Land use change on climate parameters at Samin subwatershed in Central Java, Indonesia

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Abstract. The Samin sub-watershed (SSW) is one of the critical watersheds in Indonesia which need conservation. The identification of land-use/land-cover changes (LUCC) can help in deciding the priority of conservation areas as well as limiting the widespread of critical lands in the watershed, which can contribute to climate change. The purpose of this study is to determine the impact of land use change on climate parameters, i.e., precipitation, air temperature and relative air humidity. The method is by using the descriptive explorative. The study employed Indonesian topographic map and Landsat’s imageries of 1996, 2001, 2006, 2011 and 2016. The climate data from 1996 to 2016 were obtained from surroundings weather station. Data were analyzed using Geographic Information System (GIS) and SPSS. The results showed that land use was dominated by rice fields 22,552.83 ha (69.20%), and converted to non-agricultural lands 165.05 hectares/year for the last 20 years. Forest area decreased 65.8 ha/year, and settlement (housing and industrial estates) increased 253.87 ha/year (11.07%). The statistical analysis resulted in a negative relationship between forest area and air temperature and, but no significant correlation with rainfall.

1. Introduction

Study of land use/land cover change (LUCC) or land conversion of agricultural has received considerable attention [1]. There is debate as to whether agricultural land should be maintained or converted to other uses [2]. The LUCC plays an important role in the climate system [3]. LUCC on a local, regional, and global scale is one of the key drivers of global climate change [4,5]. LUCC is one of the main causes of global climate change. At the moment, the climate impact of LUCC has become a hotly discussed topic worldwide. According to the fourth assessment report of Intergovernment Panel on Climate Change (IPCC) in 2007, human activities, such as urbanization and agriculture, accounted for 90% of global warming [6,7]. LUCC is the loss of major agricultural land, consequently vegetation lost, which has long been known to modify the climate near the soil. Geiger (1950) [8] said that canopy cover has a strong influence on extreme climatic conditions [9]. LUCC is an almost inevitable phenomenon during the period of economic growth and population growth [10]. In China, since 1980, LUCC of agricultural land to non-agricultural land has been running and widespread. The three main factors causing LUCC are high population density, urbanization processes and rapid economic growth [11].
Human activities, such as deforestation, expanded use of non-agricultural vegetation and agricultural land, grassland degradation, urbanization and other large-scale land use change the natural quality of land cover [12]. According to the Intergovernmental Panel on Climate Change (IPCC), LUCC activity can result in an average temperature rise of 4°C in 2100. Cinar [12] explains this will change the physical characteristics of the ground surface and will affect the soil interaction of atmospheric energy. They also explain that urbanization and deforestation lead to increased albedo, with rising atmospheric temperature, which will affect the thermal comfort of buildings and urban life. The increase in land use change can provide different ecosystems that affect climate parameters such as air temperature, relative humidity, precipitation and wind speed. Therefore, it is necessary to improve water-use efficiency by adjusting to future precipitation reductions due to climate change [13].

LUCC can be grouped into three categories: urban encroachment to farmland, conversion of agricultural land into the non-agricultural land, and transition of agricultural land to the natural landscape. The transition differs greatly in their degree of reversibility as well as it's associated environmental and socioeconomic consequences [1]. There is a strong correlation between monthly average temperatures and land changes that resulted from the increased urban land use, changes in forest cover and the conversion of permanent lands into artificial greenhouses. Zhang et al. [14] which studied about a simulation of the effect of urbanization on climate in the Yangtze River Delta found that the conversion of rural land and most irrigated agricultural land to urban land cover produced significant changes to near-surface temperatures, humidity, wind speed, and precipitation.

Although many studies already discussed the effects of land use changes on climate, the discussion in the Samin subwatershed has not been found. Thus, the aim of this study is to investigate the influence of LUCC in Samin Subwatershed on climate parameters.

2. Material and methods

The research was conducted from March 2015 to August 2017. The study area is Samin Subwatershed, Central Java, Indonesia, located at the coordinates of 49°00'00" S, 110°56'51.8"E, and 9144000-9160000 mU. The total area is approximately 32,590.49 ha, with 108.282 km circumference and the total population in 2015 was approximately 675,900. Morphologically, Samin Sub watershed can be divided into 2 parts for the upstream located in Karanganyar Regency while downstream areas are located in Sukoharjo Regency. The boundaries of the northern area are Mungkung Subwatershed, southern area is Walikan subwatershed, eastern part is Magetan Regency, and the western side is Bengawan Solo river, Surakarta Municipality, and Sukoharjo Regency.

The river length is 410.319 km and seasonal river length is 320.7704875 km, and the drainage density is 1.28 km/km². High drainage densities can reduce peak discharge and surface runoff is rapidly [15]. The outlet of Samin Subwatershed is Bengawan Solo River.

The research was conducted by explorative descriptive. Land use changes were analyzed using Geographic Information System (GIS) by observing Landsat imageries of 1996, 2001, 2006, 2011 and 2016. Land use was classified as rice field, settlement (settlement and industry), forest, garden, grassland, and upland. Land use type analysis on Landsat imagery is done on the basis of hue, color, shape, density, and roughness of the image

Climate data of 20 years (1996-2016) were obtained from Jumantono weather station (7°37’47.1"S, 110°56’51.8"E), including rainfall, air temperature, air relative humidity, and evaporation. Rainfall was observed using ombrometer and the data is collected daily every 7 am. Air temperature is observed manually with a thermometer and the data is recorded every 7 am, 1 pm and 6 pm, respectively, every day. Air relative humidity is observed using psychrometer dry and wet bulb, and the data is recorded in a similar way with air temperature. Evaporation is measured from class A pan evaporation, and the data is recorded every morning at 7 am. Statistical analysis was employed to find the correlation between LUCC and the climate parameters.
3. **Results and discussion**

3.1. **Results**
The land use changes analyses are presented in Figure 1 and Figure 2.

![Figure 1](image1)

**Figure 1.** Land use change distribution during 1996-2001 (a), 2001-2006 (b), 2006-2010 (c), and 2010-2016 (d).
Figure 2. Land Use Changes in Percentage

Figure 1 and 2 show that during 20 years (1996-2016) land conversion occurred. Figure 2 presents rice field decreased from 79.33% (25,854.15 ha) to 69.20% (22,552.83 ha). This means there has been a decrease of 3,301.32 ha (10%) of rice field with the mean annual decrease is 165.05 hectares/year. Rice field may have changed to non-agricultural functions i.e. settlement as it increased 221.46% over the period or approximately 253.87 ha per year. Figure 2 also shows that forest reduced 8.98% (2,926.74 ha) in 1996 to 4.94% (1,610.28 ha) in 2016, which means that 1,316 ha forest lost during 20 years or 65.8 ha per year. Grassland, plantation and dry land were changed over periods (fluctuating).

Annual rainfall, annual average air temperature, annual average relative air humidity, and annual average evaporation from pan during 20 years (1996 – 2016) are presented in Figure 3, 4, 5 and 6, respectively.

Figure 3 shows fluctuating rainfall for 20 years with increasing trend. The lowest annual rainfall was in 2007 (1,523 mm) and the highest is in 2016 (2,825 mm), with coefficient of determination ($R^2$)=0.1457.
Figure 4. Annual average air temperature 1996-2016

Figure 4 presents the average air temperature of Samin Sub watershed from 1996 to 2016, which are fluctuating. The lowest and the highest annual average air temperature is in 2005 (26.6°C) and 2007 (27.8°C), respectively. It is also shown an increasing trend of annual average air temperature with $R^2=0.1334$.

Figure 5. Annual average daily air relative humidity 1996-2016

Figure 5 figures out the annual average daily air relative humidity, which fluctuated over periods. The lowest and the highest average air relative humidity within 20 years period is 73.8% (1997) and 84.1% (2016), respectively. There is no trend shown in Figure 5, with very low $R^2$, which approached 0.

The annual average daily evaporation from evaporation pan shown in Figure 6 fluctuates with the lowest was in is 3.69 mm (2000) and the highest was 4.8 mm (2008). The evaporation performs a slightly increasing trend with $R^2=0.3533$. 
3.2. Discussion

Spearman’s correlation analysis resulted in non-significant correlations between land use changes and rainfall (P>0.05), that is probably because rainfall is a global hydrological cycle which covers a wide area. Thus the rainfall in the study site may be more influenced by the global rainfall process mainly Asian monsoonal system, which follows the global wind direction according to solar position. The land use change at research site maybe not that severe which directly impact the rainfall.

Correlation analyses obtained a significant correlation between forest-land use change with climate parameters significantly influenced the air temperature (P=0.044) with a negative correlation coefficient (r = -0.912). The regression analysis is presented in Figure 7.

Figure 7 shows that land use change of forest area negatively correlates with air temperature. That means the reduction of forest area lead to air temperature increase, with a coefficient of determination (R^2) 0.765. The reduction of forest area means decreasing leaf area index (LAI) which will promote air temperature increase [16].

Spearman’s analysis also resulted in a significant correlation between plantation-land use change with air temperature (P=0.05), also with a negative correlation coefficient (r = -0.9). The regression analysis is shown in Figure 8.
Figure 8. Linear regression of plantation – land use change vs. air temperature

It is shown in Figure 8 that similar to that of forest area change influenced on air temperature, the depletion of plantation area also consequently result in the decrease of air temperature with $R^2 = 0.9055$. The mechanism is explained by Gardiner and Miller [17], that plants need at least 17 elements for metabolism system and the elements supplied from the air are hydrogen, carbon, and oxygen for photosynthesis. Light energy split off hydrogen becomes water molecules that were delivered to the leaf through the root and stem. Hydrogen is combined with carbon and oxygen from CO$_2$ molecules which are diffused into leaf through stomata. This process resulting in lower air temperature under canopy than surroundings. The other 14 essential elements are provided to plant directly from the soil. Plant tissue transports and absorbs water, mineral, and nutrient dissolved in water from the soil through the root.

Therefore, the conversion of forest and plantation indicated by plants removal will drive high solar radiation exposure on the land surface, low infiltration, high runoff, and very low oxygen supply from the plants. The circumstance leads to heat increase in the surrounding environment. A similar mechanism occurs in urban development which changes the landscape structures and thus resulting in a higher temperature at surroundings environment.

Figure 9. Driving factors of land use change to climate change
Figure 9 illustrates when the plants are cut or removed, the leaf of area index (LAI), or also called as canopy removal will consequently effects the evaporation of air particles near the land surface, and thus promote the heat to increase air temperature [16][17][18]. Therefore, forest and plantation conservation is required to prevent higher temperature rise, as well as to minimize the impact of climate change at Samin subwatershed.

Land use changes did not influence air relative humidity (P>0.05) due to humidity is more affected by rainfall than other climatic factors. Rainfall influences surroundings humidity, and thus humidity has no correlation with land use change as a result of global precipitation pattern. However, dryland correlates with evaporation (P=0.039) with positive correlation coefficient (r = 0.921). This means that the increase of dry land resulting in high evaporation.

4. Conclusion
Land use conversion from forest and plantation to other usages increased air temperature at surroundings environment of Samin subwatershed. Forest and plantation conservation is required to prevent higher temperature rise, as well as to minimize the impact of climate change at Samin subwatershed.

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