ANALYZING THE VARIATION OF TRENDS AND PATTERNS BETWEEN CLIMATE AND LAND USE CHANGES IN THE KELANTAN RIVER BASIN, MALAYSIA

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Abstract

Climate and land use land cover (LULC) are two major key drives affecting the hydrological cycle pattern within a river basin. This study aims (1) to evaluate the capability of the European Space Agency Climate Change Initiative land cover (ESA CCI LC) product in representing land use pattern in the Kelantan River Basin (KRB), Malaysia; (2) to analyze the changes of rainfall, maximum and minimum temperatures of the KRB from 1979 to 2018; and (3) to assess the relationships between climate and land use changes within KRB. The results show that the ESA CCI LC product is applicable to represent LULC of the KRB, with an overall accuracy of 74.72% and a Kappa coefficient of 0.66. Trend analysis indicates that maximum and minimum temperatures of the KRB increased significantly at 95% confident level by 0.01 to 0.03 ºC/year and 0.01 to 0.05 ºC/year, respectively. Whereas, annual precipitation at the Pos Hau, Pos Bihai, Pos Gob and Kuala Krai stations increased significantly with the rates of 17.5 to 29.74 mm/year. The spatial correlation shows that urban expansion in Gua Musang had strong correlation with annual rainfall with a correlation coefficient (CC) value of -0.78. Furthermore, the conversion of forest into croplands over the Tanah Merah increased the minimum temperature significantly, with a CC value of -0.73. The findings show that the changes of land use in the middle basin contributed to the variations in temperature.

Keywords:Climate, ESA, Kelantan, Land Use, Rainfall, Temperature, Tropical

Abstrak

Iklim dan guna tanah merupakan dua pemacu utama yang mempengaruhi corak kitaran hidrologi di lembangan sungai. Produk guna tanah global European Space Agency program inisiatif iklim (ESA CCI LC) bagi tahun 1992 hingga 2018 boleh dijadikan data alternatif untuk menganalisis hubungan antara perubahan iklim dan guna tanah. Objektif kajian ini adalah (1) mengesahkan ketepatan produk guna tanah European Space Agency program program inisiatif iklim (ESA CCI LC) dalam mempersembahkan jenis guna tanah di lembangan Sungai Kelantan (KRB) Malaysia; (2) menganalisis trend perubahan hujan, maxima dan minima suhu di KRB dari 1979 sehingga 2018; serta (3) menilai hubungan antara perubahan dan iklim dan guna tanah di KRB. Hasil kajian menunjukkan produk ESA CCI LC boleh mempersembahkan guna tanah di KRB dengan ketepatan keseluruhan 74.72% dan pekali Kappa 0.66. Analisis tren menunjukkan suhu maxima dan minima di KRB mengalami peningkatan signifikan pada tahap keyakinan 95% pada kadar 0.01 ke 0.03 $^{\circ}$C/tahun and 0.01 ke 0.05 $^{\circ}$C/tahun. Manakala, hujan tahunan di stesen Pos Hau, Pos Bihai, Pos Gob dan Kuala Krai meningkat secara signifikan dengan kadar 17.5 sehingga ke 29.74 mm/tahun. Kolerasi ruang pula menunjukkan pengembangan bandar di Gua Musang amat berkaitan dengan hujan tahunan dengan nilai kolerasi -0.78. Tambahan pula, penukaran kawasan hutan kepada tanah penanaman di Tanah Merah meningkatkan minima suhu dengan

nilai korelasi -0.73. Hasil kajian ini telah menunjukkan perubahan guna tanah di kawasan pertengahan KRB menyumbang kepada perubahan suhu.

Kata kunci: ESA, Guna Tanah, Hujan, Iklim, Kelantan, Suhu, Tropika

Introduction

The large-scaled conversion of tropical forest into agricultural croplands reduces biodiversity and increases greenhouse gas emission which contributed to global hydro-climatic changes (Roy et al., 2020). The increasing human population resulted in an increasing of the natural resources demand, therefore, intensified the land use change rate (IPCC, 2019). Aligned with the global environmental change studies, land use change studies were intended to enhance the understanding of land use patterns and associated dynamics in the Earth's system.

Climate change is a long-termed shift in weather conditions that can be recognized by variations in rainfall, temperature, evapotranspiration, and other indicators (Thakur et al., 2020). The variations of rainfall and temperature associated with land use change have been discussed in past studies. However, realistic quantification of the relationship between climate and land use change with traditional surveying methods is a fundamental question, that happens by spatial heterogeneities and different reactions of the environment towards climatic variations.

The IPCC (2019) special report reported that under the varying climate, southern Asian countries are especially vulnerable towards intensified hydro-climatic hazards such as heat waves, heavy precipitation events, drought conditions, and increased frequency of cyclones (Avashia & Garg, 2020). Various techniques have been applied with both parametric and non-parametric tests in detecting long-term climatic parameters. Previous studies of climate change in tropical regions mainly focus solely on the climate trend analysis, however, the climatic parameters are varying from one region to another (Alexander et al., 2006). This arisen a gap where the link of land use change and the rainfall and temperature trends are uncertain as different land cover reacts differently with the climate (Faizalhakim et al., 2017). Land use change within a river basin can cause direct water related hazards (Selek & Selek, 2019), hence, it is important to understand the contributors of climate change as well as the relationship between land use and climate changes at basin scale.

The European Space Agency (ESA) established Global Monitoring of Essential Climate Variables project under their Climate Change Initiative (CCI) to provide adequate, comprehensive, and timely satellite-based earth data for climate studies. The ESA CCI land cover (LC) product is produced with a spatial resolution of 300 meters from 1992 to 2018, with the Food and Agriculture Organization (FAO) land use standards for vegetation, including to the main structural vegetation domains of sparse vegetation, herbaceous vegetation, shrubs and trees for both natural, semi-natural and man-induced vegetation covers (FAO, 2000). The ESA CCI LC products may cause uncertainties in land use dataset that could led to errors in further analyses. Alkhalil et al. (2020) demonstrated a framework to evaluate the ESA CCI LC product with common land use classification accuracy assessment methods with ArcMap. The validation of the ESA CCI LC dataset has been done over African continents, China and European regions (Reinhart et al., 2020, 2021), however, there is lack of such assessment over southeast Asia region. Hence, the present study would like to tackle this research gap.

Kelantan River Basin (KRB) is frequently affected by monsoon floods during the early phase of the Northeast Monsoon (NEM) season. Mann-Kendall and Sen's slope became common approaches to address the potential impacts of climatic change and variations of hydrologic time series (Adnan et al., 2016). Alexander et al. (2006) applied such nonparametric statistical analysis to analyze the global extremes of temperature and precipitation. Tan et al. (2017a) evaluated the changes in precipitation extremes over KRB from 1985 to 2014, where most of the precipitation extreme had a significant trend. The finding is similar to Adnan and Atkinson (2011) who applied the same methods to test the trends in streamflow and rainfall in the KRB on a seasonal basis. They found there is small magnitude precipitation increasing trend in the upstream of Kelantan river during January, March, June, October, and December from 1975 to 2006. The study discovered an expansion of 400% agriculture activities in the basin, that it contributed to the increasing trend of streamflow in the basin. Later, Adnan et al. (2016) computed the monthly, seasonal and annual trends of rainfall in the KRB using the same approaches. The above-mentioned studies focused the trends of climate and discussed about the possible causes that contributed, but the study on how the magnitude of land use change in the basin can affect the trends of changing of the climate is still limited.

This study aims (1) to evaluate the capability of the ESA product in representing land use pattern in the Kelantan River Basin (KRB), Malaysia; (2) to assess the precipitation, maximum and minimum temperatures change from 1979 to 2018; and (3) to assess the relationship between land use and climate changes. The stress of land use change on the local climate was analyzed via the spatial cross-correlation analysis as recommended by Chen (2015), in order to identify the magnitude of the respective impacts of land cover change towards climate variations.

Materials and Methods

Study Area

The KRB is the major basin in the Kelantan state of Malaysia. Situated between latitudes of 4°30'N to 6°30'N and longitudes of 101°15'E to 102°45'E, the KRB covers 12,685.42 km², as shown in Figure 1. The topography of KRB is mountainous at the west and south whilst flat to the north, with elevation between 8 to 2,174 meters above the mean sea level. Generally, the topography of KRB can be divided into three classes: 1) flat areas below 500 meters above mean sea level in the middle of Gua Musang, Kuala Krai, Machang, Tanah Merah, Kota Bahru and Tumpat; 2) hilly terrain elevated at 500 to 1000 above mean sea level; and 3) mountainous terrain elevated at 1000 to 2,174 meters above mean sea level around the Gunung Stong and Gunung Gagau that is located at the border of Perak and Kelantan where it is the upstream of Kelantan River.

Kelantan River is the major river of the basin with 248 km in length and originates from the Titiwangsa and Tahan mountain ranges. The KRB exhibits the tropical monsoon where it receives abundant rainfall amount that exceeds 2500 mm/year and mean annual temperature of about 27.5°C. The KRB is dominantly forest, followed by partial cropland for rubber, oil palm and vegetable plantations and less than 3% of built-up.

Nevertheless, the KRB often affected by natural disaster. It is a flood prone region during the wet season from November to January wet season due to the rare and prolonged rainfall (Koh et al., 2021). One of the major floods occurred in 2014 which caused loss of approximately USD$ 370 million and 12 deaths. In contrast, KRB also experiencing droughts in the dry season from March to May. According to the previous researches, these water-related disasters are expected to be severer in the future resulted from the climate change (Faizalhakim et al., 2017; Tan et al., 2017b).

Climate data

The climate data used in this study are the observed rainfall (RF), maximum temperature (Tmax) and minimum Temperature (Tmin) from 1979 to 2018 obtained from the Malaysia Meteorological Department. The information of the climate stations is listed in Table 1.

ESA land use product

Global land cover maps for three epochs under the ESA CCI project was selected for this study because long-term land use data is available. As the ESA CCI products are recorded at global scale, the tool for acquiring the datasets is made in a user-friendly website that enable study area extent data subset, coordinate system re-projection and resampling. The datasets can be accessed via the Sen2Cor website or http://maps.elie.ucl.ac.be/CCI/viewer/download.php in netCDF format (ESA, 2010; Li et al., 2016).

One of the advantages of the ESA CCI data is the comprehensive sensor data archive. The ESA CCI products is a compilation of four different satellite data that has been analyzed and filed into ready-use climate products. The sensors involved are (1) full archive of AVHRR HRPT 1 km surface reflectance of seven days composite, available from years 1992 to 1999; (2) full archive of MERIS surface reflectance of seven days composite, available from years 2003 to 2011, at 300 meters and 1km resolution; (3) PROBA-V 1km time series surface reflectance of seven days' composite, available from middle of March year 2014 to the end of year 2015 and (4) ENVISAT ASAR data for open water bodies mapping.

Methodology

Mann-Kendall trend test

The Mann-Kendall (MK) trend test was used in this study to analyze the temporal trends of RF, Tmax and Tmin. MK trend test is a non-parametric statistical approach (Kendall, 1975; Mann, 1945) recommended by the World Meteorological Organization for trend detection of climate variables (Mitchell et al., 1966). The direct and simple interpretation of MK trend test result made it a popular approach for analyzing climatic variability trends.

Sen’s slope estimator

In this study, Sen’s slope estimator is applied to measure and compare the magnitude changes of RF, Tmax and Tmin. Sen’s slope is an unbiased estimation of the monotonic trend of the original data that is able to be determined by the true slope of MK trend (Abungba et al., 2020; Sen, 1968).

Spatial-correlation analysis

Pearson’s correlation, r is a statistic that measures the linear correlation between two variables x and y (Pearson, 1895). In this study, r is used to correlate the land use change with the RF, Tmax and Tmin of each station. r is expressed as below:

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}}$$

where x_i is the values of the x-variable in a sample; $\bar{x}$ is the mean of the x-variables; y_i is the values of the y-variable in a sample; $\bar{y}$ is the mean of the y-variables.

The interpretation of r is similar to MK trend test and Sen’s slope estimator as well, at which the return value of r is between -1 and 0, where r > 0 indicates positive relation between the x and y variables, r < 0 represents negative relation between the x and y variables, and 0 shows no relationship between the two variables.

ESA data validation

Accuracy assessment is a process to quantitatively assess the effectiveness of the pixels sampled into the correct land cover class. In this study, the accuracy assessment of the ESA data is done by first reclassify the dataset into agriculture, forest, urban and water to match with the 1992, 2000, 2008 and 2015 land use maps prepared by the Department of Agriculture (DOA) and MaCGDI. The years of ESA dataset selected are 1992, 1993, 1999, 2000, 2001, 2007, 2008, 2009, 2014, 2015, and 2016, as the land cover for the years before and after the years with agency data would not have dramatical changes. A total of 160 random points at 40 points for each land cover class is generated for the validation purpose, as suggested by Wulder et al. (2006). Overall classification accuracy and the Kappa coefficient is used as the indicator of the accuracy assessment.

$$\text{Overall Accuracy} = \frac{No.of\ correctly\ matched\ pixels}{Total\ number\ of\ pixels}$$

$$\text{Kappa coefficient, } \kappa = \frac{P_o - P_e}{1 - P_e}$$

where P_o is the relative observed agreement among the raters and P_e is the hypothetical probability of chance agreement for each randomly observation (Cohen, 1960). In terms of remote sensing classification, κ will return a value in between 0 to 1, where the value can be interpreted by poor agreement: $\kappa < 0.20$, fair agreement: $0.20 < \kappa < 0.40$, moderate agreement: $0.40 < \kappa < 0.60$; good agreement: $0.60 < \kappa < 0.80$, very good agreement: $0.80 < \kappa < 1.00$. Thus, a result with accuracy of above 70% and κ value of above 0.60 is considered an acceptable result. The ESA validation process is done by extracting the pixels matched correctly to the land cover class accordingly and compute the error matrix.

Results and Discussion

Validation of ESA CCI Land Cover Data

The results of the ESA product accuracy assessment are listed in Table 2. The overall accuracy of the validation shows that ESA CCI LC data was 74.53% matched with the reference land use data, at κ of 0.66 where the assessment result is at substantial agreement. One of the major challenges in analyzing the accuracy of the ESA CCI LC data was the differentiation of forest and agricultural vegetation covers where the dataset classified vegetated covers as rainfed, rainfed herbaceous, rainfed tree or shrub, mosaic cropland, mosaic natural vegetation, broadleaved evergreen closed to open tree. Reclassifying these classes into matching land use class with the dataset from Malaysian land use information provider agency would face difficulties in the case that tropical region was often covered with combination of woody and herbaceous vegetation in the forest and oil palm and rubber dominated commercial crops. The large-scaled diversity of farming crops in the KRB have contributed to the complicated vegetation covers in the region. This may induce confusion while classifying the vegetation cover with remote sensing methods. Looking into the accuracy of each year, the overall accuracies maintained at above 0.72 except for the year 2015. This event can be explained by the devasting flood on 2014 have destroyed the diversity of croplands in the basin (Samsurijan et al., 2018).

Referring to Figure 2, the land use changes in the KRB from 1992 to 2018 can be explained through few perspectives: (i) unstable growth of agriculture lands; (ii) increment of forest; (iii) urban expansion; and (iv) open water surface remained unchanged. The trend was similar to the study done by Udin and Zahuri (2017) and Adnan and Atkinson (2011). The first event was aligned with the East Coast Economic Region (ECER) project under the ninth Malaysia plan to transform the east coast region of Peninsula into an agro-based economic region by the year of 2020 (Alam et al., 2012). According to the master plan, it was projected Kelantan would be covering with approximately 456,595 hectares of cropland by 2020, with dominating rubber plantation, due to the fertile soil cover all over the state.

The agriculture lands in the KRB are fluctuating through the study timeline (Figure 2). This is due to the flood events occurred in the basin. According to the flood reports by DID, devasting flood happened in the KRB almost every year, especially on year 1994 and 2014. Besides that, Tan et al. (2017a) discovered that the KRB experienced extreme drought events in 1998, 2004, 2006 and 2012. As for the 2014 flood which named as the most devasting flood event in Malaysia, large area of the agriculture lands including the animal husbandries in the KRB have been destroyed by the flood water (Shamshuddin et al., 2016), especially in the Pekan Hilir, Pasir Mas, Kota Bharu dan Tumpat districts. These phenomena explained that the agriculture production in the KRB is strongly depending on the climatic variables.

Through the accuracy assessment, it can be concluded that the ESA CCI land cover data is satisfactory to represent the land cover of KRB. Hence, the percentage of each land cover class reclassify from the ESA CCI land cover data is to be used for the spatial correlation, as presented in Figure 3.

RF, Tmax and Tmin Trends

Mann-Kendall trend analysis is done onto the RF, Tmax and Tmin climate variables to observe the trend of change from year 1979 to 2018 over 14 stations for RF and 4 stations for temperature as shown in Table 3. The annual RF of the entire Kelantan state showed an increasing trend with the highest value of 3187 mm in 1993 and the lowest value of 1823 mm in 2016, as shown in Figure 5. The MK trend test showed a significant increasing trend of annual RF can be found at the Pos Hau (17.50 mm/year), Pos Bihai (24.4 mm/year), Pos Gob (29.74 mm/year) and Kuala Krai (22.12 mm/year) stations at 95% confidence level, which mainly located in the southwestern and middle parts of the basin. On the other hand, the remaining stations experienced non-significant RF changes, varying from -10.58 to 7.33 mm/year. One of the functional role with the trend tests obtained here is that the magnitude of the RF trends revealed the hydrological condition in the basin, where a negative trend indicated drought events while a contrast positive trend indicated there is a tendency for more severe flood events in the future (Suhaila et al., 2010).

Annual Tmax in the KRB varies between 26.51°C to 28.12°C, while for annual Tmin the value ranges from 21.77°C to 23.93°C, for the study period of 1979 to 2018, as shown in

Figure 4. Generally, both the Tmax and Tmin in the KRB exerts significant increasing trends for the past 39 years at 95% confident level, with the rates of 0.01 to 0.03 ºC/year and 0.01 to 0.05 ºC/year, respectively. The increasing trend is significant at the Pejabat Hal Ehwal Agama Islam Jajahan Machang (Pej. Hai. Jajahan Machang) and Kota Bharu stations at 95% confidence level.

The climate trend analysis from this study which applied the climate data from Malaysia Meteorological Department (MMD) is similar as Adnan et al. (2016) and Faizalhakim et al. (2017) who reported insignificant changes of annual RF for most of the stations in KRB with climate data from Jabatan Pengairan dan Saliran (JPS). One of the issues that could be highlighted here is that similar to the previous studies, the present study also reported a decreasing rainfall trend at the upstream of KRB, as well as heavier rainfall at the downstream. Besides that, temperatures in the KRB also exerted increasing trends, especially high significant for the minimum temperatures, which is consistent with a national level temperature trend assessment conducted by Tan et al. (2021). As per reported in the above-mentioned study also, there is a notable peak of maximum temperature during years of 1997-1998, 2009-2010 and 2015-2016 which were recorded strong El Niño events in the study area, as shown in Figure 4. Furthermore, the increasing trend of minimum temperatures indicated that the KRB is experiencing warmer nights, that would be reflected in the increasing of carbon loss (Giménezab et al., 2021), which is aligned with our land cover change study where the agriculture cover in the study area experienced reduction as compared for year 1992 and 2018.

Pearson's Correlation of Land Use Change and Climate Variables in the KRB

The *r* value for each of the land cover class calculated in Excel with α = 0.05 are presented in Table 4 and 5 for RF, Tmax and Tmin respectively. Statistically, the results of *r* obtained in this study are statistically significant as 80% of the r values fall in the reasonable ranges, as the p-values for the r are below 0.05. The interpretation of the r values are based on the rule of thumb as suggested by Moore et al. (2013), where absolute value of r for two variables at which $r < 0.3$ indicated none or very weak relationship; $0.3 < r < 0.5$ represents weak correlation; $0.5 < r < 0.7$ represents moderate correlation; and $r > 0.7$ indicated strong correlation relationship, the same goes to negative correlation relationship. However, in this study, we discovered that most of the stations had none or very weak correlation between the climate variable changes and the land cover change ($r < 0.3$).

Referring to the *r* statistics done onto the RF and the land use change, it can be concluded that at 95% confidence level the urban expansion in the Gua Musang district, the southern part of the KRB decreases the annual RF with *r* of -0.78 at the Pos Tehoi station. In contrast, deforestation in the same place exerted significant increase in RF with *r* value of -0.46 at the Pos Wias station. Besides that, the spatial relationship between the land cover change and climate changes tested with the correlation test also revealed that the expansion of agricultural activities in the Gua Musang and Tanah Merah increases the RF trend, that can be seen in the Pos Wias and Pusat Latihan Pertahanan Batang Merbau (P. Pert. Batang Merbau) stations with *r* values of 0.46 and 0.43 respectively.

As for the impact of land use change towards temperature variations, deforestation has significant in increasing the maximum temperature over Tanah Merah at 95%, that can be seen from P. Pert. Batang Merbau station with *r* value of 0.37. The other factors somehow showed mild correlation.

On the other hand, the impacts of the land use change towards minimum temperature variations in the KRB is much significant. The agricultural cropland expansion in the P. Pert. Batang Merbau and Kota Bharu stations had increases the Tmin of the KRB, with *r* values of -0.72 and -0.37 respectively. The deforestation process increases the Tmin of the KRB, also can be seen from the two above mentioned stations with *r* values of 0.73 and 0.37 respectively. As for the urban expansion factor, the correlation result showed significant in three stations: P. Pert. Batang Merbau (r = 0.36), Kota Bharu (r = 0.55) and Kuala Krai (r = 0.60) where these stations were spatially located at the downstream of the KRB that major economic activities took place in the Kelantan state.

Meanwhile, the *r* of all RF, Tmax and Tmin shown distinctive negative correlation towards elevation of the KRB. The *r* of RF and elevation is -0.21; Tmax and elevation is -0.67; while Tmin is -0.95. These values can be interpreted as the higher the elevation, the lower the climate variations in the KRB.

Discussion

In this study, the ESA CCI LC dataset over KRB is validated with the land use dataset provided by Malaysian land use data provider agency. The result shows that the dataset is presenting the land cover of KRB at substantial agreement. However, one of the major issues that should be considered on using the dataset is that there are confusion of agriculture covers and forest cover found in our study area, which has been discovered by (Alkhalil et al., 2020) as well. The possible reason behind might be the reflectance value of tropical agriculture species, particularly rubber and oil palm, were similar to the ones that were analyzed as forest, particularly broadleaved evergreen forest in the FAO vegetation dictionary. It is challenging in extracting rubber and oil palm information (known as the major agriculture plantations in Malaysia) that believed to have accumulated the basin by approximately 21% (8% oil palm and 13% rubber) according to the agency land use data from the ESA CCI land cover product. In order to further increase the accuracy of the dataset at local scale, data enhancement needs to be done by spatial filtering or manually altering the pixel values to the respective vegetation class in order to match with the local real vegetation cover.

The rainfall and temperature trends in the KRB shown increasing trends from 1979 to 2018. According to Tan et al. (2021), a greater increasing warm index as well as cold extreme index was found in the southern Peninsular Malaysia, which implied climate change induced more warm days in the last decade that could be led by rapid urbanization and industrialization. The present correlation analysis between the temperature variations and the land use change in the KRB shown the same finding where the correlation is higher negative values on the forest change. These evidence of increasing trends in rainfall and temperatures could lead to severe hydroclimatic disaster in the future such as flood and drought. As Kelantan is marked as the state with high risk for flood disaster in the Peninsular, the Federal Department of Town and Country Planning had listed some regulations for the development of the state such as maintaining the flood reservoir areas as agriculture areas (Arifin Norizan et al., 2021).

Another topic to be discussed from the findings is that the *r* values computed in this study are relatively low, where most of the stations showed very weak or no relationship between land cover change and the changes of rainfall and maximum and minimum temperatures. This can be explained with the fact that the land cover changes over the stations are not large scaled, or land cover change of 26 years is not long termed enough to represent the shift of land cover change in the KRB. This issue can be later studied further with hydrological modelling such as SWAT modelling.

Conclusion

Based on the statistical analyses, it can be concluded that the annual rainfall, maximum temperature, and minimum temperature of the KRB had significant increasing trends for the past 39 years (1979 to 2018) at 95% confidence. The event is especially notable in the downstream and south-west of the KRB, which are the Kota Bharu, Tanah

Merah and Gua Musang districts. The urban expansion at the Gua Musang decreases the annual rainfall with r of -0.78, where this event can be explained by decrease of evapotranspiration in the area due to the loss of evergreen forest. Another finding to be highlighted in this study is the conversion of forest into croplands over the Tanah Merah and Gua Musang (neighbouring to Perak state) had increased the minimum temperature of the area with r of -0.72 and -0.37 respectively. This event can be explained by the conversion of evergreen forests to herbaceous covers induced land surface temperature increment in the area.

Land use change and climate change is inter-relatable. Land use change is a driver towards climate change in terms of changing the concentration of greenhouse gases, but at the same time a changing climate can lead to switching of land cover types to coop with the current climate. In tropical region such as South East Asia, the changing climate is initiating a shift in agriculture industry to plant higher economic valued crops that can adapt the changing climate. The process would then alter the hydrology systems of the region.

Meanwhile, the validation of ESA CCI land cover data also proved that the dataset is adequate to represent the actual land cover in KRB. This could open an opportunity for future studies to utilize the open-source land cover data where it would not lead to confidential data and result sharing issues.

Acknowledgements

This research was funded by the Ministry of Higher Education Malaysia under the Newton-NERC grant (IMpacts of PRecipitation from Extreme StormS, Malaysia (IMPRESS-MALAYSIA), 203.PHUMANITI.6780001). The author would like to acknowledge the Malaysia Meteorological Department (MMD), Department of Agriculture (DoA) and Malaysian Center of Geospatial Data Infrastructure (MaCGDI) for sharing the climate and

land use data.

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Table 1 Climate stations.

ID	Name	Latitude	Longitude	Height(m)	Start Year	End Year
40430	Pos Brooke	4.63	101.48	640.00	1979	2016
40431	Pos Blau	4.65	101.68	244.00	1979	2016
40432	RPS Kuala Betis	4.70	101.75	152.50	1979	2016
40433	Pos Hau	4.70	101.53	655.00	1979	2016
40470	Pos Lebir	4.93	102.38	91.00	1979	2014
40501	Pos Belatim	5.00	101.53	488.00	1979	2016
40502	Pos Bihai	5.00	101.57	274.50	1979	2016
40510	Pos Tehoi	5.05	101.75	198.30	1979	2016
40512	Pos Wias	5.12	101.82	76.00	1979	2016
40516	Pos Gob	5.28	101.63	457.00	1979	2016
40586*	Pej. Hai. Jajahan Machang	5.77	102.20	31.00	1979	2016
40487*	P. Pert. Batang Merbau	5.82	102.05	21.00	1979	2016
48615*	Kota Bharu	6.17	102.28	4.60	1979	2018
48616*	Kuala Krai	5.53	102.20	68.30	1984	2018

* represents station with precipitation and temperature data.

Table 2 Accuracy assessment results for each year of dataset.

Year	Overall Accuracy	Kappa Coefficient
1992	0.7188	0.63
1993	0.7250	0.63
1999	0.7874	0.70
2000	0.7250	0.63
2001	0.7125	0.62
2007	0.7313	0.64
2008	0.8688	0.83
2009	0.7375	0.65
2014	0.7563	0.68
2015	0.7250	0.63
2016	0.7313	0.64
Mean	**0.7472**	**0.66**

Table 3 Mann Kendall trend and Sen's slope estimate result for RF, Tmax and Tmin.

Test	Mann-Kendall Trend	Sen's Slope Estimate

	Test Z			Q		
*all variables are calculated on mean annual basis	RF	Tmax	Tmin	RF (mm/year)	Tmax (°C/year)	Tmin (°C/year)
Pos Brooke	-0.77			-5.17		
Pos Blau	1.08			6.73		
RPS Kuala Betis	0.60			3.38		
Pos Hau	**2.49**			17.5		
Pos Lebir	0.42			2.44		
Pos Belatim	1.28			6.58		
Pos Bihai	**3.17**			24.4		
Pos Tehoi	-1.43			-8.29		
Pos Wias	-1.73			-10.58		
Pos Gob	**3.55**			29.74		
Pej. Hai. Jajahan Machang	0.65	**4.8**	**5.13**	7.33	0.03	0.05
P. Pert. Batang Merbau	-0.35	0.98	**2.36**	-4.29	0.00	0.01
Kota Bharu	0.48	**3.44**	**5.93**	3.38	0.01	0.03
Kuala Krai	**2.22**	**2.81**	**4.71**	22.12	0.02	0.03

(shaded) Represents trend at $\alpha = 0.05$ level of significance

Table 4 *r* of annual RF and land use change for each station in the KRB.

Station	Cropland	Forest	Urban
Pos Brooke	-0.07	0.06	**-0.79**
Pos Blau	-0.28	0.28	-0.10
RPS Kuala Betis	-0.05	0.05	**-0.49**
Pos Hau	0.11	-0.11	0.15
Pos Lebir	0.23	-0.22	0.00
Pos Belatim	0.05	-0.05	-0.02
Pos Bihai	0.02	-0.03	-0.31
Pos Tehoi	-0.04	0.03	**-0.78**
Pos Wias	**0.46**	**-0.46**	-0.17
Pos Gob	0.20	-0.20	-0.15
Pej. Hai. Jajahan Machang	0.30	-0.30	-0.12
P. Pert. Batang Merbau	0.43	-0.42	0.18
Kota Bharu	0.00	-0.00	-0.24
Kuala Krai	0.07	-0.07	0.09

* Bolded values are of strong correlation relationship

Table 5 *r* of annual Tmax and Tmin with land use change for each station in the KRB.

Station	Cropland		Forest		Urban	
Variable	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin
Pej. Hai. Jajahan Machang	-0.38	**-0.72**	0.38	**0.73**	0.01	0.21
P. Pert. Batang Merbau	0.05	-0.06	-0.04	0.07	0.14	0.36
Kota Bharu	-0.04	-0.37	0.05	0.37	-0.05	**0.55**

Kuala Krai	0.17	-0.21	-0.16	0.22	0.24	**0.60**

* Bolded values are of strong correlation relationship

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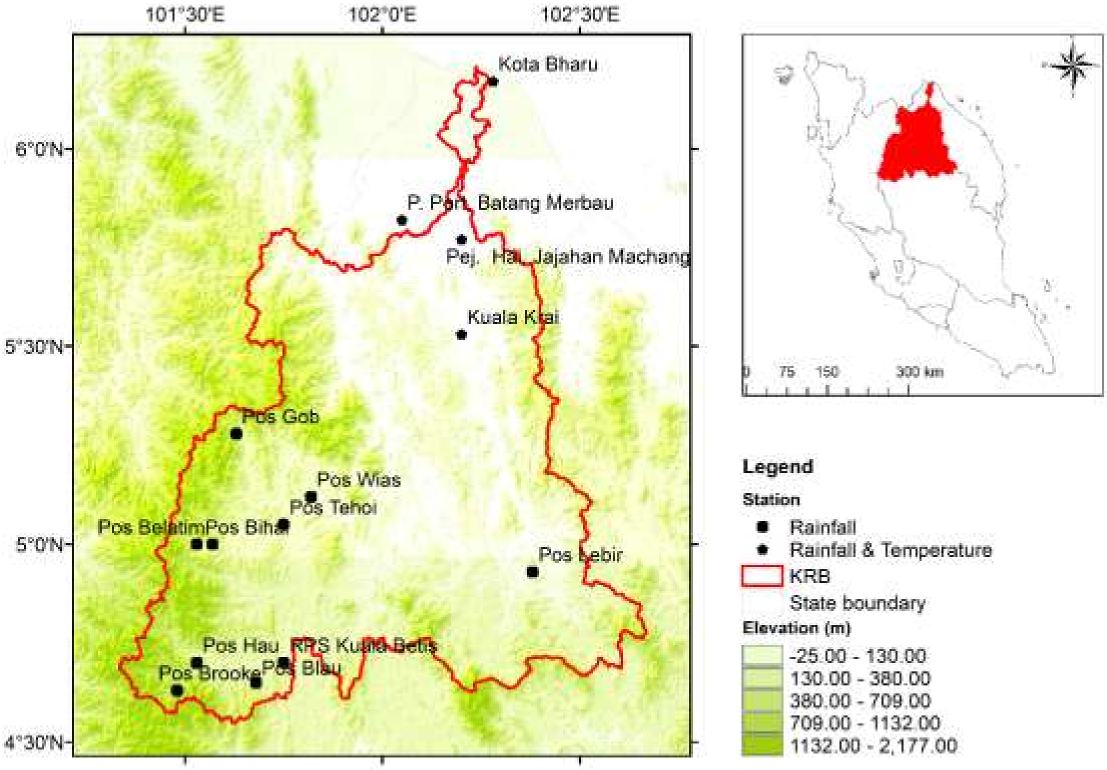
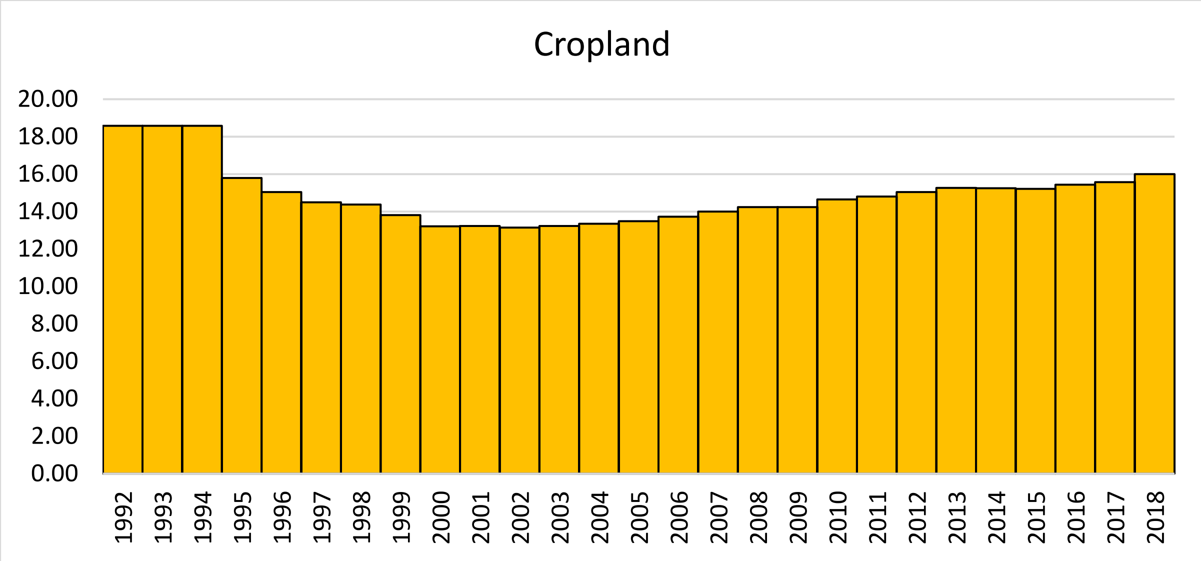
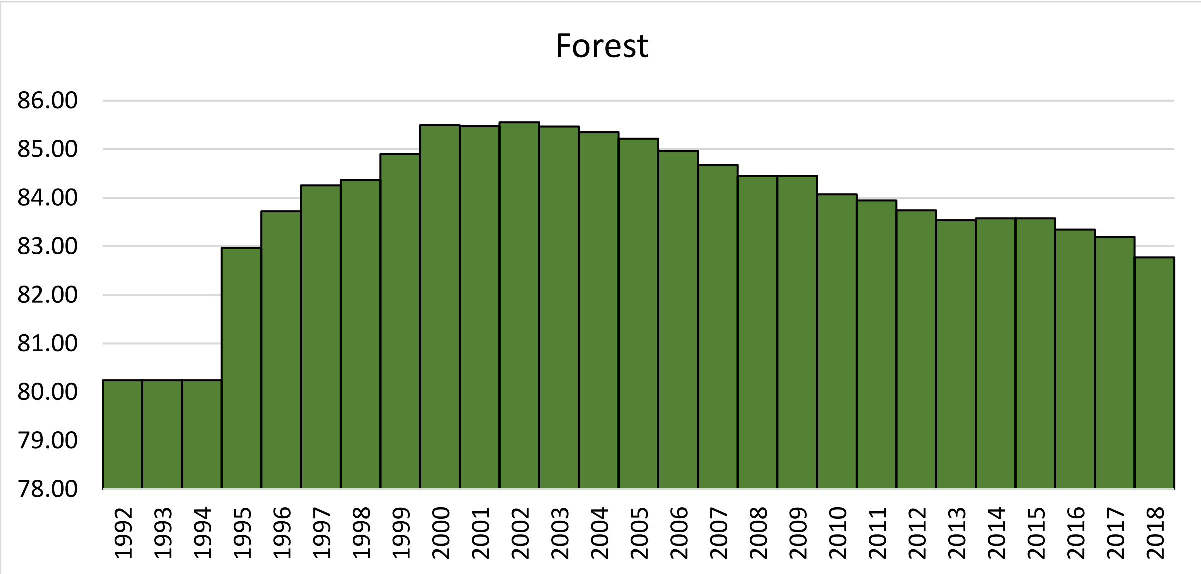
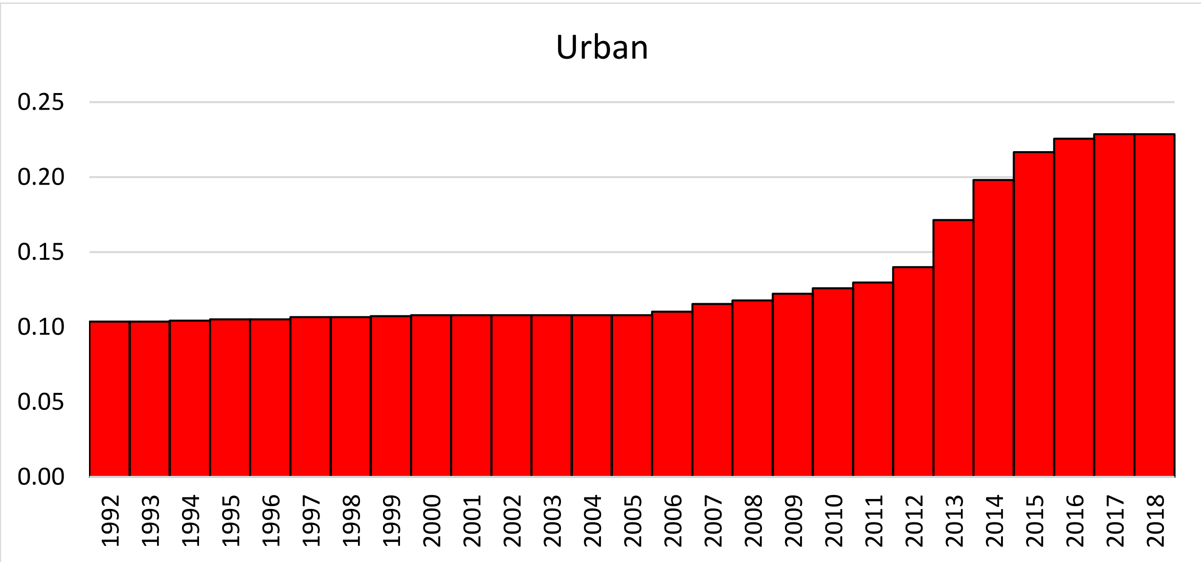


Figure 1 Kelantan River Basin and the distribution of the climate stations. Elevation source: SRTM (https://earthexplorer.usgs.gov/).


Cropland
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Forest
86.00
85.00
84.00
83.00
82.00
81.00
80.00
79.00
78.00
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Urban
0.25
0.20
0.15
0.10
0.05
0.00
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018

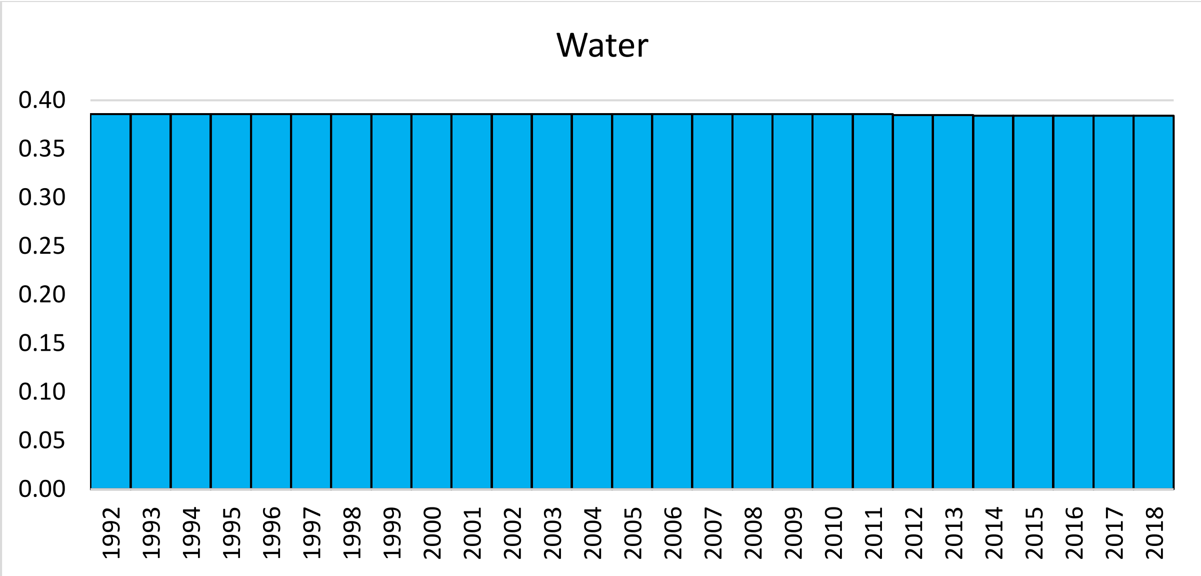


Figure 2 Percentage of each land cover class of each year extracted from the ESA CCI land cover data.

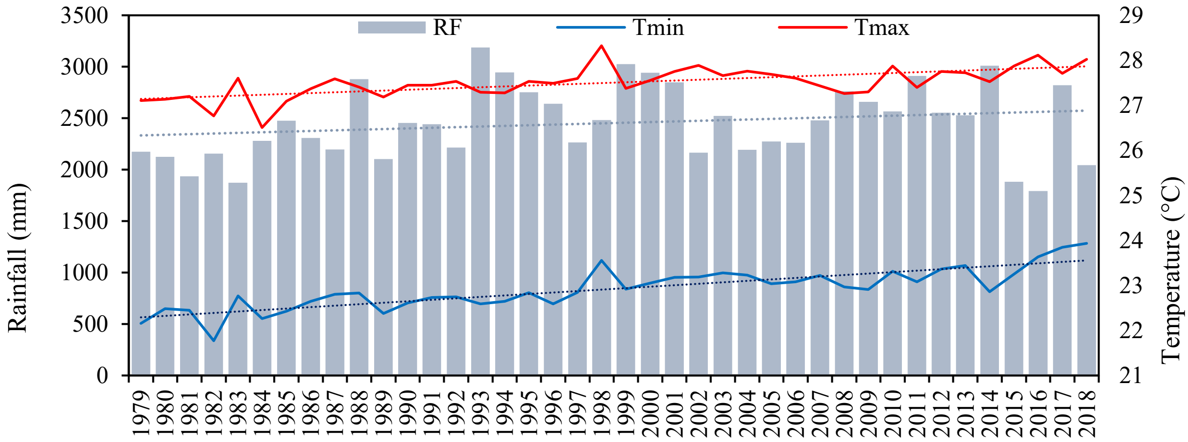


Figure 4 Trend of annual rainfall, maximum and minimum temperatures in Kelantan state from 1979 to 2018.

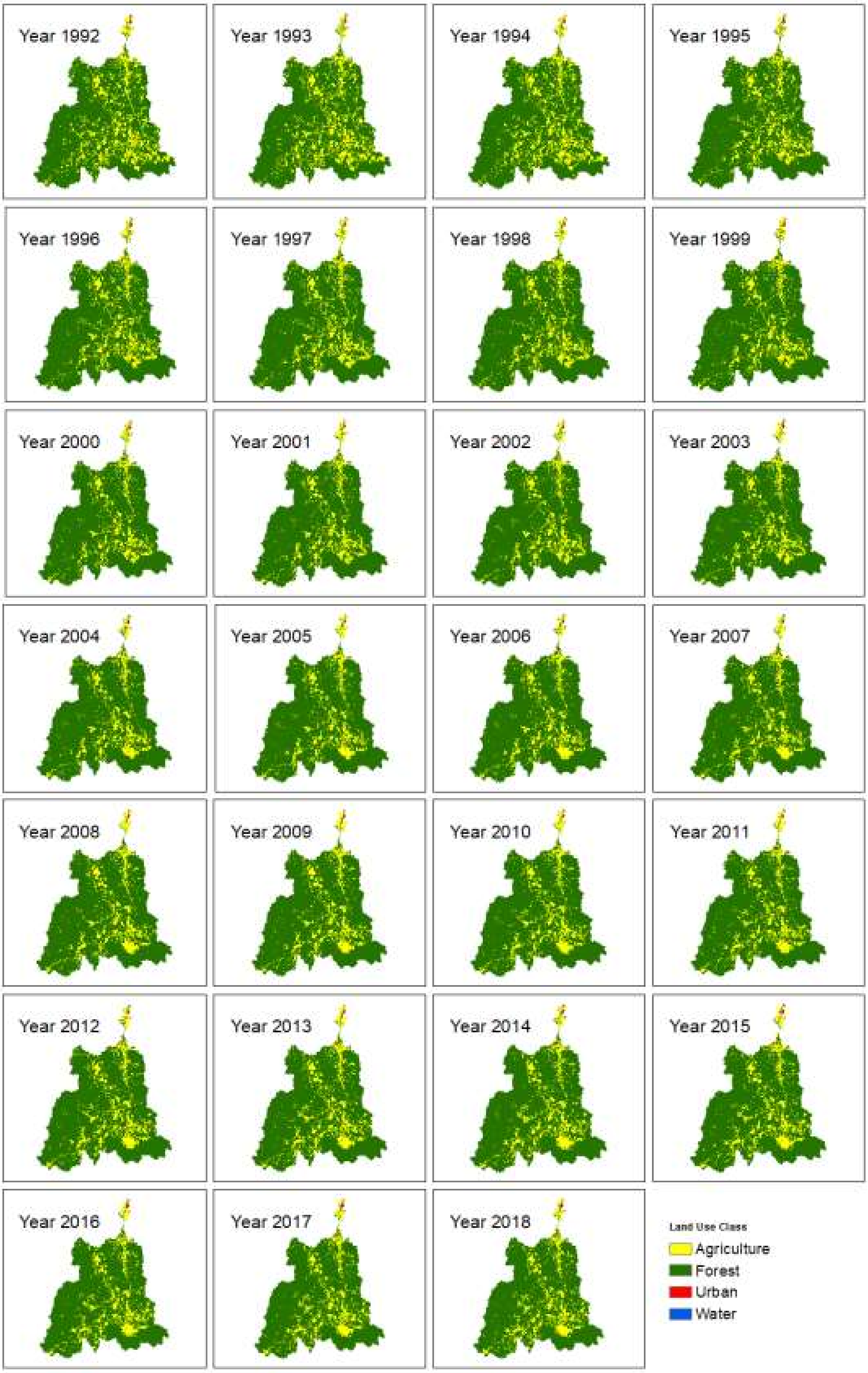


Figure 3 ESA CCI land cover data that have been reclassified into the designed class.