TEMPORAL ANALYSIS OF URBANIZATION AND RESULTING LOCAL WEATHER CHANGE: A CASE STUDY OF LAHORE, PUNJAB, PAKISTAN

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ABSTRACT: *Urbanization results in significant changes to the roughness and radiative properties of the earth's surface. These changes can influence the local weather and climate within the urban canopy. Lahore has experienced rapid urban growth over the earlier few decades and the remarkable land cover change resulting in influencing the local weather and climate. This research aims to identify the relationship between land cover change especially urbanization and local weather variations on the basis of temperature and rainfall from 1972-2013. Temperature variables include the mean monthly (MM) and mean annual (MA) of mean minimum (MMi) and mean maximum (MMx). Mean monthly rainfall (MMR) and mean annual rainfall (MAR) was also calculated to find out its relationship with rapid urban growth and resulting local weather variations. The results showed that minimum annual mean temperature increased (+1 ^{o}C) while maximum annual mean temperature decreased to (-0.3 ^{o}C) and the mean annual rainfall decreased (-3.0 mm). The results show that temperature is increasing by 0.021 ^{o}C / Year in the study area. GIS tool has been used to identify the land cover changing pattern since 1981 to 2013.*

Keywords: Urbanization, mean Min. temperature, land use, precipitation

INTRODUCTION

Almost 50 % of world's population lives in urban areas, and this urban population is growing more faster than the Earth's whole population [1]. It is expected that 61% of the world's population will inherent in the urban settlement in 2030 [2]. Urbanization is one of the most important human activities that affect the climate system [3]. It has been documented that urban areas likely to have higher temperatures than adjacent rural (or less developed) areas due to the absorption of heat and the radiative properties of impervious surfaces [4]. These differences are somewhat due to the urban expansion, which generally removes and replaces crops and natural vegetation such surfaces (metal, asphalt and concrete) which are non-evaporating and non-transpiring [5]. The basic components of climate, temperature and precipitation are interrelated and any slight changes in their pattern can affect human health, ecosystems, flora, and fauna [6]. An increase in the temperature tend to more evaporation and resulting condensation, consequently increase precipitation which in result increase the flood frequency [7].

The recent studies have indicated that there is a positive relationship between urbanization and climate change. Kalnay and Cai (2003) suggested that the decrease in the diurnal temperature was owing to urban expansion and other land-use type changes [8]. Sertel et al., (2011) concluded that in Turkey urbanization increased the average temperature as they used the results of simulation with the Weather Research and Forecasting (WRF) regional climate model. Urbanization can also affect the regional precipitation [9,10]. For example, Zhang, et al., (2009) suggested that "the urban surface was the main factor affecting the spatio-temporal pattern and the intensity of short-term rainfall in St. Louis, MO, USA" [11]. In recent times, Sajjad et al., (2009) investigated the correlation between urbanization and temperature variability. They applied regression method to find out temperature transform from 1950-2007 and found a significant change in MMiT which was 2.51 ^{o}C. On the other hand, MMxT almost remain same. On basis of MMiT and MMxT (Mean Minimum and Mean Maximum), MAT (Mean Annual Temperature) was analyzed with 0.89 ^{o}C increase [12].

Among the developing countries of the world and the countries of South Asia, Pakistan is considered the most urbanized country experiencing the rapid process of urbanization and Lahore metropolitan city stands at second while comparing to the other cities [13]. Keeping in view the extent of the issue, this study has been planned to highlight decadal temperature trend analysis by using mean minimum and mean maximum temperature and mean rainfall data of Lahore Metropolitan city over the last three decade (1981-2013). The main objective of this study is to find out the decadal change in urbanization and the resultant change in the temperature and rainfall.

MATERIALS AND METHODS

Study Area: Lahore Stretches from 31°15′—31°45′ north latitude and 74°01′—74°39′ east longitude. From the northern and western side Lahore is surrounded by Sheikhupura District, Wagah is on the eastern side and on southern side with Kasur District. In the north side of Lahore Ravi River flows. It is the capital of the largest province (Punjab) of Pakistan and is the growing metropolis after Karachi. Lahore has been given the name of Lahore Metropolitan Area (LMA) by LDA, covering some areas of Kasur District and Ferozwala Tehsil of District Sheikhupura. Covering these areas, now the total area of Lahore is 2306 sq km [14].

Data Sources: To study the temporal trend of temperature and rainfall, mean monthly meteorological data was collected from Pakistan Metrological Department Jail road, Lahore. The data included monthly average minimum and maximum temperature (^{o}C) and monthly average rainfall (mm). Data of

time series covered past three decades from 1981 to 2013. In order to study the land cover and land use (LCLU) changes of district Lahore, four Landsat satellite images of Lahore (1981, 1992, 2001 and 2013) were downloaded from USGS site. The software used for the processing of images are ERDAS imagine and ArcGIS 10.

Data Analysis: Three different data segments were made including temperature (Mean minimum monthly, mean monthly maximum) rainfall (mean monthly) and landuse (urban, cropland and water bodies) for the selected study area and were analyzed by using SPSS 19.0 and Graph Pad Prism 5. The temporal data of temperature, rainfall and landuse was computed in three decades from 1981-1991, 1992-2001 and 2002-2013 nominated as D^1, D^2, and D^3. Averages and means were calculated to identify the relationship and trends. A statistical test trend provides scholar a basic insight for quantitative decisions for process or processes [15].

The data regarding minimum and maximum temperature and rainfall was analyzed at two levels. In the first level mean was calculated for mean minimum and maximum monthly temperature and rainfall of three decades nominated as D^1, D^2, and D^3 with the following statistical formula;

$$\overline{X} = \frac{\sum X}{N}$$

Where,

$\overline{X}$ is mean of D^1, D^2, and D^3

$\sum X$ is the sum of D^1, D^2, and D^3

N is the number of decades

In the second level mean annual minimum and maximum temperature and rainfall was calculated by using the mean formula. Finally, the mean monthly and mean annual difference was calculated by subtracting the calculated mean with the mean of D^1 for both temperature and rainfall.

To quantify whether the calculated difference in the mean minimum and mean maximum temperature and rainfall, *t* test was applied. A *T* test is a procedure used for comparing samples means to see if there is sufficient evidence to infer that the means of the corresponding sample also differ. One-sample *t* test is a type of *t* test which is designated to test whether the mean of a distribution differs significantly from some present value.

$$t = \frac{\overline{x} - \mu_0}{s/\sqrt{n}}$$

$\overline{x}$ = Sample mean

μ_0 = Value of sample parameter to be tested

s= Unbiased standard deviation

n= Sample size

RESULTS AND DISCUSSION

The results have been discussed in five sub-sections;

Mean Annual Temperature Trends Analysis (1981-2013): In the mean annual temperature, a positive incremental trend has been observed (table–01 & 02). Overall 0.7 ^oC temperature has increased in the last three decades 1981-2013 with average annual increase of 0.021 ^oC. This means that till 2030 Lahore will experience almost 1.0 ^oC increment in the overall temperature. The maximum temperature increase was observed in the decade of 2002-13 with mean maximum annual temperature 30.4 ^oC and mean minimum annual temperature 19.6 ^oC. The lowest temperature increased was observed in the decade 1981-92 with mean maximum annual temperature 30.9 ^oC and mean minimum annual temperature 17.9 ^oC.

MMi (Mean Minimum Temperature) Trends Analysis (1981-2013): The results in table–01and fig –01 show that there found a significant warming trend for the whole three decades (1981- 2013) with mean maximum annual temperature 17.9 ^oC, 19.1 ^oC and 19.6 ^oC respectively. The calculated mean of the three decades (18.9 ^oC) and the mean of the first decade (17.9 ^oC) show that there found an increase of 1.0 ^oC. This difference is significant as the calculated P value (0.0007) is less than alpha 0.05. This means that the 0.03 ^oC mean minimum temperature will increase, holding all other factors constant.

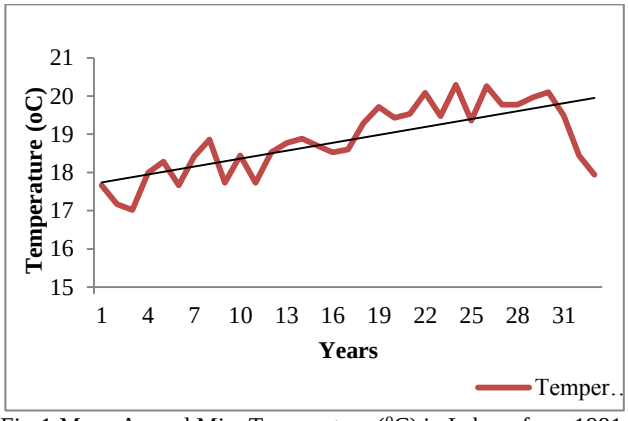

Fig-1:Mean Annual Min. Temperature (^oC) in Lahore from 1981-2013

MMx (Mean Minimum Temperature) Trends Analysis (1981-2013): The results in table–02and fig –02 show a negative trend in the mean maximum temperature of the three decades (1981-2013) with mean maximum annual temperature 30.9 ^oC, 30.6 ^oC and 30.4 ^oC respectively. The calculated mean of the three decades (30.6 ^oC) and the mean of the first decade (30.9 ^oC) show that there was a slight decrease of 0.3 ^oC. This difference is significant as the P value (0.0001) is less than alpha 0.05. It is expected that 0.009 ^oC will decrease, holding all other factors constant.

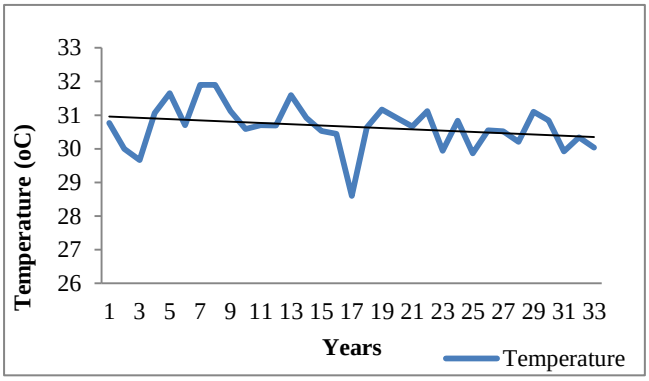

Fig-2: Mean Annual Max. Temperature (^{o}C) in Lahore from 1981-2013

MR (Mean Rainfall) Trends Analysis (1981-2013): Based on the results given in Table–03, it was found that the amount of rainfall is decreasing from 1981 – 2013. In the decade of 1981-92, mean annual rainfall was 58.9 mm then 57.6 and 51.2 mm respectively. The computed mean of the three decades (55.9 mm) and the mean annual rainfall of the first decade 1981-92 (58.9 mm) show that there found a negative trend (Fig–03) in the amount of rainfall i.e. 0.09 mm annual rainfall. This difference is significant as the P value (0.0018) is less than alpha 0.05.

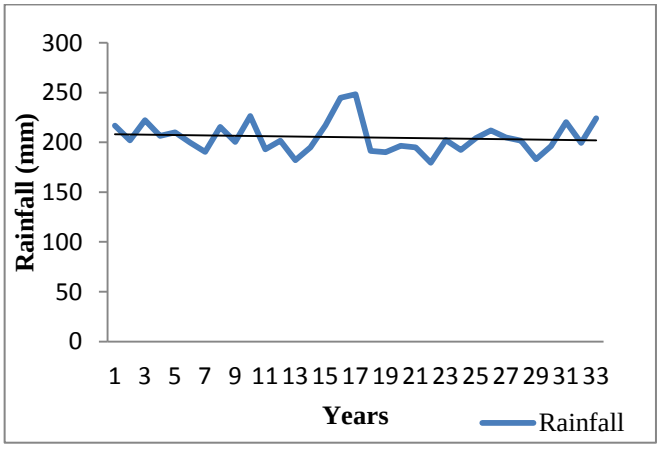

Fig-3: Mean Annual Rainfall (mm) in Lahore from 1981-2013

Urban Area Change 1981–2013: There is an obvious conversion from other land use types to the urban areas in Lahore Metropolitan city. Figure–04 shows a positive urban area change trend from 1981 to 2013 and the table–04 concluded that urban growth of Lahore at 22.65 % as compared to the urban area in 1981 i.e. 11.15%. This difference is significant as the P value (0.0279) is less than alpha 0.05. This difference is obvious from the given maps at the end (Appendix-1).

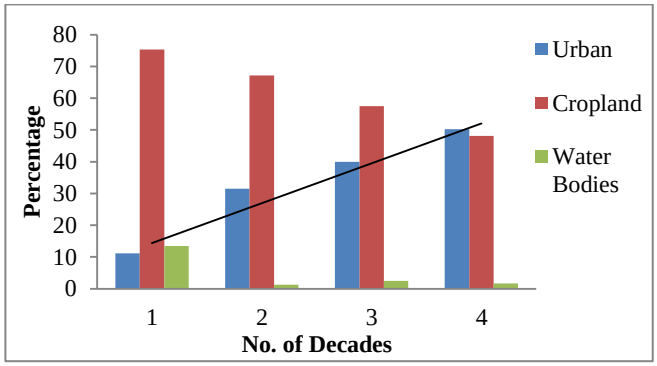

Fig-4: Decadal Change in the Land Use in Lahore from 1981-2013

CONCLUSION

The impact of urbanization on local climate change is a very complex and challenging issue and it is still indispensable to carry out more in-depth research related to this issue. It is obvious from the analysis that there is a positive trend in the convergence of other type of land use to urban areas in Lahore Metropolitan city i.e. 22.65 % from 1981 to 2013. There found a slight temperature change with increasing trend in the city with an average increasing rate 0.021 ^{o}C /year. However, the precipitation has decreased to some degree at average rate 0.09 mm/year. The findings of present research reveal that the anthropogenic land cover change has momentous impacts on the local climate of Lahore Metropolitan city, which can provide scientific reference for the optimization of the future land use in consideration of the regional climate change. The government can take some useful measures according to the result of this study to mitigate the climate change. The government should take interest in urban land use planning and consider it as an important component of the ecological infrastructure to promote the ability of city to adapt to climate change since the urbanization will continue.

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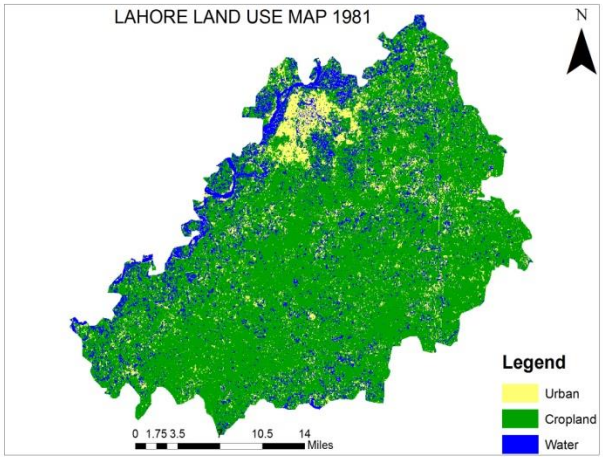
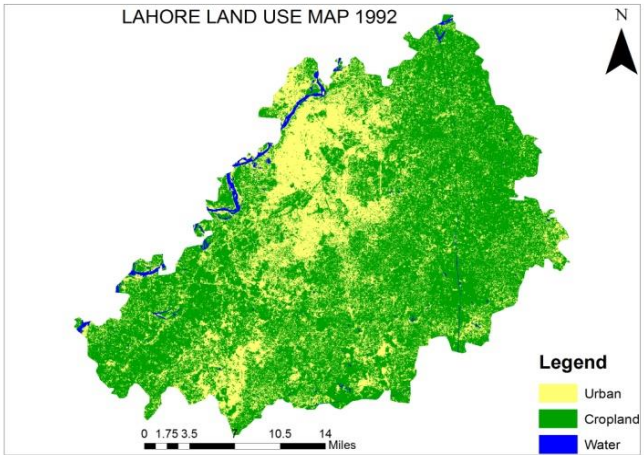
Appendix-1


LAHORE LAND USE MAP 1981
N
Legend
Urban
Cropland
Water
0 1.75 3.5 10.5 14
Miles


LAHORE LAND USE MAP 1992
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Cropland
Water
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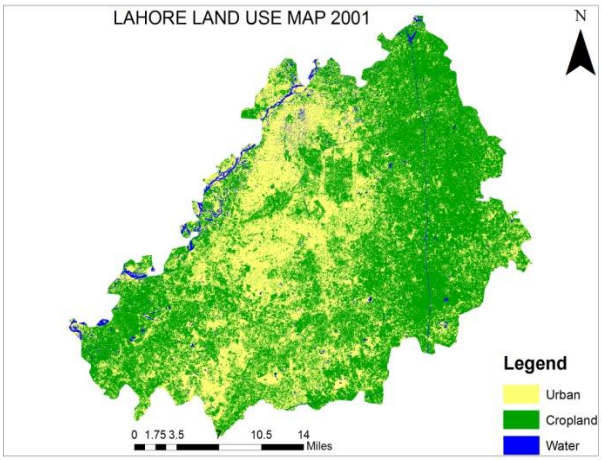
Miles


LAHORE LAND USE MAP 2001
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Water
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Miles

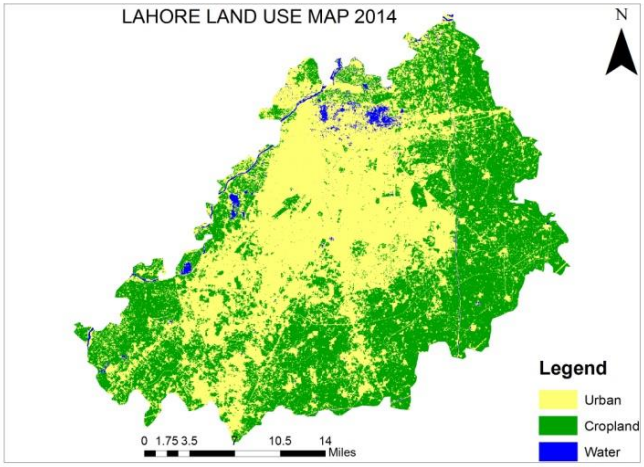
LAHORE LAND USE MAP 2014
N
Legend
Urban
Cropland
Water
0 1.75 3.5 10.5 14
Miles

Table- 01: Decadal Change in Mean Monthly & Annual Min. Temperature (^{o}C) in Lahore from 1981-2013

Years	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Mean Annual
1981-92	6.9	9.2	13.9	19.1	23.7	26.9	26.7	26.4	24.7	18.0	12.2	7.8	17.9
1993-01	7.4	10.7	15. 6	20.6	25.8	27.4	27.2	27.1	25.2	19.8	13.5	8.7	19.1
2002-13	7.8	11.3	16.8	21.9	26.1	27.8	27.3	26.9	25.2	20.6	14.3	9.1	19.6
Mean	**7.4**	**10.4**	**15.4**	**20.5**	**25.2**	**27.4**	**27.1**	**26.8**	**25.0**	**19.5**	**13.3**	**8.5**	**18.9**
Difference (^{o}C)	**+0.5**	**+1.2**	**+1.5**	**+1.4**	**+1.5**	**+0.5**	**+0.4**	**+0.4**	**+0.3**	**+1.5**	**+1.1**	**+0.7**	**+1.0**
Std. Deviation	0.45	1.08	1.46	1.40	1.31	0.45	0.32	0.36	0.29	1.33	1.06	0.67	0.87
t, df	t=28.3 df=2	t=16.7 df=2	t=18.3 df=2	t=25.4 df=2	t=33.4 df=2	t=105.1 df=2	t=145.8 df=2	t=128.7 df=2	t=150.2 df=2	t=25.3 2 df=2	t=21.8 df=2	t=22.2 df=2	t=37.4 df=2
P value (two tailed)	0.0012	0.0036	0.0030	0.0015	0.0009	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0016	0.0021	0.0020	0.0007
Significant (alpha=0.05)?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table- 02: Decadal Change in Mean Monthly & Annual Max. Temperature (^{o}C) in Lahore from 1981-2013

Years	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Mean Annual
1981-92	20.2	22.2	26.6	33.4	38.4	40.4	36.3	35.2	35.5	32.7	27.8	22.2	30.9
1993-01	18. 6	22.6	27.3	34.0	39.4	38.9	35.1	34.6	34.7	32.4	27.7	21.8	30.6
2002-13	18.1	21.9	28.2	34.8	39.1	38.7	35.8	34.4	33.9	31.9	26.9	21.4	30.4
Mean	**19.2**	**22.2**	**27.4**	**34.1**	**38.9**	**39.3**	**35.7**	**34.7**	**34.7**	**32.3**	**27.5**	**21.8**	**30.6**
Difference (^{o}C)	**-1.1**	**+0.1**	**+0.8**	**+0.7**	**+0.6**	**-1.1**	**-0.6**	**-0.5**	**-0.8**	**-0.4**	**-0.3**	**-0.4**	**-0.3**
Std. Deviation	1.09	0.35	0.80	0.70	0.51	0.93	0.60	0.42	0.80	0.40	0.49	0.40	0.25
t, df	t=29.9 df=2	t=109.7 df=2	t=59.10 df=2	t=84.0 df=2	t=131.5 df=2	t=73.3 df=2	t=102.7 df=2	t=144.5 df=2	t=75.1 df=2	t=138.6 df=2	t=96.4 df=2	t=94.4 df=2	t=210. 8 df=2
P value (two tailed)	0.0011	< 0.0001	0.0003	0.0001	< 0.0001	0.0002	< 0.0001	< 0.0001	0.0002	< 0.0001	0.0001	0.0001	< 0.0001
Significant (alpha=0.05) ?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table- 03: Decadal Change in Mean Monthly & Annual Rainfall (mm) in Lahore from 1981-2013

Years	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Mean Annual
1981-92	29.6	41.8	48.1	32.4	29.0	37.4	189.9	187.1	69.4	20.4	6.5	14.9	58.9
1993-01	19. 6	25.5	22.6	19.1	14.9	71.6	220.8	213.1	53.4	16.3	9.7	4.0	57.6
2002-13	16.4	36.2	27.9	13.2	16.4	71.3	165.3	168.5	77.6	9.5	3.6	8.9	51.2
Mean	**23**	**34.5**	**32.9**	**21.6**	**20.1**	**60.1**	**192.0**	**189.6**	**66.8**	**15.4**	**6.6**	**9.3**	**55.9**
Difference (mm)	**-6.6**	**-7.3**	**-15.2**	**-10.8**	**-8.9**	**+22.7**	**+2.1**	**+2.5**	**-2.6**	**-5.0**	**0.1**	**-5.6**	**-3.0**
Std. Deviation	6.88	8.28	13.46	9.84	7.74	19.66	27.81	22.40	12.31	5.51	3.05	5.46	4.12
t, df	t=5.5 df=2	t=7.2 df=2	t=4.2 df=2	t=3. 8 df=2	t=4.5 df=2	t=5.3 df=2	t=11.9 df=2	t=14.7 df=2	t=9.4 df=2	t=4.8 df=2	t=3.7 df=2	t=2.9 df=2	t=23.5 df=2
P value (two tailed)	0.0315	0.0187	0.0516	0.0629	0.0461	0.0339	0.0069	0.0046	0.0111	0.0401	0.0644	0.0988	0.0018
Significant (alpha=0.05) ?	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes

Table- 04: Decadal Change in the Land Use in Lahore from 1981-2013

Year/period	Urban (%)	Cropland (%)	Water Bodies (%)
1981	11.15	75.36	13.5
1992	31.53	67.21	1.27
2001	39.97	57.53	2.51
2013	50.20	48.13	1.67
Difference 1981–2013*	**22.65 %**	**-20.21 %**	**-3.67 %**
t, df	t=4.01 df=3	t=10.51 df=3	t=1.62 df=3
P value (two tailed)	0.0279	0.0018	0.2046
Significant (alpha=0.05)?	Yes	Yes	No

Note: *represents the change rate calculated with the following equation: Ai^{2013}-(Ai^{1981}+Ai^{1992}+Ai^{2001}) / 3, where (Ai^{1981}+Ai^{1992}+Ai^{2001}) / 3 means the mean area proportion of land use type from 1981-2001 and Ai^{2013} means the area proportion of land use type in 2013