Hessian Agency for Nature Conservation, Environment and Geology
Centre on Climate Change and Adaptation

HESSEN

Hessian Soils and Climate Change

Climate change in Hesse

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Foreword

Most of the time, we do not spare a thought for the ground beneath our feet. But our soils are vital because they regulate water and material flow, and provide food, animal feed and renewable raw materials.

We record significant fluctuations in the temperature and water content of the upper soil layer, depending on air temperature and precipitation. The soil structure is also influenced by wind and the weather. Consequently, climate change also affects soil.

Conversely, processes occurring in soil also affect the climate: the microbial decomposition of dead biomass releases greenhouse gases.

In this brochure, we examine the role of Hessian soils in climate change: How does the climate affect our soils? And how do the soils affect the climate?

Further information is available on the website of the Hessian Agency for Nature Conservation, Environment and Geology (HLNUG).

The ground beneath our feet

Our soil is a valuable and scarce resource. Soil, or, scientifically speaking, soils, together with water and air, are the most important basis of life for plants, animals and humans. By soil we mean the thin – varying from a few decimetres up to several metres thick – productive weathering zone of our earth's surface.

It consists of varying types and sizes of mineral components, organic matter (humus, roots and soil organisms), water and air. Solid soil particles form the different soil textures, depending on their composition and structure. Soil pores are the spaces between soil particles, which can be filled with water or air.

Soils have very high spatial variability due to differences in the parent material, thickness and climatic conditions affecting the soil's formation. This variability in the properties and functions of the soil can even be observed in the smallest of spaces, often just by considering the surface vegetation – it is much more luxuriant on some patches than it is on neighbouring patches.

Typical forest soil of the Hessian Central Uplands: a layer containing few stones covers a layer containing many stones

Soils reveal climate history

Our soils in Hesse were formed in very different climatic conditions in the last hundred thousand to one million years. Sometimes it was hot, humid and tropical, with annual average temperatures of over 20 °C, and sometimes there were glacial periods with average temperatures below 0 °C. These climatic variations led to the development of many different parent materials (sediments) and the actual formation of soils in Hesse. Most Hessian soils are characterised by sedimentation in the glacial period and soil development in the interglacial period of the last 12,000 years. A tundra climate, just like in Siberia today, prevailed in the glacial period. Bedrock was shattered due to repeated freezing and thawing, and deposited downslope. It combined with the wind-borne dust from outwash plains that was deposited in thicknesses ranging from

The Eltville Tephra, a thin layer of volcanic ash, was deposited during the last glacial period about 20,000 years ago. Today, it is largely visible as a dark band in loose rock in Hesse. Its warped structure traces the contours of the patterned ground, the earth's surface at the time of the glacial period. (Photo taken during the construction of the Limburg ICE train station).

a few centimetres to several metres during dry, cold phases.

With the transition to the current interglacial period (Holocene) about 12,000 years ago, the annual average temperatures rose to more than 10 °C. The sedimentary rocks were decalcified by the seepage of precipitation, and new clay minerals and iron oxides were formed, giving our soils their typical brown colour. This, together with mixing, enrichment and deposition processes as well as the influence of groundwater and other bodies of water, created an enormous variety of soils with completely different properties. In addition to these soils from recent climate history, we also find soils from a time when Hesse was still located on the equator, before continental drift moved it further north. These soils were mainly formed by chemical weathering in the then humid and tropically warm conditions.

Mottled horizon of a latosol. It was formed in a tropical climate many millions of years ago. While silicon, calcium and other components were leached from these soils, iron and aluminium were enriched. The red patches are haematite.

Soil temperature

Just like air temperatures, soil temperatures have already increased as a result of climate change. Soil temperature monitoring proves this.

The heat balance of a soil is controlled by the supply and loss of heat from the air and depends on the heat capacity and conductivity of the soil. In addition to its properties (such as soil type and compactness), this mainly depends on the soil water content: moist or wet soils warm up slower than dry ones, but also release the heat more slowly. Soil temperature has a similar trend to that of daily and annual air temperatures, whereby the fluctuations near the surface are more pronounced and decrease with increasing soil depth. The temperature hardly changes at a depth of 12 m, remaining at an almost constant 10 °C throughout the year.

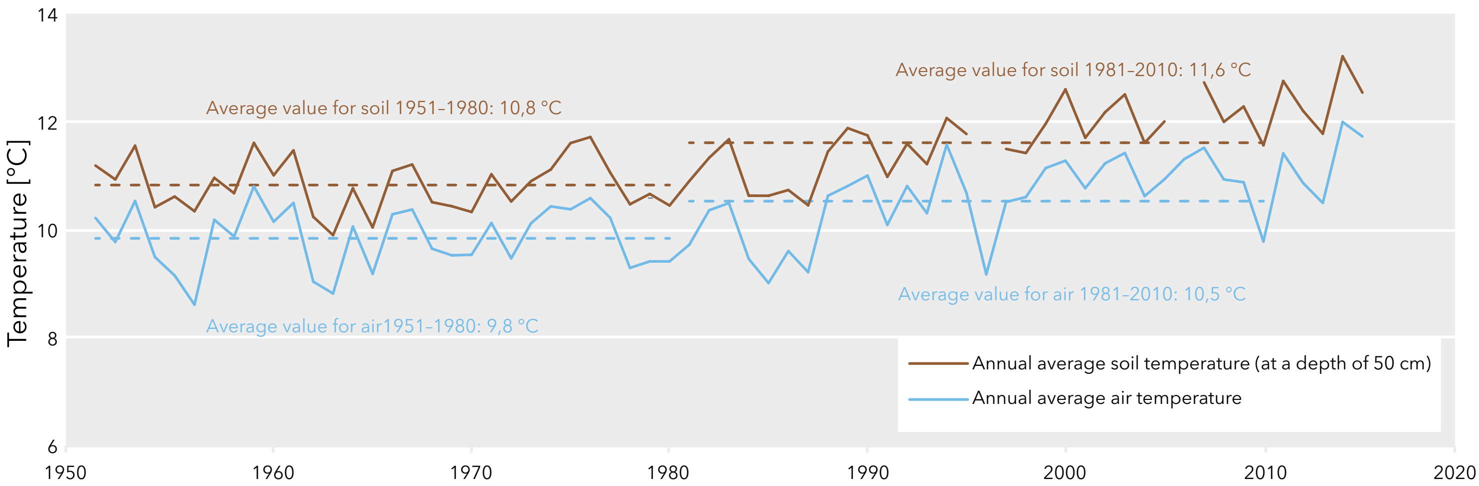
German Meteorological Service field for monitoring soil temperature in Potsdam

Temperature influences almost all chemical, physical and biological processes in the soil. Generally, the higher the soil temperature, the faster and more intensive the processes. Thus, if there is sufficient water, a higher soil temperature is expected to lead to increased activity in soil organisms. In turn, this will increase the speed of chemical decomposition and conversion reactions. In addition, a higher soil temperature prolongs the duration of the growing season, thus increasing plant growth. This leads to increased plant uptake from the soil.

The German Meteorological Service (DWD) also measures soil temperatures at various depths in unvegetated soil at many of its meteorological observatories. The time series for air temperature and soil temperature at a depth of 50 cm at the Geisenheim station have shown a comparable trend since 1951, whereby the annual average soil temperature is 1 °C higher than the air temperature.

Just like air temperature, an upward trend can be observed: the average values for the period 1981–2010 are about 0.7 to 0.8 °C higher than the average values for the period 1951–1980.

Monitoring stations in other regions of Hesse and across the nation show a comparable trend.



Annual average air and soil temperatures at the Geisenheim station for 1951–2015 (solid lines) and 30-year averages (dashed lines). Data: DWD.

Soils as carbon reservoirs

Soils play a critical role in the global carbon cycle. They are the largest terrestrial carbon sink and store more than twice as much carbon as the entire vegetation worldwide. However, soils can also become a carbon source by releasing carbon dioxide (CO_2) and other greenhouse gases such as nitrous oxide (N_2O) and methane (CH_4) into the atmosphere. Even small changes in soil processes can strongly influence the amounts of these released climate-relevant gases.

In the soil, dead plant remains are decomposed and converted by soil organisms. These processes release the greater part of the carbon back into the atmosphere as CO_2. However, a smaller part remains in the soil as stable humus over longer periods of time. Most of a soil's physical, chemical and biological properties depend on its humus content.

Humus serves as a storage, filter and buffer medium for water, nutrients and pollutants, thus critically influencing the soil's productivity as well as its ability to retain pollutants and prevent their transfer to groundwater.

Very humus-rich topsoil with a humus content of 4–8 % (dark brown) above a humus-poor subsoil (lighter area)

Soil temperature and moisture, nutrient availability and pH influence soil organisms' decomposition processes and, consequently, the humus content of the soil.

How will climate change affect future soil carbon levels? Due to the many influencing factors, a consistent prediction is difficult, since the outcomes could vary considerably. For example, if there is sufficient moisture, an increase in soil temperature will increase the decomposition of humus and release of CO_2, but also produce more biomass. However, both drier summers and increased precipitation with the consequence of waterlogged soils in winter can inhibit humus decomposition.

Due to these complex relationships and interactions between climate change and the carbon cycle, it has not yet been possible to draw any reliable conclusion with regard to changes in humus content and reserves. Rather, a location-based, differentiated assessment of the outcome is necessary. This subject still warrants considerable research.

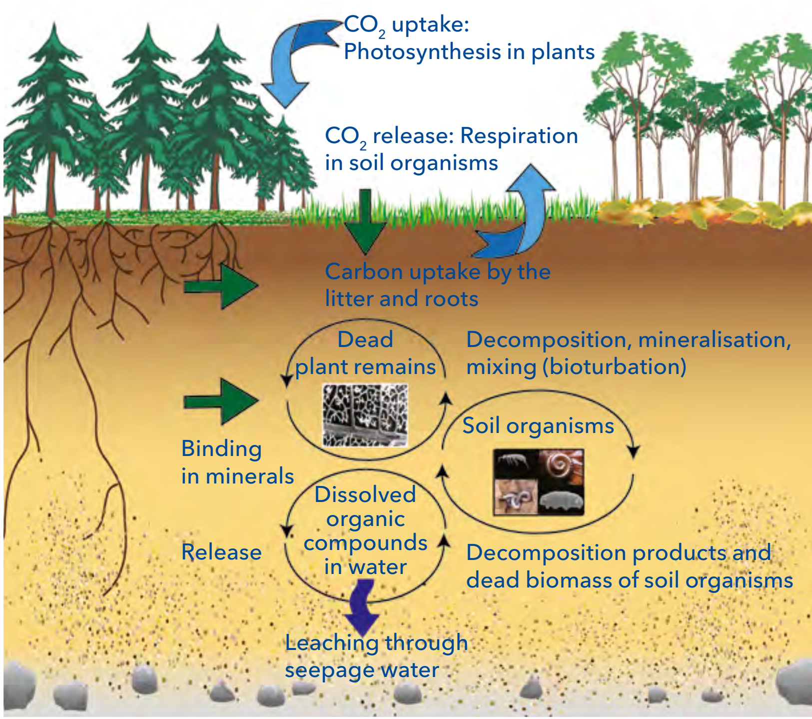


Illustration of the major carbon fluxes and conversions in soil
© Dr. Marion Schrumpf, Max Planck Institute for Biogeochemistry

Soil organisms

Many different plants and animals live in the soil. A handful of soil contains more microorganisms than there are humans on earth. We can see worms, beetles, millipedes, woodlice and ants with the naked eye. We need a magnifying glass to see larvae, mites, threadworms and springtails. However, we need a microscope to be able to see the smallest soil organisms, such as algae, fungi and bacteria. These microorganisms decompose the organic material in soil and transform it into valuable humus. Some soil organisms can take up nitrogen from the air in the soil, stabilise organic and mineral particles in the soil and improve soil quality, thus playing a key role in processing nutrients for plants. They can even decompose organic pollutants.

The weather and climate too determine the diversity of soil life: if the soil is dry or frozen, the soil organisms die or become unproductive, while if the soil is warm, moist and well-ventilated, it is extremely productive in a favourable location. Hence, the underground biomass in our latitudes is significantly larger than that above ground.

Soil water balance

Changes in the soil water balance affect agriculture, forestry and water management. Soil moisture, for example, influences the ambient temperature and is a prerequisite for a high level of biodiversity on and in the soil. Pollutants dissolved in water are retained by solid soil particles or plant roots. Thus, soil cleanses the rainwater on its way down to the groundwater and, consequently, our drinking water too.

Longer periods of drought due to climate change could lead to desiccated soils up to great depths. In the case of clay soils, cracks form on the desiccated surface and permit pollutants to quickly enter the subsoil unfiltered during fresh precipitation.

However, if it rains too long and too hard such that the soil is saturated with water for too long, the soil will then lack oxygen. Consequently, the plant roots will no longer be able to supply the required nutrients and the plants will die. Soil organisms too will no longer be able to carry on with their metabolism and food intake in such circumstances.

Soil compaction

Climate change will make winters wetter and warmer. More precipitation in winter will result in the soil being saturated with water, preventing the seepage of further precipitation.

Heavy machinery, such as that for wood harvesting in forests, construction or agriculture, can be driven on frozen or dry soil without causing undue harm.

Doing this on wet and unfrozen soil could lead to long-term and deep soil compaction. The greater the soil compaction, the less water the soil can absorb and store, and the more likely it is that surface run-off will occur. Therefore, in order to avoid compaction, we should not drive on moist soil.

Cooling capacity of soil

Soil contributes to cooling during heatwaves in summer, especially in cities. Unsealed, vegetated soil can provide local cooling through evaporation.

Parks and green spaces, and also green walls and roofs in the city are particularly valuable in summer: they reduce the negative effects of climate change on our urban environment.

The cooling capacity of soil is determined by the soil water balance. The plants can only cause as much water to evaporate as is stored in the soil. Soil is often compacted and mixed with coarse components such as rubble, especially in cities. Therefore, in the case of urban soil, the pore volume for the storage of water is usually very small.

Extreme soil compaction additionally restricts the root zone of plants. Hence, care should be taken to minimise compaction during construction work. The soil quality in undeveloped areas should be retained or improved, and appropriately vegetated.

Redirecting precipitation that falls on sealed surfaces, such as roads, into green areas rather than the sewer system would relieve the latter and provide the plants with more water for evaporation.

© Kathrin39 / Fotolia

Moor protection is climate protection

As long-term carbon reservoirs, moors are essential for climate protection. They are formed when the dead plant material in permanently water-saturated soil is not at all or only incompletely decomposed due to a lack of oxygen. Thus, peat bodies with thicknesses of up to several metres, which can store large amounts of CO_2 in the long term, can be formed in the course of thousands of years.

Hesse itself has only a few moorland areas. Fens, first and foremost, form in wetlands as a result of the silting of old streams (such as former loops in the Neckar in the Hessian Ried) or silted lakes, or in the vicinity of springs. In Hesse there are only two larger contiguous raised bogs: the Red Moor in the Rhön Mountains and the Breungeshain Heath on the uplands of the Vogelsberg.

Draining moors to make them usable for agriculture, forestry or peat extraction exposes the peat to air, decomposing the organic material and releasing considerable amounts of climate-related gases.

Climate change is a threat to raised bogs in particular, when water levels fall due to less precipitation and higher temperatures in summer.

If carefully planned and implemented, reflooding decomposed bogs can reduce the release of greenhouse gases and, if applicable, restore their function as carbon sinks. Hence, moor protection is active climate protection.

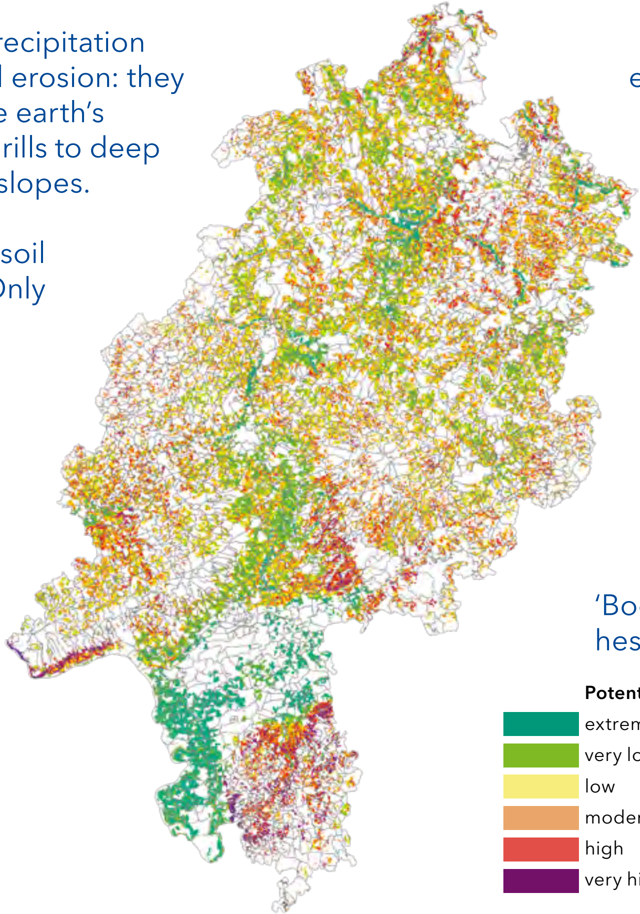
Peat extraction in the Red Moor
© Wilma Gutermuth, Gersfeld archive

View of the Red Moor in the Hessian Rhön Mountains from the south (aerial photo dated 18 September 1989) © Siegfried Reimann

Soil erosion due to heavy rainfall

Particularly extreme precipitation events often cause soil erosion: they displace the soil on the earth's surface, forming small rills to deep gullies, even on slight slopes.

There is practically no soil erosion in the forest. Only paths and clearings (such as those due to wood harvesting) are susceptible to surface run-off and thus also erosion. Soil erosion mainly occurs on unvegetated areas, primarily arable land, which are exposed to heavy rainfall events, particularly in spring.



The major factors for the threat of erosion to an area are the gradient and length of the slope, the crop (that is, the amount of unvegetated soil between the plants) and the soil structure. In the case of the latter, we consider the aggregate stability: the grain size (from sand to clay) as well as the humus and stone content of the soil. The more stable an aggregate is, the lower the threat of erosion. The HLNUG provides maps of potential threats of erosion in Hesse in its 'Bodenviewer' at http://bodenviewer.hessen.de (available only in German).


Erosion furrow around a parcel of arable land

Soil erosion has various consequences. It directly impedes cultivation and reduces soil fertility in the medium to long term, and causes sediment discharge into gullies, retention basins, water bodies and urban and traffic zones. This does not only displace fertile soil but also contributes to the undesirable accumulation of leached nutrients in water bodies.

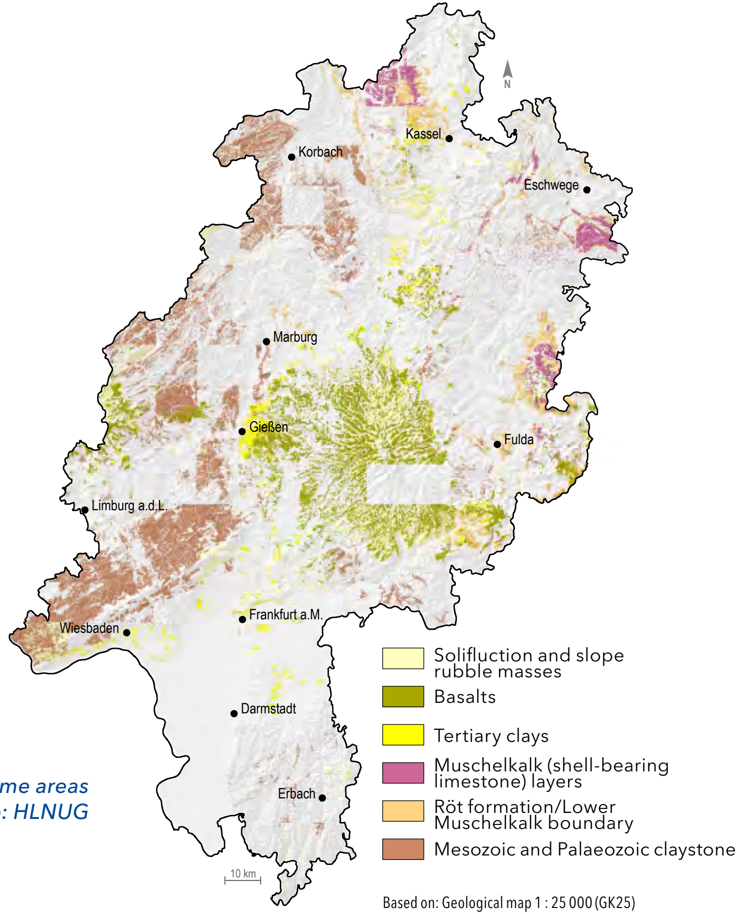
Climate change is also likely to lead to more frequent heavy rainfall events in Hesse. Consequently, if cultivation does not change, soil erosion may become considerably more widespread than it is today. Hence, climate adaptation measures that additionally aim to reduce the threat of erosion are also being recommended for Hesse.

In agriculture, erosion is precluded by ploughless soil tillage. Crop rotation and intercropping with the shortest possible unvegetated intervals are effective measures to protect soil from erosion.

Landslides

Large amounts of precipitation over a longer period of time could, under certain geological conditions, cause landslides or rockfalls. In contrast to erosion, in which only surface material is displaced, a landslide causes a thicker layer of rock or soil to detach from the underlying rock or soil and slide off completely.

Often, steep slopes are particularly susceptible to landslides. A major relevant factor is the types of soil and rock layered in the bedrock. Some materials are particularly unstable and tend to slide, especially if they are directly above a relatively smooth or slippery layer of soil or rock. The coloured geological elements on the map are considered to be particularly susceptible.



Rocks in Hesse that are highly susceptible to sliding. Some areas have not yet been mapped. Source: HLNUG

Studies have shown that there is an increased risk of landslides when monthly precipitation is more than 100 mm or the three-day total is 35 mm or more.

Since more precipitation is expected in winter due to climate change, the threat of landslides increases in the winter months.

Rockfall in the Aar valley in 2014

Landslide in the Markwald Berstadt.
Destroyed paths and roads are typical of landslides.

Conclusion

In Hesse, climate change also affects the ground beneath our feet. Many soil processes depend on temperature and soil moisture. Since these are both affected by climate change, soil processes will also change. The plants and animals on and in the soil are affected too, be it due to waterlogging, drought or higher temperature. In addition, the threat of soil compaction can increase if the soil gets wetter and freezes less in winter.

A lot of carbon, which had been absorbed from the atmosphere by plants during photosynthesis and stored in the plant material, is subsequently stored in the soil. Part of this carbon is released back into the atmosphere through natural processes in the course of time. Climate change could cause a larger proportion of carbon to escape back into the atmosphere and contribute to further warming. This is how soil affects the climate.

If we treat our soils with care, they will provide coolness in summer, store and clean rainwater, and form the basis of our nutrition. Soils are important for climate protection and can help us mitigate the consequences of climate change.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The following information brochures in the
'Climate Change in Hesse' series have been published.

- Observed Climate Change
- Climate Change in the Future
- Extreme Weather Events in Hesse
- Climate Change and Water
- Impacts of Climate Change on Human Health
- Agriculture, Forestry and Climate Change
- Observing the Effects of Climate Change – Climate Impact Monitoring
- Hessian Soils under Climate Change

An information brochure for schoolchildren is available in German:

- Have you heard …? The Climate is changing!

HLNUG

Hessisches Landesamt für
Naturschutz, Umwelt und Geologie

Für eine lebenswerte Zukunft