南開大學 循环经济与低碳发展研究中心

Center for Resource & Energy & Environmental Policy Research, Nankai University

Impacts of CO2 emission on extreme precipitation in the Pearl River Basin

Lin Huang, Xiaogang Shi, Junfeng Wang

Contents

Part 1: Introduction of PRB

1.1 Location of PRB

PRB is located between 102°14' E to 115°53'E and 21°3'N to 26°49 'N. This river which is the largest river in south China originates from the Wumeng mountain. PRB is one of the major industrial, agricultural and economic centers in south of China. PRB includes 6 provinces in China, but half of pearl river is in Guangdong and Guangxi. Therefore, we take cities in these 2 provinces as the study area.

Fig 1. The study area

1.2 Economic development in PRB

Base on the GDP in these 2 provinces, it is found that GDP is increasing over the years. However, the growth rate is change. The rate during 2012 to 2017 is lower than before. Guangdong is a developed economic province where Guangzhou and Shenzhen which is the super city in China located in. The GDP in Guangdong is much higher than Guangxi which is undeveloped regions. From the structure of GDP by Industry, it is found there is difference between these 2 regions. In Guangdong, the proportion of primary industry is the smallest over the years. The structure in Guangdong changed after 2012. Before 2012, the proportion of the second industry is the largest. After that, the third industry became larger than second industry. In Guangxi, the proportion of first industry became small over the years. The second industry in Guangxi are always the largest part in the GDP structure.

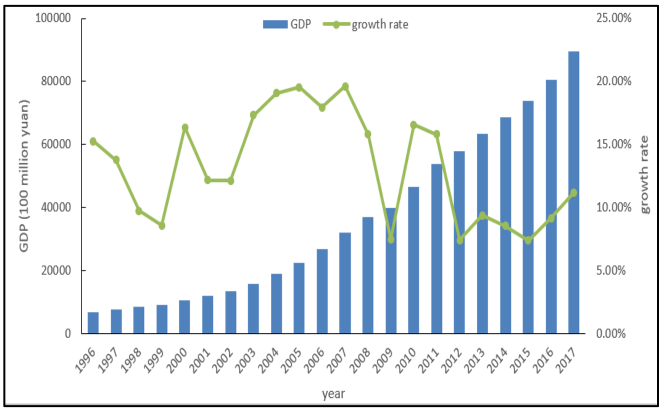


Fig 2. GDP and the growth rate in Guangdong

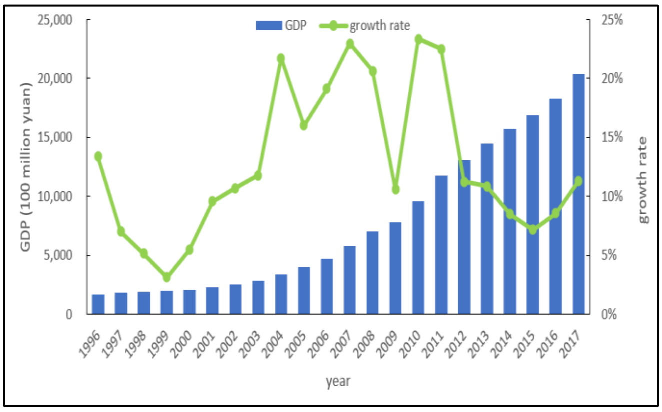


Fig 3. GDP and the growth rate in Guangxi

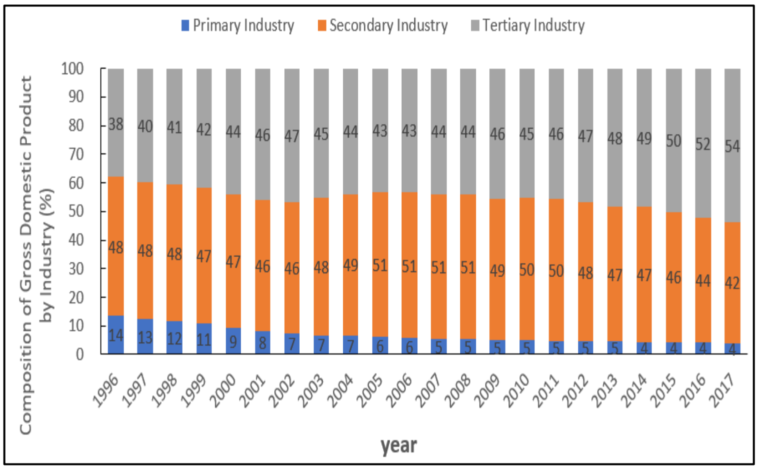


Fig 4. Composition of GDP by Industry in Guangdong

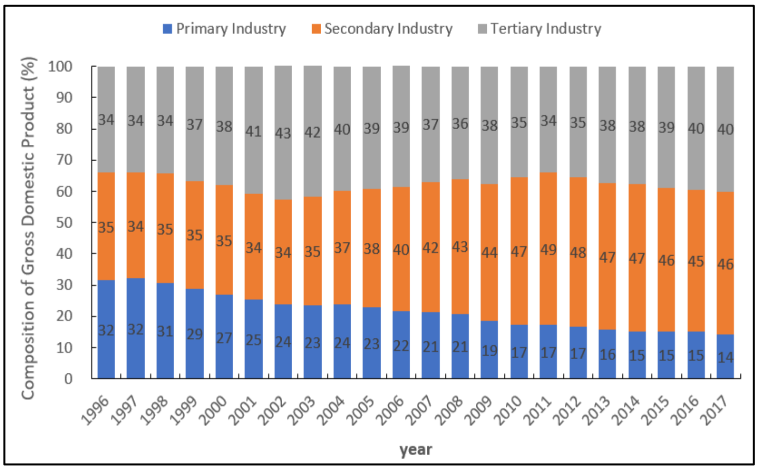
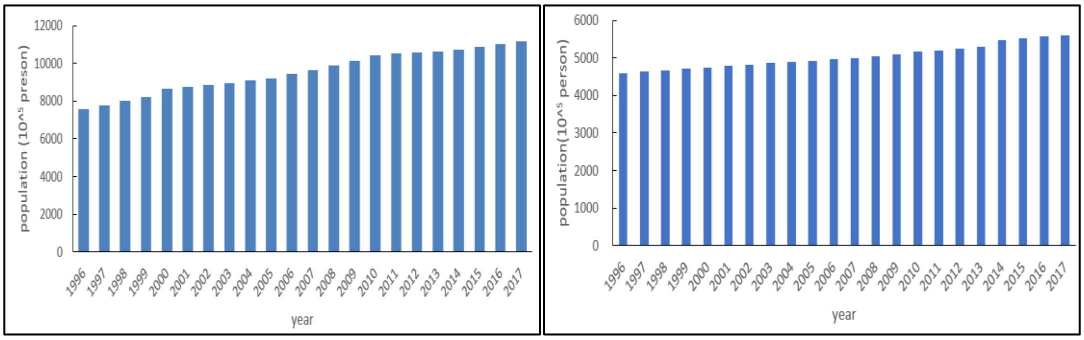


Fig 5. Composition of GDP by Industry in Guangxi

1.3 Population in PRB

The population is increasing over the years in 2 regions.



A. Guangdong B. Guangxi

Fig 6. Population in PRB

1.4 Energy consumption structure in PRB

In Guangdong and Guangxi, the main energy consumption type is the electricity and raw coal. The energy consumption industrial structure is similar. The sector that consumes the most energy is industry and the residential. The total amount of energy consumption in Guangdong is higher than Guangxi.

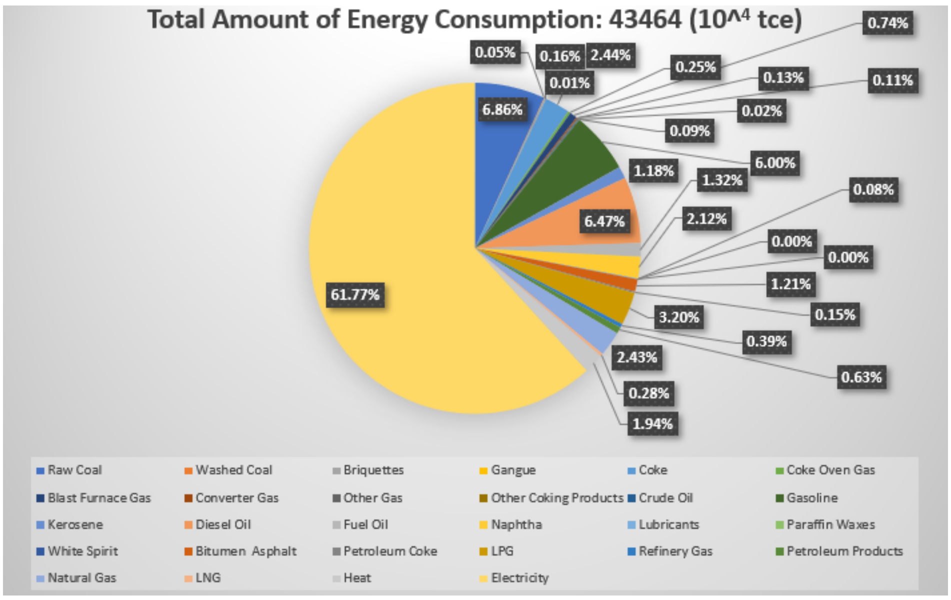


Fig 7. Energy consumption structure in Guangdong in 2017

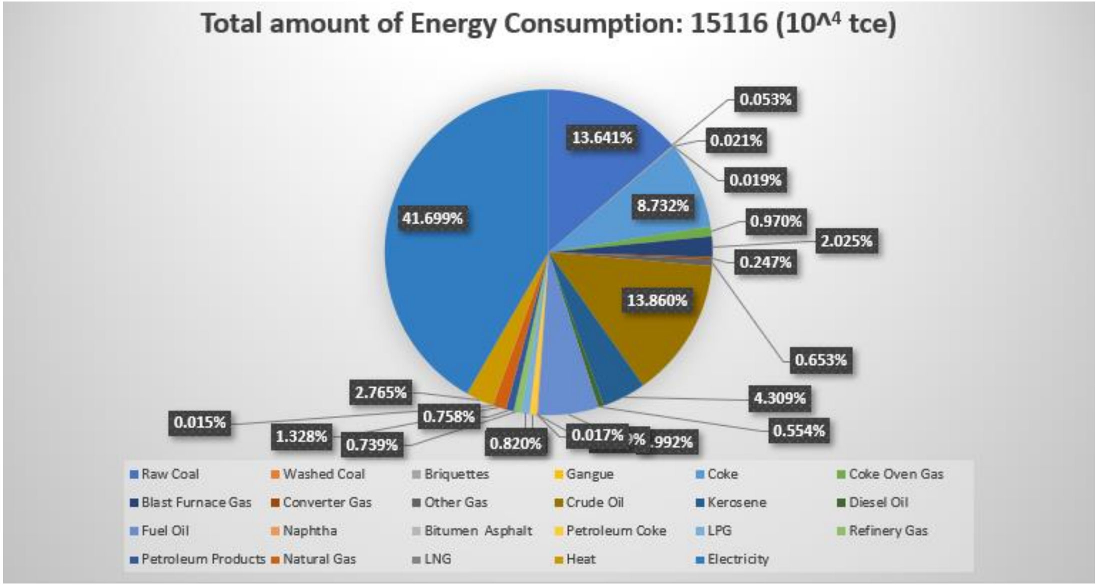
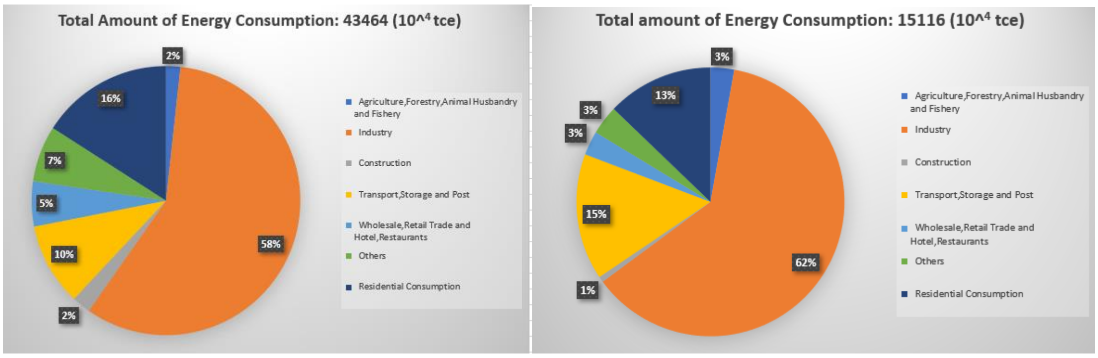


Fig 8. Energy consumption structure in Guangxi in 2017



A. Guangdong B. Guangxi

Fig 9. Energy consumption industrial structure in PRB in Guangdong and Guangxi in 2017

Part 2: Extreme precipitation in PRB

2.1 Temporal evolution of the extreme precipitation in PRB

PRB has suffered more extreme precipitation and the higher risk of flood disasters over years. The trend shows that all extreme precipitation indexes are increasing.

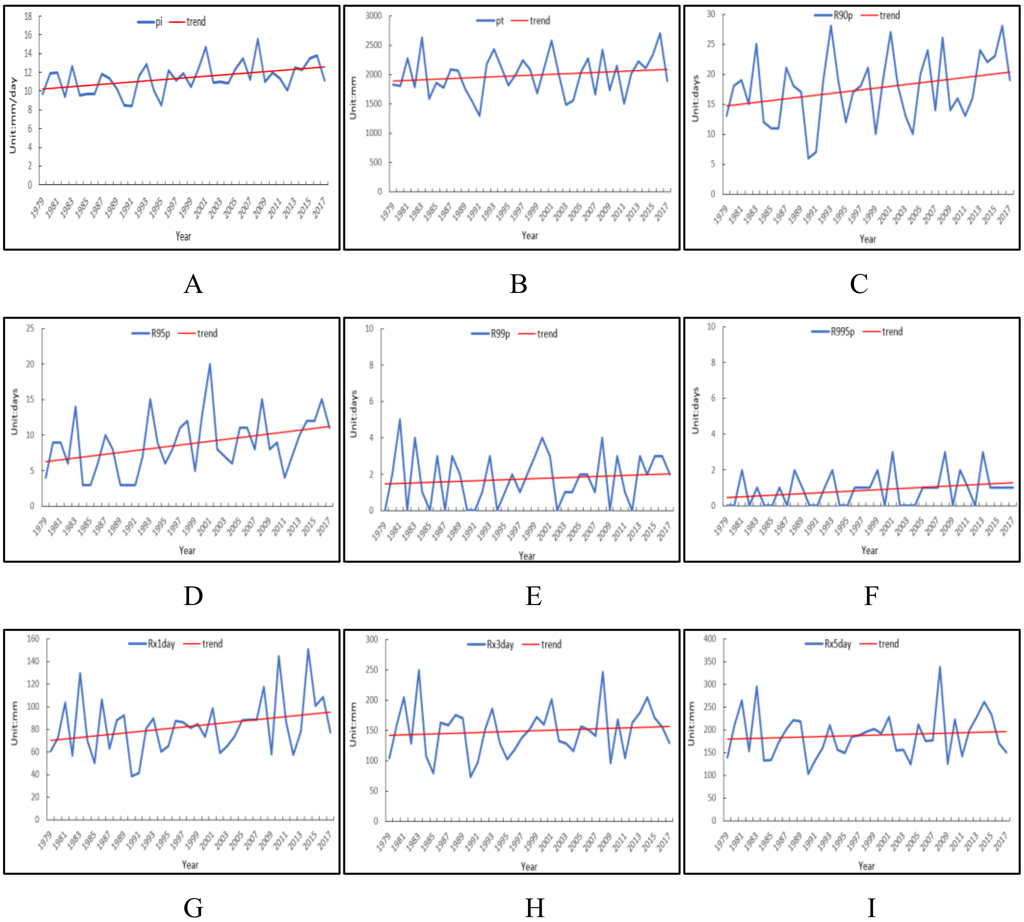
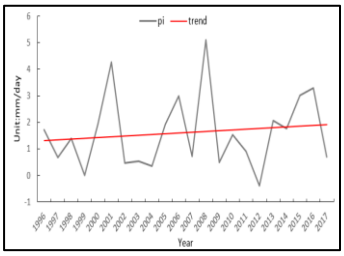


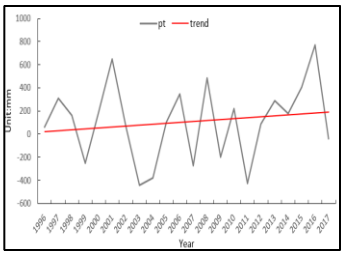
Fig 10. Temporal evolution of the extreme precipitation in PRB. The blue curve represents true value, and the red line represents the trend of index. A. pi, B. pt, C.R90p, D. R95p, E. R99p, F. R995p, G. Rx1day, H. Rx3day, I. Rx5day.

2.2 Temporal evolution of the annual extreme precipitation anomaly

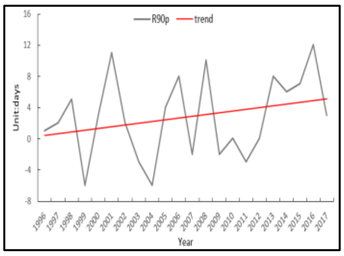
The extreme precipitation during 1996 to 2017 is more than before. The anomaly is positive in most years. All extreme precipitation indicators of PRB showed a significant increase trend.



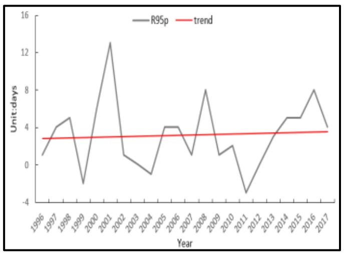
A



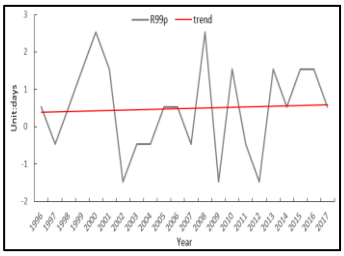
B



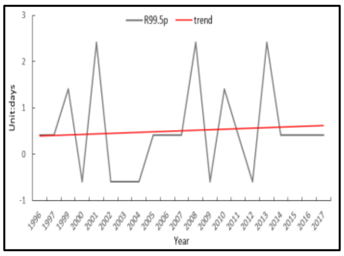
C



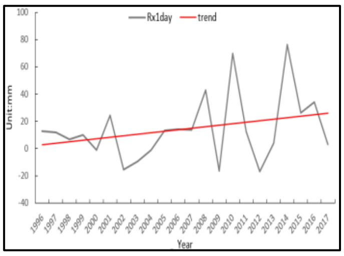
D



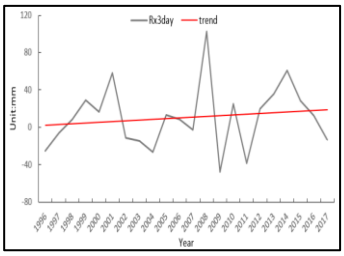
E



F



G



H

I

Fig 11. The grey curve represents true value, and the black straight line represents the trend. A. pi, B. pt, C.R90p, D. R95p, E. R99p, F. R995p, G. Rx1day, H. Rx3day, I. Rx5day.

2.3 Temporal evolution of specific humidity and temperature in PRB

The obvious increasing specific humidity and temperature are showed in PRB.

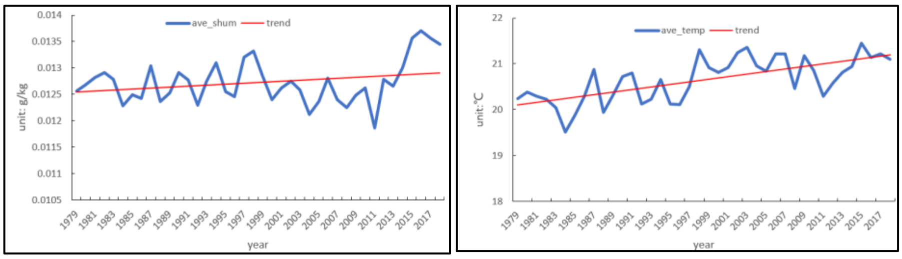


Fig 12. The blue curve represents true value, and the red line represents the trend of index.

2.4 Spatial distribution of the annual extreme precipitation

The average value of extreme precipitation in PRB is from west to east. The high value area is concentrated in coastal cities. The change trends in most cities are basically increasing. The tendency in most city of intensity, total precipitation, R90p, R95p, R99p, Rx1day and Rx3day are increasing. It is noted that the intensity trend in all cities are all increasing.

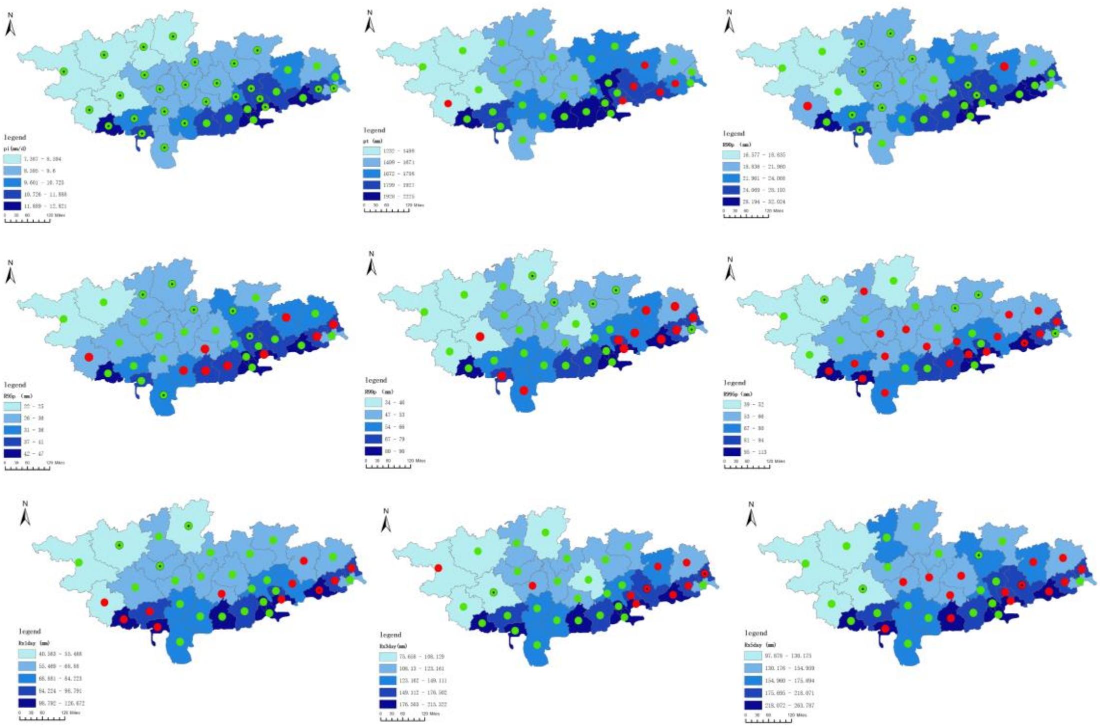


Fig 13. The trend is indicated by circle. Green circle means an increasing trend and red circle means a decreasing trend and. Black dot represents that the trend is through the MK-test.

2.5 Spatial distribution of annual extreme precipitation anomaly

In most area, the extreme precipitation during 1996 to 2017 is more than before. The spatial structure may change over the years. The anomaly in is positive in most cities. For intensity, R90p and R95P, the anomaly in cities are all positive. The negative anomaly is located in east and coast. The max value areas are mainly in the middle of PRB and some in the PRD. Compare with annual average extreme precipitation which max value center is located in coastal area, the anomaly structure is different. The extreme precipitation structure may change in the future.

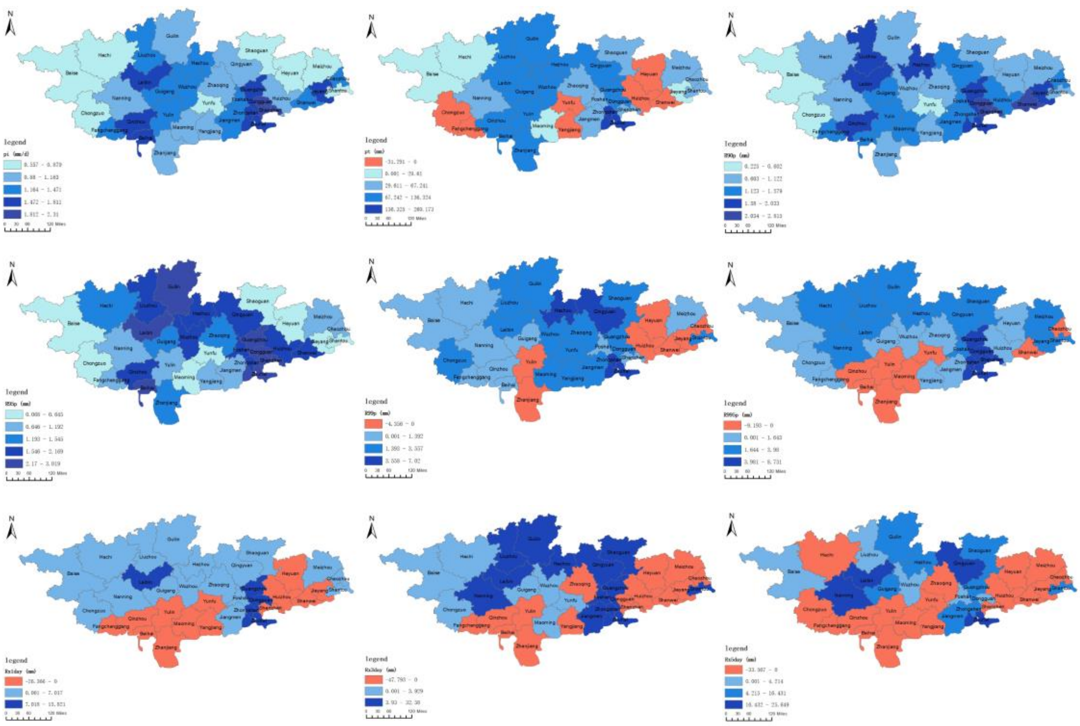
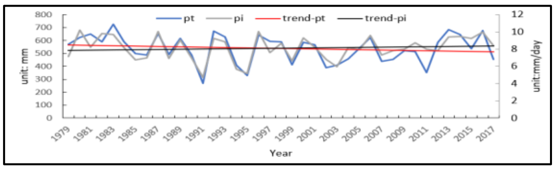


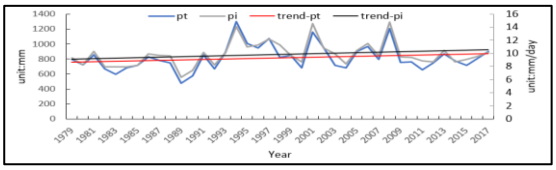
Fig 14. Blue represents the positive anomaly area and orange represents the negative anomaly area.

2.6 Seasonal temporal evolution of extreme precipitation in PRB

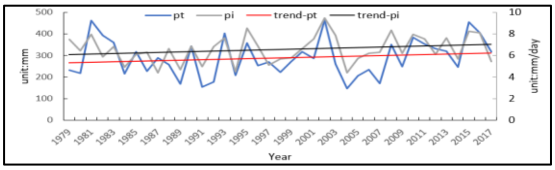
The seasonal extreme precipitation in PRB is increasing. The change in autumn and winter are more obvious.



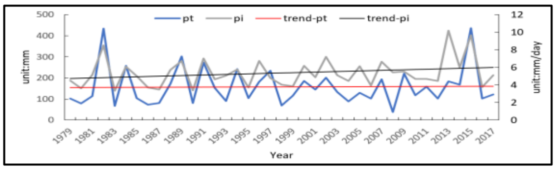
Spring-pi, pt



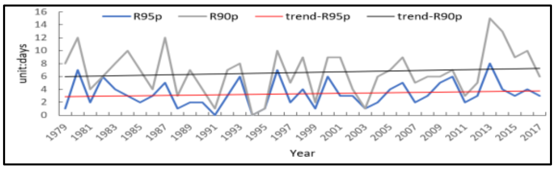
summer-pi, pt



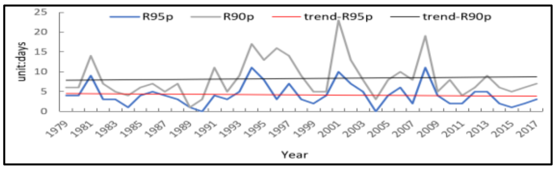
autumn-pi, pt



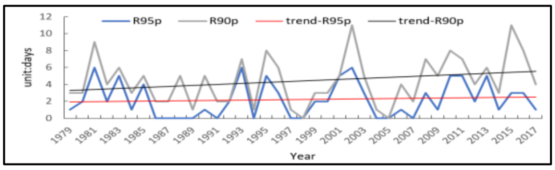
winter-pi, pt



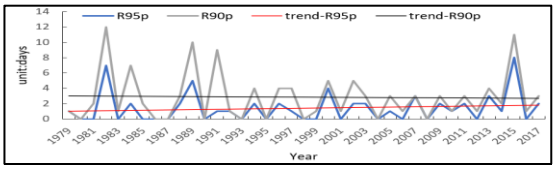
spring-R90p, R95p



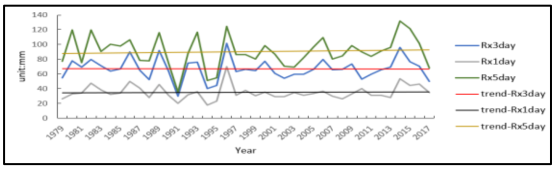
summer-R90p, R95p



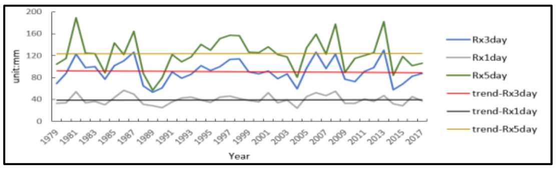
autumn-R90p, R95p



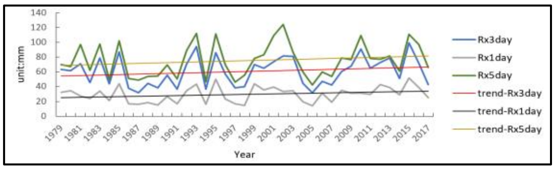
winter-R90p, R95p



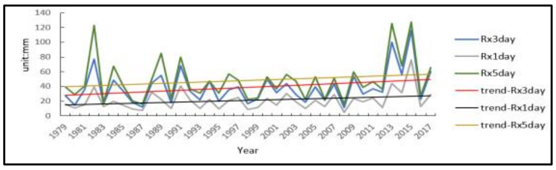
spring-Rx1day, Rx3day, Rx5day



summer-Rx1day, Rx3day, Rx5day



autumn-Rx1day, Rx3day, Rx5day



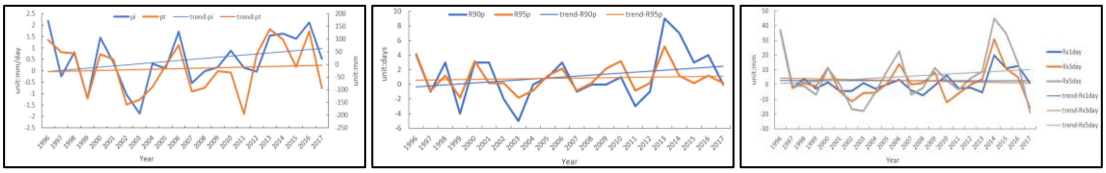
winter-Rx1day, Rx3day, Rx5day

Fig 15. The full line curve represents true value, and the dotted line represents the trend.

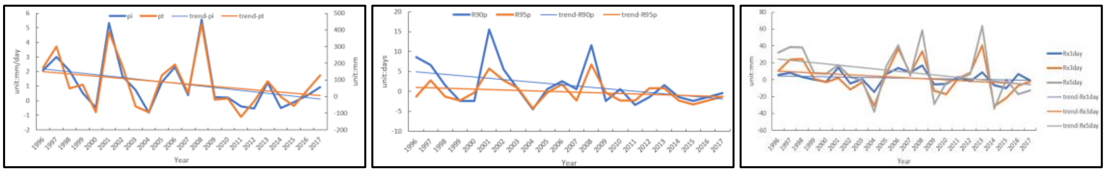
2.7 Temporal evolution of the seasonal extreme precipitation anomalies

A clear upward trend can be observed for extreme precipitation indicator in spring, autumn and winter. The anomaly in most year is positive. In summer, anomalies of all indicator show a downward trend. however, the anomaly in summer is positive. The evolution character of summer extreme precipitation is extreme precipitation is decreasing from 1996 to 2017 but it is still more than 1979-1995.

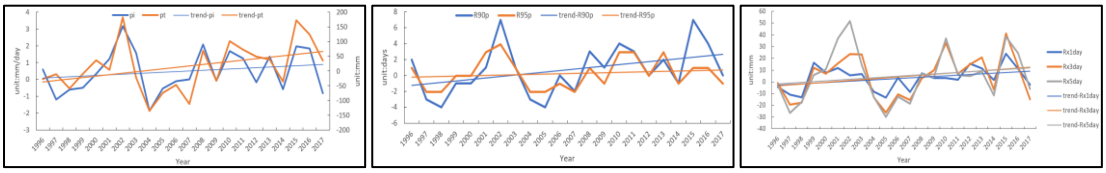
Spring



Summer



Autumn



Winter

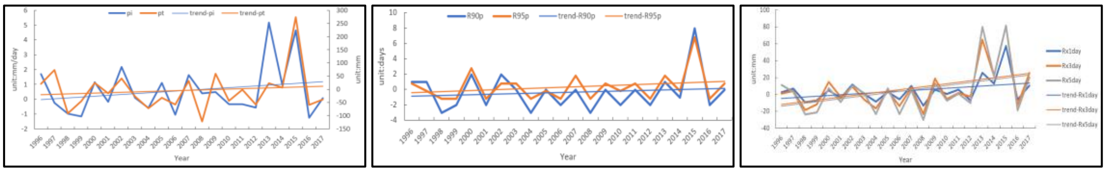


Fig 16. The full line curve represents true value, and the dotted line represents the trend.

2.8 Spatial distribution of the average spring extreme precipitation

The spring extreme precipitation is increasing. The tendency of precipitation intensity is increasing in most cities. The spring extreme precipitation in PRB increases from west to east.

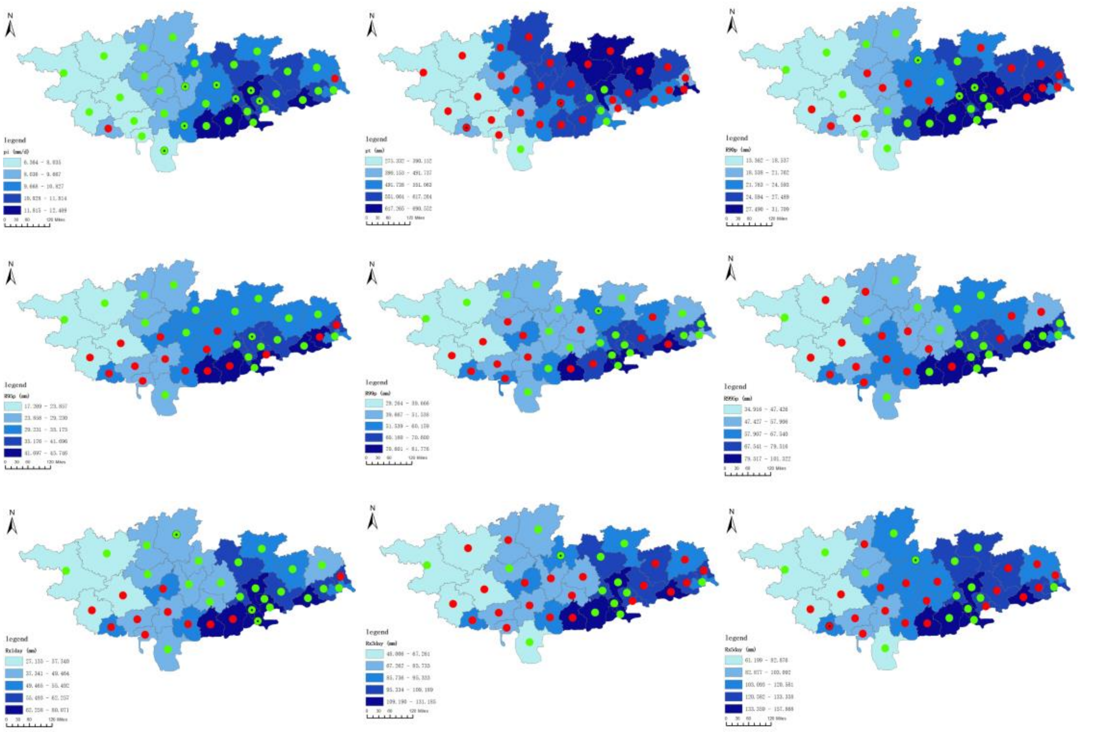


Fig 17. Spatial distribution of the spring average extreme precipitation. The trend is indicated by circle. Green circle means an increasing tendency and red circle means a decreasing tendency and. Black dot represents that the trend is through the MK-test.

2.9 Spatial distribution of spring extreme precipitation anomaly

The spring extreme precipitation during 1996 to 2017 is more than before. The spring extreme precipitation anomalies are positive in most cities. The anomalies of intensity in cities are all positive. The negative anomaly area is mainly located in southwest and east.

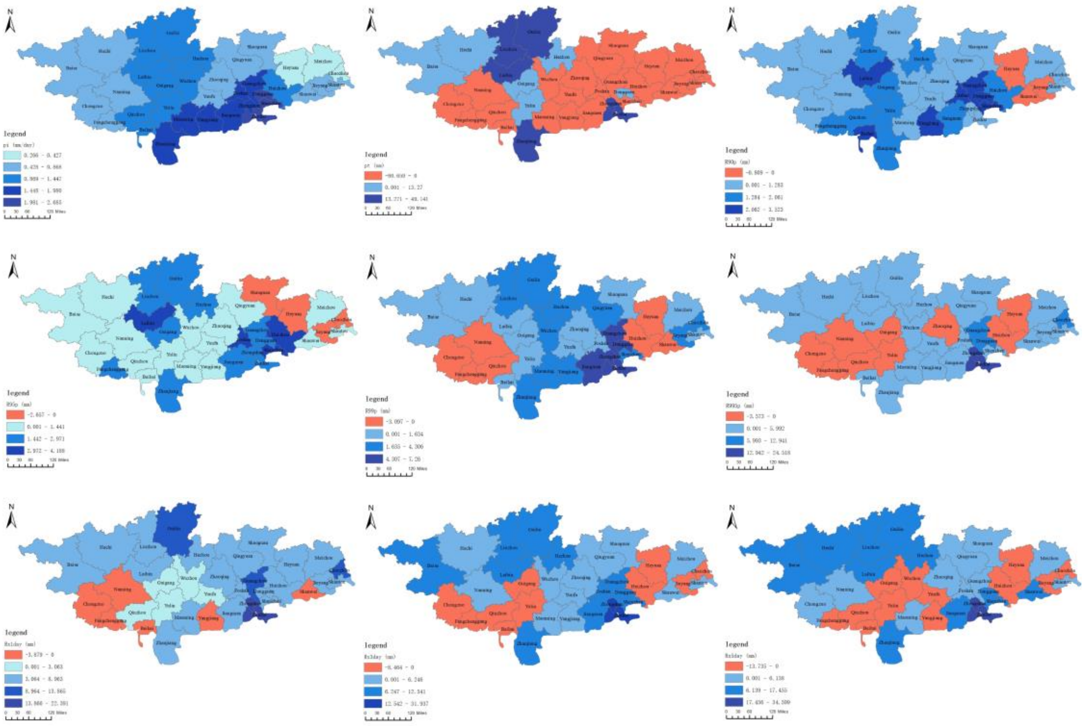


Fig 18. Spatial distribution of spring extreme precipitation anomaly from 1996 to 2017. Blue represents the positive anomaly area; orange represents the negative anomaly area.

2.10 Spatial distribution of the average summer extreme precipitation

The extreme precipitation in summer is significantly increasing at city scale. The tendencies of most cities are increasing. For intensity, most cities show the upward trend and 62% of them pass the MK-test. All indicators in inland cities show the increasing trend. The large - value centers are mainly located in coastal areas.

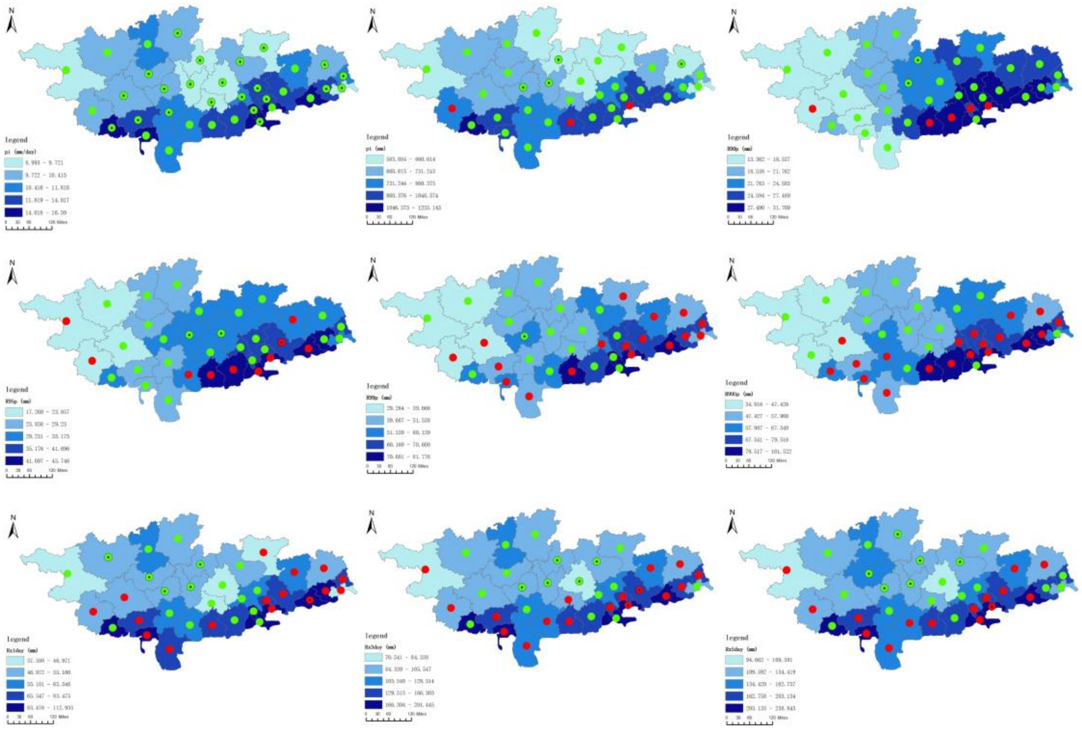
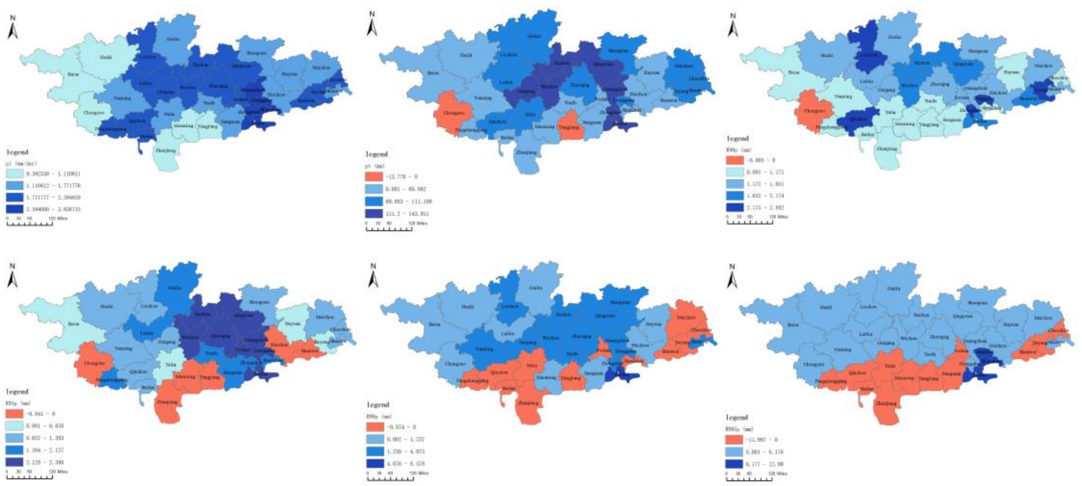


Fig 19. Spatial distribution of the average summer extreme precipitation. The trend is indicated by circle. Green circle means increasing and red circle means decreasing. The black dot represents that the trend is through the MK-test.

2.11 Spatial distribution of the summer extreme precipitation anomaly

The summer extreme precipitation during 1996 to 2017 is more than before. The summer extreme precipitation anomalies are positive in inland cities. For intensity, the anomalies of cities are all positive. The negative anomaly area is mainly located in coast.



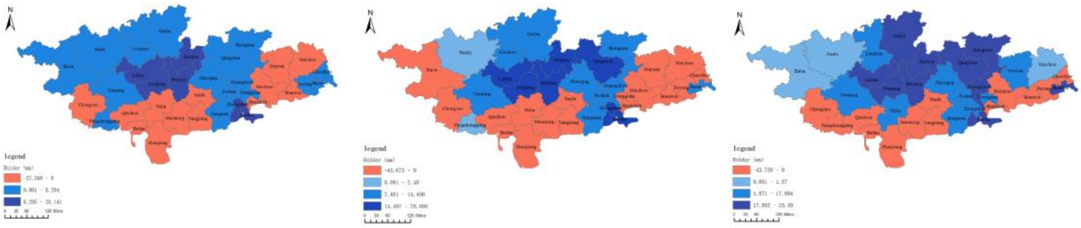


Fig 20. Summer extreme precipitation anomaly from 1996 to 2017. Blue represents the positive anomaly area; orange represents the negative anomaly area.

2.12 Spatial distribution of the autumn average extreme precipitation

The extreme precipitation in autumn is significantly increasing in most cities. For intensity, the change trends are increasing in all cities. For other indexes, most of cities showed the upward tendency. The large - value centers are mainly located in coastal areas.

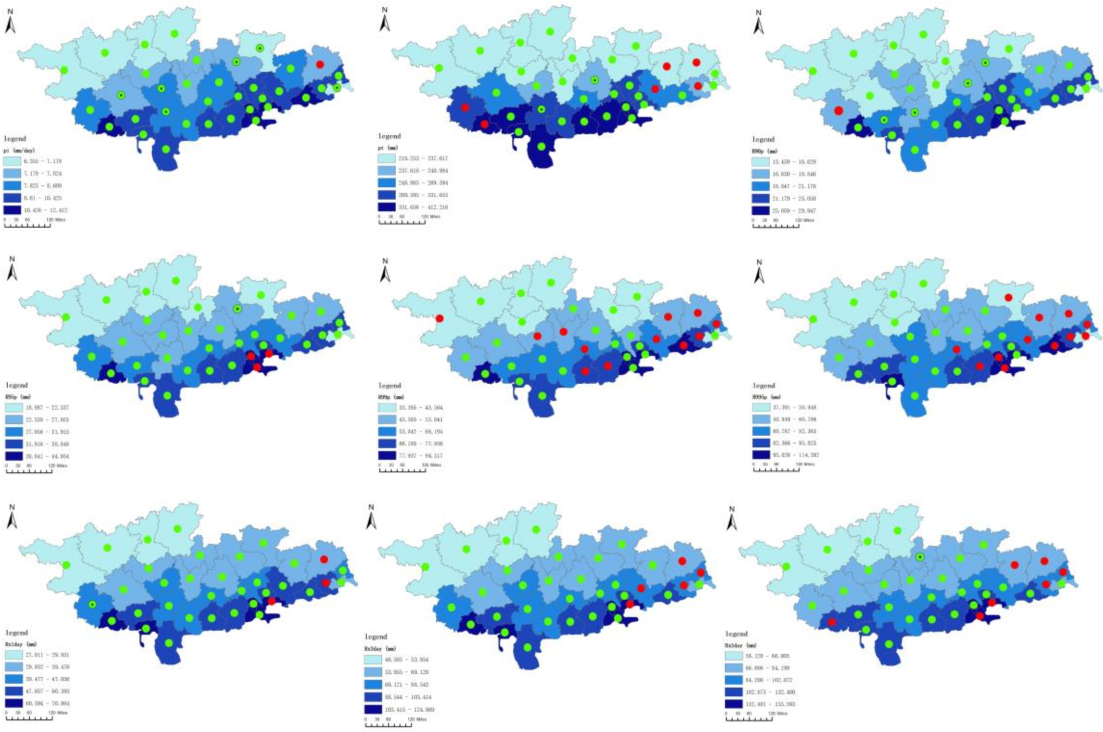


Fig 21. Spatial distribution of the autumn average extreme precipitation. The trend is indicated by circle. Green circle means an increasing trend and red circle means a decreasing trend and. Black dot represents that the trend is through the MK-test.

2.13 Spatial distribution of autumn extreme precipitation anomaly

The autumn extreme precipitation during 1996 to 2017 is more than before in most area. The autumn anomalies of intensity and R90p are positive in all cities. For other indexes, the anomalies of most cities are positive. The negative anomaly area is mainly located in north, middle and west part.

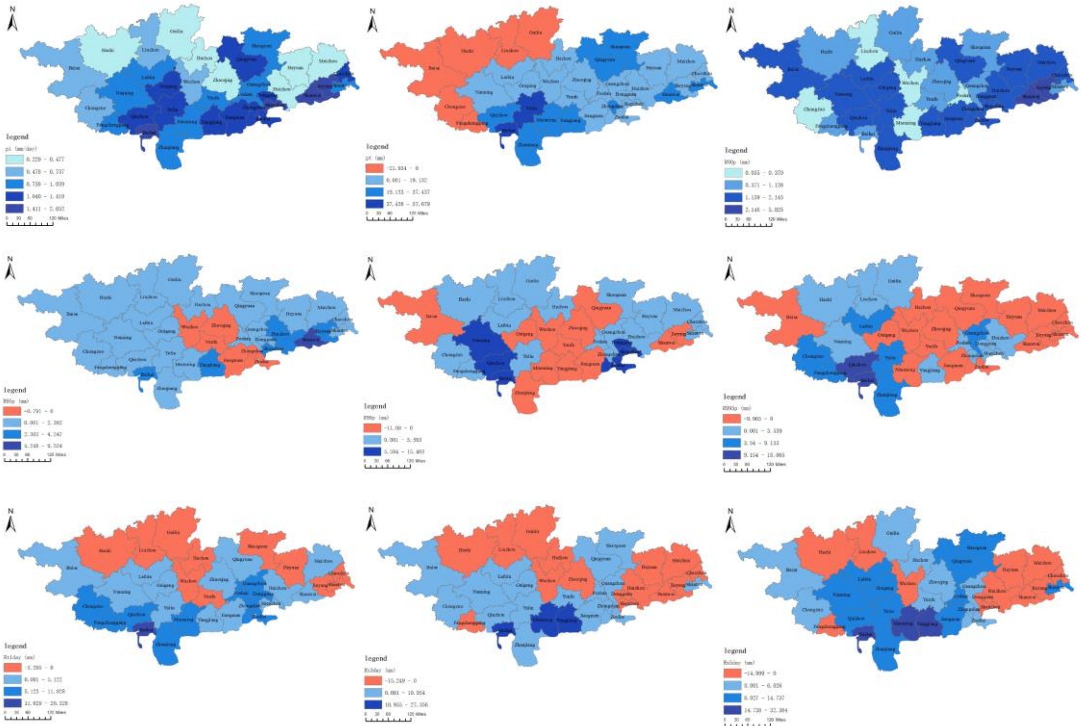


Fig 22. Spatial distribution of autumn extreme precipitation anomaly. Blue represents the positive anomaly area; orange represents the negative anomaly area.

2.14 Spatial distribution of the winter average extreme precipitation

The winter extreme precipitation is increasing obviously. The trend of Rx1day is increasing in all cities. Other indexes trends in most cities are upward. The large value center of pi is mainly located in the northeast. It increases from west to east.

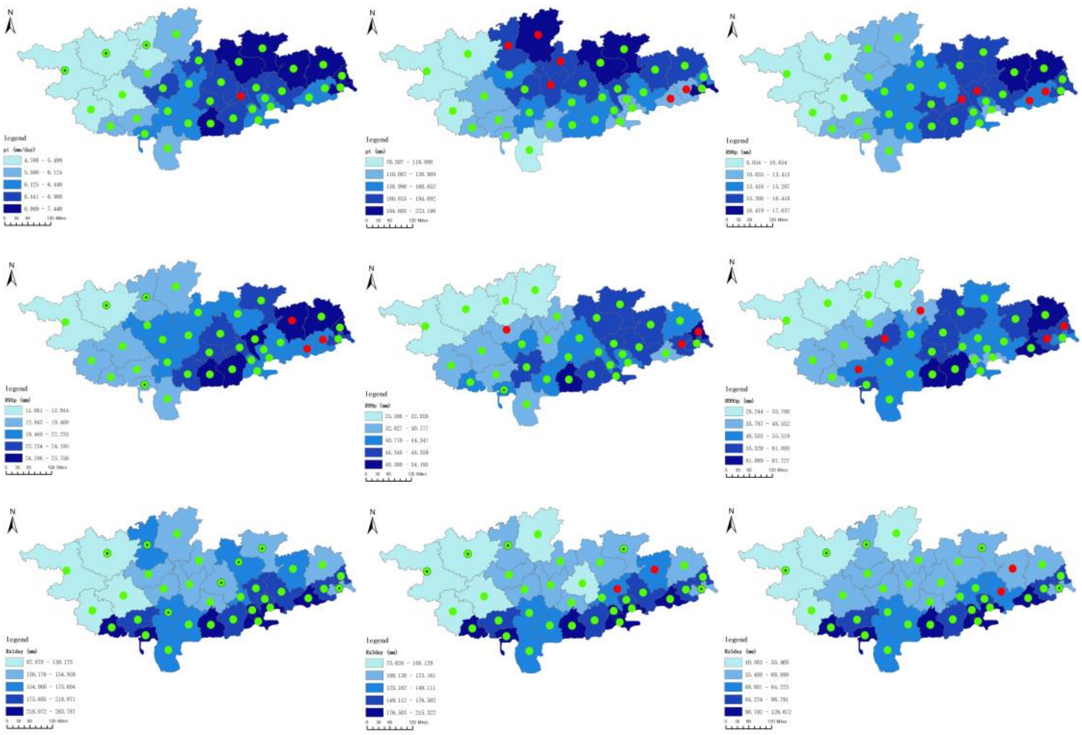


Fig 23. Winter average extreme precipitation. The trend is indicated by circle. Green circle means an increasing trend and red circle means a decreasing trend and. Black dot represents that the trend is through the MK-test.

2.15 Spatial distribution of winter extreme precipitation anomaly

The winter extreme precipitation during 1996 to 2017 is more than before in most area except for total precipitation. The anomalies in Rx1day are positive in all cities in RPB. Other indexes anomalies are positive in most area. The negative anomaly area is mainly located in middle and west part.

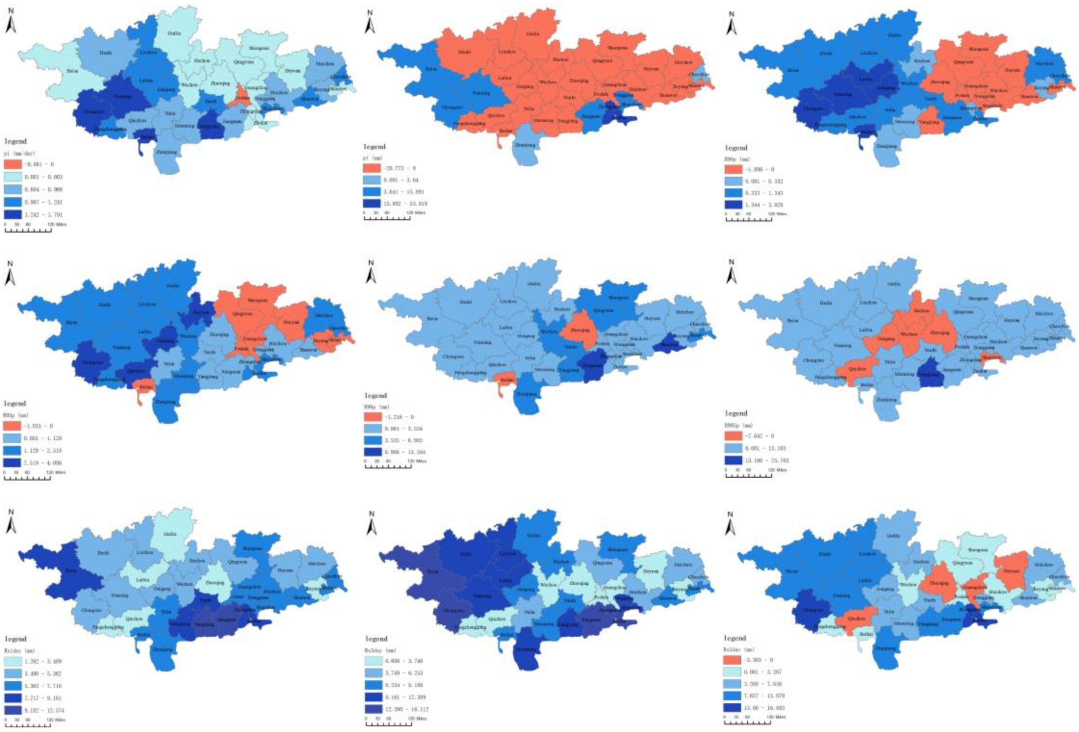


Fig 24. Spatial distribution of winter extreme precipitation anomaly from 1996 to 2017. Blue represents the positive anomaly area; orange represents the negative anomaly area.

Pat 3: Correlation between CO2 emission and precipitation

3.1 CO2 emission in PRB

It is found that the CO_2 emission in PRB, Guangdong province, Guangxi province, coastal and non-coastal regions are all increasing over the years. The cities with higher CO_2 emission are concentrated in the urban cluster in the Pearl River Delta and the 3 leading economic cities in Guangxi Province.

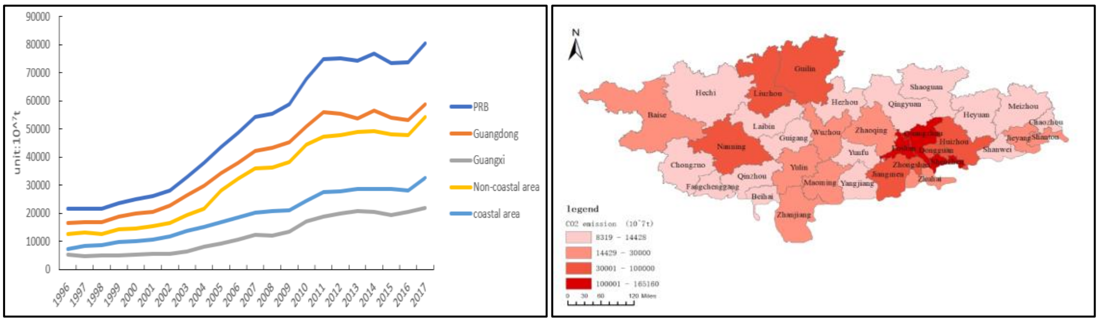


Fig 25. Spatial-temporal characteristics of CO2 emission in PRB.

3.2 CO2 emission at city scale from 1996-2017

The CO2 emission of each city is obviously increasing over years. Guangzhou and Shenzhen are the highest emission city in PRB.

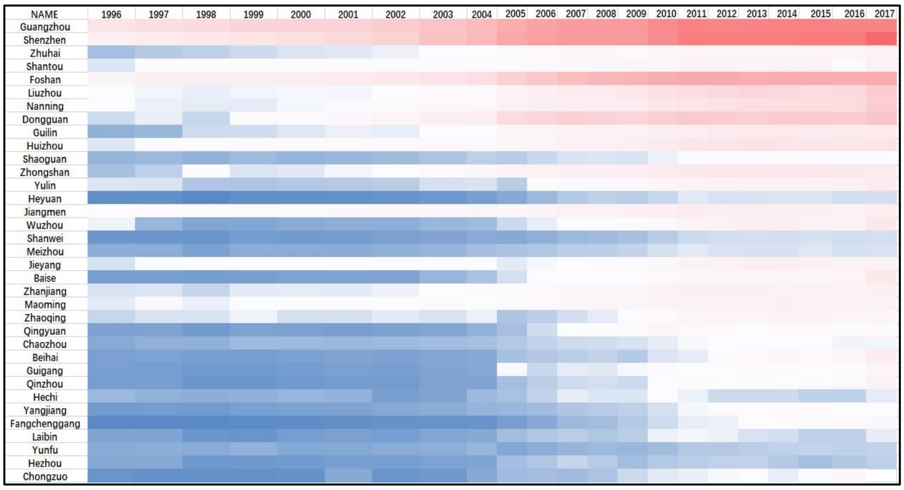


Fig 26. CO2 emission in PRB from 1996-2017. Red represents the high value and blue represents the low value.

3.3 Correlation between annual extreme precipitation and CO_2 emission at regional scale

The change of annual extreme precipitation is time-lagging correlated with CO2 emission. Under the impact of CO2 emission, the increasing of Rx1day and Rx3day in PRB are obvious. In Guangdong Province, the change of Rx1day is positive corelated with CO_2 emission. In Guangxi Province, the change of pt and Rx1day are positive corelated with CO_2 emission. In non-coastal regions, it is found that the change of Rx3day is positive corelated with CO_2 emission. In coastal regions, the change of Rx1day and Rx3day are positively related to CO2 emission.

Table 1. Time-lagging correlation between annual extreme precipitation and CO_2 emission.
* represents the significant level P<0.1. ** represents P<0.05 and *** represents P<0.01.

	PRB	**Guangdong Province**	**Guangxi Province**	**Non-coastal area**	**Coastal area**
pi	0.0733	-0.0296	0.1710	0.1401	-0.0256
pt	0.2450	0.1739	0.3615*	0.2600	0.1958
Rx1day	0.3426*	0.3688*	0.4182**	0.2802	0.4397 **
Rx3day	0.4172 **	0.2193	0.1401	0.3426*	0.4125**
Rx5day	0.2666	0.0390	-0.1184	0.1811	0.2136
R90p	0.0398	-0.0223	-0.1470	0.0348	0.0498
R95p	-0.0023	0.1392	0.0776	0.0665	-0.0128
R99p	-0.0321	0.0350	-0.0391	0.0125	-0.1250
R995p	0.2343	-0.0270	-0.0525	0.2581	0.2479

3.4 The result of lagging-correlation analysis between annual extreme precipitation and CO_2 emission at city scale

CO2 emission mainly causes the increasing of the annual extreme precipitation in southwest, middle and northeast area.

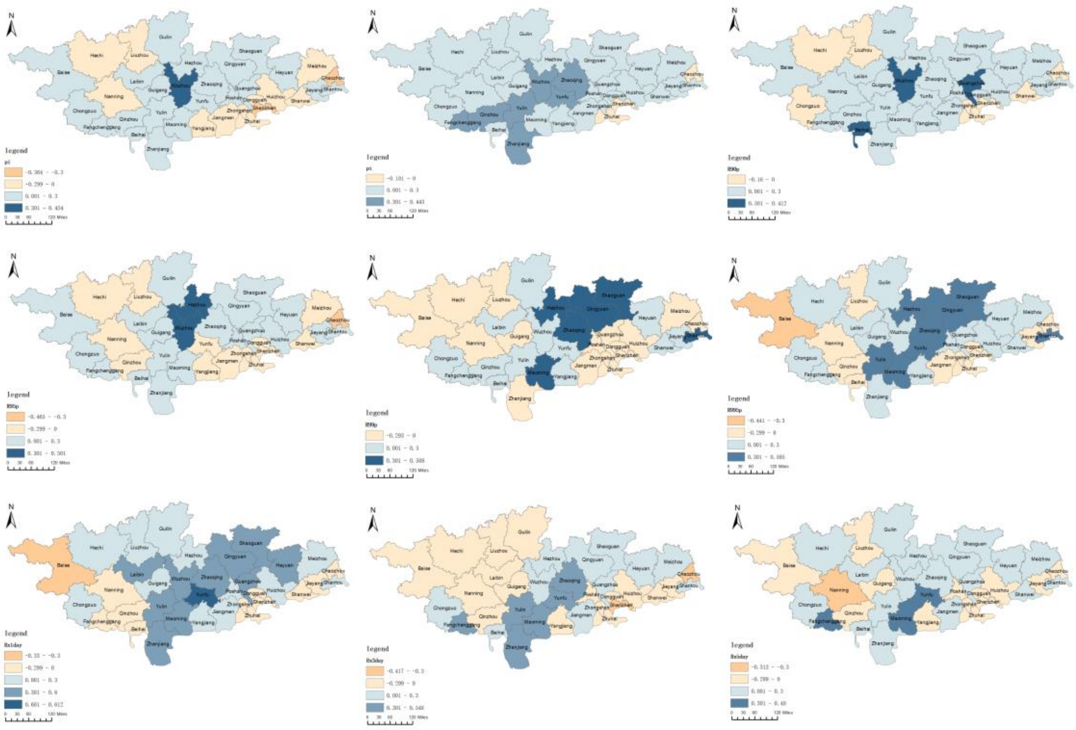


Fig 27. The result of lagging-correlation analysis at city scale from1996-2017. Blue mean the positive lagging correlation, yellow means the negative lagging correlation.

3.5 Time-lagging correlation between seasonal extreme precipitation and CO_2 emission in PRB

In PRB, CO2 emission has a positive impact on extreme precipitation in spring autumn and winter. The coefficients are significant positive in these seasons. The correlation in summer is lower than other seasons.

Table 2. Time-lagging correlation between seasonal extreme precipitation and CO_2 emission in PRB. * represents the significant level P<0.1, ** represents P<0.05, and *** represents P<0.01.

	Spring	Summer	Autumn	Winter
pi	0.5074**	-0.2927	0.1291	0.3152*
pt	0.3618*	-0.1737	0.3855**	0.2811
Rx1day	0.0119	0.3174 *	0.5055**	0.1475
Rx3day	0.4409**	-0.1045	0.3025*	0.4584**
Rx5day	0.2459	-0.0964	0.22	0.5270***
R90p	0.4490**	-0.1558	0.0696	0.5083**
R95p	0.4141**	0.3852**	0.3686*	0.2553
R99p	0.1819	0.172	0.1774	0.2629
R995p	-0.0982	-0.0892	-0.0485	0.4368**

3.6 Time-lagging correlation between seasonal extreme precipitation and CO_2 emission in Guangdong

In Guangdong, CO2 emission has a positive impact on extreme precipitation in spring and winter. The coefficients in these seasons are significant positive. The correlations in autumn are lower. The extreme precipitation change in summer is not related with CO2 emission.

Table 3. Time-lagging correlation between seasonal extreme precipitation and CO_2 emission in Guangdong. * represents the significant level P<0.1, ** represents P<0.05, and *** represents P<0.01.

	Spring	Summer	Autumn	Winter
pi	0.4584**	-0.2573	-0.3089*	0.3038*
pt	0.3952**	-0.1916	0.1472	0.2822
Rx1day	0.0979	0.2306	0.4927 **	0.1513
Rx3day	0.3752*	-0.2474	-0.1257	0.3976 **
Rx5day	0.2199	-0.2235	-0.2653	0.4712**
R90p	0.4285**	-0.2343	-0.2607	0.4515**
R95p	0.3701*	0.2339	0.1438	0.0794
R99p	0.2658	0.1635	-0.0816	0.1984
R995p	0.3106*	0.0271	-0.2551	0.5950***

3.7 Correlation between seasonal extreme precipitation and CO_2 emission in Guangxi

In Guangxi, CO2 emission has a positive impact on extreme precipitation in autumn and winter. The coefficients in these seasons are significant positive. The extreme precipitation change in spring is not related with CO2 emission.

Table 4. Time-lagging correlation between seasonal extreme precipitation and CO_2 emission in Guangxi. * represents the significant level P<0.1, ** represents P<0.05, and *** represents P<0.01.

	Spring	Summer	Autumn	Winter
pi	0.0636	-0.1843	0.5538 ***	0.224
pt	0.0473	-0.0399	0.6319***	0.2069
Rx1day	0.0111	0.2714	0.5047**	0.0914
Rx3day	-0.1977	-0.2919	0.4479**	0.2237
Rx5day	-0.2557	-0.3879 *	0.5390***	0.4031**
R90p	-0.1847	-0.2302	0.5692***	0.3584*
R95p	0.0501	0.3595*	0.4960**	0.3619*
R99p	-0.1031	0.183	0.4888*	0.3377*
R995p	-	0.0206	0.4331**	0.1613

3.8 Correlation between seasonal extreme precipitation and CO_2 emission in non-coastal region

In non-coastal region, CO2 emission has a significant positive impact on extreme precipitation in spring, autumn and winter. The extreme precipitation change in summer is lower because of the overmuch nature factor interference.

Table 5. Time-lagging correlation between seasonal extreme precipitation and CO_2 emission in non-coastal region. * represents the significant level P<0.1, ** represents P<0.05, and *** represents P<0.01.

	Spring	Summer	Autumn	Winter
pi	0.5279***	-0.3032	0.2605	0.157
pt	0.3396*	-0.1917	0.4559**	0.2553

Rx1day	-0.0564	0.2025	0.4732**	0.2151
Rx3day	0.3431*	-0.1226	0.2608	0.4489**
Rx5day	0.2842	-0.0845	0.3628*	0.5492***
R90p	0.3561*	-0.1254	0.2198	0.5215***
R95p	0.3496*	0.4264**	0.5649***	0.2487
R99p	0.3494*	0.1904	0.3572*	0.3517*
R995p	0.2845	-0.1232	0.2714	0.4013**

3.9 Correlation between seasonal extreme precipitation and CO_2 emission in coastal region

In coastal region, CO2 emission has a significant positive impact on extreme precipitation in spring and winter. The extreme precipitation change in summer and autumn is lower because of the overmuch nature factor interference in these seasons.

Table 6. Time-lagging correlation between seasonal extreme precipitation and CO_2 emission in coastal region. * represents the significant level $P<0.1$, ** represents $P<0.05$, and *** represents $P<0.01$.

	Spring	Summer	Autumn	Winter
pi	0.4197**	-0.2401	-0.1363	0.3214*
pt	0.3174*	-0.1515	0.2368	0.3413*
Rx1day	0.0409	0.2902	0.5677***	0.2542
Rx3day	0.4035**	0.0024	0.2914	0.4413**
Rx5day	0.1502	-0.1129	0.0774	0.4774**
R90p	0.3587*	-0.1487	-0.0358	0.4575**
R95p	0.3118*	0.3670*	0.0678	0.3046*
R99p	0.243	0.1565	-0.0755	0.2257
R995p	-	0.029	0.0771	0.5359***

3.10 The correlation at city scale in spring

In spring, CO_2 emission has a significant positive impact on extreme precipitation in middle and east cities. With continued high emissions, these regions are at higher risk of extreme precipitation in spring.

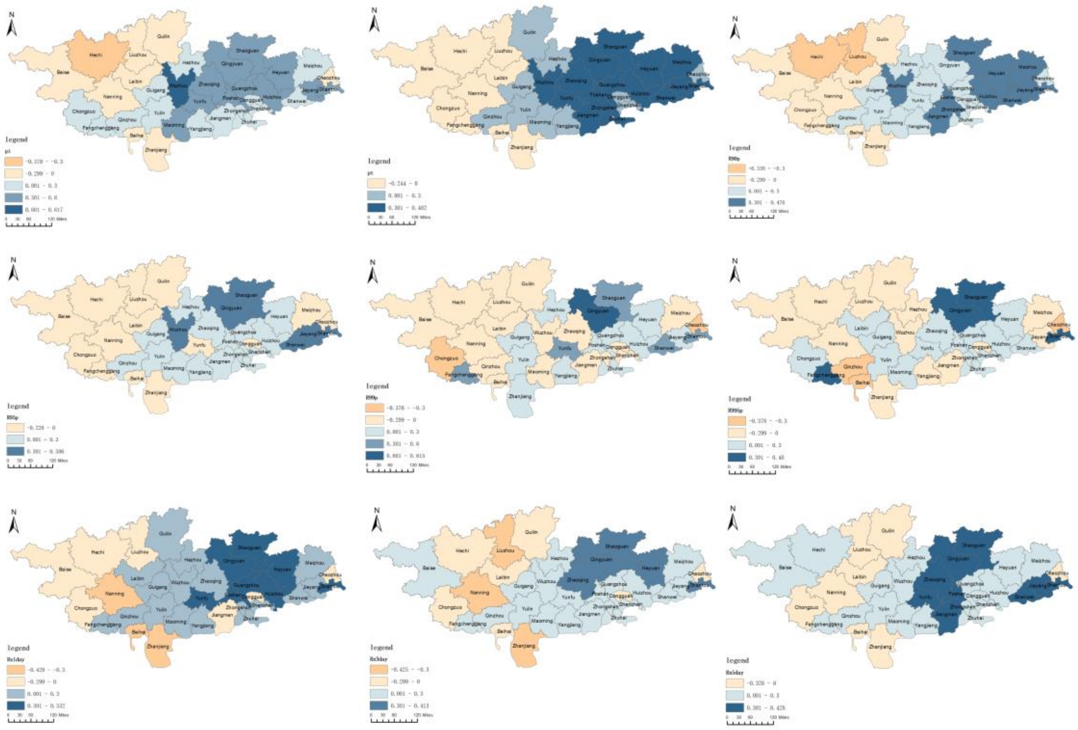


Fig 28. The result of lagging-correlation analysis at city scale from1996-2017 in spring. Blue mean the positive lagging correlation, yellow means the negative lagging correlation.

3.11 The correlation at city scale in summer

There is no obvious relation between summer extreme precipitation and CO_2 emission.

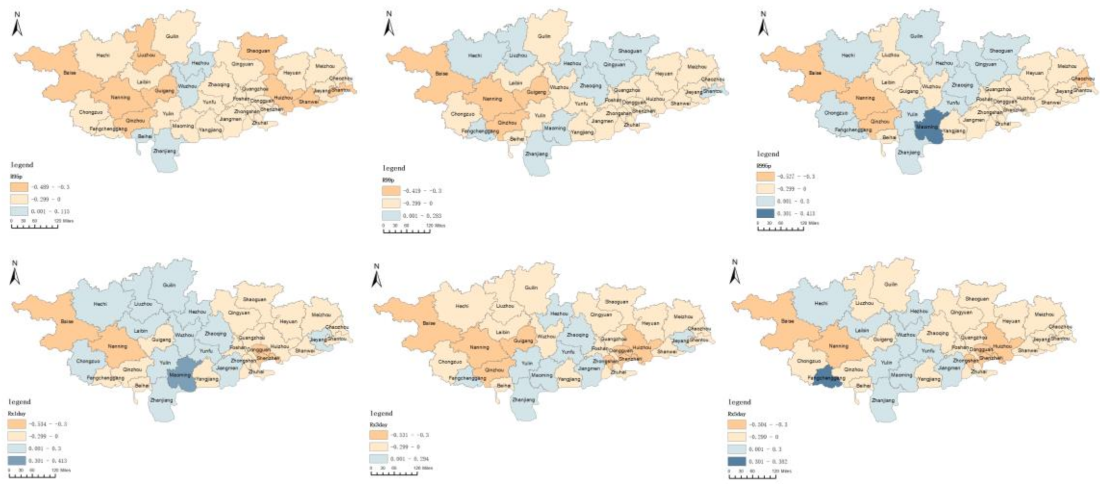


Fig 29. The result of lagging-correlation analysis at city scale from1996-2017 in summer. Blue mean the positive lagging correlation, yellow means the negative lagging correlation.

3.12 The correlation at city scale in autumn

In autumn, CO_2 emission has a significant positive impact on extreme precipitation in middle and west cities. With continued high emissions, these regions are at higher risk of extreme precipitation in autumn.

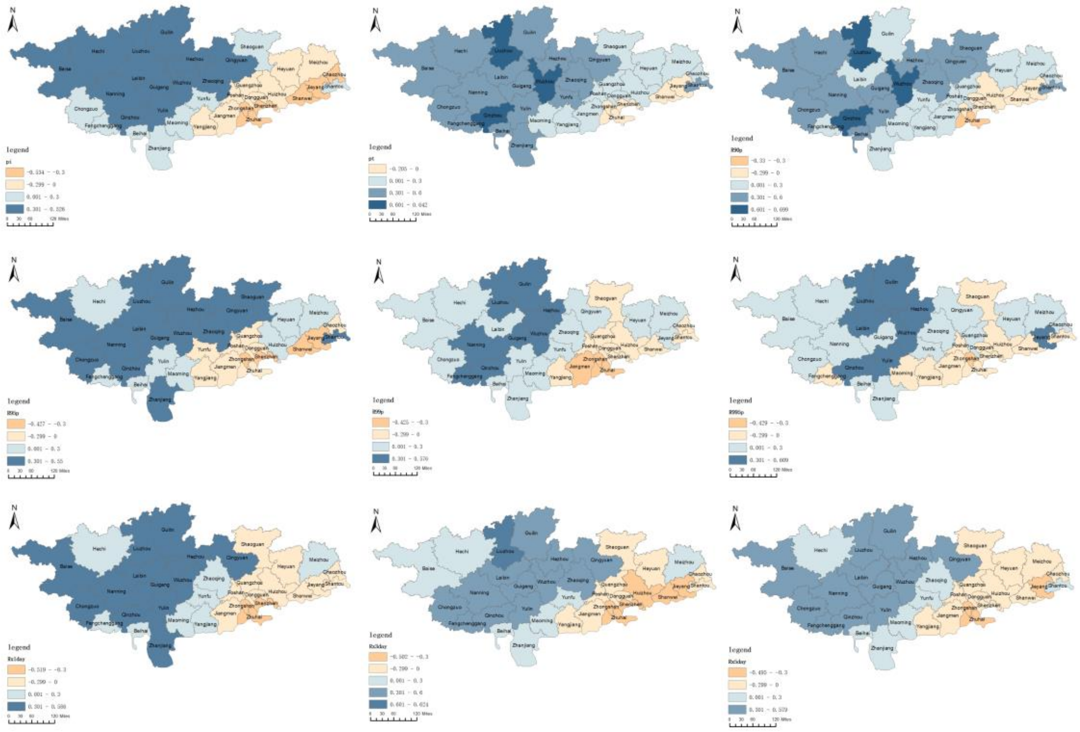


Fig 30. The result of lagging-correlation analysis at city scale from1996-2017 in autumn. Blue mean the positive lagging correlation, yellow means the negative lagging correlation.

3.13 The correlation at city scale in winter

In winter, CO2 emission has a significant positive impact on extreme precipitation in most cities in PRB. These cities in PRB will face high risk in autumn with the high CO2 emission.

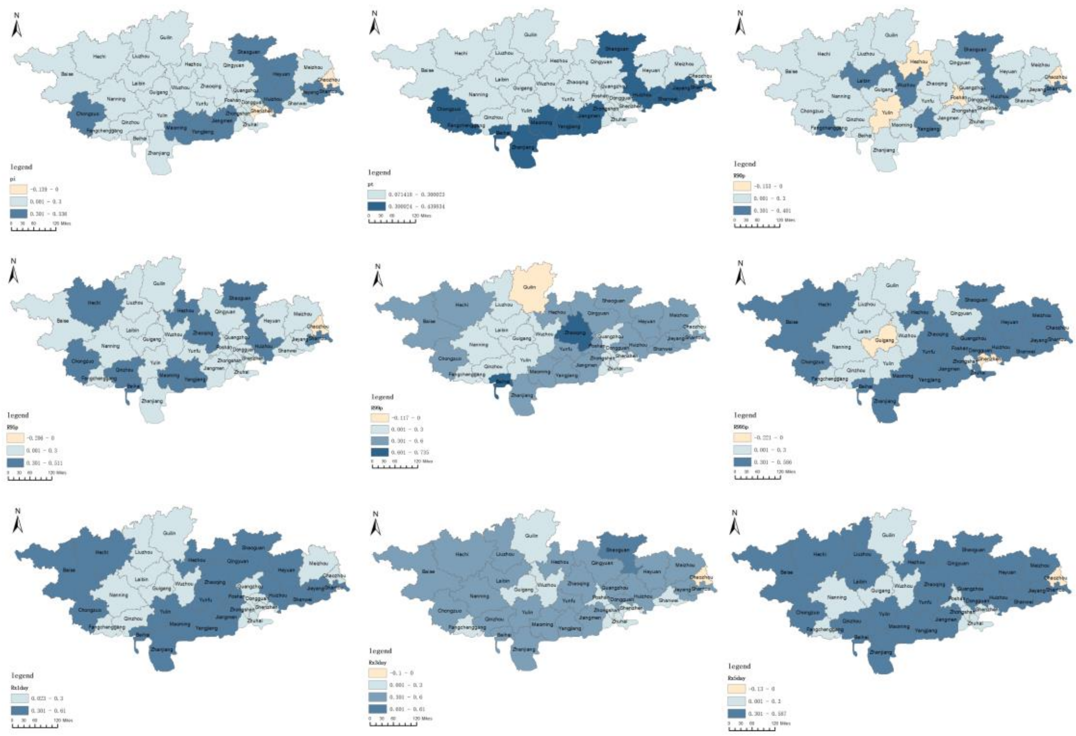


Fig 31. The result of lagging-correlation analysis at city scale from1996-2017 in winter. Blue mean the positive lagging correlation, yellow means the negative lagging correlation.