Monitoring the impacts of spatio-temporal land-use changes on the regional climate of city Faisalabad, Pakistan

Arfan Arshad, Wanchang Zhang, Muhammad Awais Zaman, Adil Dilawar and Zulqarnain Sajid

*Key Laboratory of Digital Earth Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing, China; bDepartment of Irrigation and Drainage, University of Agriculture Faisalabad, Faisalabad, Pakistan; cInstitute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China; dInstitute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China

ABSTRACT
The eco-environment in city Faisalabad has attained much consideration due to rapid urbanization and land-use changes in past few years. The purpose of this study is to analyse the impacts of land-use changes on regional climate by linking them with temperature and precipitation trend using spatio-temporal analysis and statistical method. Geospatial and remote sensing technique provides essential tools which can be used to interpret the land-use changes. Spatio-temporal land-use changes from 1985 to 2016 were analysed using unsupervised image classification technique. Land-use maps were classified into three main classes, namely agriculture, built-up and open land. The results indicate that agricultural land has continuously decreased by 37.79–10.23%, built-up area has increased by 33.07–88.19% and open land has decreased by 29.13–1.5% from 1985 to 2016. Statistical analysis indicates that transformation of agriculture and open land into built-up land has led to rise in temperatures and annual rainfall trend in Faisalabad. Average increase in annual $T_{\text{Min}}$, $T_{\text{Max}}$ and $T_{\text{Mean}}$ was 1.2, 0.3 and 0.7°C, respectively from 1985 to 2016. Overall contribution of urban warming to total annual $T_{\text{Min}}$, $T_{\text{Max}}$ and $T_{\text{Mean}}$ was 12.31%, 1.95% and 5.42%, respectively. Annual rainfall is also increasing and it has increased by 120 mm from 1985 to 2016. Results indicate that temporal variations of annual temperature and rainfall are consistent with land-use changes in city Faisalabad, and significant correlation coefficients were found between them. It is recommended that this type of study is helpful for urban planners to control the urbanization properly especially in larger cities of Pakistan.

1. Introduction
It is considered that land-use changes at regional and global scales are the crucial driving factors of climate change (Foley et al. 2005). According to fourth assessment report of Inter-governmental Panel on Climate Change, anthropogenic activities have been contributed to 90% of global warming (Team, Pachauri, and Reisinger 2007). Some studies have shown that land-use changes induced by anthropogenic activities are the key factors which influence the regional climate (Bonan 1997; Paeth et al. 2009). Urbanization is an extreme way in changing land use by human activities, according to their needs (Singh, Grover, and Zhan 2014). Urbanization takes place when people migrate from rural areas to urban areas for getting better job opportunities and improving the standard of life. All the resources in urban regions are well built and easily available which make human life more comfortable (Soh 2012). From the statistical analysis, it has been considered that the number of people living in the world’s urban zones is projected to increase by 80% from 2010 to 2050 (Mitchell L. Moss 2012). Lahore, Karachi, Multan, Faisalabad, Rawalpindi, Hyderabad and Gujranwala are the most populated cities of Pakistan, and in last few years population of these cities has increased rapidly. In 1981, number of people living in these cities were 1000,000 but later on there was a tremendous increase in population of these mentioned cities from 40% to 50% in 1998 (Arif and Hamid 2009).

The rapid land-use changes compared to earlier are usually classified as built-up development, land abasement or the transformation of agricultural land to settled space, resulting massive cost to the environment (Sankhala and Singh 2014). Urban growth, especially the transformation of agriculture and commercial land to built-up land, has long been considered as an indicator of regional climate change. It has been seen that the climate change due to
urban development can affect the hydrological, geomorphologic and thermal features which subsequently may bring untoward changes in the environment (Nelson et al. 2009). At present, regional climatic change in urbanized areas is more evident to the scientists (Ichimura 2003). Many studies have been planned to analyse relationship between urbanization and climate change (Singh and Shi 2014). The unplanned urban growth has resulted in serious adverse impacts on the urban environment (Chadchan and Shankar 2012). Urban growth is also associated with risks like contamination of air, water and social change (Li et al. 2012). Different researches have conducted to analyse trend of temperature and rainfall in Pakistan (del Rio et al. 2013; Salma, Shah, and Rehman 2012; Zahid and Rasul 2011). All these studies indicated that temperature and rainfall in major cities of Pakistan have been increased especially in Punjab province. It is the need of the time to detect the land-use changes, so that their impacts on the environment can be analysed and proper land-use planning and management can be formulated (Muttitanon and Tripathi 2005).

Various techniques have been applied to detect the trend of climatic parameters. Khattak, Babel, and Sharif (2011) applied non-parametric test to detect long-term trend of climatic parameters. Fowler and Archer (2006) used parametric as well as non-parametric test to analyse trend of climatic indicators in the same region. Most of these studies were conducted on large scale while climatic parameters varied region to region and they are not uniform throughout the region (Alexander et al. 2006; Frich et al. 2002). None of the above-mentioned studies correlated changes in trend of climatic parameters with land-use dynamics. It is necessary to conduct a comprehensive study on regional scale to link land-use changes with temperature and rainfall trend so that signals of climate changes based on these driving factors could be detected. Present study has made an attempt to examine land-use changes and their impacts on temperature and precipitation trend. Thus, this study has a great importance to assess the signal of climate change in urbanized city of Pakistan.

Nowadays satellite remote sensing data is available to prepare land-use maps for change analysis (Patino and Duque 2013). Satellite imagery with the traditional field survey is helpful in making land-use maps due to advancements in remote sensing. Land-use change detection is the technique of identifying changes in a feature of a particular area over different time spans (Ruiz-Luna and Berlanga-Robles 2003; Turner and Ruscher 1988). Different change detection techniques like image classification, image differencing, image regression and change vector analysis (CVA) have been used for land-use mapping (Berberoglu and Akin 2009). All these techniques have their own merits but not a single technique can be used for all circumstances; therefore, selection of an appropriate technique is crucial (Lu et al. 2004). For example, (1) CVA excelled in temperate forest areas (Nackaerts et al. 2005); (2) image differencing and regression techniques provide better interpretation of land-use changes in tropical regions and urban environment (Liu, Nishiyama, and Yano 2004; Lu et al. 2005); and (3) post-classification presented the advantage of indicating the nature of the changes (Mas 2005). Image differencing is a simple and straightforward technique and interprets results in easier way while CVA is computationally intensive and time consuming (Berberoglu and Akin 2009). In this study, change analysis of different land use in city Faisalabad was carried out using simple comparison of classified images of particular region taken at different time spans.

In the present study, land-use maps were prepared by using image classification technique. Many studies have been reported in many countries, in which the authors have used remote sensing data and prepared land-use maps by applying image classification technique (Basawaraja et al. 2011; Feng and Li 2012; Guzelmansur 1 and Kilic 2010; Guzelmansur 2010; Hegazy and Kaloo 2015; Jat, Garg, and Khare 2008; Moghadam and Helbich 2013; Rahman et al. 2011; Sudhiramandh inchandra, and Jagadish 2004). A comprehensive study on regional climatic change in Faisalabad city was performed through time series analysis of satellite imagery, temperature and rainfall. The main objectives of this study were to analyse (1) land-use changes from 1985 to 2016 and (2) statistical-based relationship of land-use changes with temperature and precipitation trend.

2. Material and methods

2.1 Study area

The area under study is city Faisalabad, Pakistan, which is situated between the river Ravi and Chenab (Figure 1). Faisalabad is located at latitude 31° 26’ , longitude 71° 06’ and 184.4 m from mean sea level. The total geographic area under study is 127 km². During summer, mean maximum and minimum temperature are recorded as 39°C and 27°C, respectively. In winter, it reaches up to maximum temperature of 17°C and minimum 6°C (project 2014). The average annual rainfall recorded in the study area is about 300 mm. In the nineteenth century, British government established Faisalabad as an
Agronomic Market. At present, Faisalabad is the third largest city of Pakistan after Karachi and Lahore, with an estimated population of 3 million (project 2014).

2.2 Data used in study

Three types of data sets, i.e. satellite images, temperature and rainfall were used to judge the comprehensive climatic face of Faisalabad. Satellite images of this area were obtained from Google Earth at maximum resolution (4800 × 2718) for the year of 1985, 1990, 2000, 2005, 2010 and 2016. Climatic data of temperatures ($T_{\text{Max}}$, $T_{\text{Min}}$ and $T_{\text{Mean}}$) and rainfall were obtained from the Metrological Observatory of Faisalabad, University of Agriculture Faisalabad. Rainfall data was based on monthly total rain in millimetres (mm) for each year. Temperature data sets were obtained on average monthly basis for all months of each year. The measurement techniques for both temperature and rainfall were remained same from 1985 to 2016. Table 1 illustrates the mean monthly values of climatic parameters over the time span of 32 years.

2.3 Data preprocessing

High resolution Google Earth satellite images were used to analyse land-use changes from 1985 to 2016 in city
Faisalabad. For preparation of land-use maps, satellite imagery were downloaded from Google Earth pro. A total of six images on different time spans were downloaded covering the entire study area. All the images were individually georeferenced in ArcGIS software. The images downloaded cover large areas while the actual area being studied only covers a small portion of the image that is why required study area was extracted by Mask in GIS software. The data set of temperatures and rainfall were harmonized and subjected to further analysis to assess the statistical relationship of land-use changes with temperature and rainfall trend. Stepwise procedure on how to process the data is presented in Figure 3.

### 2.4 Image classification

Image classification is a technique of extracting useful information from a multiband raster image. The resulting images after classification can be used to make land-use maps. All the images after preprocessing were classified using unsupervised classification technique. In unsupervised classification technique, ISODATA clustering algorithm was applied which classifies the image according to require number of classes and the digital number of each pixel (Abbas et al. 2016). All images after classification were corrected manually using ground truth data. Reclassify option in ArcGIS tool box was used to recode the misclassified areas based on ground truth data for each year. The study area was classified into three main classes, namely agricultural land, built-up land and open land. Built-up area includes all buildings and road networks, open land includes barren and unused land and agriculture land includes trees, shrubs, grass and crop land.

### 2.5 Image interpretation and change analysis

Unsupervised classified images of Faisalabad were then cross-checked using visual image interpretation technique. Interpretation of satellite imagery involves the clarification of various image features using different key elements like location, colour, size, shape, tone, shadow, texture, pattern, etc. This technique is commonly used in evaluating the areas which were coming under settlements. Change analysis is a technique of identifying changes in a feature of a particular area over different time spans. In this study, change analysis of different land use in city Faisalabad was carried out using simple comparison of classified images of particular region taken at different time spans. After classification, area under each class was estimated using raster calculator in ArcGIS by multiplying pixel size with total number of pixels under each class. All images were compared to analyse quantitative aspects of land-use changes for the periods of 1985–2016.

### 2.6 Accuracy assessment

Accuracy assessment of land-use classes for each year was carried out in ArcGIS software. Different ground truth points of each class were collected from random locations. The image pixel values and ground truth points were compared for each land-use map to assess their accuracy by applying different tools in ArcGIS. A total of 73 ground truth points were collected for three land-use classes out of which 31 points selected for agriculture, 24 for built-up and 18 for open land. Figure 2 illustrates the accuracy assessment framework adapted in ArcGIS.

### 2.7 Impacts of land-use changes on regional climate

Urbanization is an extreme way in which human activities change the land use according to their needs. Urban growth replaces the natural land surface with a built-up area that has a little soil moisture and makes the urbanized area as dry place. Urbanization changes the land use, forms the urban canopy, develops many layers of buildings upward and converts the natural land into the urban sprawl, making it relatively different from surrounding areas. The transformation of agricultural land into urban land causes the considerable change in humidity, temperature and rainfall. A comprehensive study on regional climatic change in Faisalabad city was performed through time series analysis of satellite imagery, temperature and rainfall. Statistical technique was used to check the consistency of land-use changes with temperature and rainfall trend. Linear regression was applied to identify the relationship between land-use changes and climatic data from 1985 to 2016. Land-use changes were correlated with temperature and rainfall trends using

### Table 1. Climatic data of Faisalabad over past 32 years (1985–2016).

| Month     | Min | Max | Mean | Rainfall (mm) |
|-----------|-----|-----|------|---------------|
| January   | 7.5 | 21.3| 14.4 | 45.7          |
| February  | 11.5| 26.1| 18.8 | 84            |
| March     | 15.5| 32.4| 23.95| 112.2         |
| April     | 21.4| 38.8| 30.1 | 114.9         |
| May       | 27.9| 42.2| 35.05| 129           |
| June      | 28.6| 42.5| 35.55| 153           |
| July      | 29  | 40.6| 34.8 | 256.3         |
| August    | 27.7| 38.1| 32.9 | 267.1         |
| September | 25.7| 37.7| 31.7 | 234.5         |
| October   | 21.1| 35.2| 28.15| 39            |
| November  | 14.7| 28.6| 21.65| 18            |
| December  | 8.6 | 25  | 16.8 | 46.2          |
Pearson correlation method. Pearson correlation is the commonly used method to measure the strength of the relationship between two variables. Analysis was carried out in three steps as follows: (1) the trend analysis of land-use changes based on different time spans (1985–2016). Temporal increase in urban area helped to judge the comprehensive climatic phase of Faisalabad; (2) trend analysis of climatic data: the climatic data of Faisalabad city for the period of 1985–2016 were used for $T_{\text{Min}}$, $T_{\text{Max}}$, $T_{\text{Mean}}$ and rainfall. In order to analyse the variability of temperature, the coldest and the warmest periods were highlighted. The effect of urban heating to the total annual temperature was evaluated in percentage. Time series analysis of rainfall was also carried out to analyse the trend of rainfall in either case of decrease or increase; (3) impacts of land-use changes in term of any change in climatic parameter were assessed statistically.

3 Results and discussion

3.1 Classification accuracy

The ground truth data so obtained was used to verify the classification accuracy. Overall classification accuracy of classified images for the years 1985, 1990, 2000, 2005, 2010 and 2016 was 67.12%, 71.23%, 73.97%, 78.08%, 67.12% and 64.38%, respectively (Table 2).

3.2 Land-use changes from 1985 to 2016

The classified images obtained after preprocessing and unsupervised classification are showing the land-use changes from 1985 to 2016 (Figure 4). These images provide spatial and temporal information about land-use pattern of the study area. The quetzal green colour represents the agricultural land, ginger pink shows the built-up land and topaz sand colour shows the barren/open land. Table 3 illustrates temporal variation in area covered by land-use classes from 1985 to 2016. In 1985, about 37.69% (48 km$^2$) area of city Faisalabad was under agriculture, 33.07% (42 km$^2$) under built-up land and 29.13% (37 km$^2$) under open land. During 1990, about 36.23% (46 km$^2$) area of city Faisalabad was under agriculture, 38.58% (49 km$^2$) under built-up land and 25.19% (32 km$^2$) under open land. From 1985 to 1990, area of agriculture and open land reduced by 6 and 24 km$^2$, respectively. Built-up

Figure 2. Procedural framework of accuracy assessment for land-use classes.

Figure 3. Flow chart of data processing.
area increased to cover 56.69% (72 km²) of the total area due to urban growth. From 1985 to 2005, area of agriculture and open land drastically reduced by 17 and 32 km², respectively, while built-up area is increased more than two times than before, to cover 71.62% (91 km²) of the total area. From 1985 to 2016, about 72.91% (35 km²) of agriculture land and 94.5% (35 km²) has been transformed into built-up. Due to the gradual transformation of agricultural and open land, built-up area reached up to 88.19% (112 km²) of the total area while agriculture and open areas have reduced to 13 and 2 km², respectively. Classified raster images show that land use has been changing throughout the periods from 1985 to 2016. Small decrease in agricultural land was observed from 1985 to 2000, but from 2000 to 2016 there was drastic reduction in it. During the time period of 2000–2016, 69.04% of agricultural land transformed into built-up. This change shows that the urban sprawl and expansion of the city was very fast during this period which was mostly in the form of new housing schemes and colonies. In 1985, built-up area in Faisalabad was mostly concentric and major portion of city Faisalabad was covered with green agricultural land. It is clear from Figure 4 that the open area remained almost unchanged from 1985 to 1990, but during the period 1990–2016 these proportions changed significantly and transformed into urban land.

### 3.3. Climatic data trend analysis

Figure 5(a) shows the graphical view of $T_{\text{Min}}$, $T_{\text{Max}}$, and $T_{\text{Mean}}$ from 1985 to 2016. The linear trend of $T_{\text{Min}}$ illustrates that annual minimum temperature in Faisalabad city has increased from 16.9°C to 18.09°C. Annual $T_{\text{Max}}$ in city Faisalabad has slightly increased from 30.9°C to 31.2°C from 1985 to 2016. Linear trend of $T_{\text{Mean}}$ shows that it has been increased from 23.9°C to 24.6°C. Over the time span of 32 years, total increase in annual $T_{\text{Min}}$, $T_{\text{Max}}$, and $T_{\text{Mean}}$ was 1.2°C, 0.3°C and 0.7°C, respectively. The trend of the maximum temperature increased with a little variation while more increasing trend was observed for $T_{\text{Min}}$ and $T_{\text{Mean}}$. Annual $T_{\text{Max}}$ from 1985 to 2000 was 30.97°C, while from 2001 to 2016 it was 31.2°C and difference of $T_{\text{Max}}$ was 0.23°C increase. The $T_{\text{Max}}$ reflected a rise during 1985–2000 with a temperature variation of 0.1°C and by 2001–2016, the increase in temperature reached up to 0.2°C. Annual $T_{\text{Min}}$ from 1985 to 2000 was 17.08°C, while from 2001 to 2016 it was 17.74°C and difference of temperature was 0.7°C increase. Annual $T_{\text{Mean}}$ from 1985 to 2000 was 24.21°C, while from 2001 to 2016 it was 24.76°C and difference of $T_{\text{Mean}}$ was 0.55°C increase. Figure 5(b) illustrates percentage change in annual $T_{\text{Min}}$, $T_{\text{Max}}$ and $T_{\text{Mean}}$ over the time span of 32 years. Overall contribution of total annual $T_{\text{Min}}$, $T_{\text{Max}}$ and $T_{\text{Mean}}$ to urban warming was 12.31%, 1.95% and 5.42%, respectively. Figure 6 shows the time series analysis of total annual rainfall from 1985 to 2016. In the time series analysis of rainfall, it was seen that from 1985 to 1992 average rainfall was 331.52 mm and it was decreased to 314.9 mm from 1993 to 2000. The wettest period was 2001–2008 with an average rainfall of 421.61 mm while it was further decreased to 394.4 mm from 2009 to 2016 (Figure 6). The overall linear trend of rainfall shows that total amount of annual rainfall in Faisalabad has increased from 300 to 420 mm during past 32 years.

#### 3.3.1 Urbanization growth and temperatures change

As a cultural and educational centre of Pakistan, Faisalabad, has attracted a large entry of population from rural areas. Currently population in city Faisalabad is almost 3 million, whereas the population was 10,000 in 1905 and 1.9 million in 1998 (PDS 2010). The urban area of Faisalabad has grown up to 112 km² in 2016 which was 42 km² in 1985. Urbanization rate of city Faisalabad has increased from 1.7 to 2.6 km² per year (Figure 7). Urbanization has caused an increase of impermeable surfaces, atmospheric heating and thermal conditions of the city, thus affecting the regional temperature (Pu and Xiaodong 2012). Many studies revealed that urbanization and land-use changes have increased the temperature in urban areas (Gadgil and Dhorde 2005; Jeganathan and Andimuthu 2013). A similar study in Pakistan has shown that temperature in city Faisalabad has increased significantly in the past few years (Cheema et al. 2006).

This study also shows an increasing trend in the annual mean, minimum and maximum temperature from 1985 to 2016. This change may be related to
Figure 4. Spatio-temporal land-use changes from 1985 to 2016 in city Faisalabad.
rapid urbanization and transformation of agriculture land into built-up land. Table 4 shows the Pearson correlation coefficients between trend of land-use classes and temperature changes. Figure 8 illustrates the relationship of land-use classes with minimum, maximum and mean temperature from 1985 to 2016. It was found that increase in mean and minimum temperature is strongly correlated with built-up and correlation coefficient of 0.55 and 0.64 at 95% confidence level indicates that more urban development leads to larger rise in mean and minimum temperature. However, weak correlation was found between maximum temperature and built-up. On the contrary, the decreasing trend in the agricultural area is consistent with rise in mean and minimum temperature. Reduction in agriculture area is negatively correlated with mean and minimum temperature and correlation coefficient of 0.47 and 0.61 at 95% confidence level indicates that decrease in agriculture area leads to rise in mean and minimum temperature in city Faisalabad. However, the correlation coefficient between agriculture area and maximum temperature is significant to some extent, which shows that decrease in agriculture land leads to slight rise in maximum temperature. Statistical analysis indicates that conversion of agriculture land into built-up has significantly contributed to rise in temperature trend in city Faisalabad. Larger rise in night temperature
temperature variability? There are different driving factors which could affect temperature variability. First, rapid urban growth from 1985 to 2016 has caused in gradual rise of surface temperature. It has been considered that the concentration of heat in urban areas arises from a numerous aspects like conversion of natural vegetation into heat absorbing material, compact air mixing, motor vehicle emissions and other heat sources (Lee, Wenig, and Yang 2009). According to Punjab development statistics report, number of vehicles and industries in Faisalabad city were 358, 4919, respectively in 1985 while after that it has been reached to 1890, 1,038,083 in 2014. Industrial development and transportation in urban areas have increased the concentration of CO₂ in atmosphere that contributes to global warming (Niaz, Jiti, and Zhang 2015). CO₂ emission is a global pollutant that causes 58.8% of universal warming and climate change (WHO 2017). Trees are essential tools to stop warming because they have a capability to absorb greenhouse gases, discharged from industrial units and transports (ThoughtCo 2017). But this study revealed that 72.91% of agriculture land has transformed into built-up which could be a serious climatic signal in future because the
large quantity of CO₂ is going towards atmosphere. Recently, the level of CO₂ emission in urban area of Faisalabad has been reached to 601.96 tons minimum, 894.4 tons average and 1190.23 tons maximum, respectively (Usman et al. 2017). Second, land surface albedo is also a key driving factor that influences the temperature variability. The land surface albedo is the portion of solar radiations reflected from earth surface into space (Lynch et al. 1999). The change in land surface albedo directly varies the solar energy absorbed by earth surface, which subsequently influences the temperature (Chapin et al. 2005). Lower surface albedo indicates large quantity of solar radiations absorb by earth while less radiations reflect backward to atmosphere. Higher value of surface albedo indicates more radiations reflect back from earth surface to atmosphere and thereby increase the atmospheric temperature. As an example, land surface albedo of forest coverage is generally lower as compared to other vegetation types (Houldcroft et al. 2009). In the present study, analysis of land-use change shows that 72.91% of agriculture land has been transformed into urban development which has influenced surface albedo in Faisalabad, resulting more radiations to come back to atmosphere and ultimately has increased temperature in city environment. Similarly, studies conducted by Zia et al. (2015) and Sajjad et al. (2009) show that increase in built-up land, number of industries, number of vehicles and reduction in agriculture land has increased temperature in city environment.

### 3.3.2 Urbanization growth and precipitation change

Built-up development leads to rise in surface temperature, which ultimately affects regional precipitation variability. In this section, we analyse precipitation change due to the land-use changes and urbanization effect. Table 4 summarizes Pearson correlation coefficients between trend of rainfall and land-use classes from 1985 to 2016. Figure 9 shows the scatter plot between land-use classes and rainfall trend in study area from 1985 to 2016. It was found that the amount of rainfall is strongly correlated with increasing trend in built-up area. The correlation coefficient of 0.36 at 95% confidence level indicates that more urban development leads to larger rise in annual rainfall. On other hand, decreasing trend in agricultural area is consistent to some extent with rainfall and it is negatively correlated with rainfall. The correlation coefficient of 0.20 at 95% confidence level indicates that decrease in trend of agricultural area enhances the annual amount of rainfall. Previous section has shown that the decreasing trend in the agricultural land is consistent with rise in temperature, which ultimately enhances the evaporation rate. Due to increase in evaporation rate, more water evaporate from earth surface to atmosphere, condense in atmosphere and come back to earth in the form of precipitation.

How do land-use changes and urban growth affect the precipitation variability? There are different driving factors of precipitation variability. First, surface heating such as heat-island can influence the precipitation process. Higher land surface albedo warms the lower atmospheric layer by radiating more heat waves. Temperature in urban areas is higher than the regions without the urbanization around it, as much as about 2–10°C (Shepherd, Pierce, and Negri 2002). Several studies suggested that the dry areas play an important role in introducing convective rainstorms and resulting rainfall on the downwind side of urban areas (Baik, Kim, and Chun 2001; Bornstein and Lin 2000; Rozoff, Cotton, and Adegoke 2003). Second, the urbanization leads to enhance the concentration of aerosol particles in the atmosphere which also increases the precipitation rate. Many studies investigated that aerosols concentration in urban areas increases the rainfall occurring rate (Andreea et al. 2004; Diem and Brown 2003; Han and Baik 2008; Koren et al. 2005; Mölders and Olson 2004). Han and Baik (2008) analysed the effect of the urban-induced aerosol on precipitation variability. They concluded that the higher concentration of aerosols in atmosphere leads to a large number of tiny cloud

### Table 4. Correlations matrix between land-use class and climatic data.

|          | Mean_temp | Mean_temp | Mean_temp | Rainfall |
|----------|-----------|-----------|-----------|----------|
| Agriculture Pearson correlation | −.47<sup>a</sup> | −.61<sup>a</sup> | −.014 | −.27<sup>b</sup> |
| Sig. (two-tailed) | .006 | .000 | .94 | .132 |
| N | 32 | 32 | 32 | 32 |
| Built-up Pearson correlation | .55<sup>a</sup> | .64<sup>a</sup> | .084 | .38<sup>b</sup> |
| Sig. (two-tailed) | .001 | .000 | .646 | .106 |
| N | 32 | 32 | 32 | 32 |

<sup>a</sup>Correlation is significant at the 0.01 level (two-tailed).
<sup>b</sup>Correlation is significant at the 0.05 level (two-tailed).
drops, which result in precipitation enhancement. Third, land surface roughness also affects the precipitation variability. Spatial land-use changes in surface roughness lead to changes in flow of air. Larger surface roughness in urban areas slowdown the air approaching the city, tends to divert around it and finally diverted air converge on the downwind side of the city, resulting upward motion there (Cotton 2007). Similar studies conducted by Thielen et al. (2000) and Torres-Valcárcel et al. (2014) show that surface roughness in urbanized areas has increased the precipitation rate.
4. Conclusions and recommendations

This study examines the impacts of land-use changes over the regional climate of city Faisalabad, where green cover and open land have been replaced with built-up land. The major cities of Pakistan are facing the urbanization problem as more people are migrating from rural areas towards urban areas. Examining the impacts of urbanization on the regional climate of any city or urbanized area is a difficult process as numerous factors influence climate change. The present study has made an attempt to provide signal that there is a close relationship between land-use changes, urbanization and regional climate change in terms of $T_{\text{Min}}$, $T_{\text{Max}}$, $T_{\text{Min}}$ and annual rainfall. Statistical analysis indicated that transformation of green cover and open land with built-up has led to rise in temperature and precipitation rate. Analysis indicated that minimum, maximum and mean temperature in city Faisalabad have been increased by 1.2°C, 0.3°C and 0.7°C, respectively. Overall contribution of urban warming to total annual $T_{\text{Min}}$, $T_{\text{Max}}$ and $T_{\text{Mean}}$ was 12.31%, 1.95% and 5.42%, respectively. Time series analysis of rainfall shows that annual rainfall has been increased by 120 mm from 1985 to 2016. Our analysis of study clearly indicates that land-use changes and urban growth are driving factors of temperature and rainfall variability in city Faisalabad. In particular, our assumptions on increased in temperature and precipitation by urban growth, green land transformation to built-up, land surface albedo, surface roughness or by the aerosol effect should be further examined. It is recommended that this type of study can be helpful for urban planners to control/manage the urbanization especially in large cities of Pakistan.

Acknowledgments

This study was financially supported by the National Key Research and Development Program of China (Project Nos. 2016YFA0602302 and 2016YFB0502502) and great thanks should be given to Punjab Meteorological Department (PMD) for providing meteorological data.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This study was financially supported by the National Key Research and Development Program of China [2016YFA0602302] and [2016YFB0502502].

ORCID

Arfan Arshad https://orcid.org/0000-0002-0726-1807
Wanchang Zhang https://orcid.org/0000-0002-2607-4628

References

Abbas, A., N. Minallah, N. Ahmad, S. Abid, and M. Khan. 2016. “K-Means and ISODATA Clustering Algorithms for Landcover Classification Using Remote Sensing.” *Sindh University Research Journal-SURJ* (Science Series) 48: 2.

Alexander, L., X. Zhang, T. Peterson, J. Caesar, B. Gleason, A. Klein Tank, M. Haylock, D. Collins, B. Trewin, and F. Rahimzadeh. 2006. “Global Observed Changes in Daily Climatic Extremes of Temperature and Precipitation.” *Journal of Geophysical Research: Atmospheres* 111: D5. doi:10.1029/2005JD006290.

Andreea, M. O., D. Rosenfeld, P. Artaxo, A. Costa, G. Frank, K. Longo, and M. Silva-Dias. 2004. “Smoking Rain Clouds over the Amazon.” *Science* 303 (5662): 1337–1342. doi:10.1126/science.1092779.

Arif, G., and S. Hamid. 2009. “Urbanization, City Growth and Quality of Life in Pakistan.” *European Journal of Social Sciences* 10 (2): 196–215.

Baik, -J.-J., Y.-H. Kim, and H.-Y. Chun. 2001. “Dry and Moist Convection Forced by an Urban Heat Island.” *Journal of Applied Meteorology* 40 (8): 1462–1475. doi:10.1175/1520-0450(2001)040<1462:DDCMCF>2.0.CO;2.

Basawaraja, R., K. Chari, S. Mise, and S. Chetti. 2011. “Analysis of the Impact of Urban Sprawl in Altering the Land-Use, Land-Cover Pattern of Raichur City, India, Using Geospatial Technologies.” *Journal of Geography and Regional Planning* 4 (8): 455.

Berberoglu, S., and A. Akin. 2009. “Assessing Different Remote Sensing Techniques to Detect Land Use/Cover Changes in the Eastern Mediterranean.” *International Journal of Applied Earth Observation and Geoinformation* 11 (1): 46–53. doi:10.1016/j.jag.2008.06.002.

Bonan, G. B. 1997. “Effects of Land Use on the Climate of the United States.” *Climatic Change* 37 (3): 449–486. doi:10.1023/A:1005305708775.

Bornstein, R., and Q. Lin. 2000. “Urban Heat Islands and Summertime Convective Thunderstorms in Atlanta: Three Case Studies.” *Atmospheric Environment* 34 (3): 507–516. doi:10.1016/S1352-2310(99)00374-X.

Chadchan, J., and R. Shankar. 2012. “An Analysis of Urban Growth Trends in the Post-Economic Reforms Period in India.” *International Journal of Sustainable Built Environment* 1 (1): 36–49. doi:10.1016/j.ijsebe.2012.05.001.

Chapin, F. S., M. Sturm, M. Serreze, J. McFadden, J. Key, A. Lloyd, A. McGuire, T. Rupp, A. Lynch, and J. Schimel. 2005. “Role of Land-Surface Changes in Arctic Summer Warming.” *Science* 310 (5748): 657–660. doi:10.1126/science.1117368.

Cheema, M. A., M. Farooq, R. Ahmad, and H. Munir. 2006. “Climatic Trends in Faisalabad (Pakistan) over the Last 60 Years (1945–2004).” *Journal of Agriculture and Social Sciences* 2 (1): 42–45.

Cotton, W. R. 2007. “Human Impacts on Weather and Climate.” *International Journal of Climatology* 28 (2): 281–282.

del Rio, S., M. Anjum Iqbal, A. Cano-Ortiz, L. Herrero, A. Hassan, and A. Penas. 2013. “Recent Mean Temperature Trends in Pakistan and Links with Teleconnection Patterns.”
Koren, I., Y. J. Kaufman, D. Rosenfeld, L. A. Remer, and Y. Rudich. 2005. “Aerosol Invigoration and Restructuring of Atlantic Convective Clouds.” Geophysical Research Letters 32: 14. doi:10.1029/2005GL023187.

Lee, Y., M. Wenig, and X. Yang. 2009. “The Emergence of Urban Ozone Episodes in Autumn and Air Temperature Rise in Hong Kong.” Air Quality, Atmosphere & Health 2 (2): 111–121. doi:10.1007/s11869-009-0038-y.

Li, X.-H., J.-L. Liu, V. Gibson, and Y.-G. Zhu. 2012. “Urban Sustainability and Human Health in China, East Asia and Southeast Asia.” Current Opinion in Environmental Sustainability 4 (4): 436–442. doi:10.1016/j.cosust.2012.09.007.

Liu, Y., S. Nishiya, and T. Yano. 2004. “Analysis of Four Change Detection Algorithms in Bi-Temporal Space with a Case Study.” International Journal of Remote Sensing 25: 2121–2139. doi:10.1080/0143116031000160647.

Lu, D., P. Mausel, E. Brondizio, and E. Moran. 2004. “Change Detection Techniques.” International Journal of Remote Sensing 25 (12): 2365–2401. doi:10.1080/0143116041000139863.

Lu, D. S., P. Mausel, M. Battista, and E. Moran. 2005. “Land-Cover Binary Change Detection Methods for Use in the Moist Tropical Region of the Amazon: A Comparative Study.” International Journal of Remote Sensing 26: 101–114. doi:10.1080/01431160410001720748.

Lynch, A., F. Chapin III, L. Hinzman, W. Wu, E. Lilly, G. Vourlitis, and E. Kim. 1999. “Surface Energy Balance on the Arctic Tundra: Measurements and Models.” Journal of Climate 12 (8): 2585–2606. doi:10.1175/1520-0442(1999)012<2585:SEBTA2.0.CO;2.

Mas, J. F. 2005. “Monitoring Land-Cover Changes: A Comparison of Change Detection Techniques.” International Journal of Remote Sensing 26: 139–152. doi:10.1080/014311699213659.

Mitchell L. Moss, H. O. N. 2012. Urban Mobility in the 1st Century. NYU Rudin Center for Transportation Policy.

Mohgadam, H. S., and M. Helbich. 2013. “Spatiotemporal Urbanization Processes in the Megacity of Mumbai, India: A Markov Chains-Cellular Automata Urban Growth Model.” Applied Geography 40: 140–149. doi:10.1016/j.appgeo.2013.01.009.

Mölders, N., and M. A. Olson. 2004. “Impact of Urban Effects on Precipitation in High Latitudes.” Journal of Hydrometeorology 5 (3): 409–429. doi:10.1175/1525-7541(2004)005<0409:IOUEOP>2.0.CO;2.

Muttitanon, W., and N. Tripathi. 2005. “Land Use/Land Cover Changes in the Coastal Zone of Ban Don Bay, Thailand Using Landsat 5 TM Data.” International Journal of Remote Sensing 26 (11): 2311–2323. doi:10.1080/01431160520124325.

Nackaerts, K., K. Vaesen, B. Muys, and P. Coppin. 2010. “Comparative Performance of a Modified Change Vector Analysis in Forest Change Detection.” International Journal of Remote Sensing 26: 839–852. doi:10.1080/014311601000160462.

Nelson, K. C., M. A. Palmer, J. E. Pizzuto, G. E. Moglen, P. L. Angermeyer, R. H. Hilderbrand, M. Dettinger, and K. Hayhoe. 2009. “Forecasting the Combined Effects of Urbanization and Climate Change on Stream Ecosystems: From Impacts to Management Options.” Journal of Applied Ecology 46 (1): 154–163. doi:10.1111/j.1365-2664.2008.01599.x.
Niaz, Y., Z. Jiti, and Y. Zhang. 2015. “Influence of Automotive Emission on Air Pollution Using GIS in Faisalabad, Pakistan.” *International Journal of Agricultural and Biological Engineering* 8 (1): 111.

Paeth, H., K. Born, R. Girmes, R. Podzun, and D. Jacob. 2009. “Regional Climate Change in Tropical and Northern Africa Due to Greenhouse Forcing and Land Use Changes.” *Journal of Climate* 22 (1): 114–132. doi:10.1175/2008JCLI2390.1.

Patino, J. E., and J. C. Duque. 2013. “A Review of Regional Science Applications of Satellite Remote Sensing in Urban Settings.” *Computers, Environment and Urban Systems* 37: 1–17. doi:10.1016/j.compenvurbsys.2012.06.003.

PDS. 2010. *Punjab Development Statistics*. Lahore: Bureau of Statistics, Government of Punjab.

project, P. c. g. i. 2014. Faisalabad Peri-Urban Structure Plan Final Report.

Pu, S., and Z. Xiaodong. 2012. “Progress in the Study of the Effects of Land Use and Land Cover Change on the Climate System.” *Climatic and Environmental Research (In Chinese)* 17 (1): 103–111.

Rahman, A., S. P. Aggarwal, M. Netzband, and S. Fazal. 2011. “Monitoring Urban Sprawl Using Remote Sensing and GIS Techniques of a Fast Growing Urban Centre, India.” *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 4 (1): 56–64. doi:10.1109/JSTARS.2010.2084072.

Rozoff, C. M., W. R. Cotton, and J. O. Adegoke. 2003. “Simulation of St. Louis, Missouri, Land Use Impacts on Thunderstorms.” *Journal of Applied Meteorology* 42 (6): 716–738. doi:10.1175/1520-0450(2003)042<0716:SOSML>2.0.CO;2.

Ruiz-Luna, A., and C. A. Berlanga-Robles. 2003. “Land Use, Land Cover Changes and Coastal Lagoon Surface Reduction Associated with Urban Growth in Northwest Mexico.” *Landscape Ecology* 18 (2): 159–171. doi:10.1023/A:1024461215456.

Sajjad, S., S. A. Shirazi, M. Ahmed Khan, and A. Raza. 2009. “Urbanization Effects on Temperature Trends of Lahore during 1950–2007.” *International Journal of Climate Change Strategies and Management* 1 (3): 274–281. doi:10.1108/17568690910977483.

Salma, S., M. Shah, and S. Rehman. 2012. “Rainfall Trends in Different Climate Zones of Pakistan.” *Pakistan Journal of Meteorology* 9: 17.

Sankhala, S., and B. Singh. 2014. “Evaluation of Urban Sprawl and Land Use Land Cover Change Using Remote Sensing and GIS Techniques: A Case Study of Jaipur City, India.” *International Journal of Emerging Technology and Advanced Engineering* 4 (1): 66–72.

Shepherd, J. M., H. Pierce, and A. J. Negri. 2002. “Rainfall Modification by Major Urban Areas: Observations from Spaceborne Rain Radar on the TRMM Satellite.” *Journal of Applied Meteorology* 41 (7): 689–701. doi:10.1175/1520-0450(2002)041<0689:RMUMUA>2.0.CO;2.

Singh, R., and C. Shi. 2014. “Advances in Observation and Estimation of Land Use Impacts on Climate Changes: Improved Data, Upgraded Models, and Case Studies.” *Advances in Meteorology* 2014: 7. doi:10.1155/2014/748169.

Singh, R. B., A. Grover, and J. Zhan. 2014. “Inter-Seasonal Variations of Surface Temperature in the Urbanized Environment of Delhi Using Landsat Thermal Data.” *Energies* 7 (3): 1811–1828. doi:10.3390/en7031811.

Soh, M. B. C. 2012. “Crime and Urbanization: Revisited Malaysian Case.” *Procedia-Social and Behavioral Sciences* 42: 291–299. doi:10.1016/j.sbspro.2012.04.193.

Sudhira, H., T. Ramachandra, and K. Jagadish. 2004. “Urban Sprawl: Metrics, Dynamics and Modelling Using GIS.” *International Journal of Applied Earth Observation and Geoinformation* 5 (1): 29–39. doi:10.1016/j.jag.2003.08.002.

Team, C. W., R. Pachauri, and A. Reisinger. 2007. *Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland: IPCC.

Thielen, J., W. Wobrock, A. Gadian, P. Mestayer, and J.-D. Creutin. 2000. “The Possible Influence of Urban Surfaces on Rainfall Development: A Sensitivity Study in 2D in the meso-γ-scale.” *Atmospheric Research* 54 (1): 15–39. doi:10.1016/S0169-8095(00)00041-7.

ThoughtCo. 2017. https://www.thoughtco.com/which-trees-offset-global-warming-1204209

Torres-Valcárcel, Á., J. Harbor, C. González-Avilés, and A. Torres-Valcárcel. 2014. “Impacts of Urban Development on Precipitation in the Tropical Maritime Climate of Puerto Rico.” *Climate* 2 (2): 47–77. doi:10.3390/cli2020047.

Turner, M. G., and C. L. Ruscher. 1988. “Changes in Landscape Patterns in Georgia, USA.” *Landscape Ecology* 1 (4): 241–251. doi:10.1007/BF00157696.

Usman, M., H. Yasin, H. Rashid, and A. Nasir. 2017. Quantification of CO2 Emissions from Vehicles and Possible Remedial Strategies in Faisalabad City. WHO. 2017. A Safer Future: Global Public Health Security in the 21st Century.

Zahid, M., and G. Rasul. 2011. “Frequency of Extreme Temperature and Precipitation Events in Pakistan 1965–2009.” *Sciences International (Lahore)* 23 (4): 313–319.

Zia, S., S. Shirazi, M. Bhalli, and S. Kausar. 2015. “The Impact of Urbanization on Mean Annual Temperature of Lahore Metropolitan Area, Pakistan.” *Pakistan Journal of Science* 67: 3.