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Forest clearing, water loss, and land surface heating as development costs

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Abstract: This paper documents the effects of development in Kenya and its subsequent influence on surface temperatures. The assumption is that deforestation leads to a decrease in evapotranspiration, and causes an observed temperature increase. The study was realised in the Mau Forest of Central Kenya, where extensive deforestation over the past 20 years has caused changes in climate and hydrology. The analyses are based on processing of Landsat satellite images. Field observations during the 'dry' rainy season in October 2008, and testimonies of local people and scientists, confirm the decline of precipitation, low water level in lakes and discharge of rivers.

Keywords: deforestation; surface radiation temperatures; climate change; Landsat satellite; remote sensing; Mau forest; desertification.

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1 Introduction

1.1 Role of the biosphere in temperature control

For billions of years, the biosphere has reacted to climate changes and has been involved in gradual atmospheric composition changes. Living systems play a key role in solar energy dissipation and reduction of the Earth's radiation/temperature gradients. According to the theory of dissipative structures and self-organisation (Capra, 1996), dissipation is a transformation of solar radiation energy into other forms of energy. Dissipation is the process of energy use and distribution in living systems (Prigogine and Glansdorff, 1971; Nicolis and Prigogine, 1977). The dissipation process takes place at many levels – from intercellular (microscale), individual organisms, ecosystems, landscapes (mesoscale), up to global level (macroscale). At the level of landscape, major energy processes take place when solar energy is dissipated, in particular, on the surface of the landscape. Solar energy dissipation is thus closely linked with landscape cover, ecosystem structure and diversity, ecosystem succession age, possible existence of stress factors and, above all, water availability and content in the ecosystem (Olejnik et al., 2002; Foley et al., 2005; Pielke, 2005). Vegetation is an important thermoregulatory factor that influences not only the temperature of the Earth's surface, but also the Earth's entire climatic system. It participates in the distribution of solar radiation, thus influencing energy and water fluxes. Therefore, plants should be considered an active part of the hydrological and climatic cycle that facilitates the exchange of energy between the land surface and atmosphere through water vapour exchange.

The most powerful and dynamic flux is evapotranspiration whereby water changes from liquid to gaseous state and the latent heat of vaporisation is consumed. Evapotranspiration means the transpiration of water from plants and the evaporation of water from ground surface to the atmosphere (Ryszkowski and Kedziora, 2008). The maximum amount of evapotranspiration is determined by temperature and air humidity: warm air holds more water vapour than cool air. When air cools, condensation occurs and water returns to the landscape in the form of precipitation. In periods with no frontal precipitation transmission, this small water cycle provides sufficient precipitation supply and, at the same time, cools the land surface. During the evaporation process, energy is used up in transforming water into vapour, the latent heat of vaporisation is consumed (to ensure kinetic movement of water vapour molecules), and the active land surface thus cools down. Latent heat is released when water vapour condenses in cold places. This reduces temperature differences. Where evaporating structures such as forests occupy large areas of the landscape, the evaporated water condenses above them again, and water is thus kept in a closed cycle. If there is a lack of water, evaporation does not occur and solar radiation is transformed into sensible heat and the Earth's surface warms up, resulting in turbulent heat fluxes. Warm air holds large amounts of water, and so water disappears from the landscape (Pokorný and Rejšková, 2008). Rain forests are the best evidence of the existence of small water cycle mechanism, but the small water cycle that influences and often determines local climate is not well understood by scientists. Its closer investigation is crucial to the restoration of functional landscapes and to the climate stability that depends on this integration.

Landscape temperature is one of the key characteristics behind a number of biophysical and ecological processes determining the balance between water circulation and landscape energy balance. Temperature has both direct and indirect impacts on the water cycle (Melesse, 2004; Makarieva et al., 2006) and on the climate (wind flow, air moisture). Losses of functional vegetation over large areas may impact on the hydrological cycle and movement of air masses. Temperature is an important factor in assessing the physiological activity and health of ecosystems (Wagendorp et al., 2006). It also influences the movement of matter within a landscape (Ripl, 1995, 2003). Landscape surface temperature is a functional indicator expressing the ability of a system to dissipate solar energy. In other words, it is an indicator of how efficient the dissipation of net radiation is, which means that it is the result of flux distribution among sensible heat, latent heat and ground heat flux. Temperature changes are caused by changes in radiation fluxes and energy balance. Ripl (1995, 2003) has suggested a method for assessing the ecological functions and efficiency of landscape based on temperature distribution, i.e., the dissipation of solar energy, and on matter loss flowing away with water, the degree of recycling. The proportion and properties of incident and reflected solar radiation are a result of the interaction of solar fluxes with the active land surface. On the basis of this interaction, it is possible to define 'exergy' or the amount of internal work in an ecosystem as a change in radiation. In other words, exergy measures the amount of energy capable of being transformed into nature's work and the 'quality' of energy supplied.

Exergy maximisation and dissipation are considered the main functions of ecosystems (Jørgensen and Mejer, 1979; Ripl, 2003). According to Schneider and Kay (1994), the more complex an ecosystem structure is, the more efficient it will be in dissipating energy. If we compare two systems, which receive the same amount of radiation, have the same soil properties and water balance, but differ in structure, the more complex system will radiate more energy with a low exergy level, i.e., its temperature will be lower (Kutsch et al., 2001).

This explains why large forest complexes play a specific role in the energy and water exchange and distribution cycle. However, scientific opinions on the role of forests in the hydrological and climatic cycle differ.

Surface temperature is often understood to be related to surface reflectance (Betts and Ball, 1997), but this approach reduces forests to a physical surface. According to this assumption, having a low reflectance, forests absorb the majority of solar radiation, which results in temperature growth (Bala et al., 2007; Matthews et al., 2003, 2004; Meissner et al., 2003; Gallimore et al., 2005). Bonan (2008) reports that tropical forest mitigate warming through evaporative cooling, but he adds that the low reflectance of boreal forests is a positive climate forcing (warming the global climate). However, forests are living organisms, with continual biological processing, so despite low reflectance (and relatively high absorption of solar radiation), most forests are characterised by low temperature. This is a result of their ability to transform energy efficiently – and it stands as a refutation of researchers who reduce forests to a mere physical surface.

1.2 Thermal remote sensing

Temperature analysis can serve as a comprehensive tool to assess the functioning of an ecosystem (Holbo and Luvall, 1989; Van de Griend and Owe, 1993). To determine how solar energy is dissipated in large areas, multispectral satellite data can be used, especially data from the thermal part (3–5 µm and 8–14 µm) of the electromagnetic spectrum (Schmugge et al., 1998; Gillespie et al., 1998; Peres and DaCamara, 2004; Dash et al., 2002; Norman et al., 1995). As individual sensors have different spatial resolution, different algorithms have been developed (mono window, split-window, multi-angle) to obtain surface temperature (Sobrino et al., 2004; Wan and Dozier, 1996; Qin and Karnieli, 2001).

The Landsat TM and ETM+ satellite images, which have been available since the 1980s and 1990s, respectively, constitute one of the most important satellite systems for observing the Earth's surface on a systematic, repetitive basis. The satellite scans the Earth's surface in seven/nine spectral bands, with a spatial resolution of 15/30/60/120 m. In addition to the study of landscape cover, the images can be used to evaluate landscape temperature (Jimenéz-Munos and Sobrino, 2003; Thome et al., 1997; Chander and Markham, 2003). The distribution of surface temperature can be observed by the thermal infrared sensor (TM6/ETM+ 6) that scans the radiation in wavelengths 10.4–12.5 µm. This temperature is actually recoded thermal radiation of the Earth's surface. The wavelengths identify the emitted radiation of objects within reflected solar radiation. The objects radiate energy as a function of their temperature. This emitted energy is an external manifestation of an object's energy state and that is remotely sensed using thermal scanners and satellite sensors. The emitted energy is used to determine the radiation temperature of the surface and there is a relationship between kinetic (real) and radiation temperature (see basic laws of thermodynamics – Wien's displacement law, Stefan-Boltzmann's law and Kirkhof's law).

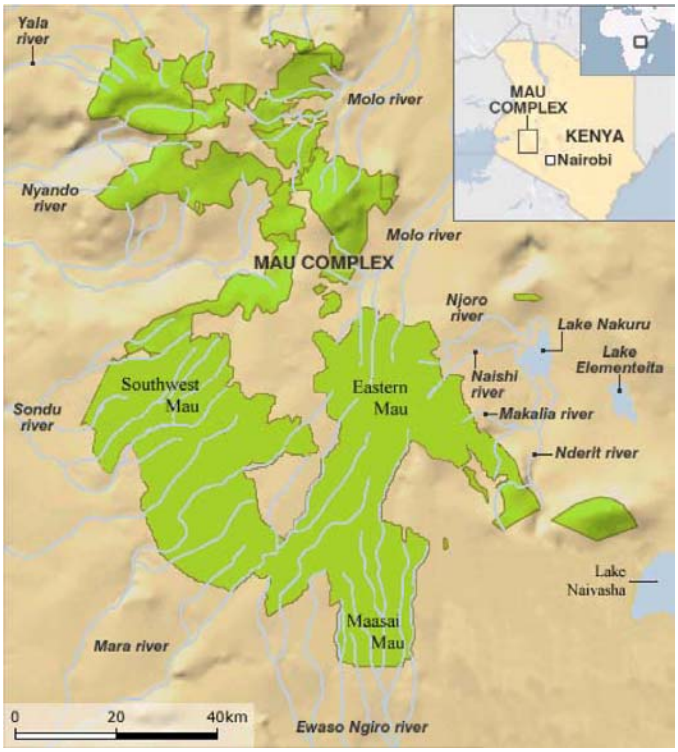
1.3 Mau Forest in Central Kenya

East African deforestation reached its peak with the push to economic development of the second half of the 20th century. Today, at the beginning of the 21st century, the original tropical forests occupy less than 3% of the area of Kenya. The equatorial belt of contiguous forest left in Kenya consists of five fragments in the regions of Mt. Kenya, Aberdare, Mt. Elgon, Cherangani Hills and the largest stand Mau Forest.

The Mau Forest complex (Figure 1) extends about 150 km northwest of Nairobi. It covers the western slopes of the Mau Escarpment in the Gregory Rift Valley, at altitudes of 1200–2600 m. The Mau Forest complex consists of six main parts: Eastern, Western and South-Western Mau, Trans Mara, Ol Pusimor and Maasai Mau. The Mau Forest is located on fertile volcanic soils, with plenty of rainfall. Annual totals vary from 1000 mm on the eastern slopes, with the seasonal operation, up to more than 2000 mm on the west. The Mau Forest is the source area of rivers feeding the Great Rift Valley lakes (Lake Natron, Turkana, Victoria, Nakuru, Naivasha, Ementaita and Baringo).

It is estimated that more than 10 million people depend directly on the hydrological system of the Mau Forest. The whole area has been gradually deforested, inhabited and agriculturally used; the density of population rises to about 500 inhabitant/km^2. The remaining original forest has kept height zoning character. At an altitude of about 2300 m, sklerophyllous mountain forest prevails, and at lower altitudes grows tall-trunk formation (*Aningeria Adolf-friedericii* and *Strombosia Scheffler*), which gradually merges into bamboo (*Arundinaria alpina*) and grassland. In places where the forest has been excised, pioneer tree species such as *Tabernaemontana stapfiana*, *Syzygium guineense* and *Neoboutonia macrocalyx*, *Olea capensis*, *Albizia gummifera* or *Podocarpus latifolius* appear. The cause of the Mau Forest has come to the fore as a result of 'development induced' illegal deforestation, impacting not only on natural processes, but also on humanitarian concerns – political, economic and social (Amnesty International, 2007; Waki Report, 2008).

Figure 1 The map of the area of interest



Source: Adapted according to: http://news.bbc.co.uk/2/hi/8057316.stm

2 Data and methods

Landsat satellite data available from the 1980s enable long-term qualitative and quantitative monitoring of land cover, including the assessment of surface temperature. Thick clouds over tropical rain forests often make it impossible to assess the multispectral images. However, the regular occurrence of dense cloud above forest complexes indicates good climatic function of the forests.

The main region of research interest was delineated as a subset of two adjacent Landsat scenes 124 km × 125 km (15,500 km^2). According to availability, cloudlessness, as well as same seasonality, selected scenes were acquisitioned on 28 January 1986 (Landsat 5), 27 January 2000 and 21 December 2009 (both Landsat 7). The selection across decades allows a large time horizon. The dates correspond to the end of the dry season. To interpret the temperature properly, it is advisable to know the time of image acquisition. For Landsat 5, scene centre scan time is 7:30 GMT (10:30 local time), Landsat 7 passes over the same areas ten minutes later. Supervised classification (algorithm maximum likelihood) was used to discriminate dense and humid forest in all three scenes. The classifier considers both variances and covariances of the class signatures. The assumption is a Gaussian distribution of a training class, and classes are characterised by the mean vector and the covariance matrix. Each pixel in the image is valued by statistical probability to determine the membership of the pixels in the class. Each pixel is assigned to the class for which it has the highest probability of being a member. The maximum likelihood classifier is considered to give relatively accurate results.

Dense forest, as detected in 1986, was created by a step-by-step classification. The class was divided into four sub-categories. A maximum likelihood algorithm was used, threshold value 10%, channels used TM 6-4-5-2. The same procedure was applied to the scenes from both 2000 and 2009. Since the Scan Line Corrector anomaly, the scene from the year 2009 appears as narrow diagonal stripes with no data.

Surface radiation temperatures were calculated from the thermal radiance values of Landsat thermal infrared channel using the expression (equation (1))

$$T = \frac{K_2}{\ln\left(\frac{\varepsilon K_1}{L_\lambda} + 1\right)}$$

where T is the land surface temperature (K), ε is the surface emissivity introduced by Sobrino et al. (2005), K_1 and K_2 are calibration constants for Landsat, L_λ is the spectral radiance at channel 6 in W/(m^2 sr µm), calculated as equation (2)

$$L_\lambda = \left(\frac{LMAX_\lambda - LMIN_\lambda}{Q_{\max}}\right) + Q + LMIN_\lambda$$

where $LMAX_\lambda$ and $LMIN_\lambda$ are maximum and minimum spectral radiance, respectively, in W/(m^2 sr µm) that is scaled to $Q_{\max/\min}$, and Q is the quantified calibrated pixel value in DN_s.

Because the data were acquired at slightly different times (seasonality, different years), the scenes and calculated values of temperature may vary significantly. The values cannot be compared directly or implemented in other syntheses without normalisation. One of the methods used is scaled land surface temperature (Melesse, 2004) that is given as equation (3)

$$T_i = \frac{T_i - T_{\min}}{T_{\max} - T_{\min}}$$

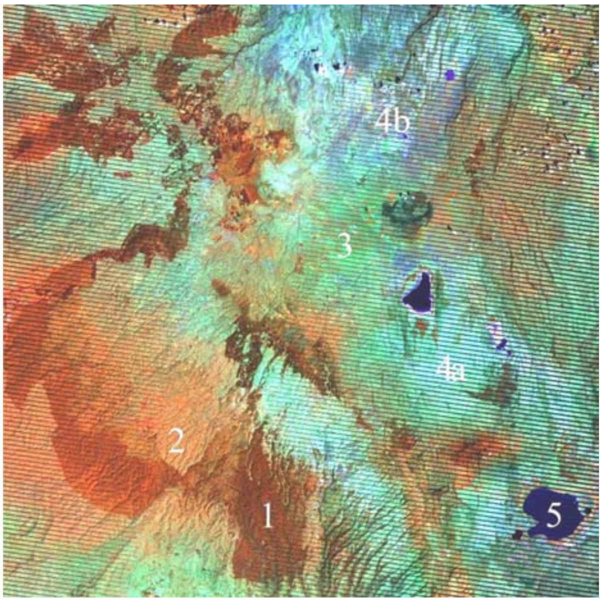
where T_i is the land surface temperature of pixel i, $T_{\min/\max}$ are the lowest and the highest temperatures in the image.

The comparison and change detection of two or more images has to accomplish the condition of the pixel coincidence and value compatibility, realised by different calibration procedures. To detect changes in deforestation between the years 1986 and 2009, a two-channel-colour composition was used. The difference of standardised temperature images displays time changes between assessed terms.

3 Results and satellite image interpretation

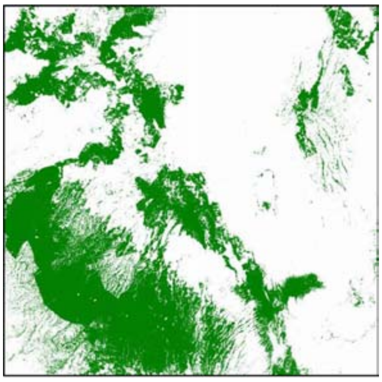
The information provided in Figure 2 shows main land cover types in the selected area. Having involved red visible, near and mid-infrared parts of electromagnetic spectra into RGB colour synthesis of the Landsat ETM+ channels 4-5-3, data on land cover and its wetness characteristics have been encompassed. The Mau Forest complex is displayed in reddish brown, lakes as black, dark or navy blue. Green tones indicate pastures or grassland with dry vegetation, cyan represents mostly dry, bare ground.

Figure 2 The extent of the forest in December 2009 can well detect the synthesis of the spectral channels of Landsat ETM+. The image is displayed in a false colour composition, since it contains mainly the near and mid-infrared spectrum, which are invisible for the human eye. Therefore, colours may not match the reality. Colour image interpretation is as follows: 1 – dense, humid forest, 2 – Forest area converted to farmland with the remnants of forest, or plantations; 3 – dry non-forest vegetation, 4a, b – bare surfaces and 5 – lakes (water)

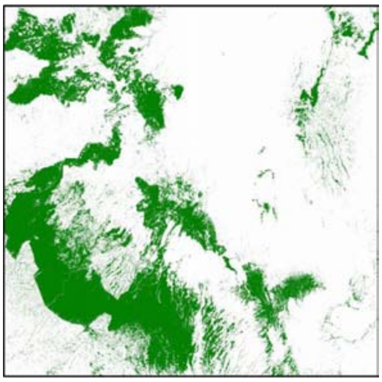


The satellite image classification shows the extent of Mau Forest complex in the years 1986 (Figure 3(a)), 2000 (Figure 3(b)) and 2009 (Figure 3(c)). Visual comparison of these images enables evaluation of changes over the 23-year period. The most affected regions are the Eastern, Southwest and Maasai Mau complexes. In 1986, the forest total area in the image detected was 5200 km^2. In 2000, forests covered a little less than 4000 km^2, and in 2009 it was only 3400 km^2. This means that in 23 years, the total area of forest decreased by 1800 km^2.

Figure 3 (a)–(c) Extent of the Mau forest in the years 1986 (a), 2000 (b) and 2009 (c). The central part (Eastern Mau) and the eastern part of Maasai Mau are the areas, most affected by deforestation



(a)

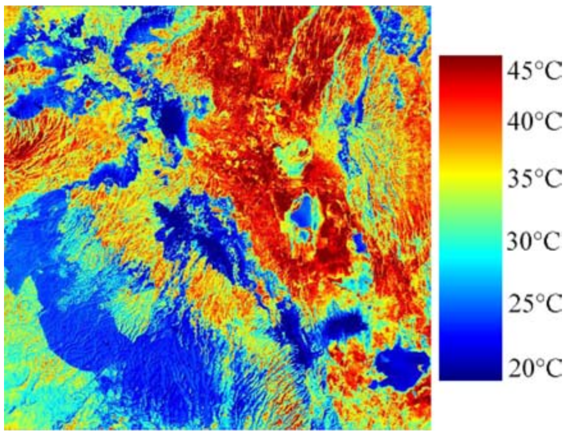


(b)

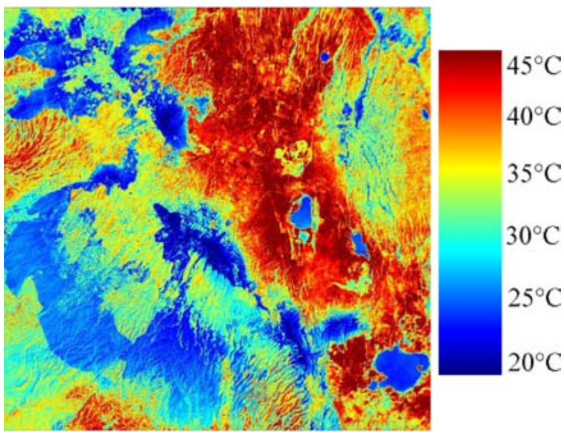
(c)

There are some areas where an opposite trend of afforestation was detected. This relates mainly to regions in the north of the Southwestern Mau. Considering the homogeneous texture and shape of these plots, one may assume the existence of plantation forests. The land surface temperature in degrees of Celsius is shown in Figure 4(a)–(c). It is evident that the temperature distribution is affected by land cover. The sharp temperature contrast between forested and non-forested areas is distinctive in all three processed images. Whereas the lowest temperature categories are bounded to dense and humid forests, or to the Rift Valley lakes, ranging approximately between 20°C and 28°C, the highest temperature values are reached on bare ground. The surface temperature of those areas in the Rift Valley usually exceeds 40°C, in extreme cases 50°C. Depending on the amount of green biomass of non-forest vegetation, the temperature ranges from 32°C to 40°C. Even with a distance of 10 km, the temperature variation between two regions may be as large as 30°C.

Figure 4 (a)–(c) Shows the land surface temperature distribution in the years 1986 (a), 2000 (b) and 2009 (c). The comparison with Figure 3(a)–(c) confirms the forest belong to the coldest areas within the landscape. The temperature differences may reach even 30°C at very short distances

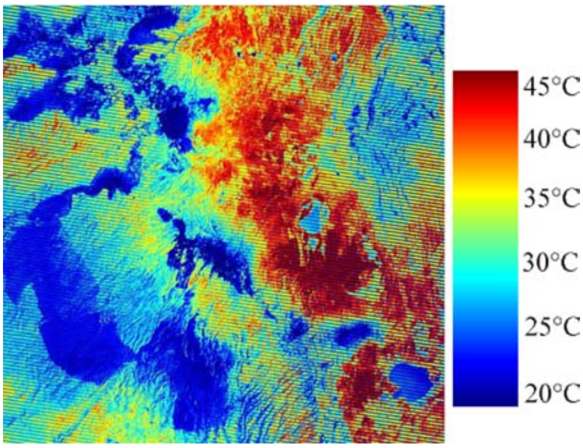


(a)



(b)

Figure 4 (a)–(c) The land surface temperature distribution in the years 1986 (a), 2000 (b) and 2009 (c). The comparison with Figure 3(a)–(c) confirms the forest belong to the coldest areas within the landscape. The temperature differences may reach even 30°C at very short distances (continued)



(c)

The visual time change analyses of ongoing deforestation, disappearance and thinning of vegetation, show temperature increases. Temperature increase can be observed in areas with sparse tree cover where indigenous dense forest has been cleared. If the surface is cleared of well-watered vegetation, this has an effect of rapid temperature increase. This finding confirms the detrimental effect of excising large forest blocks mainly in the region of the Eastern Mau, or in the Maasai Mau. To support this statement, further analyses of deforestation and temperature time changes were done.

Figure 5 shows the deforestation changes of tropical forests as a bi-temporal synthesis of the years 1986 and 2009 in R-G (red–green) colour system. Both results of multispectral classification are integrated into one image, where red indicates the presence of forest only in the year 1986, light green shows the forest detected only in 2009 and dark green displays the presence of forest in both terms. To express the temperature change, it is necessary to use standardised temperature images. Figure 6 is the result of image differencing of the two scaled land surface temperature images from the years 1986 and 2009, representing the increase/decrease in surface temperature within the 23-year time horizon. Places retaining a constant temperature are shown as cyan; the yellow – dark red part of the colour scale grades the positive temperature shift; on the contrary bluish hues indicate temperature decrease, depending on colour saturation. The higher the saturation, the higher the temperatures change. As is apparent from these two images (Figures 5 and 6), the most significant rise of temperature is linked to deforested areas. Temperature change at these plots may be up to 15°C as seen from Figure 4(a)–(c). A significant rise of temperature was observed in the areas of the south Eastern Mau, and the Maasai Mau, especially; these are the areas affected by clear-cuts. In addition to those areas affected by forest excision, higher temperatures are also measured in the entire region between the Great Rift Valley lakes Nakuru and Naivasha.

Figure 5 Changes of the extent of the Mau forest between the years 1986 and 2009. From the original area of 5200 km^2 (in 1986), only 3400 km^2 remained (in 2009)

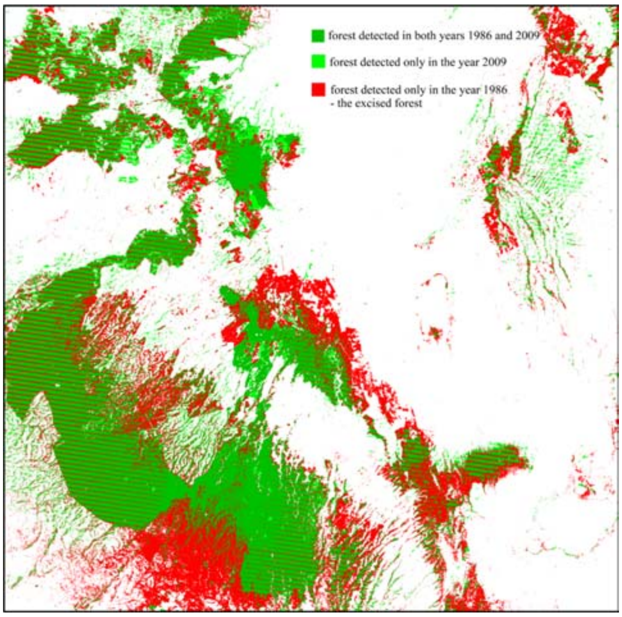
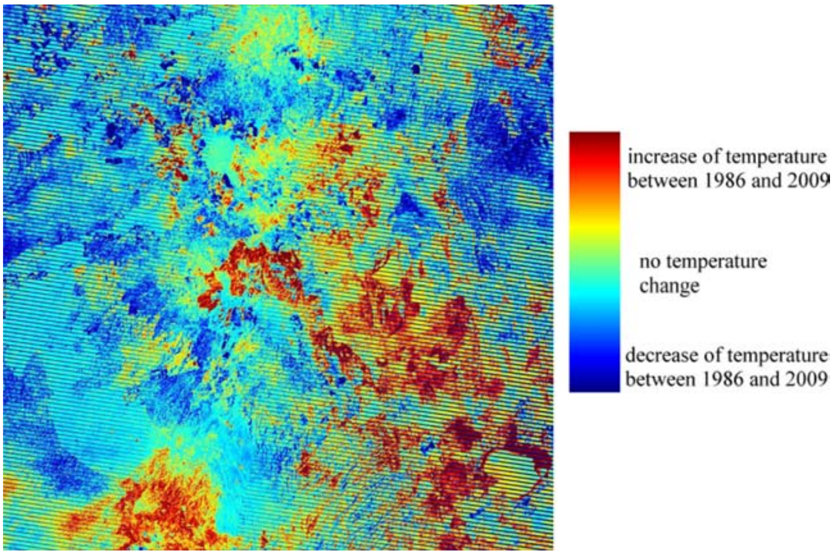


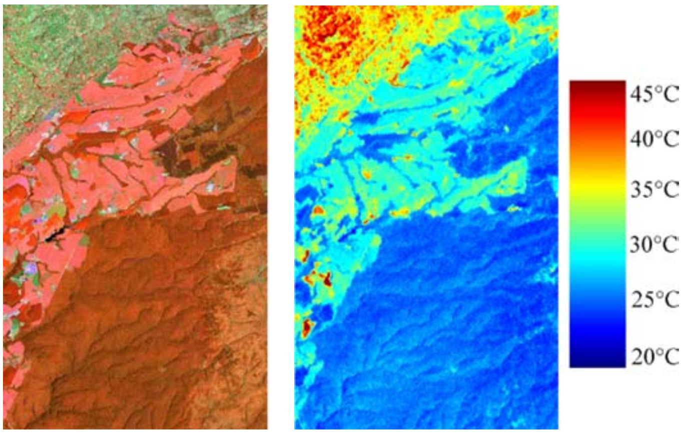
Figure 6 Changes of temperature between the years 1986 and 2009, gained as image difference of the standardised temperature. It is evident; the extreme rise of temperature (by more than 20°C) is bounded with the areas of deforestation. Its consequences are also evident in the Rift Valley region, between the great Lakes Nakuru and Naivasha. Some areas having been converted into fast-growing plantation forest show the opposite trend



Vegetation is generally regarded as a factor that reduces surface temperature. Figure 7 shows the temperature distribution of different vegetation types in the detail of Kericho region (19 km × 12 km) in the year 2000, where tea plantations, typical farmland

and rain forest are represented. Although, in comparison with forest, tea plantations on the satellite images are characterised by a higher proportion of green biomass (the brighter the hues of red in Figure 7 that is RGB colour synthesis of Landsat channels 4-5-3, the higher the amount of green biomass), their surface temperature is at least higher by 10°C. It is evident that the mosaic of different crops and farmland is presented by temperatures 30–45°C, and forest by the range 22–25°C.

Figure 7 (Left) RGB colour synthesis of Landsat ETM+ channels 4-5-3 displaying different land cover types in the Kericho region (west edge of the image) in the year 2000. The scene size is 19 × 12 km. Bright and homogeneous red colour, caused by very high chlorophyll content, is typical of the tea plantations; dark and light brown (caused by different illumination of the terrain) indicates rain forest; the patch of green display a farmland. (Right) Temperature differences between the three different vegetation types in the same region. Despite having the highest amount of chlorophyll (being the greenest), the temperature of tea plantations ranges between 30°C and 35°C that is more than in case of forest. The highest temperature is characteristic for the crops (35–45°C), depending on the crop cover, type, wetness, and other factors. This fact shows that the surface temperature depends on the type of land cover and confirms forests as the coldest landscape segments



4 Discussion

Land cover type and its changes, mainly of forest cover, significantly influence thermal characteristics of the landscape (Procházka et al., 2006). Despite having a low spectral reflectance (Bala et al., 2007; Bonan, 2008), it is evident that forests are characterised by the lowest temperature values within the landscape. Clearing of well-watered vegetation, which undoubtedly the rain forests are, results in a rapid temperature increase due to dewatering and consequent decrease in evapotranspiration. As a result, incident solar radiation is converted mainly into sensible heat, whereas only a small part of incident radiation converts to surface cooling latent heat (Pokorný and Rejšková, 2008). Thus, the temperature changes in the landscape, as analysed from thermal satellite images, can be regarded as consequences of changes in radiation balance.

The role of forests in the hydrological cycle is explained by Bruijnzeel (2004, 2005), Bradshaw et al. (2007), Diáz et al. (2007) and Farley et al. (2005). Within this context, Makarieva and Gorshkov (2007, 2008) introduce the principle of ‘biotic pump’.

These authors study the distribution of continental precipitation from the ocean, showing that in a deforested or semi-arid landscape, precipitation becomes scarcer towards the inland. By contrast, over a forested landscape the amount of precipitation remains constant or even increases inland (Makarieva et al., 2009). They describe two principles for how forests maintain water in a closed cycle:

- during the day temperature, inversion takes place in forests, which prevents the flow of air and water vapour into treetops
- during the night treetops, which are relatively cold compared with their environs, cool down even more, water vapour condenses, air pressure falls, and surrounding air, which contains water vapour, flows towards the forest.

As air pressure decreases – the biotic pump 'sucks in' air mixed with water from the surrounding area towards the forest. The biotic pump concept receives a mixed reception from scientists. According to Meesters et al. (2009), the theory rests on an incorrect interpretation of basic physical principles operating in the free atmosphere. On the other hand, Sheil and Murdiyarso (2009) support the biotic pump theory as a revolutionary contribution, with the potential to turn modern meteorology on its head.

Air saturated with water at temperature 25°C contains approximately 22 g of water vapour per m^3, while air at 40°C has a doubled holding capacity (50 g/m^3). Deforestation and consequent rise of temperature leads to a transport of warm and relatively dry air into the upper atmosphere. By comparison with cold air, warm air brings higher amounts of water and energy into the upper atmosphere, which results in intense rainfall. The deforested or agricultural landscape is considerably warmer than the forested one. The explanation may consist in either the lack of water caused by rapid runoff or by the transport of water vapour in overheated air out of the short water cycle. A decrease in evapotranspiration of about 2 mm per 1 km^2 per day is equal to the decrease in evaporation of 2 million litres. The latent heat of vaporisation of 2 million litres of water is approximately 1.4 million kWh. Considering a decrease in evapotranspiration by 2 mm per day per 1 km^2, this will result in the release of 1.4 million kWh of sensible heat in a day. If solar energy is not bound into the latent heat of vaporising water, it is released as sensible or felt heat.

The Mau Forest complex has lost 1800 km^2 of vegetation in 23 years. This means 2.6 billion kWh of sensible heat released from this area per day. This is nearly two times more than monthly production of the Czech nuclear power plant at Temelin (2000 MW) in January 2010. Most studies and scientific papers, especially those referred to by the IPCC (2007), focus on the role of greenhouse gases in climate change (Matthews et al., 2009; Bala et al., 2007). This approach reduces the climatic relevance of forests to that of a carbon sink and a physical surface of low reflectance. In a review of research on how land cover affects temperature, Denman et al. (2007) present conclusions based on modelling the coupling of vegetation, moisture, precipitation and surface temperature. One such study claims that:

> "Shorter vegetation with more leaves has the most latent heat flux and the least sensible flux. Replacement of forests with shorter vegetation together with the normally assumed higher albedo could then cool the surface. However, if the replacement vegetation has much less foliage or cannot access soil water as successfully, a warming may occur. Thus, deforestation can modify surface temperatures by up to several degrees Celsius in either direction depending on what type of vegetation replaces the forest and the climate regime."

This conclusion neglects the fact that, due to evapotranspiration and temperature inversion (Makarieva et al., 2006), a functional forest is one of the coldest ecosystems in the landscape, one that plays an important role in the water cycle, and thus in solar energy dissipation.

The hydrological, landscape and climate changes observable in Africa today have been taking place for several decades and their effects have been felt by one generation of people. The pace at which these changes are happening is several times faster than when European forests were colonised in the Middle Ages. This is why the region represents an invaluable area for modelling and documenting the roles of vegetation and water as determinants of regional climate. Likewise, Africa is a laboratory for assessing the effects of restoration on the hydrological cycle and landscape.

The experience of East Africa seems to accord with the biotic pump theory introduced by Makarieva et al. (2006), although, from a continuous belt of mountain rainforests in Kenya, only small fragments are left. Africans understand that deforestation leads to water loss and poor water quality (Mathooko, 2001; Raini, 2009; Shivoga et al., 2007). They aptly call the remaining forest complexes ‘water towers’ – these being the source areas for big rivers. Deforestation, taking place on thousands of square kilometres, and conversion into farmland result in decreases in precipitation, loss of river water and critical water shortages in the lower parts of river basins. Field research in the ‘dry’ rainy season of October 2008 has affirmed a serious situation in the region. Researchers from the Egerton University have confirmed extensive changes to local climate and hydrology in the last 10 years and attribute this to deforestation of the Mau Forest complex. These findings also confirm the drying up of the Great Lakes (Hesslerová and Pokorný, 2010). As seen from satellite images in 2009, Lake Elmentaita has almost disappeared. The main tributaries of the lakes show no water, even in the rainy season.

This deforestation has an international dimension, in that an expected hydroelectric power capacity of 60 MW to be provided by a dam completed in 2007 on the Sondu-Miriu River has not eventuated due to the extremely low discharge. The Japanese investor has sued the Kenyan Government for having provided false information about the flow of the river and stopped work on a nearly completed second hydroelectric power station. Kenya’s Prime Minister Odinga said in July 2008 that at least 1000 km^2 of the Mau Forest had been illegally converted into farmland in the last 10 years. He has also confirmed the government’s plan to enclose the existing forest, evict about 200,000 people, and restore forest to return water to the landscape. An earlier wave of forcible displacement involving more than 100,000 people occurred between 2004 and 2006. The extensive changes in Kenya’s hydrology and climate speak of anthropogenic interference with the environment, exacerbated by several decades of European style ‘development’. Changes in the hydrology and local climate patterns of Kenya do not appear to be attributable to the effect of greenhouse gases.

5 Conclusion

The Mau Forest provides an invaluable example of deforestation and its consequences for landscape function through solar energy dissipation. As shown by the analysis of satellite images available from the 1980s, forest excision has induced a rapid rise of surface temperatures. Detailed documentation of the Kericho region shows the dependence of temperature on land cover type – plantation, farmland, or forest. The loss of evapotranspiration, decrease in water discharge and higher temperatures in deforested areas contrast sharply with the positive effect of forests in maintaining the water balance of catchments and corresponding landscape functions. The study affirms the case that human mismanagement of land, water and plants is directly implicated with climate change on a regional scale.

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