Chapter 8

Quantification and Prediction of Land Consumption and Its Climate Effects in the Rhineland Metropolitan Area Based on Multispectral Satellite Data and Land-Use Modelling 1975–2030

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Additional information is available at the end of the chapter

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Abstract

Land use and soil sealing are particularly high in metropolitan regions. They bring about conflicts of use: the demand for housing, business and economy is enormous, but at the same time, quality of life depends on a network of green spaces. With the aid of remote sensing, the change of urban areas can be observed and quantified over time. This study investigates the change dynamics of land cover and land use in North Rhine-Westphalia (NRW) with multispectral satellite data, focussing on imperviousness. Landsat data is used to monitor and analyse half a century of landscape development. In addition, recent trends in land surface temperature (LST) are estimated from MODIS data. Changes to the LST are caused by land cover and land use changes amongst other factors. Accordingly, a link can be shown between the medium-term LST changes and the hotspots of landscape transformation in NRW. Due to global climate change, land consumption is increasingly affecting the densely populated urban areas, which calls for measures to increase their resilience. The results of the study can be used by decision makers to assess the environmental impact of land use, the loss of agricultural land or the resulting effects of climate change.

Keywords: land consumption, land use and land cover change, land use modelling, climate adaptation, land surface temperature trends

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1. Introduction

Anthropogenic climate change is widely accepted as a major challenge to human society. Climate change is a worldwide phenomenon that is also described in detail for Germany [1]. The mitigation of climate change impacts is one strategy to deal with the consequences of a changing climate. Climate change-related events are increased flooding frequency, increased frequency of storm events, heat waves or droughts, amongst other things. Nonetheless, most of the coming consequences of climate change have been caused in the past, fostered by the release of greenhouse gases [2]. Even if climate mitigation strategies do succeed, this will not prevent us from increasing average air temperatures and the hazards mentioned above [2]. The means we are taking today are supposed to limit the expected temperature rise to a certain level, e.g. the two degrees´ goal compared to pre-industrial levels as declared by the United Nations Framework Convention on Climate Change (UNFCCC). In other words, temperatures will increase in the next decades even if the agenda of the UNFCCC is implemented successfully. Therefore, climate mitigation will not be sufficient to prepare the world's inhabitants for future conditions [2].

It is well documented that climate change impacts differ widely in a global perspective [1, 2]. However, even on a regional or local scale, there are pronounced differences. Vegetation in general and forests in particular function as a buffer against warming, for example, whereas artificial surfaces such as urban fabric often have contrasting characteristics and heat up easily. This leads to an increased vulnerability of urban areas against climate change. Many places of the world have experienced dramatic land cover and land use changes over the past decades, usually characterised by the conversion of natural environments into artificial landscapes such as industrial cropland and urban areas. Although some experts argue that land use change has an impact on river runoff [3], it is not yet well understood how climate change relates to land use change. At the same time, many administrative units and urban decision makers have identified the necessity to take action against climate change. Besides climate mitigation programmes, they have started implementing climate adaptation strategies for sustainable urban life. Moreover, urban areas host the majority of people in most parts of the world, hence their particular importance.

In industrial societies, cities often experience money scarcity and need to cooperate with one another on a broader scale to bridge the financial gaps. German metropolitan areas are consortia offering approaches of integrated strategies for regional development. They integrate the strengths of economy, science and the public sector, link urban and rural areas and implement regional projects towards sustainable development. In particular, in conurbations, the need for land leads to conflicts of use since the demand for both housing space and land for economic development is enormous. At the same time, it is important to ensure and improve the livability of the region by providing and sustaining green areas. Rural and urban areas are supposed to complement each other to satisfy all interests. There are, however, big challenges regarding infrastructure planning, energy supply and organisation of our living environment. The demand for recreational sites, housing, traffic and commercial space must be balanced and translated into purposeful planning structures.

In 2002, the federal government of Germany presented a national sustainability strategy, "Perspektiven für Deutschland" ("Outlooks for Germany"), in which they defined the so-called 30-ha goal. Its purpose is to reduce Germany's land consumption to a maximum of 30 ha per day until 2020—meanwhile the time limit has been extended to 2030 [4]. Land consumption is commonly defined as the conversion of agricultural and silvicultural areas into built-up areas [5], where built-up areas include also non-impervious surfaces like parks or golf courses. Land consumption in Germany currently amounts to 66 ha per day [4]. While daily land consumption has decreased over the past years, it was still at 10 ha per day in the German federal state of North Rhine-Westphalia (NRW) in 2011 alone [6]. The motivations for the 30-ha goal are of both qualitative and quantitative natures: soil, the essential component for food production, is a finite resource. Landscape structure is a considerable factor for fauna and flora, which again is significant for the existence of individual species. The consumption of contiguous areas leads to a dissection of associated habitats and has various impacts on several biocenoses. Furthermore, the cultural landscape, grown over centuries, might lose its outstanding characteristics. Considering the ageing society and population decline, an increase of built-up areas also involves growing maintenance costs for supply lines, sewer systems, roads, etc. [7].

Considering this background, we assess land use and land cover change (LULCC) in NRW over the past four decades with a focus on the Rhineland Metropolitan area. We demonstrate the relationship between LULCC and land surface temperature, a parameter linked to climate. Finally, we develop different land use scenarios to offer options for future development.

2. Study site: The Rhineland Metropolitan area

The Rhineland Metropolitan area is located in the western part of NRW (**Figure 1**). It is a federation of 35 districts and cities in the realm of the district governments of Cologne and Duesseldorf. **Figure 1** shows the mean normalised difference vegetation index (NDVI) [8] of NRW, calculated from a series of Landsat-8 OLI summer time images taken between 2014 and 2017. The index is sensitive to vegetation condition and cover. Green tones indicate high vegetation cover; red tones indicate non-vegetated areas. Hence, red areas in **Figure 1** can be interpreted as mainly urban areas. They are concentrated along the Rhine River and in the Ruhr area, a former coal-mining district and industrial hotspot of Central Europe. Other areas characterised by low vegetation cover (red areas) are formed by the Rhenish open pit mining area in the western part of NRW. The central southern part of NRW and its eastern part are characterised by high NDVI values due to high forest cover. North of the Ruhr area, NRW is characterised by agricultural use.

Besides large industrial districts, the Rhineland Metropolitan area is characterised by intensive agriculture supported by fertile soils and favourable climatic conditions. It is one of the most populous areas in Europe with 690 inhabitants per square kilometre. As most parts of the world, NRW is experiencing urbanisation with a population increase in larger agglomerations with strong economies and a population decrease in rural areas. Migration takes place

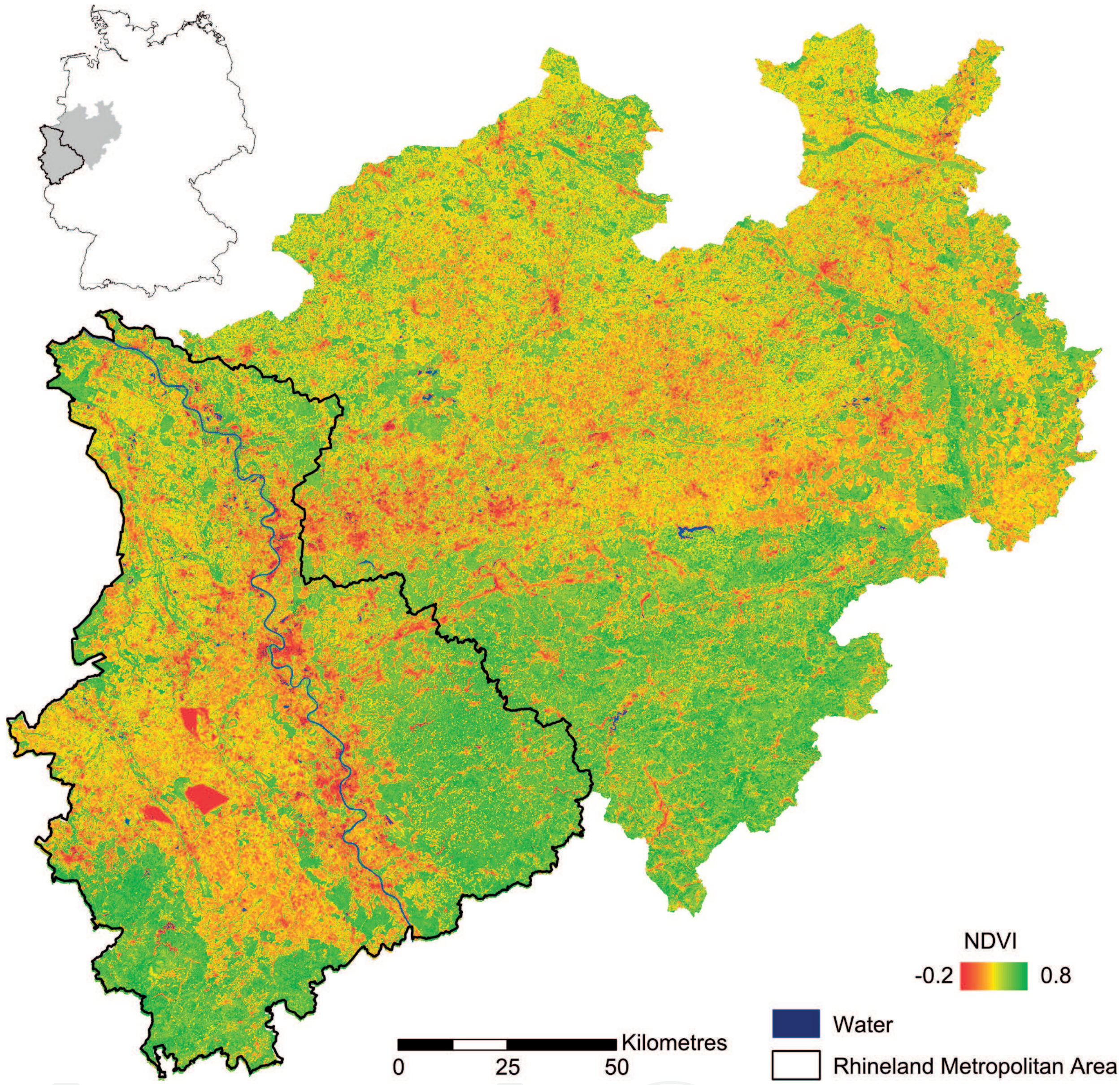

Figure 1. Rhineland Metropolitan area (black outline) in North Rhine-Westphalia (NRW), western Germany. The mean NDVI image shows urban areas and the Rhenish open pit mining area in the western part of NRW in red tones; vegetated areas are depicted in green tones. Yellowish tones can be attributed to agricultural areas.

between rural and urban areas, but there is also migration from outside NRW. **Figure 2** shows the population dynamics in NRW between 2005 and 2015. In larger urban areas such as Bonn, Cologne, Duesseldorf or Muenster, the numbers of inhabitants are increasing, whereas the greater Ruhr area suffers from a loss of population. The Ruhr area is characterised by a huge economic transformation after the breakdown of the coal and steel industry. In this context, the town of Gelsenkirchen exemplifies current population decrease (**Figure 2**) within a generally densely populated urban area. However, declining population numbers pose also a rural challenge in NRW.

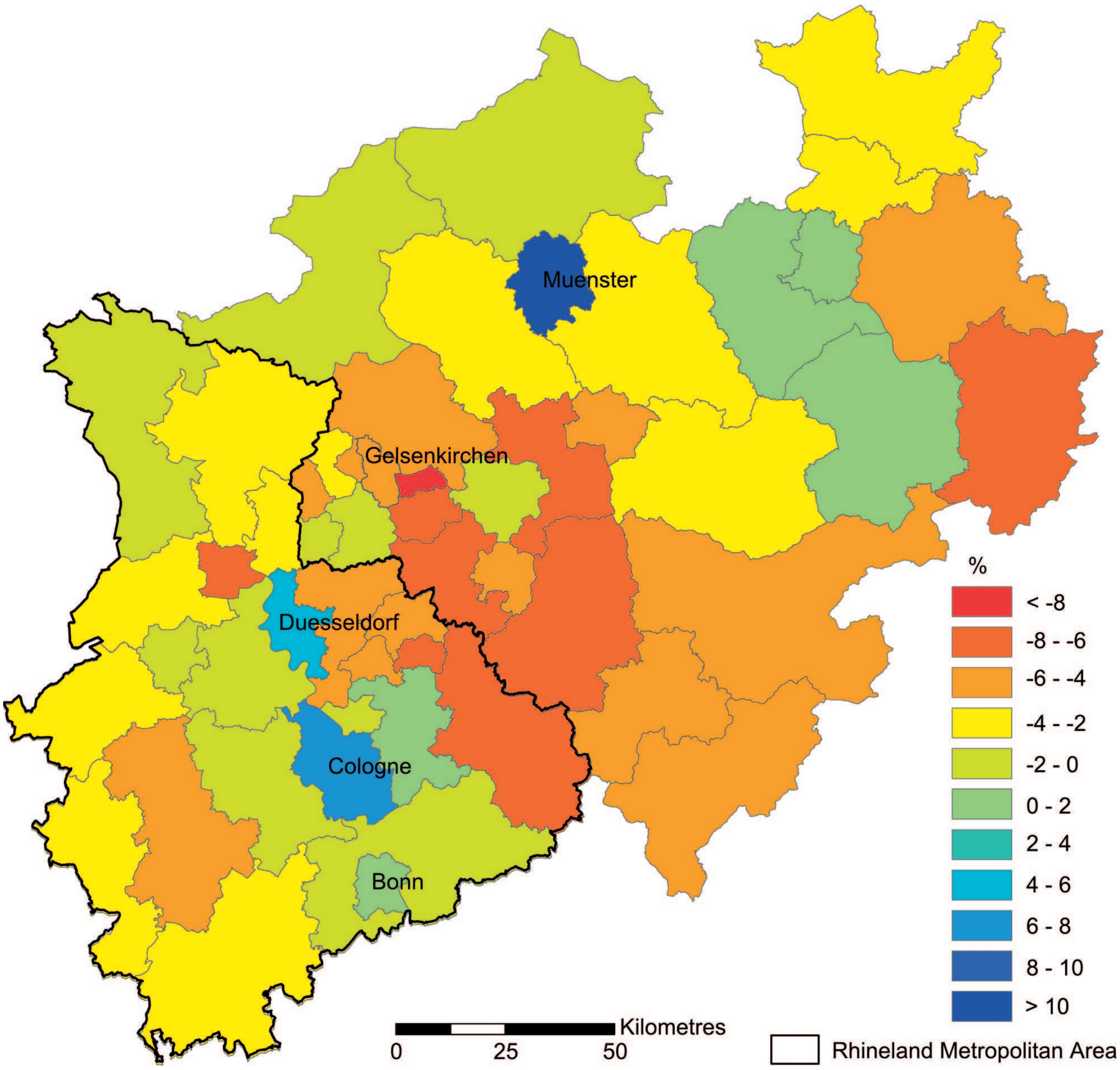

Figure 2. Population dynamics in NRW between 2005 and 2015 (data source: © IT.NRW, Duesseldorf, 2018).

3. Methods and data

3.1. Long-term LULCC assessment

Landscapes can be characterised by either land cover or land use. The former refers to the different materials on the Earth's surface such as vegetation, bare soil or water bodies. Land use, on the other hand, describes how these surfaces are used by humans, e.g. as forests, parks or commercial areas. Information on land cover and land use is usually provided by agencies in the form of statistical figures often relating to administrative units. Therefore, small-scale heterogeneities are often not captured. Remote sensing products based on satellite data or aerial images can help detect structures, processes and dynamics at various spatial and temporal scales. Thanks to long-term satellite programmes like the Landsat programme by NASA, there are image archives that cover a period of over 45 years. Since 2015, this valuable long-term archive is complemented by data from the Sentinel satellites within the European Copernicus programme (http://www.copernicus.eu/). The Satellite image archives comprise spectral information, which can be visualised as coloured images for various purposes but are mostly used for scientific analyses. Currently, the Landsat-7 and Landsat-8 satellites are collecting data of the same area every 16 days. The scanning track is around 180 km wide and has a spatial resolution of 30 m [9]. Sentinel-2 collects data in similar spectral bands in the visible, near-infrared and short-wave infrared spectrum. Its spatial resolution is 10 m, 20 m and 60 m, respectively. The scanning track is 290 km wide, and repetition time is up to 5 days with Sentinel-2A and B operating in one constellation [10]. The calibrated data can be compiled into time series, which allow an insight into the Earth's dynamics.

Although man-made land consumption propagates rather slowly compared to the effects of most natural hazards such as storms or floods, its constant behaviour and its widespread occurrence make it a serious threat to any well-balanced environment. Monitoring at regular intervals is required to accurately quantify recent land consumption rates. In this example, we classify satellite images of the Rhineland metropolitan region from 1975, 1984, 2001 and 2015 using the Random Forests classifier [11].

3.2. Land surface temperature (LST) trends

The satellite sensor Moderate Resolution Imaging Spectroradiometer (MODIS), developed to observe the dynamics of the Earth's surface, is recording data since 2000. Many products can be derived from its data, including datasets on the condition of the atmosphere, land surfaces as well as oceans and ice/snow expanses [12]. One of the land products is the dataset MOD11A2, which holds information on land surface temperature and emissivity. The data has a spatial resolution of 1 km and is provided as a composite at a repetition rate of 8 days [13, 14]. This data is available free of charge and can be explored using cloud-based applications like the Google Earth Engine platform (https://earthengine.google.com/), which is currently free of charge for scientific purposes. By calculating trends, it is possible to visualise regions of heating or cooling in a specific period. Further analyses are needed to reveal the causes for these trends, though.

Here, we calculate LST trends with different methods as there is no agreement on an optimal algorithm. First, we compute a simple linear trend per pixel only considering data from July and August between 2000 and 2015. In doing so, we can assess long-term effects of summer LST. Second, we make use of the Annual-Aggregated-Trends (AAT) method implemented in the "greenbrown" package [15, 16] using the free statistical software R [17]. This method calculates trends on annual aggregated time series using the annual mean and an ordinary least squares (OLS) regression. The significance of the trend is estimated using the Mann-Kendall test. The AAT method accounts for seasonal effects and considers all observations, thereby assessing annual effects rather than seasonal effects.

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3.3. Land use and land cover modelling

Land consumption and the ecological problems associated with it are a huge unresolved challenge for Germany. Even in shrinking regions, urban sprawl can be observed. Land use and land cover modelling can shed light on processes, causes and effects of urban growth—socially and ecologically. There are several types of land use and land cover models. Spatially explicit models often simulate the future urban structure based on classified satellite data. Cellular automata (CA) are typical "bottom-up" models, which depict cities as systems and try to comprehend their complexity. They combine spatial units and model, based on spatial structures in a cellular environment, neighbourhood relations and simple transformation rules.

To model the land consumption in the Rhineland Metropolitan area, the cellular automaton SLEUTH is applied. The model was developed at the University of California in Santa Barbara

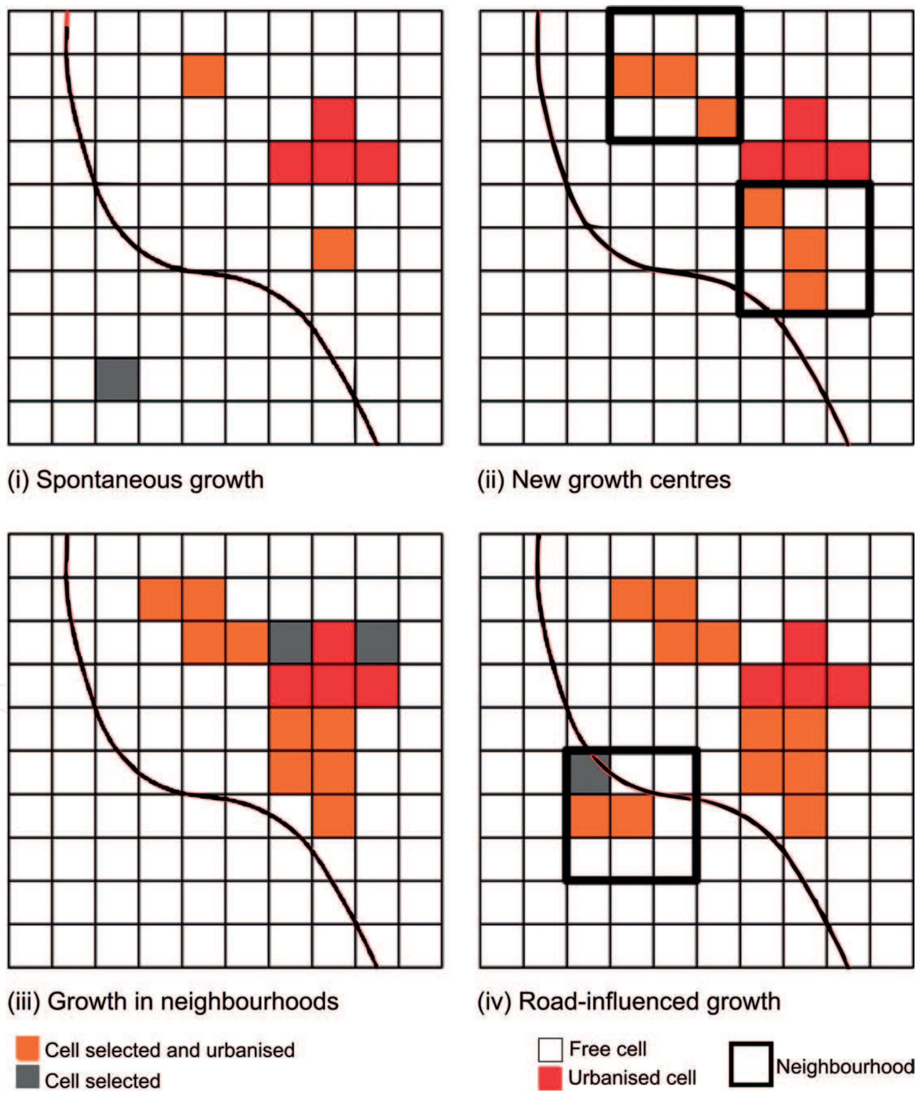

Figure 3. Rules for growth of SLEUTH's simulation cycle (adapted from [21, 22]).

(USA) back in 1996 and was used to answer various issues in many different cities [18, 19]. The land use maps serve as the main data basis; classifications from 2010 and 2015 are used to calibrate the CA. For SLEUTH, the binary version of the data with a spatial resolution of 100 m is sufficient to distinguish impervious from non-impervious surfaces. In its core, SLEUTH is an urban growth model. Its name is an acronym that consists of its main input data: slope, land use, exclusion, urban extent, transportation and hillshade. “Exclusion” includes all those areas where urban growth is restricted (e.g. nature reserves). Five growth coefficients control the four rules of the CA. These include spontaneous growth, which simulates the random development of settlements in their distinct neighbourhood, the growth of city centres, extensive growth in the direct neighbourhood and specific road-influenced growth (**Figure 3**).

The calibration of the model is necessary to synchronise the individual coefficients and to calculate the volume of the settlement areas to be distributed. It is possible to implement different scenarios for land consumption after calibration. In this study, the base year is 2015. One decade after the deadline of the 30-ha goal, the year 2030 is defined as the final year of the simulation, to demonstrate how the Rhineland Metropolitan area will look like both if the goal is achieved and, more importantly, if the goal cannot be reached [20]. For the simulation of land consumption, three scenarios are defined:

- Scenario A: “sustainable development”. The 30-ha goal has been adopted by municipal planning, economy and the general public. Inner-urban development takes precedence over urban expansion. The focus lies on space-saving designs; development of land-intensive housing is reduced. Residents use public transportation rather than individual transport.
- Scenario B: “business as usual”. Land consumption continues at the pace of the past. Caused by economic developments, land consumption is on the rise again, after a short-term decrease in the early 2000s. Cities are expanding, and the process of densification is advancing as well. Most of the settlement area is used for single-family homes. The construction of apartment buildings only accounts for 10% of the settlement area.
- Scenario C: “desire to live in a green area”. Land consumption is increasing. The main driver is the increased construction of single-family homes. Cities are expanding rather than densifying inner-city areas. The “green meadow” is the preferred location for the construction of commercial areas and logistic centres. The parish-pump politics of the municipalities lead to an increasing designation of commercial areas in the periphery. The ageing population causes remnant effects, while society is oriented towards single households; the demand for housing rises.

4. Results

4.1. Remote sensing in support of the 30-ha goal

The maps resulting from the LULCC classification differentiate between water, arable land, grassland, deciduous forest, coniferous forest, mixed forest, open-pit mines as well as low, medium and high levels of imperviousness. A low level of imperviousness is defined as containing less than 40% impervious surfaces, medium level as 40 to 80% impervious surfaces and high level as more than 80% impervious surfaces per pixel. **Figure 4** shows how land consumption has altered the region's settlement structure. The impervious surfaces are constantly increasing since 1975, while arable land and grassland are decreasing. The analysis of the region's satellite images shows that impervious surfaces comprised about 126,800 ha in 1975. 40 years later, impervious surfaces have almost doubled, amounting to 245,600 ha in 2015. Between 2010 and 2015, land consumption was as high as 8 ha per day in the Rhineland Metropolitan area alone. It should be kept in mind that the goal for 2030 is to stay below 30 ha per day—nationwide. Increasing land consumption as well as the densification of urban areas not only affects our immediate living environment; they also have measurable impacts on the Earth's radiation budget and therefore on micro- and mesoclimate. **Figure 4** shows that some hotspots of land use change pop up in the LST trend map as places of heating and cooling.

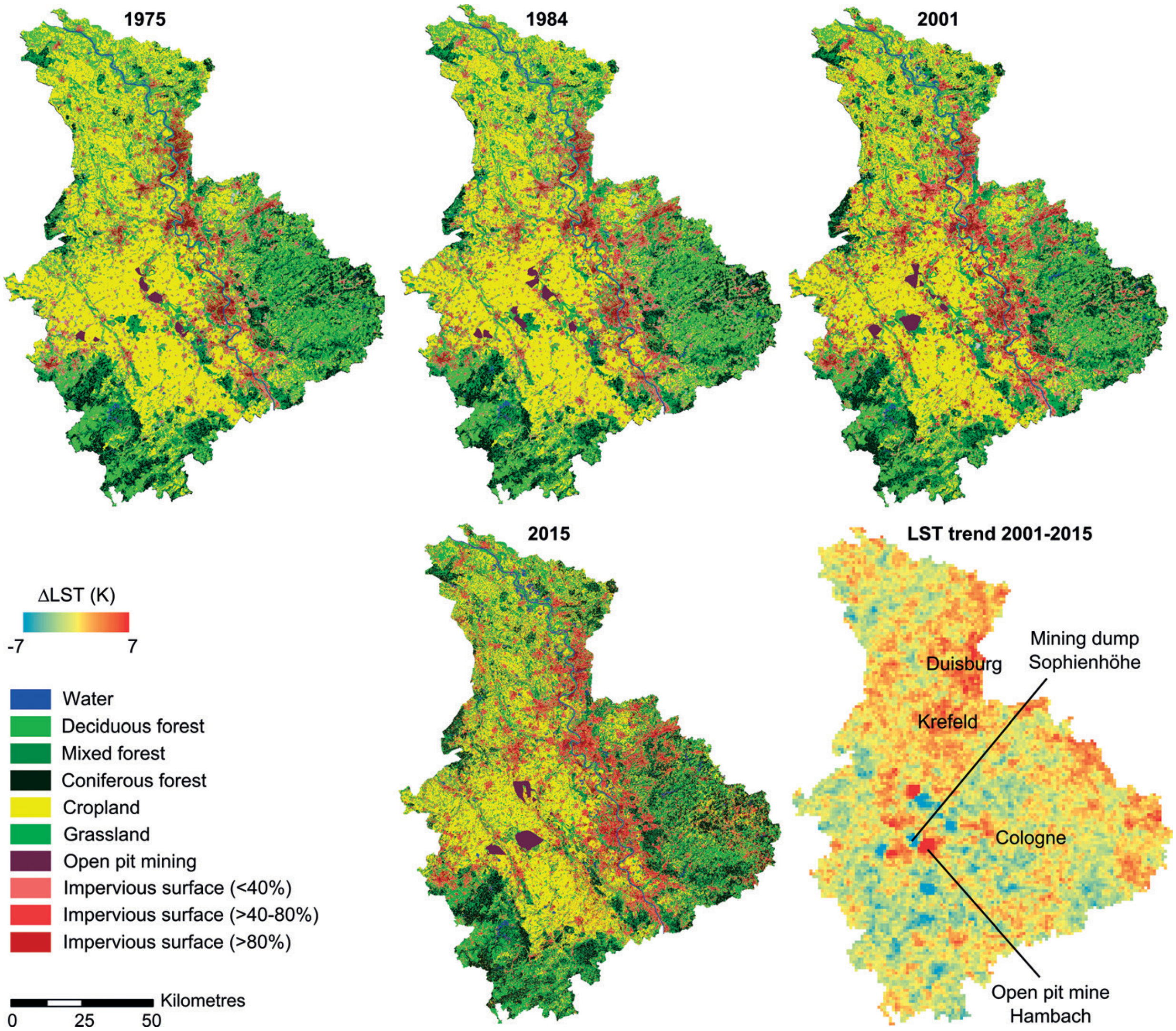

Figure 4. LULCC maps of 1975, 1984, 2001 and 2015 as well as LST linear trends of the Rhineland Metropolitan area (adapted from [23]).

Most prominent and shown in red indicating heating are the open pit mines of the Rhenish lignite mining area. The respective dump sites—meanwhile recultivated with vegetation—show cooling trends, indicated by blue colours. Other areas of LST warming trends are urban areas related to the cities of Cologne, Krefeld, Duesseldorf and Duisburg.

Figure 5 depicts trends in land surface temperature for the entire NRW, where LST trends from July and August between 2000 and 2015 are shown in **Figure 5a**. This figure complements the LST trend map in **Figure 4** but extends further east and covers areas beyond the Rhineland Metropolitan area. Accordingly, it shows some additional eastern hotspots of warming (red) and a few areas of cooling (blue). Areas that show no trend are depicted in yellow. Statistically irrelevant areas have not been masked out in **Figure 4** and **Figure 5a**. The hotspots are primarily urban areas; the cities of Krefeld and Duisburg as well as the western part of Cologne are easy to spot. Most of the named regions have an increased level of imperviousness and experience urban sprawl as a consequence of population growth (**Figure 2**). Usually, such alterations happen at the expense of green cover and agricultural land. Agricultural and vegetated areas usually display a cooling effect as a consequence of the vegetation's evaporation.

Densified urban areas on the other hand are commonly characterised by excessive heating compared to their surroundings, since runoff is accelerated and man-made materials heat up considerably. The newly developed open-cast mining areas in the Rhenish lignite mining region are also areas of significant heating, mainly caused by the removal of vegetation and the exposure of soil, sand and sediments. In addition to that, groundwater has to be drained in the excavation area, which leads to a shortfall of water and a diminished cooling effect of evapotranspiration. The mining process also exposes sand and coal seams to the surface, which heat up more than the cultivated land and the forests that covered the region before. Other areas that have shown

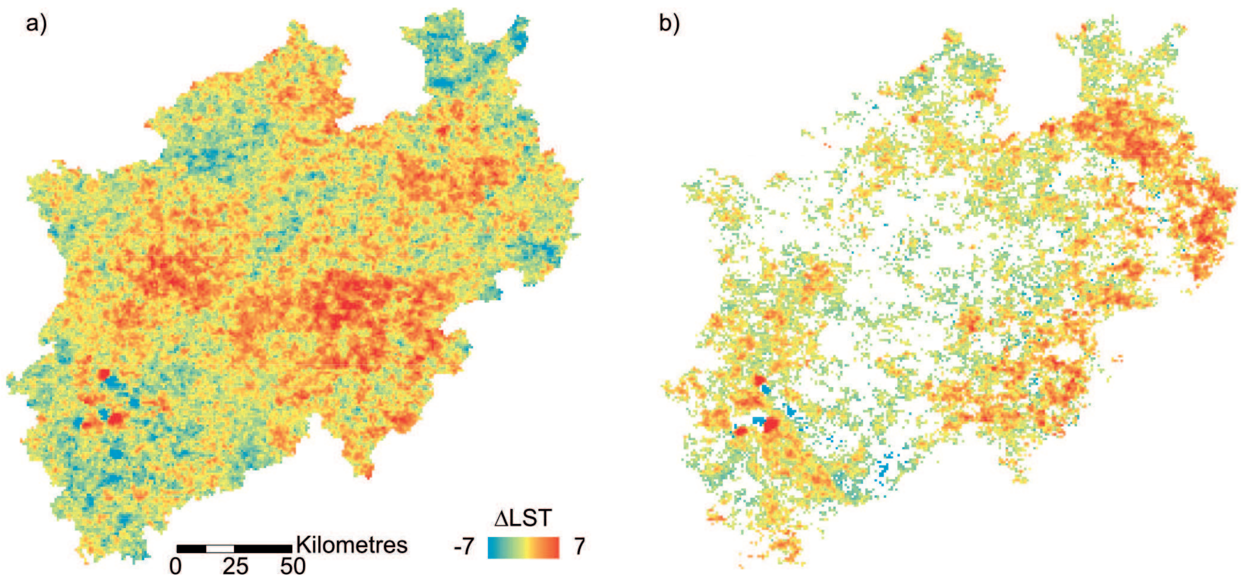

Figure 5. Trends of LST: (a) linear trend of July and august observations between 2000 and 2015 and (b) significant trends of all observations between 2000 and 2015 based on AAT.

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an increase in LST are further east in vegetated areas (see **Figure 2**). The warming here is probably the result of forest damage and degradation caused by storms like Kyrill in 2007 [23].

Areas of summer cooling trends are primarily surfaces that have been classified as arable land or grassland in 2001 as well as in 2015 but also recultivated opencast mining sites (**Figure 4**). A possible explanation for this cooling is that the harvest date of the crops may have been delayed from year to year, so that the fields were vegetated for a longer period, hence the prolonged vegetative cooling effect. Another possible cause could be the cultivation of crops like corn and sugar beets that are harvested in autumn as opposed to the common winter cereals like wheat and barley, which are harvested in July and August. The impact of land use change on the surface temperature has not yet been fully investigated and shows different patterns for different time periods. In contrast to **Figure 5a**, in which only the LST trend of the summer months between 2000 and 2015 is shown, **Figure 5b** displays the statistically significant trends ($p < 0.05$) for all measured values based on AAT, i.e. the whole course of the year has been considered. The patterns are identical to some extent, as seen in the areas of opencast mining, but for some parts, they differ considerably.

Figure 5b makes two things abundantly clear: on the one hand, areas with statistically significant trends are predominantly detected in urban spaces and to some extent in agricultural land and forests. On the other hand, the trends indicate a rise in LST nearly everywhere—up to 3 K in urban spaces and agricultural land and even more in forests. Only a few recultivated opencast mines show a striking decrease in temperature. The temperature increase in urban spaces is caused by the expansion and concentration of urban structures. The temperature increase in agricultural land could be caused by increasing periods of drought in spring, fall and winter, when the fields lack vegetation regulating temperature. If and to what extent crop rotations or other causes can influence the change in LST has not been investigated yet. However, our findings are in line with other studies that show correlations between land use change, vegetation decrease and LST increase [24].

The cooling effect of recultivated opencast mines is juxtaposed to the long-term warming of newly developed mining areas in **Figure 6**. Cooling already sets in when a population of pioneer plants develops on formerly barren land, regulating water and radiation budget. During vegetation growth and succession, biomass, the level of transpiration and finally the cooling effect increase. The lines showing a linear trend in **Figure 6** have been added to emphasise the land surface temperature evolution since 2000. The warming might actually be an abrupt change from one state into another. **Figure 6** shows that in the area of the recultivated dump site “Sophienhöhe”, temperature has decreased by about 3 K between 2000 and 2015, while the temperature of the newly developed mining area of the “Hambach” open pit mine has increased by about 3 K.

4.2. Perspectives on future land consumption in the Rhineland Metropolitan area in 2030

Figure 7 shows the results of the modelling for 2030. The quantity of newly urbanised and occupied areas oscillates between 29,200 ha and 79,000 ha, depending on the scenario

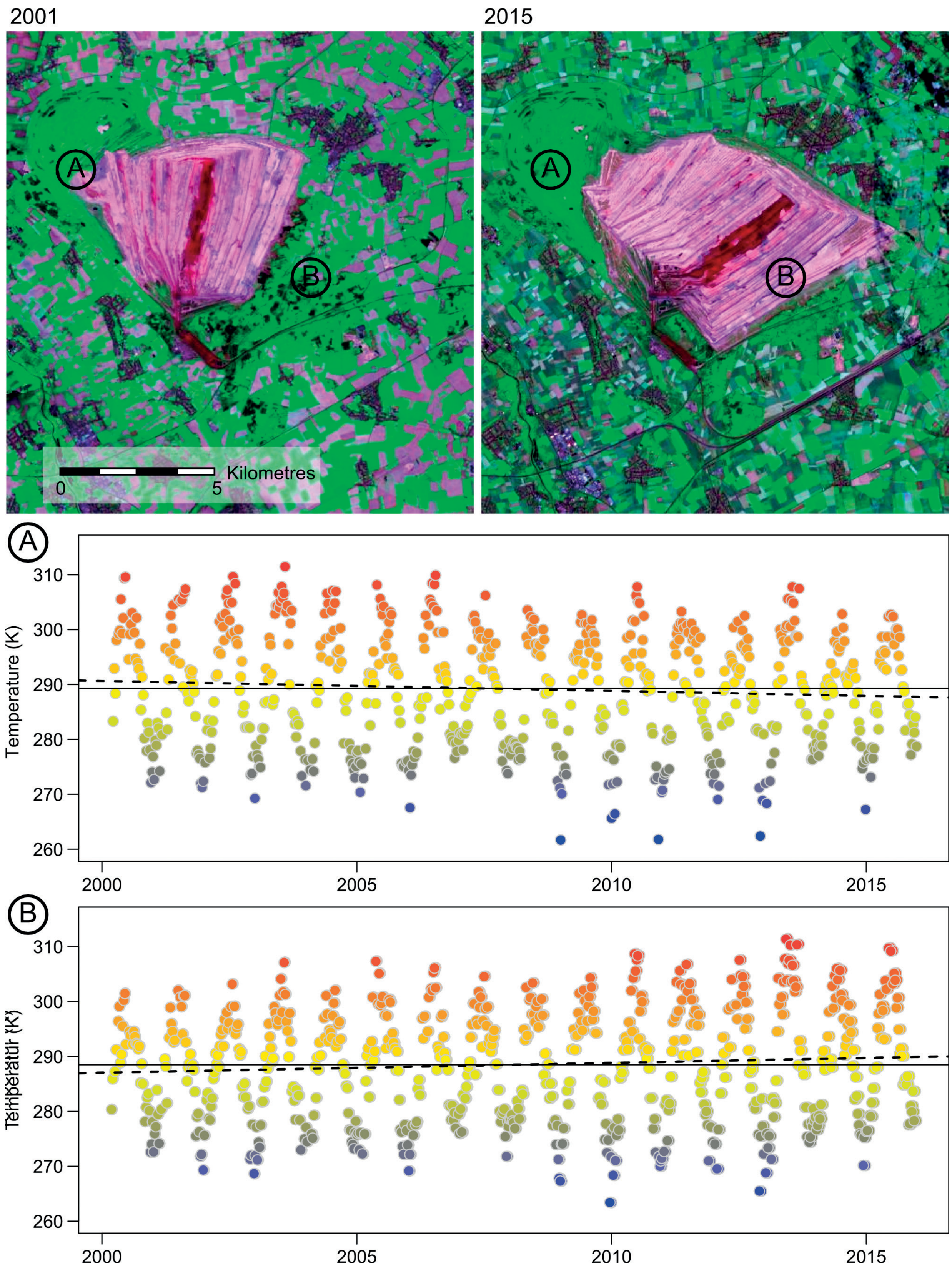

Figure 6. LULCC in Rhenish open pit mining between 2001 and 2015. (A) Indicates the location of "Sophienhöhe" mining dump and (B) the migration of "Hambach" open pit mine towards southeast. The respective time series of a (cooling trend) and B (warming trend) of all observations of LST between 2000 and 2015. Red colours indicate warmer LST during summer; blue colours indicate cold winter LST.

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(**Figure 8**). This would represent a daily consumption of 5 ha, 10 ha and 15 ha, respectively. The "business as usual" scenario would already exceed the 30 ha benchmark. In the scenario of "sustainable development", the land consumption in the Rhineland Metropolitan area would reduce by 3 ha per day. In the opposite scenario "desire to live in a green area", land consumption would almost double (**Figure 8**). All areas that are consumed in scenario A (red) are consumed in the other scenarios, too. All areas that are consumed in scenario B (yellow) would be added to those of scenario A (red + yellow). In scenario C, most areas would be consumed (red + yellow + blue). Note that cellular automata only issue an outlook on what could happen and not necessarily what will. The outcome visualises a basic trend, which occurs in all three scenarios: the settlement area increase firstly leads to a densification of present settlements. Looking at the distance that lies between newly developed settlement areas and present ones, this statement is underlined. In addition to that, the development of new urban areas is taking place in the suburban and exurban space, which leads to disperse structures. The next step could be to link the land consumption modelling to a prediction of the development of LST. This could emphasise the importance of a sustainable management of land resources and add to the debate on climate change. Densification and infill development are to be preferred over expansion and the development of new building areas, since forests and agricultural areas can be preserved that way. However, increasing densification also holds challenges, especially concerning logistics and urban climate.

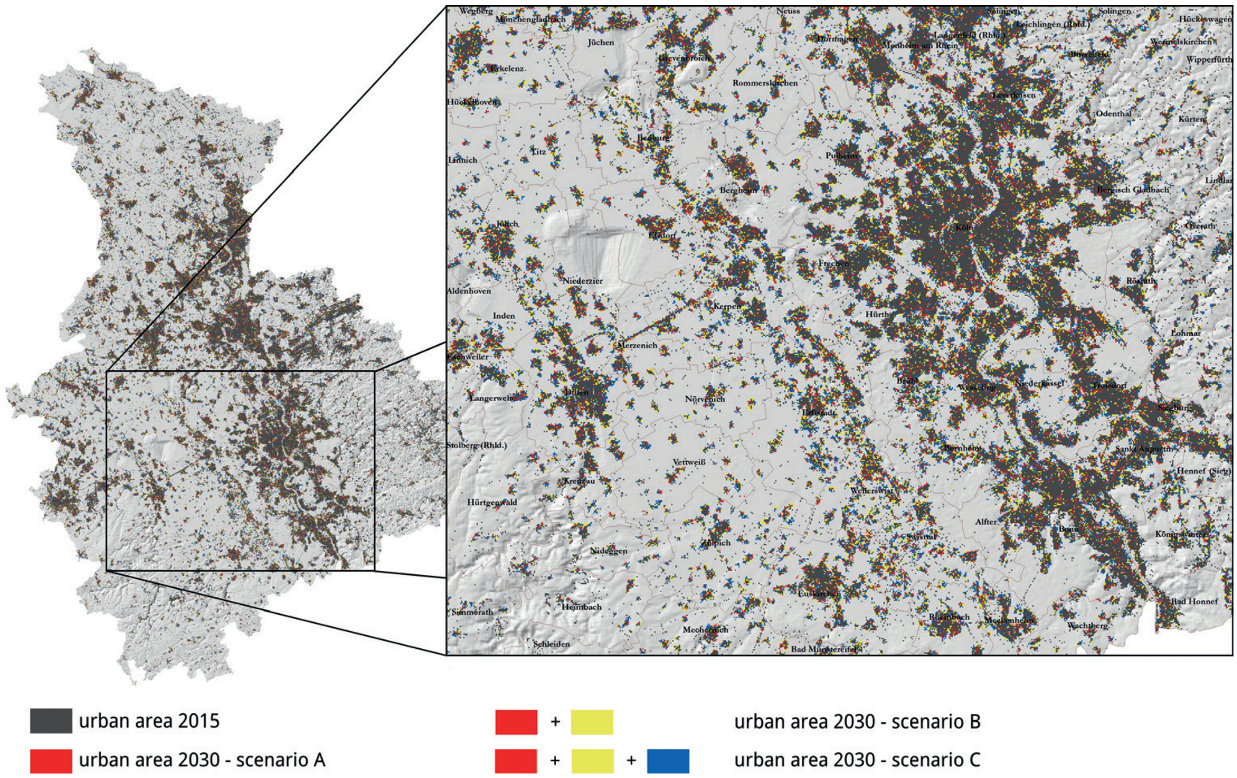

Figure 7. Modelling of land consumption in the Rhineland Metropolitan area in 2030 according to the scenarios "sustainable development" (A), "business as usual" (B) and "desire to live in a green area" (C) (figure modified after [25]).

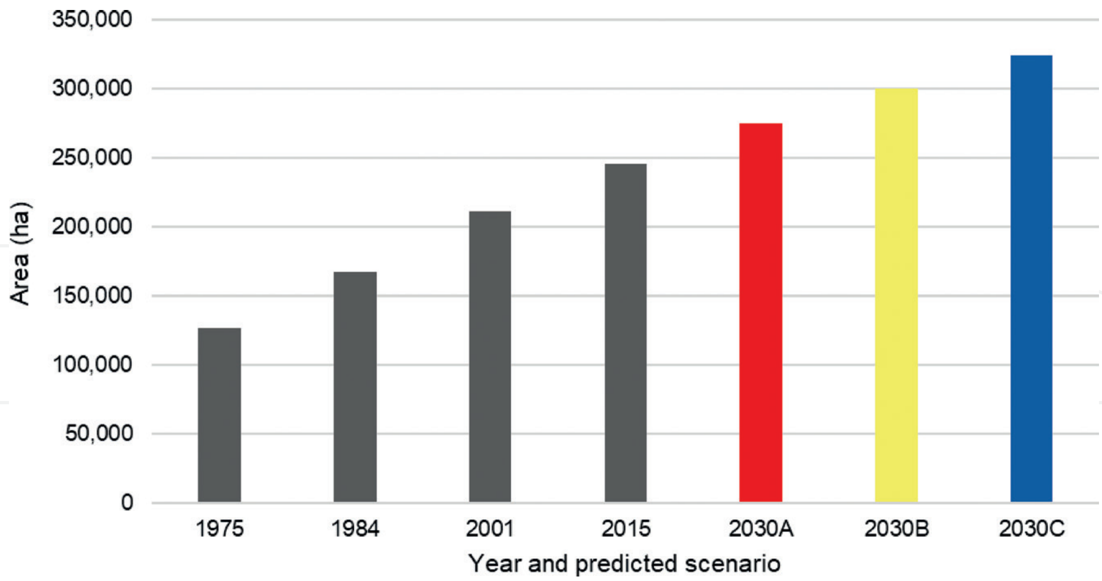

Figure 8. Urban development in the Rhineland Metropolitan area between 1975 and 2030 from an analysis of the region's satellite images (1975–2015) and from modelling (2030) according to the scenarios "sustainable development" (A), "business as usual" (B) and "desire to live in a green area" (C).

5. Conclusion and outlook: Land consumption and climate adaptation: A glance beyond the metropolitan area

Due to current climate change, the topic of land consumption and change of landscape structure particularly concerns the densely populated areas and requires measures to increase their resilience. The classified satellite data (**Figure 4**) illustrate how settlement structure, building density and green structure of the Rhineland Metropolitan area have changed over the past decades. This can be seen when looking at the settlement development along the Rhine, in particular between Dusseldorf and Cologne, where open spaces are constantly receding. Looking at the individual neighbourhoods and roads, more links between land use and microclimate become clear—ventilation, heat development and percolation ability, for example. Areas with a high degree of imperviousness are at a higher risk to develop urban heat island effects than green spaces [25]. This is primarily caused by the heat storage of asphalted surfaces, the missing cooling effect of vegetation, limited air exhaustion due to dense construction and, of course, anthropogenic emissions. On some days, it might be nice when it is a little warmer and calmer in the street canyon than in the open field, but the development of such heat islands causes many problems in summer, be it for health, water budget or vegetation growing conditions [1, 2].

The link between the land cover maps and LST trends increases the validity of the results and establishes new courses of action. That way, it is possible to detect areas that have the same degree of imperviousness but still differ with regard to their respective microclimate. The next step would be to take a closer look at the current situation and derive solutions. The orientation, the height, or the design of the different building structures might all imply reasons for differences in the respective LULCC and LST results.

In order to bring those aspects in accordance with requirements for future development and to make upcoming plans as climate friendly as possible, many cities already run map services showing urban climate, which not only show the status quo but also predictions. Although these maps are a valuable basis for planning, they are not strictly necessary to take initial steps towards resilience. Many measures can be taken without detailed climate prognoses. Besides politics and administration, local parties like homeowners and housing associations have to contribute, too.

To fulfil the potential at hand and to inspire willingness to act, it is useful to raise awareness of climate change and the associated need for adaption. To do that, there are no measurements needed; observations can be sufficient. Satellite images—supplemented by climate data—can be very helpful in doing so. Other examples, besides the already mentioned heat islands, are rivers and creeks, which, over the last years, have been subject to floods caused by climate change. While many things can cause a river to overflow, flooded creeks are much very suitable to identify causal climatic relationships and to raise awareness.

The Rhineland Metropolitan area is just one of many examples. The observations made here can be applied to numerous regions in NRW and Germany. It is a promising strategy to consider both short- and long-term approaches as well as local and regional approaches. The development of small-scale solutions on how to handle climate change can help to raise awareness and build a basis for political action. This is first and foremost the responsibility of urban development planning, as can be seen in many local climate change adaption concepts [5]. Politics and administration can make suggestions and requirements for newly planned construction projects, which are based on the insights gained by remote sensing data. Especially the urban sprawl over the past decades becomes alarmingly clear when looking at the classified satellite images of 1975 and 2015 (**Figure 4**). Even though many municipalities are required to favour inner development over outer development, land consumption is still at a high level—especially when considering the consumption per capita.

Urban development planning is not the only determining factor for climate adjustment, though. Modifications of portfolio properties can also contribute to the task at hand. The use of sustainable materials and the greening of roofs and facades of private residences, logistics centres, company premises, commercial and industrial parks and communal buildings can also move things forward. Numerous models and pilot projects show the potential and the willingness of companies and associations to contribute to a climate-friendly remodelling [1, 5]. The topics selected as examples here reveal how important it is to combine sectoral-based strategies. The link could be created by regular sustainability reporting on a municipal level. Surveys done by the statewide Agenda 21 workgroup "LAG 21 NRW" (Landesarbeitsgemeinschaft Agenda 21 NRW) show that only a few municipalities are taking advantage of this opportunity so far [5]. However, those who do can record short- and long-term success. Communities which are willing to address these problems find assistance in a special training session offered by the Education Centre for the Supply and Disposal Economy (Bildungszentrum für die Ver- und Entsorgungswirtschaft, BEW). The Ministry for Environment, Agriculture, Conservation and Consumer Protection of the State of NRW supports this approach and awards municipalities that successfully finish the course with a certificate [5].

Climate adaption is a very complex topic, which is hard to impart. Small-scale possibilities of change like the renaturation of a creek are a well-suited starting point to demonstrate individual and local courses of action. The inclusion of the public also creates the opportunity for creative potential, which no city should pass up. Cities in the Rhineland Metropolitan area have already taken action. In association with the Universities of Bonn and Bochum, the Bonn Science Shop (Wissenschaftsladen Bonn, WILA) and the cities of Bonn and Gelsenkirchen are developing practical climate adaptation measures and guidelines in the project called "Town and Country in the Flow – Network for the Creation of a sustainable Climate Landscape (KlimNet)" to include parties at all levels as well as citizens (www.klimalandschaften-nrw.de).

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Conflict of interest

The authors declare no conflict of interest.

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