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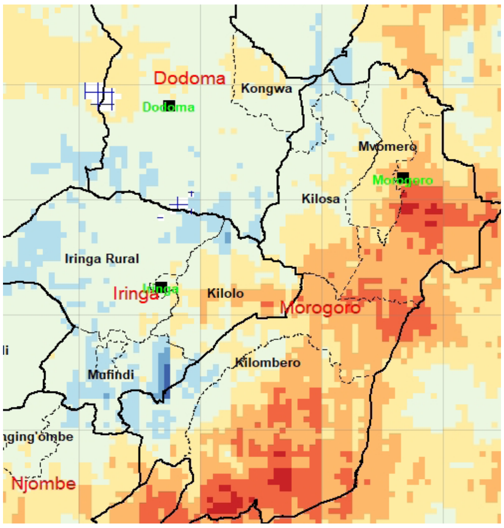
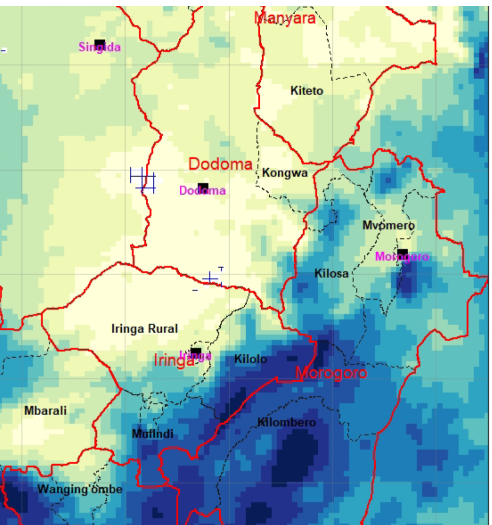
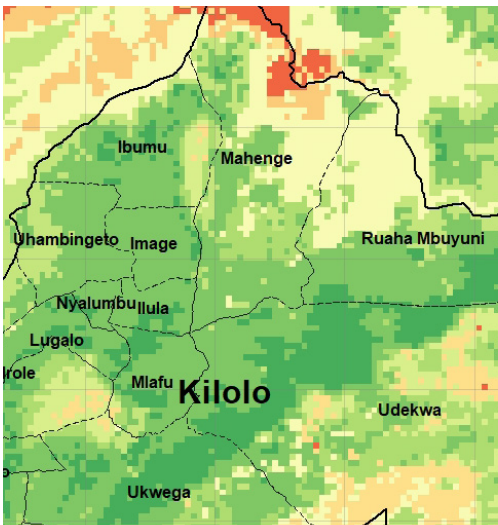
A compendium of maps on biophysical and socioeconomic context, suitability of maize varieties and inorganic fertilizers in Tanzania

Francis Kamau Muthoni, Mateete Bekunda, Irmgard Hoeschle-Zeledon, Haroon Sseguya, Fred Kizito, Frederick Baijukya, Silvanus Mruma







A compendium of maps on biophysical and socioeconomic context, suitability of maize varieties and inorganic fertilizers in Tanzania

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The "Enhancing partnership among Africa RISING, NAFAKA, and TUBORESHE CHAKULA programs for fast tracking delivery and scaling of agricultural technologies in Tanzania project" is an interdisciplinary and inter-institutional project that aims to address the needs of smallholder farmers in the semiarid and subhumid zones of Tanzania. The project is funded by the USAID Mission in Tanzania as part of the US Government's Feed the Future initiative.
Through participatory and on-farm approaches, candidate technologies are identified and evaluated for scaling by the project team. This is achieved through the already established networks by Tanzania Staples Value Chain (NAFAKA), Tuboreshe Chakula (TUBOCHA), and other institutional grassroots organizations, creating an opportunity for mainstreaming into broader rural development programs beyond Africa RISING's current zones of influence.

The project is led by the International Institute of Tropical Agriculture (IITA) and the USAID Tanzania mission-funded programs NAFAKA and TUBOCHA. Developmental activities addressing the project's objectives are implemented in Manyara, Dodoma, Morogoro, Iringa, and Mbeya regions in Tanzania.

The Project partners appreciate the support from the American people delivered through the USAID Feed the Future initiative. We also thank the CGIAR system, and farmers and local partners at all sites for their contributions to the project.

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List of acronyms

ACDI/VOCA	Agricultural Cooperative Development International/Volunteers in Overseas Cooperative Assistance
Africa RISING	Africa Research in Sustainable Intensification for the Next Generation
B	Boron
CaO	Calcium oxide ions
CDC	Collapsible dryer cases
CEC	Cation exchange capacity
CIAT	International Centre for Tropical Agriculture
CIMMYT	International Maize and Wheat Improvement Center
CMSD/NAFAKA	USAID-funded project under the Feed the Future (FtF) Initiative in Tanzania
Cu	Copper ions
DAP	Diammonium phosphate
ESI	Extrapolation Suitability Index
FtF	Feed the Future
GIS	Geographic Information Systems
HB	Hybrid seed
IBSTI	Impact Based Spatial Targeting Index
IITA	International Institute of Tropical Agriculture
ICRAF	World Agroforestry Centre
Kg	Kilogram
Masl	Meters above sea level
MgO	Magnessium oxide
mm	Milimeters
MTD	Minjingu top-dressing fertilizer
N	Nitrogen ions
P	Phosphorous ions
PAN	Pannar seed company
P_2O_5	Phosphorus Pentoxide
S	Sulphur ions

SC – Seed Co	The African seed company
SOC	Soil organic carbon
TARI	Tanzania Agricultural Research Institute
t/ha	Tonnes per hectare
Tmax	Maximum temperature
Tmin	Minimum temperature
TOSCI	Tanzania Official Seed Certification Institute
USAID	United States Agency for International Development (USAID)
VAEO,s	Village agricultural extension officer’s
WOCBA	Women of children bearing age
WorldVeg	World Vegetable Center
Zn	Zinc ions
ZoI	Zone of Influence

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Summary

This document presents a compendium of maps detailing the biophysical and socioeconomic conditions that influence the adoption of integrated technologies in the Feed the Future (FtF) Zone of Influence (ZoI) in Tanzania. Maps on the suitability of selected integrated agronomic technologies are also presented. The primary aim of the maps presented is to enhance better spatial targeting of integrated agronomic technologies to improve yields and promote a healthy environment. This compendium is organized into four chapters: Chapter 1 provides background information on the Africa RISING-NAFAKA partnership project and the applicable scaling model. Chapter 2 contains maps on the biophysical and socioeconomic parameters that influence the adoption of integrated packages of agronomic technologies. Chapter 3 includes maps on the suitability of integrated technological packages that were promoted by the project in the FtF-ZoI in Tanzania, while Chapter 4 provides a brief synthesis of the information presented in other chapters. Maps presented in this compendium are expected to help the extension and development agencies to better target improved maize varieties and inorganic fertilizers in the scaling out programs. The maps will require updating to integrate data generated from more on-farm demonstration plots and the constantly improving spatial and temporal resolutions of remote-sensing data.

Chapter 1: Introduction to Africa RISING NAFAKA Partnership project and the scaling model

The Africa RISING-NAFAKA partnership project was funded by the USAID mission in Tanzania (2014–2020) as part of the Feed the Future (FtF) Initiative. The project focused on the delivery and scaling of promising interventions that enhance agricultural productivity in Tanzania (https://africa-rising.net/category/nafaka/). It promoted and scaled-out a variety of integrated technological packages with a climate-smart orientation. The technologies disseminated include improved crop varieties (maize, legumes, rice, and vegetables) that are high-yielding and drought-tolerant. The project also promoted best-bet agronomic management technologies using external inputs like inorganic fertilizers, lime, and the judicious application of pesticides. The improved postharvest management practices that were promoted include motorized shelling machines, collapsible dryer cases (CDC), and airtight bags for grain storage and food safety. Farmers were trained on protecting land and water resources through the introduction of soil and water management technologies. Soil fertility was improved through the application of inorganic fertilizers, organic amendments, and intercropping with legumes (soy and common beans). The use of tied ridges was promoted in semiarid regions to conserve the available soil moisture.

IITA led the project and key partners were CMSD/NAFAKA (a USAID-funded project under the FtF Initiative in Tanzania), Tanzania Agricultural Research Institute (TARI-Dakawa, Hombolo, and Uyole), district councils, four international agricultural research centers (CIMMYT, CIAT, ICRAF, and WorldVeg), as well as private sector representatives (agro-input companies, millers, and processors). The project was implemented in two phases: the first from 2014 to 2017 and the second from 2018 to 2020. It was implemented in Tanzania's Feed the Future - Zone of Influence (FtF-ZoI) regions of Manyara, Dodoma, Morogoro, Iringa, Njombe, Mbeya, and Songwe. The first and the second phases of the project activities were implemented in eight and 10 districts, respectively (Fig. 1).

The achievements of the Africa RISING project are:

1. Improved access by over 80,000 smallholder maize farmers to new crop varieties that are proven to be disease resistant, pest and drought tolerant, and contributing to better nutrition and increased income.
2. Over 100,000 ha of better managed land through accelerated adoption of technologies that promote sustainable management and protect land and water resources.
3. Strengthening and capacity development of farmers and local government institutions to offer extension advice and access to seed based on an informed diagnosis of production and nutritional constraints, and production and dissemination of quality declared seeds of legumes at the village level.

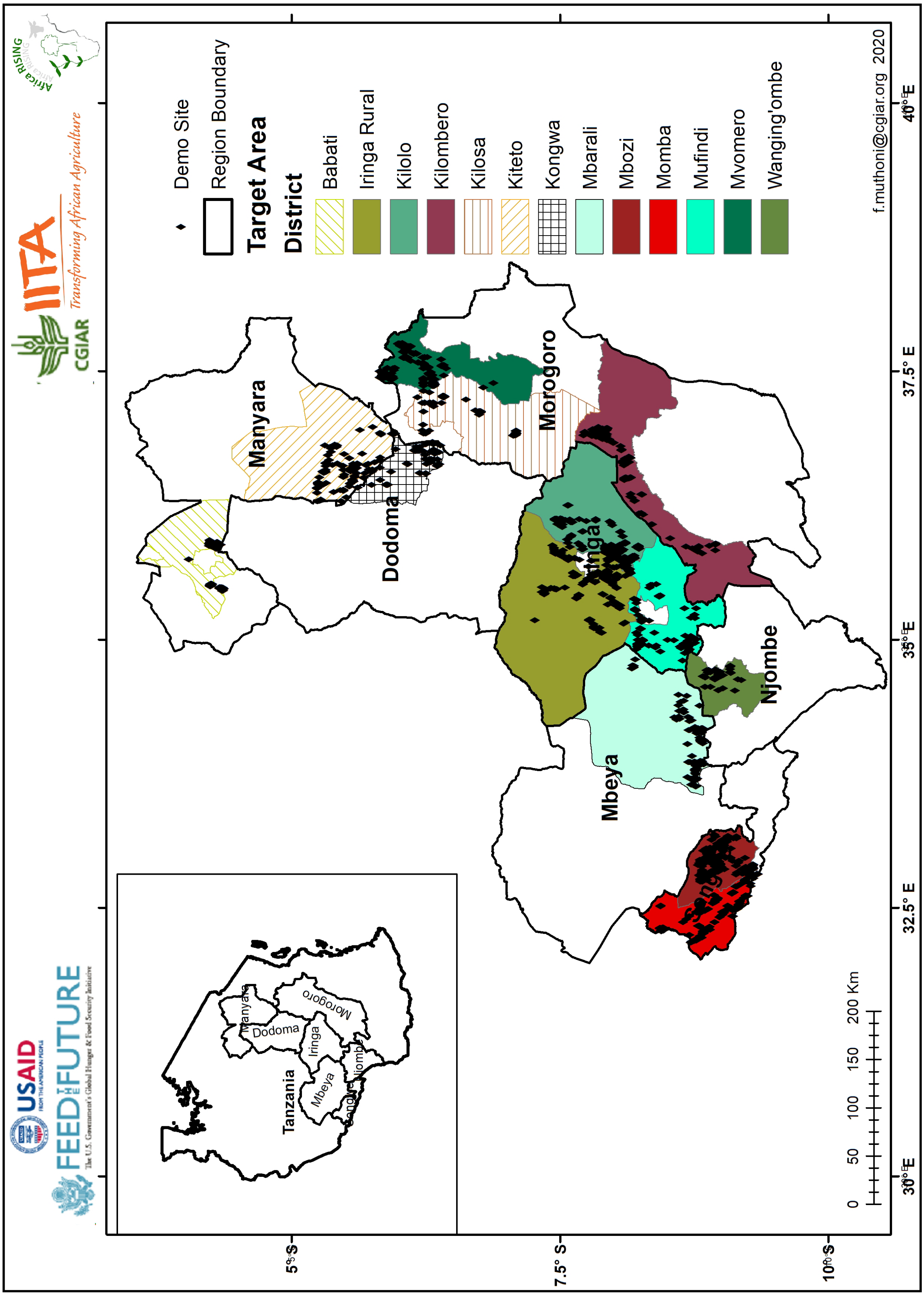

Figure 1. The action districts and the location of the demonstration plots for the Africa RISING-NAFAKA Partnership project. The action districts during phase 1 and 2 are represented by hachured lines and different colors, respectively. The demonstration plots were implemented from 2015 to 2020.

The scaling model of the Africa RISING-NAFAKA Partnership project

The Africa RISING-NAFAKA Partnership project approach involves village agricultural extension officers (VAEOs) as an integral part of the process in promoting improved cereals (maize and rice) and legumes (soybean and common beans) production technologies among farmers. The project promoted other technologies that included postharvest food handling and nutrition management, and soil and water conservation measures. However, this compendium focuses on the production of maize grains and the application of inorganic fertilizers. The project's scaling model introduces improved cereal & legume production technologies in the communities using mother-baby-grandbaby demonstration sites which serve as training or learning sites for extension staff and farmers. The extension staff and lead farmers undergo season-long training using the first year demonstration sites. They then train other farmers in a cascading mode in the consequent seasons with technical backstopping from staff from participating research and development institutions (Fig. 2).

The fundamental principles that guided the success of the scaling model were:

1. The partnership between the international agricultural research institutions and the national research institutions at the demonstration sites.
2. The close working relationship with the development partners (both government and nongovernment/private) that implemented activities in and around the project area.
3. Leveraging resources among participating institutions.
4. Close collaboration with district and ward agricultural extension officers and VAEOs.
5. Use of geographic information systems (GIS) to better target interventions.
6. Regular communication via different modes (WhatsApp groups, reports, meetings) among stakeholders—farmers, implementing partners, government, and donors.

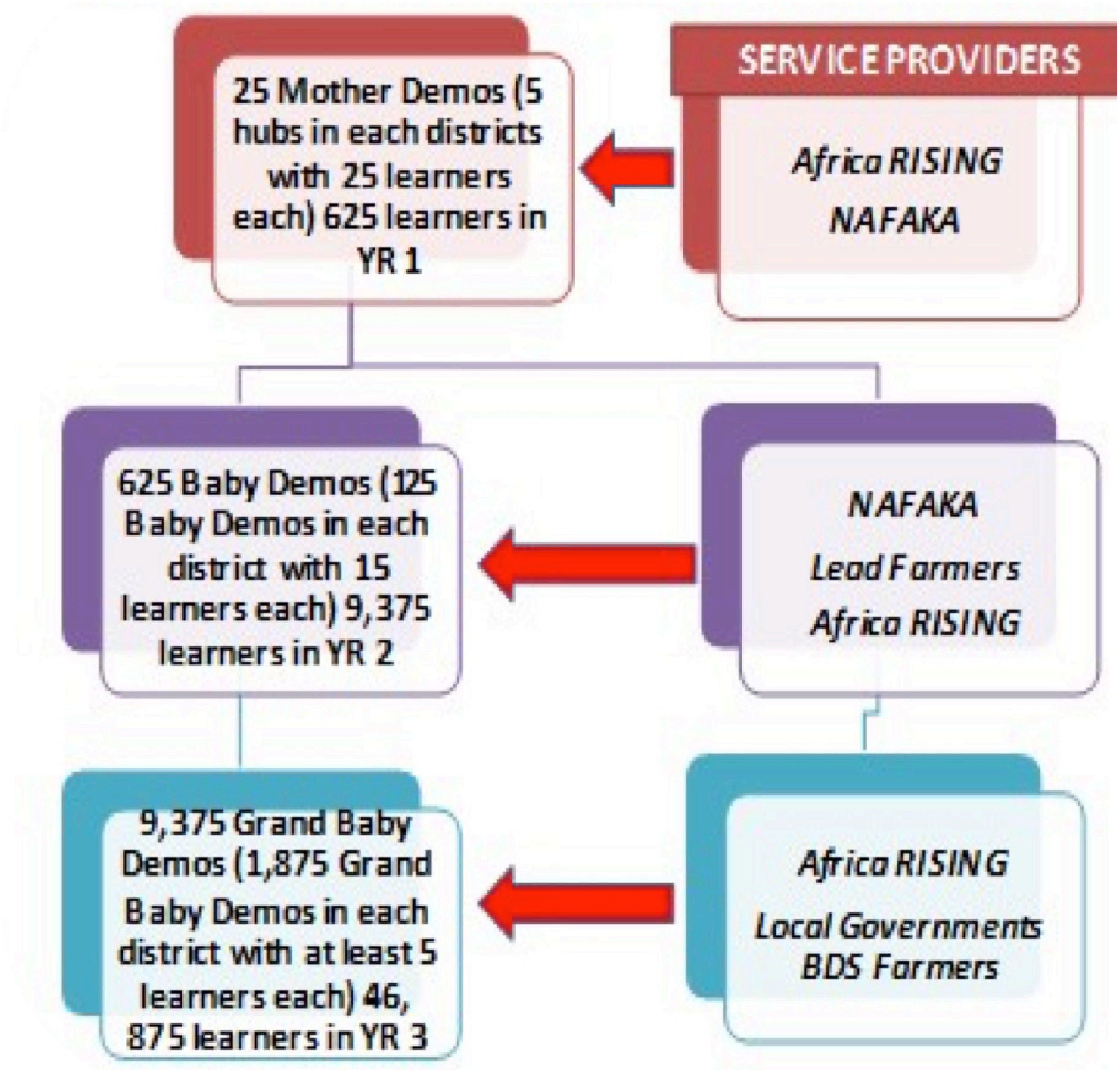

Figure 2. The scaling model for the Africa RISING-NAFAKA Partnership project. The scaling followed a cascading approach with the number of farmers trained in demonstration plots reaching others in the subsequent year.

Role of GIS in targeting agronomic technologies

The purpose of the scaling program was to facilitate the delivery of improved technologies to be adopted by farmers on a large scale in suitable agroecologies. The project demonstrated the best-bet integrated agronomic technologies at sites identified by communities within selected villages of defined agroecologies (Fig. 3). The integrated technologies were chosen with the participation of farmers, extension staff, and researchers from international and national research institutes. After the best-bet integrated technologies were demonstrated and their performance evaluated, the next question that emerged was, "where else, beyond the demonstration sites, can the technologies be scaled out with expected similar outputs"? The Africa RISING-NAFAKA partnership project utilized GIS's spatial analysis to resolve the above question. Maps for the suitability of selected integrated technologies were generated using a bottom-up approach that utilized crop yields and spatial data from the demonstration plots (Fig. 1) and the earth-observing satellites, respectively.

The purpose and target users of maps

The primary aim of the maps presented in this compendium is to enhance the targeting of agronomic technologies to improve yields and promote a healthy environment. This is based on the realization that scaling out technologies in their suitable biophysical and socioeconomic context enhances their probability of adoption. The maps and accompanying agronomic information in this compendium are intended to be used by extension staff and development agencies that focus on scaling-out agronomic technologies in the FtF-ZoI regions of Tanzania (Fig. 1). The information provided in the maps is expected to guide the extension agencies to fine-tune agro-advisories to the local biophysical and socioeconomic contexts. The specific objectives of the compendium are to:

1. Identify the spatial variation of the factors that limit agricultural productivity and adoption in the FtF-ZoI in Tanzania.
2. Identify the integrated technologies that alleviate the limiting factors at specific biophysical contexts, based on information generated from the demonstration plots from the project.
3. Identify the priority areas for scaling the integrated agronomic technologies so that the impact can be maximized with limited resources in the FtF-ZoI in Tanzania.

Chapter 2: Spatial variation of biophysical and socioeconomic parameters that limit the adoption of integrated agronomic technologies

This chapter illustrates the spatial variation of biophysical and socioeconomic conditions in the project area that influence the productivity and adoption of integrated agronomic technologies. The digital information was obtained from earth-observing satellites and GIS. The maps represent the altitude (height above sea level), slope, elements of weather, and physical and chemical characteristics of soils. Agriculture productivity largely depends on these biophysical conditions.

Biophysical parameters

Agriculture in the FtF-ZoI regions in Tanzania is mainly rainfed, therefore significant changes in rainfall have a significant influence on agricultural productivity. The occurrence of frequent and widespread extreme weather events such as droughts, floods, hailstorms, and frost is a major risk to crop production in the regions. Targeting appropriate climate-smart agricultural technologies requires a good understanding of weather conditions over space and time.

Although weather is critical for agricultural production, the availability of reliable data in the ZoI is low. There are a few weather stations in the vast area, and the few that exist have huge data gaps. Comparison of rainfall and temperature estimates from earth-observing satellites at a monthly scale showed high agreement with available data from weather stations. Reliance on earth-observing satellites is advantageous since they cover every space with frequent repetitive measurements, some of which are near real-time. Therefore, the satellite estimates of weather elements were used to complement the few existing rain gauges to deliver reliable agro-advisories at local levels.

Topography

Ground surface elevation

Earth-observing satellites directly measure the ground surface elevation (height above sea level; Fig. 3). Lowlands occur in Kilombero district (44–334 masl) of Morogoro region. Highlands (> 1200 masl) occur in parts of Wanging'ombe, Mufindi, Iringa rural, Kilolo, Kiteto, and Babati districts (Fig. 3). Crop varieties are bred for specific ranges of elevation (see Chapter 3). Elevation also determines weather conditions since highlands experience cooler temperatures (Figs. 11 and 12) and longer growing seasons. Lowlands experience warmer temperatures (Figs. 11 and 12) and shorter growing seasons compared to highlands.

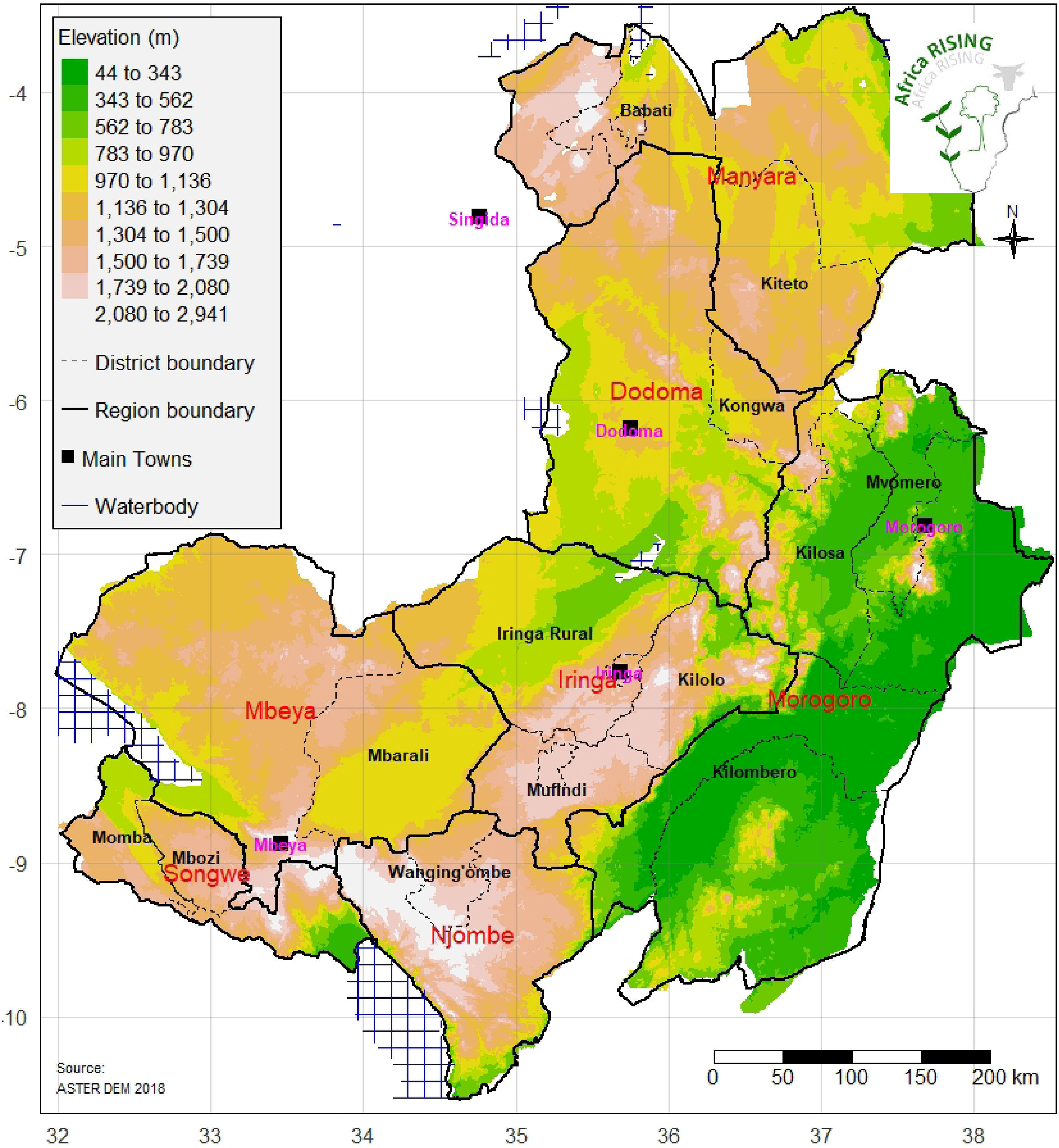

Figure 3. Digital Elevation Model (DEM) showing the height above sea level in meters in the FtF-ZoI in Tanzania.

Terrain slope

Important topographical elements such as slope level (Fig. 4) were generated from the surface elevation layer. The slope level is an indicator of soil erodibility. Soil loss is faster on slopes that are steeper than 5.15⁰. Land in Mbarali and Kilombero districts is mainly flat and is suitable for growing paddy rice that requires irrigation. Steep slopes occur in Wanging'ombe, Kilolo, Kilosa, Mvomero, Kiteto, and Babati districts (Fig. 4). Soils eroded from land located on steep slopes is deposited on flat bottomlands that, consequently, tend to be more fertile, although they may experience waterlogging due to poor drainage. The slope layer is an essential guide on regions to target soil and water conservation measures such as contour bunds and forage strips.

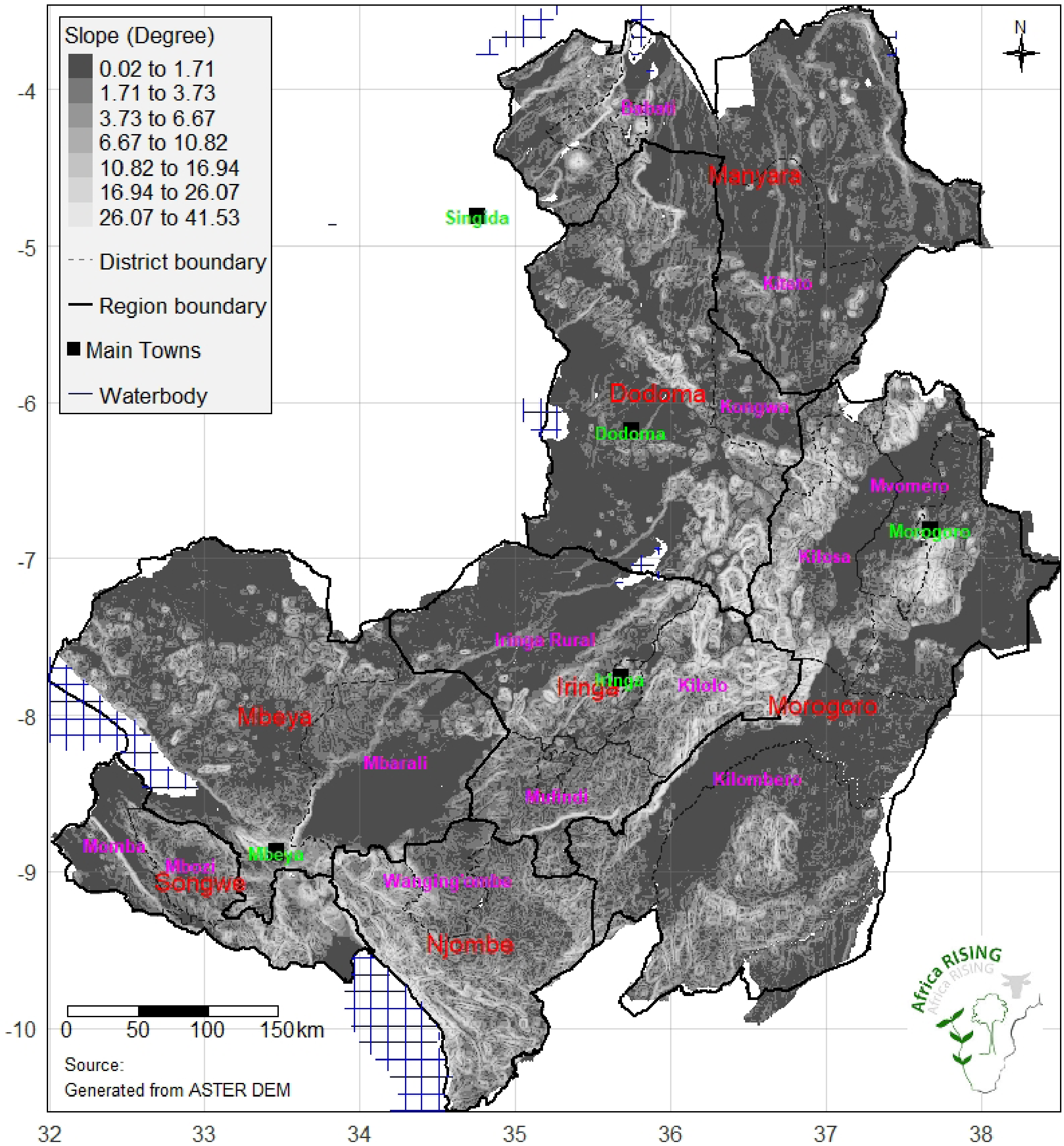

Figure 4. The degree of slope of the terrain in the FtF-ZoI in Tanzania. Flat and steep slopes are shown in dark grey and light grey colors, respectively.

Rainfall

Mean annual rainfall

Agriculture in the FtF-ZoI is mainly rainfed. Therefore, the amount and distribution of rainfall are among the most important determinants of agricultural productivity. Fluctuations of rainfall determine the variability in soil moisture, which limits plant growth and yield. The availability of satellite weather data enables quantification of climate change over space and time that is crucial for targeting climate-smart agricultural technologies. Using this approach, maps on the spatial-temporal distribution of annual rainfall (Fig. 5) were generated and are shown together with their long-term trends (Fig. 6). Within the FtF-ZoI are wide variations in rainfall ranging from semiarid lands in Dodoma to humid climate in the Southern Highlands within Mbeya and Iringa regions.

The mean annual rainfall ranges from 350 to 1800 mm (Fig. 5). High annual rainfall (> 1200 mm) occurred in Songwe, Njombe, and Morogoro regions, commonly referred to as the Southern Highlands of Tanzania. Semiarid lands that experience less than 650 mm of annual rain occur in large areas of Dodoma and Manyara regions (Fig. 5). Large areas of Mbarali and Mvomero districts in Mbeya and Morogoro regions, respectively, are within the dryland.

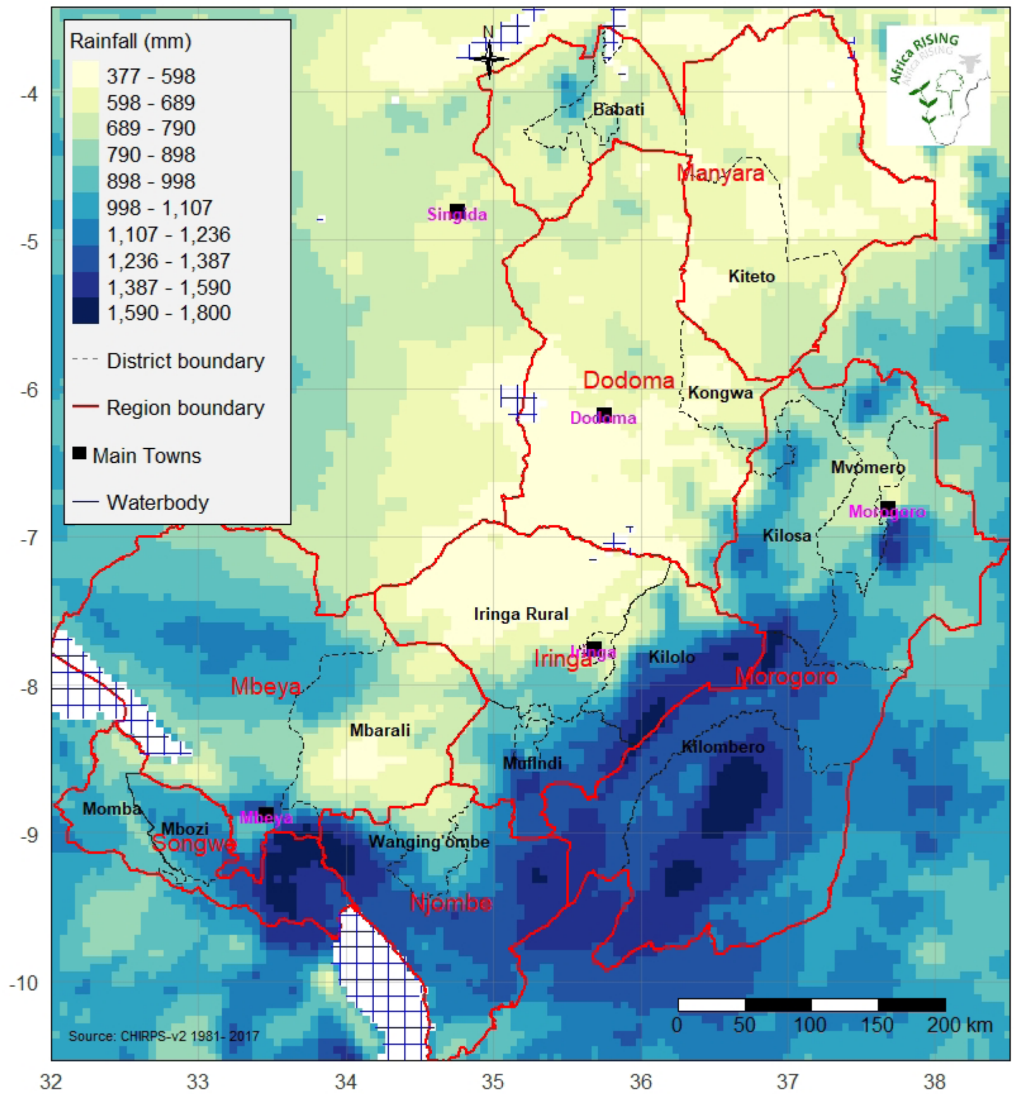

Figure 5. Spatial distribution of mean annual rainfall in the FtF-ZoI in Tanzania. The mean annual rainfall data was generated by averaging total monthly rainfall for 37 years (1981–2017).

Annual rainfall trend

Climate change is one of the factors attributed to the decline of crop production in the FtF-ZoI. Between 1981 and 2017, there was an increase of annual rainfall primarily in the semiarid lands of parts of Mufindi, Iringa rural, Wanging'ombe, Kilombero, Kongwa, and Kiteto districts (Fig. 6). A decrease in annual rainfall occurred in humid areas in Morogoro and Songwe regions and Babati district. The changes in the rainfall amount require an adaptive targeting of agronomic technologies that suit the new conditions.

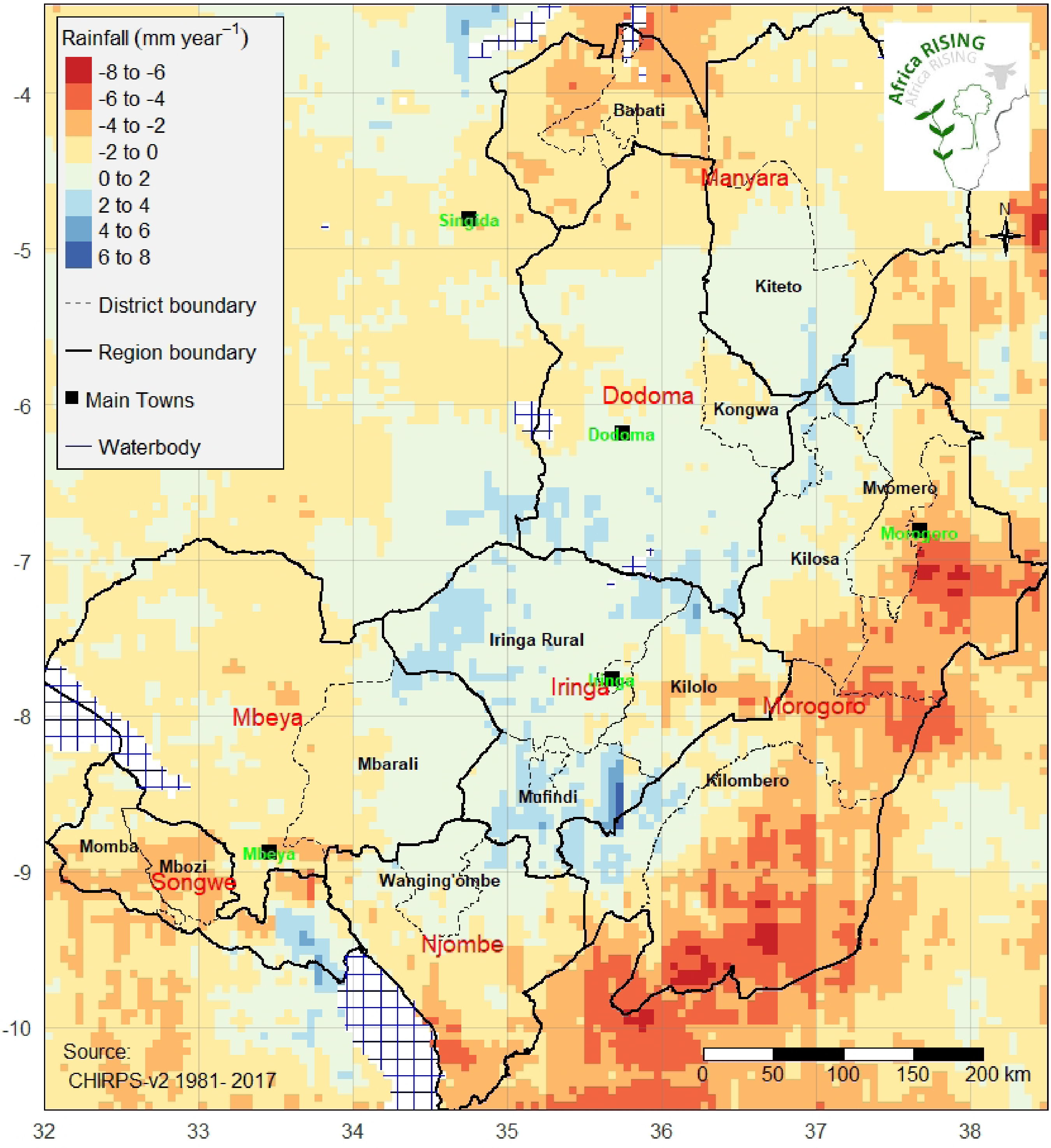

Figure 6. The trend of annual rainfall over the last 37 years (1981 - 2017) in the FtF-ZoI of Tanzania. The red-yellow color tones represent the area where annual rainfall is declining while the blue shades represent areas experiencing an increase in annual rainfall.

Trends of monthly rainfall

Climate change causes a temporal shift of rainfall that can significantly affect the cropping calendar activities such as the timing of harvesting and the length of the growing season. Cereal crops like maize are most sensitive to soil moisture deficit during the germination, flowering, and silking stages. Figure 7 shows the trend of rainfall over 37 years for December; that is usually a planting or germination period in a large area of the FtF-ZoI. December rainfall increased (< 1.3 mm/year) in Mbeya, Songwe, and Njombe regions and decreased in the rest of the areas. Morogoro region had the most pronounced decline of December rainfall (–2.3 to –3.3 mm/year).

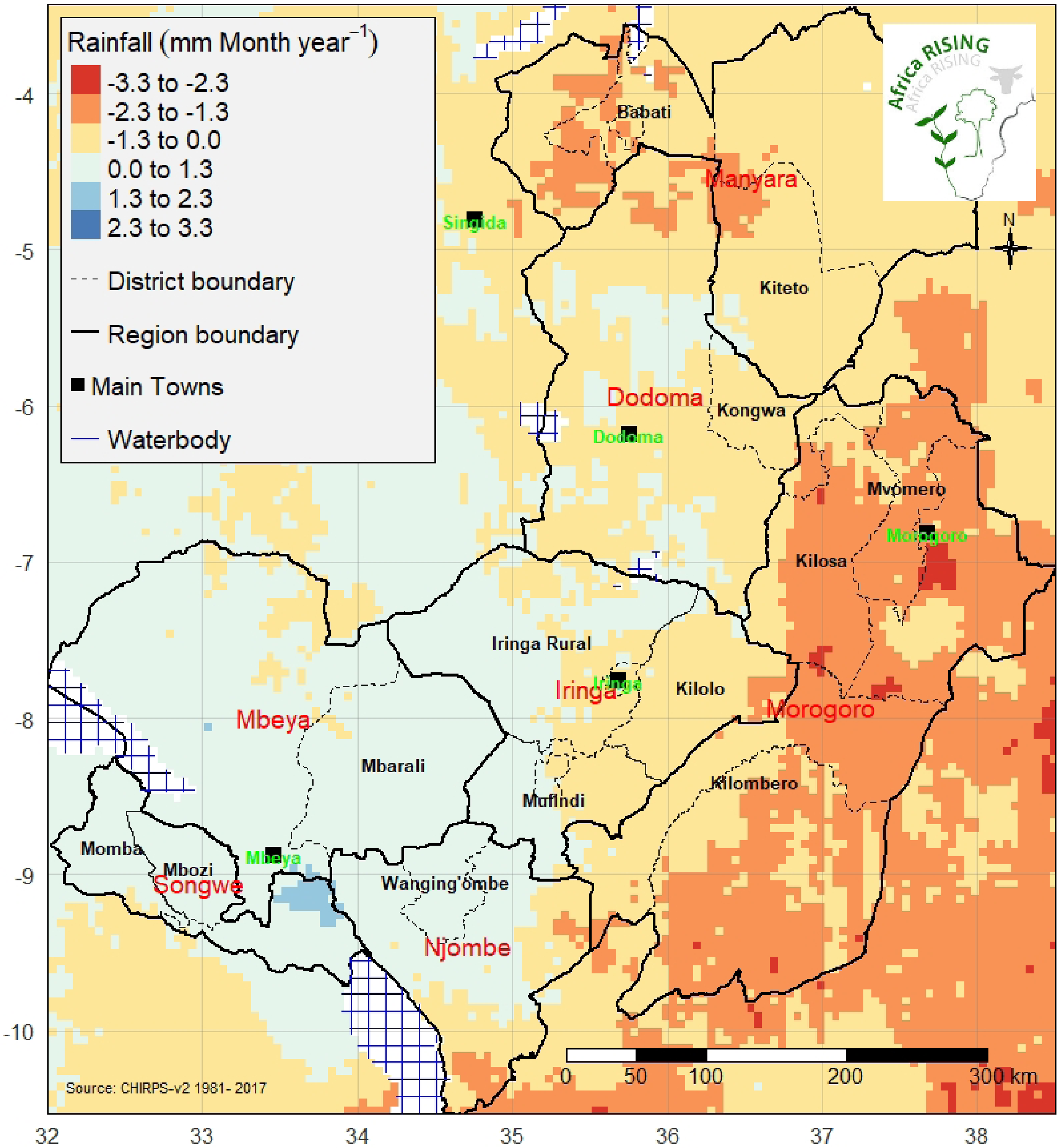

Figure 7. The trend of December rainfall over the last 37 years (1981–2017) in the FtF-ZoI in Tanzania. The red-yellow color represents areas where annual rainfall is declining while the blue shades represent areas experiencing an increase in annual rainfall.

Severe droughts during the flowering stage could result in total crop failure even if normal rainfall were experienced in the rest of the growing season. Maize reaches the flowering stage in February in most areas in the FtF-ZoI. There was a low magnitude increase of February rainfall (< 1 mm/year) in Babati, Kongwa, Kiteto, Kilosa, Mvomero, and Iringa rural districts (Fig. 8). For the last 37 years (1981–2017), February rainfall declined in Momba, Mbozi, Tunduma, Wanging'ombe, and part of Mbarali districts located in the most productive part of the Southern Highlands of Tanzania.

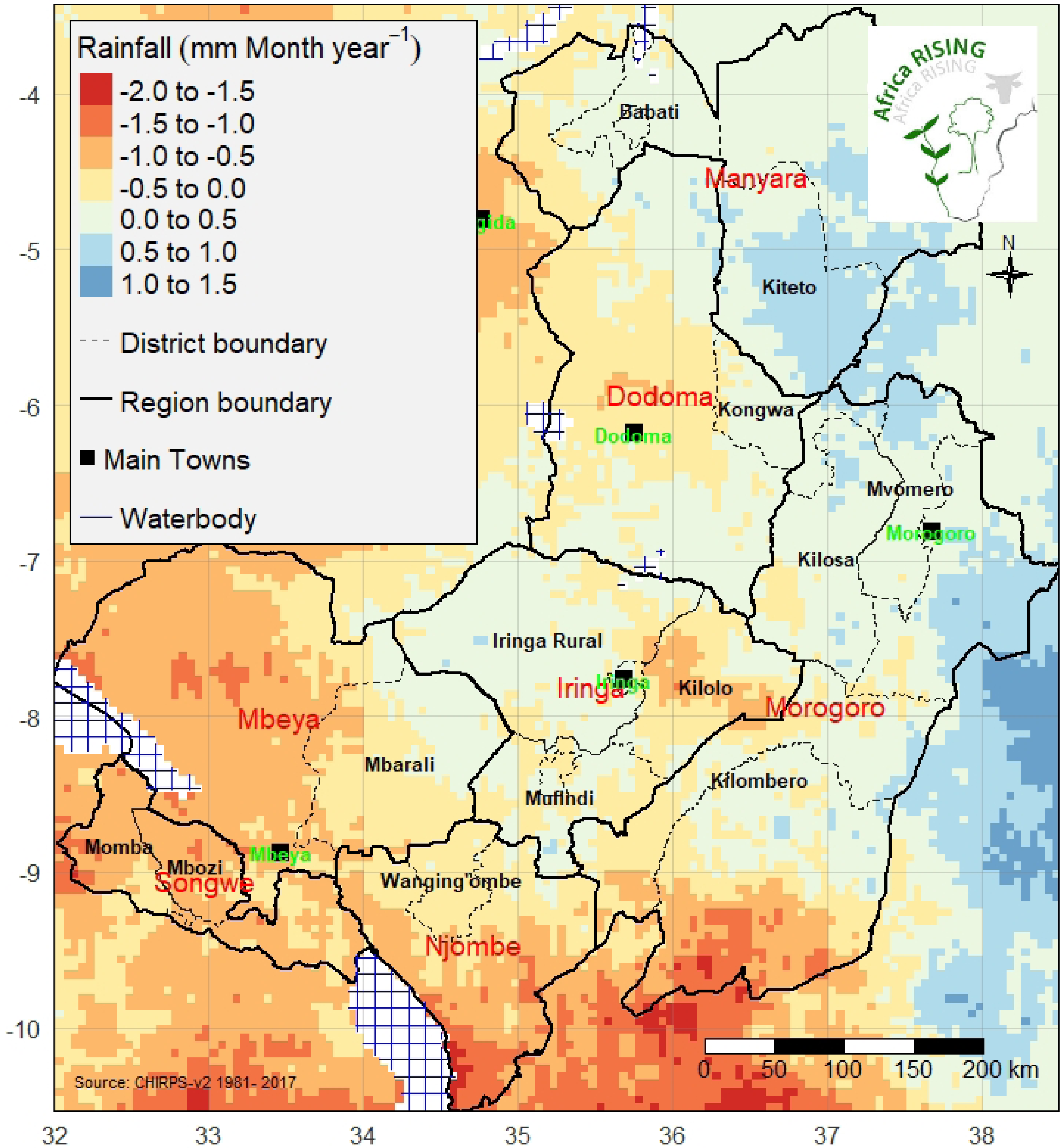

Figure 8. The trend of February rainfall over the last 37 years (1981–2017) in the FtF-ZoI in Tanzania. February is usually the flowering period of the maize crop in large areas of the zone. The decline of rainfall during the flowering stage can reduce the yields even when the rest of the growing season experiences normal rain.

Increased rainfall when maize has reached physiological maturity may lead to rotting and infestation by mold and aflatoxins. Except in Mbarali District, rainfall during May declined in almost the entire FtF zone (Fig. 9). The reduced rainfall in May can reduce instances of pre-harvest losses resulting from maize rotting, and infestation of molds and aflatoxins. In Morogoro Region, rainfall declined in December (Fig. 7) and May (Fig. 9), though with a higher magnitude in May.

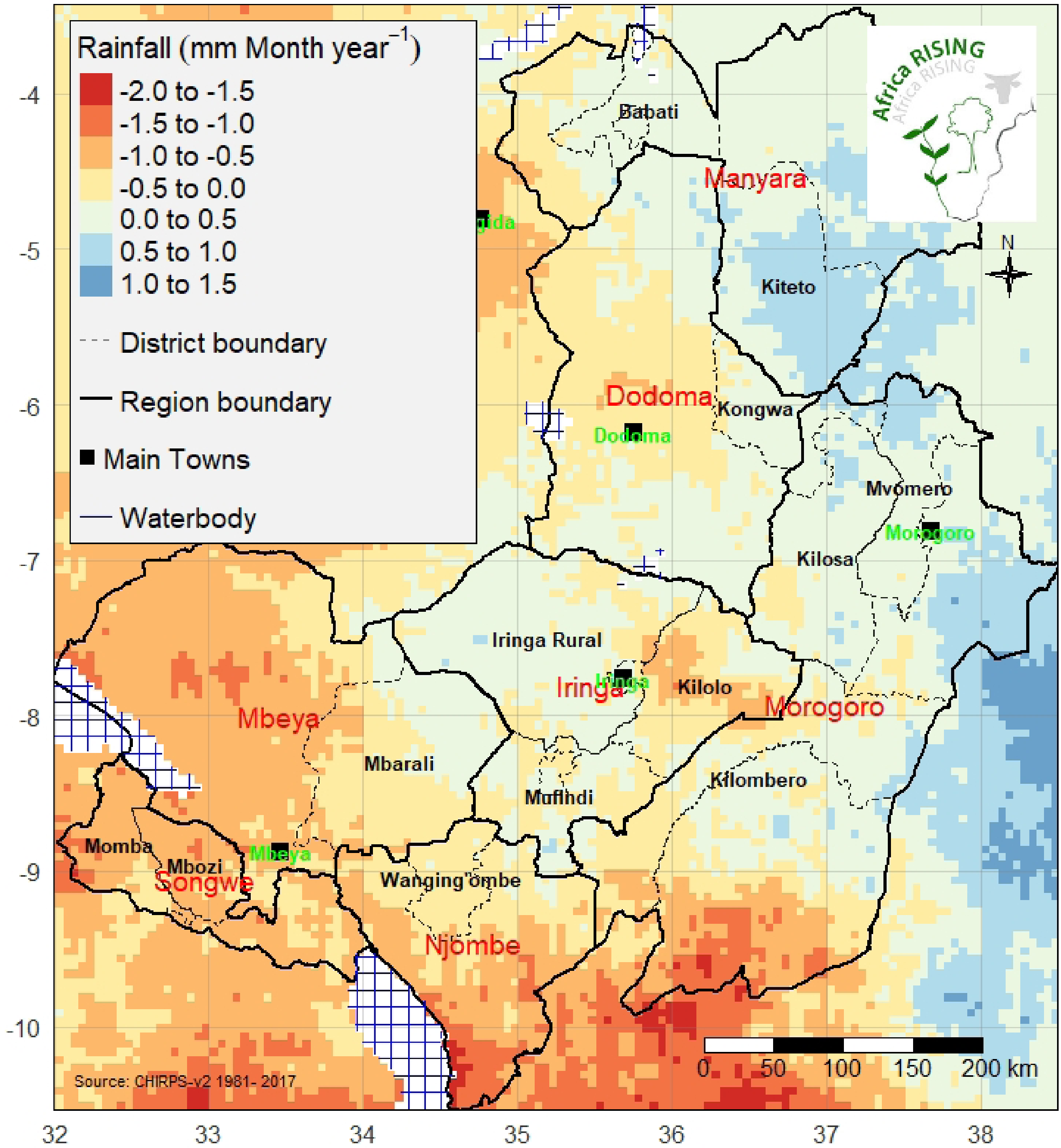

Figure 9. The trend of May rainfall over the last 37 years (1981–2017) in the FtF-ZoI in Tanzania. May is usually the harvesting period for maize crops in large areas of the zone. Increased rainfall when maize has reached physiological maturity may increase pre-harvest losses.

Annual rainfall anomaly

The difference between total annual rainfall for each year and the long-term mean annual rainfall (Fig. 5) was divided by the standard deviation to derive the annual rainfall anomalies. The anomalies indicate the departure from the long-term mean. Negative values represent the below normal rains (droughts), while the positive values indicate above normal rains associated with flood risk. Frequent droughts of different magnitude are common in the FtF-ZoI in Tanzania. The FtF zone in Tanzania experienced widespread droughts in the following years: 1983, 1987, 1988, 1993, 2002, 2005, 2010, and 2012 (Fig. 10). The above-normal rains occurred in 1986, 1989, 1997, 2002, 2006, and 2014. Exceptionally high rainfall is associated with floods that damage crops. The other years experienced a share of drought and above normal rains that varied over space.

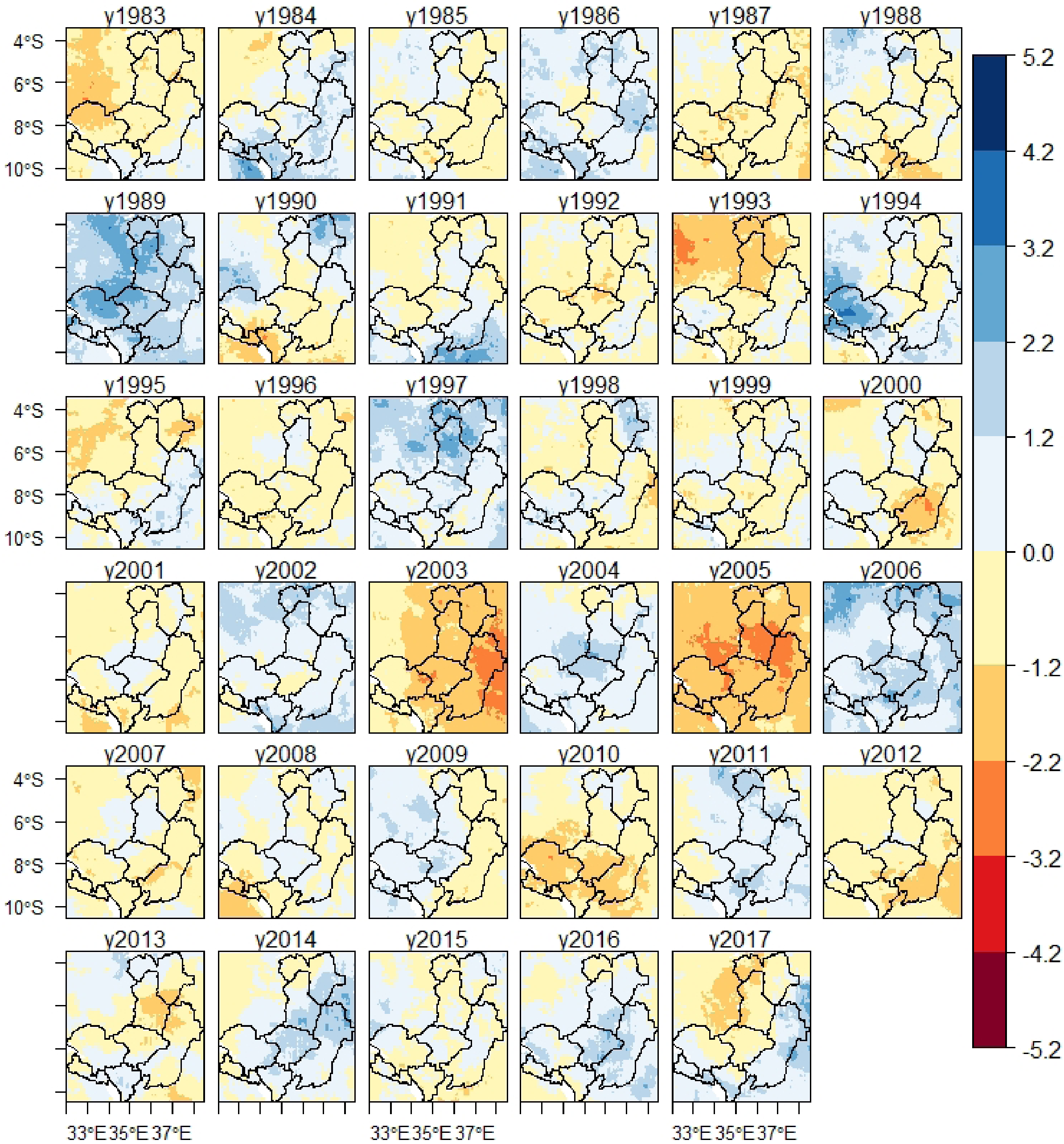

Figure 10. The standardized anomalies for annual rainfall (1983–2017) in the FtF region in Tanzania (black polygons). The anomalies indicate the magnitude of departure from long-term mean rainfall. Negative values represent areas that experienced below normal rainfall that is associated with droughts. The zone with positive values (blue color), received above-normal rainfall that may lead to floods.

Temperature

Maize thrives well in areas where the maximum temperature (Tmax) is below 30ºC, and minimum temperature (Tmin) is above 8ºC. Tmin below 8ºC leads to frost that damages the leaves and retards growth and grain filling in maize crop. Extreme maximum temperatures higher than 38ºC reduce yields and viability of pollens. Extreme maximum temperatures during droughts accelerate the loss of soil moisture through evapotranspiration. Each day with temperature above 30ºC reduced maize yield by 1% under optimal rainfed conditions, and by 1.7% under drought conditions. Crop varieties differ in their tolerance to frost. The optimum temperature range for germination is between 20 and 30ºC. Under warm moist conditions, seedlings emerge after about 6–10 days, but under cool or dry conditions, it may take two weeks or longer.

Maximum temperatures (Tmax)

Dodoma and Morogoro regions experience the most extreme mean annual Tmax (> 30ºC; Fig. 11). Cooler zones (Tmax < 25ºC) occur in highlands with altitudes above 1500 m (Fig. 3) located in Wanging'ombe, Mufindi, Kilolo, Iringa Rural, and Babati districts.

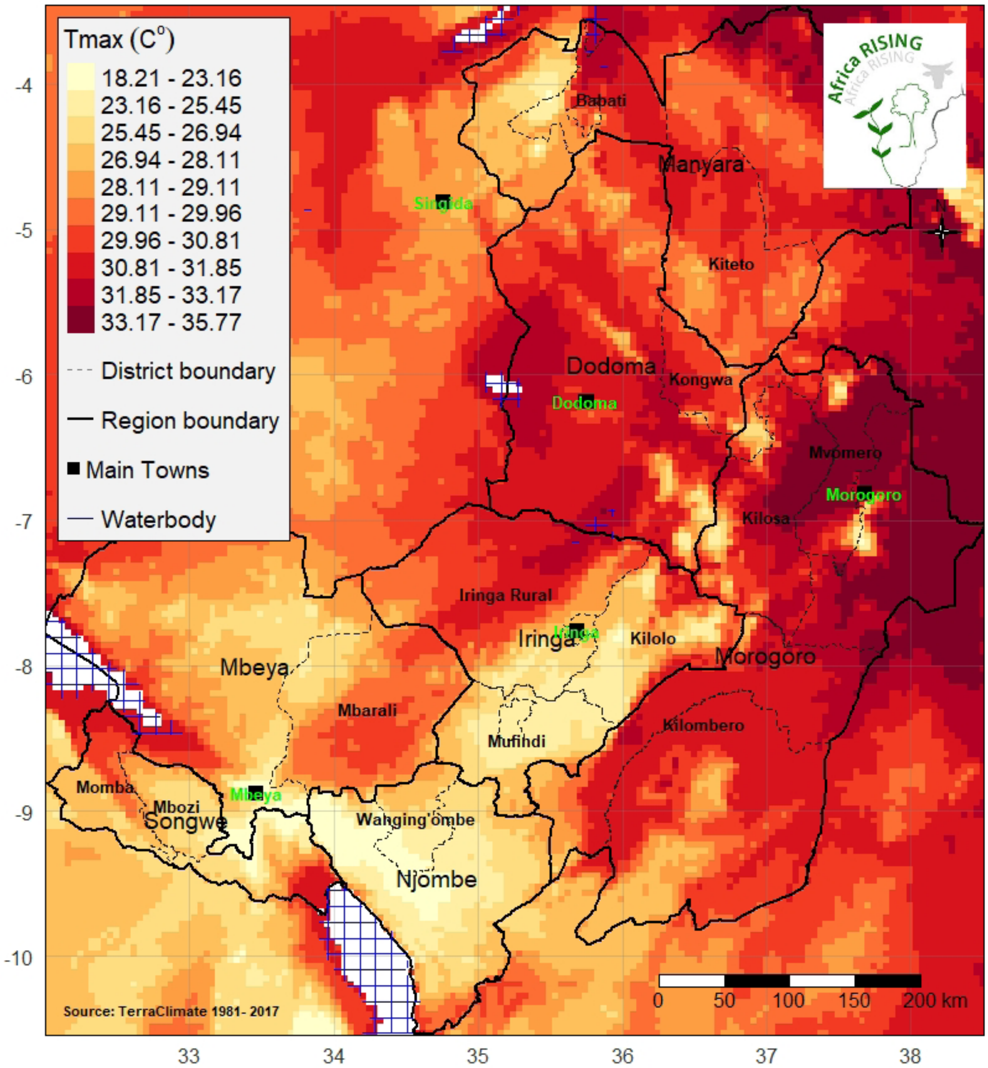

Figure 11. The spatial distribution of the mean maximum annual temperature (TMax) in the FtF-ZoI in Tanzania.

Minimum temperatures (Tmin)

Cooler regions are associated with a longer growing season. Extreme low temperatures may cause frost that damages crops. The highlands (> 1500 masl, Fig. 3) in Njombe and Iringa regions experienced the lowest minimum temperatures. In these regions, low Tmin causes frost and hailstorms that damage crops on the farm.

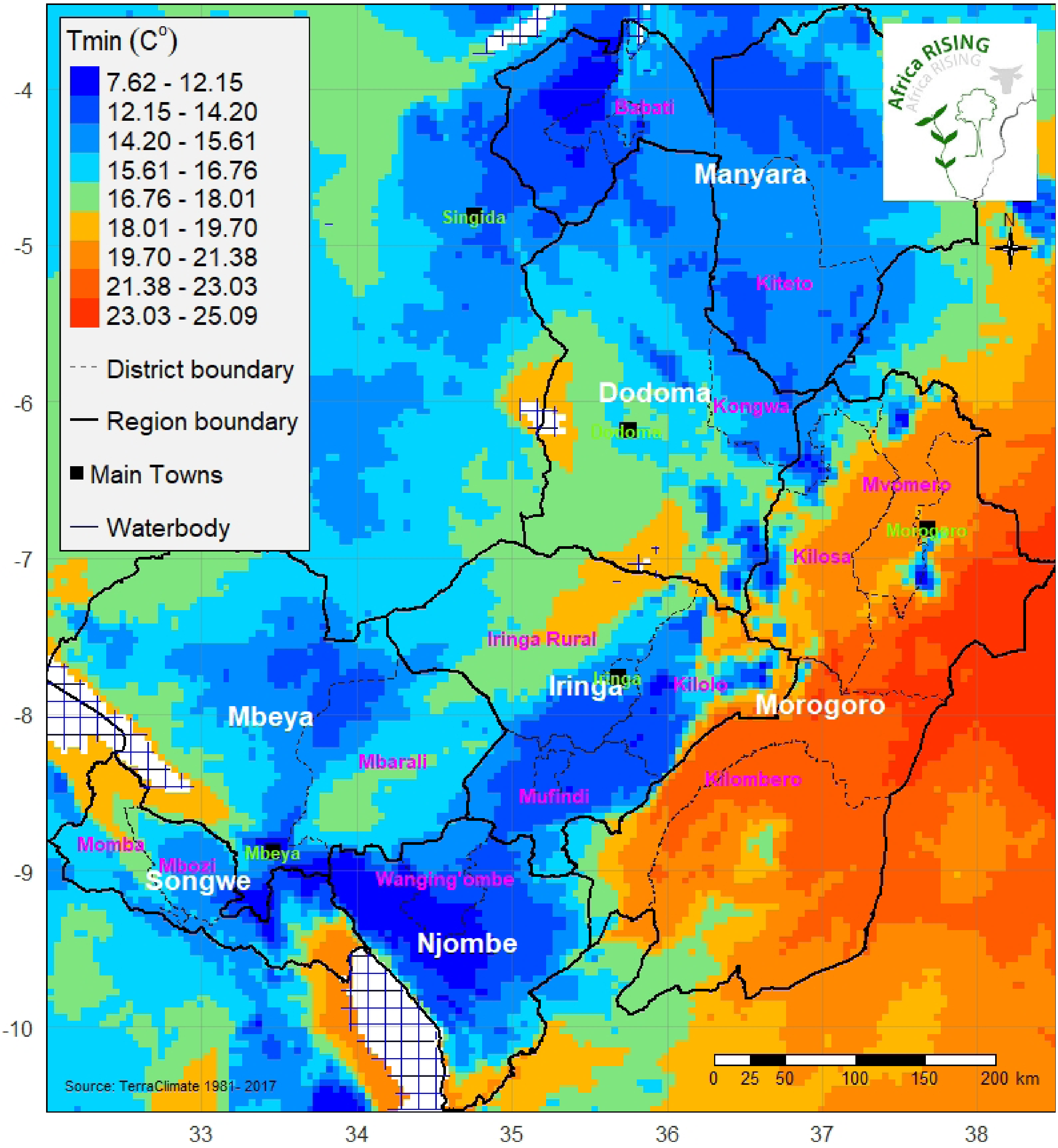

Figure 12. The spatial distribution of the mean minimum temperature (TMin) in the FtF-ZoI in Tanzania.

Soil characteristics

Moreover, different surfaces produced from earth-observing satellites are used to generate digital maps of different soil physical and chemical characteristics such as soil pH, texture, bulk density, and nutrient contents. The available gridded maps for soil physical and chemical properties have 250 × 250 meters spatial resolution, although soil properties change at a much finer scale. Therefore, the fine-scale variability of the soil layers is masked out. However, these are the best available digital maps of the soil's physical and chemical characteristics. The soil physical properties were originally mapped at 6 standard depths (0–5 cm, 5–15 cm, 15–30 cm, 30–60 cm, 60–100 cm, and 100–200 cm). The grid layers for the first three standard depths (0–5 cm, 5–15 cm, 15–30 cm) were averaged to produce one grid layer for each soil variable.

Soil pH

Soil pH determines the availability of nutrients to plants. The optimum pH for growing maize ranges from 6 to 7.2. Maize has poor tolerance to low soil pH (< 5.0) because such soils are susceptible to aluminum toxicity that, in turn, reduces root development. Figure 13 shows that soils in the southern highlands (Kilolo, Mufindi, Wangingo'mbe, Kilosa, Kilombero, and Mbozi districts) are largely moderately acidic (pH 5–6). In Kilolo and Mbozi districts, the project introduced lime to increase soil pH, and gypsum to improve soil structure and calcium saturation. The entire Dodoma and Manyara regions and large parts of Iringa rural and Mbarali districts are slightly acidic (pH 6–7).

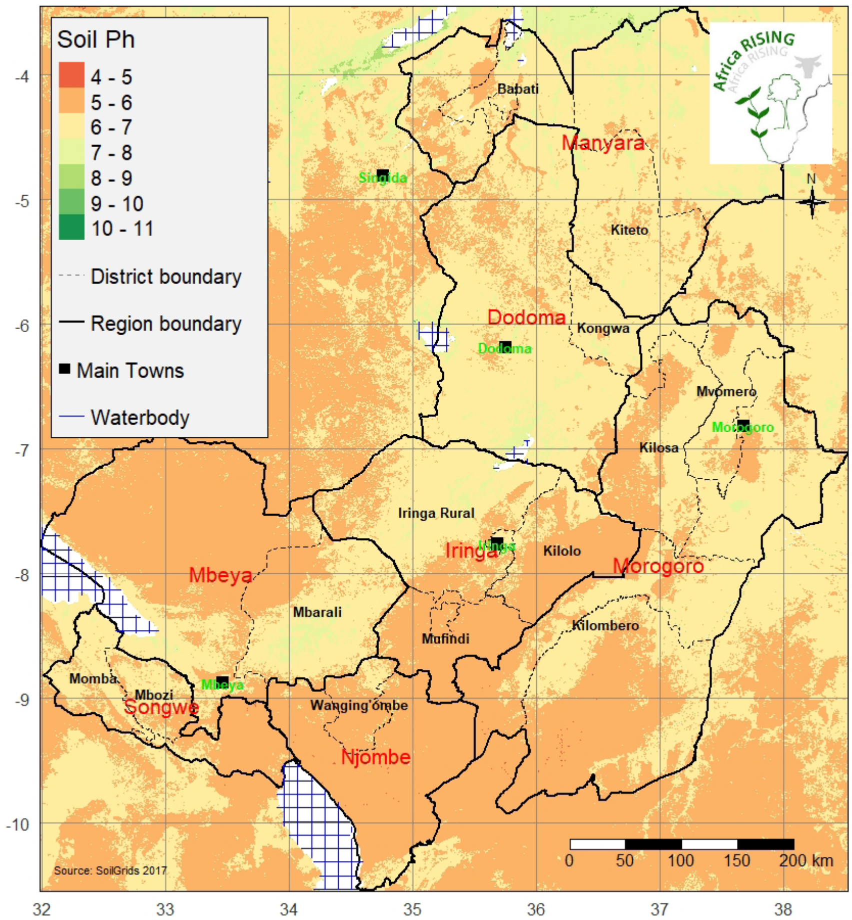

Figure 13. The spatial distribution of soil pH of the topsoil (0–30 cm) in the FtF-ZoI region in Tanzania. The maps have 250 meters spatial resolution, and therefore, fine-scale variability of the soil pH is masked out.

Soil organic carbon (SOC)

Soil organic carbon (SOC) is an indicator of soil health. The decomposition of SOC releases nitrogen, phosphorus, and other nutrients. SOC improves soil structure that consequently enhances water-holding capacity, infiltration, and soil microbes. SOC is highest in a narrow belt running in the Southwest direction from Morogoro to Mbeya cities (Fig. 14). This belt is wet and humid (Fig. 5) and comprises forest plantations in the area. The highlands occurring in Babati District (Fig. 3) have high SOC (> 26 g/kg; Fig. 14). Among the target districts for the Africa RISING NAFAKA Partnership project, Kongwa, Iringa Rural, and Mbarali districts had the lowest SOC (< 9 g/kg).

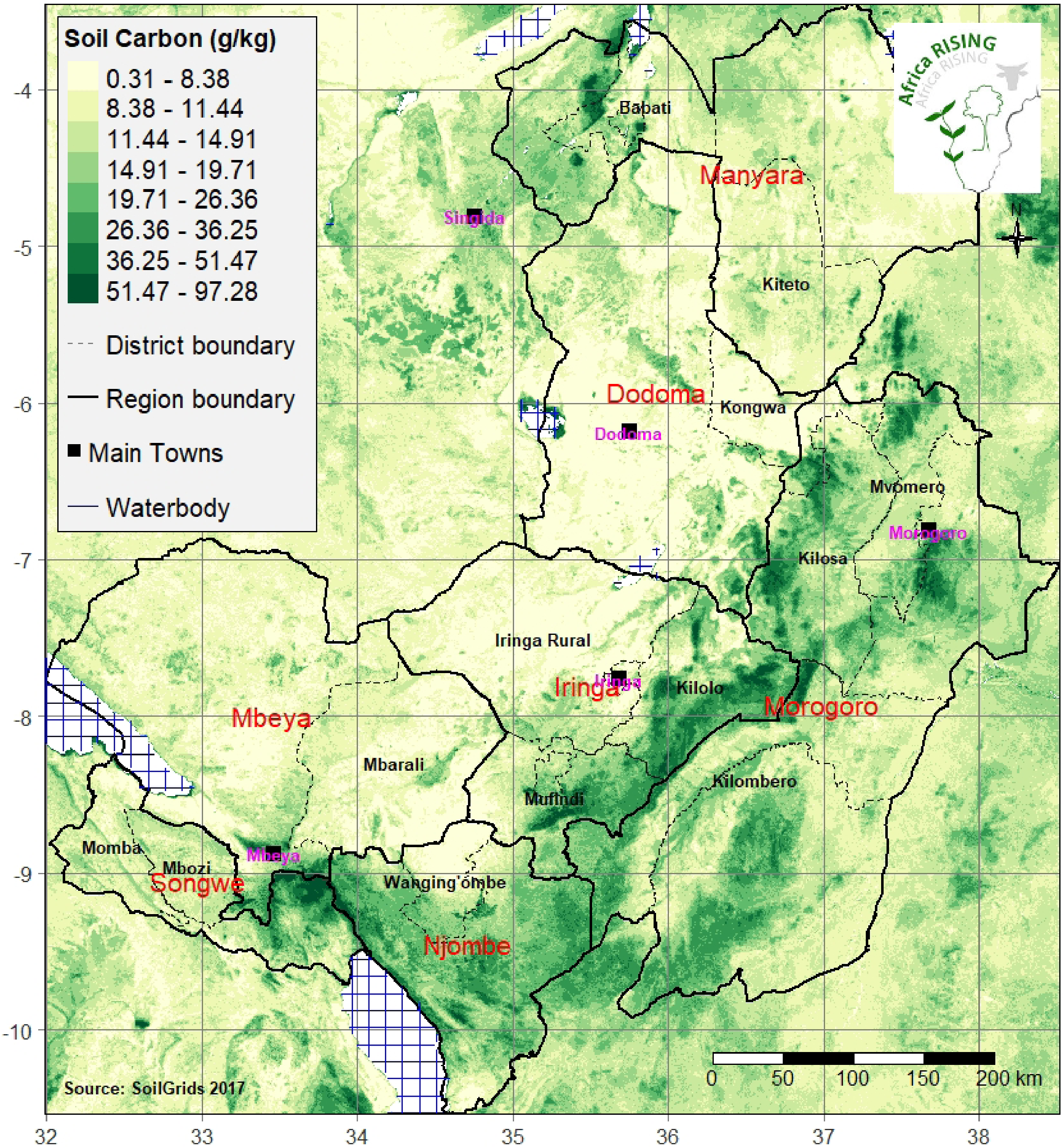

Figure 14. The spatial distribution of soil organic carbon (SOC; g/kg) in the FtF region in Tanzania.

Soil bulk density

Bulk density is an indicator of soil compaction which is dependent on soil texture, mineral content (sand, silt, and clay), and organic matter particles. Bulk density determines soil's structural stability, water and solute movement, and aeration. High bulk density is an indicator of low soil porosity and compaction that hinders root development, aeration, and infiltration of water. By reducing infiltration, compaction can lead to increased runoff and soil erosion, especially on steep slopes shown in Figure 4. Bulk density was lowest in Dodoma and the northern half of Iringa Region (Fig. 15). The highest bulk density was recorded in the Southern Highlands in Morogoro, Njombe, and Songwe regions.

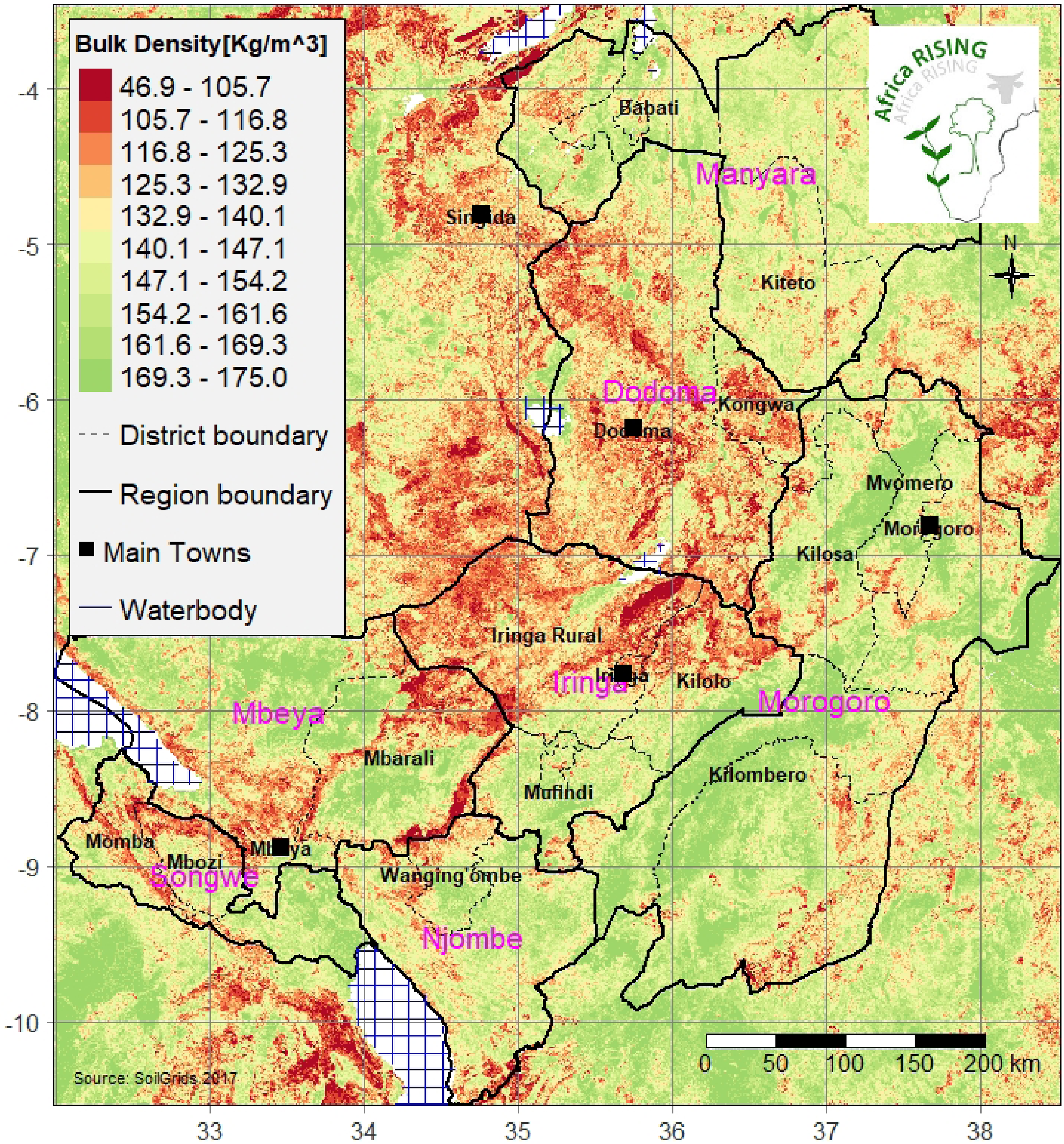

Figure 15. The spatial distribution of soil bulk density (kg/m3) of the topsoil (0–30 cm) in the FtF-ZoI in Tanzania.

Cation exchange capacity (CEC)

CEC is the total capacity of a soil to hold exchangeable cations. It is a very crucial soil property that influences the soil's structural stability, nutrient availability, soil pH, and the reaction to fertilizers and other amendments. The primary ions associated with CEC in soils are the exchangeable cations calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), and potassium (K^{+}). Soils with a higher fraction of organic matter (Fig. 14) tend to have a higher CEC. Soils with low CEC are more likely to develop deficiencies in potassium (K^{+}), magnesium (Mg^{2+}), and other cations. Soils with high CEC are less susceptible to leaching of these cations. CEC was highest around Mbeya city (Fig. 16), in the area with the most SOC (Fig. 14).

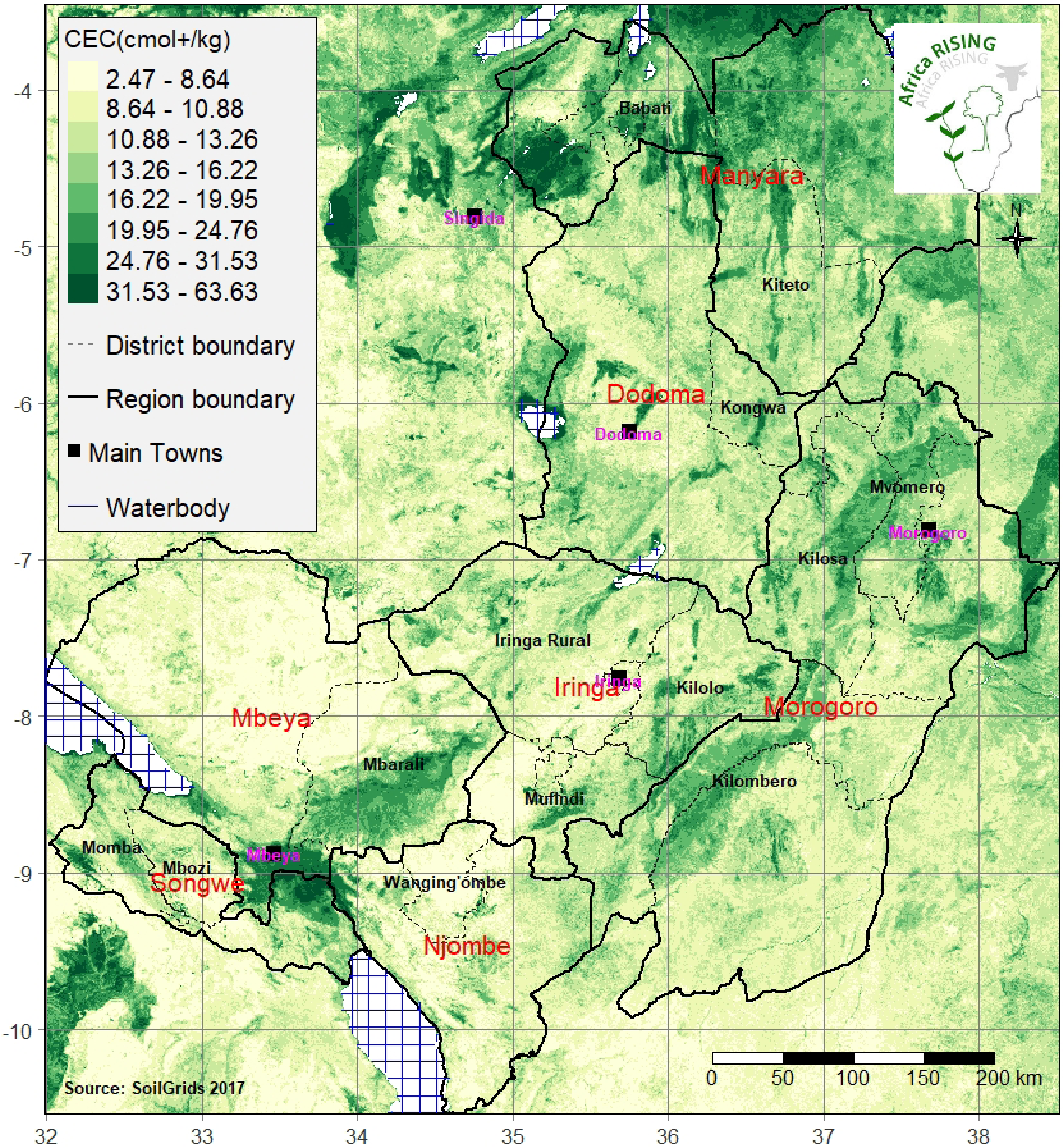

Figure 16. The spatial distribution of soil cation exchange ions (CEC, cmol+/kg of fine earth) in the FtF region in Tanzania.

Socioeconomic parameters

The spatial variation of socioeconomic parameters such as population density, access to markets, and livestock density has a large bearing on the level of productivity and the adoption of improved agricultural practices. The combination of high population density, extreme poverty levels, and low access to production resources has led to land degradation in the FtF-ZoI in Tanzania. Understanding the spatial variations of socioeconomic parameters is crucial for guiding the dissemination of agricultural produce in different contexts.

Population density

Human population density is an indicator of the availability of labor and the market for farm produce. Zones with high population density such as Mbeya and Songwe regions (Fig. 18) are characterized by high agricultural production, but the land is subdivided into small parcels. The Songwe and Mbeya regions have high agricultural potential since they are located in high altitude area (> 1500 m; Fig. 3), which receives high rainfall (> 1200 mm; Fig. 5).

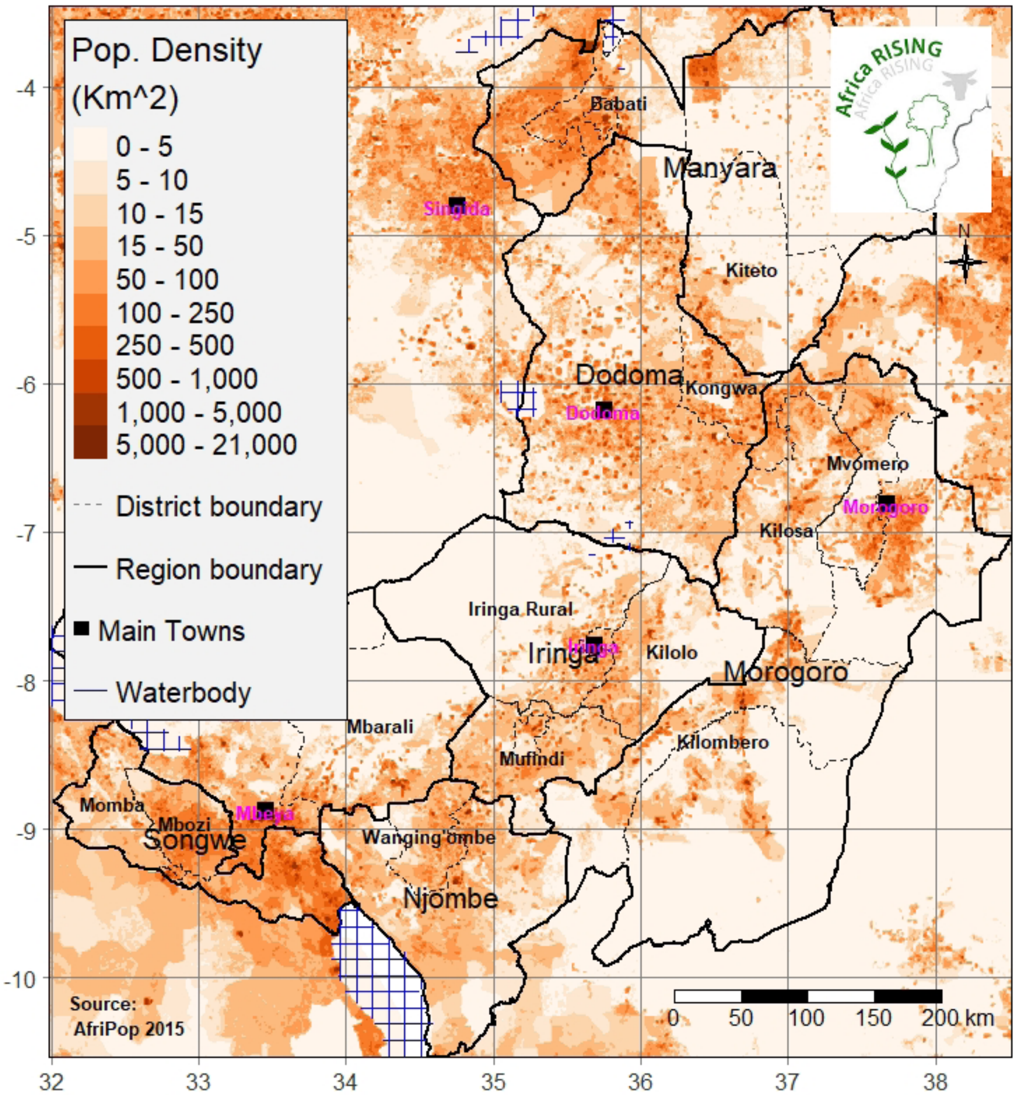

Figure 17. The spatial distribution of human population density in the FtF-ZoI region in Tanzania.

The population of women of childbearing age (WOCBA)

WOCBA is a crucial demographic group that is targeted for specific programs such as the promotion of family nutrition. WOCBA provides the largest farm labor force in the FtF region. The map presented in Figure 18 is crucial for identifying the areas with the highest density of WOCBA that could help in the dissemination of agronomic technologies targeted to this demographic group.

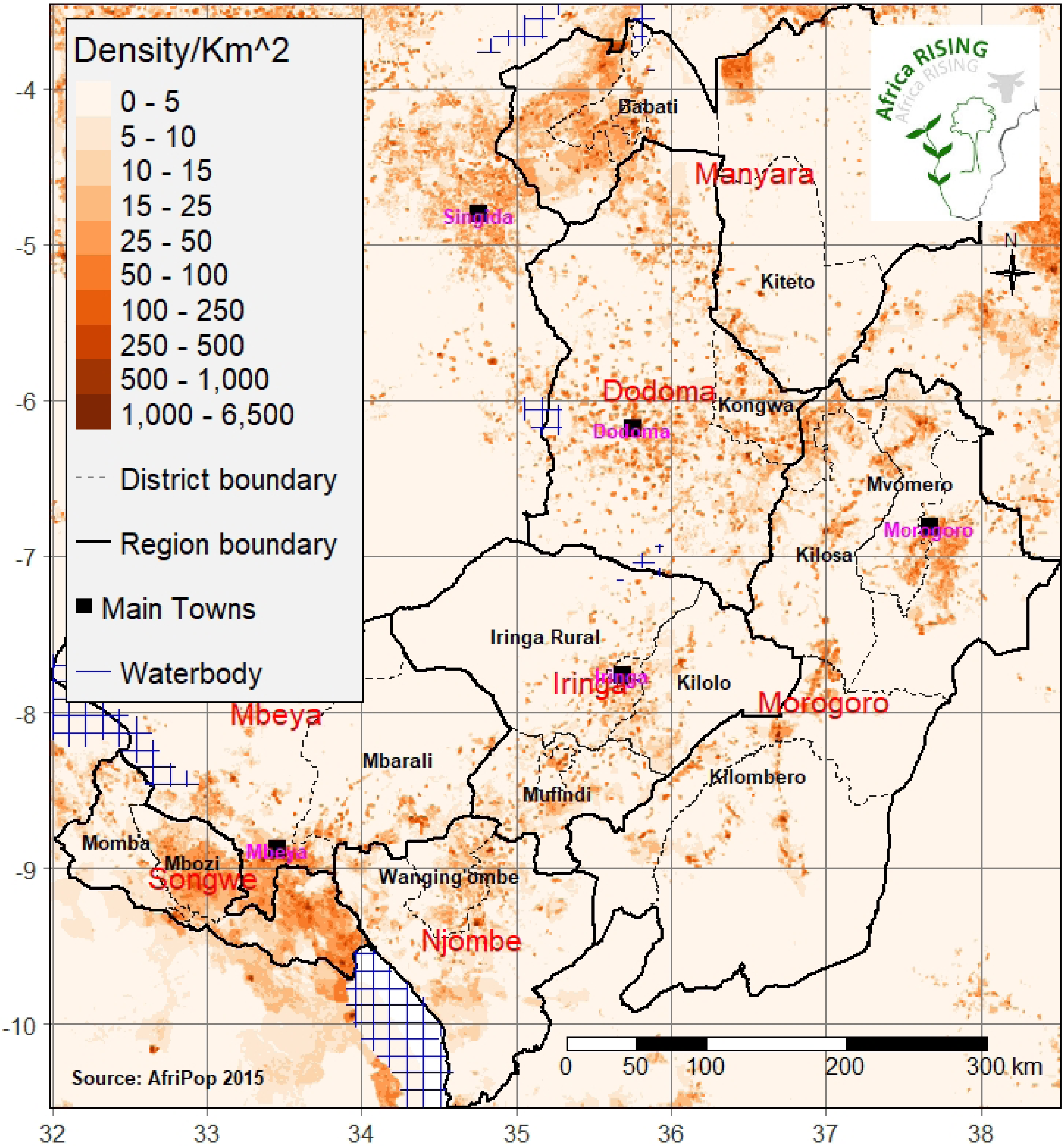

Figure 18. The spatial distribution of women of childbearing age (WOCBA) in the FtF region in Tanzania.

The population of children under five years

Mapping this group is important because programs to alleviate stunting and malnutrition are targeted at children under five years. These programs include scaling out of nutrient-dense crops such as traditional African vegetables (e.g., amaranthus) and legumes (e.g., soybeans). The population density of children under five years is highest in Mbozi District, followed by Babati District (Fig. 19).

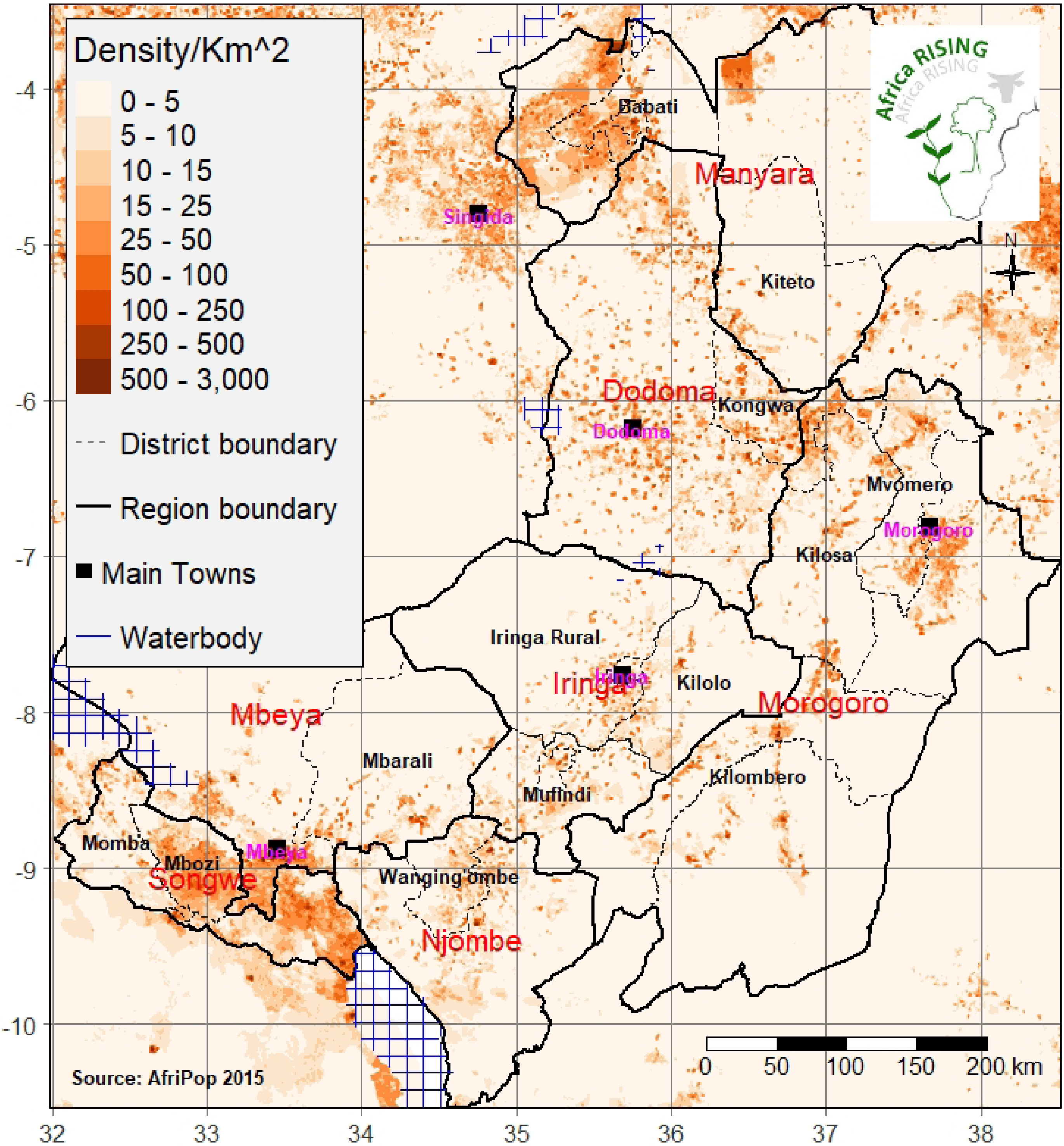

Figure 19. The spatial distribution of children under five years (male and female) in the FtF region in Tanzania.

Distribution of youth population

Youth is a key demographic group targeted to promote their involvement in agricultural enterprises. The Africa RISING NAFAKA Partnership project trained youth to offer services in the agricultural value chain such as timely and judicious spraying of pesticides. The highest population of youth occurred in Mbozi and Babati districts (Fig. 20).

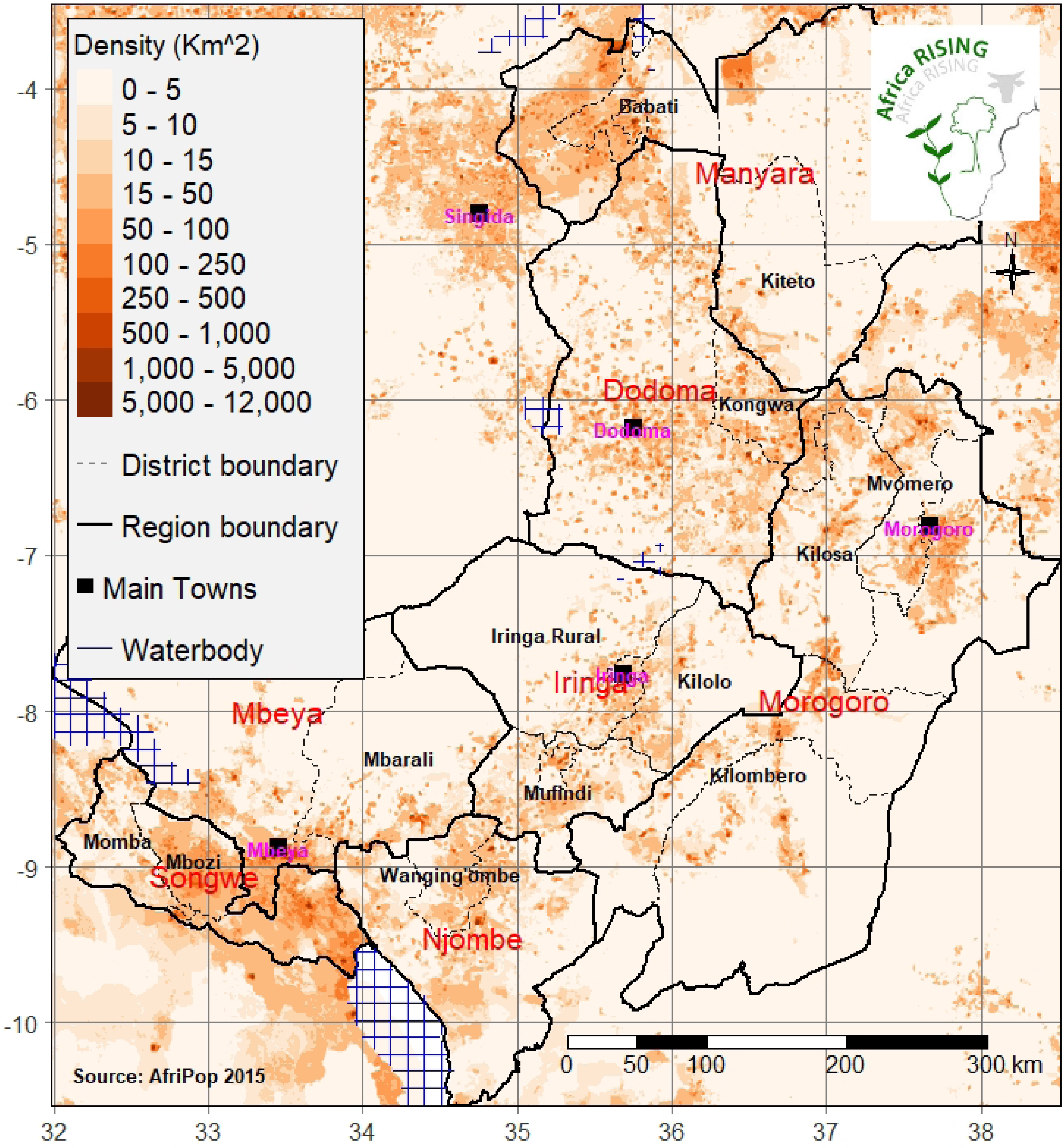

Figure 20. The spatial distribution of youth population (male and female) density in the FtF-ZoI region in Tanzania.

Livestock density

The density of livestock, especially cattle, is an indicator of the availability of manure. Oxen constitute an essential source of draft power in most smallholder farms. Milk from cattle is an important source of protein for most households. In the mixed-cropping farming systems, a proportion of the crop residues are fed to livestock as fodder. The partitioning of crop biomass to fodder and residues affects the nitrogen cycle. However, high cattle density can lead to overgrazing, especially in marginal rangelands. Figure 21 shows the density of cattle per 10 × 10 km grid cells. Cattle density could also indicate the farming system, such as the mixed-livestock systems and the pure pastoralism system. The high density of cattle in Mbozi and Babati districts (Fig. 21) that have large agricultural potential zones as they experience high annual rainfall (Fig. 3), suggests the mixed system dominates where the cattle are fed on crop residues and provide manure for growing crops. Moderately high cattle density (1232–1964 heads/10 km²) occurs in the semiarid Kongwa and Kiteto districts (Fig. 3). In these two districts, cattle rearing is largely practiced in traditional pastoralism, though there is sizable crop farming. After crops are harvested, cattle graze on the crop residues. Overgrazing is among the main causes of land degradation in Kongwa and Kiteto districts. In these semiarid districts, the cattle density is high but crop biomass production is low, leading to intense competition for crop residues between use as a soil cover and feed for cattle.

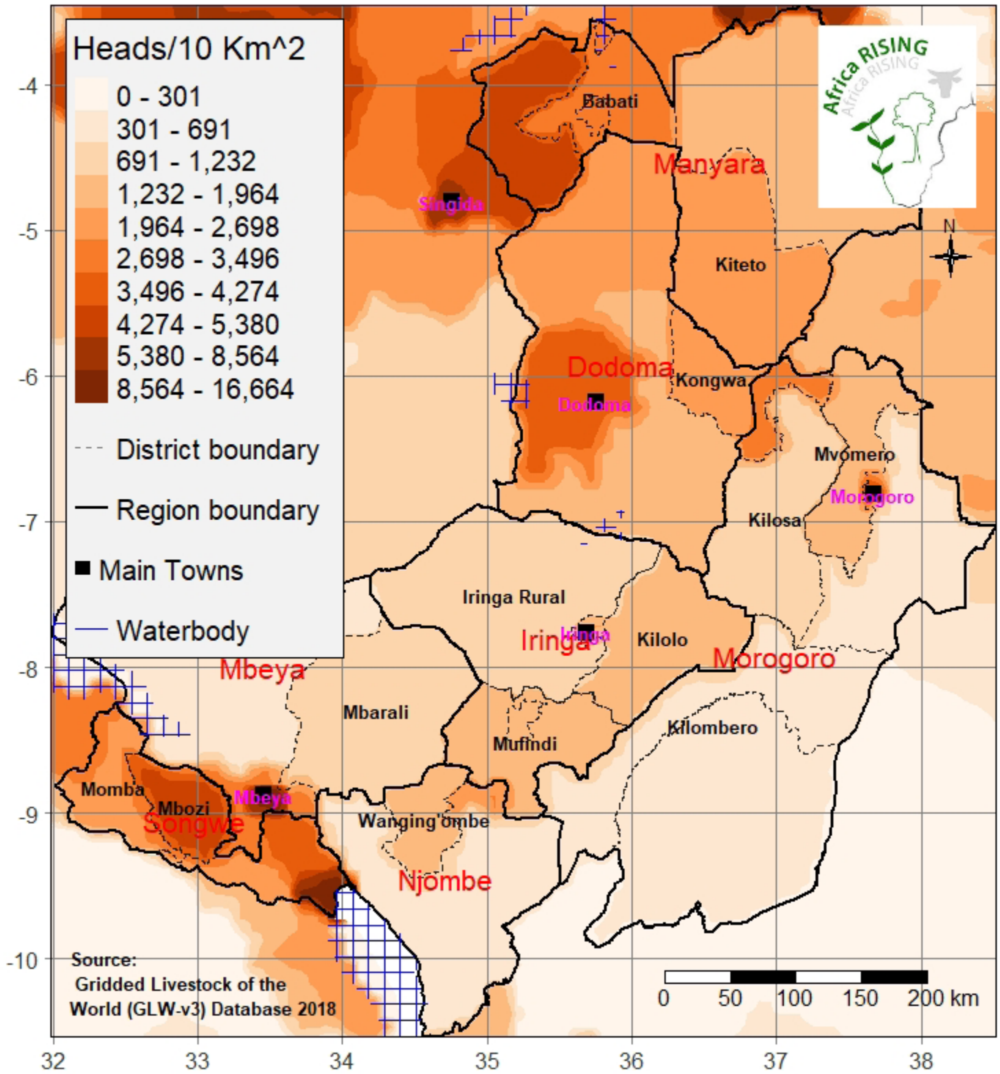

Figure 21. The spatial distribution of cattle density in the FtF region in Tanzania. The grid layer had 10 × 10 km resolution.

Access to markets

Access to markets is a major factor that determines investment in agriculture. Urban centers have the highest population (Fig. 17) and, therefore, high demand for farm produce. Urban centers are a source of industrial agro-inputs such as fertilizers and tools. Poor access to markets increases the transportation costs of farm produce and agro-inputs. Figure 22 shows the travel time (minutes) to urban centers with a population of over 20,000 people as an indicator of access to markets. The travel time to the markets was shortest along the major highways that connect main towns such as Mbeya, Iringa, Morogoro, and Dodoma (Fig. 22).

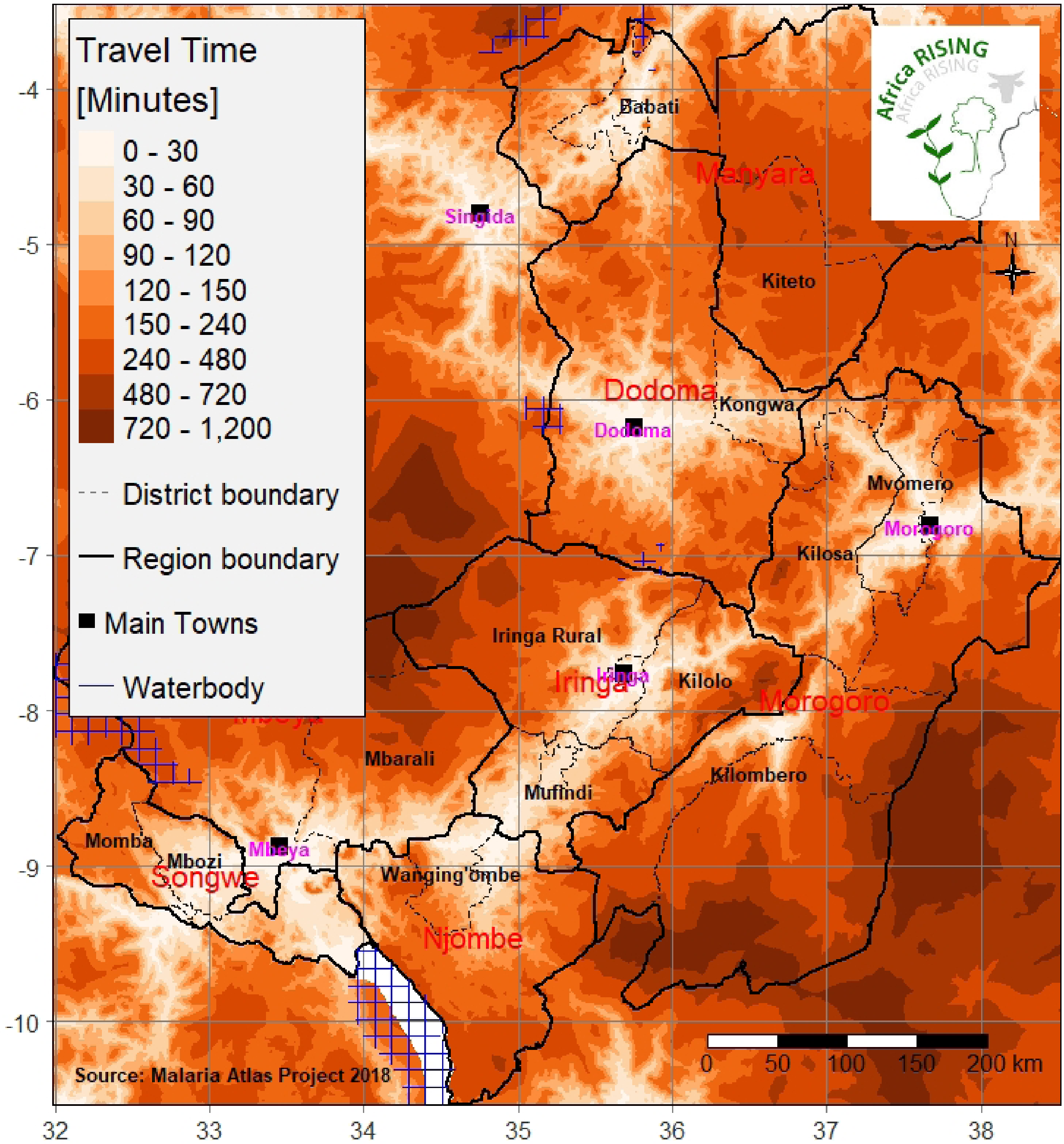

Figure 22. The travel time in minutes to the nearest urban center with a total population over 20 000, as an indicator of access to the market in the FtF region in Tanzania. The layer has 1 × 1 km resolution.

Chapter 3: Spatial tools for mapping suitability and potential impact of integrated agronomic technologies

This chapter presents suitability maps of improved technologies that were scaled out by the Africa RISING - NAFAKA Partnership project. We showcase the potential of spatial tools in guiding evidence-based targeting of agronomic technologies that integrate improved maize varieties and inorganic fertilizers. Maps of suitability indices are decision support tools that help identify potential zones for extrapolating specific technologies with minimal risk. The biophysical and socioeconomic factors that are outlined in Chapter 2 influence the suitability of integrated agronomic technologies.

Importance of technology suitability maps

Spatial targeting is crucial in programs that aim at scaling out agricultural technologies. It addresses the questions; where is the most suitable location for a technology or set of integrated technologies? Spatial analysis seeks to answer these questions by integrating digital maps representing weather, topography, and soil physical and chemical properties like those presented in Chapter 2. Scaling out technologies in areas with similar conditions to their successful trial sites reduces the risk of technology failure and may increase the adoption rate by farmers.

Identifying suitable areas for a technology can be through either a top-down approach or a bottom-up approach. The top-down approach is primarily explorative and more applicable in situations with no or limited in-situ knowledge on the performance of a technology. The bottom-up approach is applied to delineate extrapolation domains for specific technologies where considerable reference trial sites exist. The bottom-up approach is applied to gauge the similarity of the conditions in the reference sites to the broader area targeted for scaling out the technology. Areas where the environmental conditions are more like those in the reference trial sites are more suitable for scaling the technology.

Suitability index layers were developed by integrating remote sensing data and yield data obtained from Africa RISING demonstration plots where the project is scaling-out improved maize varieties and application of inorganic fertilizers. The lower values of the index indicate higher suitability for the integrated maize variety - fertilizer technology..
Two complementary spatial indices were developed to guide evidence-based spatial targeting of improved maize varieties and the application of inorganic fertilizers in the FtF region of Tanzania. These indices are the Extrapolation Suitability Index (ESI) and the Impact Based Spatial Targeting Index (IBSTI). The two spatial indexes were first designed to explore extrapolation domains for integrated technologies that combined the introduction of improved maize varieties and the application of inorganic fertilizers. ESI utilizes data from agronomic trials and remote sensing layers to generate maps on the suitability of a technology beyond the demonstration sites. IBSTI is a tool for priority setting when scaling agricultural technologies. It is applied for ex-ante estimation of the potential impact of the integrated technology if adopted at scale in a suitable zone. IBSTI is maximized in a pixel that has a high total population, a population with a high poverty index, a large population of women of childbearing age, and a high population

of children less than five years, but these impact variables can be adjusted depending on the nature and aim of a technology. For an area to have high IBSTI, it should be outside the protected natural reserves and wetlands to ensure the continuous provision of ecosystem services.

The application of the two indices in scaling-out programs reduces the risk of failure of technologies and helps the extension and development agencies to rationalize investment of limited resources. The ESI map can guide seed companies and agro-dealers involved in the production or distribution of improved seeds and fertilizers to target supplies to regions where their technologies are suitable or have the highest potential societal impact. Based on the size of the suitable zone and socioeconomic parameters, the demand for improved seeds and fertilizers can be estimated before the start of the planting season, thereby improving the input supply systems. The maps guide agro-dealers to target suitable zones for disseminating agro-advisory services. It is expected that the suitability zones will form the central basis for prioritizing the dissemination of agricultural technologies rather than the traditional way of focusing on administrative boundaries that have no ecological significance.

Maps for suitability and priority zones for scaling out selected integrated technologies

Integrated technology 1: The HB614 maize variety and Minjingu mazao and Minjingu top dressing fertilizers

Box 1. Description of the technology: HB614 variety and Minjingu mazao™ and Minjingu Top Dressing™ (MTD) fertilizers

- HB614 grows well between altitudes of 1500 and 2800 masl and annual rainfall of 800–1500 mm.
- Daytime temperatures seldom exceed 28 °C and night-time temperature drop to as low as 8 °C.
- It is adapted to the long growing season and matures in 180–190 days.
- The potential yield of HB614 is 7 t/ha.
- It is tolerant to most leaf diseases, blight, rust, and lodging.
- Minjingu Mazao is a compound fertilizer that is ideal for basal application and contains N (10%), P (8.8%), S (5%), Zn (0.5%), Cu (0.5), and B (0.1%).
- Minjingu Top Dressing (MTD) is a compound blended fertilizer with all nutrients N (27%), P2O5 (10%), CaO (15%) in one granule, ensuring uniformity in application.
- The two fertilizers supply micro and macronutrients that address multiple deficiencies in soil, and CaO that remedies soil acidity.

Suitability map for Integrated Technology 1

This technology was demonstrated at Utengule ward in Kilolo District from which yield data for generating the ESI map were generated. Figure 23 shows that the Integrated Technology 1 is most suitable in other areas of the FtF-ZoI, specifically some parts of Kilolo, Iringa Rural, Mufindi, Mbarali, and Wangingómbe districts. Within Kilolo District, the variety is not suitable in the southern and eastern parts of the district (Fig. 24) since that area is at low altitude (Fig. 4). And within Momba and Mbozi districts, the technology had moderate suitability both in Western Momba and Eastern Mbozi (Fig. 25). The technology showed below-average suitability in the central part of the two districts.

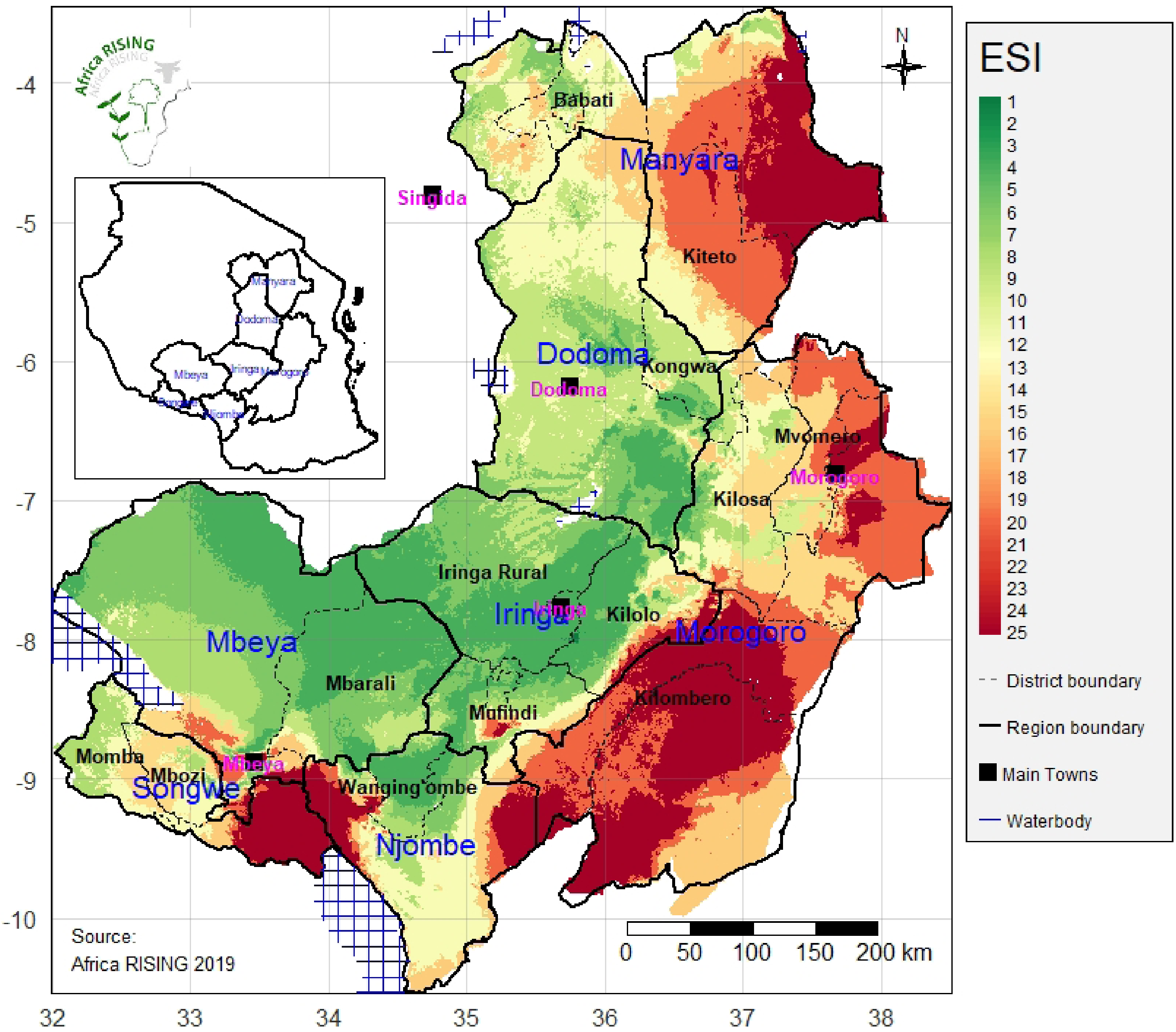

Figure 23. Extrapolation suitability index (ESI) of HB614 maize variety grown with Minjingu Mazao (basal application) and Minjingu top dressing fertilizers in the FtF zone in Tanzania. Areas with a lower suitability index value (light green color) are the most suitable since they had the lowest yield gap. Areas with the highest suitability index value (25, light red color) are the most unsuitable for scaling out the integrated technology.

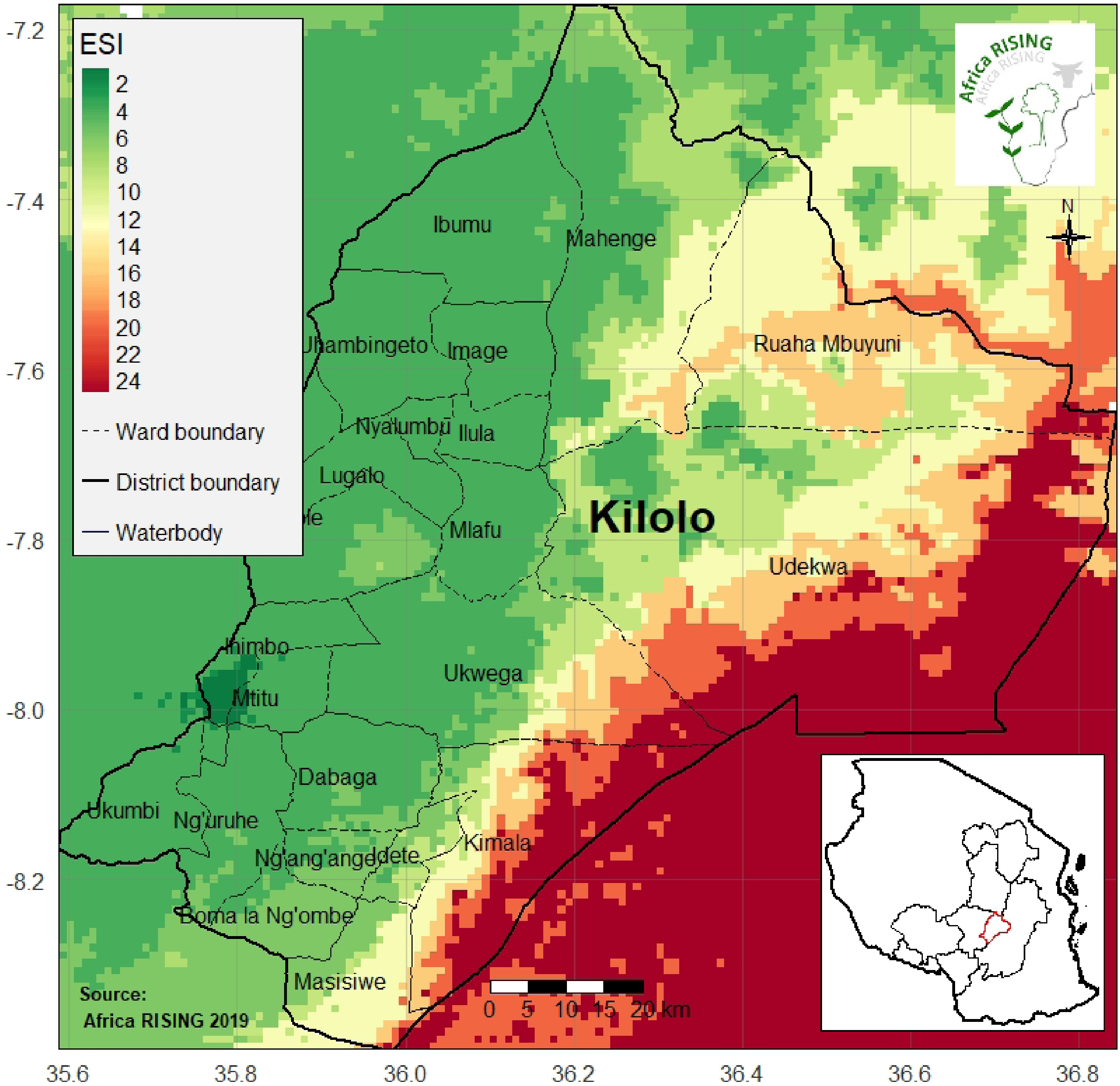

Figure 24. Extrapolation suitability index (ESI) of HB614 maize variety grown with Minjingu Mazao and Minjingu top dressing fertilizers for Kilolo District in Tanzania. Details are like those in Figure 23.

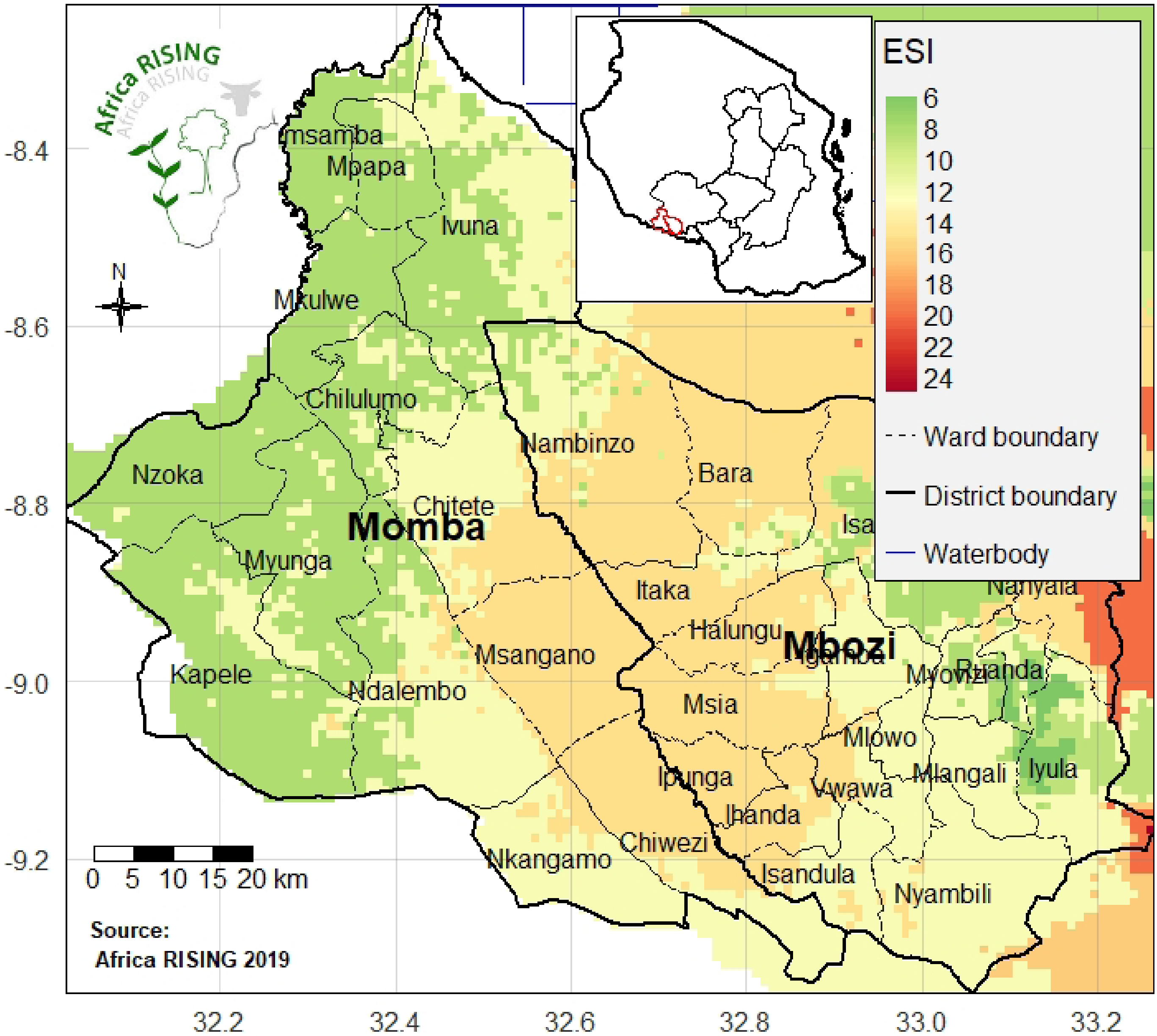

Figure 25. ESI of HB614 maize variety grown with Minjingu Mazao and Minjingu top dressing fertilizers in Mbozi and Momba districts in Tanzania. Details are like those in Figure 23.

IBSTI of Integrated Technology 1

The IBSTI was utilized to identify the priority areas for scaling out in the zones that showed high suitability (ESI < 4 in Figure 23) for the technology. The high priority zones for scaling this technology (IBSTI = 20) are in Wangingo'mbe, Iringa Rural, and Kilolo districts (Fig. 26). Although the technology is highly suitable in Northern Mbeya region (ESI = < 4, Fig. 23), the area is of low priority for scaling (IBSTI = 4, Fig. 26) since it is sparsely populated.

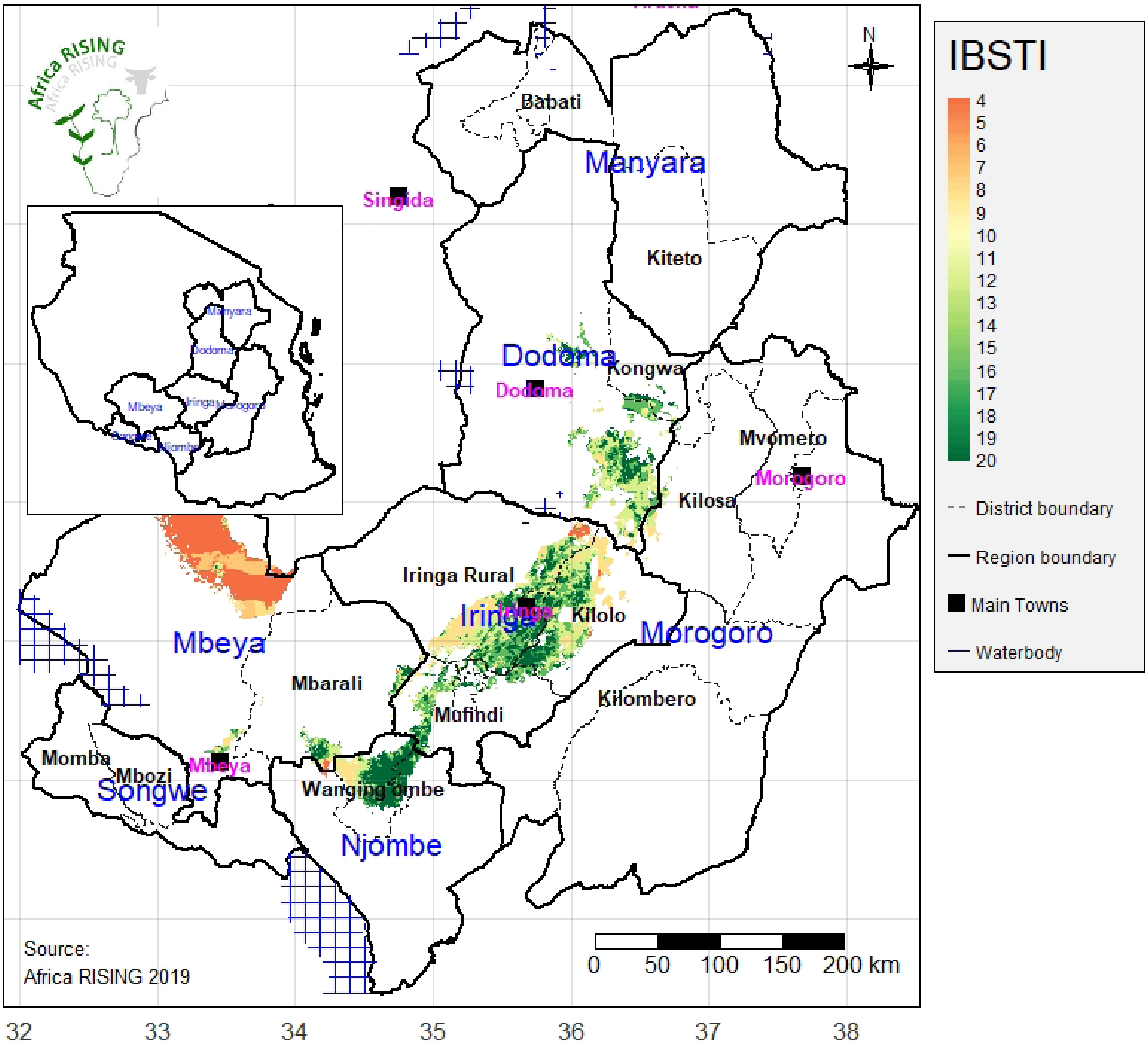

Figure 26. IBSTI of agronomic technology comprising HB614 maize variety grown with Minjingu Mazao and Minjingu top dressing fertilizers in the FtF-Zolin Tanzania. The pixel with high IBSTI value has the highest potential impact and, therefore, is accorded higher priority. Zones with index value 20 (light green color) have the most potential impact and, therefore, should be prioritized in scaling programs. Areas with index value 4 (light red color) have the lowest possible impact for scaling out this integrated technology.

Integrated Technology 2: SC719 maize variety with YaraMila Cereal™ and Yara-Bela Sulfan™ fertilizers

Box 2. Description of the integrated technology: SC719 maize variety with YaraMila Cereal™ and Yara-Bela Sulfan™ fertilizers

SC719 maize variety is:

- White grained with a semi dent characteristic.
- High yielding 12.5–14 t/ha (50–56 bags of 100 Kg per acre).
- Optimal altitude between 800 and 1500 meters.
- Late maturing variety (135–150 days).
- Tolerant to streak viruses.
- Tall and large in structure, lodging tolerant, has early growth vigor, and high grain yielding, which make it an ideal choice for making sillage.
- Resistant to grey leaf spot maize streak and mottle viruses.
- Tolerant to northern corn leaf spot and phaeosphaeria leaf spot disease.
- Resistant to both stalk and root lodging.

Fertilizers

- YaraMila Cereal compound fertilizer contains N (23%), P (10%), K (5%), MgO (2%), S (3%), and Zn (0.3%).
- Each granule of the compound fertilizer contains each nutrient in its formula providing even distribution of nutrients, whether spread by hand or machine.
- YaraMila Cereal™ dissolves quickly and evenly when in contact with the soil in humid conditions or after a night's dew. It rapidly releases nutrients at the correct time to feed the growing crop.
- In dry climates, the higher solubility of YaraMila Cereal™ helps the nutrients to reach the roots where limited soil moisture is available.
- The base cations in this fertilizer reduce soil acidity.
- YaraBela Sulfan comprises N (24%) and S (6%).
- YaramilaCereal and YaraBelaSulfan fertilizers have micro and macronutrients that address multiple deficiencies in soil.

Suitability map for Integrated Technology 2

This integrated technology was demonstrated at Isansa, Itumpi, Iganya, and Magamba wards in Mbozi District from which yield data for generating the ESI map were generated. Figure 27 shows that the integrated technology is most suitable in Songwe, Njombe, Western Mbeya, and southern Iringa regions of Tanzania. This belt has a high altitude (Fig. 3), experiences high rainfall (Fig. 5), and a long growing season.

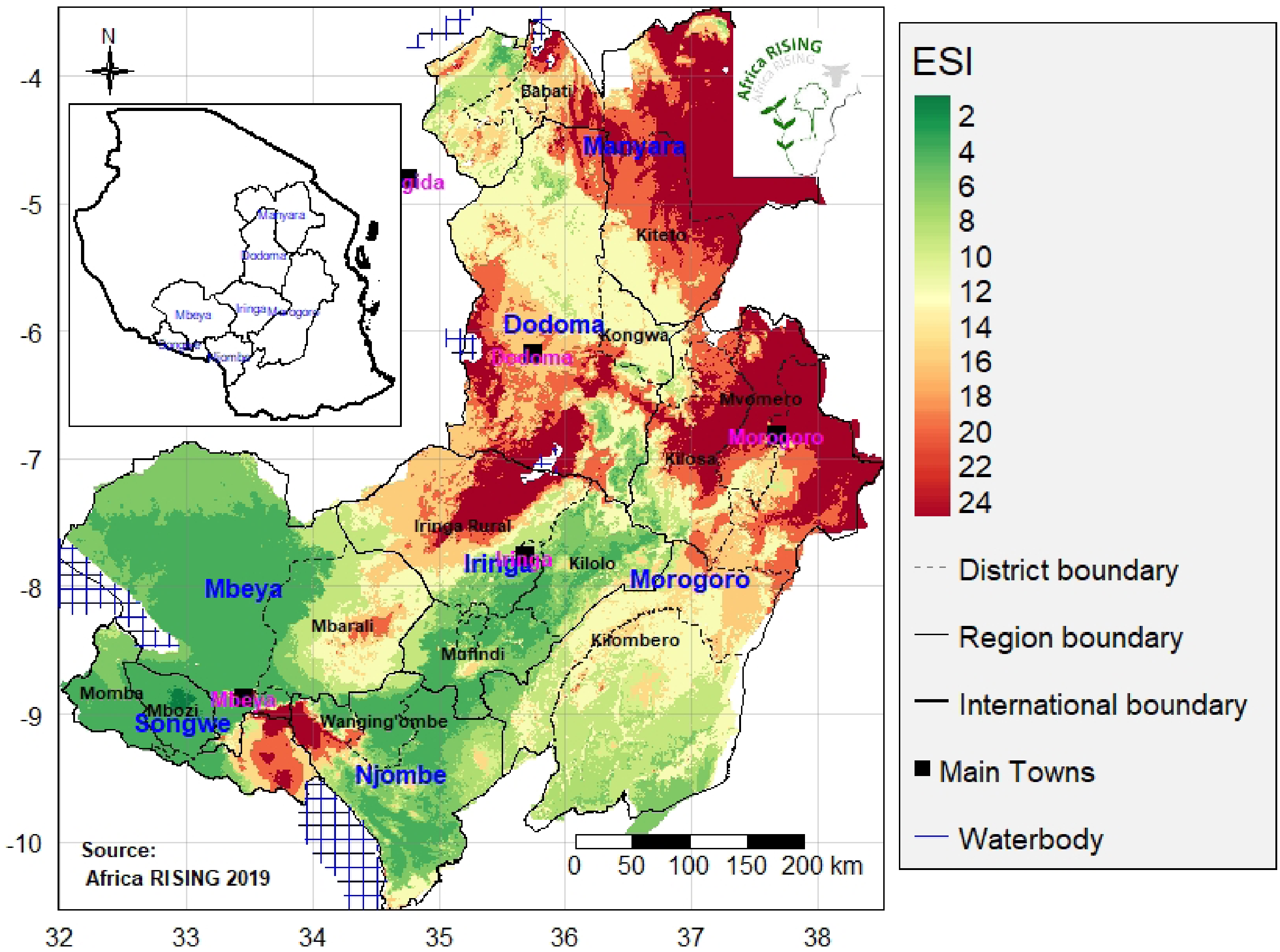

Figure 27. Suitability of SC719 maize variety grown with Yaramila-Cereal and Yara-Bela Sulfan fertilizers in the Feed the Future zone of Tanzania. Details are like those in Figure 23.

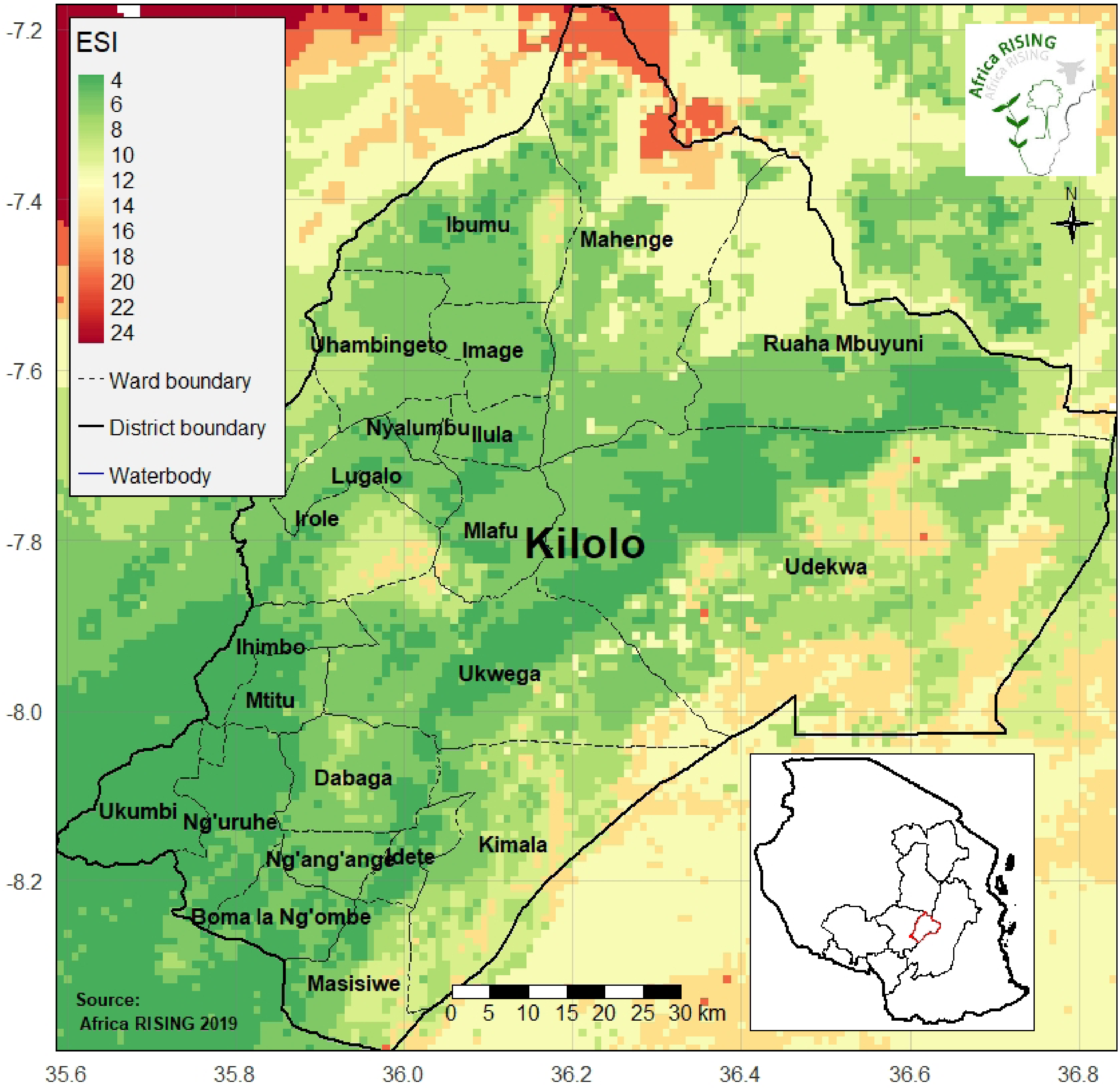

Figure 28. Suitability of SC719 maize variety grown with Yaramila-Cereal and Yara-Bela Sulfan fertilizers in Kilolo District in Tanzania. Details are like those in Figure 23.

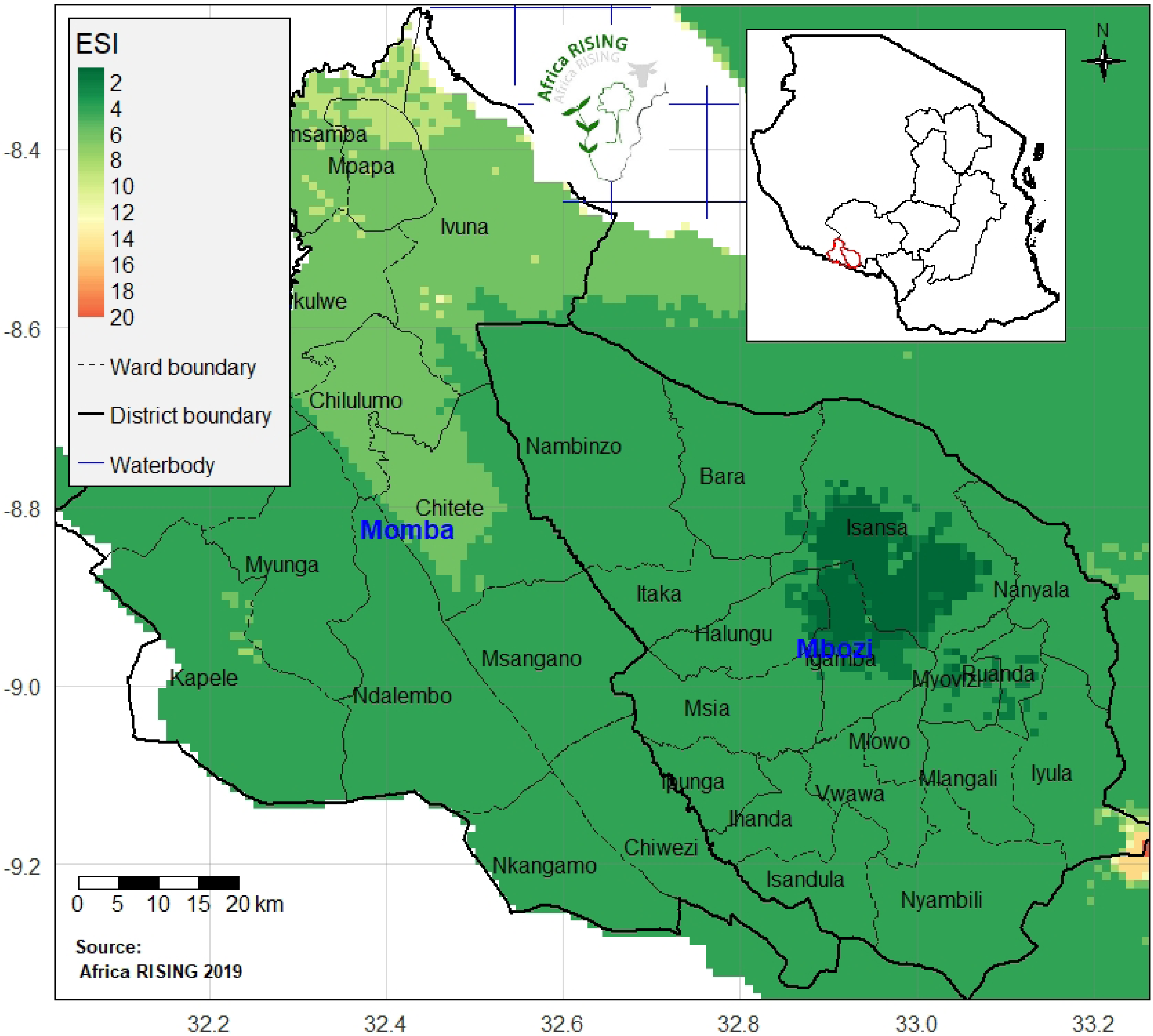

Figure 29. Suitability of SC719 maize variety grown with Yaramila-Cereal and Yara-Bela Sulfan fertilizers in Mbozi and Momba districts in Tanzania. Details are like those in Figure 23.

IBSTI of Integrated Technology 2

The highest potential impact for the Integrated Technology 2 occurs in Mbozi, Momba, Wangi'ngombe, Iringa, and Kilolo district (Fig. 30). A considerable region in Mbeya region is of low priority due to low population density (Fig. 17). The priority zones may change depending on which impact variables are desirable in a technology scaling program.

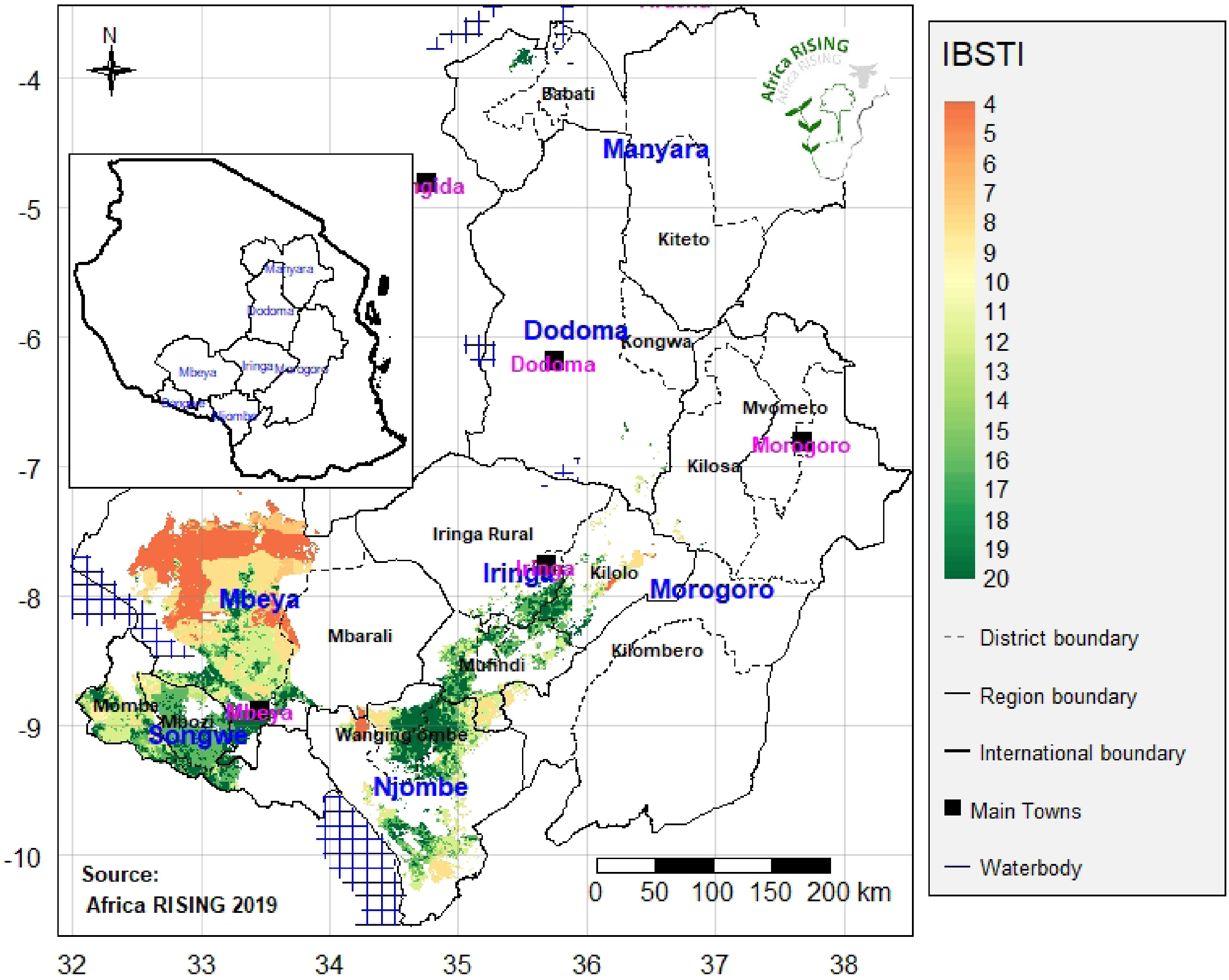

Figure 30. IBSTI for SC719 maize variety grown with Yaramila-Cereal and Yara-Bela Sulfan fertilizers in the FtF-Zolin Tanzania. Details are like those in Figure 26.

Integrated Technology 3: Staha maize variety with YaraMila Cereal™ fertilizer.

Box 3. Description of Integrated technology 3: The Staha maize variety with YaraMila Cereal™ fertilizer

Staha maize variety:

- Optimal altitude ranges from 0 to 900 masl
- Suitable for zones that experience short periods of rainfall.
- Potential yield is 4–5 t/ha.
- Matures in 4 months (120 days).
- Tolerant to maize streak.

YaraMila Cereal™ fertilizer

- Chemical composition of YaraMila Cereal fertilizer is N (23%), P_2O_5 (20%), K (5%), MgO (3%), S (3%), and Zn (0.3%)
- The compound fertilizer contains micro and macronutrients that address multiple deficiencies in soil.

Suitability map for Integrated Technology 3

This integrated technology was demonstrated at Mlali and Moleti wards in Kongwa and Kiteto districts, respectively. Integrated Technology 3 is most suitable in the semiarid zone in Manyara, Dodoma, and southern Iringa and Eastern Mbeya regions (Fig. 31). Staha variety is not suitable in Morogoro region that experiences high rainfall (Fig. 5).

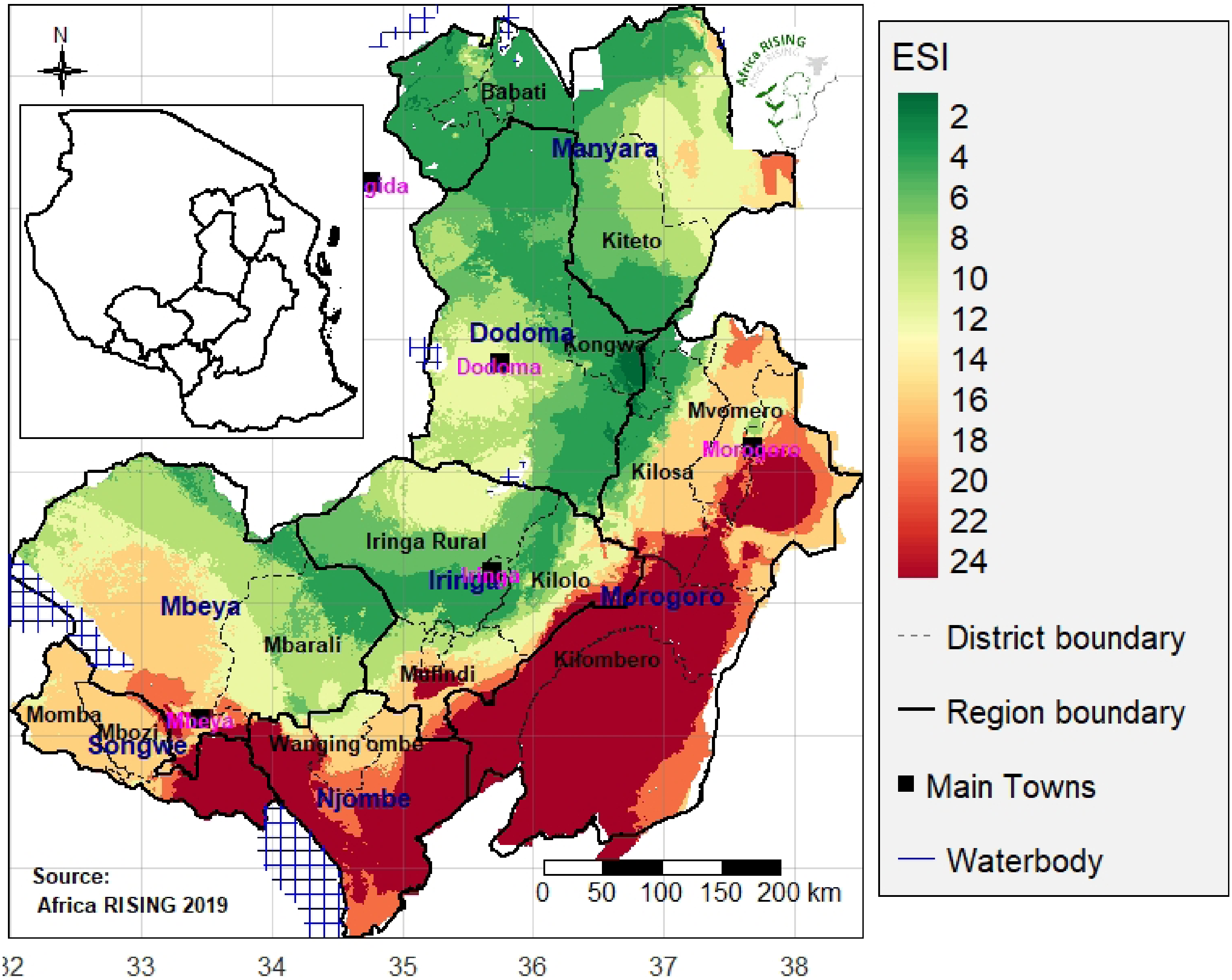

Figure 31. Suitability of Staha maize variety grown with Yaramila-Cereal fertilizer in the FtF-ZoI of Tanzania. Details are like those in Figure 23.

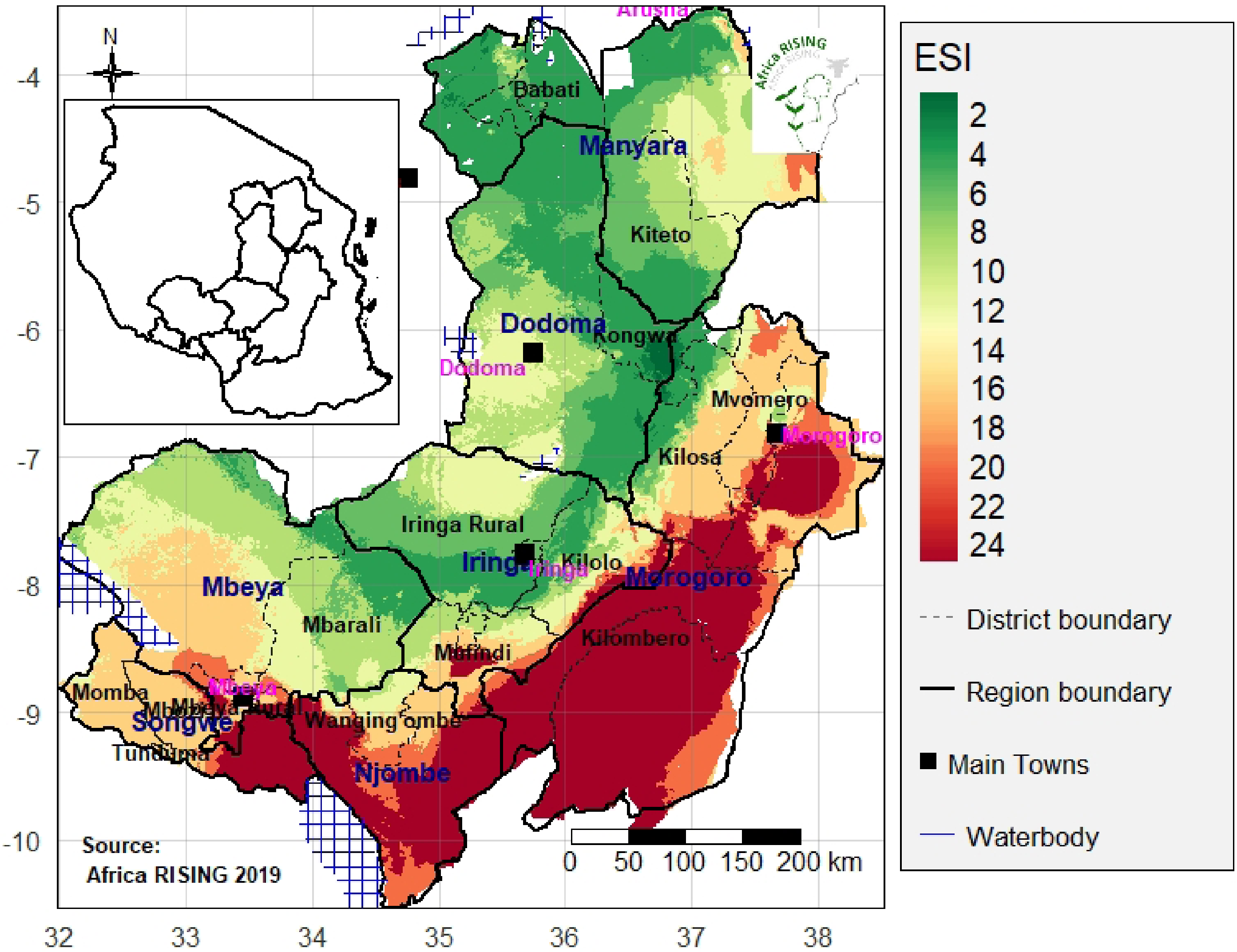

Figure 32. Suitability of Staha maize variety grown with Yaramila-Cereal fertilizer in Kongwa and Kiteto districts of Tanzania. Details are like those in Figure 23

IBSTI of Integrated Technology 3

The priority area for scaling out Integrated Technology 3 are Kongwa, southern Kiteto, western Babati, southern Iringa Rural districts (Fig. 33).

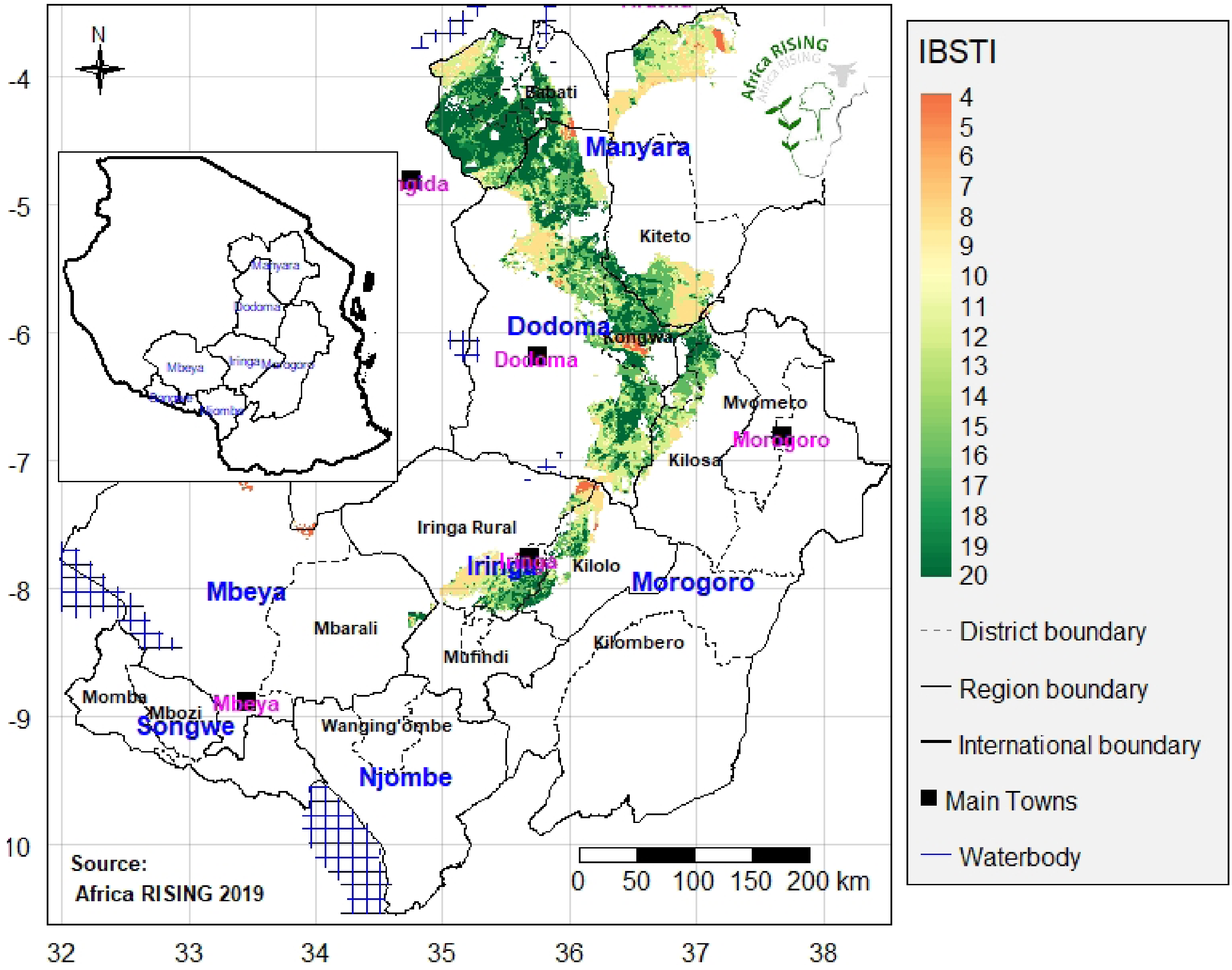

Figure 33. IBSTI for Staha maize variety grown with Yaramila-Cereal fertilizer in the FtF zone of influence in Tanzania. Details are like those in Figure 26.

Integrated Technology 4: PAN691 maize variety with DAP™ and urea™ fertilizer

Box 4. Short description of Integrated Technology 4: PAN691 maize variety with DAP™ and urea™ fertilizer

PAN691 maize variety

- Optimal altitude for PAN691 maize variety is above 1500 meters.
- Matures after 150–160 days.
- Have large cobs with medium flint grain.
- Excellent leaf disease tolerance, including common rust, northern corn leaf blight, and grey leaf spot
- Potential yield of PAN691 is between 4.5 and 7.5 t/ha.

YaraMila Cereal™ fertilizer

- DAP contains N (18%), P_2O_5 (56%) and urea contains N (46%).
- DAP for basal application and urea as top-dressing is a conventional farmer practice, although this combination is known to increase soil acidity.

Suitability map for Integrated Technology 4

The Integrated Technology 4 was demonstrated in Kitowo, Mtitu, and Utengula wards in Kilolo District. Technology 4 showed more suitability in parts of Kilolo, Iringa Rural, Mbarali, Mufindi, and Wangingómbe districts (Fig. 34).

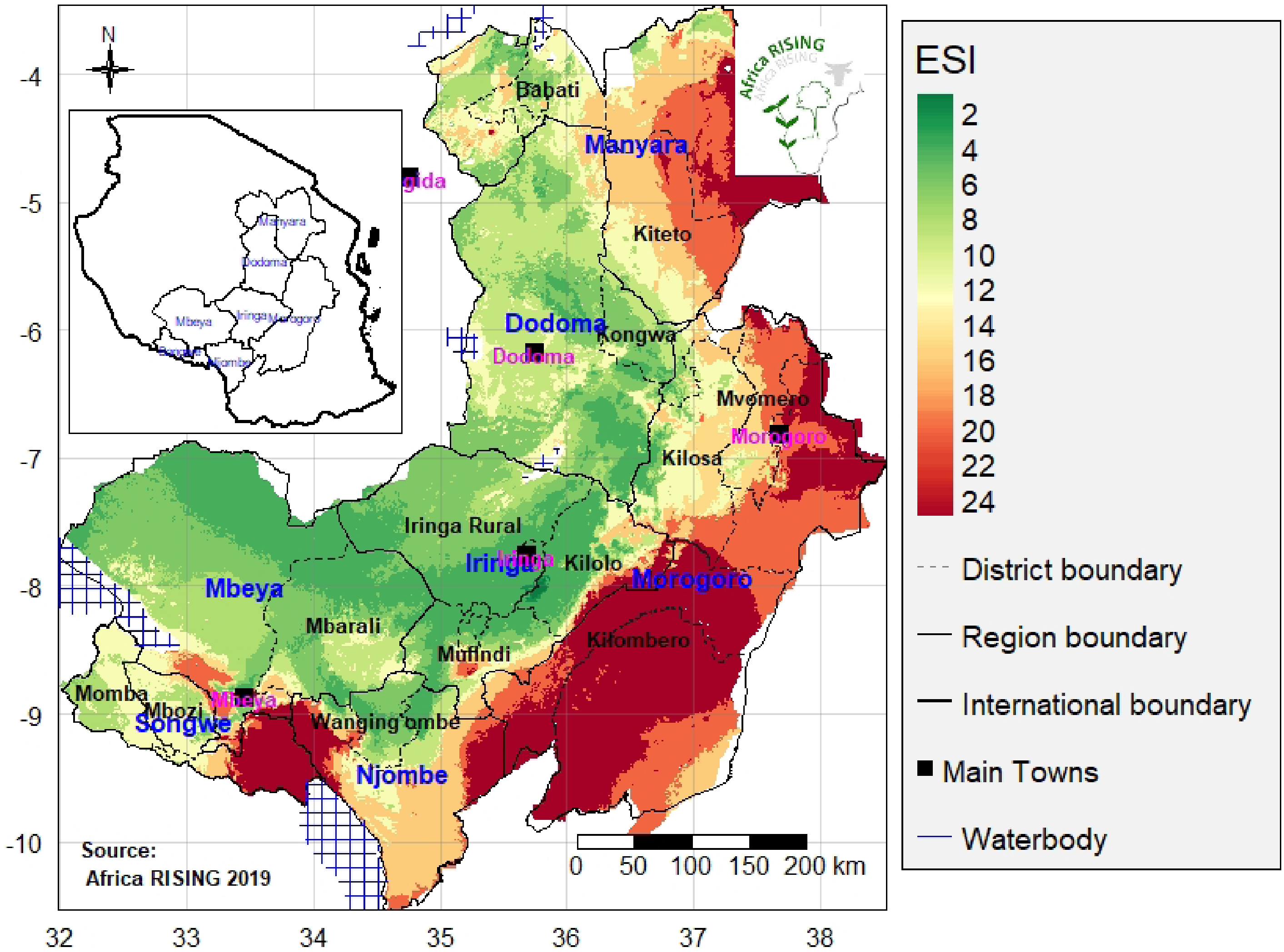

Figure 34. Suitability of PAN691 maize variety grown with DAP for basal application and urea fertilizer in the FtF zone of Tanzania. Details are like those in Figure 23.

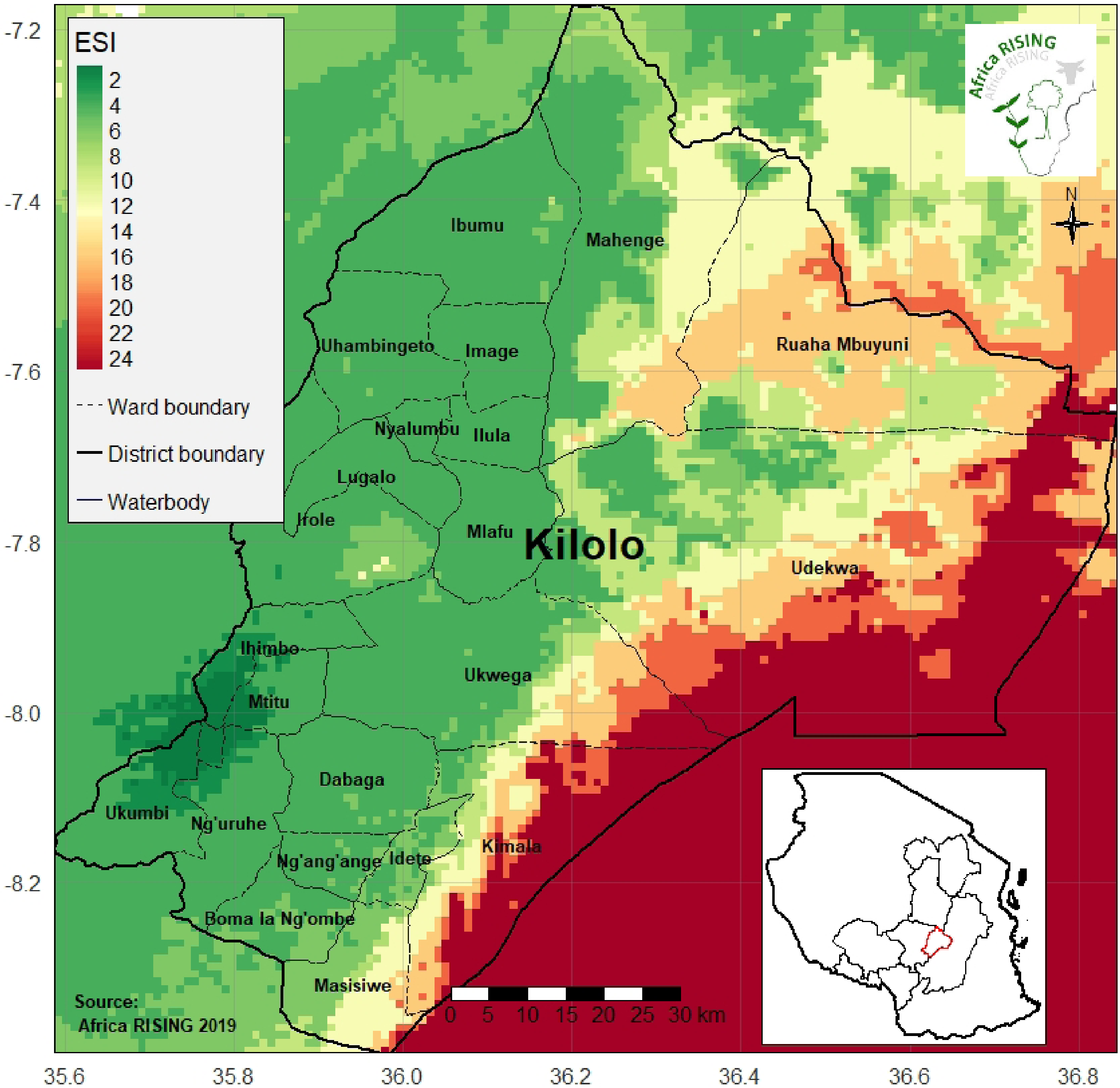

Figure 35. Suitability of PAN691 maize variety grown with DAP for basal application and urea as top-dressing fertilizer in Kilolo District of Tanzania. Details are like those in Figure 23.

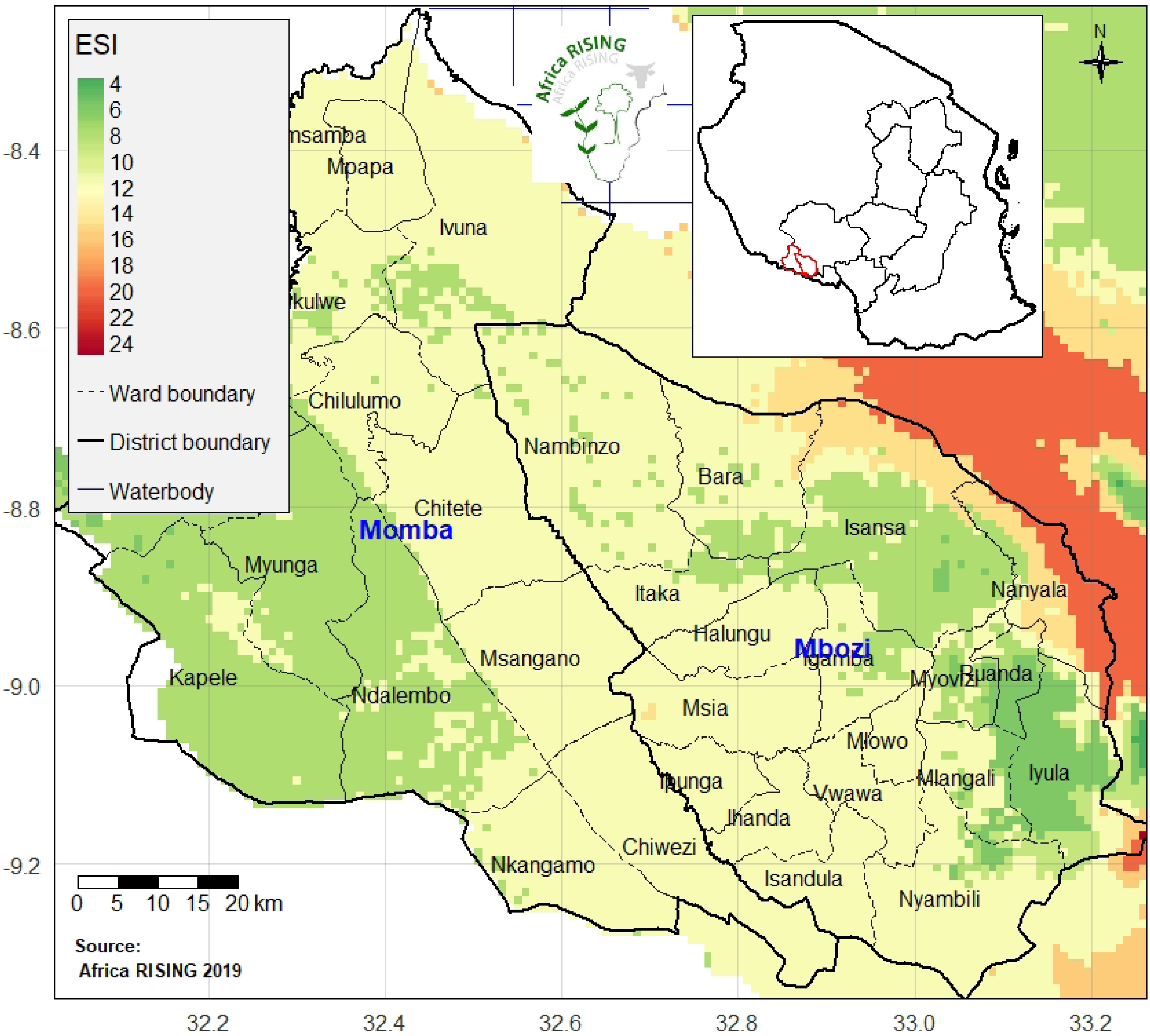

Figure 36. Suitability of PAN691 maize variety grown with DAP for basal application and urea as top-dressing fertilizer in Mbozi and Momba districts in Tanzania. Details are like those in Figure 23.

IBSTI of Integrated Technology 4

The priority zone for scaling out Integrated Technology 4 occurred in Iringa rural, Kilolo, and Wangi'ngombe districts (Fig. 37). A section of in north Mbeya region showed high ecological suitability for Technology 4, but is of low priority for scaling due to low population density (Fig. 17).

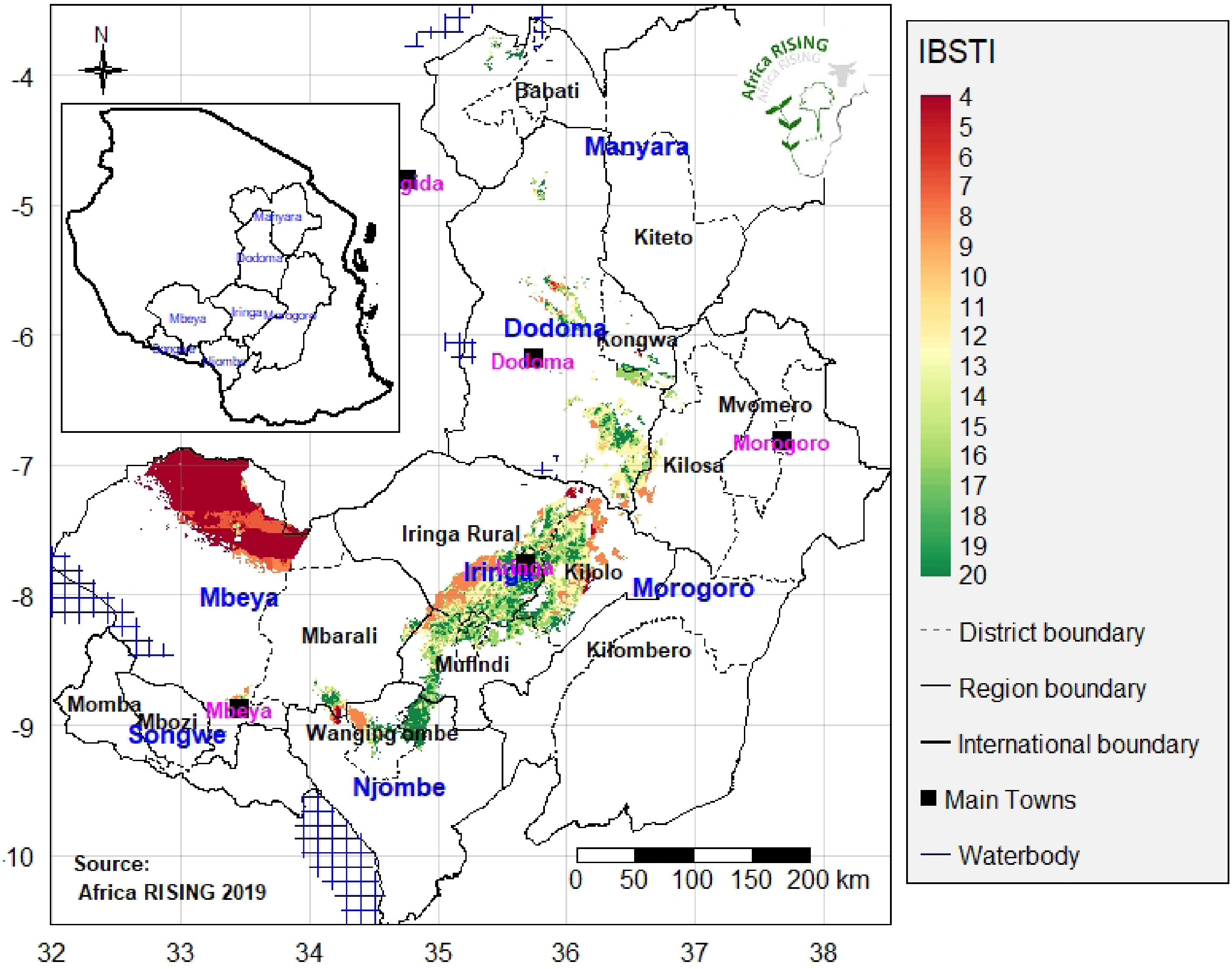

Figure 37. SIBSTI for PAN691 maize variety grown with DAP and urea fertilizer in the FtF zone of influence in Tanzania. Descriptions are like those in Figure 26.

Chapter 4. Synthesis on the relevance of information

This compendium presents maps on the biophysical and socioeconomic environment in the FtF-ZoI in Tanzania. The spatial layers were applied to develop maps of two complementary indices that help extension agencies to improve evidence-based scaling of agricultural technologies. ESI utilized data from agronomic trials and remote sensing layers to generate maps on the suitability of an integrated technology beyond the trial sites. IBSTI is applied for ex-ante estimation of the potential impact of an integrated technology if adopted at scale in a suitable zone. Spatial targeting indices were generated for four integrated technologies comprising improved maize varieties and inorganic fertilizers. The application of the spatial targeting indices in scaling-out programs is expected to reduce the risk of failure of technologies. It is also envisaged to help the extension and development agencies to rationalize investment of resources. The suitability indices presented in this compendium are not static, but should be updated occasionally to capture the changing biophysical and socioeconomic realities. The indices are expected to be improved by incorporating more data from agronomic trials as they become available. Moreover, extensive consultations with appropriate stakeholders is necessary to capture their views and user experiences. The feedback from farmers, extension and development partners will be important for further refining the spatial targeting indices.

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