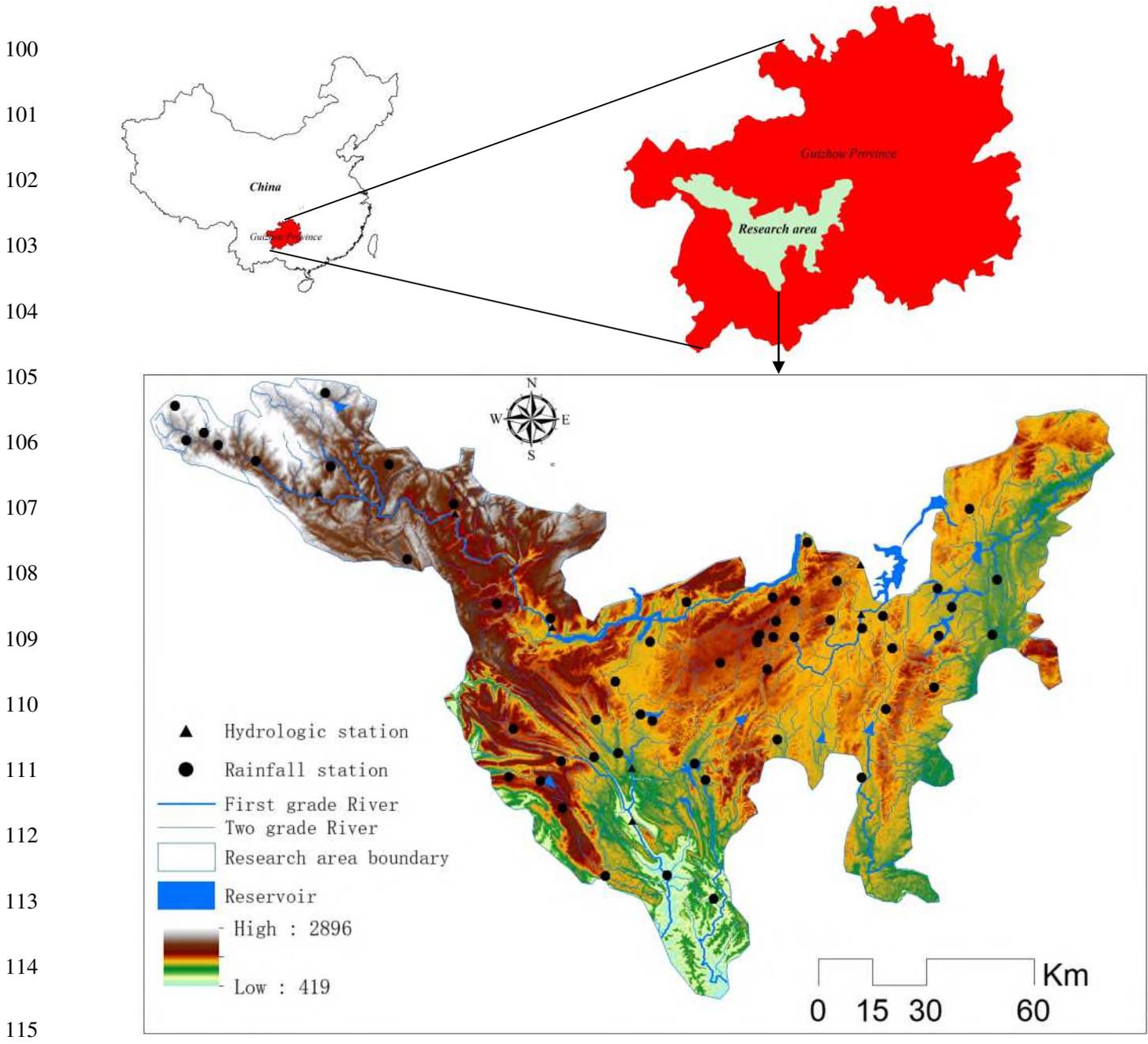
72 Meanwhile, the lagged effect of hydrological drought on meteorological drought has particularly significant differences
73 in the different basins, and the climate and land use/land cover are the main factors affecting the propagation process
74 from the meteorological to hydrological drought (Zhao et al., 2019; Zhou et al., 2019). The response of vegetation to
75 rainfall varies with the changing of soil types. It is found that there is a linear relationship between the *NDVI* and
76 rainfall when the rainfall is lower than the *saturation* threshold. However, the *NDVI* value increases slightly only with
77 additional rainfall when the rainfall exceeds the threshold (Nicholson et al., 1994; Niu et al., (2018).

78 Therefore, this paper will firstly judge the lagged response of runoff to rainfall by the distribution-lagged
79 regression model in Central Guizhou of China (CGC), and calculate the Lagging Index (*LI*) based on the meteorological
80 and hydrological data during the periods 1971-2016. Secondly, to simulate the human activities of the 1970s, 1980s,
81 1990s, 2000s and 2010s based on land use/land cover data of the 1975, 1985, 1995, 2005 and 2015, respectively. To
82 analyze the spatial-temporal evolution characteristics of human activities in the CGC. Finally, it is discussed for the
83 driving mechanism of human activities on watershed lagged effect. Therefore, the research of this paper will establish a
84 theoretical basis for the monitoring and prediction of droughts in Karst drainage basins.

85 **2. Study areas**

86 Qianzhong Regions are located in Central Guizhou of China (CGC) enclosed by the eastern longitudes of
87 $104^{\circ}19'10''\sim 107^{\circ}1'11''$ and northern latitudes of $25^{\circ}24'30''\sim 26^{\circ}52'30''$ with an area of 1,6563.5 Km² and an average
88 elevation of 1367.02 m (Fig. 1). The climate belongs to the subtropical monsoon humid climate area with the annual
89 average precipitation 850~1510 mm. A high value areas of rainfalls are formed in the Puding, Zhenning, Anshun to
90 Zhijin. The rainfall volumes are decreasing from the middle to the northwest and eastward in Qianzhong Regions, with
91 the largest (1508.2 mm) in the Liuzhi Station and the smallest (854.2 mm) in the west of the Hezhang Station. The
92 annual precipitation varies little with the uneven distribution within a year, and the precipitation is concentrated in
93 summer, accounting for about 80% of the annual precipitation. The study area is located in the wide and gentle slope
94 zone that is the Karst Hilly Landform of Yunnan-Guizhou Plateau, and the Second Step of Eastern Slope and Dividing

95 Ridge of Yangtze River and Pearl River Basins. The north of the ridge line belongs to the Wujiang River System in the
96 Yangtze River Basin. It mainly includes the main stream of Sancha River and its tributaries, Baiyan River, Laolongqiao
97 River, Boyu River, Chengguan River, Maotiao River and Nanming River, etc. The south of the ridge line belongs to the
98 Beipanjiang and Hongshui river water systems in the Pearl River Basin. It mainly includes the Wanger River and Baling
99 River of Beipan River tributaries, and the Maoying River and Getu River of the Hongshui River tributaries, etc.



116 Fig. 1 Distribution Diagram of Research Areas

117 **3. Data and Methods**

118 3.1 Land use/land cover data

119 The land use/land cover changes were represented by the land use data of 1975, 1985, 1995, 2005 and 2015 in this
120 paper, which was mainly come from the resource and environmental science and data center (<http://www.resdc.cn>)
121 (Resource and Environment Science and Data Center, China) (Fig.2). The land use types was divided referring to the
122 *National Classification System for Remote Sensing Monitoring of Land Use / Land Cover*, which was considered the
123 primary and secondary classification standards in this paper.

124 3.2 Rainfall and hydrological data

125 Rainfall and hydrological data used in this paper were come from the *Hydrology Statistical Yearbook* compiled by
126 Ministry of Water Resources of the People's Republic of China^①. We selected the monthly measurement data of 56
127 rainfall stations and 11 hydrological stations from 1971 to 2016. Considering the influence of basin areas, the rainfall
128 and hydrological data were standardized in this paper.

129 3.3 Lagging index

130 Firstly, we analyzed and judged the lagged effect using the cross y, x of Eviews 9.0. It was judged that the lagged
131 effect of runoff on rainfall in Karst drainage basins is overall shown as three periods (lag months 3).

132 Secondly, the PDL of Eviews 9.0 was used to build the distribution-lagged regression model, namely,

133 LS $y = \alpha + \text{PDL}(x, k, m, d)$

134 The distribution-lagged regression model was calculated as follows:

$$135 \quad y_t = \alpha + \sum_{i=0}^k \beta_{t-i} X_{t-i} + \mu_t \quad (1)$$

136 Where y_t represents the runoff volume at the t-th time, β_{t-i}, X_{t-i} represent the lagged coefficient and variable
137 (rainfall volume) at the t-th time, i-th period, respectively. $\beta_{t-i} X_{t-i}$ is the lagged-flow volume in the i-th period for
138 the t-th time rainfall. It means that the smaller the value of $\beta_{t-i} X_{t-i}$, the smaller the lagged-flow volume, and the

① Hydrologic Year Book of People's Republic of China *Hydrologic Data of Yangtzi River Basin*, Volume 6 and *Hydrologic Data of Pearl River Basin*, Volume 8.

139 stronger the lagged effect. Or the contribution rate of the i -th lagged variable (X_{t-i}) to the current period variable (Y_t)
 140 is small. μ_t represents a random variable at the time t . α is a constant, k represents a length of lagged periods, m is a
 141 polynomial order, and d is a controlling parameter of lagged characteristics, respectively. Among them, $k=3$, $m=2$, and d
 142 is the defect value in this paper.

143 Finally, to calculate the Lagging Index (LI) that can be expressed as follows:

$$144 \quad LI_{i,s} = \frac{V_{i,s} - \bar{V}_i}{S_i}, \quad i = 0,1,2,3, \quad s = 1,2, \Lambda, 6 \quad (2)$$

145 Where $V_{i,s} = \beta_{t-i} X_{t-i}$ represents the lagged-flow volume at the s -th reference period, i -th lagged period.
 146 \bar{V}_i, S_i represent the mean value and standard deviation of lagged-flow volume at the i -th lagged period, respectively.
 147 In this paper, $i=0$ represents the lag-0 period (i.e., current month), $i=1$ represents the lag-1 period (lag month 1), ... $i=3$
 148 represents the lag-3 period (lag months 3), and $s=1$ represents the 1960s, $s=2$ represents the 1970s, ..., $s=6$ represents
 149 the 2010s, respectively.

150 LI is positive, indicating normal (i.e., no lagged effect). LI is negative, and the larger the absolute value, the more
 151 serious the lagged intensity (He et al., 2018a & 2018b).

152 **4. Results and analysis**

153 *4.1. Spatial distribution pattern and evolution characteristics of land use/land cover*

154 *4.1.1 Analysis of land use type characteristics*

155 (1) In general, the land use types in Central Guizhou of China (CGC) were mainly shown the wood land (41.2%),
 156 cultivated land (30.4%), grass land (26.6%), construction land (1.37%), water land (0.355) and unused land (0.02%) in
 157 the 1970s-2010s (Fig. 2). It means that there was great difference of human activity intensities in the 1970s-2010s. (2)
 158 The spatial distribution differences of different land use types are larger ($C_v=1.1$) within a year (age). Among them, the
 159 wood land and cultivated land are mainly distributed in the Central, Eastern and Southern of research areas with the
 160 Puding as the center, as well as in the Northwest of Liupanshui. The grass land is distributed in the Southeast of

161 Liupanshui, and the water land is scattered distributed in the central part with Puding as the center. Indicating that the
162 interconversion rate between different land use types is larger within the same period (age), namely, human activities
163 are stronger. (3) The spatial distribution difference of the same land use type is smaller ($C_v=0.1$) between different
164 periods (ages). Among them, there are no differences ($C_v=0.0$) for the spatial distributions of wood land, grass land and
165 unused land. Indicating that the interconversion rate of same land use type is smaller between different periods (ages),
166 namely, the differences of human activity intensities are not significant.

167 4.1.2 Evolution analysis on spatial pattern of land use/land cover

168 (1) In general, the overall changing rate of land use/land cover in the CGC was shown an upward trend in the
169 1970s-2010s. Among them, the changing rate of land use types was 1.26% in the 2000s-2010s, 0.53% in the
170 1990s-2000s, 0.01% in the 1980s-1990s, respectively. By comparison, the overall changing rate of land use types in the
171 CGC was the largest in the 2000s-2010s, the smallest in the 1980s-1990s. Meaning that the land use/land cover changes
172 were relatively rapid and human activities more intense in the 2000s-2010s, and relatively slow and human activities
173 relatively gentle in the 1980s-1990s (Fig. 3a). (2) The annual variation rate of the same land use type was larger
174 between different periods (ages), and showed a *positive-negative* difference (Figs.3 b-e). Among them, the negative
175 change was found in cultivated land and grass land in the 1970s-1980s, positive change in the rest types; and there was
176 negative maximum (-45.74%) for the cultivated land changes, and positive maximum (10%) for the unused land
177 changes (Fig. 3b). There was negative change observed in the cultivated land (-32.1%) and grass land (-40.96%) in the
178 1980s-1990s, positive change in the wood land (8.86%), and no change in the rest types (0%) (Fig. 3c). A negative
179 change (-49.89%) for the wood land in the 1990s-2000s, and a positive or no change for other types (Fig. 3d). The
180 negative change was presented in the cultivated land, grass land and unused land, and positive change in the rest types.
181 It is the negative maximum (-13.83%) in the grass land and positive maximum (10%) in the water land (Fig. 3e). (3) In
182 summary, a decreasing trend was found in the cultivated land and grass land areas in the 1970s-2010s, an increasing
183 trend in the water land and construction land areas, and the increasing and decreasing trends in the woodland and

184 unused land areas. Among them, there was the fastest declining rate of areas for the cultivated land (-45.74%) in the
185 1970s-1980s, the wood land (-49.89%) in the 1990s-2000s, and the grass land (-40.96%) in the 1980s-1990s,
186 respectively. And there was the fastest increasing rate of areas for the wood land (10%) and construction land (9.62%)
187 in the 2000s-2010s. However, the unused land area was decreased from the positive maximum (10%) in the
188 1970s-1980s to the negative maximum (-1.85%) in the 2000s-2010s.

189 4.1.3 Morphological characteristics analysis of land use types

190 The morphological characteristic of land use types is an important parameter reflecting land use/land cover, and an
191 important index reflecting human activities. The 48 indicators of morphological characteristics, such as the Largest
192 Patch Index (*LPI*) (Range: $0 < LPI \leq 100$), Edge Density (*ED*) (Range: $ED \geq 0$), as well as the Shape index (*SHAPE*)
193 (Range: $SHAPE \leq 1$) and Fractal dimension index (*FRAC*) (Range: $1 \leq FRAC \leq 2$), were extracted based on the land use
194 data of 1975, 1985, 1995, 2005 and 2015 by the Software Package of Fragstats 4.0 in this paper (Fig.4). And for the *LPI*,
195 *ED*, *SHAPE* and *FRAC* were analyzed as follows.

196 (1) In general, the *LPIs* have more differences between different land use types. Among them, the largest *LPI* is the
197 grass land (4.0-7.0), followed by the wood land (4.0-5.0) and cultivated land (4.0-4.5), and the smallest (0.1) the water
198 land. It demonstrates that the relatively concentrated and continuous the grassland distribution is, and the relatively
199 scattered and broken the water land distribution. There was more difference for the *LPI* of grass land, an increasing
200 trend with the increase of years (ages) in the 1970s-2010s, followed by the wood land and cultivated land, and no
201 difference for the unused land, construction land and water land. It indicates that there is larger impact of human
202 activities on wood land and cultivated land than on grass land in the 1970s-2010s, not significant impact on the unused
203 land, construction land and water land (Fig.4a). (2) The Fig.4 shows that the most complex the patch boundary
204 condition of cultivated land is, followed by the wood land and grass land, and the relatively single the unused land,
205 construction land and water land. Meanwhile, the patch boundary conditions of six types of land use/land cover varied
206 little with the increasing of years (ages) in the 1970s-2010s. (3) The *SHAPE* of six types of land use/land cover is less

207 than 1, which indicates that the relatively complex the patch shape distributions of six types of land use/land cover are.
208 Among them, there is relatively smaller (<0.3) for the *SHAPEs* of the wood land, grass land and cultivated land, and
209 relatively larger (<0.6) for the he unused land, construction land and water land. Meanwhile, the *SHAPEs* of six types of
210 land use/land cover changed less with the increasing of years (ages) in the 1970s-2010s, which indicates that there is
211 smaller impact of human activities on shapes of land use types in different years (ages) (Fig.4c). (4) Similarly, the
212 *FRACs* of six types of land use/land cover are greater than 1, and remain basically unchanged with the increasing of
213 ages (Fig.4d). Indicating that the patch shapes of six types of land use/land cover are relatively complex, and the smaller
214 differences between the different years (ages), which shows that there is smaller impact of human activities on shapes of
215 land use types (Fig.4d).

216 *4.2 Response relationship between the land use/land cover and watershed lagged effect*

217 *4.2.1 Response relationship between land use type and watershed lagged effect*

218 (1) In general, the land use/land cover all have some impacts on the watershed lagged effects, and different types
219 of land uses show a *positive and negative* differences. Among them, the positive effect on the lagged intensity is found
220 in the wood land and water land, the negative effect in other types, and the effect on the lagged frequency is just the
221 opposite (Figs.5,6). (2) The impact difference of the same type of land use/land cover on watershed lagged effect is
222 larger in different time scales (1-12 months). Among them, the largest impact difference on lagged intensity is found in
223 the wood land and grass land, and it is gradually decreased with the increase of time scales, followed by the cultivated
224 land and construction land, and the smallest in the water land and unused land increased with the increase of time scales
225 (Fig.5). The largest impact difference on lagged frequency is observed in the wood land, and it is declined with the
226 increase of time scales, followed by the grass land and cultivated land with the optimal time scales of 3-month and
227 6-month, respectively, and the smallest in the construction land, water land and unused land with the optimal time scales
228 of 3-month (Fig.6). On the whole, the impact differences of different types of land use/land cover on watershed lagged

229 intensity/frequency are particularly significant ($P<0.001$) in the same time scale by the variance analysis. Especially the
230 F value of the impacts on lagged intensity is the largest (199.735) in the 3-month scale, and that of the impacts on
231 lagged frequency is gradually decreasing with the increase of time scales. Meanwhile, the coupling impacts between
232 land use types and time scales (1-12 months) on the watershed lagged frequency are particularly significant ($P=0.02$),
233 but the impacts on the watershed lagged intensity do not pass the significance test ($P>0.05$). (3) Except for the unused
234 land, the impact difference of the same type of land use/land cover on watershed lagged intensity was particularly
235 significant ($P<0.001$) in the 1970s-2010s. Among them, the impact difference was gradually increasing for the wood
236 land, grass land and cultivated land with the increase of time scales, and reached the maximum for the cultivated land in
237 the 2000s. However, the impact difference was smaller for the water land and construction land with the change of ages
238 (Fig. 5). It was very significant ($P<0.001$) for the influence difference of the wood land, grass land and unused land in
239 the 1970s-2010s, and very small ($P>0.05$) for the cultivated land, water land and construction land (Fig. 6). The impact
240 difference of different types of land use/land cover on watershed lagged effect was particularly significant ($P<0.001$)
241 in the same age. Especially the impact of different types of land use/land cover on lagged intensity was gradually
242 increasing with the increase of ages, and reached the maximum in the 2000s with the F value 280.15, and the impact on
243 lagged frequency was the largest in the 1970s with the F value 57.78 (Figs. 5,6). Meanwhile, the coupling influence
244 between different types of land use/land cover and different ages on the lagged intensity/frequency is particularly
245 significant ($P<0.001$). (4) It does not pass the significant test ($P>0.05$) for the influence of the same type of land
246 use/land cover on lagged effect in different lagged periods ($X_{t-0}-X_{t-3}$), and is particularly significant ($P<0.001$) for
247 different types of land use/land cover in the same lagged period. Especially the influence on lagged intensity, the F
248 value gradually increases with the prolongation of lagged periods, and reaches the maximum (179.176) in the lag-2
249 period. And the impact on lagged frequency tends to increase first, then decrease, and then increase again. The coupling
250 impact between different types of land use/land cover and different lagged periods on watershed lagged effect does not
251 pass the significance test ($P>0.05$).

252 4.2.2 Response relationship between land use type transfer and watershed lagged effect

253 (1) The impacts of the land use type transfer on the watershed lagged effects is very significant ($P < 0.001$) with a
254 *positive and negative* difference shown as the Fig.7. Among them, the positive impact of land use type transfer on the
255 watershed lagged intensity was observed in the wood land (1970s-1990s & 2000s-2010s) and water land (1980s-2000s),
256 the negative impact in the rest types. And the positive impact of land use type transfer on the watershed lagged
257 frequency was found in the cultivated land (1970s-1980s & 1990s-2000s), grassland (1980s-2000s) and construction
258 land regions, the negative impact in other types. (2) The impact difference of land use type transfer on the watershed
259 lagged effect was particularly significant ($P < 0.001$) with the changing of ages (1970s-2010s). Among them, the R
260 absolute value of impacts between the wood land and grass land on lagged intensity was shown the same changing
261 direction, namely, a *increase-decrease-increase* trend, and just the opposite in the cultivated land, presented a
262 *decrease-increase-decrease* trend. There was an *inverted V-shape* in the water land reached the maximum in the
263 1990s-2000s, and the smaller in the construction land and unused land. And the R absolute value of the impacts on the
264 lagged frequency was appeared an *increase-decrease-increase* trend in the wood land and grass land, and a
265 *decrease-increase-decrease* trend in the cultivated land and unused land. While it was an *inverted V-shape* in the water
266 land and a gradually decline in the construction land. The coupling impact between land use types and age factors on
267 watershed lagged effect is particularly significant ($P < 0.001$). (3) The impact difference of land use type transfer on
268 watershed lagged effect is not significant ($P > 0.05$) between different lagged periods ($X_{t-0} - X_{t-3}$). However, the impact on
269 lagged intensity gradually increases for wood land transfer with the prolongation of lagged periods, and reaches the
270 maximum for the construction land transfer in the lag-1 period (X_{t-1}), and changes little for other types. The R absolute
271 value of the influences on lagged frequency is shown an *inverted V-shape* for the transfer of grass land and wood land,
272 that is, the maximum in the lag-1 period (X_{t-1}) and lag-2 period (X_{t-2}), respectively. There is a *V-shape* for the transfer of
273 water land and cultivated land, and reaches the minimum values in the lag-1 period (X_{t-1}) and lag-2 period (X_{t-2}), and
274 shows an *increase-decrease-increase* trend for that of the unused land.

275 4.2.3 Response relationship between the characteristics of land use types and watershed lagged effects

276 To eliminate the correlation between different indicators of morphological characteristics for land use types and
277 reduce the number of variables, the 48 indices of morphological characteristics were made the principal component
278 analysis in this paper, and were extracted the principal components with the eigenvalue greater than 1. Therefore it
279 extracted the six principal components (Z_1 - Z_6) of the cultivated land and grass land, five principal components (Z_1 - Z_5) of
280 the wood land, five and six principal components (Z_1 - Z_5 , Z_6) of the water land, and four principal components (Z_1 - Z_4) of
281 the construction land. However, it is relatively small for area percentage of unused land, and is not significant for the
282 morphological characteristics. Thus the principal component analysis was not carried out (Figs. 8-10).

283 (1) In general, the Z_s of land use types all have some the influences on watershed lagged effect in different lagged
284 periods (X_t - X_{t-3}), different ages (1970s-2010s) and different time scales (1-12 months), and show the *positive and*
285 *negative* differences. Among them, the impact of grass land on lagged intensity/frequency is the largest, followed by the
286 water land and wood land, and the smallest in the cultivated land and construction land. The impact of the Z_s on lagged
287 intensity is overall shown a *negative-positive-negative* phenomenon for the morphological characteristics of wood land,
288 grass land and construction land, a *negative-positive alternating* phenomenon for the cultivated land (Z_1 - Z_6) and water
289 land (Z_1 - Z_5). There is just the opposite of the impacts on lagged frequency (Fig.8). The impact on lagged intensity was
290 observed a *negative-positive alternating* phenomenon for the Z_1 - Z_6 of cultivated land in the 1970s-2010s, a
291 *negative-positive-negative* phenomenon for the Z_1 - Z_4 of construction land, and more complex for other types. However,
292 it was just the opposite for the influence on lagged frequency (Fig.9). The impact of the Z_s on lagged intensity is
293 appeared a *negative-positive alternating* phenomenon for cultivated land (Z_1 - Z_6) and water land (Z_1 - Z_5) in different time
294 scales (1-12 months), a *negative-positive-negative* phenomenon for wood land, grass land and construction land.
295 However, it is just the opposite of influences on lagged frequency (Fig.10). (2) The impact difference of different Z_s on
296 lagged effect is particularly significant ($P < 0.001$) for the morphological characteristics of single land use type in
297 different lagged periods (X_{t-0} - X_{t-3}), different ages (1970s-2010s) and different time scales (1-12 months). Among them,

298 the F value of the largest impact on lagged intensity/frequency is found in the grass land in the X_{t-0} - X_{t-3} , followed by the
299 water land and wood land, and the smallest in the cultivated land and construction land. And that of the impact on
300 lagged intensity/frequency is more larger in construction land than in cultivated land and woodland in the 1970s-2010s,
301 and the smallest in the water land and grass land (Fig.9). The F value of the impacts on the lagged intensity/frequency is
302 the grass land>water land and cultivated land>wood land and construction land in the 1-12 month scales (Fig.10).
303 Meanwhile, the influence differences of the Z_s on lagged intensity/frequency are also significant ($P<0.001$) in the
304 X_{t-0} - X_{t-3} ,1970s-2010s and 1-12 month scales, respectively (Figs.8,9,10). (3) For the Z_s of morphological characteristics
305 of single land use type in the X_{t-0} - X_{t-3} , the R absolute value of the impacts on lagged intensity is the grass land and water
306 land (lag-2 period)>cultivated land (lag-2 period) and wood land (lag-1 period)>construction land (lag-2 period). The R
307 absolute value of the impacts on lagged frequency gradually increases for the Z_s of grass land, water land, wood land
308 and construction land with the prolongation of lagged periods, and reaches the maximum in the lag-3 period (X_{t-3}).And
309 it is the largest for the cultivated land in the lag-2 period (X_{t-2}) (Fig.8). The R absolute value of the Z_s impacts on the
310 lagged intensity was the largest for the grass land in the 1970s-2010s, and gradually decreased for the cultivated land,
311 water land and wood land with the increase of years (ages). And that of the Z_s impacts on the lagged frequency was the
312 largest for the cultivated land and grass land with the maximum in the 1980s,and gradually declined for the wood land
313 and water land with the increase of years (ages),and varied little for the construction land (Fig.9). The R absolute value
314 of the influences on lagged intensity is to increase for the Z_s of land use types in the 1-12 month scales. Among them, it
315 is the largest for the grass land and water land, and reaches the maximum in the 9-month scale, followed by the wood
316 land (the maximum in the 9-month scale) and cultivated land (the maximum in the 6-month scale),and the smallest for
317 the construction land (the maximum in the 9-month scale). And with the increase of time scales, that of the influences
318 on lagged frequency is to increase for the cultivated land, wood land and construction land, and to decline for the grass
319 land and water land. Among them, there is the largest in the cultivated land with the maximum in the 9-month scale
320 (Fig.10).

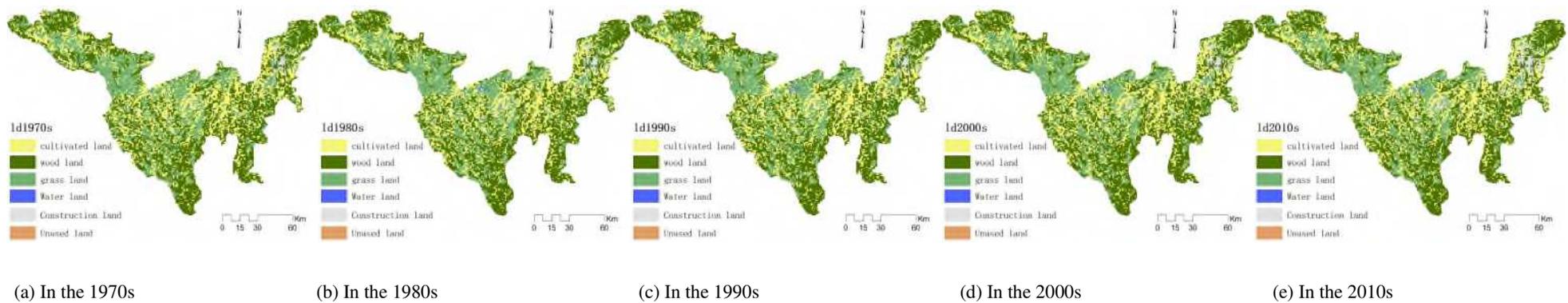


Fig. 2 Spatial distribution pattern of land use types in the 1970s-2010s

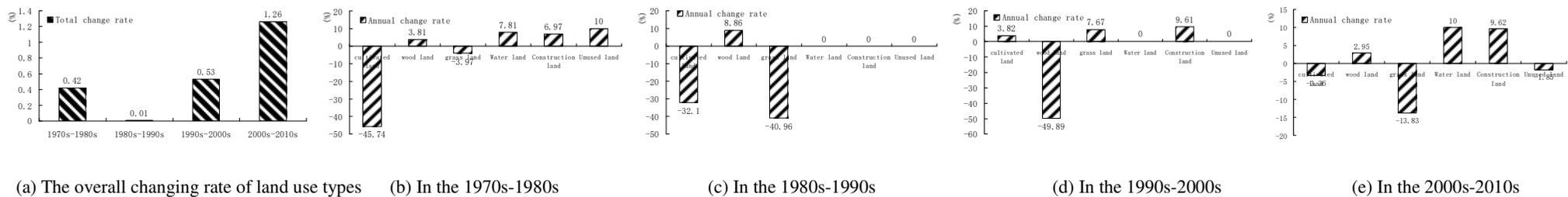


Fig.3 The changing rate of land use types in the different ages

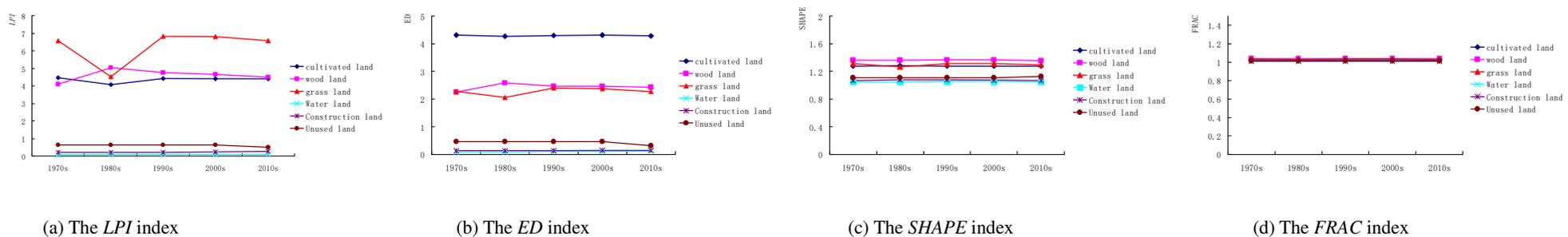


Fig.4 The morphological characteristic of land use types in the 1970s-2010s

1 month

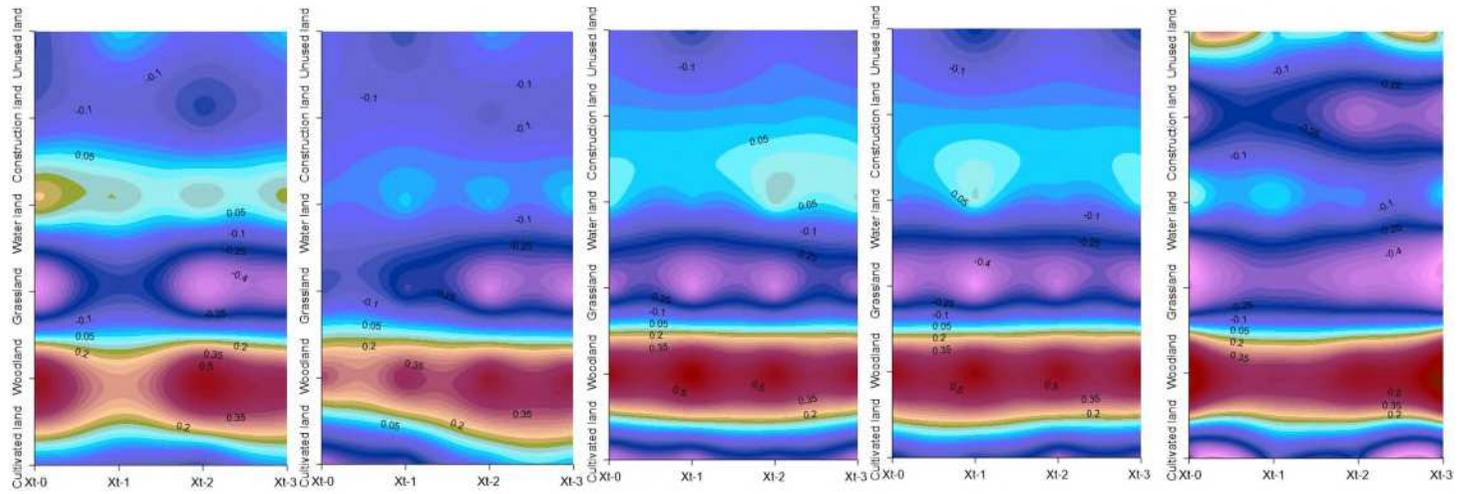
1970s

1980s

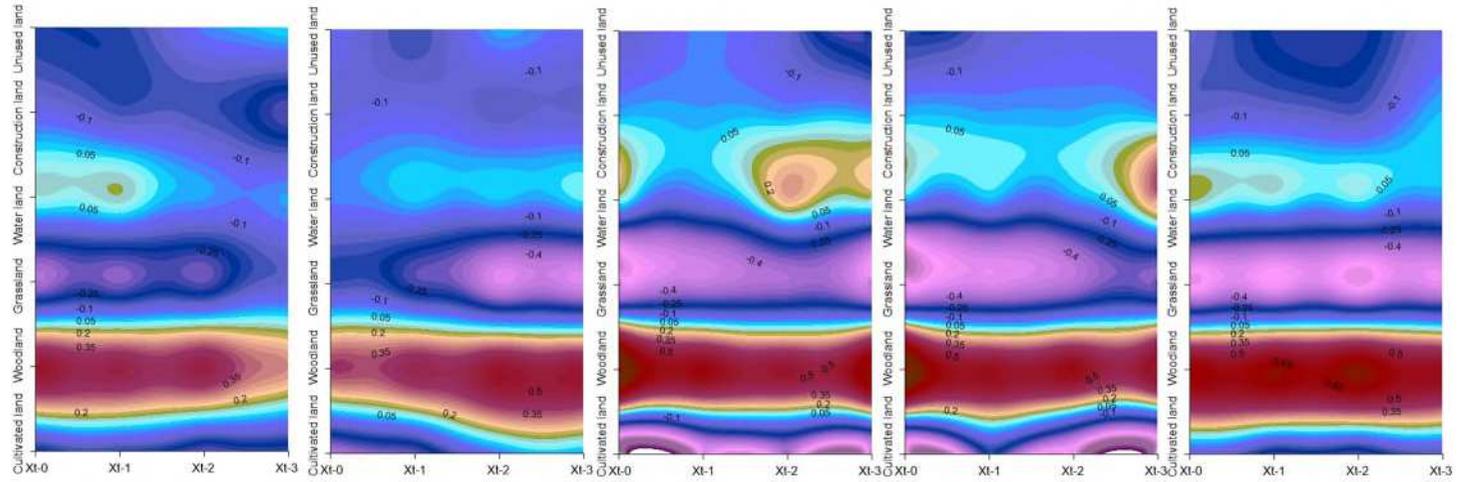
1990s

2000s

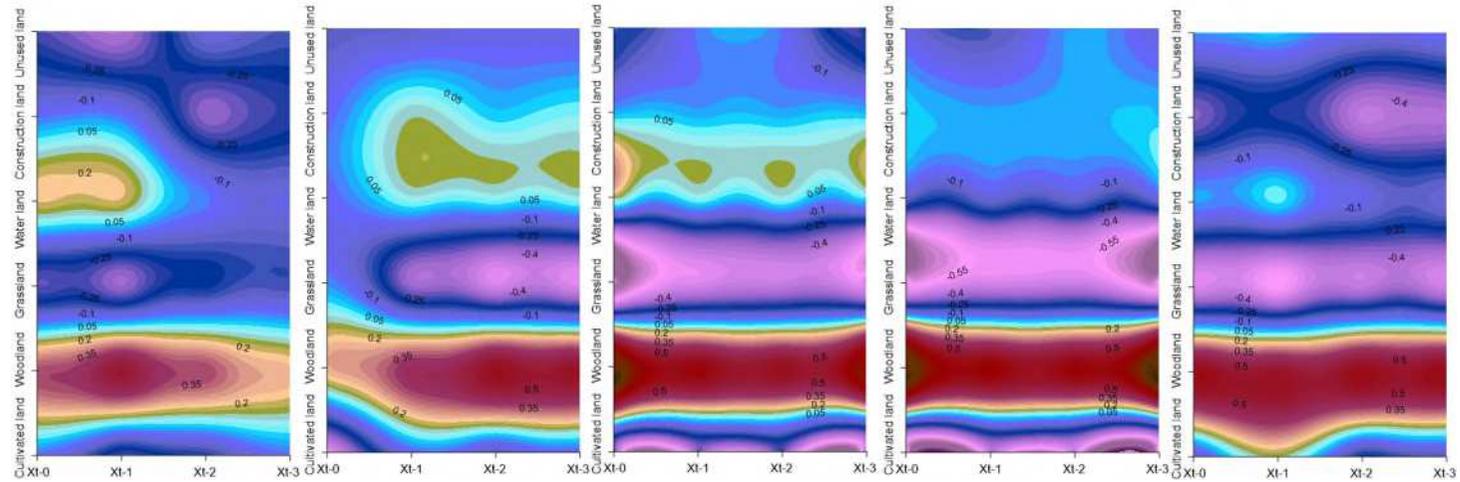
2010s



3 months



6 months



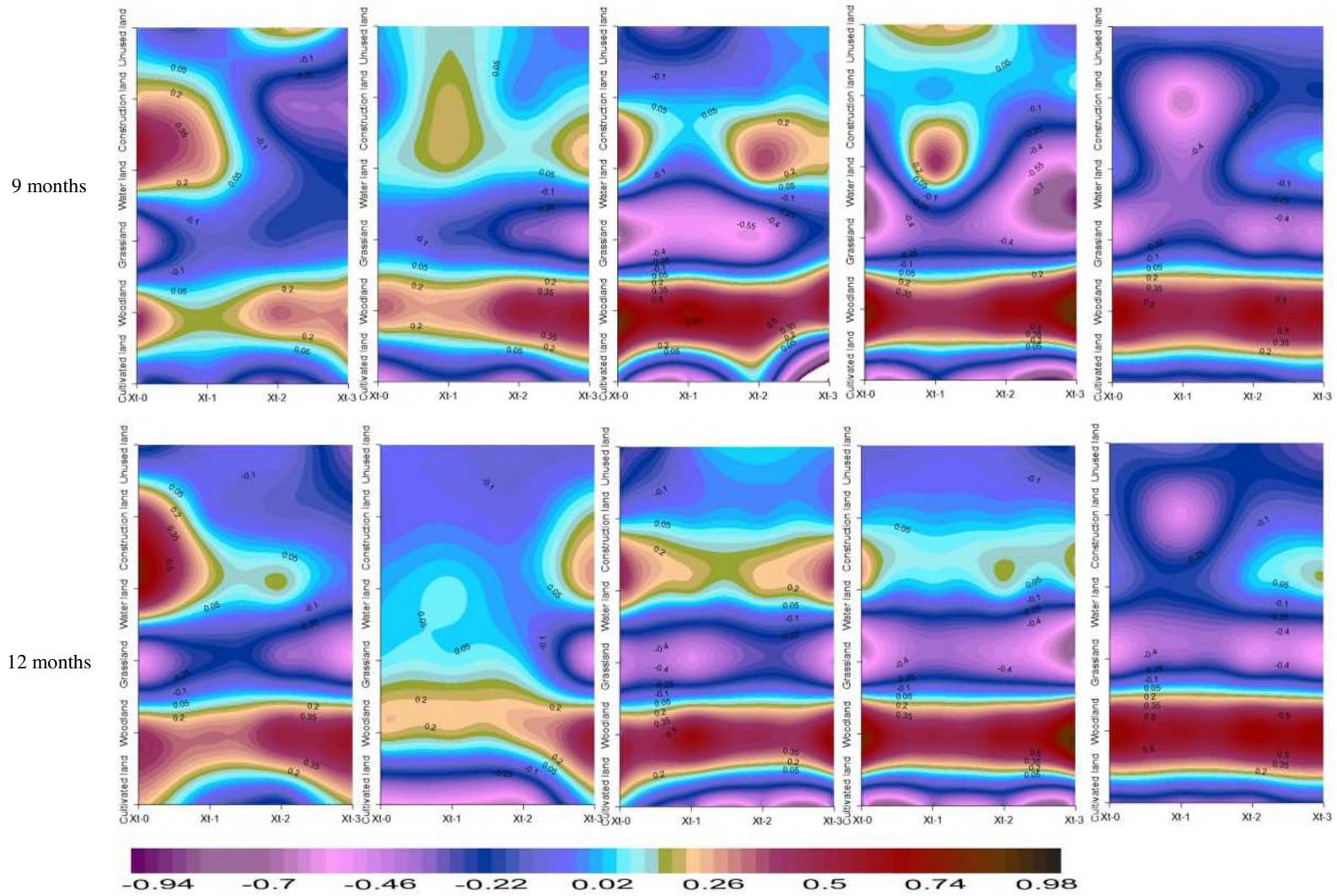


Fig.5 The relationship between land use types and watershed lagged intensities

1970s

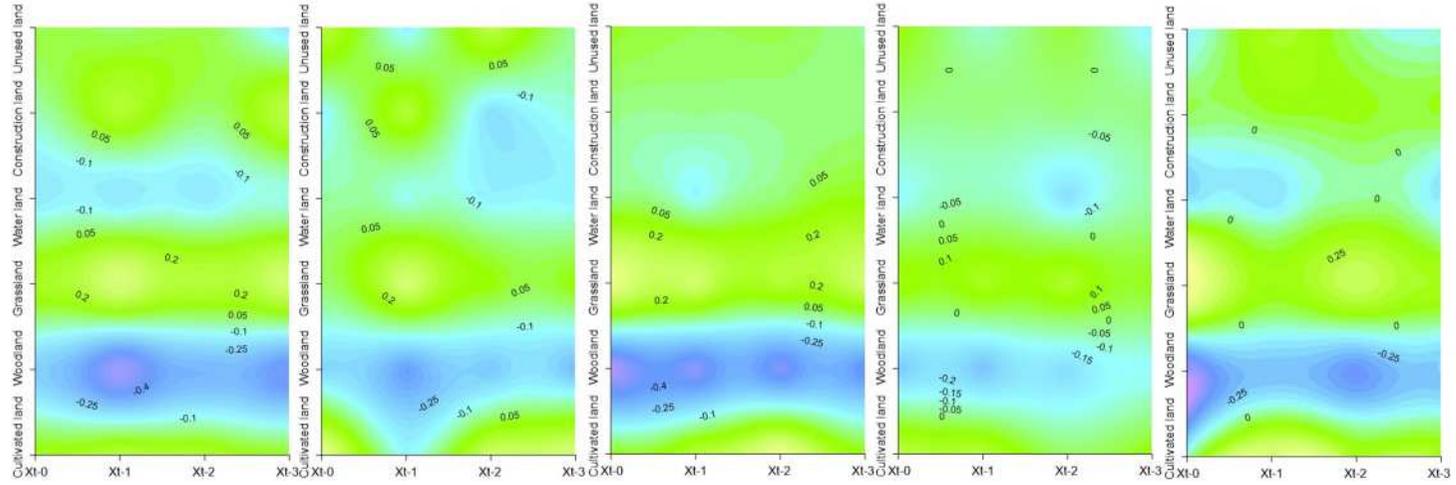
1980s

1990s

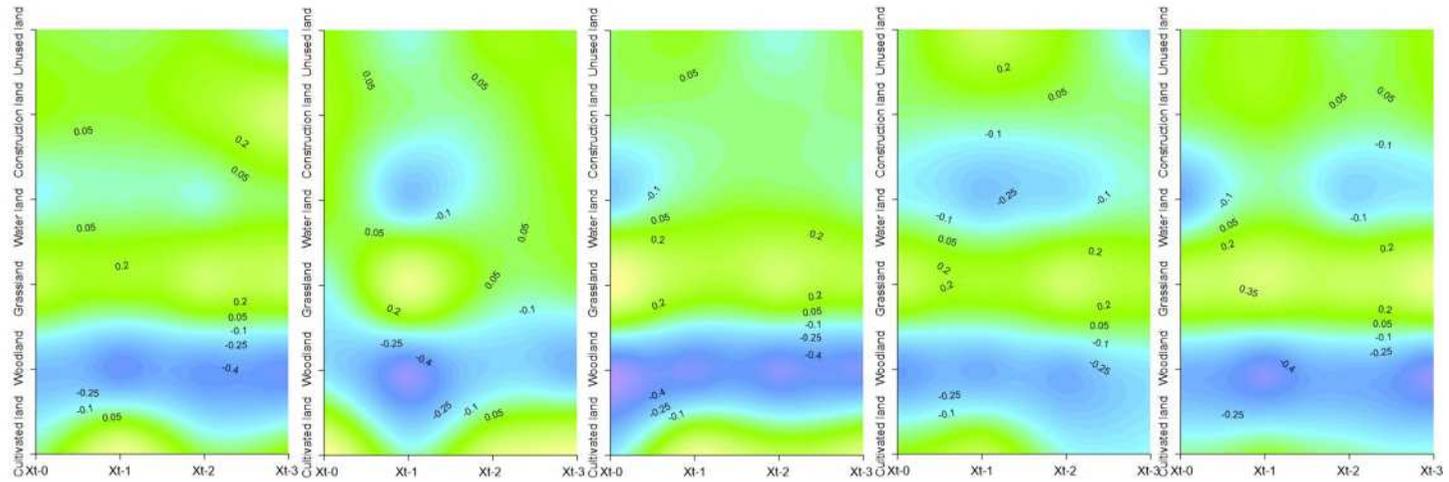
2000s

2010s

1 month



3 months



12 months

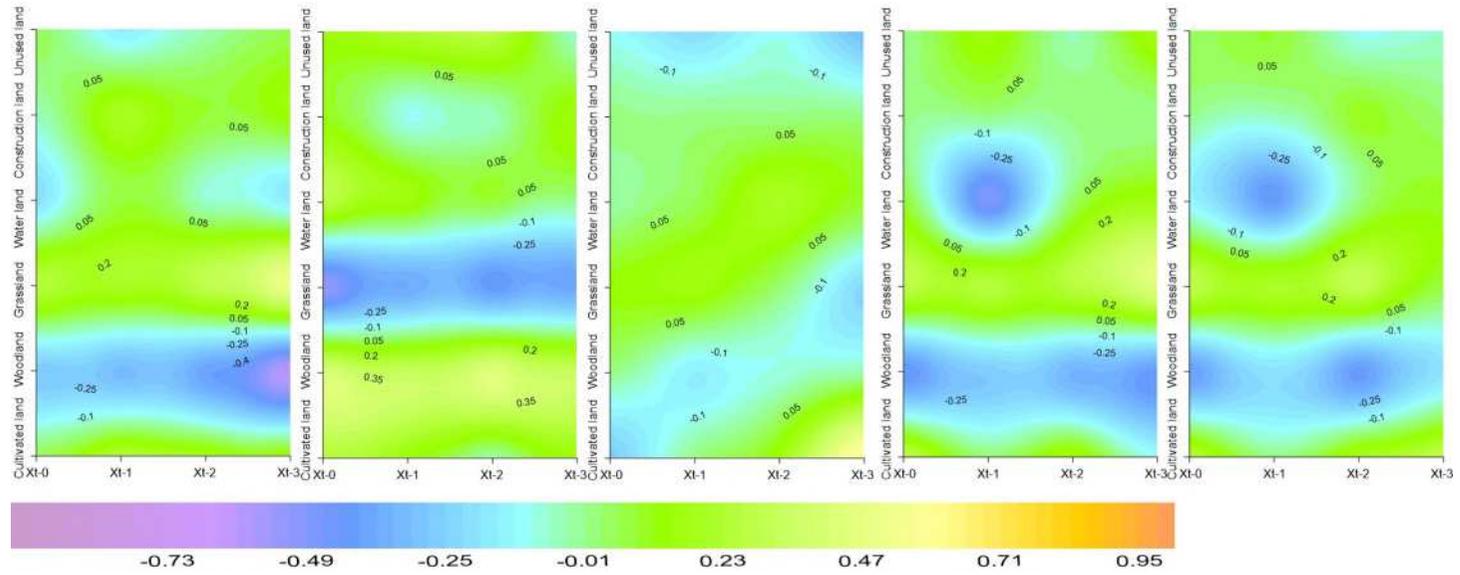


Fig.6 The relationship between land use types and watershed lagged frequencies

Cultivated land

Wood land

Grass land

Water land

Construction land

Unused land

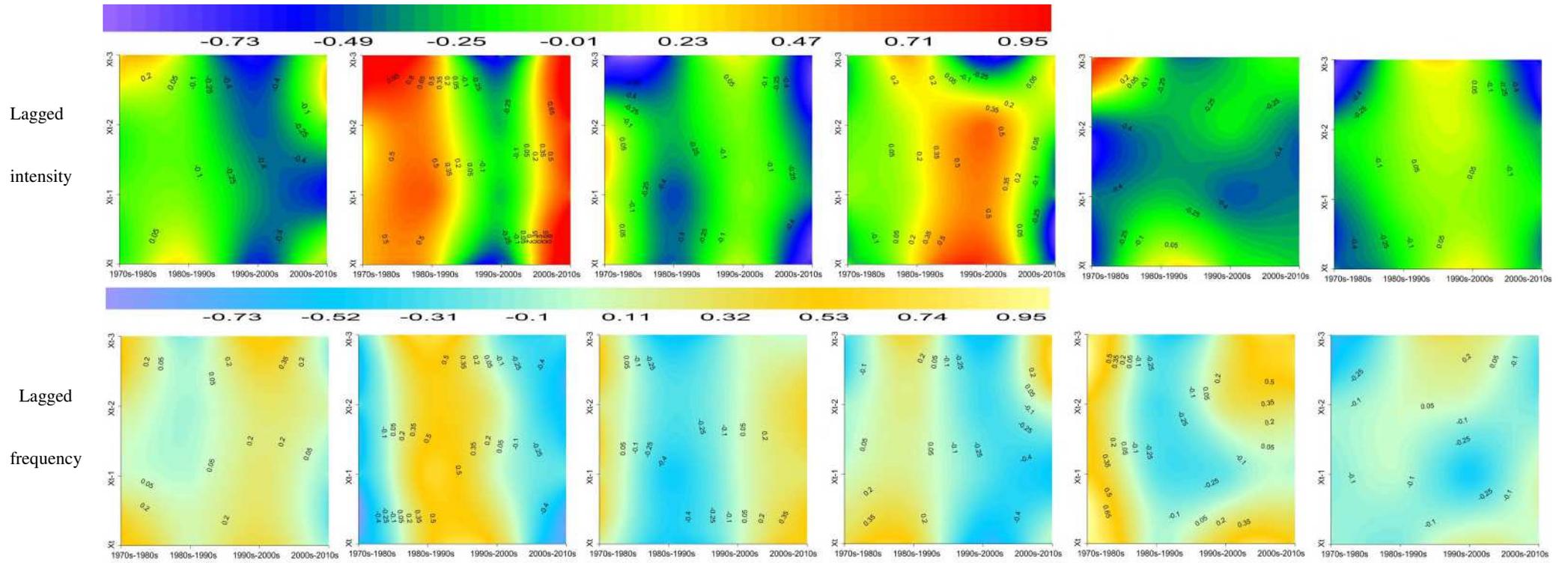
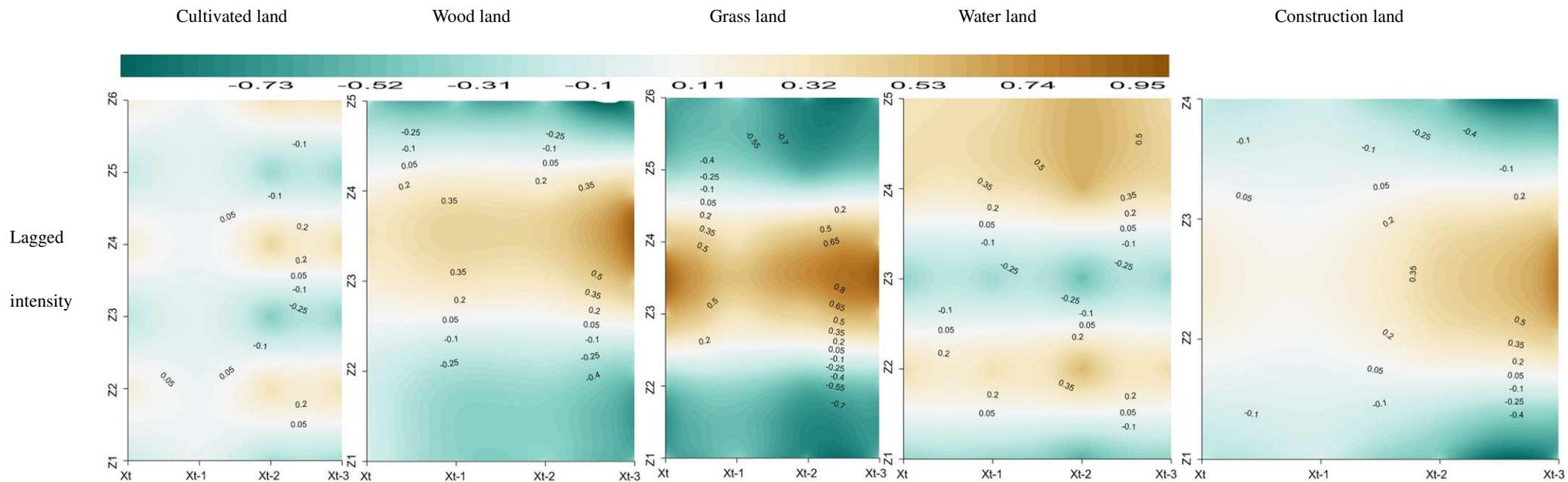


Fig.7 The relationship between land type transfer and watershed lagged effect in the 1970s-2010s



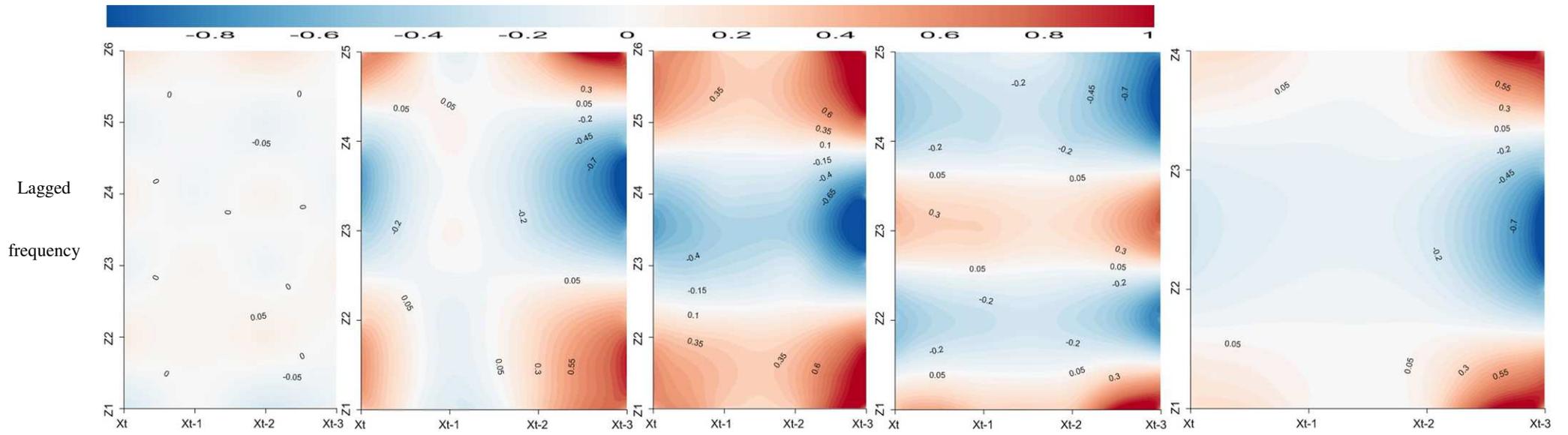


Fig.8 The relationship between land type morphological characteristics and lagged variables

Cultivated land

Wood land

Grass land

Water land

Construction land

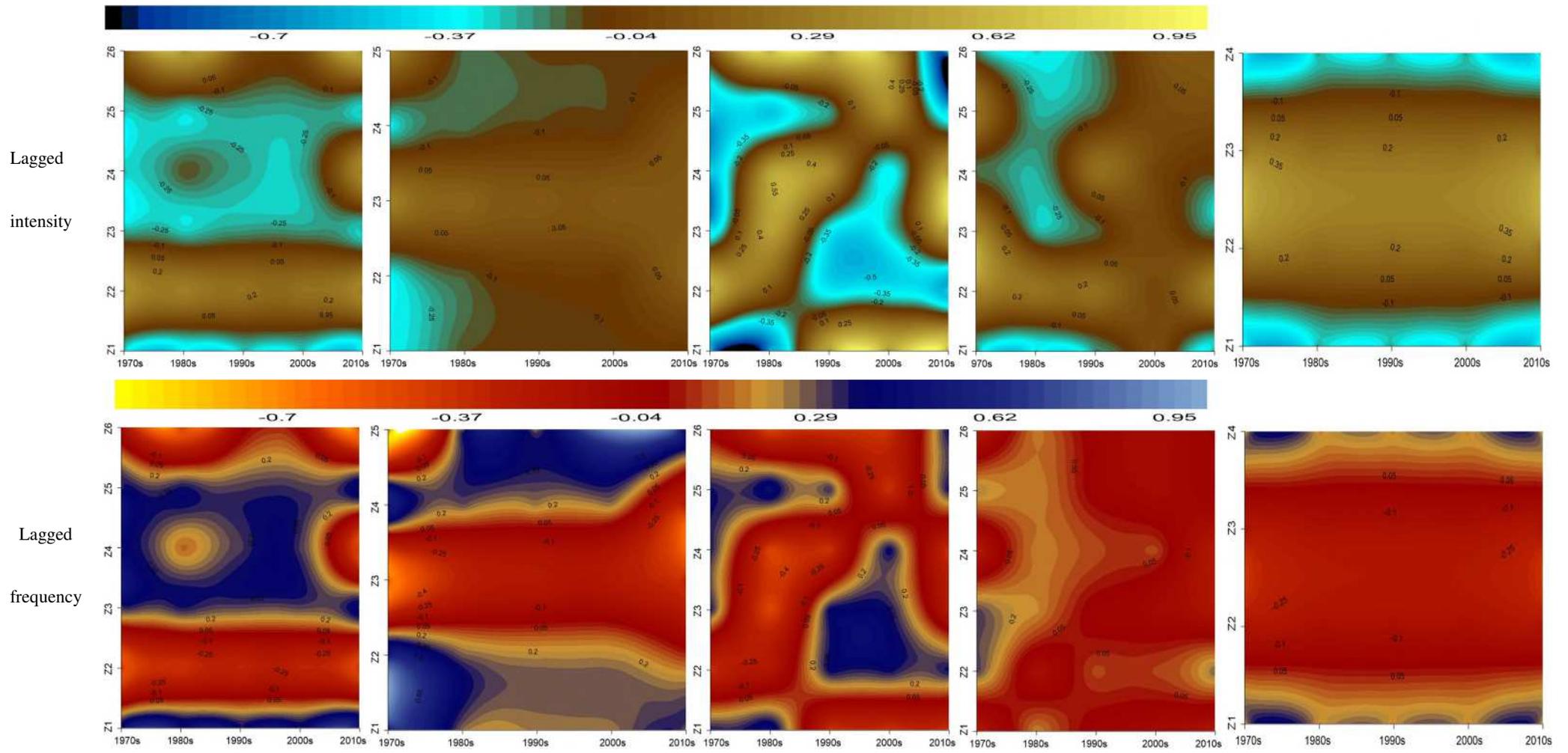


Fig.9 The relationship between land type morphological characteristics and ages

Cultivated land

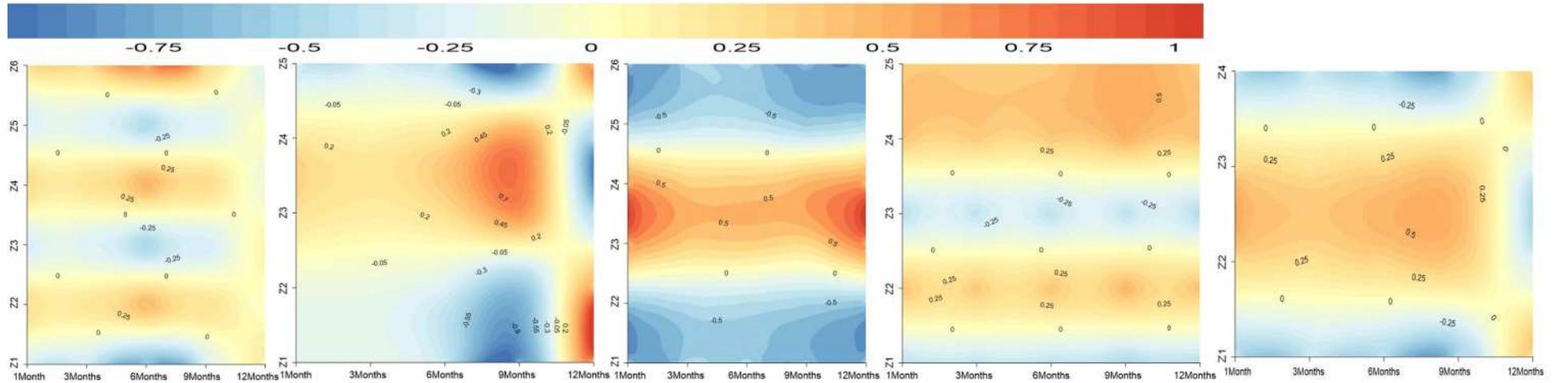
Wood land

Grass land

Water land

Construction land

Lagged
intensity



Lagged
frequency

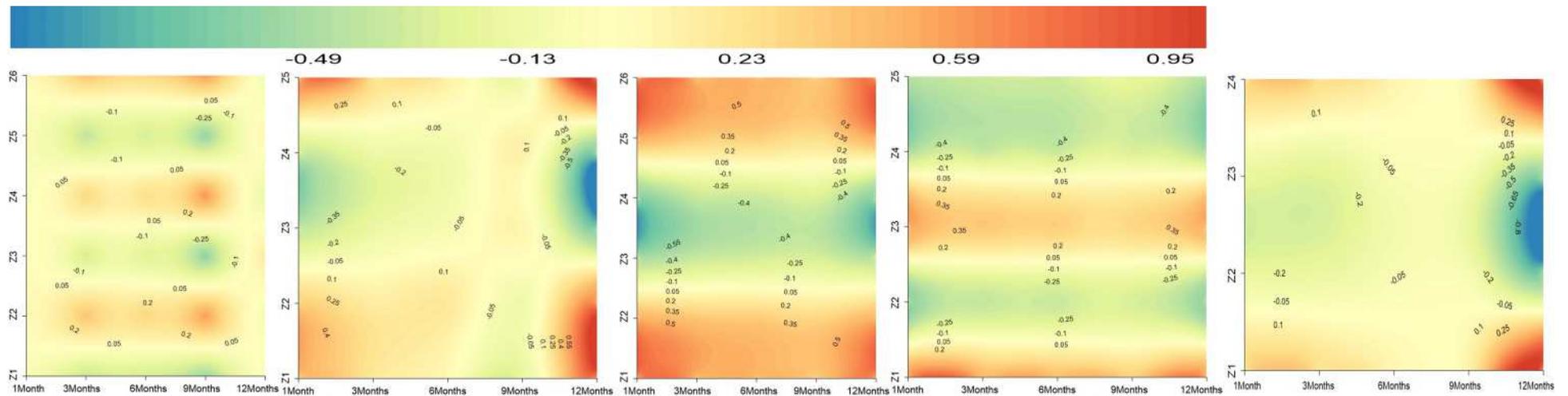


Fig.10 The relationship between land type morphological characteristics and time scales

317 **5. Discussion**

318 It is well known that the streamflow is an integrated response to basin inputs (climate), water transfer, water
319 losses by evapotranspiration storage processes, and the effects of human activities on natural water flows
320 (López-Moreno et al., 2013; Vicente-Serrano et al., 2005; McGuire et al., 2006). Prior to reaching the stream
321 network a large proportion of precipitation is stored in various hydrological subsystems (including snowpack, soil
322 moisture, groundwater reserves, reservoir storages) depended on the basin medium types (geology, topography,
323 soils and vegetation) and their spatial coupling structures (Post et al., 1996; Soulsby et al., 2006; Lorenzo-Lacruz
324 et al., 2010; McDonnell et al., 2010; Fleig et al., 2011). There are the double aquifer media on the surface and
325 underground, and double water system structures on the surface and underground in Karst drainage basins compared
326 with the normal basins, which is very significant response to the atmospheric precipitation (Wang et al., 2002; He et al.,
327 (2015). Especially different sizes of water-stored spaces, such as the solution gap, solution hole and pipeline, as
328 well as the underground cave and underground corridor, are formed in the Karst drainage basins under the
329 differential erosion or solution effect of soluble water, which will make the basins have a certain water storage
330 capacity. Therefore, the response of runoff to rainfall shows a certain lag. There are the different aquifer media and
331 spatial coupling structures in the different basins, which will cause the watershed water-stored capacity. The previous
332 studies have shown that drought propagation is different in an semi-arid climate and a climate with snow accumulation
333 in winter, and it differs between mountainous catchments, catchments with many lakes and wetlands, and catchments
334 with mild slopes and large, porous aquifers (Van Loon 2013). For example, the propagation time is 1 month from the
335 meteorological to hydrological drought, 2 months from the hydrological to agricultural drought, and 2-3 months from
336 hydrological to vegetation drought (Li et al., 2020b).

337 The watershed medium (geography, topography, soils and vegetation) is an important component of basins, and
338 human activities affect or destroy the watershed medium types and their spatial coupling structures. Land use/land cover
339 is the effect manner of human activities on the watershed media, and the spatial pattern of land use/land cover is the

340 effect result of human activities on the watershed media. The spatial pattern of land use types is determined by the type,
341 quantity, shape, spatial distribution and combination of land use/land cover, and the patch is the basic component unit of
342 spatial pattern of land use/land cover (Liu, et al.,20012 & 2002). The patches of different land use types, such as the
343 cultivated land, woodland, grassland, construction land, etc., show the different graphic characteristics due to different
344 formation mechanisms, and the graphic characteristics are mainly shown the shape and spatial distribution of land
345 use/land cover patches. Human activities eventually lead to the changes of land use types, quantity and morphological
346 characteristics. This study prove that the land use and change all have an impacts on the watershed lagged effect, and
347 show the positive and negative differences. Human activities not only lead to the increasing or decreasing of land use
348 types, and the interconversion between the different land types, but also lead to the complexity of the boundary
349 distribution of land types, which will affect the integrity of watershed water-stored spaces, and further influence the
350 watershed lagged effect characteristics. Landscape index is the most effective quantitative index of the land types'
351 morphological characteristics. For example, the larger the patch density index is, the more concentrated and fragmented
352 the land type distribution is, on the contrary, the more scattered and continuous. The larger the largest patch index is, the
353 smaller the intensity and frequency of human activities are, which shows that the more concentrated the land type
354 distribution is, and the simpler the boundary condition is. Conversely, the larger the intensity of human activities, the
355 higher the frequency. It means that the more scattered the land type distribution is, and the more complex the boundary
356 condition is. The smaller the patch shape index is, the more complex the morphological characteristic of land types is,
357 on the contrary, the simpler it is. The larger the patch fractal dimension index is, the more complex the land use types is,
358 and the more circuitous the boundary distribution is. On the contrary, the simpler the land use type distribution is, the
359 more regular the boundary is (Li et al., 2019; Song et al.,2017). This study demonstrates that the principal component
360 factors (Z_1 - Z_4 , Z_5 , Z_6) of 48 indicators of land type morphological characteristics all have influences on the lagged
361 intensity/frequency, and it shows the positive and negative differences in the different lagged periods (X_{t-0} - X_{t-3}), different
362 ages (1970s-2010s) and different time scales (1-12 months). Indicating that human activities not only affect the spatial

363 pattern of land use types, but also affect the morphological distribution characteristics, which will influence the
364 watershed lagged effect. Meanwhile, the Z_s of different morphological characteristics of the same land use type or
365 different land use types all have particularly significant impacts ($P<0.001$) on the lagged intensity/frequency with the
366 prolongations of lagged periods (X_{t-0} - X_{t-3}), the change of ages (1970s-2010s) and the increasing of time scales (1-12
367 months).

368 In summary, the watershed medium is an important component in Karst drainage basins, where there are some
369 water-stored spaces formed under the differential erosion or dissolution effects of soluble water. It will provide the
370 spaces and places for the atmospheric precipitation lagged flow on the surface and underground, promote the basins
371 showing the lagged effect characteristics. Land use/land cover is the effect manner of human activities on the watershed
372 media, and the spatial pattern of land use/land cover is the effect results of human activities on the watershed media,
373 which will promote or inhibit the characteristics of watershed lagged effects.

374 **6. Conclusion**

375 (1) The land use/land cover all have the significant impact on the watershed lagged effects, and show a *positive*
376 *and negative* difference. Among them, the impact of the wood land and water land on lagged intensity is positive, others
377 are negative, and the impact on the lagged frequency is just the opposite. The impact differences of land use types on
378 watershed lagged effects are particularly significant ($P<0.001$) with the changing of ages, the prolongation of lagged
379 periods, as well as the increasing of time scales.

380 (2) The R absolute values of the Z_s impacts on the lagged intensities were shown an *increase-decrease-increase*
381 trend with the changing of ages (1970s-2010s) in the wood land and grass land, and shown just the opposite in the
382 construction land region. And that of the Z_s impacts on the lagged intensities was shown an *inverted V-shape* in the
383 water land, and reached the maximum in the 1990s-2000s, and changed less in the construction land and unused land.
384 The R absolute values of the Z_s impacts on the lagged frequencies reached the maximum in the grass land and wood
385 land in the lag-1 period (X_{t-1}) and lag-2 period (X_{t-2}) with the prolongation of lagged periods, and the minimum in the

386 cultivated land and water land in the lag-1 period (X_{t-1}) and lag-2 period (X_{t-2}), respectively.

387 (3) The principal component factors (Zs) of morphological characteristics of land use types all have the impacts on
388 the lagged effects with the particularly significant differences in the different lagged periods (X_{t-0} - X_{t-3}), different ages
389 (1970s-2010s) and different time scales (1-12 months). Among them, the F statistic values of the Zs impacts on the
390 lagged intensity/frequency are the largest in the grass land in the X_{t-0} - X_{t-3} , followed by the water land and wood land, the
391 smallest in the cultivated land and construction land. The impacts of the Zs on the lagged intensity were the largest for
392 the grassland, cultivated land and water land in the 1970s-2010s, and reached the maximum in the 1980s. And that of
393 the Zs gradually decreased for the wood land with the increasing of ages, and changed less in the construction land. The
394 R absolute values of the Zs impacts on the lagged intensities are the largest for the grass land and water land in the 1-12
395 month scales, and increase with the increasing of time scales (the maximum value in the 9-month scale), followed by
396 the wood land and cultivated land with the maximum in the 6- and 9- month scales, And that of the Zs impacts on the
397 lagged intensities is the smallest for the construction land, and gradually increases with the increasing of time scales
398 (the maximum in the 9-month scale).

399

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