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The Impacts of Decreasing Paddy Field Area on Local Climate in Central Java, Indonesia

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ABSTRACT: This article is discussing the impacts of land cover change from paddy field to barren land in small scale area (1,516.5 km^2), on the surrounding local climate components in central Java, Indonesia. Data of several climate components from 2000-2010 were collected from weather stations that located separately. The land covers were dominated with cropland and little forest on eastern site, and settlements (urban) on western site. This study confirmed that the decrease in 13.1% of paddy field and the increase in 12.4% of barren land had significantly resulted in low daily actual vapor pressure (ea) during dry months with low rainfalls. The eastern areas that were originally occupied by croplands and trees, responded to the decrease of paddy fields by the increasing of air temperatures. The air temperatures and their variations at urban areas located in the western part were not distinctly affected by the land cover change.

KEYWORDS: local climate, land cover change, air temperature, actual vapor pressure, vapor pressure deficit, paddy field

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Introduction

Land cover change caused by human activities is responsible for local and regional climate alterations. Increased rates of forest and vegetation disturbance have altered the weather, causing drought,[1] global increase in CO_2,[2] and significant temperature increases and precipitation decreases.[3]

Wetlands are among the most valuable and productive ecosystems in the world, providing multiple resources and products, and performing important functions.[4] Many wetlands around the world are being lost or are under threat, because of conversion to agricultural land, reclamation for urban expansion, habitat destruction, etc.[5] Indonesian Ministry of Agriculture data indicates that from 1981 to 1985 and from 1998 to 1999, the conversion of paddy rice land to non-paddy or non-agricultural land affected approximately 246,000 ha, with a conversion rate of almost 50,000 ha annually.[6] Unfortunately, the majority of rice field conversion (90%) took place in Java, which had accounted for 60% of national rice production. It is not easy to compensate for the loss of fertile land in Java by developing new land on other islands, because most land outside Java is not as productive as that of Java.

Wetland destruction, through drainage or in-filling, is a common feature of urban and industrial development. Drying of wetlands will reduce CH_4 emissions and increase CO_2 emissions,[7] thus the net effect on greenhouse gas (GHG) emission could range from negligible to a small increase.[8]

Wetlands are considered to be vulnerable to climate change, but changes in wetlands themselves may also affect at least the local and regional climate. Successes in wetland conservation and wise use need to be measured against the potential impacts of these pressures.[9] The impacts of climate change on wetlands, especially rice fields, are widely discussed. Stigter and Winarto found that higher air temperatures in the surrounding area resulted in more frequent crop failure, which led to increased conversion of paddy fields into other land uses.[10] But only a few studies have discussed the effects of lost rice fields on local and regional climate. This paper will discuss the effects of rice field loss on local climate in a small area of Central Java, Indonesia.

Material and Methods

The study site, in Central Java, Indonesia, covered an area of 1,516.5 km^2 at 110°37′–111°05′ E and 7°23′–7°46′ S. The research site consisted of 17 districts and 177 villages. All available climatic data for an 11-year period (2000–2010) were collected from the two weather stationsin the observation area. The first station is located in the eastern part (hereafter referred to as *Eastern*), and the second one is located in the western part (hereafter called *Western*). The *Eastern* weather station is located at 7°39′15″ S and 110°59′26″ E with elevation of 277 m above sea level (asl), while the *Western* weather station is located at 7°30′55″ S 110°45′24″ E and 104 m asl. The distance between these two weather stations is approximately 27 km, and for the purposes of the study, the observation area was considered in two parts, each defined by a radius of approx 15 km from one weather station. The topography of the research area is relatively flat (slope: 0–8%) in the western part, and flat to moderately undulating (slope: 0–30%) in the eastern part. The elevation of the western area is 0–400 m asl, and it is 0–800 m asl in the eastern part (Fig. 1). The description of the weather station locations and study area boundaries are presented in Figure 1.

Land cover changes were analyzed using Landsat Imagery and Quickbird of 2000 and 2010, which were composites of band 3[R], band 2[G] and band 1[B]. Land cover classification referred to data from the Indonesian Ministry of Environment, under the supervised Maximum Likelihood method.[11] Noises were corrected with interpolation method, and accuracy level was calculated using a confusion matrix with software Envi 4.5.

The weather components observed in this study included rainfall, air temperature, relative humidity, sunshine duration and wind speed.[12] The measurement methods in the weather stations are manual. Daily rainfall is measured using an ombrometer with a funnel diameter of 113 mm and height of 120 cm from ground surface. The daily rainfall is observed every morning at 7 am by pouring the collected rainwater into the calibrated rainfall measuring cylinder and noting the reading in mm. Air temperature is measured using a mercury thermometer three times a day: 7 am, 1 pm and 6 pm. Relative humidity is measured using a wet-and-dry-bulb thermometer (psychrometer) three times a day: 7 am, 1 pm and 6 pm. In accordance with Jensen et al,[13] saturated air vapor pressure (e_s, kPa) is calculated using formula (1), actual air vapor pressure (e_a, kPa) is calculated using formula (2), and vapor pressure deficit (*VDP*, kPa) using formula (3).

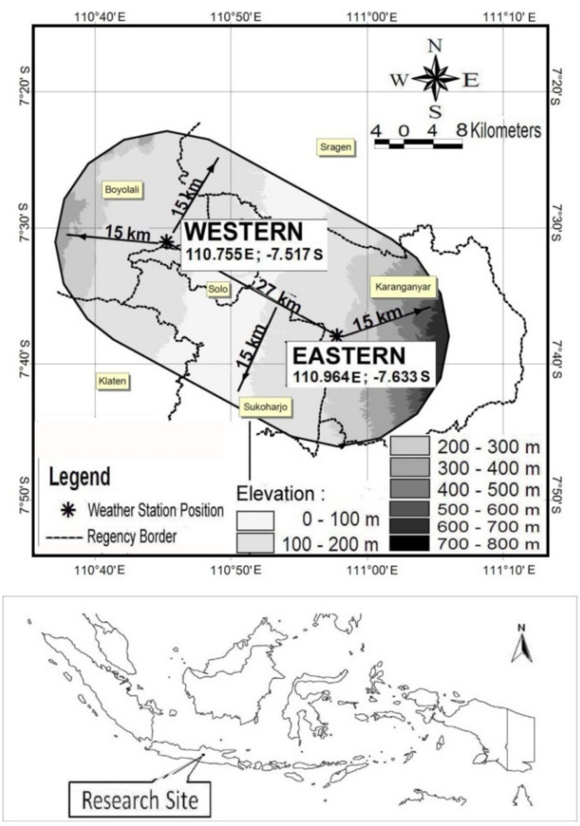

Figure 1. Research site and topography.

$$e_s = 0.6108 exp\left[\frac{17.27T}{T+237.3}\right] \tag{1}$$

$$e_a = e_s(T) \times RH/100 \tag{2}$$

$$VPD = e_s - e_a \tag{3}$$

Note: *T*: air temperature (°C); *RH*: relative humidity (%).

Sunshine duration was measured with Campbell-Stokes Sunshine Recorders, which concentrate sunlight through a glass sphere onto a recording card placed at its focal point. The length of the burn trace left on the card represents the sunshine duration. Wind velocity was measured using three hemispherical cup anemometers, and data collected every day at 7 am was used to generate an average for the 24-hour period. The anemometer was installed 0.5 m from the ground surface at Eastern, and 10 m at Western. The conversion of wind speed to standard height (2 m) is using the formula recommended by Allen et al.[14] Wind direction was only measured at Western, using a wind vane, and observed at 7 am.

Stochastic analysis of ANOVA F-test was employed to determine differences for air temperatures, actual vapor pressure (e_a) and vapor pressure deficit (VPD), then followed by the Waller-Duncan Post-Hoc test if the F-test showed significant differences. The Waller-Duncan Post-Hoc test was applied because the principles were based on Bayesian analysis frequently used for time series data.[15]

Results

Land cover changes. The comparison of land cover changes between 2000 and 2010 is presented in Figure 2 and Table 1. It can be seen in Figure 2 that major land cover conversion was from wetland (paddy field) to barren land. It is also shown in Table 2 that the area of barren land increased from 210.3 km^2 to 397.6 km^2, or 13.9% to 26.2%, while the area of wetland (paddy field) decreased from 584.3 km^2 to 386.4 km^2 (38.5% to 25.5%). The land cover changes from wetland to barren land included the transition of paddy fields to be converted to another land use in the future, such as settlement or industry, and thus left barren. Small increases of land cover occurred in forest, from 140.5 km^2 to 170.3 km^2 (9.3% to 11.2%), and in settlement, from 192 km^2 to 205.6 km^2 (12.7% to 13.6%). The increased forest area, which is mixed forest or agro-forestry,

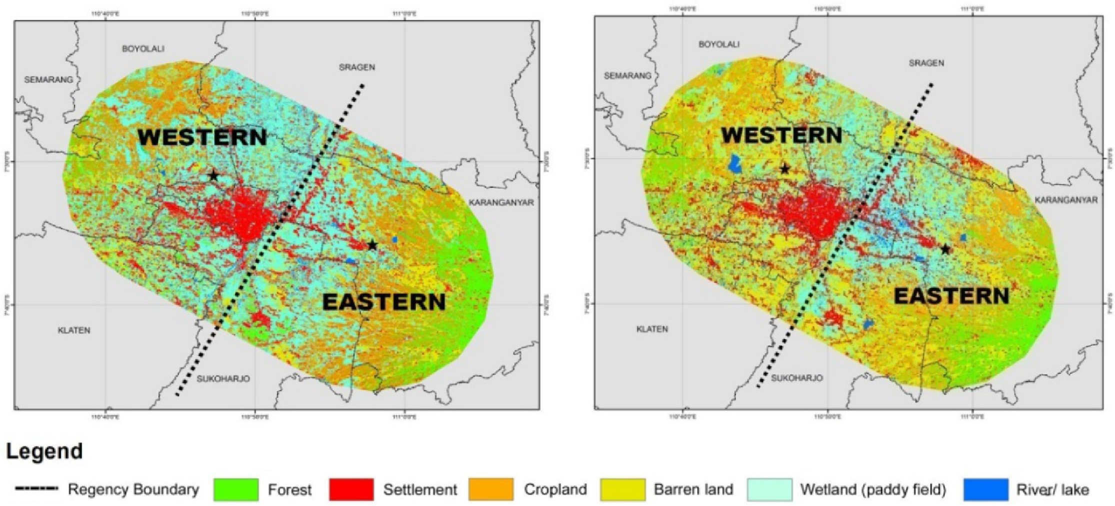

Figure 2. Analysis of land cover in 2000 (left) and 2010 (right) using landsat imagery with Quickbird (Supervised classification based on Maximum Likelihood method, and accuracy using Confusion Metrix method).

appeared in the western part, whereas forested area clearly decreased in the eastern part. Additionally, small decreases occurred in cropland from 335.6 km^2 to 308.3 km^2 (22.1% to 20.3%), and also in river/lake land cover, from 53.7 km^2 to 48.2 km^2 (3.6% to 3.2%). The alteration of land cover, especially the decrease in paddy fields and the increase of barren land in the research site may influence the local climate, as discussed in the discussion section.

Climate conditions. Annual rainfalls from 2000 to 2010 in the research area are highly varied, ranging from 1421 mm in 2003 to 3780 mm in 2010 at Eastern and 1713 mm (year 2003) to 4524 mm (year 2005) at Western. Mean annual rainfall during the 11-year period was 2224 mm at Eastern and 2611 mm Western. Figure 3 shows that generally a rainy season, with mean monthly rainfall exceeding 200 mm, occurred from November to April and a dry season, with mean monthly rainfall less than 200 mm, occurred from June to September. At Eastern, maximum mean monthly rainfall occurred in March (358.5 mm) and minimum in August (14.8 mm), while at Western, maximum occurred in February (425.6 mm) and minimum also in August (12.2 mm). The standard deviation of monthly rainfall ranged from 34.0 mm (August) to 208.7 mm (December) at Eastern, and from 36.4 mm (August) to 266.8 mm (December) at Western. Figure 3 shows that typically, monthly rainfalls at Western were higher than at Eastern. Rainfall is a climate component that is the result of complex processes on a large scale, including the monsoonal system. In Indonesia, the changes in rainy and dry seasons are driven by the Asia-Australia monsoon, which also influences the wind direction patterns in particular periods. Therefore, rainfall in the research area was not influenced by the land cover changes of research site, because of its small area.

Table 1. Land cover area of research site in the year 2000 and 2010.

LAND COVER	(km^2)		(%)	
	2000	2010	2000	2010
Forest	140.5	170.3	9.3	11.2
Settlement	192.0	205.6	12.7	13.6
Crop land	335.6	308.3	22.1	20.3
Barren land	210.3	397.6	13.9	26.2
Wet land (paddy field)	584.3	386.4	38.5	25.5
River/lake	53.7	48.2	3.6	3.2

The mean annual sunshine durations were 65.8% and 69.5% of possible sunshine duration at Eastern and Western, respectively. Mean sunshine duration ranged from 58.4% (year 2001) to 73.1 % (year 2009) at Eastern, and from 57.1% (year 2010) to 78.6% (year 2003) at Western. Figure 4 shows the monthly pattern of daily sunshine from 2000 to 2010. It can be seen in Figure 6 that daily sunshine durations were rather short in January (49.1 and 51.6%), February (46.4 and 37.2%), March (52.1% and 50.6%), and December (48.4 and 44.3%) at both sites. Rainfall during those months was high, so the cloud cover was likely higher than in dry months and thus daily sunshine durations were short in the wet months. Daily sunshine duration during dry months (June to September) was in the range of 73.3%–86.4% at Eastern site and 84.0%–91.6% at Western. Daily sunshine duration is influenced by wider area circumstances, and the paddy field decrease in the research site was assumed not to influence the daily sunshine duration, because of the small scale of the area.

Wind velocity. Mean annual wind velocities are 1.6 m/s at Eastern and 3.9 m/s at Western. At Eastern, the highest wind velocity occurred in 2004 (2.1 m/s) and the lowest in 2010 (0.6 m/s), while at Western, the highest occurred in 2004 (4.3 m/s) and the lowest in 2009 (3.4 m/s). The wind velocity at Western is higher than at Eastern, as shown in Figure 5, because the landscape at Western is more flat and open. Eastern is dominated with high tree coverage that breaks up the

Table 2. Statistical analysis of daily air temperature (°C) in dry months (Aug.–Sept.).

YEAR	EASTERN				WESTERN			
	RAINFALL (mm)	T (°C)			RAINFALL (mm)	T (°C)		
		7 AM	1 PM	6 PM		7 AM	1 PM	6 PM
2000	50	24.8^{b}	31.9^{a}	28.6^{a}	79	23.9^{a}	31.9^{b}	29.1^{c}
2001	42	24.6^{b}	32.6^{b}	28.4^{a}	26	23.8^{a}	32.0^{b}	29.0^{b,c}
2002	6	24.5^{b}	32.8^{b}	28.5^{a}	1	23.0^{a}	31.6^{a,b}	28.4^{a,b}
2008	0	23.7^{a}	32.2^{a}	30.5^{b}	0	24.0^{a}	32.2^{b}	29.4^{c}
2009	0	24.1^{a,b}	32.6^{b}	30.1^{b}	0	23.6^{a}	32.0^{b}	29.0^{b,c}
2010	444	24.5^{b}	31.9^{a}	28.2^{a}	418	24.8^{b}	31.4^{a}	28.0^{a}
Sig.		HS	HS	HS		HS	HS	HS

Note: *Number followed by the same letter (a, b or c) in same column is not significantly different in the same site at $\alpha = 0.01$ using Waller-Duncan multiple range test.
Abbreviations: NS, Non significant; HS, Highly Significant using ANOVA F-test.

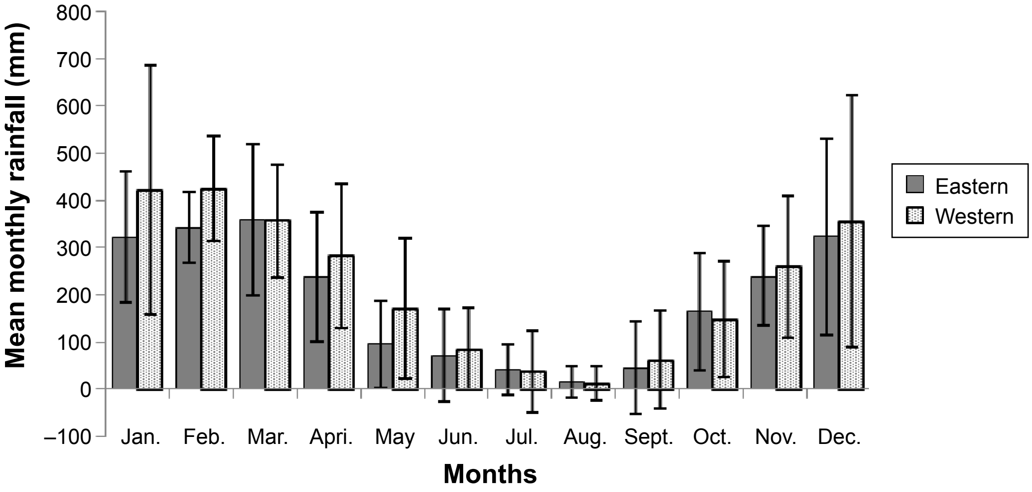

Figure 3. Mean monthly rainfall (2000–2010).

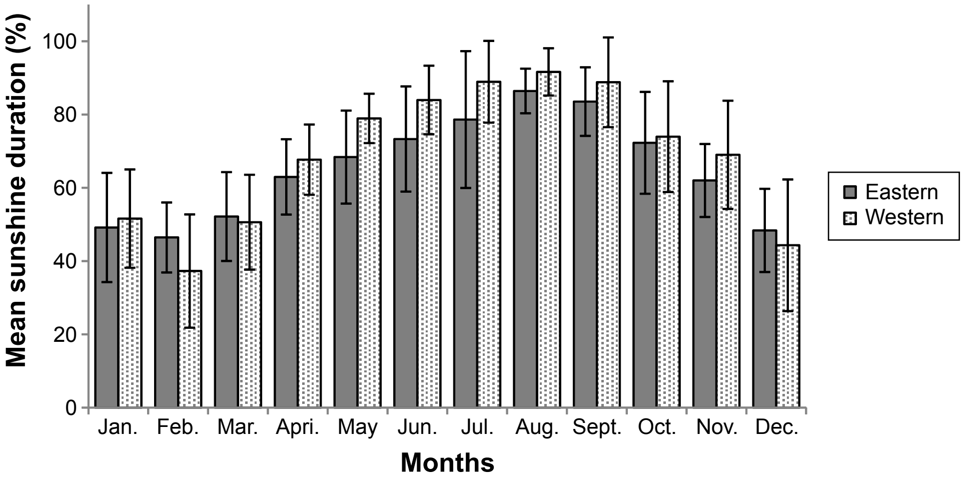

Figure 4. Mean monthly sunshine duration (%) from 2000–2010 of eastern and western sites.

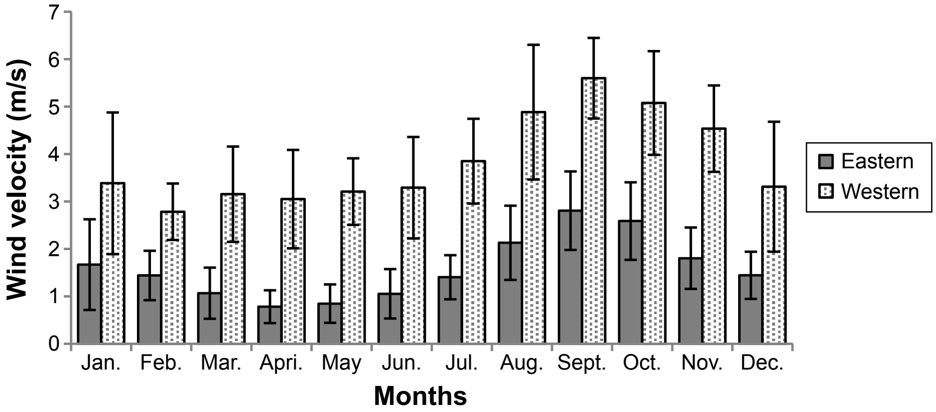

Figure 5. Mean monthly wind velocity at both sites (2000–2010).

wind force. Figure 5 shows that wind velocities are higher during the dry season (June–Sept.), and rather low during rainy season (Dec.–April). The highest mean wind velocity occurred in September (2.8 m/s at Eastern and 5.6 m/s at Western) and the lowest in April (0.8 at Eastern and 3.0 m/s at Western). The patterns of mean monthly wind velocity, as shown in Figure 5, are rather similar at both sites. Standard deviation ranged from 0.3 to 0.9 m/s at Eastern and 0.5 to 1.5 m/s at Western.

Air temperature. Air temperature is one of the climate components that were highly affected by local circumstances, and highly correlates with the existing energy in the area, as derived from the shortwave radiation from solar energy, and outgoing longwave radiation from the earth's

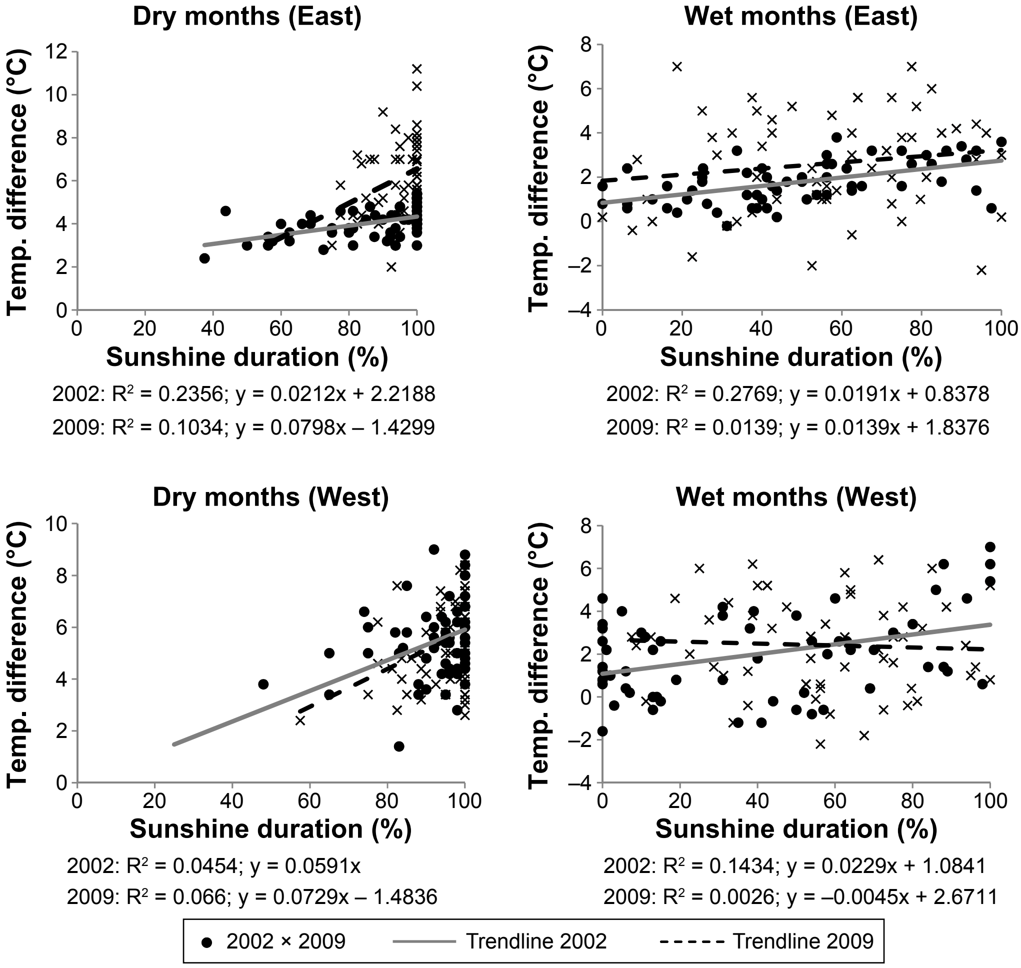

Figure 6. The relation between temperature difference ($T_{18\text{-}7}$) and sunshine duration in 2002 and 2009.

Table 3. Statistical analysis of daily air temperature (°C) in wet months (Feb.–Mar.).

YEAR	EASTERN				WESTERN			
	RAINFALL (mm)	T (°C)			RAINFALL (mm)	T (°C)		
		7 AM	1 PM	6 PM		7 AM	1 PM	6 PM
2000	925	24.7^{b}	30.9^{a,b}	26.3^{a}	702	23.8^{a}	29.7^{a}	25.7^{a,b}
2001	770	24.6^{b}	30.9^{a,b}	26.7^{a,b}	812	23.8^{a}	29.9^{a,b}	25.8^{a,b}
2002	557	24.8^{b,c}	31.2^{b,c}	26.5^{a,b}	747	24.2^{b}	30.4^{b,c}	26.1^{a,b}
2008	863	24.0^{a}	30.5^{a}	28.3^{c}	899	23.8^{a}	29.9^{a,b}	25.6^{a}
2009	663	24.6^{b}	30.9^{a,b}	27.2^{b,c}	622	24.1^{b}	30.0^{a,b}	26.5^{b,c}
2010	844	25.1^{c}	31.5^{c}	27.8^{c}	717	25.0^{c}	30.7^{c}	27.2^{c}
Sig.		HS	HS	HS		HS	HS	HS

Note: *Number followed by the same letter (a, b or c) in same column is not significantly different in the same site at $\alpha = 0.01$ using Waller-Duncan multiple range test.
Abbreviations: NS, Non significant; HS, Highly Significant using ANOVA F-test.

surface. Therefore, to determine the effects of paddy field conversion into barren land on air temperature, wet months and dry months must be selected from Figure 3. Tables 2 and 3 present the statistical analysis of air temperature in the morning (6 am), noon (1 pm) and evening (6 pm) at dry months (August and September) and wet months (February and March) from the first three years (2000–2002) and the last three years (2008–2010).

Table 2 illustrates that air temperatures at morning, noon and evening both at eastern and western sites during dry months showed highly significant differences. In general, Table 2 shows that at Eastern, air temperatures at 6 pm were higher in 2008 (30.5°C) and 2009 (30.1°C) than 2000–2002, while clear differences cannot be seen at Western. The air temperatures at Western are not significantly different to each other, but the air temperatures in 2010 were rather low due to very high rainfall. Rainfall is associated with frequent cloud cover, which minimized incoming solar radiation, and thus daytime temperature was rather low. The cloudy day led to high moisture in the air, and thus the sensible heat was low. This results in rather low air temperature in daytime, because less energy is employed to heat the air. The high air temperature in the morning was due to outgoing longwave radiation released by the earth that could not escape through the cloud cover.

Table 3 showing the air temperature at 7 am, 1 pm and 6 pm in the wet months (February–March) from 2000–2002 and 2008–2010 at Eastern and Western, respectively. It can be seen from Table 3 that the air temperatures at Eastern at 6 pm were higher in the last three years than in the first three years, similar to that of dry months. Air temperatures at 2008, 2009 and 2010 were 28.3, 27.2 and 27.8°C, respectively. The air temperatures at Western do not show clear differences. However, the air temperatures in 2010 were significantly high at all times and in both locations, probably because of the shrinkage of paddy field area.

Actual vapor pressure (e_a). Relative humidity (*RH*) is an important climate component that shows the ratio of the actual vapor pressure of the air (e_a) to the saturated vapor pressure of the air (e_s) at a given temperature. The statistics analyses of e_a at both sites, in dry months and wet months, are presented in Tables 4 and 5.

Table 4 shows that during dry months, e_a at Eastern in 2008 and 2009 was significantly lower than in 2000–2002, but there is no significant difference with e_a in 2010. The high e_a in

Table 4. Statistical analysis of daily actual vapor pressure (e_a) in dry months (August–September).

YEAR	EASTERN				WESTERN			
	RAINFALL (mm)	e_a (kPa)			RAINFALL (mm)	e_a (kPa)		
		7 AM	1 PM	6 PM		7 AM	1 PM	6 PM
2000	50	2.86^{b}	2.63^{b}	2.67^{b}	79	2.43^{a}	2.23^{a}	2.43^{a}
2001	42	2.89^{b}	2.61^{b}	2.72^{b}	26	2.54^{b}	3.10^{b}	2.95^{b}
2002	6	2.76^{b}	2.62^{b}	2.65^{b}	1	2.43^{a}	2.93^{b}	2.75^{b}
2008	0	2.37^{a}	2.12^{a}	2.28^{a}	0	2.38^{a}	2.30^{a}	2.41^{a}
2009	0	2.39^{a}	2.24^{a}	2.46^{a,b}	0	2.34^{a}	2.29^{a}	2.38^{a}
2010	444	2.77^{b}	2.89^{b}	3.04^{c}	418	2.73^{b}	2.64^{a,b}	2.81^{b}
Sig.		HS	HS	HS		HS	HS	HS

Note: *Number followed by the same letter (a, b or c) in same column is not significantly different in the same site at $\alpha = 0.01$ using Waller-Duncan multiple range test.
Abbreviations: NS, Non significant; HS, Highly Significant using ANOVA F-test.

Table 5. Statistical analysis of daily actual vapor pressure (e_a) in wet months (February–March).

YEAR	EASTERN				WESTERN			
	RAINFALL (mm)	e_a (kPa)			RAINFALL (mm)	e_a (kPa)		
		7 AM	1 PM	6 PM		7 AM	1 PM	6 PM
2000	925	2.97^{b}	2.82^{b}	$2.89^{a,b}$	702	23.8^{a}	29.7^{a}	$25.7^{a,b}$
2001	770	2.93^{b}	2.90^{b}	2.80^{a}	812	23.8^{a}	$29.9^{a,b}$	$25.8^{a,b}$
2002	557	2.98^{b}	2.71^{a}	2.81^{a}	747	24.2^{b}	$30.4^{b,c}$	$26.1^{a,b}$
2008	863	2.76^{a}	2.97^{b}	$2.97^{a,b}$	899	23.8^{a}	$29.9^{a,b}$	25.6^{a}
2009	663	$2.85^{a,b}$	2.93^{b}	$2.90^{a,b}$	622	24.1^{b}	$30.0^{a,b}$	$26.5^{b,c}$
2010	844	2.98^{b}	3.09^{c}	3.03^{b}	717	25.0^{c}	30.7^{c}	27.2^{c}
Sig.		HS	HS	HS		HS	HS	HS

Note: *Number followed by the same letter (a, b or c) in same column is not significantly different in the same site at $\alpha = 0.01$ using Waller-Duncan multiple range test.
Abbreviations: NS, Non significant; HS, Highly Significant using ANOVA F-test.

2010 at Eastern was due to the high rainfall (444 mm), which meant the e_a measurements were not significantly different from e_a in 2000–2001, where paddy fields still largely covered the land. Western shows similar results, with e_a in 2008–2009 significantly lower than 2001–2002 especially at 1 pm and 6 pm, but e_a in 2010 was high because of high rainfall in the dry months. In general, Table 4 shows that in dry months air is drier in 2008–2009 than 2000–2002, because the irrigated paddy fields that contributed to water vapor in the air decreased and thus the air became dry. Specifically, by comparing e_a of 2002, where rainfall was very low, only 6 mm during August and September (nearly no rainfall), with e_a of 2008 and 2009, it can be seen clearly that the lower e_a recently is not only effected by weather, especially rainfall. And thus, there must be another factor influencing the e_a, presumably the wetland decrease.

Table 5 shows that during wet months, at Eastern especially at 7 am, e_a of 2008–2009 was lower than 2000–2002, although rainfalls were also high. This means that the air was drier in 2008–2009 inspite of high rainfall, especially in the morning (7 am). But, e_a at Western does not exhibit clear differences.

Discussion

Air temperature variation. The impact of decreased paddy field areas on air temperature is investigated in more detail by comparing the air temperatures in dry months and wet months at 2002 with 2009, as shown in Figure 6. The reasons to compare air temperatures in 2002 and 2009 is because they represent the land cover before and after paddy field conversion into barren land, and the total rainfall during dry months of both years were similar, at 1 mm and 0 mm, respectively.

As shown in Figure 6, the regression coefficient (R^2) of all months and locations are very low (0.0367 to 0.3037), which means that the variation is very high, resulting in very low confidence levels for the means. However, Figure 6 shows that on the eastern site, the air temperatures during dry months in 2002 did not increase steeply as the sunshine duration increased, shown by the gentle slope of the trend line. By contrast, air temperatures increased steeply as sunshine duration increased in 2009. As discussed previously, the e_a during dry months in 2009 was lower than in 2002, and thus the air temperatures rose more easily in 2009.

The patterns of air temperature changes in dry months in both 2002 and 2009 were similar, as shown by the similar slopes of their trendlines. The longer the sunshine duration, the higher the air temperatures, because the e_a levels of both years were not clearly different, as a result of high rainfall. It can also can be seen that the variations of air temperatures in 2009 were higher in both dry and wet months. This is probably because the land conversion from paddy field into barren land or cropland led to higher fluctuation of e_a. Fluctuation of e_a can be identified by calculating standard deviation of e_a, and these were determined to be 0.124 kPa in 2002 and 0.20 kPa in 2009. The higher standard deviation of e_a in 2009 also resulted in higher standard deviation of air temperatures in 2009 (1.23°C) than 2002 (0.38°C). The lower standard deviation of e_a in 2002 is likely due to larger irrigated paddy field areas, which contributed to air moisture through evapotranspiration during sunny days.

Figure 6 also shows that on the western site, air temperatures in 2009 show the same variation as 2002. For instance, in dry months, standard deviation of e_a in 2002 and 2009 were 0.261 kPa and 0.213 kPa, respectively; and standard deviation of mean air temperatures were 1.68°C and 1.76°C, respectively. In other words, it is clearly shown that decreasing paddy field areas did not affect the air temperatures. The high variation and similar pattern of air temperature differences at Western is probably due to settlement domination since 2000, as the western part of the test area is a more urban area. Thus the decrease in paddy fields did not significantly influence the air temperature because the air temperature in the urban area had already been high since 2000. Conversely, the air temperature and its variation at Eastern are very influenced by the decrease in paddy field area because land cover in the area

Table 6. Statistical analysis of daily vapor pressure deficit (*VPD*) in dry months (August–September).

YEAR	EASTERN				WESTERN			
	RAINFALL (mm)	*VPD* (kPa)			RAINFALL (mm)	*VPD* (kPa)		
		7 AM	1 PM	6 PM		7 AM	1 PM	6 PM
2000	50	0.27^{a}	2.10^{a}	1.25^{a}	79	0.55^{b}	2.50^{b}	1.62^{b}
2001	42	0.20^{a}	2.32^{a}	1.16^{a}	26	0.41^{a}	1.66^{a}	1.02^{a}
2002	6	0.31^{a}	2.34^{a}	1.25^{a}	1	0.38^{a}	1.73^{a}	1.14^{a}
2008	0	0.57^{b}	2.68^{b}	2.08^{c}	0	0.62^{b}	2.51^{b}	1.68^{b}
2009	0	0.62^{b}	2.69^{b}	1.83^{b}	0	0.57^{b}	2.45^{b}	1.63^{b}
2010	444	0.31^{a}	1.85^{a}	0.81^{a}	418	0.41^{a}	1.95^{a}	1.00^{a}
Sig.		HS	HS	HS		HS	HS	HS

Note: *Number followed by the same letter (a, b or c) in same column is not significantly different in the same site at $\alpha = 0.01$ using Waller-Duncan multiple range test.
Abbreviations: NS, Non significant; HS, Highly Significant using ANOVA F-test.

is dominated by cropland and forest. This finding is in agreement with Eliasson and Svensson, who found that settlements in which urban area dominates the land cover significantly influence the diurnal air temperature variations.[16]

Vapor pressure deficit (VPD). Vapor pressure deficit (VPD) is the difference between the e_a and e_s at a particular temperature. The statistical analysis of VPD is presented in Tables 6 and 7 for dry and wet months, respectively.

Table 6 shows that VPD during dry months on both the eastern and western sites were significantly higher in 2008–2009 than in 2000–2002, because of low e_a (Table 4). The low e_a in 2008–2009 was promoted by the decreased area of irrigated paddy fields, and thus less air moisture contributed through evapotranspiration. The existence of paddy fields contributed to higher vapor in the air, because irrigated paddy fields encourage more incoming energy to be stored in the water and absorbed by vegetation, and then to be used for water evaporation and plant transpiration, resulting in higher actual water vapor in the surrounding atmosphere. The energy dissipation in paddy fields is dominated by latent heat, which leads to high evapotranspiration and lower temperature, with only a small amount of energy dissipated into sensible heat.[17] The high VPDs in 2010 were caused by high rainfalls that led to high air humidity.

It is shown in Table 7 that during wet months, VPDs on the eastern site at 7 am and 6 pm were higher than in previous years. This was because of the high air temperatures that occurred at 6 pm, as shown in Table 3, since VPD positively correlates with temperatures.[18] The high air temperatures at 6 pm increased the VPD, and this circumstance occurred until morning, so that the VPD in the morning remained high. There are no clear differences in VPD at Western, probably because there are no clear differences in air temperatures (Tables 3 and 5).

Conclusion

The decrease of paddy field area by approximately 13.3% from 2000 to 2010 affected surrounding climate, especially during dry months in the more rural eastern area, which was dominated by crop lands with some forest, more so than in the more urban western area, dominated by settlements. During dry months with low rainfalls in the rural area (eastern part), the e_a decreased, and thus VPD increased, which led to high fluctuation in air temperature. The western area, which

Table 7. Statistical analysis of daily vapor pressure deficit (*VPD*) in wet months (February–March).

YEAR	EASTERN				WESTERN			
	RAINFALL (mm)	*VPD* (kPa)			RAINFALL (mm)	*VPD* (kPa)		
		7 AM	1 PM	6 PM		7 AM	1 PM	6 PM
2000	925	0.14^{a}	1.65^{b}	0.54^{a}	702	0.20^{a}	1.43^{b}	0.53$^{a–c}$
2001	770	0.17^{a,b}	1.57^{a,b}	0.70^{a,b}	812	0.22^{a,b}	1.45^{b}	0.54$^{a–c}$
2002	557	0.14^{a}	1.85^{c}	0.66^{a,b}	747	0.17^{a}	1.23^{a}	0.43^{a}
2008	863	0.22^{b,c}	1.41^{a}	0.89^{c}	899	0.19^{a}	1.36^{a,b}	0.45^{a,b}
2009	663	0.25^{c}	1.55^{a,b}	0.74^{b,c}	622	0.24^{a,b}	1.09^{a}	0.70^{c}
2010	844	0.23^{c}	1.54^{a,b}	0.72^{b}	717	0.30^{b}	1.46^{b}	0.62^{b,c}
Sig.		HS	HS	HS		HS	HS	HS

Note: *Number followed by the same letter (a, b or c) in same column is not significantly different in the same site at $\alpha = 0.01$ using Waller-Duncan multiple range test.
Abbreviations: NS, Non significant; HS, Highly Significant using ANOVA F-test.

was from the beginning of the study period occupied by more settlements (urban area), did not clearly experience changes in air temperatures and their fluctuations because the air temperature had already been high since 2000.

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Author Contributions

Conceived and designed the experiments: K, S, and WSD. Analyzed the data: MS, KY, and ANR. Wrote the first draft of the manuscript: K. Contributed to the writing of the manuscript: MS, KY, and ANR. Agree with manuscript results and conclusions: K and MS. Jointly developed the structure and arguments for the paper: K, MS, S, WSD, KY, and ANR. Made critical revisions and approved final version: K. All authors reviewed and approved of the final manuscript.

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