Ecosystem-Based Adaptation and Mitigation in Botswana's Communal Rangelands

Annex 16: Maps

Prepared by Conservation International and C4 EcoSolutions through a Project Preparation Facility (PPF) Grant from the Green Climate Fund

Contents

1. Executive Summary

The maps provided in this annex are presented here with additional context than in the FP section they are extracted from. The Climate Change Vulnerability Assessment (CCVA) maps were extracted from Annex 2, Section 1 and the Carbon and Water Baseline Assessment (CWBA) maps have been extracted from Annex 2, Section 3 of the FP package. Brief narratives to give context to the maps are provided below, but more detailed interpretations and implications for the project Funding Proposal are provided in the relevant source annex.

2. Maps from the CCVA

This study — commissioned by the government of Botswana in partnership with Conservation International — has the objective of establishing the level of vulnerability of pastoral communities to climate change. Specifically, the study is aimed at quantifying the social, livelihoods, livestock, and rangeland vulnerabilities in Bobirwa, Kgalagadi and Ngamiland (Figure 1).

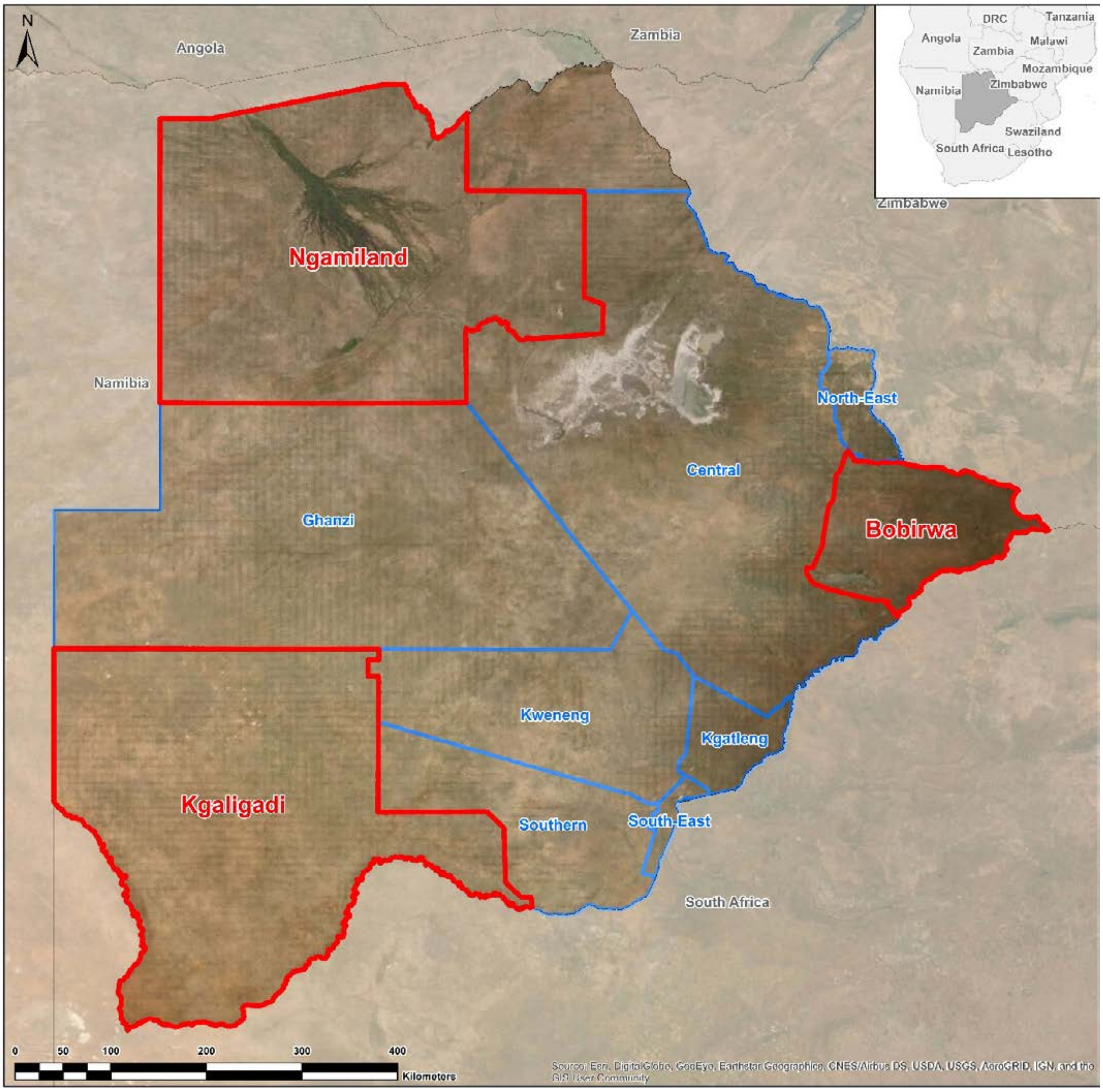


Figure 1. Project Study Areas

Botswana, being landlocked and not subject to large water body temperature mitigation, will experience large increases in both maximum and minimum temperatures. Day time maximum temperatures are likely to increase by ~2.0°C in the south west and ~3.4°C in the northern and eastern regions by 2050 under RCP 4.5 (Figure 2). Increased day time temperatures are closely matched by increased night-time temperatures with the average diurnal range rising by 0.1–0.2°C over most of Botswana (with the exception of the southernmost area of Kgalagadi).

The projected precipitation level over Botswana shows a general annual total volume decrease of 5 to 18 mm annually. This is greater in more northern areas where a decrease of ~32 mm is expected (Figure 2F). However, the three-month precipitation peak (Figure 2G) associated with summertime convective precipitation, exhibits an increase over most of Botswana of 4–13 mm across these three peak rainfall months. The southern area of Kgalagadi is an exception as it shows a near normal to slight decrease trend over these peak months. The coefficient of variation (Figure 2H), already high in the central to northern areas of Botswana, will increase further. This will be most evident in the central areas with an increase of up to 10%. This will further worsen the year-on-year precipitation variability.

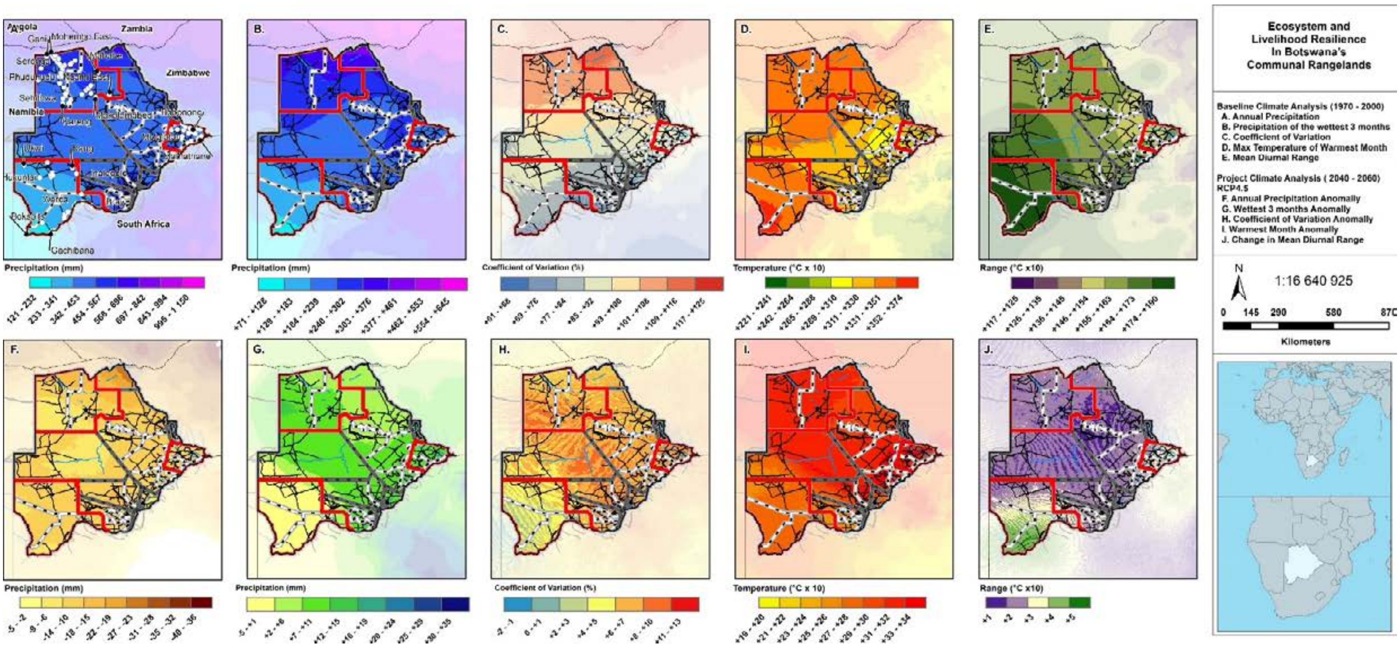


Figure 2. Principle current variables (top) and projected climate anomalies (bottom) for Botswana[1].

Climate change will also likely affect the characteristics of fires in Botswana. Fires occurs throughout Botswana, though they are more prevalent in the Ngamiland region than anywhere else in Botswana. The largest occurrence of fire is in the northernmost areas along the Namibian border, as well as in the Delta itself (Figure 3). The majority of these fires occur from August to October. The peak fire brightness also occurs over this time. The number of fire detections over time shows a slight linear increase from 2001 to 2019, with peak activity being in 2008 and 2011. There is also a linear increase in average fire brightness from 2001 to 2019, with average brightness consistently higher in more recent years than the more variable early years.

There are many complex factors that contribute to a particular fire season having a higher occurrence of fires or hotter fires than other seasons (such as point of origin and vegetation dryness, wind speed on ignition day, or the speed of extinguishing). The fire danger index (FDI) is a trusted measure utilised by wildland firefighters to call extra resources or prepare standby crews because of its strong correlation to fire intensities. FDI is

[1] Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high-resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978

calculated using scales of recent rainfall and evaporation as a measure of vegetation dryness along with current temperature, humidity and wind speed. The projections of wind speed and direction are not clearly suggesting any particular trend; however, the daily meteorological wind will have a greater impact on FDI than general climatological wind changes.

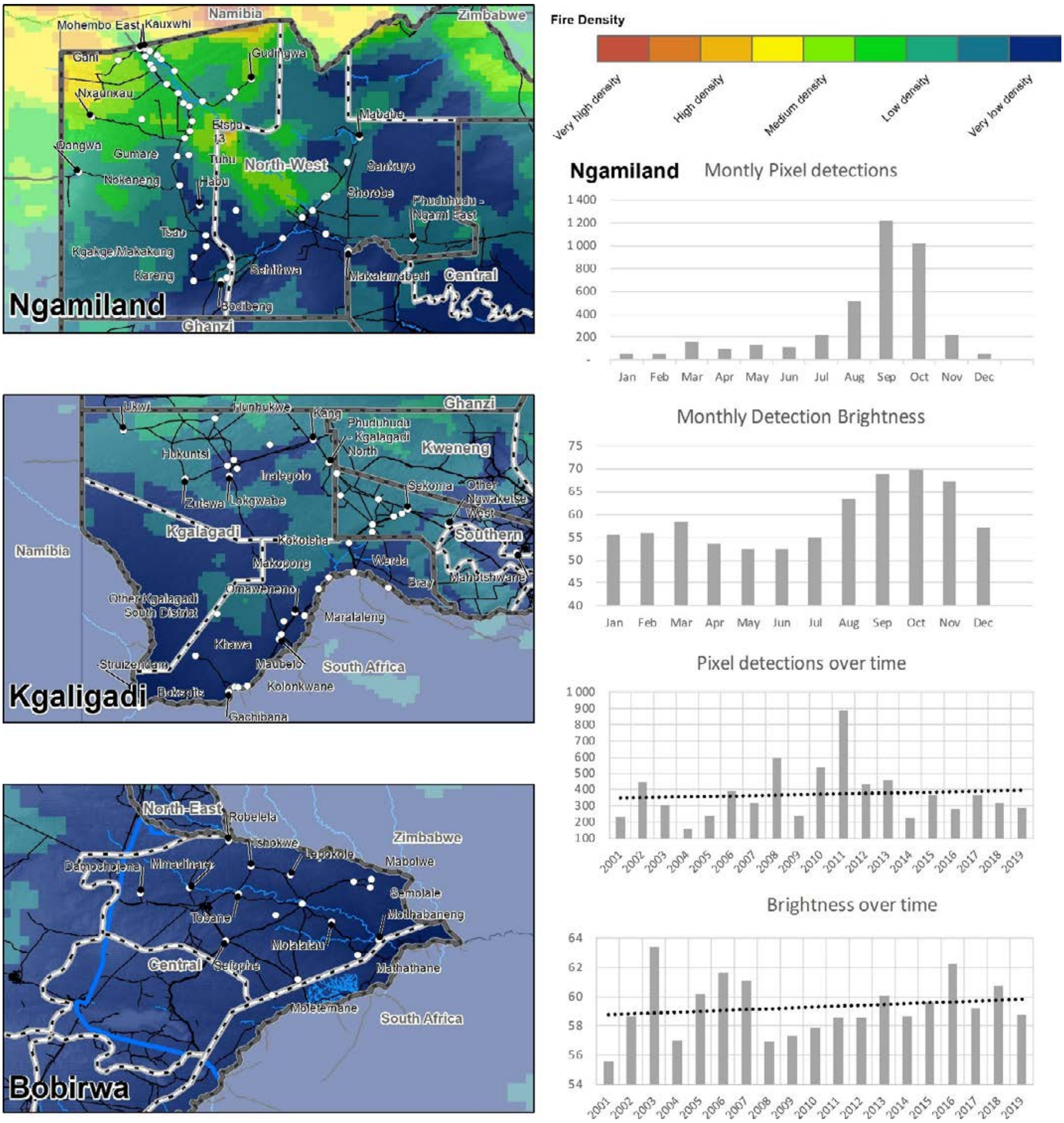


Figure 3. Fire occurrence heat map (left panel) and fire character (right panel)[2].

Bobirwa, on the eastern side of Botswana, has an annual baseline precipitation of 300–450 mm, with a majority of that being convectively forced rainfall occurring over the peak summer months (Figure 4 A, B, C). The seasonal variation (coefficient of variation) is moderate to high in Botswana. The local, rainfall-dependent economy will be subjected to this high precipitation variation and associated uncertainty. The anticipated precipitation changes in Bobirwa show an annual decrease of 8–14 mm. However, precipitation in the peak summer months is set to increase by up to 14 mm. Precipitation is therefore being concentrated into these months while shoulder seasons will exhibit reduced rainfall to account for the overall decreased annual

[2] Fire Information for Resource management System (FIRMS), https://firms.modaps.eosdis.nasa.gov/

volume. The seasonal variation is set to increase by 7–10%, further increasing vulnerability of the rain-reliant economy.

Bobirwa's maximum temperatures are more moderate compared to the rest of Botswana, with average maximum temperatures being ~28–33°C. The diurnal variation is also not as large compared to elsewhere in the region. Projected increased temperatures (Figure 4 I, J) show an increase of 3.1°C in the warmest months under RCP 4.5 by 2050. The minimum temperatures are also increasing, though to a slightly lesser extent than maximum temperatures. The diurnal range will increase by ~0.3°C meaning night-time temperature profile shift is similar to the higher day time temperature profile shift.

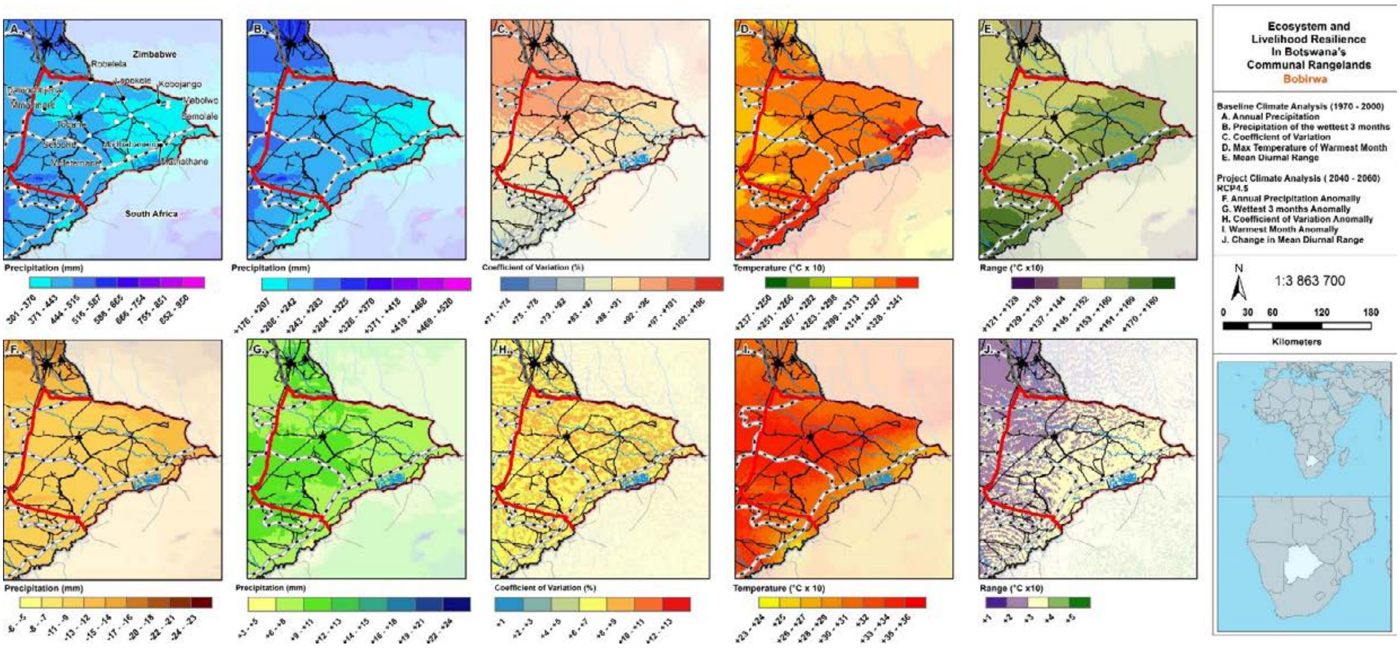


Figure 4. Current (top) and projected climate anomalies (bottom) for Bobirwa[3].

Ngamiland, in the north of Botswana, has the highest baseline precipitation of 453–564 mm annually. The majority of this precipitation occurs as a result of convectively forced rainfall occurring over the peak summer months (Figure 5 A, B, C) with an average of 300–366 mm in these three months. Ngamiland has the highest seasonal variation (coefficient of variation) in Botswana with a very large degree of variability, year on year, in this region.

Precipitation volume is projected to decrease by 2050 across Botswana. Projections suggest that rainfall is expected to decline across Ngamiland, becoming drier in the northern part of the district by 19 mm annually (Figure 5 F). This is a low change in volume compared to the observational volume of ~396–563 mm. Additionally, when considered against the high levels of inter annual precipitation variability, this decrease is not clearly indicative of a long-term trend and may merely be a representation of the 2050 decade. However, precipitation in the peak summer months is set to increase by up to 13 mm in Qangwa, in the west of Ngamiland. Precipitation decreases are therefore mostly resigned to the shoulder seasons to account for the overall decreased annual volume. The seasonal variation is projected to increase by 5–10%.

Ngamiland, is among the warmer areas in Botswana from a maximum temperature perspective with average maximum temperatures being ~33–35°C. Projected increased temperatures (Figure 5 I, J) show an increase of 3.3°C in the warmest months under RCP 4.5 by 2050. The minimum temperatures are also projected to

[3] Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high-resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978

increase, though to a slightly lesser extent than maximum temperatures. The diurnal range is projected to increase by ~0.2°C meaning night-time temperatures are closely tracking the higher day time temperatures.

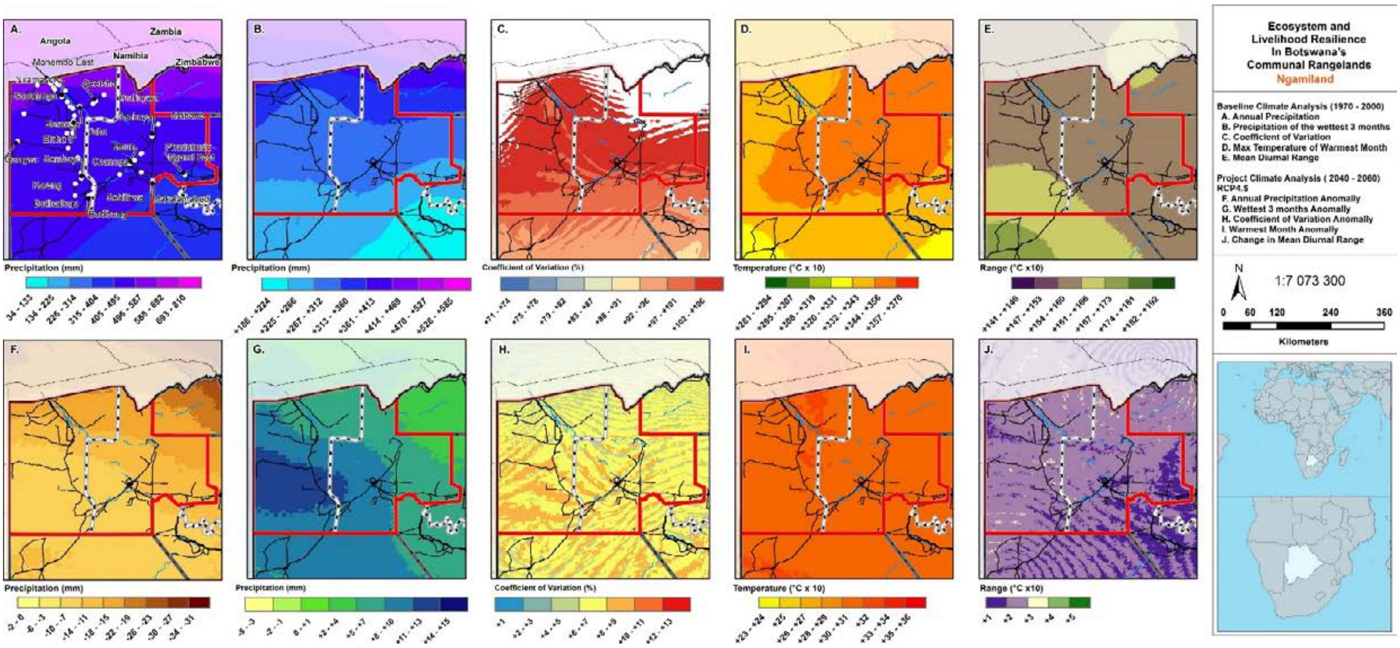


Figure 5. Current (top) and projected climate anomalies (bottom) for Ngamiland[4].

The Okavango basin has a baseline precipitation of 350–519 mm (Figure 6A). The three-month precipitation peak (Figure 6G) associated with summertime convective precipitation exhibits an increase over most of Botswana of 3–20 mm across these three peak rainfall months. The southern area of Kgalagadi and western Namibia are exceptions as they show a decrease trend over these peak months. The seasonal variation (coefficient of variation) is projected to be moderate to high over the basin (Figure 6H), further increasing vulnerability of the rain-reliant economy.

Maximum temperatures vary across the Okavango basin, ranging between 31.4–37.5°C. Projected increased temperatures (Figure 6 I, J) show an increase of ~3.3°C by 2050 under RCP 4.5. The diurnal range is projected to increase by ~0.3°C over most of the basin and by ~0.5°C over Kgalagadi, south of the basin. Minimum temperatures are set to increase and track the changes in the higher day time temperatures but to a lesser degree, therefore increasing the diurnal range.

[4] Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high-resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978

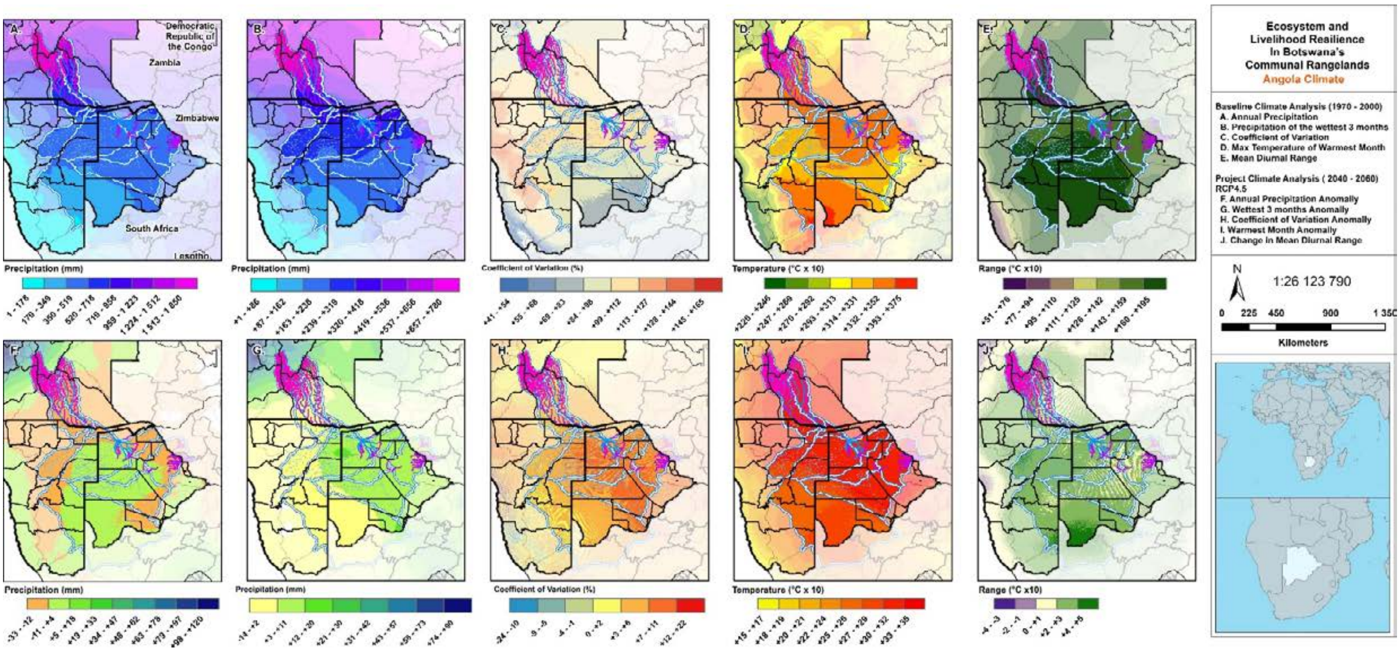


Figure 6. Okavango basin climate data current (top) and projected climate anomalies (bottom)[5].

Kgalagadi, in the south of Botswana, has the lowest average baseline precipitation ranging from 130 to 350 mm annually. The majority (81–243 mm) of this rainfall occurs in the warm summer months (Figure 7). Kgalagadi, with lower total precipitation, has the lowest year-on-year seasonal variability. Precipitation volume is projected to decrease by 2050 in Kgalagadi by between 7 and 14 mm annually. The peak months show a slight increase of up to 5 mm in precipitation over the three months, as is noted in the other study areas (Figure 7 G). The low seasonal variability is also set to increase by up to 6% annually.

Maximum temperatures in Kgalagadi are the warmest in Botswana, particularly in the southernmost area which peaks at average maximum of 37.4°C. Maximum temperatures in Kgalagadi will likely increase by ~3.0°C by 2050 under RCP 4.5. The anomalous diurnal temperatures are the highest in the far south of Kgalagadi at ~0.5°C. Minimum temperatures are set to increase and track the changes in the higher day time temperatures but to a lesser degree, therefore increasing the diurnal range.

[5] Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high-resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978

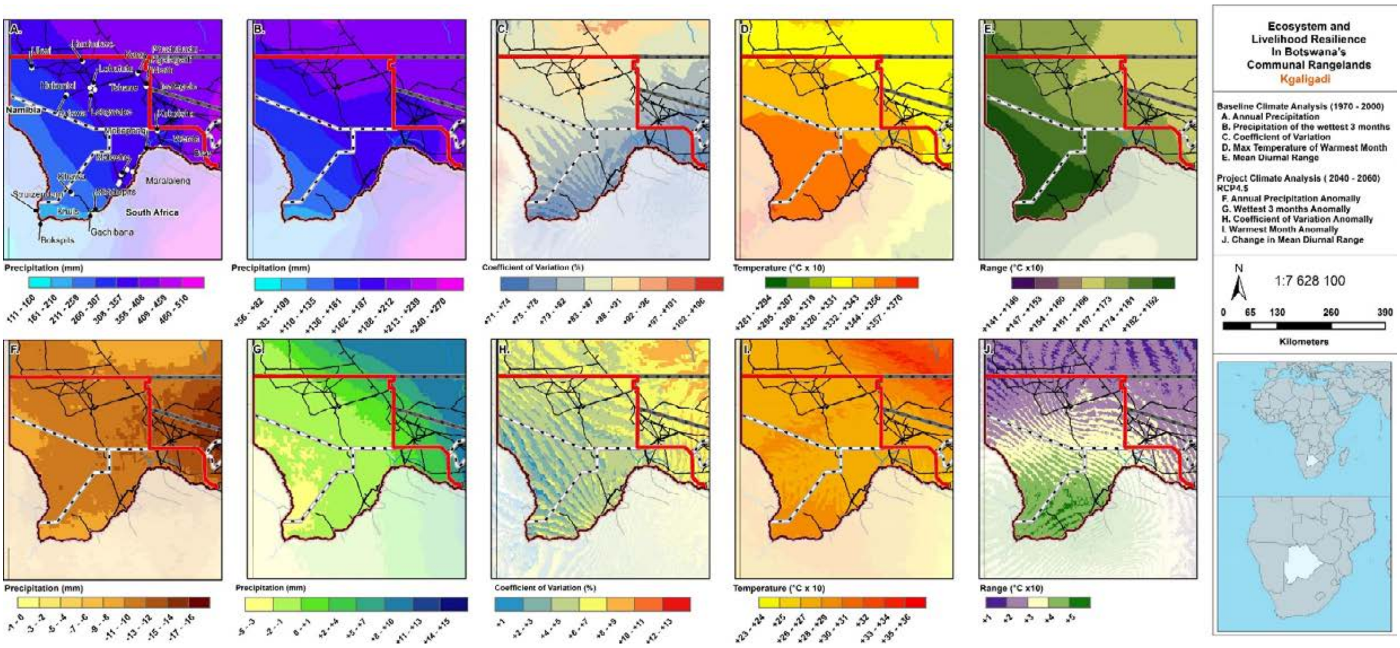


Figure 7. Current (top) and projected climate anomalies (bottom) for Kgalagadi[6].

It is important to understand exposure of climate effects on livelihood strategies that are the target of the project, namely livestock farming. The FAO analysis exposure is an index (Figure 8 left) that calculates the potential commutative impact on people, livestock and agriculture by spatial density, as a result of climatic stresses. Areas of larger population, higher infrastructure density or area under agriculture will have a higher element at risk index. Livestock being more mobile are assessed by the climate stress index (Figure 8 right) and are less influenced by spatial population densities. The climate stress is predominantly precipitation exposure focused but considers factors that have highly correlated relationships with agriculture suitability and ecosystem function. The metrics that make up the climate stress are interannual rainfall seasonal variation, probability of precipitation being 300 mm or less, reliable annual precipitation, rainfall trend coefficient and the negative years of Standardised Precipitation Index (SPI).

Noted areas of increased exposure and stress are those that correspond to the principal climate anomalies with a large driver being the increase in maximum temperature, decreased annual precipitation, and increased coefficient of variation (seasonal variation) being more prominent in the northern part of the country (RCP 4.5 2050). This data was used as an exposure component for the livelihoods and livestock primary CCVA analysis. However, where local statistics are not reported, these indices have data gaps. This data was therefore augmented with the WRI data as an alternative set of indicators.

[6] Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high-resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978

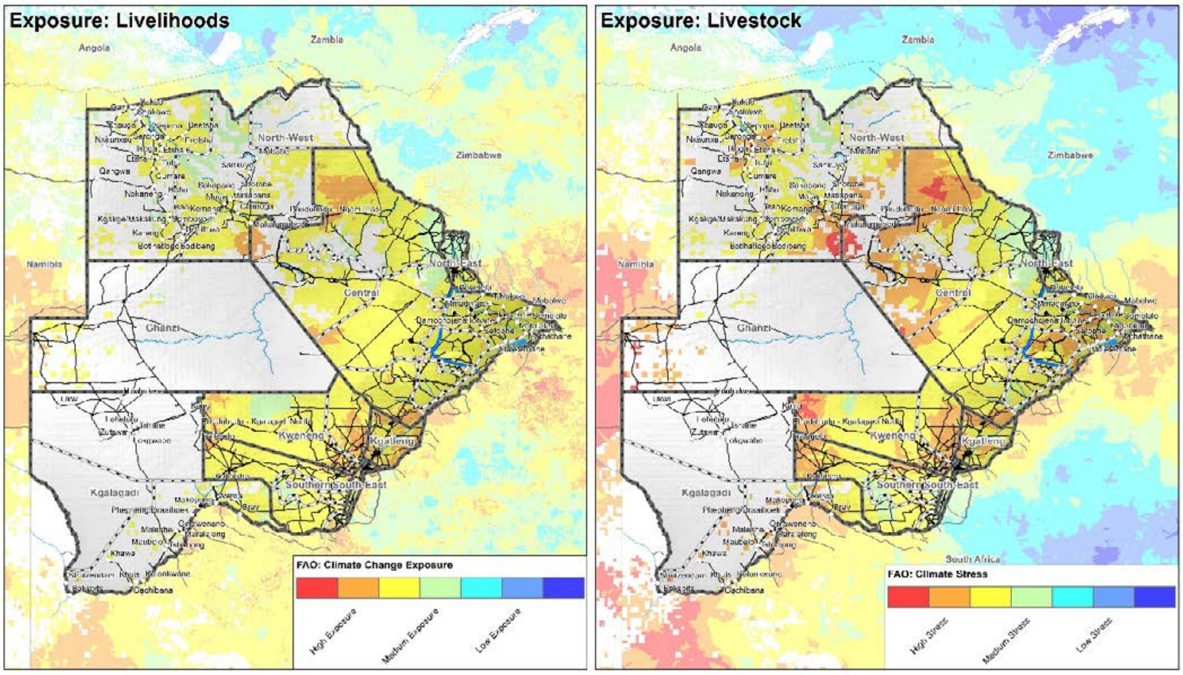


Figure 8. Livelihood and livestock custom exposures[7].

The need for alternative indicators allowed for further targeted assessment. The seasonal variability (Figure 9 left) would compromise a livelihood that relied on consistent or predictable precipitation. Areas further to the south, while having reduced annual and peak seasonal precipitation, also have smaller projected precipitation anomalies and will be less variable. The precipitation coefficient variation is lower in the south under current conditions and lower under projected conditions. Livestock compete with humans for water resources and therefore increase the water supply and demand pressure exposure (Figure 9 right). Areas of lower pressure are the urban centres and the areas in the further north with increased precipitation. The more remote areas, particularly in the south corresponding to lower rainfall totals have the highest water supply and demand pressure.

[7] Exposure Index (2010) - ClimAfrica WP4 http://www.fao.org/geonetwork/srv/en/main.home

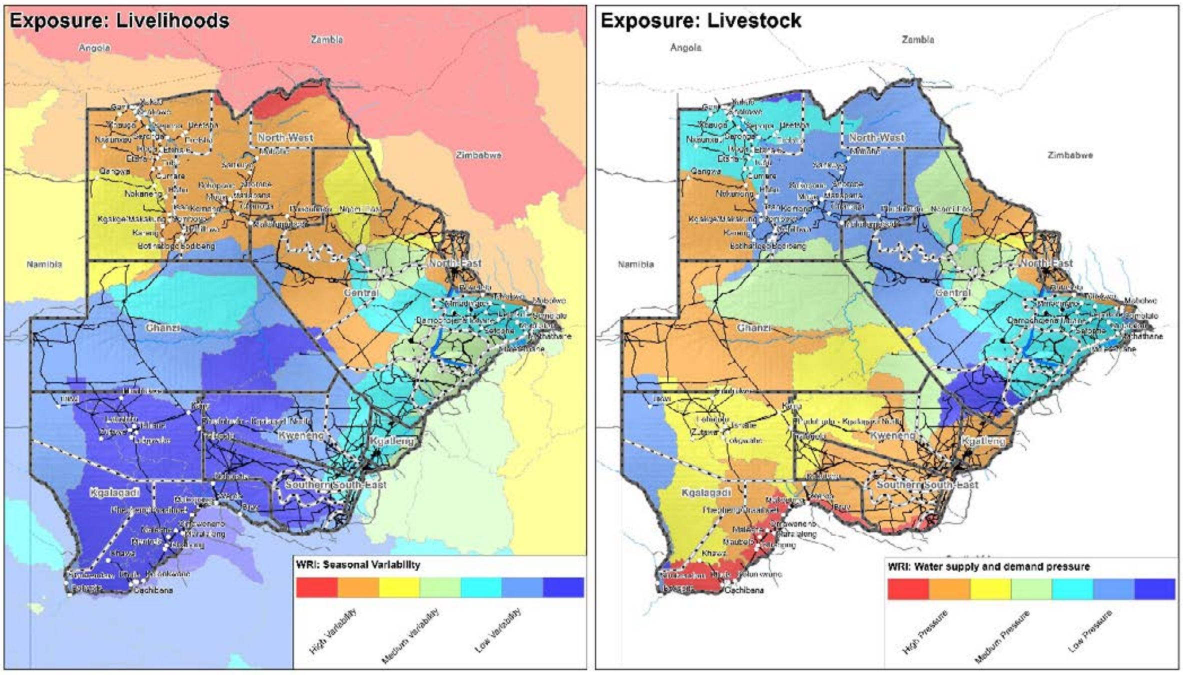


Figure 9. WRI livelihood and livestock exposures[8].

The assessment of different pastoral communities at local scale suggested that their sensitivity, and adaptive capacity to climate change is relatively diverse and driven by multiple stressors. In Bobirwa's Central Bobonong district, there is a wide range in anticipated social vulnerabilities of the different pastoral communities. Both Damochojena and Tshokwe communities had high to extreme vulnerability scores, whereas the vulnerability of communities of both Molalatau and Robelela was very low to low. The strongest cause of the poor vulnerability score in Damochojena and Tshokwe are the high dependency ratio (+100%), particularly in the <5-year-old range and the relative unemployment rates for all genders (~26%). However, it is anticipated that women likely engage more in unpaid and unreported work resulting in higher dependency/lower adaptive capacity. In contrast, Molalatau and Robelela have lowered dependency ratios (~64%) and lower reported unemployment rates (~18%). These communities also have greater resilience as a result of having greater access to goods and services – access to sanitation, water sources and reliance on electricity for cooking and heating are higher in Molalatau and Robelela. By contrast Damochojena and Tshokwe have ~45% sanitation access, 11% private household access to water resources and 4% private household electricity access and therefore lower adaptive capacity.

Kgalagadi's north and south have a wide disparity in the sensitives and adaptive capacities but generally have lower overall vulnerability than the other study areas. Ngwaketse West, in close proximity to cross-administration-grazing areas, exhibit low vulnerability. Kang and Bokspits in the north and south districts, respectively, have low vulnerability profiles resulting from the low total unemployment rates (~7%) and lowered dependency ratios (51%), which means that the communities are less sensitive to disruption. Moreover, they have higher adaptive capacity resulting from having access to piped water within private households (~57%). Some other villages in districts do not have similar capacities. Inalegolo and Kokotsha have low access to sanitation services and only 23% private households have water access. These settlements also have high illiteracy rates and a high dependency ratio of 93%.

Ngamiland's Ngami East and Ngami West districts, in the northern area, have the largest number of villages and include the town of Maun. There are large discrepancies in the community's vulnerabilities, which is likely a result of the diverse livelihoods in the area. The vulnerability profiles are driven by differences in the dependency ratios and employment sensitivities in this area. Gudingwa and Botlhatlogo both have dependency ratios of ~135%, while Botlhatlogo has an unemployment rate of 25%. The limited adaptive capacity in these areas is driven by the high reliance on communal taps (66% of the population), rather than having private water access (10% of the population) and the limited access to formalised sanitation services (23.5% of the population). The town of Maun, having a large local population and well-developed infrastructure, has greater access to services. Water is available to ~70% of the population either within

[8] Aqueduct Global Maps 3.0 Data, https://www.wri.org/aqueduct/data - RCP 4.5 2040

private dwellings or still on the same property. 66% of dwellings also have access to electricity as an energy source. Seronga does not have the same access to these services but has a similar sensitivity profile, with an average dependency ratio of 74% and a low unemployment rate of 16%.

The adaptive capacity in Kgalagadi is varied over the area, but villages that are clustered together do show greater capacity than more isolated villages such as Zutshwa and Ukwi, which are characterized by low adaptive capacity. The area as a whole has a tendency for higher sensitivities than Bobirwa or Ngamiland. Populations in Kgalagadi will not gain the collective benefits of some of the other villages and will suffer from limited accessibility. In general, Bobirwa sub-district had higher adaptive capacity and lower sensitivities relative to other sites and that could be linked to diversified livelihood and therefore employment options that include farming and higher employability (literacy rate above 80% Statistic Botswana 2013). Bobirwa seems to be well-served by transport infrastructure connecting the settlements. Ngamiland is more varied in its vulnerability but areas to the south around Maun appear to have decreased sensitivity and greater capacity than those further north where several locations with very low adaptive capacity and that could be explained by high poverty levels of 46 and 33.4% in 2009/10 and 2015/16 respectively. It has been reported that poverty is one of the determinants of farmers' adaptive capacity in Botswana (Kgosikoma et al 2018). The reoccurrence of Foot and Mouth disease (FMD) in Ngamiland could also be contributing to pastoralists' low adaptive capacity as access to market is continuously be disrupted during disease outbreaks and as a result livestock prices are relatively low and therefore limit earning potential of communities.

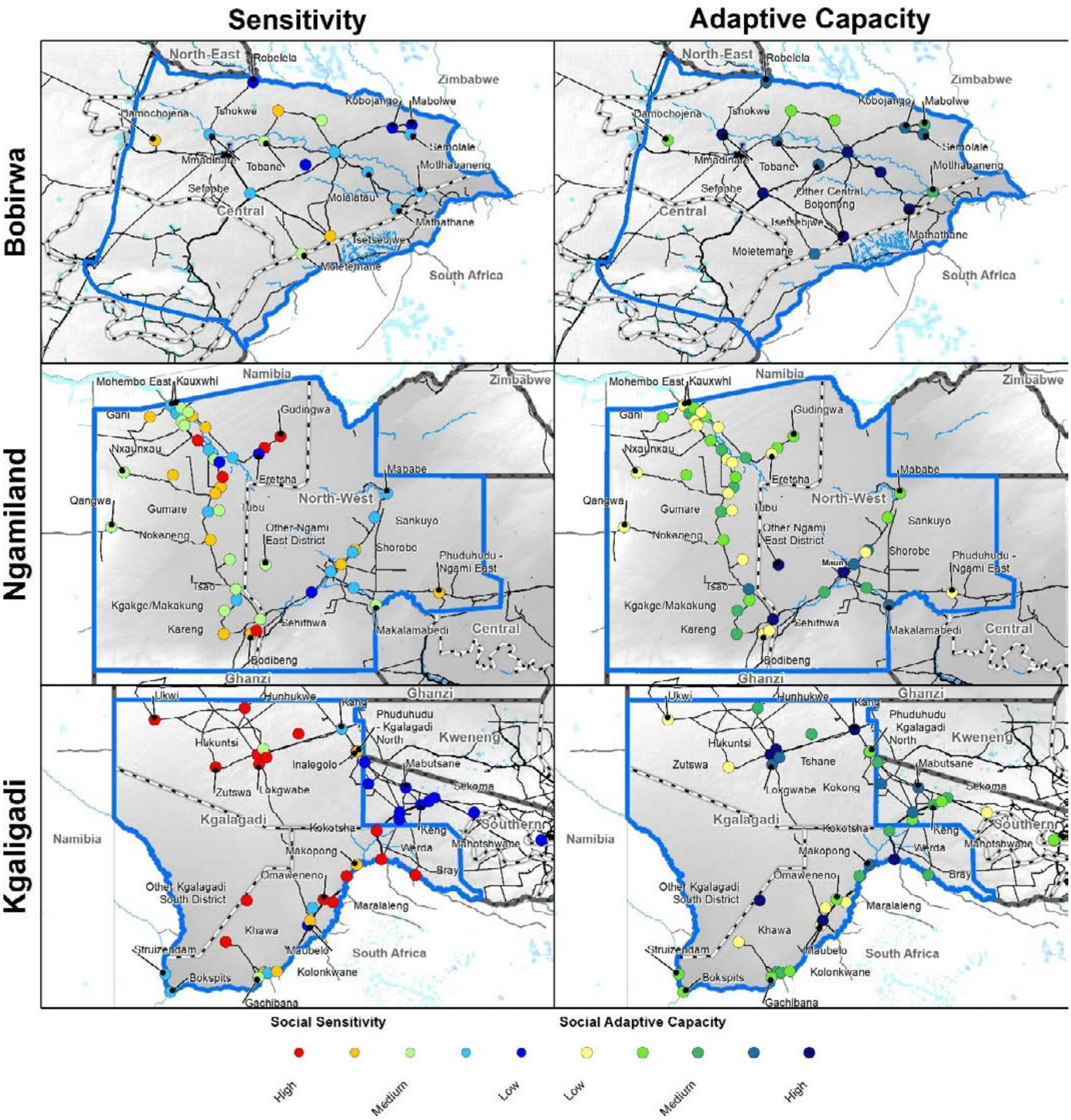


Figure 10. Current social sensitivity and adaptive capacity in the village in the study areas.

The social climate change vulnerability was calculated by reviewing the baseline social sensitivities and adaptive capacities in the presence of the spatial climate change exposures for RCP 4.5 and RCP 8.5 by 2050 and applying them to the future Shared Socioeconomic Pathway 2 population scenario. In a water-scarce country with livelihoods often reliant on rainfed agriculture and ecosystem services (such as flood mitigation, nutrient cycling, etc), baseline and decreased precipitation — along with enhanced increased precipitation variability and drought severity — were considered greater contributors to social exposure than more rare flooding events with more severe impacts. The cumulative vulnerability is highest in Kgalagadi, this is followed by Ngamiland, with Bobirwa being the least vulnerable.

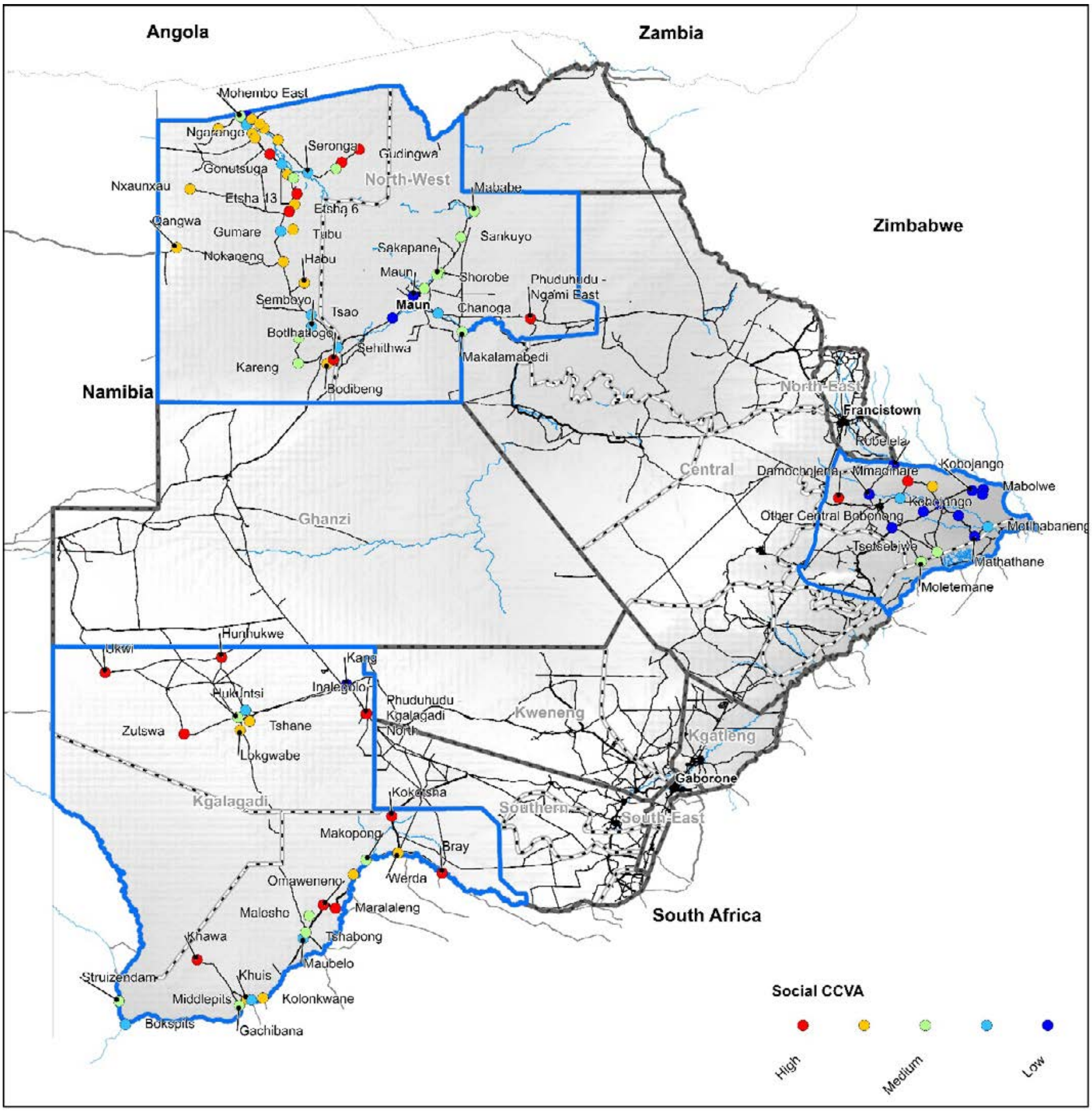


Figure 11. Projected social vulnerability across Botswana.

Bobirwa, with the middle range for precipitation, is moderately exposed to shifts in seasonal variation, but is highly sensitive to variable soil moisture, which can be seen in severely degraded ecosystems, rangelands and a high dependency on surface water which compromises producers' ability to sustain their families. The livelihood options in Bobirwa for both males and females — such as crop farming, livestock production and harvesting of NTFP such as phane (mophane worms) — are dependent on natural ecosystems and therefore vulnerable to climate variability, however the local access to markets and various good and services does reduce this overall vulnerability (Figure 12).

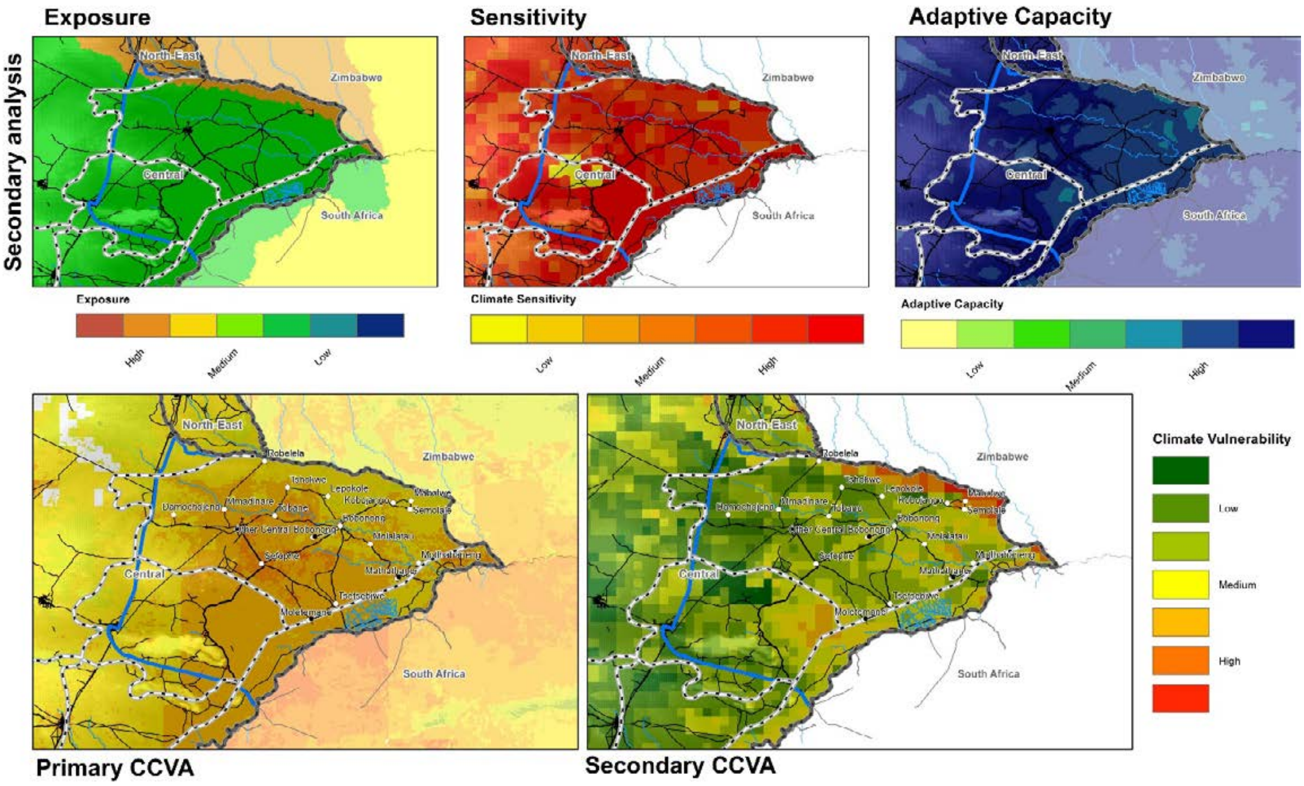


Figure 12. Components of livelihood climate vulnerability for Bobirwa.

Kgaligadi, with generally reduced precipitation, has lower possible seasonal variation, and communities have adapted to this lowered threshold. Kgaligadi has the lowest connectivity with much of the area being highly isolated. Goods and services are more spread out and markets are not as accessible. In Kgalagadi, vulnerability appears to be high in settlements dominated by San ethnic groups and could be because they have limited resources to buffer their livelihoods against climate shocks (Figure 13).

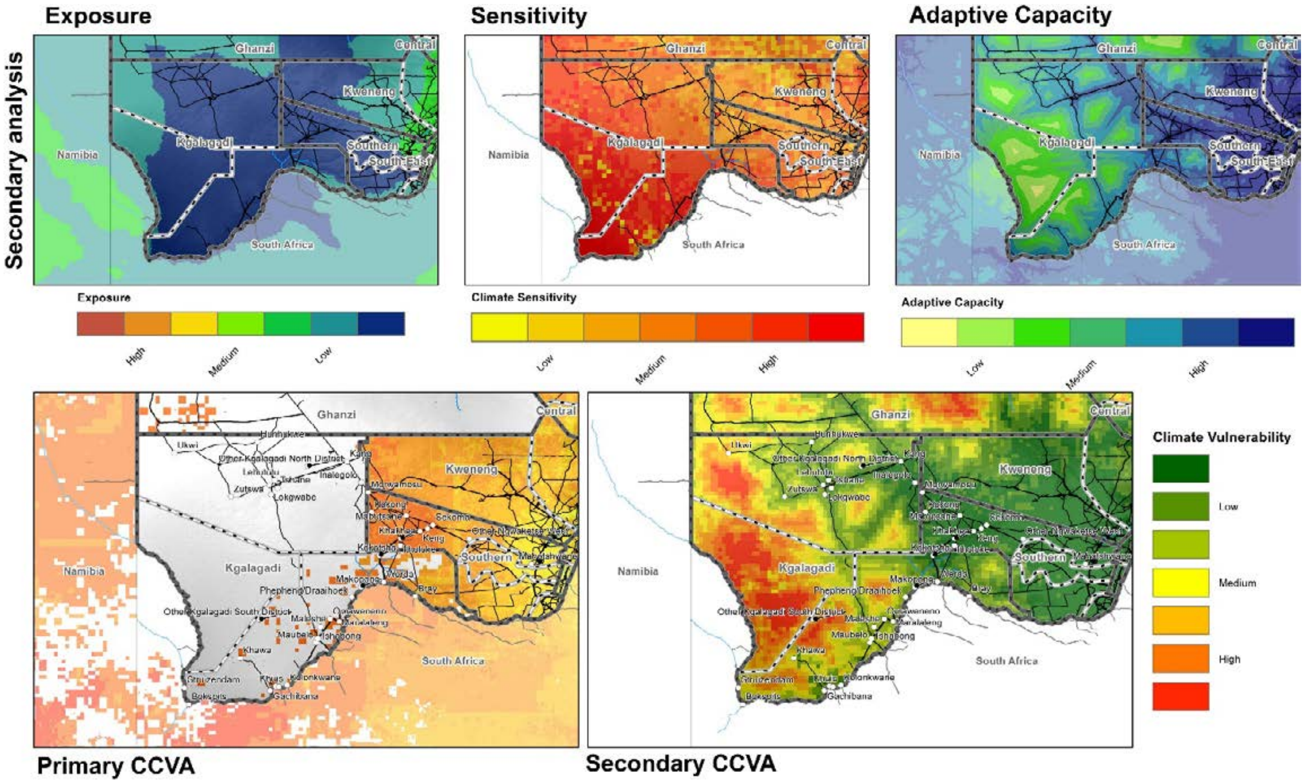


Figure 13. Components of livelihood climate vulnerability for Kgaligadi.

The ecosystems around the Okavango Delta and Sehitwa in Ngamiland are also highly exposed and therefore lead to increased vulnerability. The increases in seasonal variation will expose the livelihoods of rural communities to disruption (Figure 14). The most vulnerable groups will likely be those whose access to livelihood sources and food security depends on both crop farming and pastoralism, as both are influenced by soil moisture sensitivity especially during drought events. Specifically, these groups will be those whose livelihoods are reliant on regular rainfall due to high seasonal variation of rainfall in Ngamiland, particularly female-headed households.

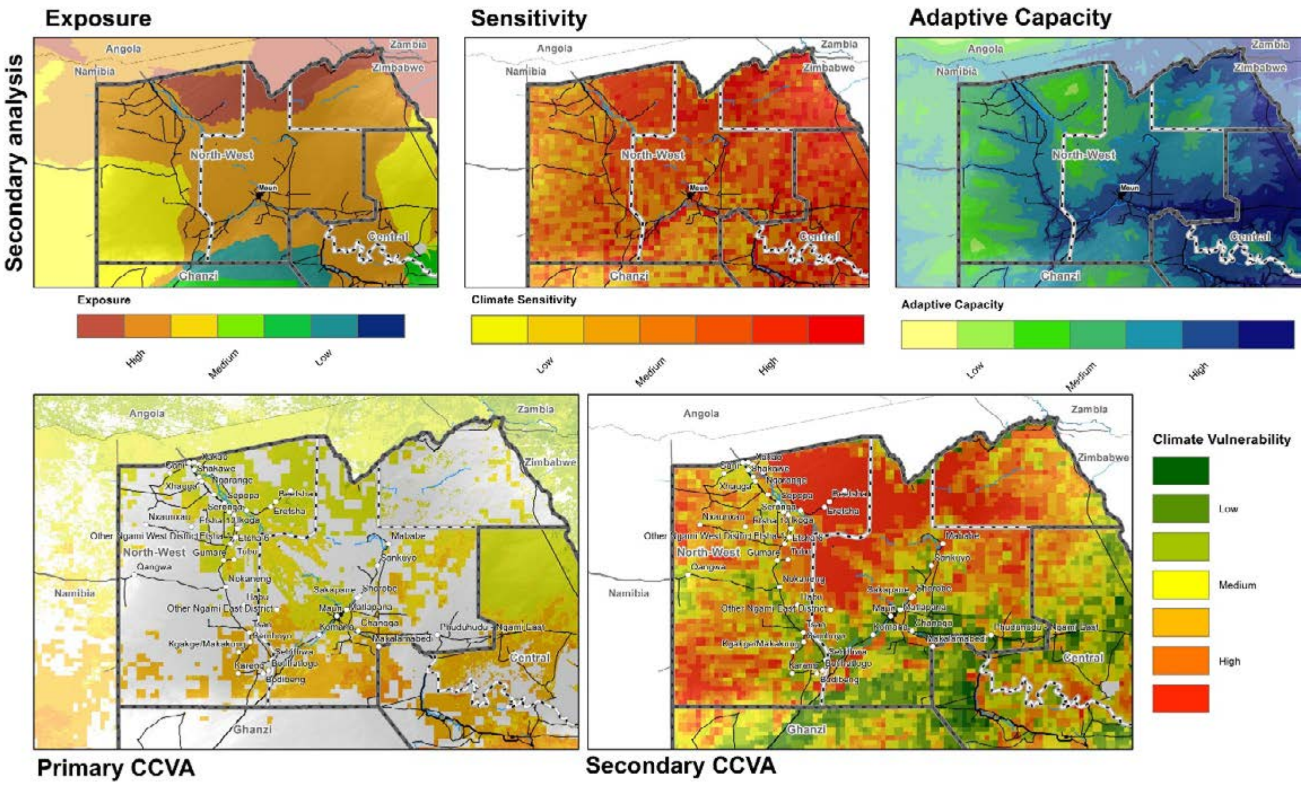


Figure 14. Components of livelihood climate vulnerability for Ngamiland.

The climate and soils in the Bobirwa environment are most suitable for medium-high and low-medium value grazing grass species. This could be attributed to high soil fertility and moisture in high veld areas. However, low cover of palatable grasses such as Schmidtia pappophoroides and Panicum maximum and attributed this to land degradation in Bobirwa. In Ngamiland, the lands around the Okavango delta and Sehithwa were also well-suited for grasses of high grazing value. Outside of these regions the suitability is limited in Ngamiland. The Kgalagadi ecosystem has the lowest overall suitability for both grasses of high or low grazing value and that because soil moisture and fertility are limiting.

Future vulnerability of rangeland grazing species — which pastoralist communities are dependent upon to support livestock herds — has been determined by assessing the climatic suitability of these species under future climate change, namely using RCP8.5. The projected climate changes indicate more extreme day and night-time temperatures, decreasing precipitation and large variability in the rainfall reliability, particularly in the first part of the season. These climate changes will alter the suitability of the species by 2070 (RCP 8.5). Bobirwa shows consistent decreased suitability of both medium-high and low-medium value grazing grass species (Figure 15). While this does not necessarily mean that will change under RCP8.5 because of factors such as climate shocks and competition from climate-change tolerant species.

These species may also be outcompeted in this region by species suited to the modified climate parameters. Low-medium value grazing grass species show a large decrease in suitability in Ngamiland, with the exception of some of the north eastern areas. These same areas will likely be more climatologically suitable to some of the medium-high value grazing grass species. Elsewhere however, species suitability is decreased. Kgalagadi, which already had low species suitability, sees this suitability further decrease in the future with the exception of the furthest south areas for low-medium value grazing grass species.

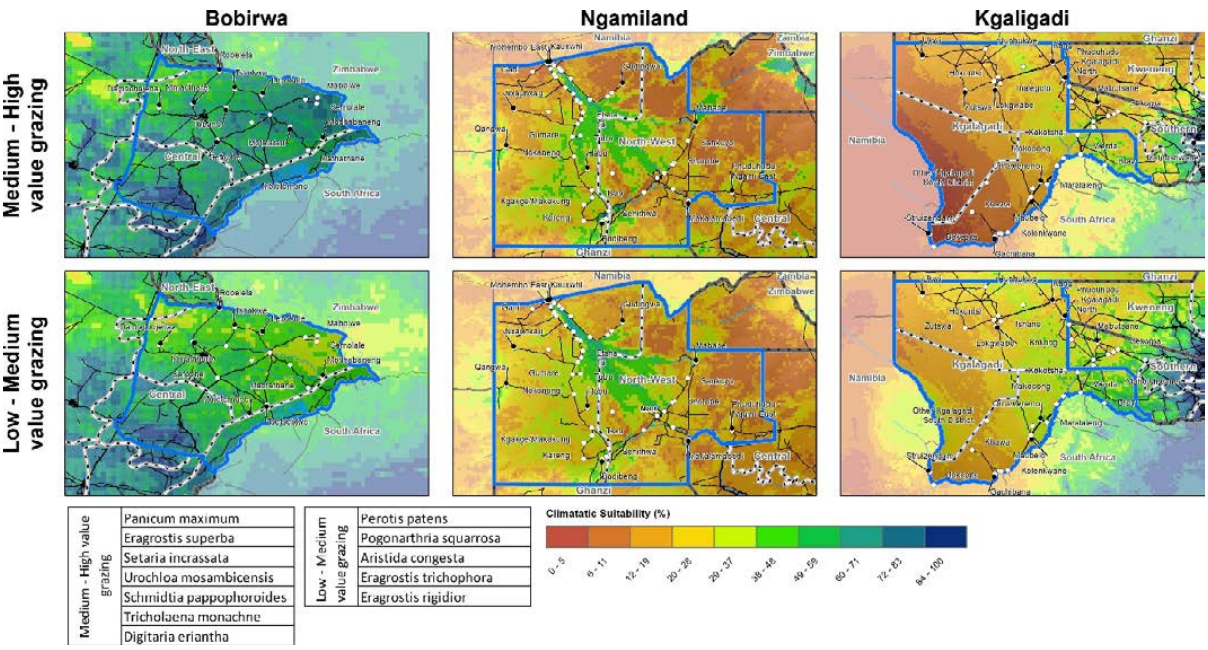


Figure 15. Current environmental suitability of different grass species across Botswana.

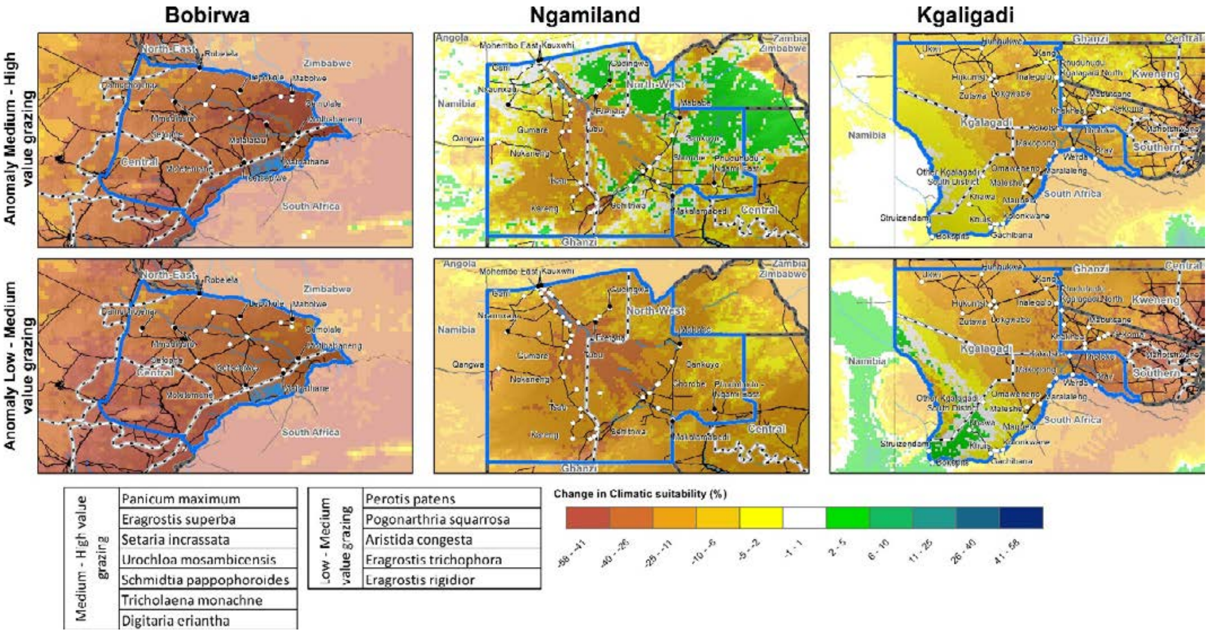


Figure 16. Future changes in rangeland herbaceous composition under RCP 8.5 2070 scenario.

During the consultative discussions, the pastoral communities confirmed that recurring rainfall anomalies threatens the sustainability of their livestock production and livelihoods. The future precipitation (2040–2060) is expected to decline by at least 8 to 16 mm, even when using the moderate emission pathway (RCP 4.5). This downward future trend in precipitation has also been demonstrated in work by other researchers. The rainfall is also likely to be more unreliable in the future, as indicated by increased coefficient of variation. These climate changes noted by the communities will become more severe in the future and will have both direct and indirect implications for communal livestock. Bobirwa (Figure 17), in the east of the country see medium to high exposure for people, livestock and crop lands.

Sensitivity analysis in Bobirwa used the water available to agriculture and livestock. The anticipated sensitivity is low to medium resulting in lower overall competition between sectors for access to water resources. This lower sensitivity to climate risks could be attributed to multiple factors such as high surface water availability for irrigation and diversified employment activities where water-use is less intensive. However, small-scale livestock without the diversification of activities would be highly sensitive to drought and drying of ponds in these extreme events. With the high anticipated exposure changes, the future vulnerability will increase because of high dependence on surface water which is highly variable depending on river flows. The adaptive capacity in Bobirwa was assessed through the resolve of natural ecological systems focusing on livestock and agriculture sustainability. The adaptive capacity is considered low to medium. The large number of cattle in this area will place additional stress on these natural systems.

The projections indicated that livestock environment is likely to be more unfavourable in Bobirwa (Figure 17) particularly in the south, western and northern parts of the district. Nonetheless, this district is likely to have more cattle population in the future and loss of this assets due to climate change will lead to increased poverty. This will likely force pastoralists to seek alternative livelihoods such as employment in urban areas or harvesting of increased volumes of non-timber forest products (for example, mophane worms and firewood). This could potentially disrupt family life through migrations and exacerbate land degradation. Additionally, with expanding livestock populations and decreasing rangeland and water availability, resource competition is likely to increase between farmers. The combination of increasing poverty and competition for dwindling resources may increase the likelihood of conflict among pastoralists. Previous research has indicated that Ngamiland, for example, is characterised by this with land use competition, conflicts and environmental problems cited as some of the most common issues faced by pastoralists. Moreover, surveys conducted in Bobirwa have shown that men, as the primary holders of livestock, are particularly distressed by water and livestock feed shortages. This is because livestock is reared for both income and consumption, so reduced productivity leads to a reduced ability to provide and subsequently an increase in the likelihood of behaviours such as alcohol abuse, criminal activities and family breakdown. Social issues of water scarcity extend also to women and their children as it is often the responsibility of the female household members to ensure water is available for household use.

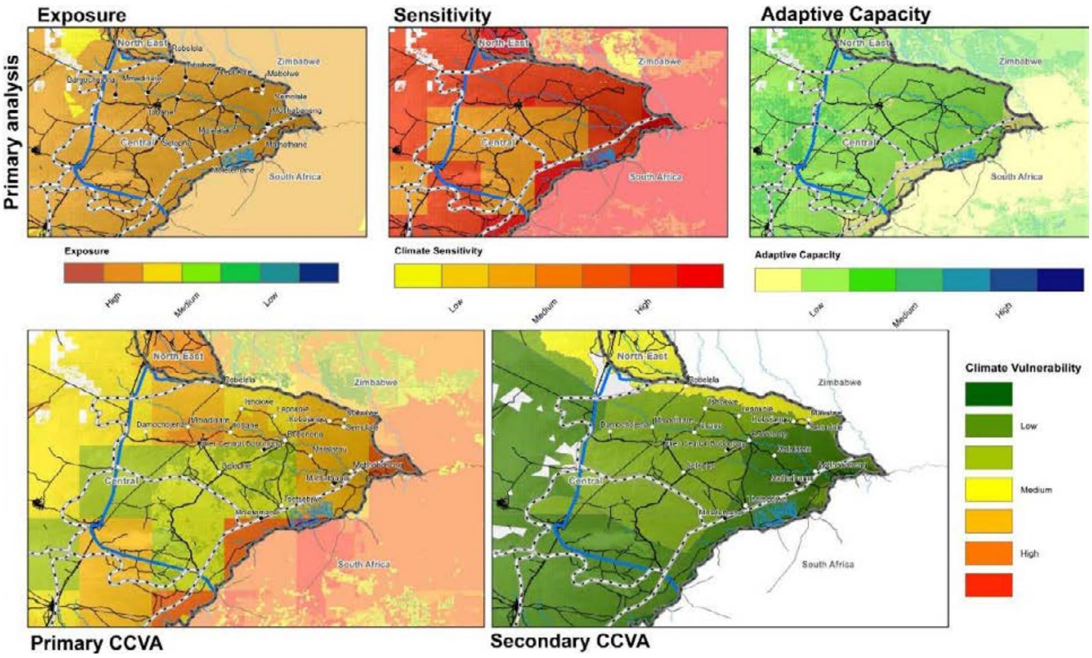


Figure 17. Components of livestock climate vulnerability for Bobirwa.

Kgalagadi communities (Figure 18), in the south of the country, are currently extremely exposed to climatic changes. The anticipated decreased precipitation is very high proportional to the low annual precipitation totals. Kgalagadi is currently characterized by low annual rainfall ranging between 212 mm in the southwest and 317 mm in the north of the district. The coefficient of variation is very high indicating high rainfall uncertainty including all rangeland ecosystem and livestock production system as there highly correlated. The annual rainfall is projected to decline by at most 15 mm under changing climate (RCP 4.5) and similar pattern had been reported at Tshane.

Kgalagadi has a high concentration of boreholes which provides some relief for livestock but are often of high salinity. The sensitivity in water supply, given the low precipitation in this region comes from groundwater as a viable potential alternative. The low rate of groundwater replenishment means that the sensitivity is medium to high in this area. The adaptive capacity in Kgalagadi is based on the economic impact to livestock associated with largescale drought in the region. The lower proportion of commercial cattle in the region does however show lower economic impact from drought. The impacts of subsistance farmers, of which there are fewer, will still be high because of high dependence on communal grazed livestock system, which are highly exposed to recurring droughts.

The high exposure and sensitivity in Kgalagadi suggest future livestock suitability will decrease per livestock unit. However, the reduced number of cattle in the area will lower the rangeland impacts of these cattle. The future vulnerability is low to medium and high in some further south areas. This vulnerability is highly dependent on the lowered number of cattle in the area. With high exposure and sensitivity, increasing the cattle density will rapidly increase the climate vulnerability of the area. Moreover, an increase in cattle density will likely exacerbate both the direct and indirect consequences of climate change on livestock suitability — with increasing temperatures and frequency and intensity of heatwaves and droughts leading to, inter alia, a higher incidence of heat stress, increased pathogen transmission and a reduction in grazing and water resources. In 2015/16, a period during which there was drought, cattle experienced the highest mortality of all livestock in Botswana, with Kgalagadi being the second most affected district with 2,698 cattle deaths (~21% of all cattle deaths during this period).

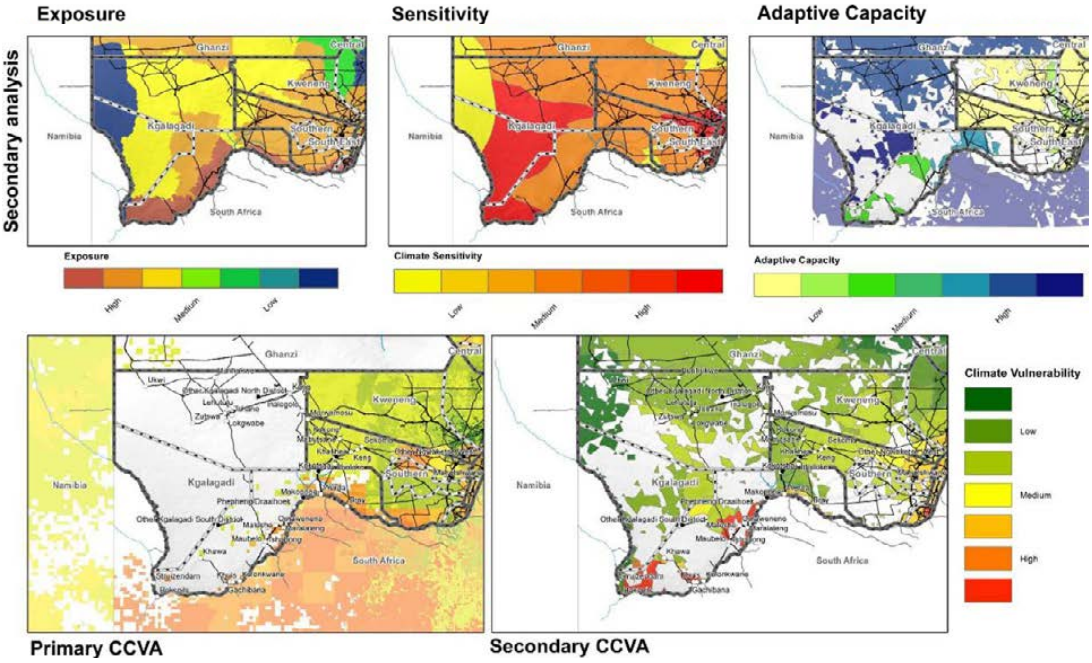


Figure 18. Components of livestock climate vulnerability for Kgaligadi.

Ngamiland, in the northern delta region of the country, has the highest average precipitation in the country as well as being subject to the annual Okavango flooding event and as such has a lower exposure of future water stress. Sensitivity is based on ground water reliability. With the higher annual average precipitation and the flood inundation, from a purely water volume perspective, this area has decreased potential ground water stress. The sensitivity in the southern area of Ngamiland is also driven by the high cattle densities in this area resulting in land degradation and ecosystem pressure.

The adaptive capacity of the region is medium - mostly a result of key variable economic activities of agriculture and tourism. Both of these activities are highly rainfall-sensitive with ecosystems responding to an extreme extent to seasonal changes. Smallholder livestock, not benefiting from the economic activity from tourism around the delta, would still be exposed to these changes.

Given the higher total precipitation in the area and the various economic activities, this area as a whole will likely have the highest overall resilience to future climate changes. However, in the event of precipitation failing and floods being of reduced magnitude, the small-scale livestock farmers will need to find water and rangeland resources for their cattle and compete in the area of the country with the highest average cattle density. In a water scarce country, the climate change vulnerability is driven primarily by the shifted exposures of surface and ground water resources, the sensitivity of natural resources and the livestock density competing for resources.

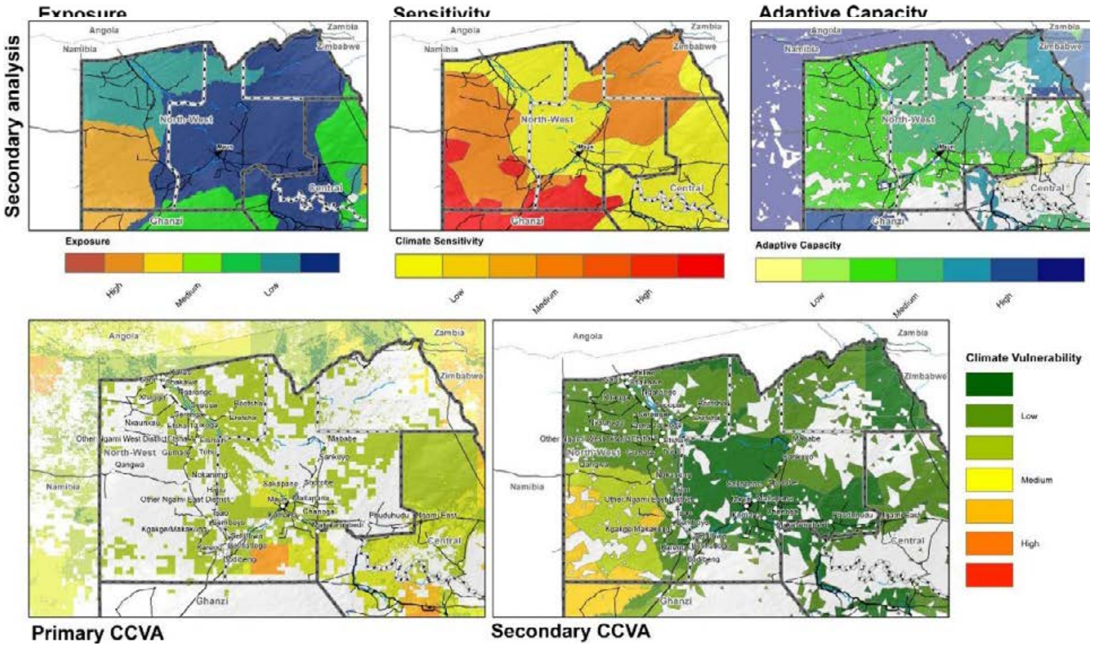
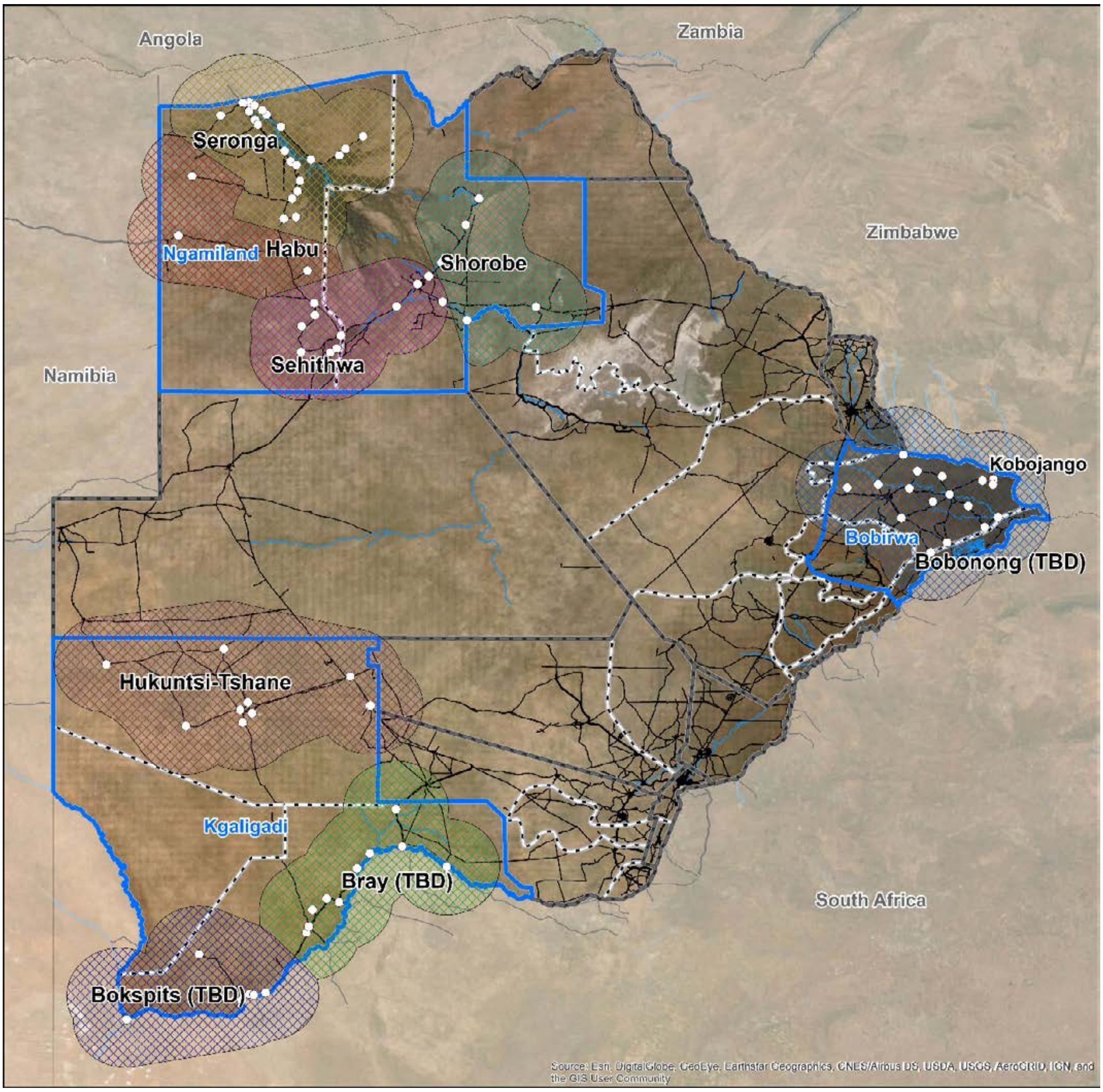
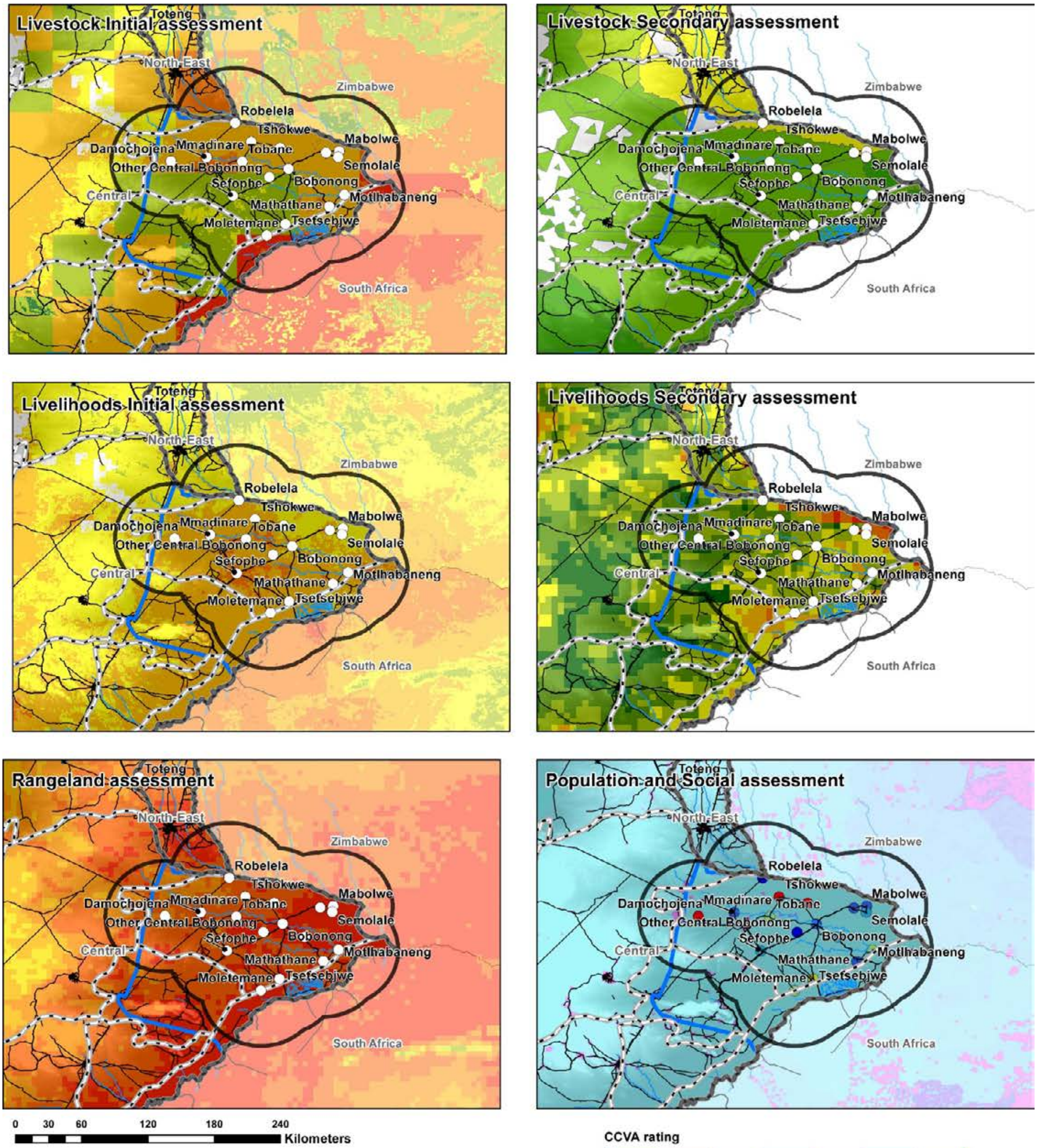


Figure 19. Components of livestock climate vulnerability for Ngamiland.

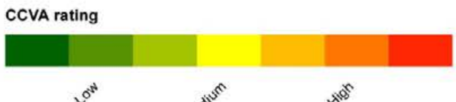
1.1 Appendixes: Clustered Results



2.1.1. CCVAs Bobirwa



Assessments are the output of the CCVA equation and are relative rankings ranks.
Data that went into each assessment as ia follows



Livestock initial assessment
Projected Climate Stress, Natural vegetation Sensitivity, Water Resilience

Livestock Secondary assessment
Projected water supply and demand pressure, Drought sensitivity, Drought Economic Resilience

Livelihoods initial assessment
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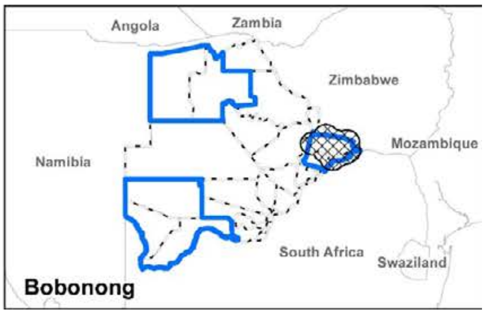
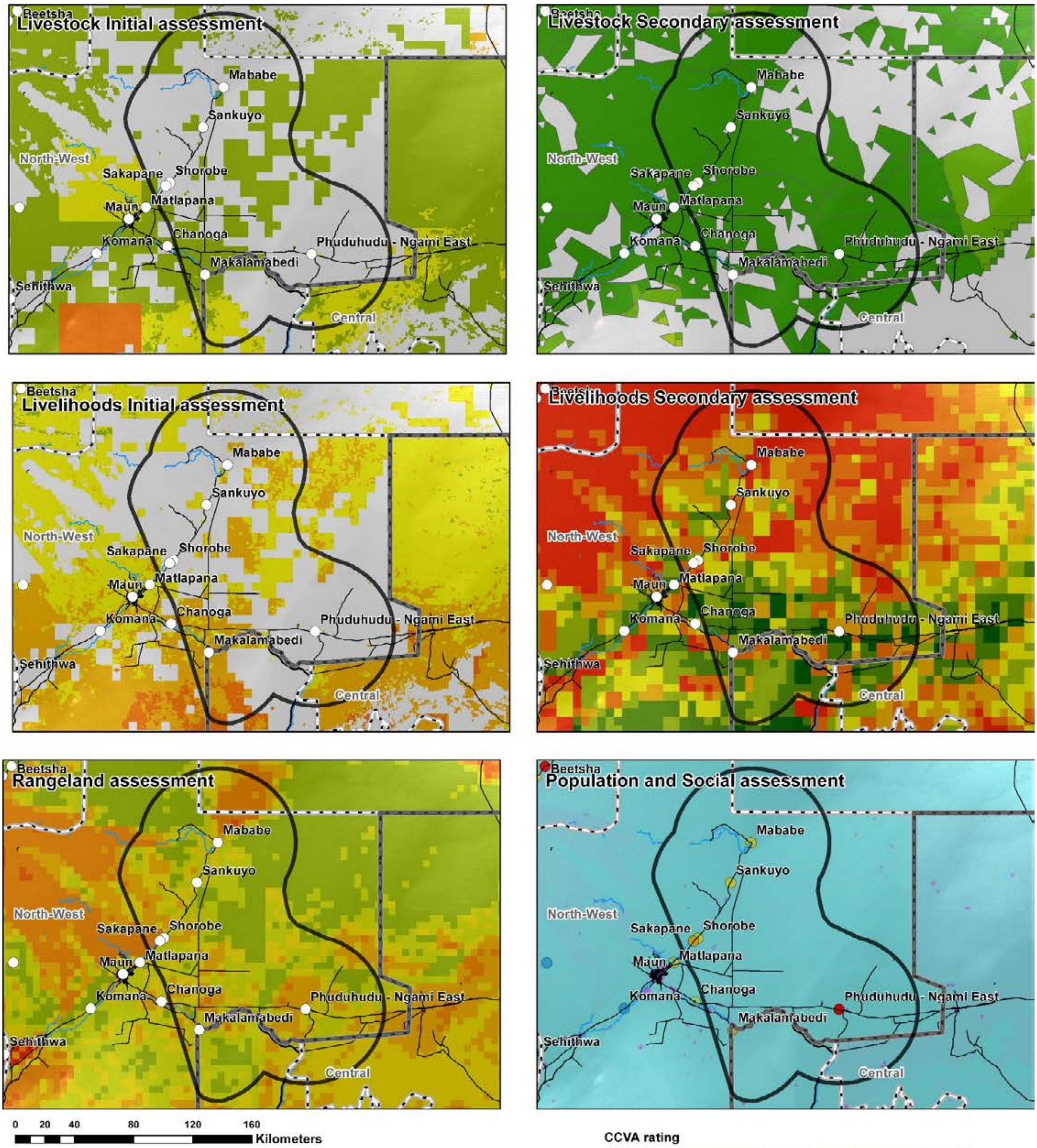
Livelihoods secondary assessment
Projected Sessional Variability, Soil moisture sensitivity, Rural Accessibility

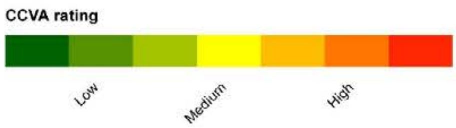
Rangeland
SPARK High value grazing grasses climatic suitability

Social
Demographic Indicators of Sensitivity Capacity in projected climate scenarios



2.1.2. CCVAs Ngamiland





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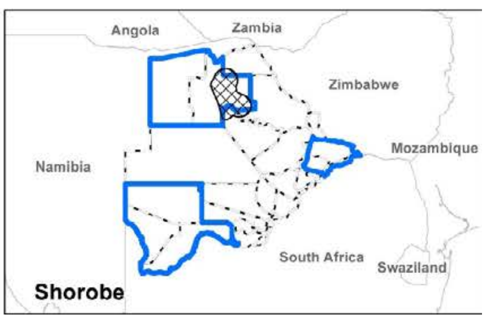
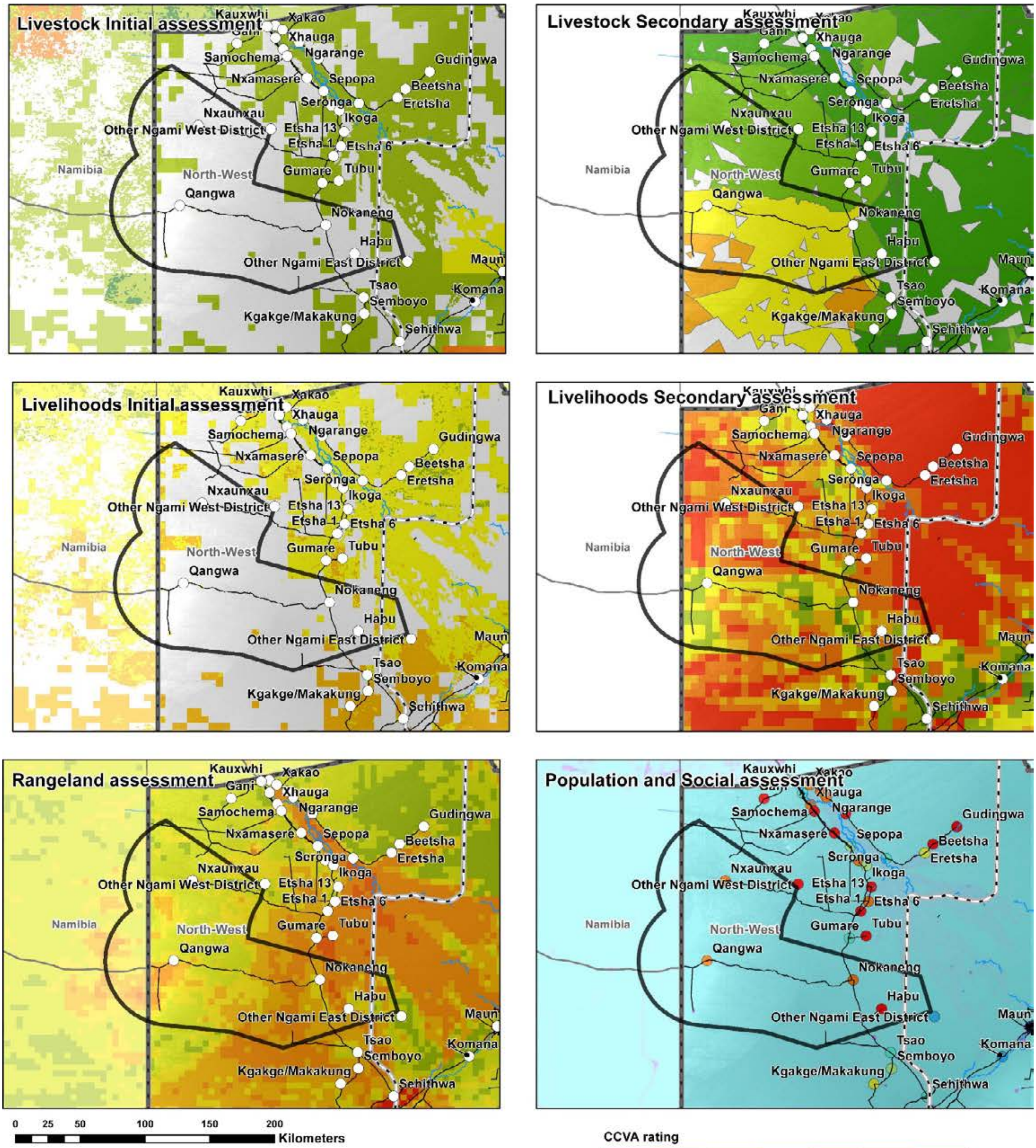
Demographic indicators of Sensitivity Capacity in projected climate scenarios





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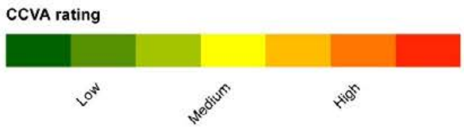

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SPARK High value grazing grasses climatic suitability

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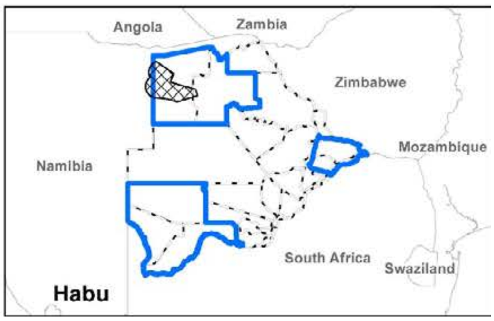
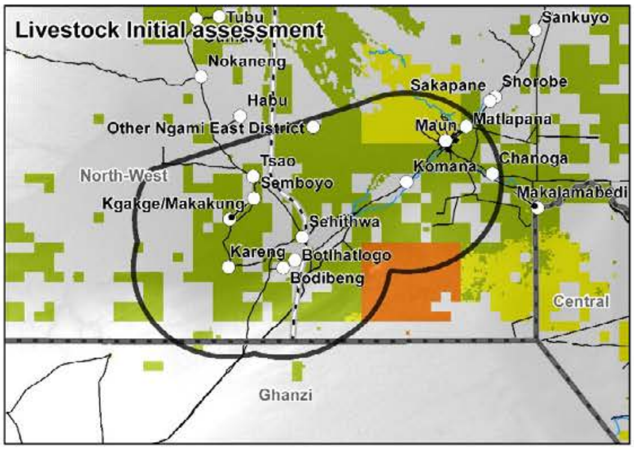
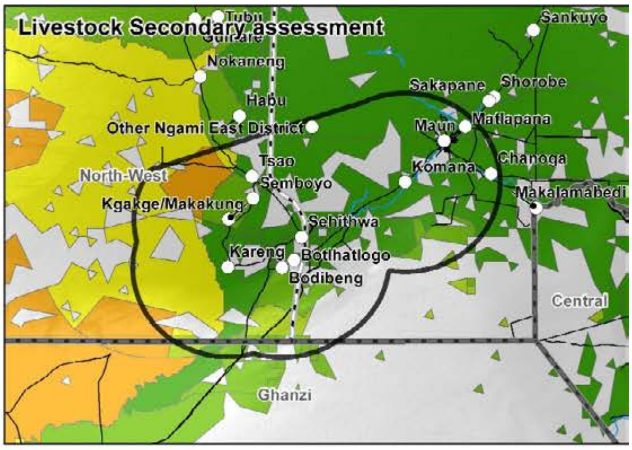
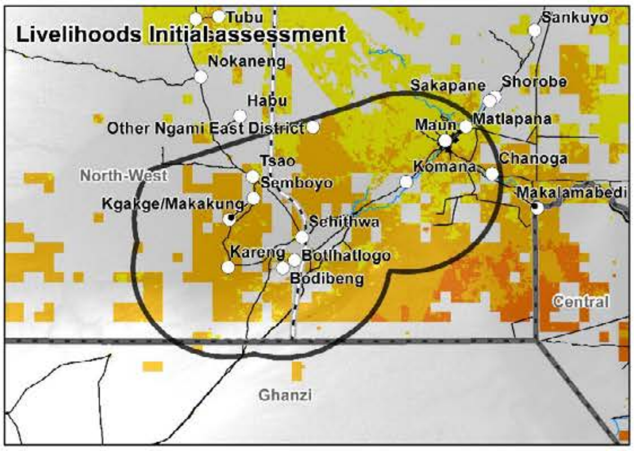
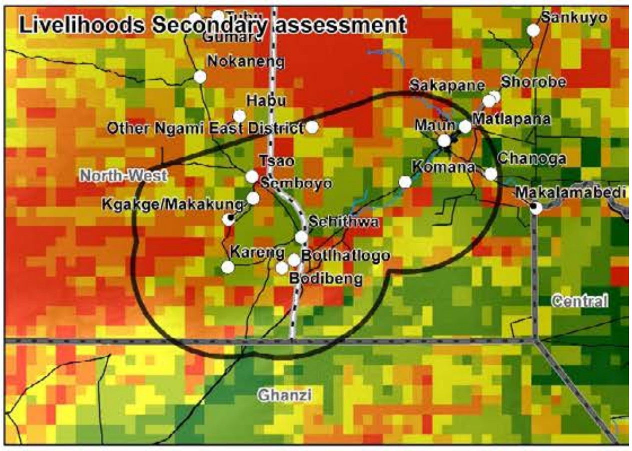
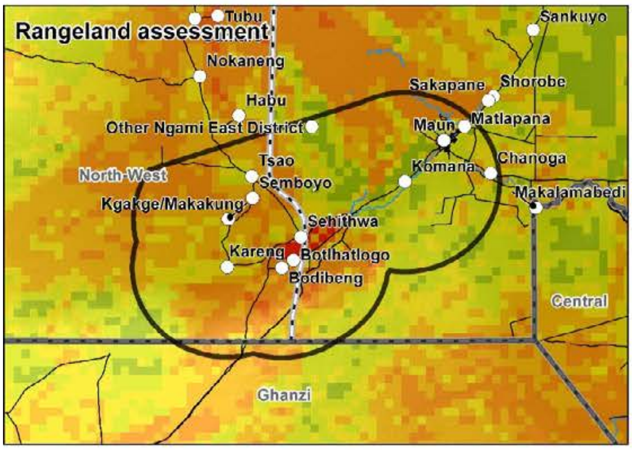


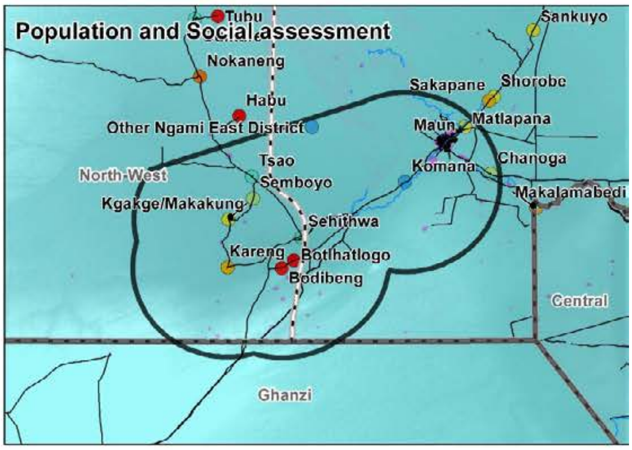






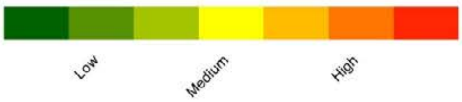






0 20 40 80 120 160 Kilometers

CCVA rating



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Livelihoods initial assessment
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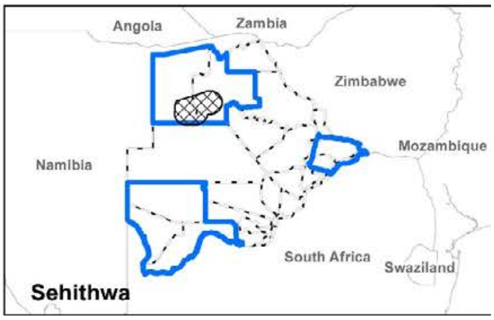
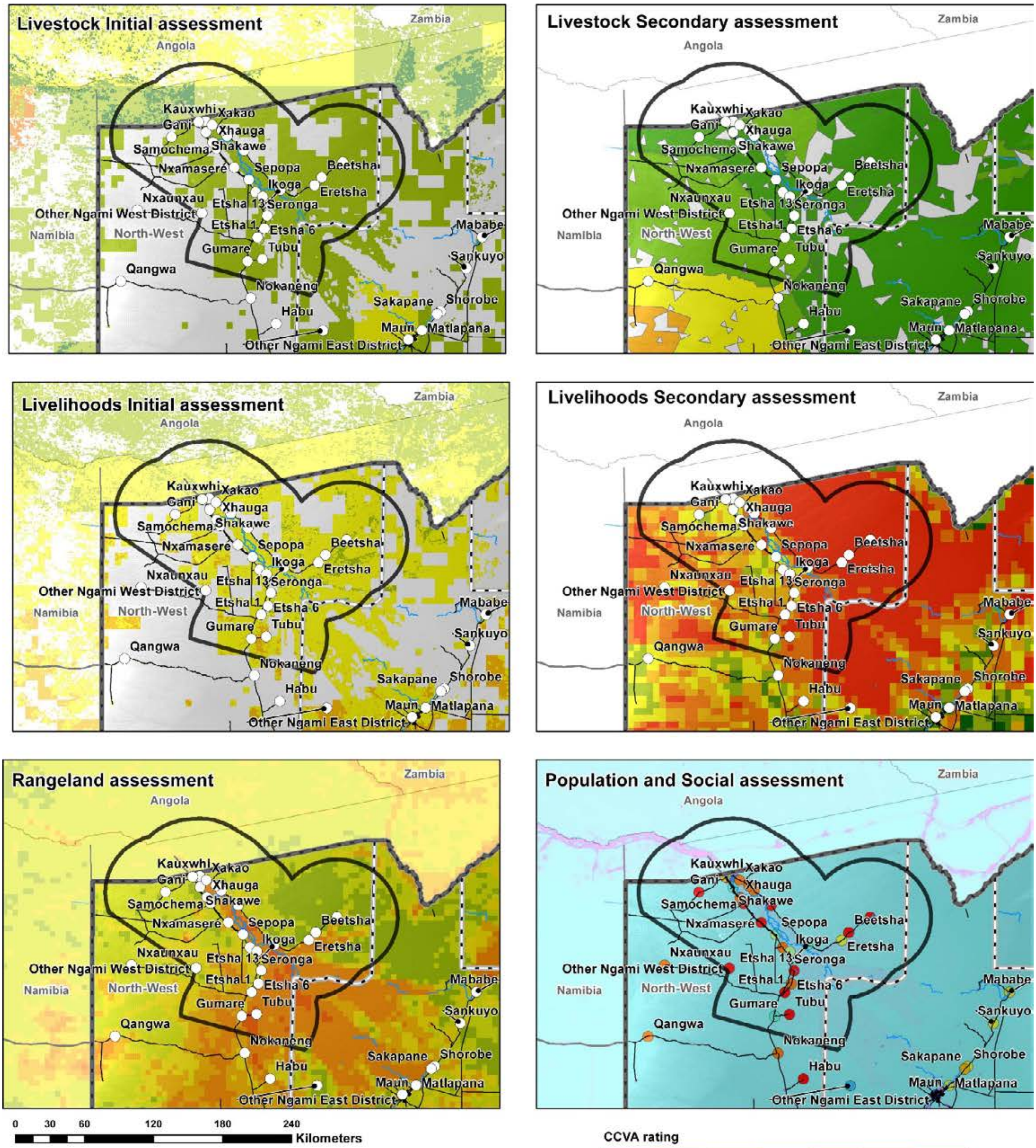
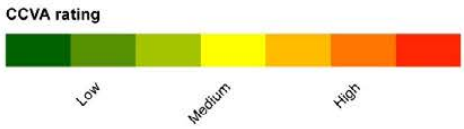
Livelihoods secondary assessment
Projected Sessional Variability, Soil moisture sensitivity, Rural Accessibility

Rangeland
SPARK High value grazing grasses climatic suitability

Social
Demographic indicators of Sensitivity Capacity in projected climate scenarios







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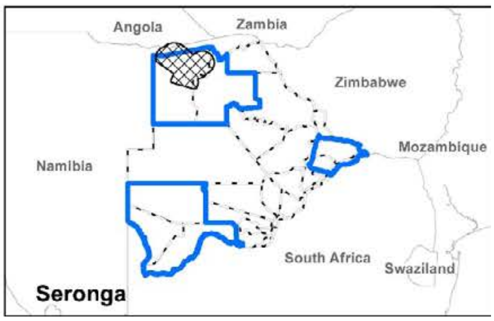
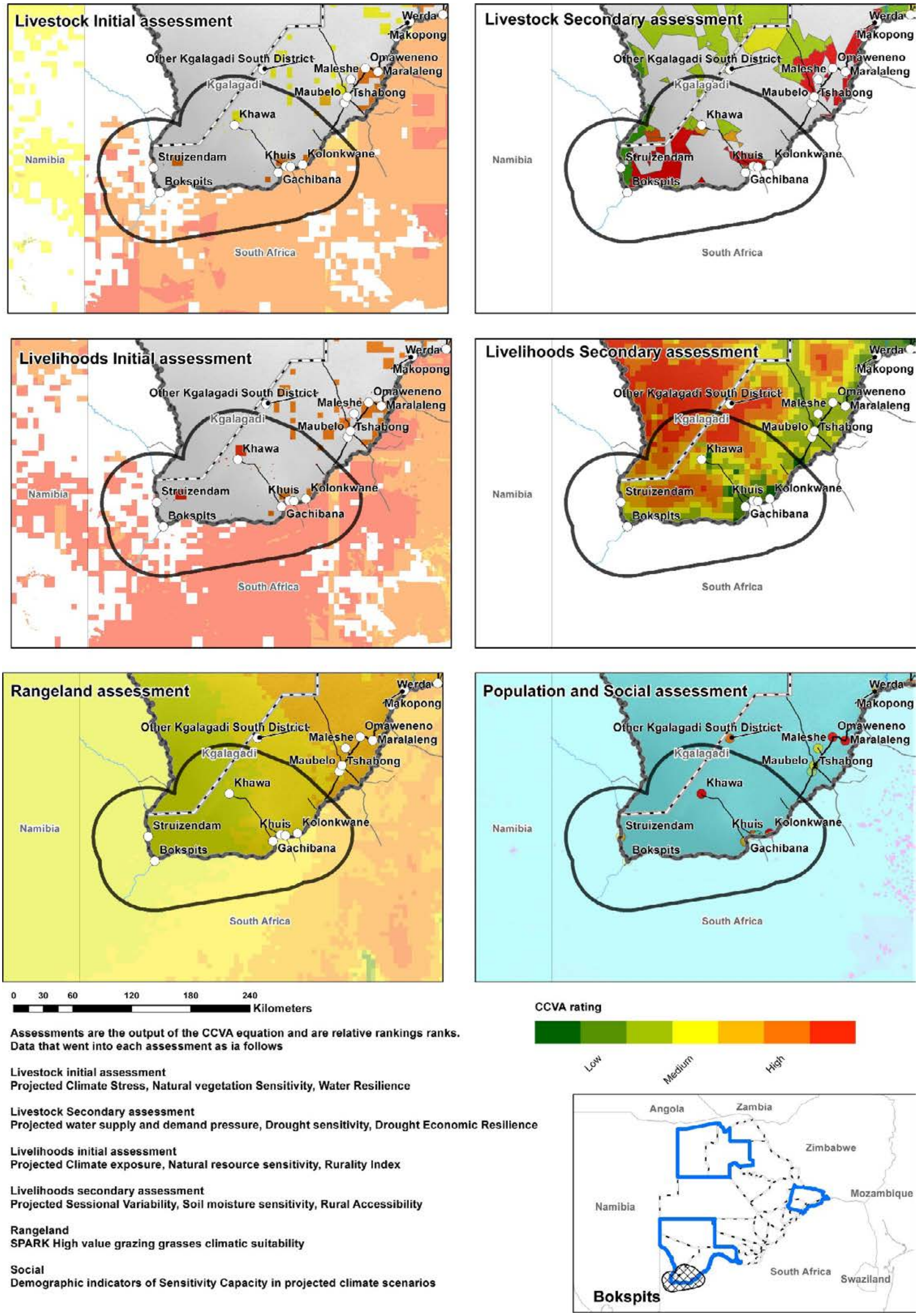
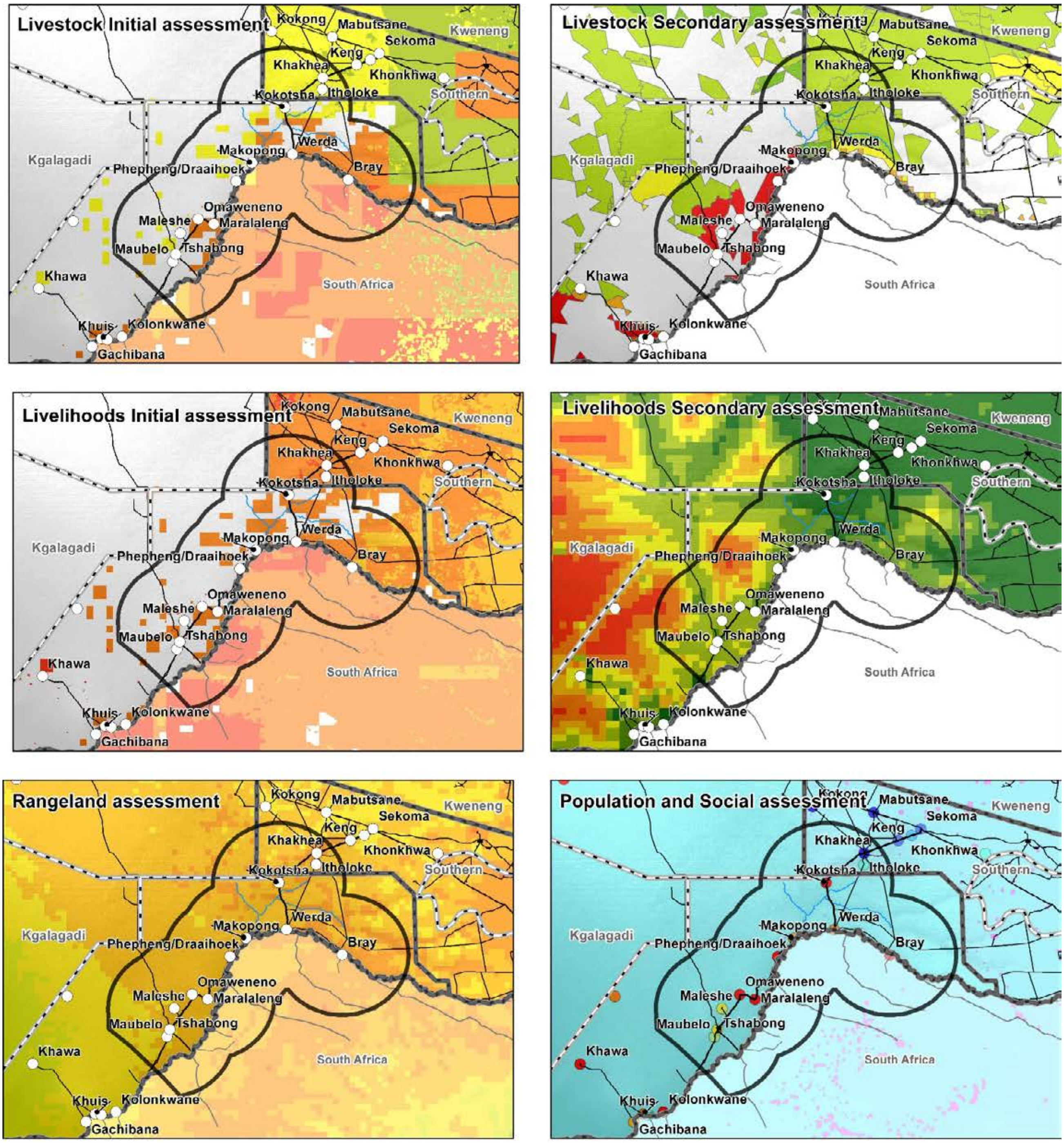


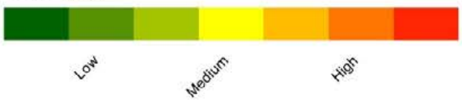
2.1.3. CCVAs Kgalagadi





0 25 50 100 150 200 Kilometers

CCVA rating



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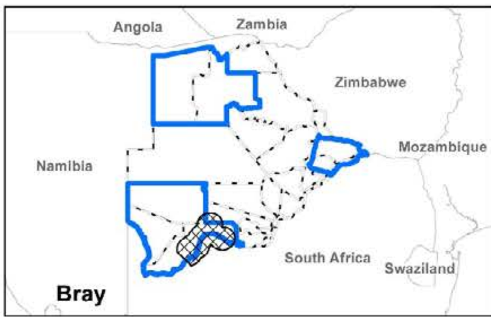

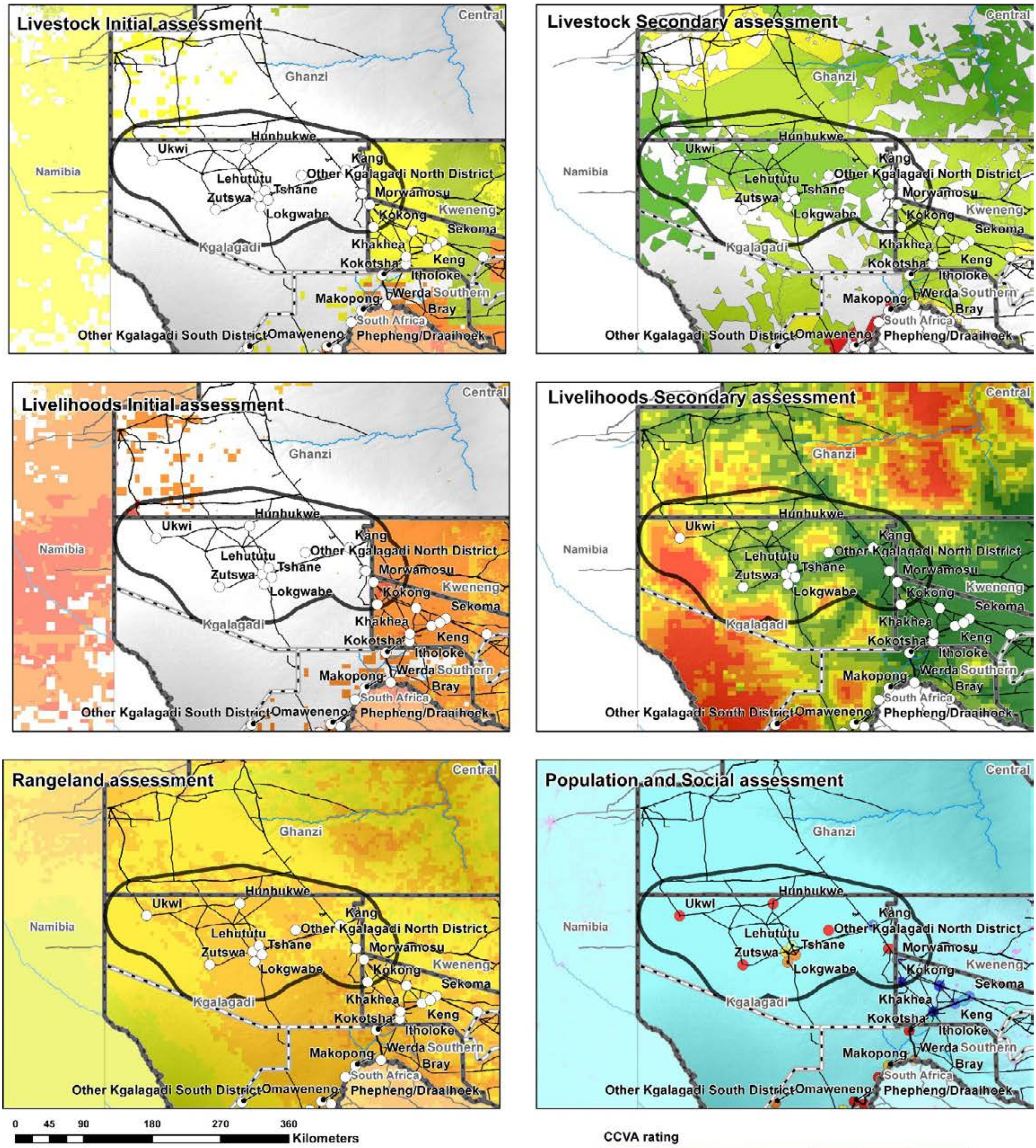

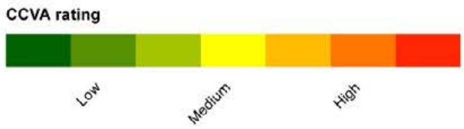

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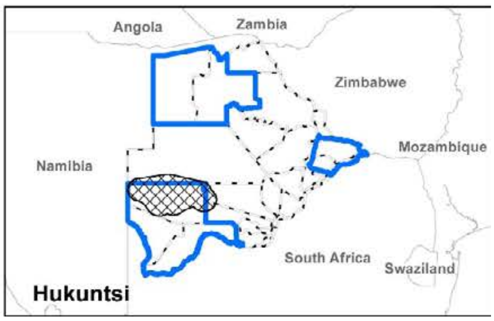

3. Maps from the CWBA

3.1. Section 4: Baseline Carbon Assessment

The total annual biomass production, as calculated by FAO[9], was used to validate the vegetative carbon estimate and to determine the spatial variability of this estimate. The total biomass production expresses the total amount of dry matter produced over the year. It is calculated in approximately 10-day increments at 250 m resolution and summarised as an annual total. This allows for an estimate of the total gross biomass production rather than the net change in biomass following defoliation. Figures 20–22 present the 2018 total biomass production for the three project areas in Botswana.

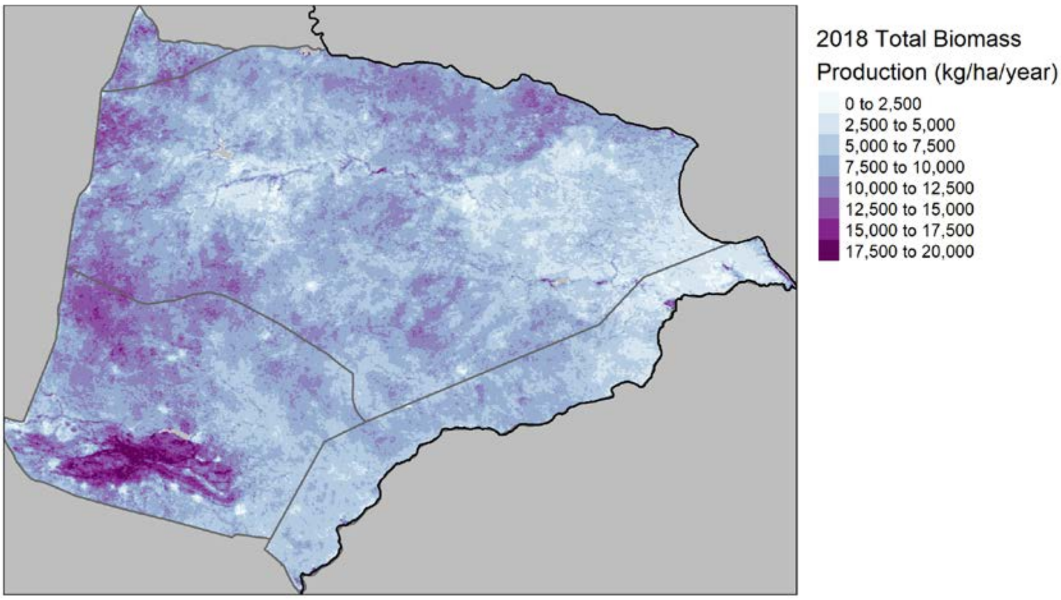

Figure 20. Total biomass production[10] in 2018 for the Bobirwa project area.

[9] FAO, "Portal to Monitor Water Productivity through Open Access of Remotely Sensed Derived Data (WaPOR). Version 2.0," 2019, https://wapor.apps.fao.org/catalog/WAPOR_2/1/L1_TBP_A.
[10] Ibid.

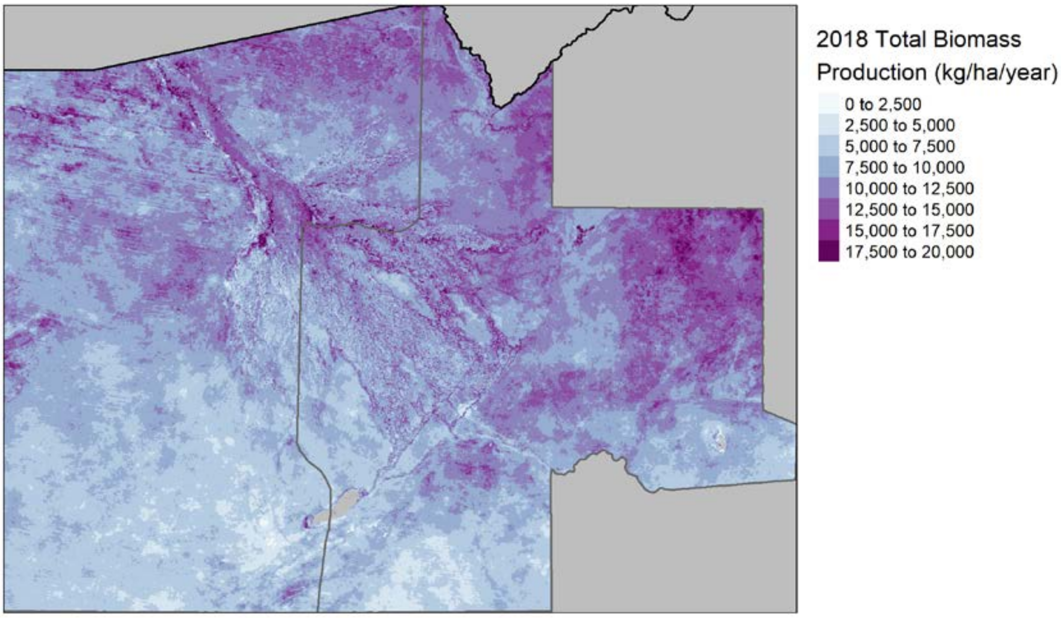

Figure 21. Total biomass production[11] in 2018 for the Ngamiland project area.

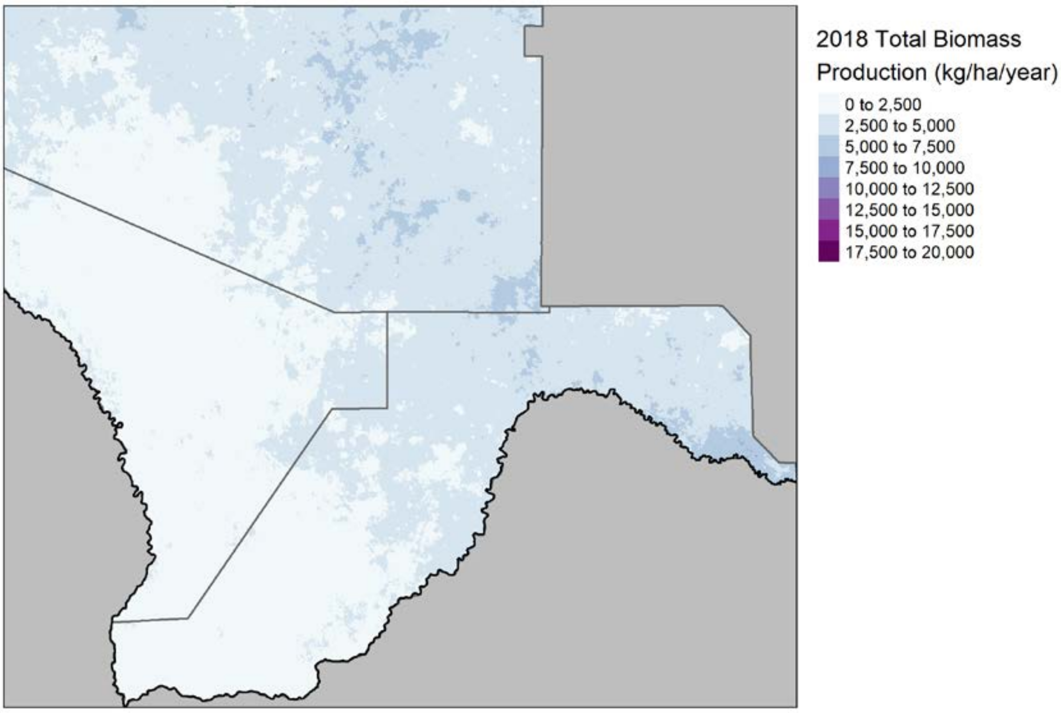

Figure 22. Total biomass production[12] in 2018 for the Kgalagadi project area.

[11] Ibid.
[12] Ibid.

Baseline soil organic carbon (SOC) density has been modelled for the three project areas up to a depth of 100 cm. The model results are presented in Figures 23–25.

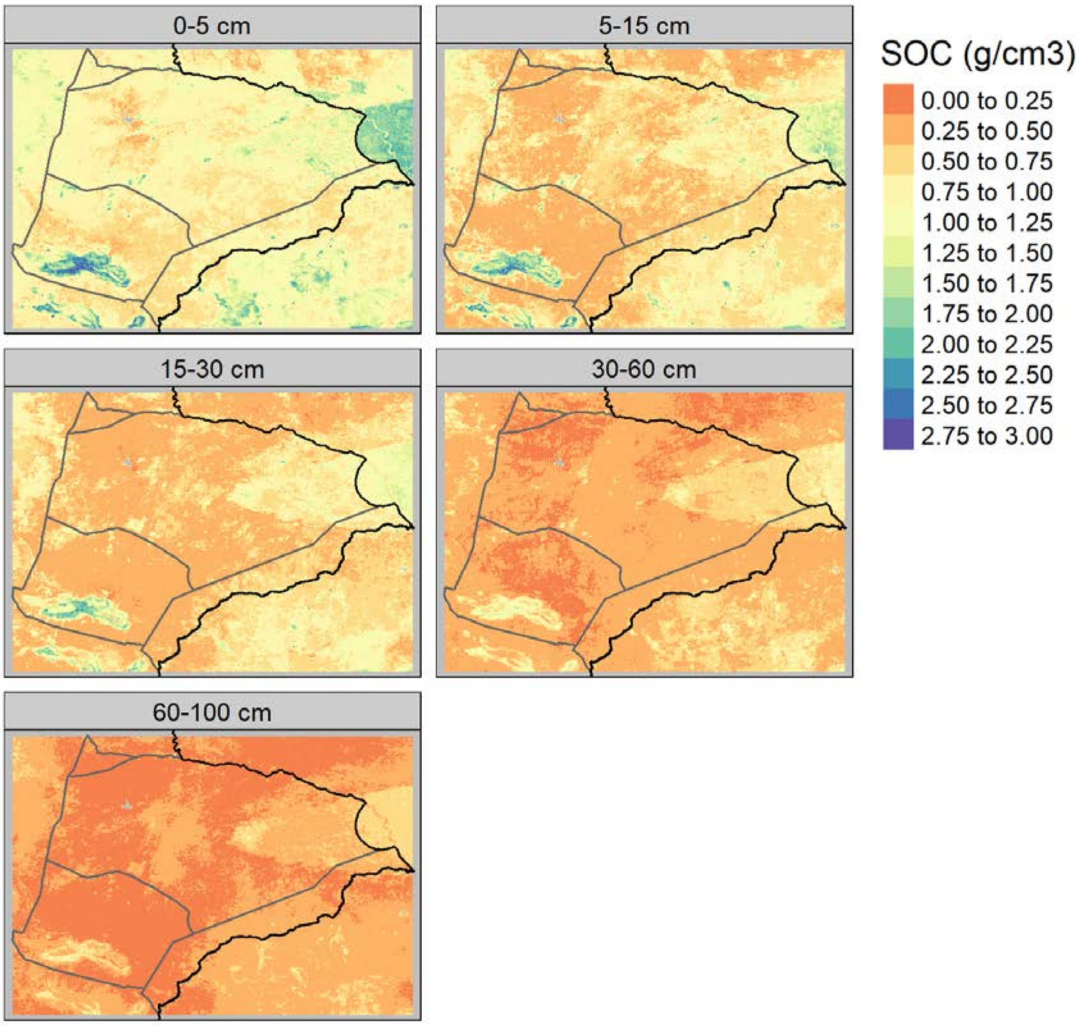

Figure 23. Modelled soil organic carbon density (gC/cm³) for the Bobirwa project area across five depth increments.

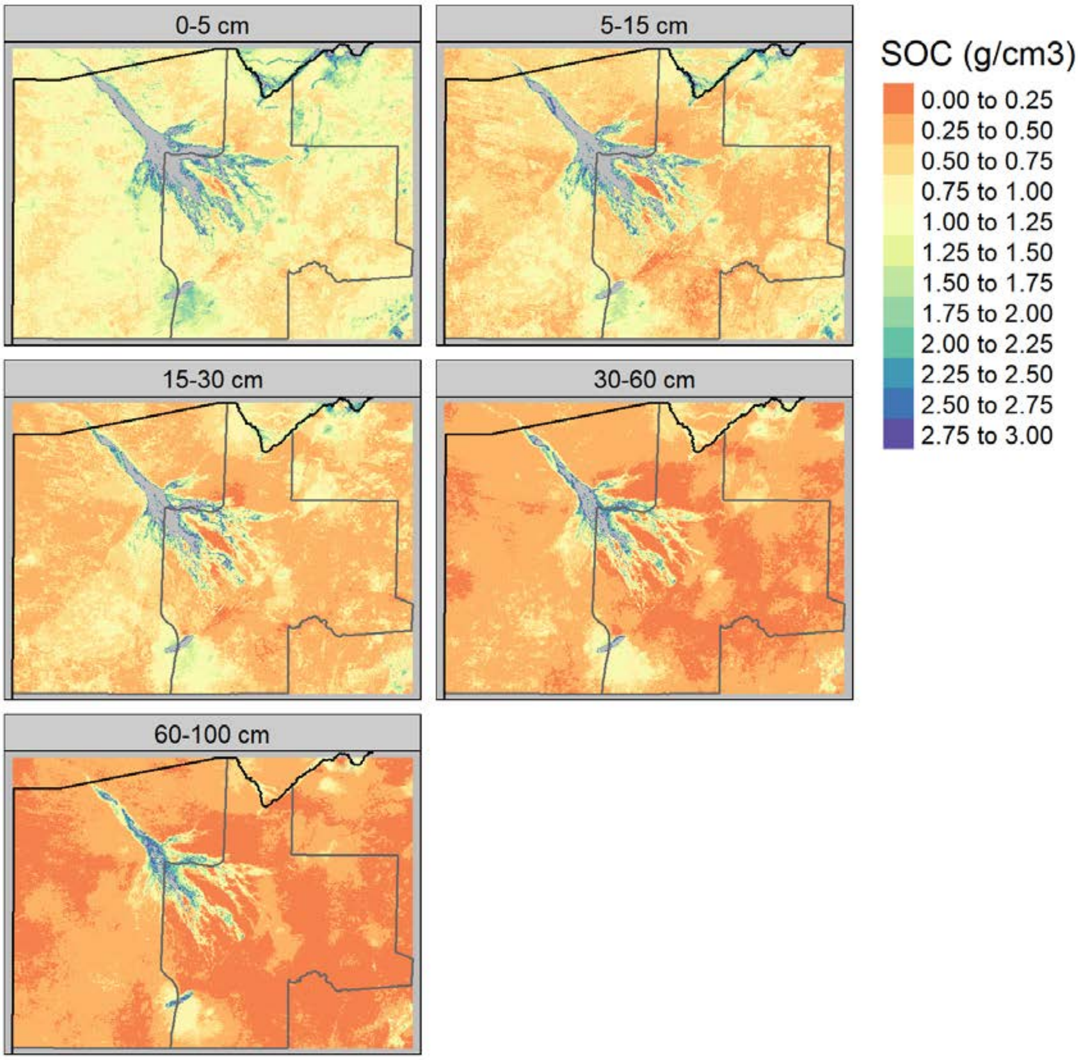

Figure 24. Modelled soil organic carbon density (gC/cm³) for the Ngamiland project area across five depth increments.

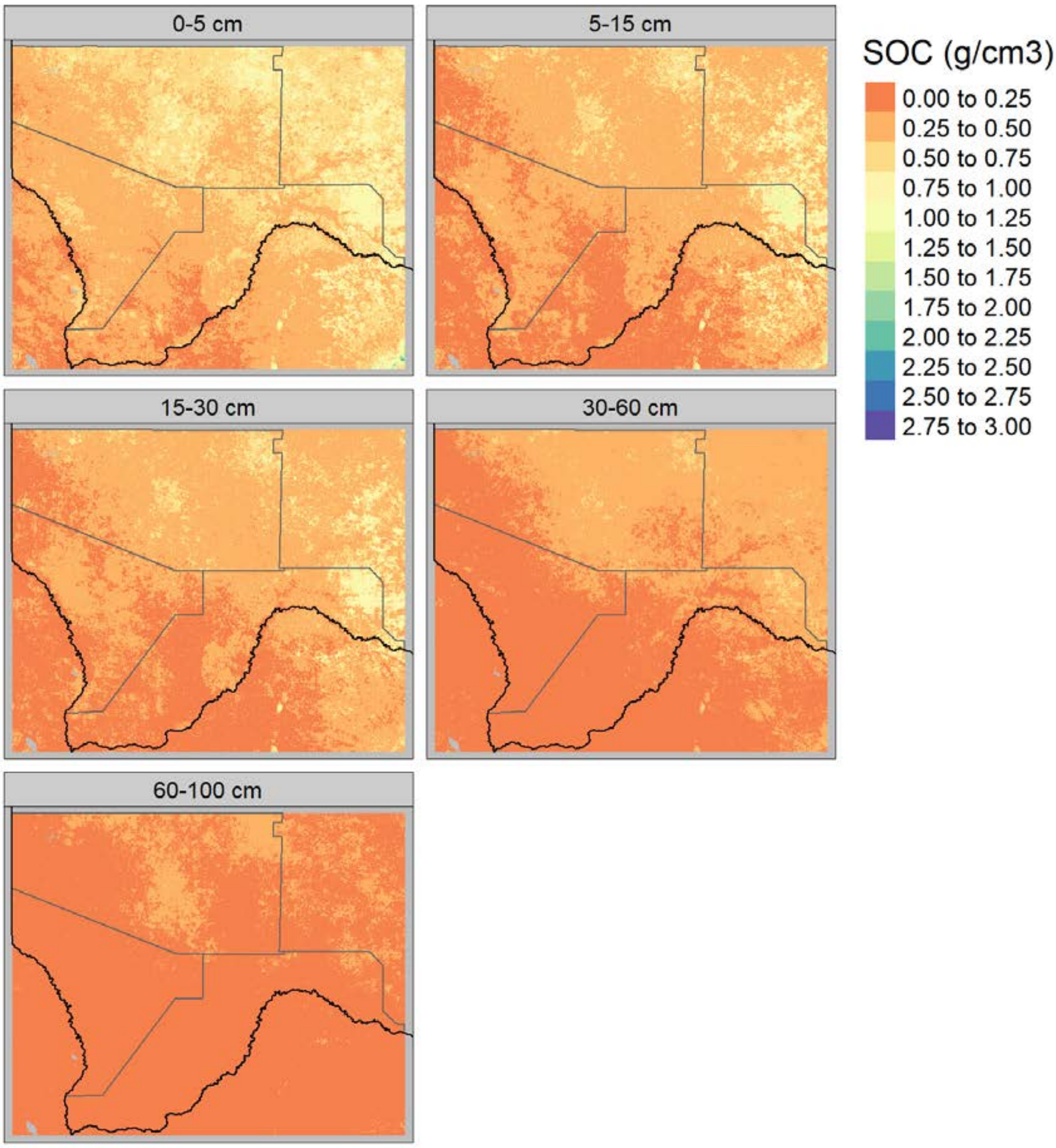

Figure 25. Modelled soil organic carbon density (gC/cm^3) for the Kgalagadi project area across five depth increments.

The surface water resources in Botswanna are heavily dependent on transboundary rivers. Besides the Okavango Delta in the North, all the rivers experience seasonal drying making them unreliable for the communal livestock sector. The average stream power (Figure 26) is an informative proxy for the water input contribution relative to the neighbouring region.

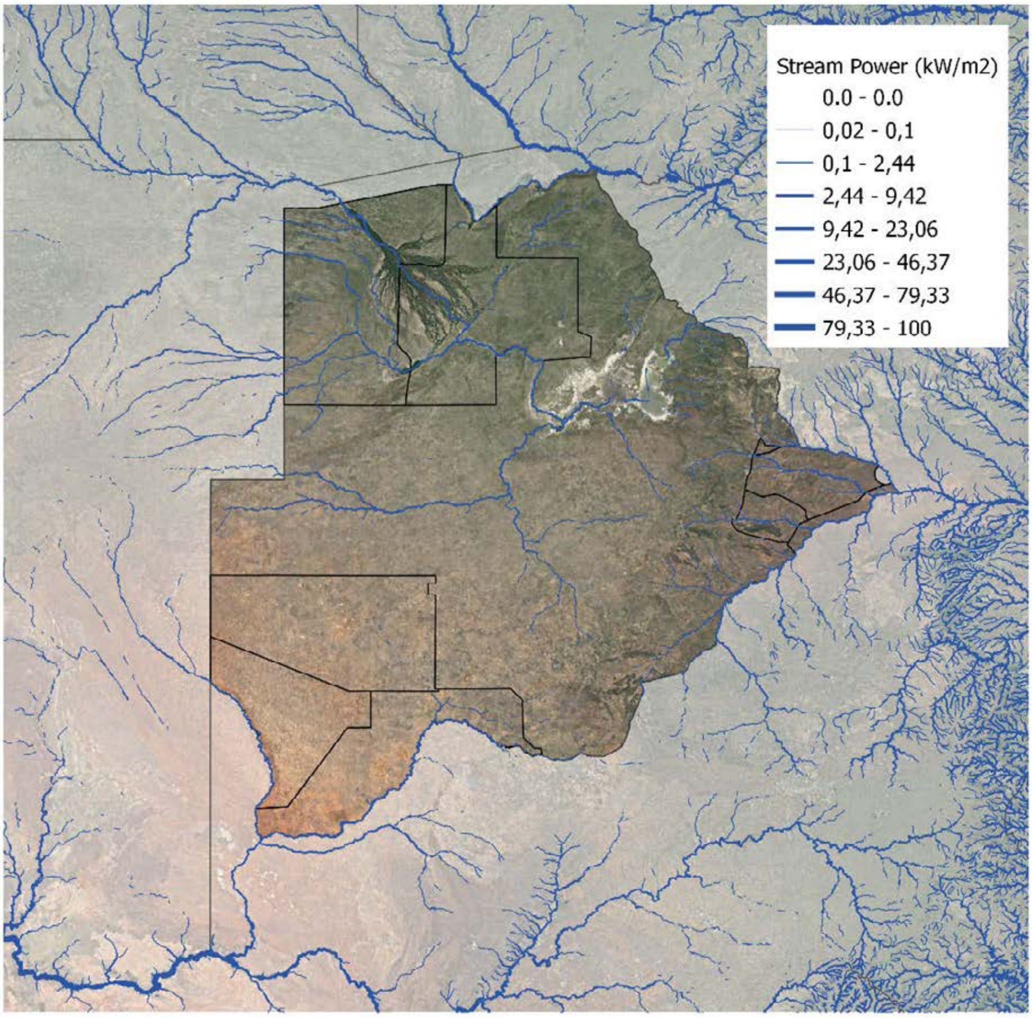

Figure 26. Stream power (kW/m²) of rivers in and around Botswana[13] as a proxy for water inputs.

[13] Camille Ouellet Dallaire et al., "A Multidisciplinary Framework to Derive Global River Reach Classifications at High Spatial Resolution," *Environmental Research Letters* 14, no. 2 (2019), https://doi.org/10.1088/1748-9326/aad8e9.

Technological improvements in borehole drilling have increased their affordability and availability in Botswana over the last 50 years. The boreholes that are being drilled across the three project areas are therefore abstracting water from deeper aquifers than has been the case historically and the amount of drilling has been accelerating since the 1970s (Figure 27–30).

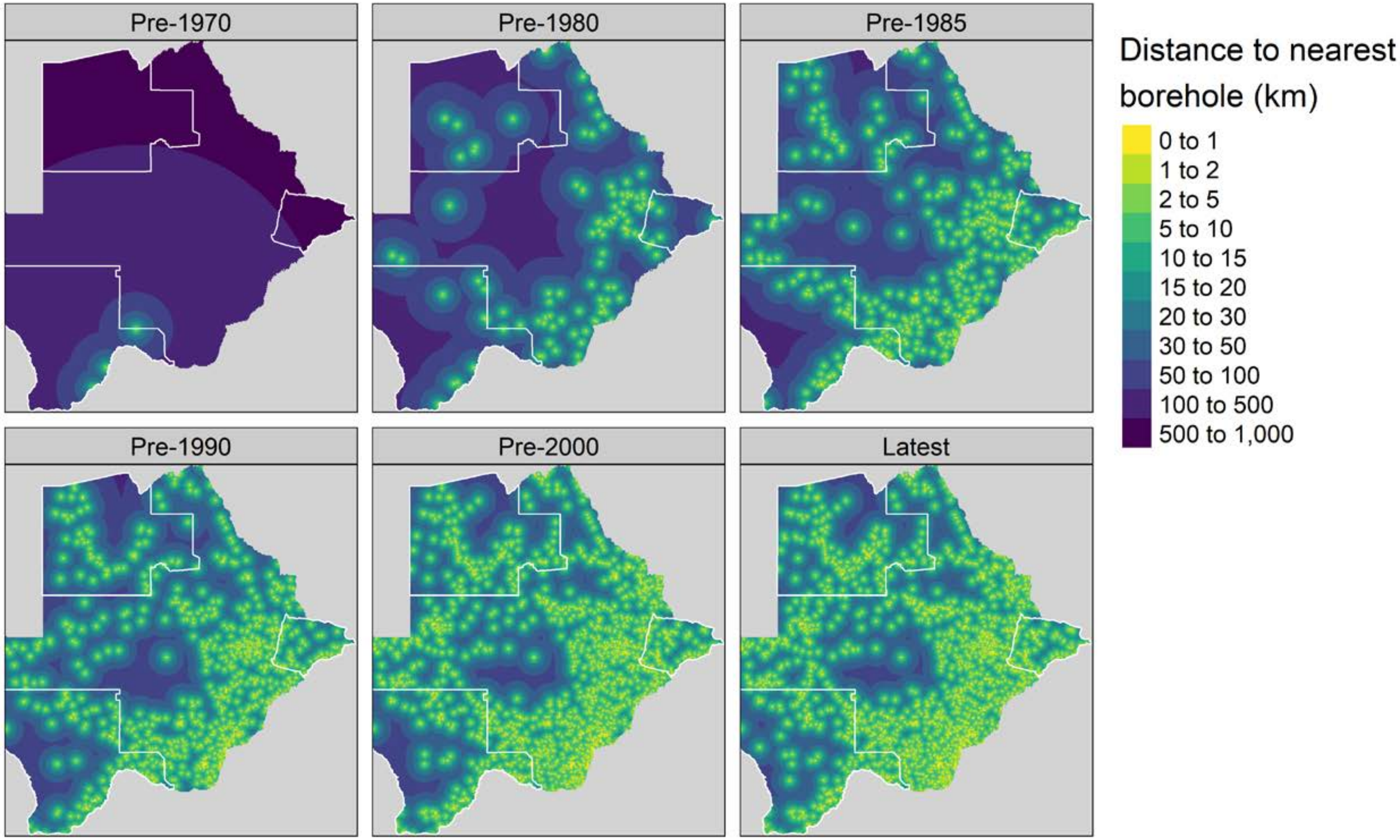

Figure 27. Distance to nearest registered borehole in Botswana over time, separated into six epochs. Data source: Botswana Department of Water Affairs

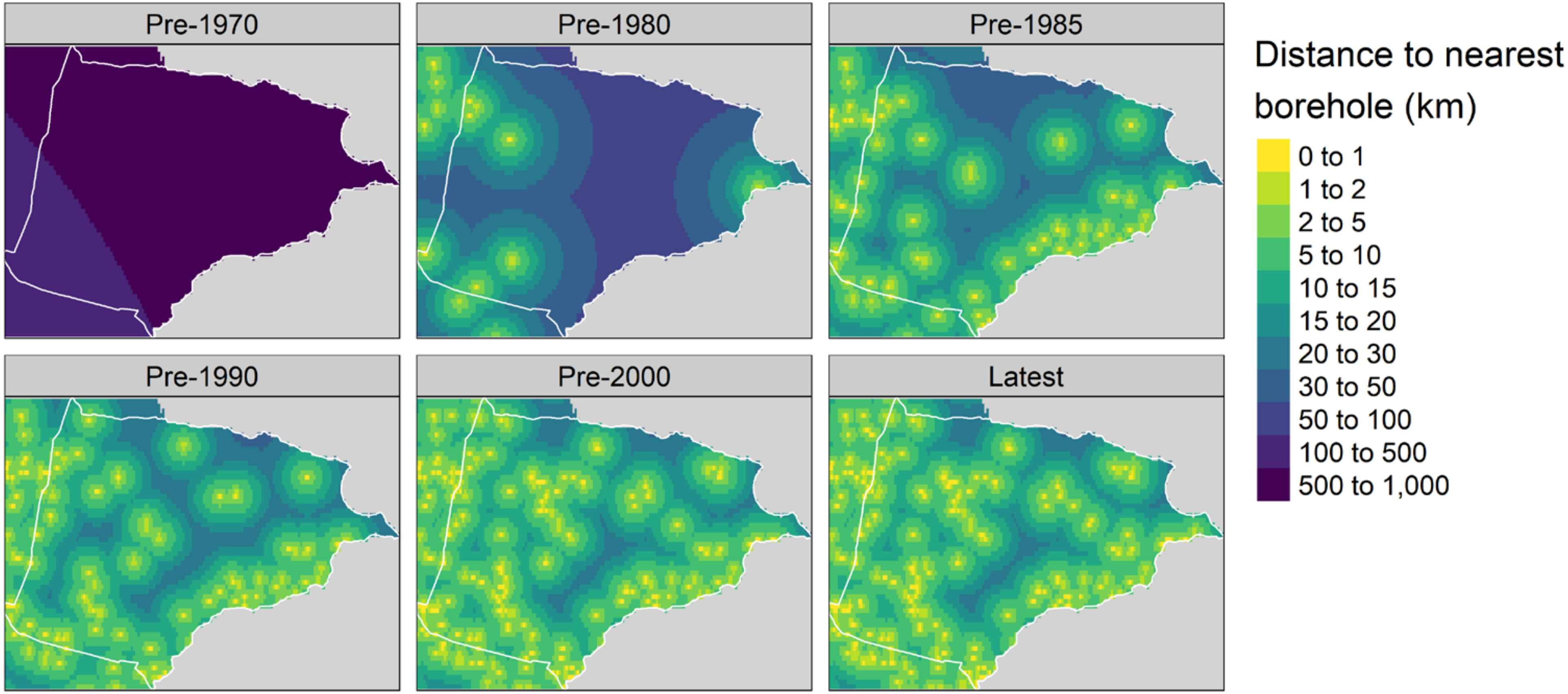

Figure 28. Distance to nearest registered borehole in Bobirwa over time, separated into six epochs. Data source: Botswana Department of Water Affairs

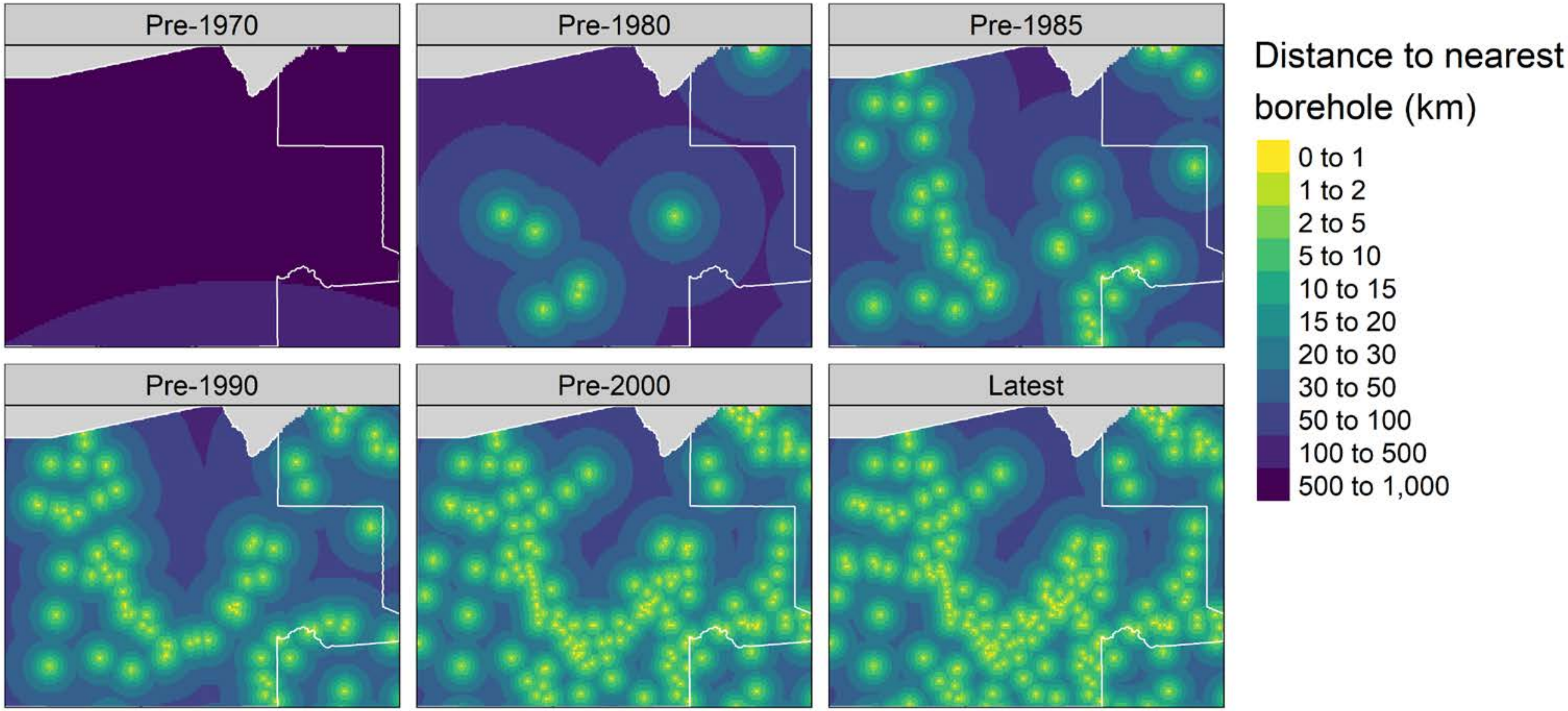

Figure 29. Distance to nearest registered borehole in Ngamiland over time, separated into six epochs. Data source: Botswana Department of Water Affairs

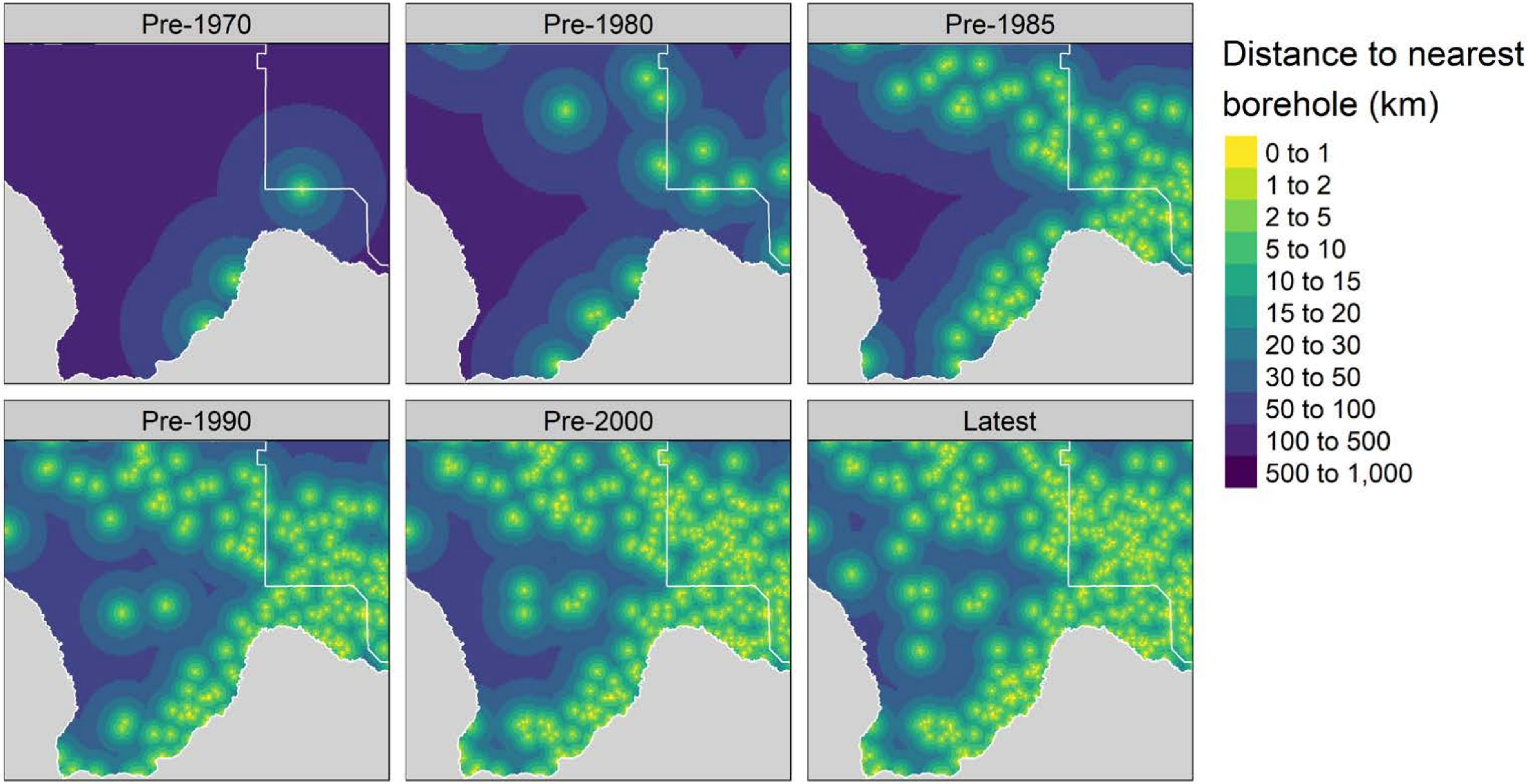

Figure 30. Distance to nearest registered borehole in Kgalagadi over time, separated into six epochs. Data source: Botswana Department of Water Affairs

The quality of borehole water, as represented by the electrical conductivity (EC), fluorine (F), nitrate (NO3), and total dissolved solids (TDS), differs across Botswana (Figure 31) and within each project area (Figure 32–34).

Despite the increase in the number of boreholes drilled in the last five decades, they are plagued by high abstraction costs, low yields and poor water quality . According to the World Health Organisation , TDS concentrations >1,200 mg/L are unacceptable for human consumption. The FAO recommends EC levels <500 mS/m for livestock, further stating that EC >1,600 mS/m cannot be recommended under any conditions, with a decline in animal condition expected . In Botswana, TDS in borehole water are commonly >1,000 mg/L throughout the country and >10,000 mg/L in Kgalagadi and parts of Ngamiland (Figure 33). EC in borehole water is commonly >1,000 mS/m, particularly in Kgalagadi (Figure 34). The quality of available water can, in general, therefore be concluded to be below acceptable standards for livestock production. Differences in the distribution of borehole depths are evident between the three project areas, with the shallowest boreholes on average located in Ngamiland and Bobirwa (mean depth <100 m) and the deepest boreholes in Kgalagadi (mean depth >100 m).

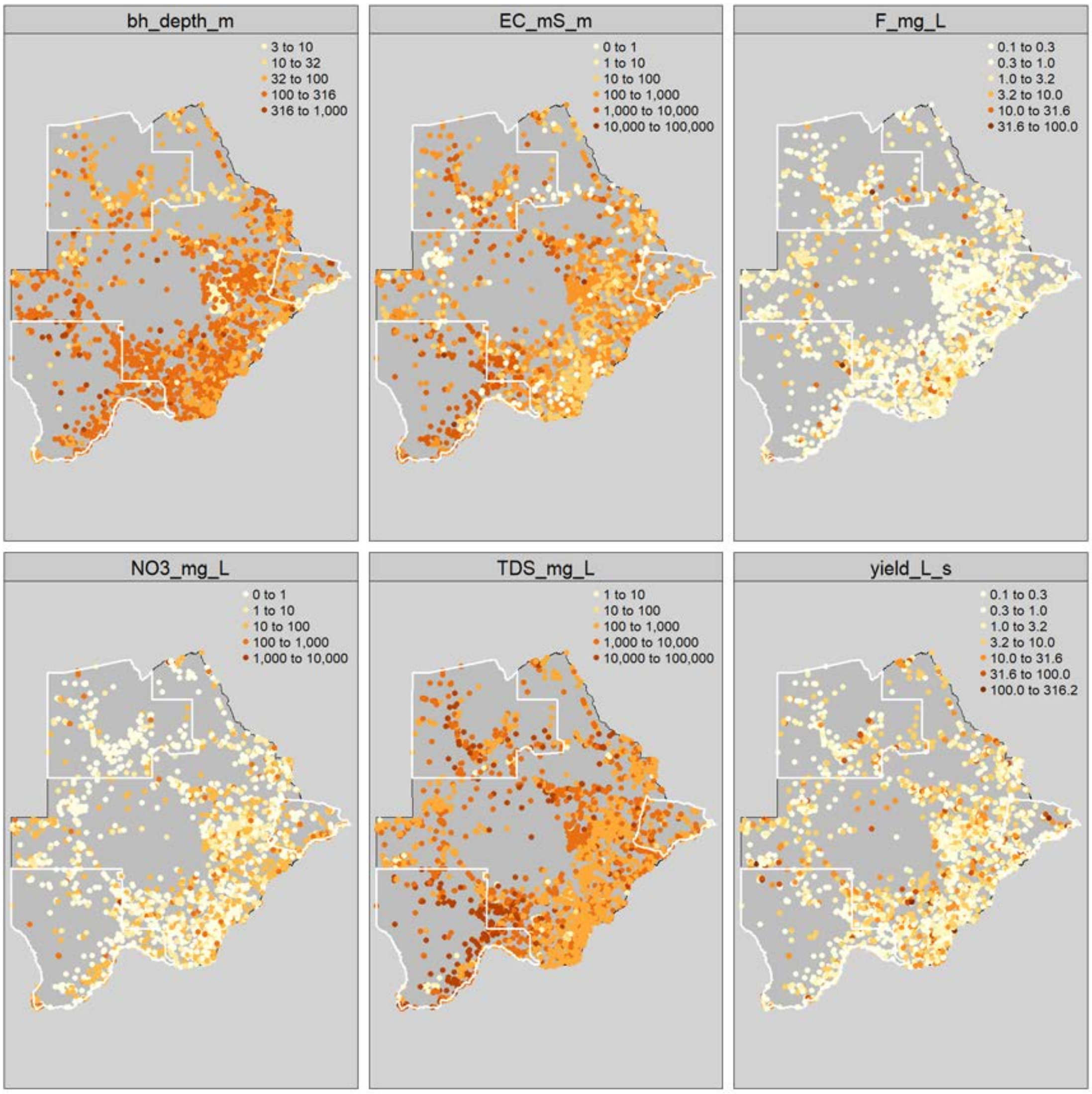

Figure 31. Borehole water depth (top left), yield (bottom right), and quality (electrical conductivity (top middle), F (top right), NO_3 (bottom left) and total dissolved solids (bottom middle)) in Botswana. Data source: Botswana Department of Water Affairs

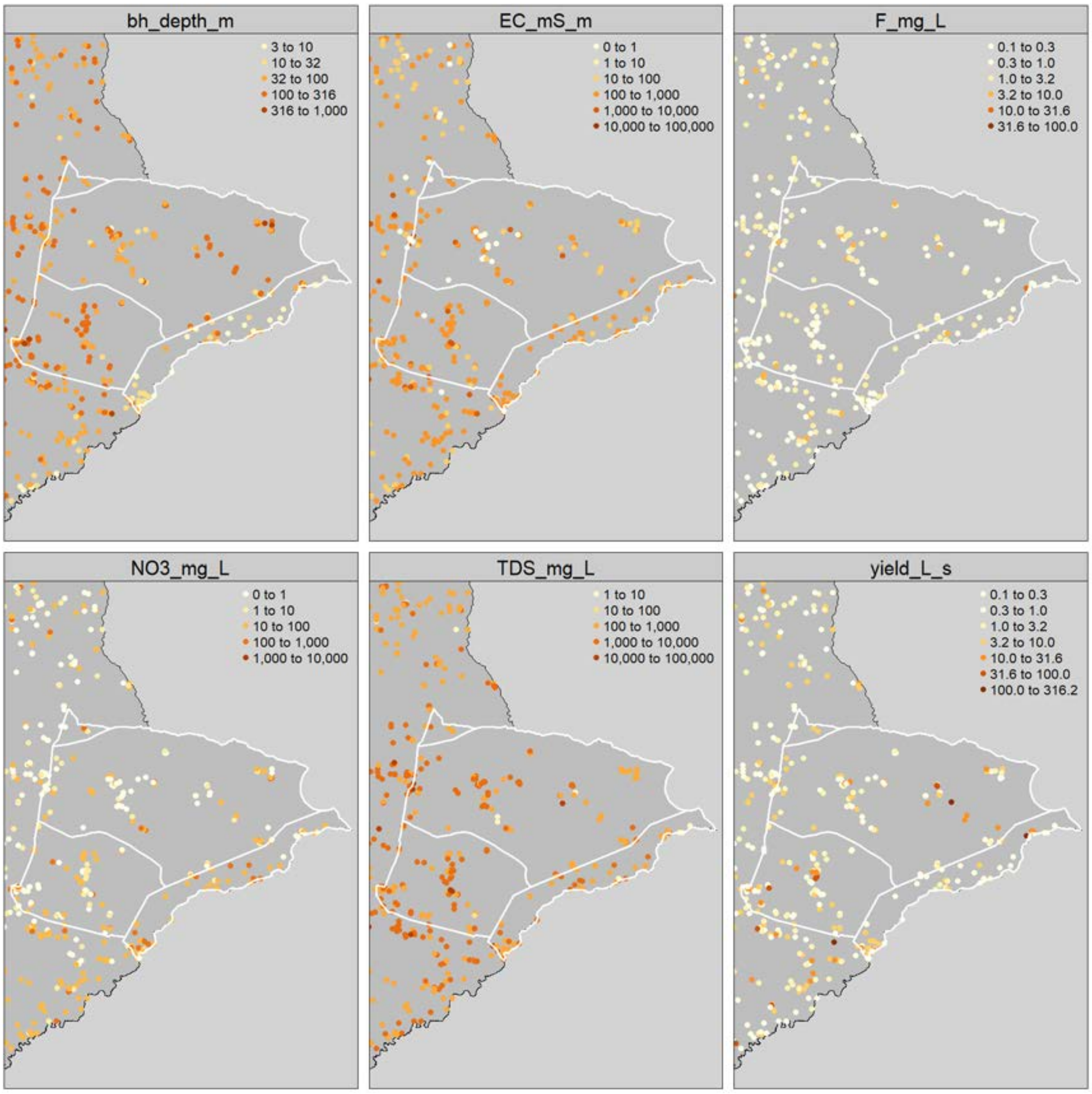

Figure 32. Borehole water depth, yield, and quality (electrical conductivity, F, NO_3 total dissolved solids) in Bobirwa. Data source: Botswana Department of Water Affairs

Figure 33. Borehole water depth, yield, and quality (electrical conductivity, F, NO_3 total dissolved solids) in Ngamiland. Data source: Botswana Department of Water Affairs

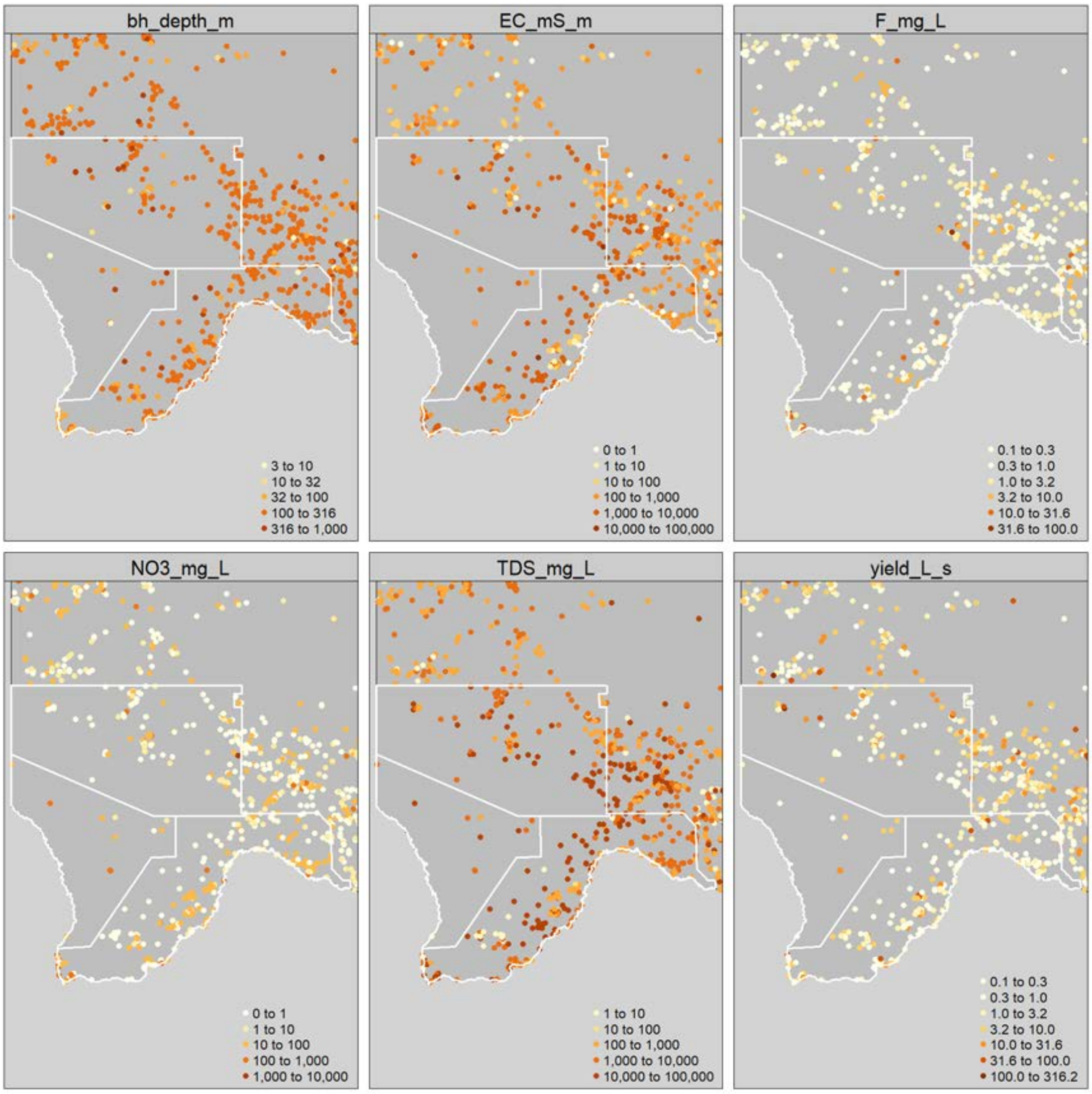

Figure 34. Borehole water depth, yield, and quality (electrical conductivity, F, NO_3 total dissolved solids) in Kgalagadi. Data source: Botswana Department of Water Affairs

3.3. *Appendix B: Baseline maps*

The maps below provide greater context to the project areas and were either summarised in the Baseline Carbon and Water Assessment or are representative of the soil carbon model inputs. The change in total biomass production indicates where there may have been changes in the rangeland productivity. The vegetation cover results are all subject to in-field validation. No inferences are made from these baseline maps; they are for context and information purposes only.

3.3.1. Vegetation Cover

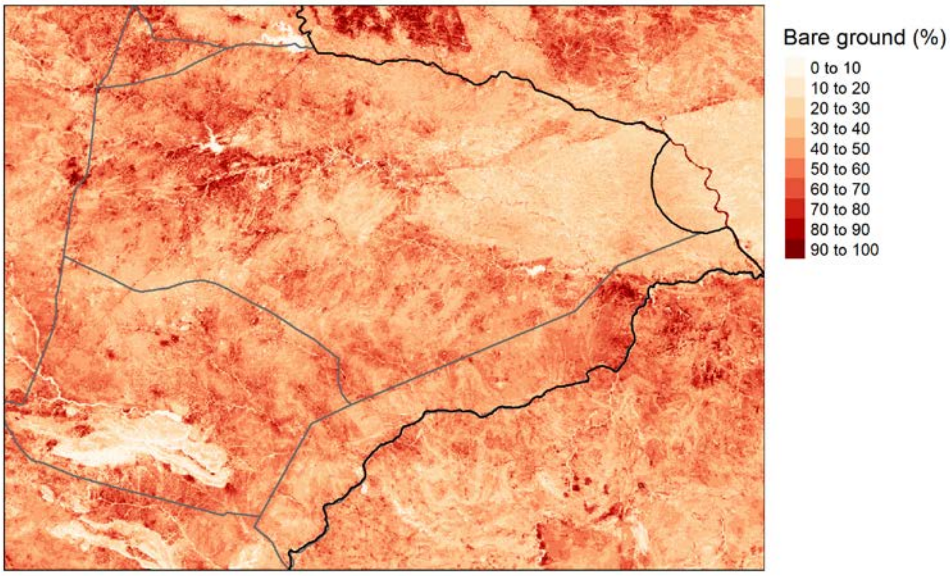

Figure 35. Predicted bare ground cover (%) for Bobirwa.

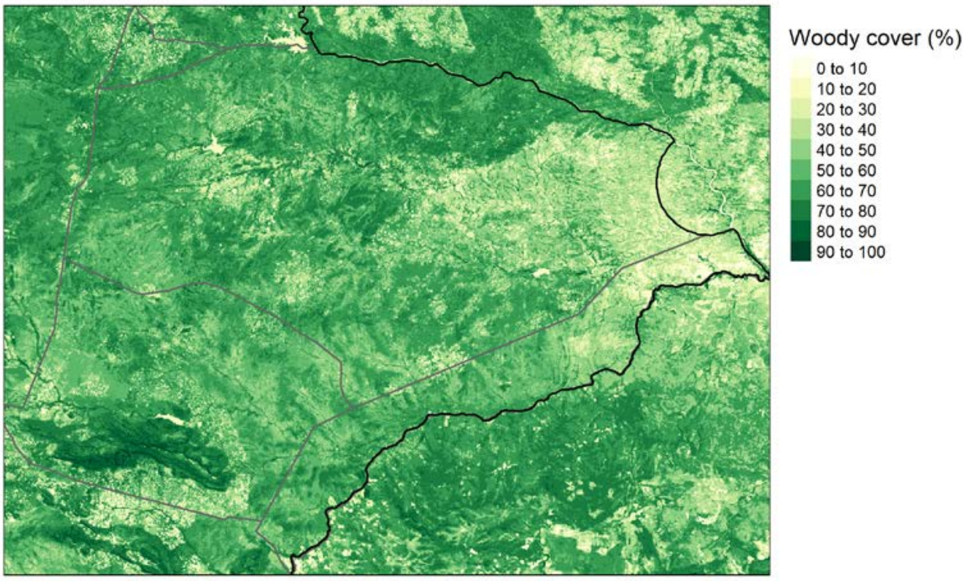

Figure 36. Predicted woody cover (%) for Bobirwa.

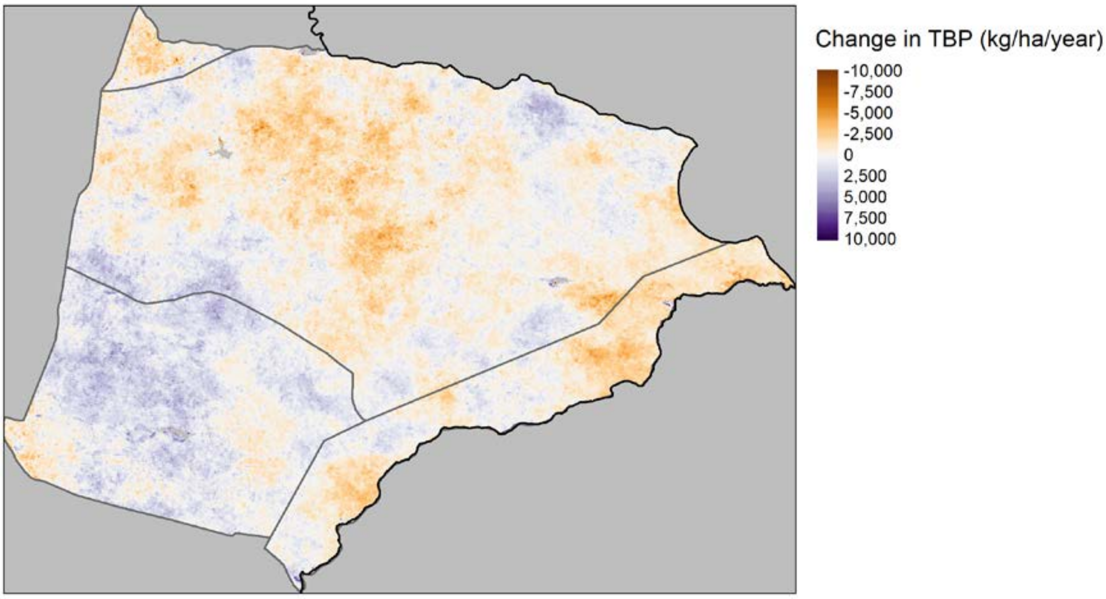

Figure 37. Change in the total biomass production (kg/ha/year) for Bobirwa between 2010 and 2018.

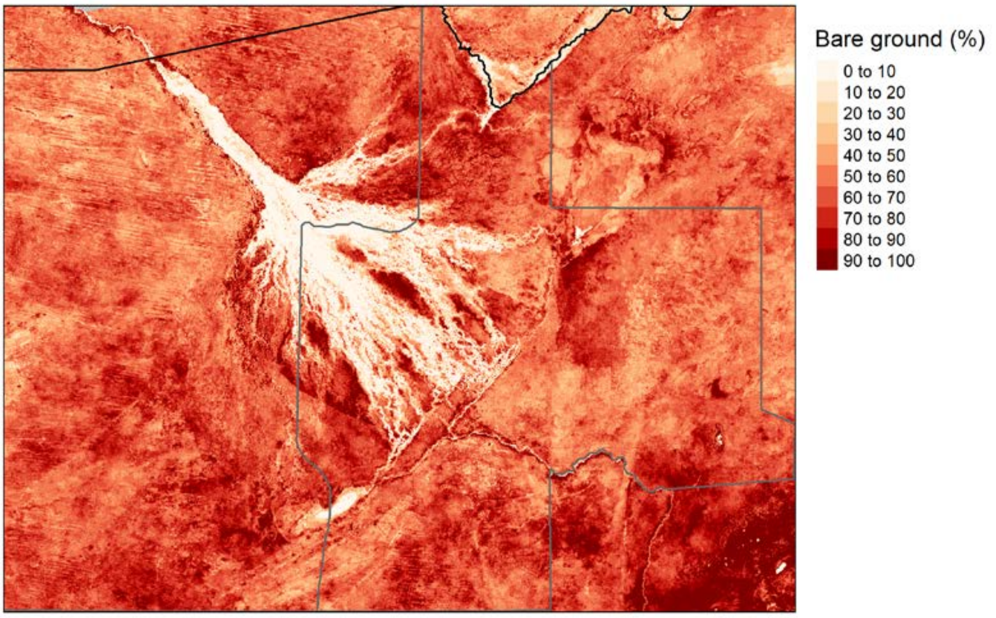

Figure 38. Predicted bare ground cover (%) for Ngamiland.

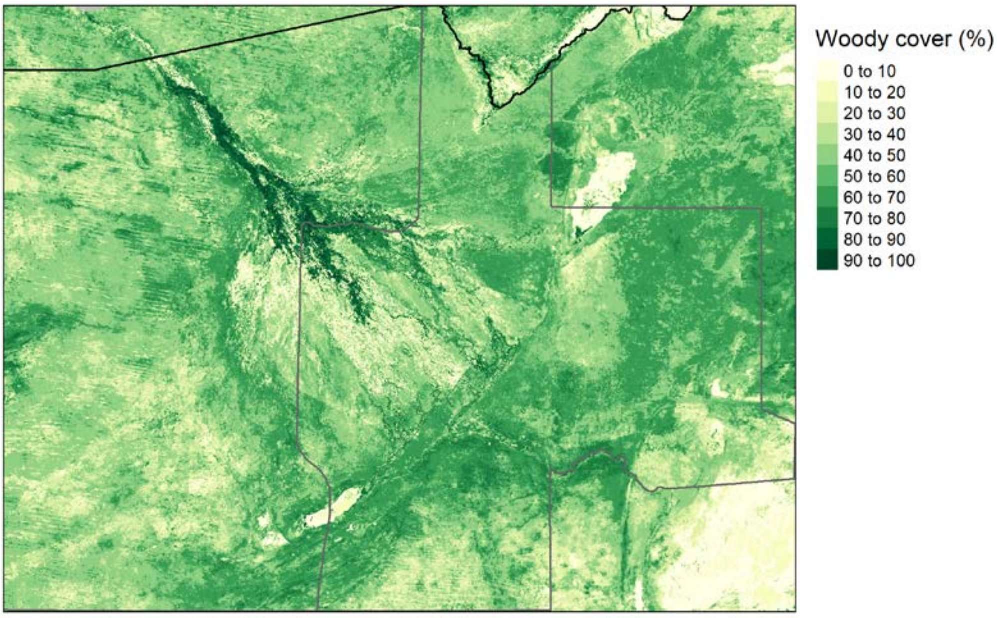

Figure 39. Predicted woody cover (%) for Ngamiland.

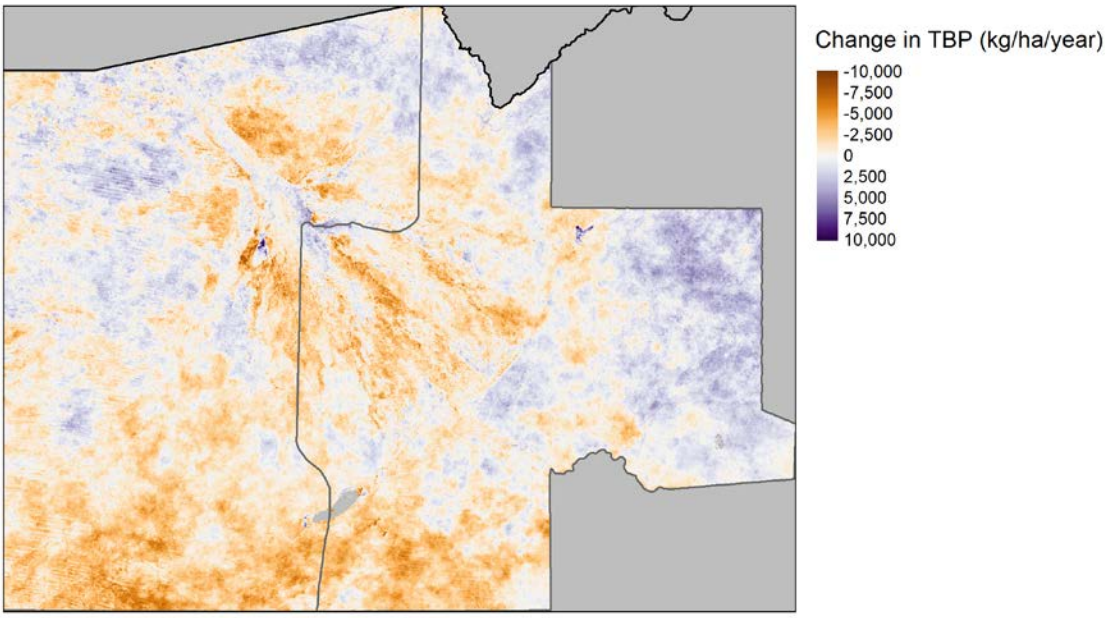

Figure 40. Change in the total biomass production (kg/ha/year) for Ngamiland between 2010 and 2018.

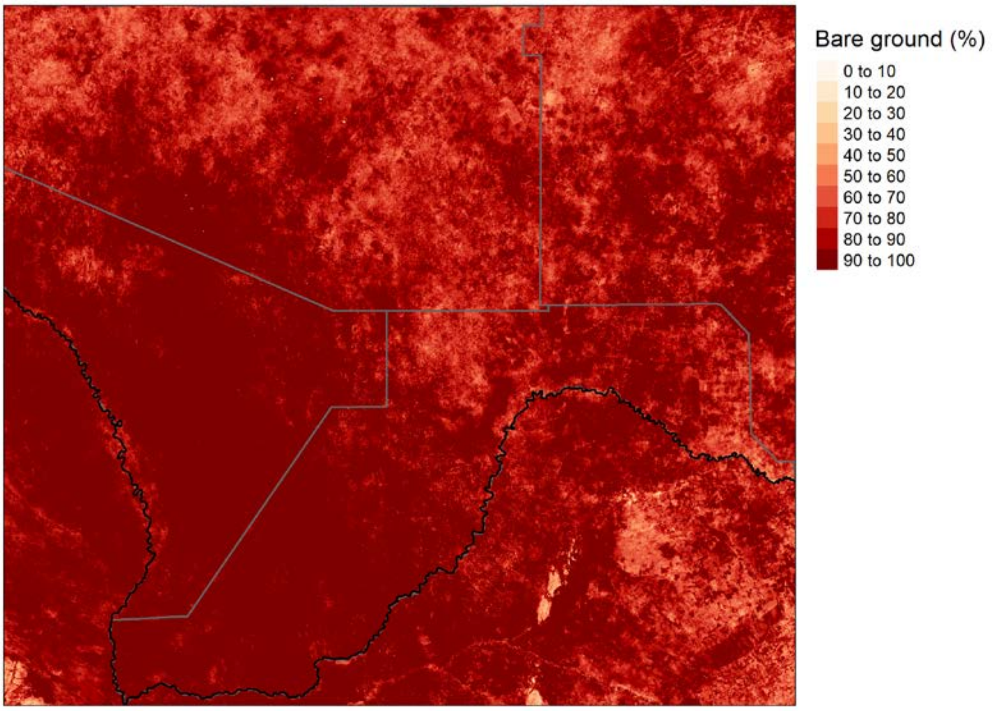

Figure 41. Predicted bare ground cover (%) for Kgalagadi.

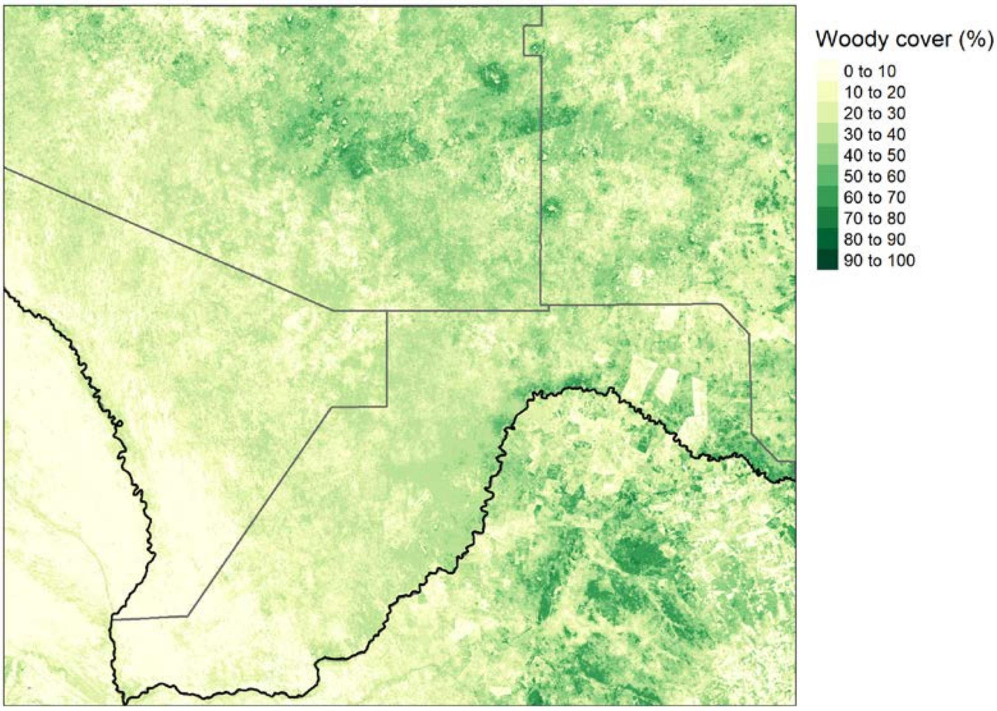

Figure 42. Predicted woody cover (%) for Kgalagadi.

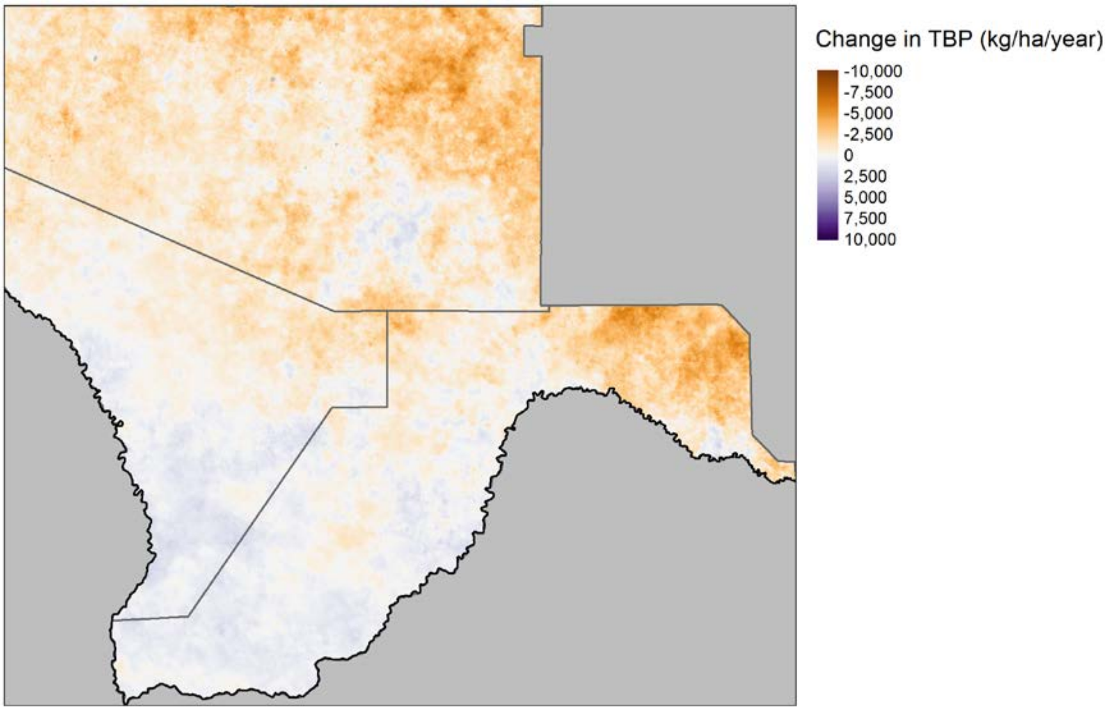

Figure 43. Change in the total biomass production (kg/ha/year) for Kgalagadi between 2010 and 2018.

3.5.1. Enhanced Vegetation Index (EVI)

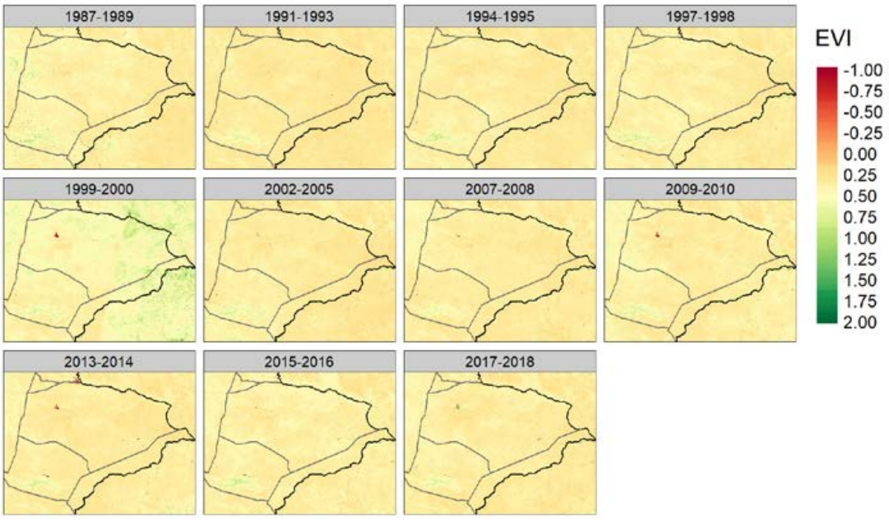

Figure 44. Average enhanced vegetation index (EVI) for Bobirwa in the dry months between 1987 and 2018.

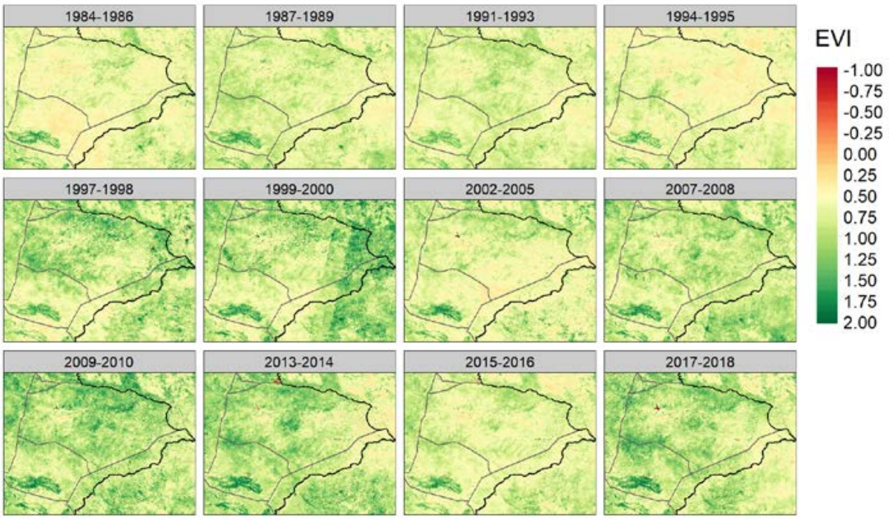

Figure 45. Average enhanced vegetation index (EVI) for Bobirwa in the wet months between 1984 and 2018.

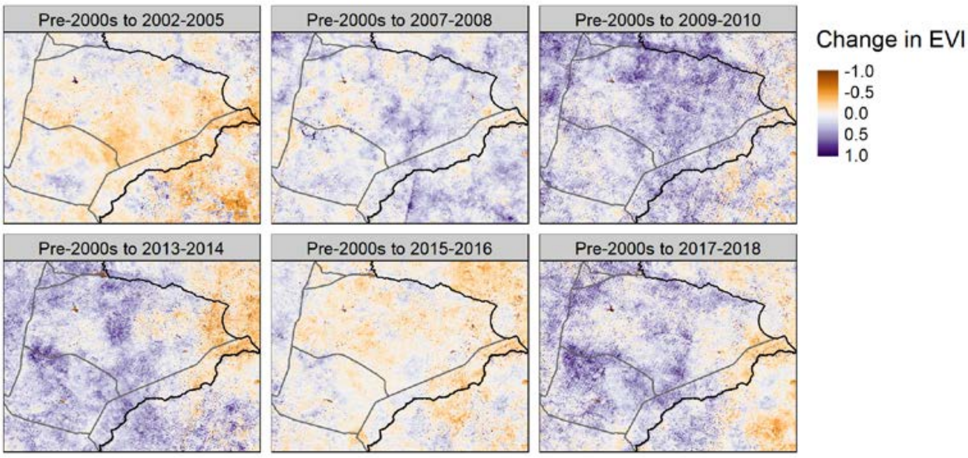

Figure 46. Gradient of the enhanced vegetation index (EVI) for Bobirwa in the wet months between the average pre-2000s values to five epochs between 2002 and 2018.

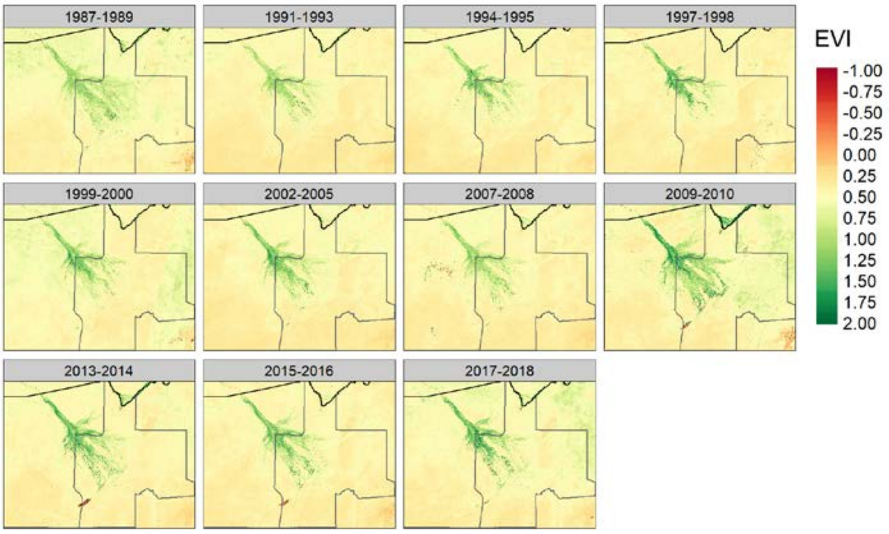

Figure 47. Average enhanced vegetation index (EVI) for Ngamiland in the dry months between 1987 and 2018.

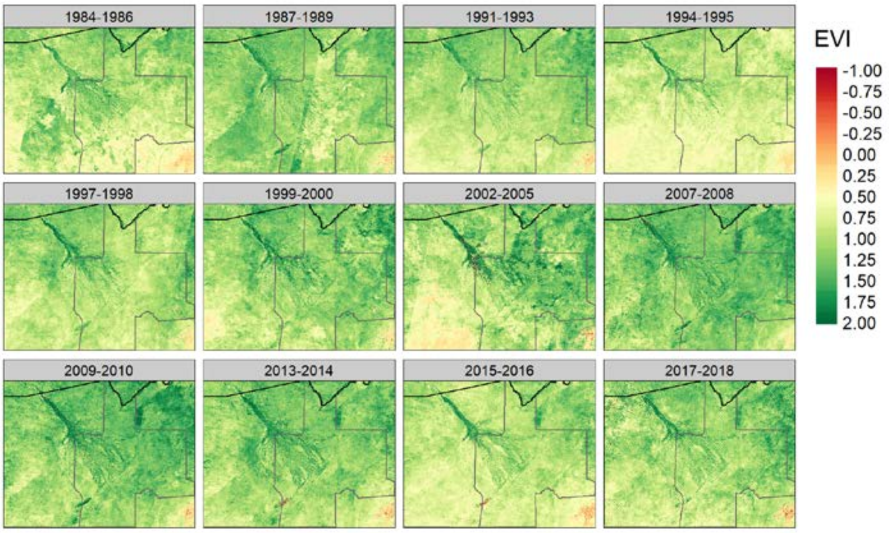

Figure 48. Average enhanced vegetation index (EVI) for Ngamiland in the wet months between 1984 and 2018.

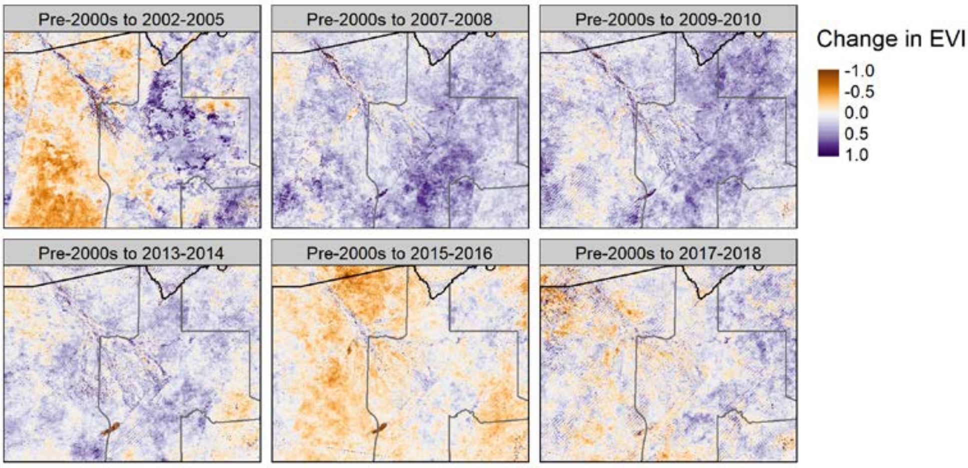

Figure 49. Gradient of the enhanced vegetation index (EVI) for Ngamiland in the wet months between the average pre-2000s values to five epochs between 2002 and 2018.

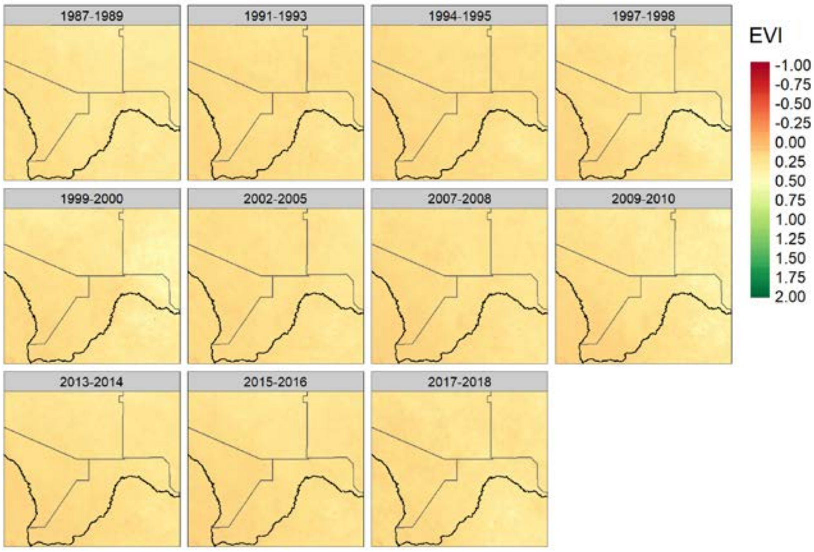

Figure 50. Average enhanced vegetation index (EVI) for Kgalagadi in the dry months between 1987 and 2018.

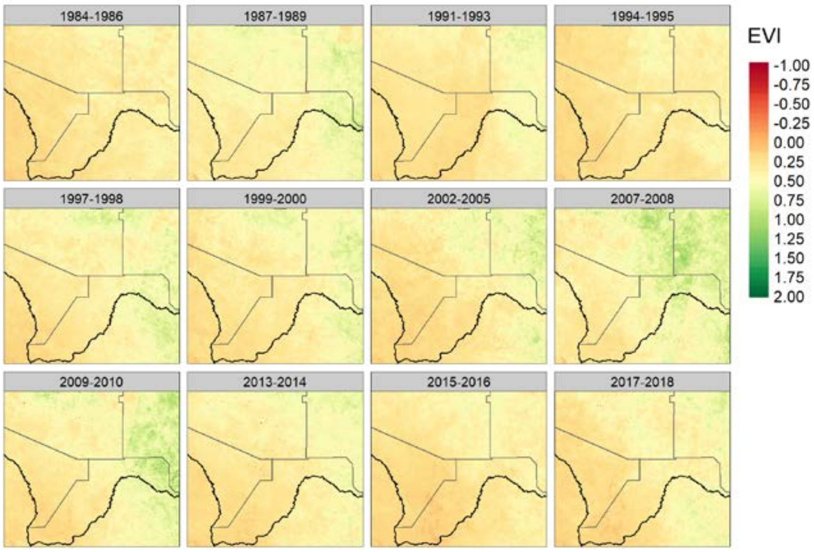

Figure 51. Average enhanced vegetation index (EVI) for Kgalagadi in the wet months between 1984 and 2018.

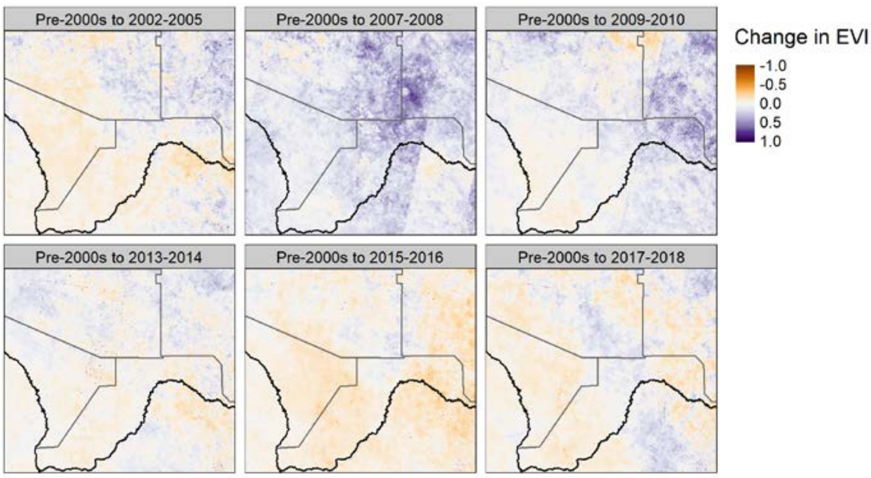

Figure 52. Average enhanced vegetation index (EVI) for Kgalagadi in the wet months between 1984 and 2018.

3.5.2. Abiotic covariates

Figure 53. Abiotic covariates for Bobirwa used to train the soil carbon prediction maps.

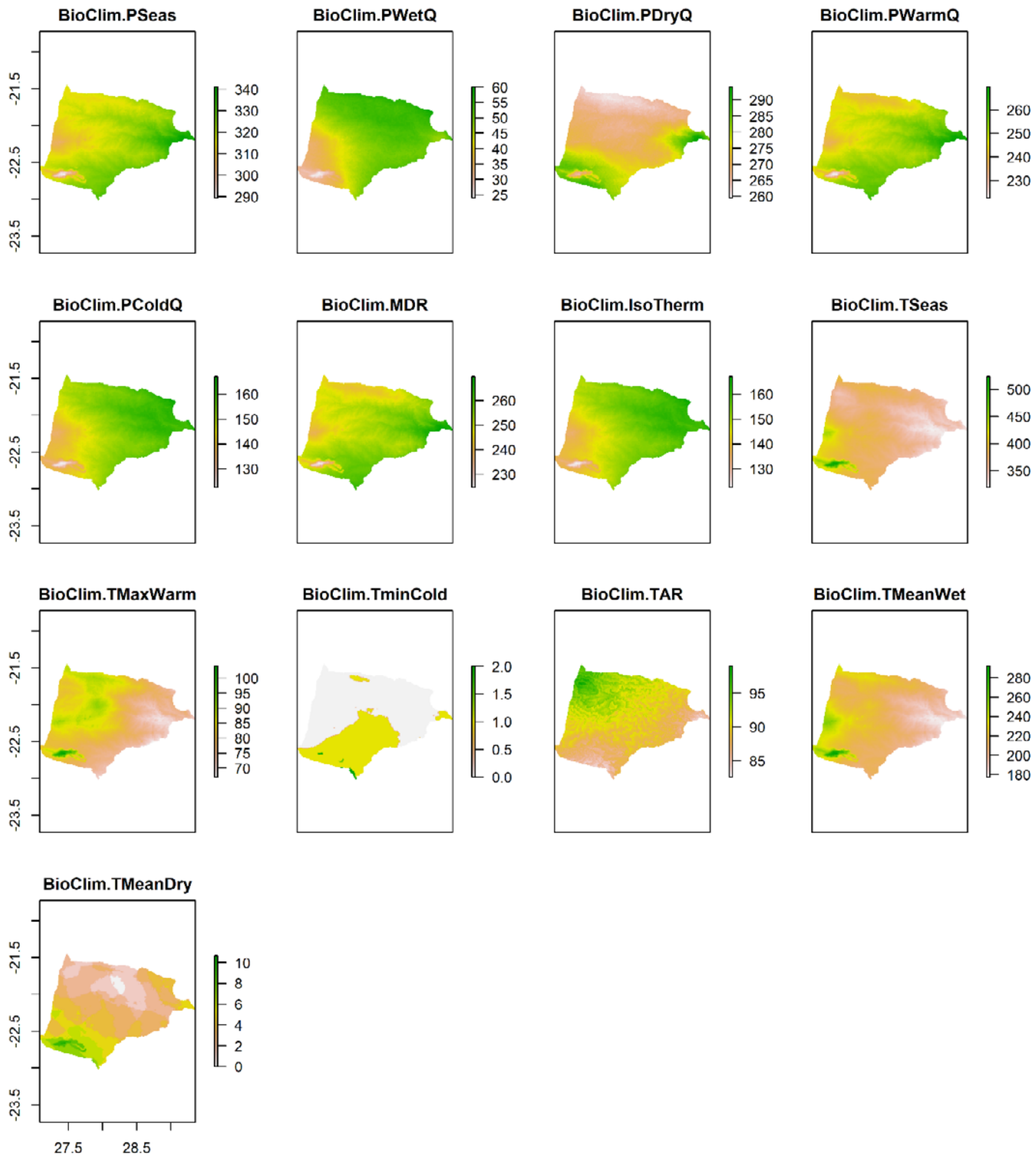

Figure 54. Abiotic covariates for Bobirwa used to train the soil carbon prediction maps (continued).

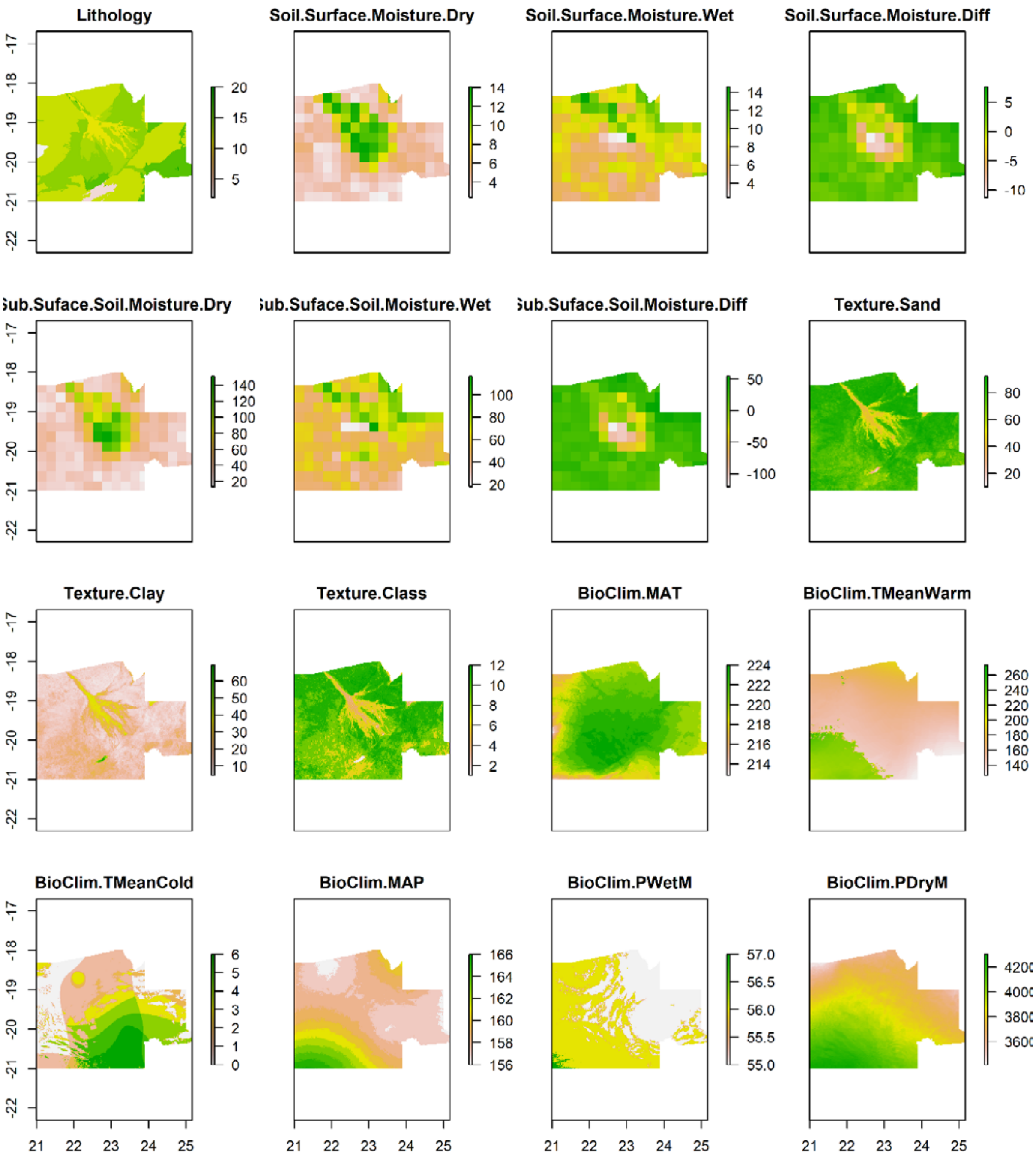

Figure 55. Abiotic covariates for Ngamiland used to train the soil carbon prediction maps.

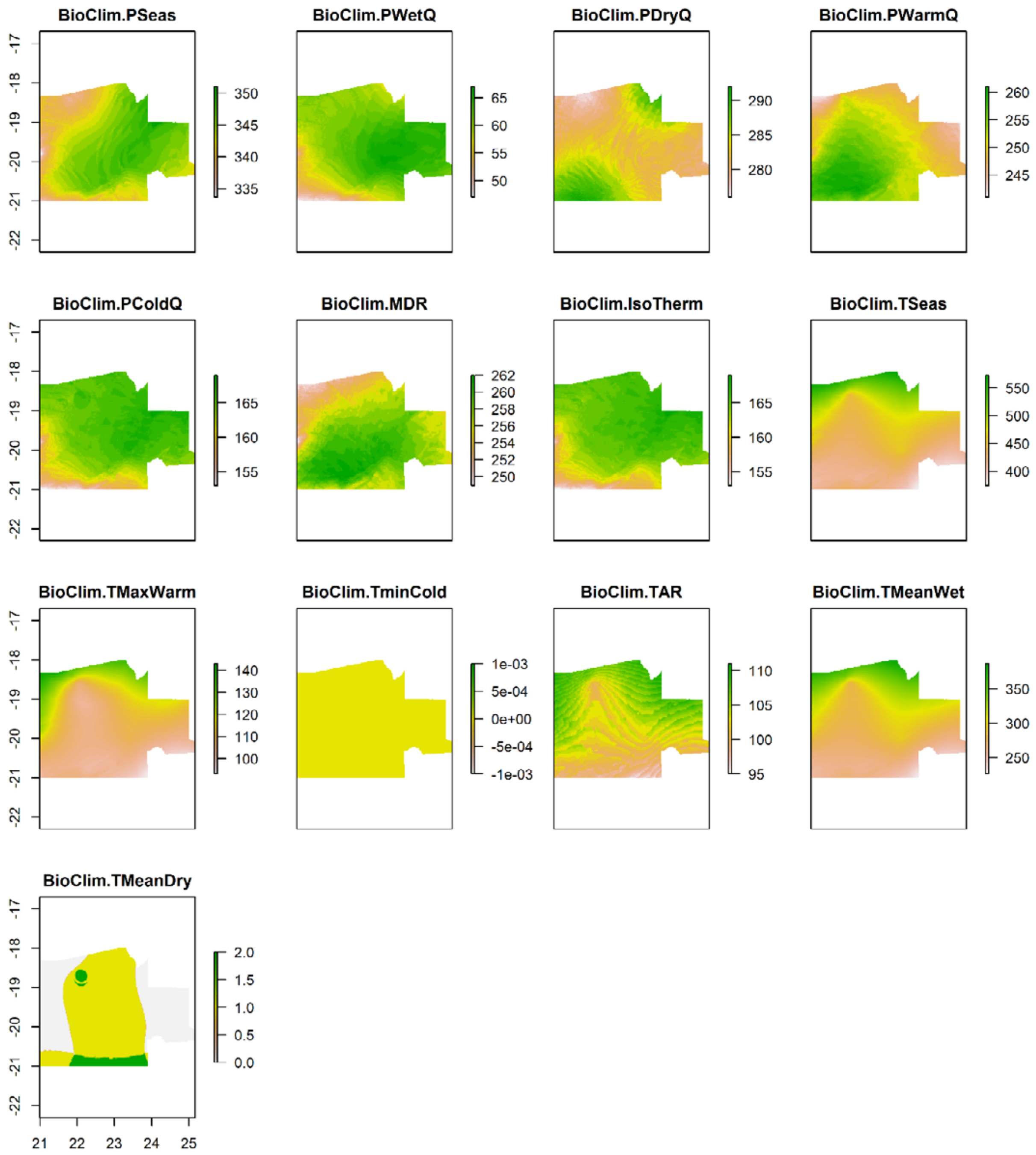

Figure 56. Abiotic covariates for Ngamiland used to train the soil carbon prediction maps (continued).

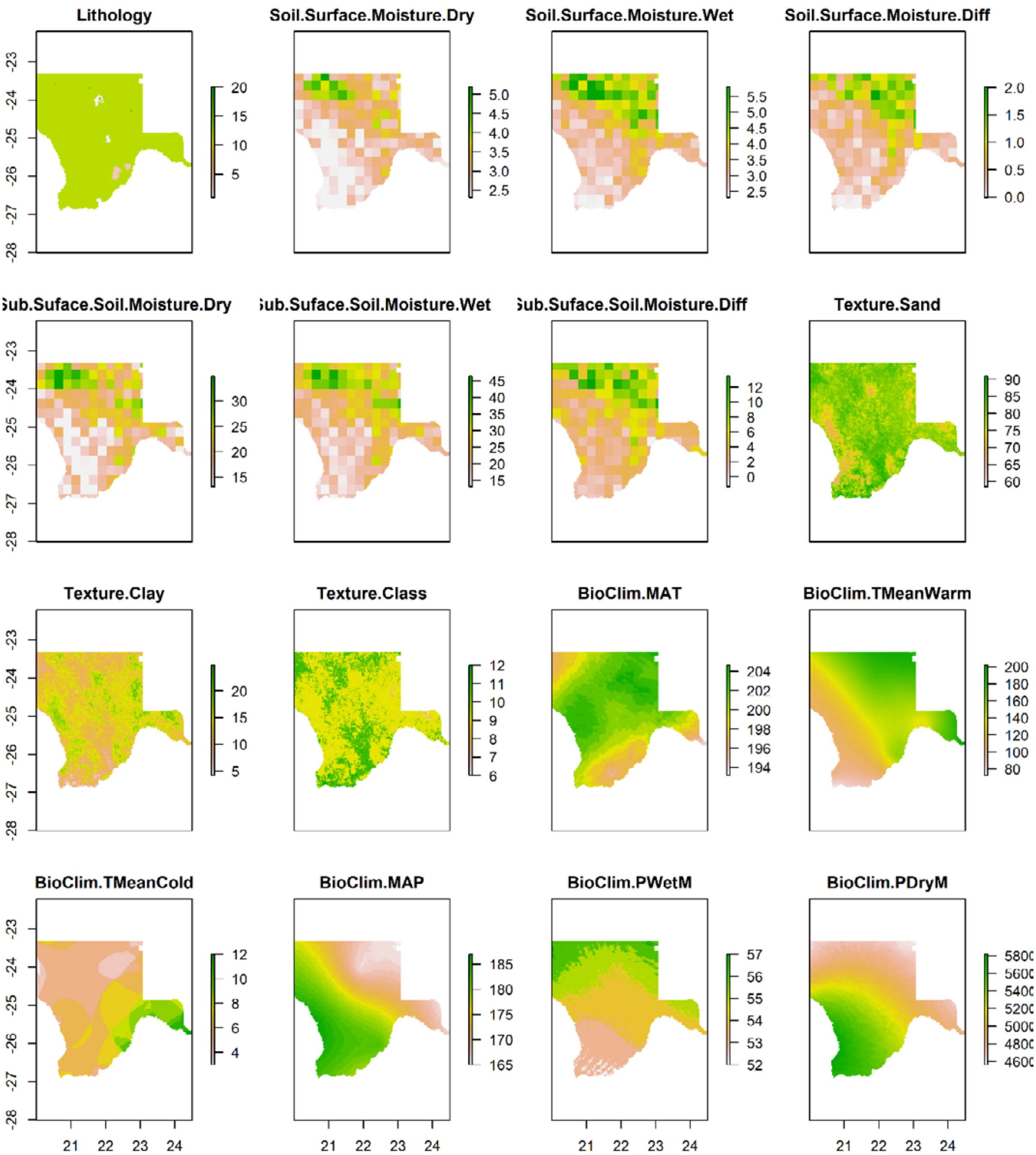

Figure 57. Abiotic covariates for Kgalagadi used to train the soil carbon prediction maps.

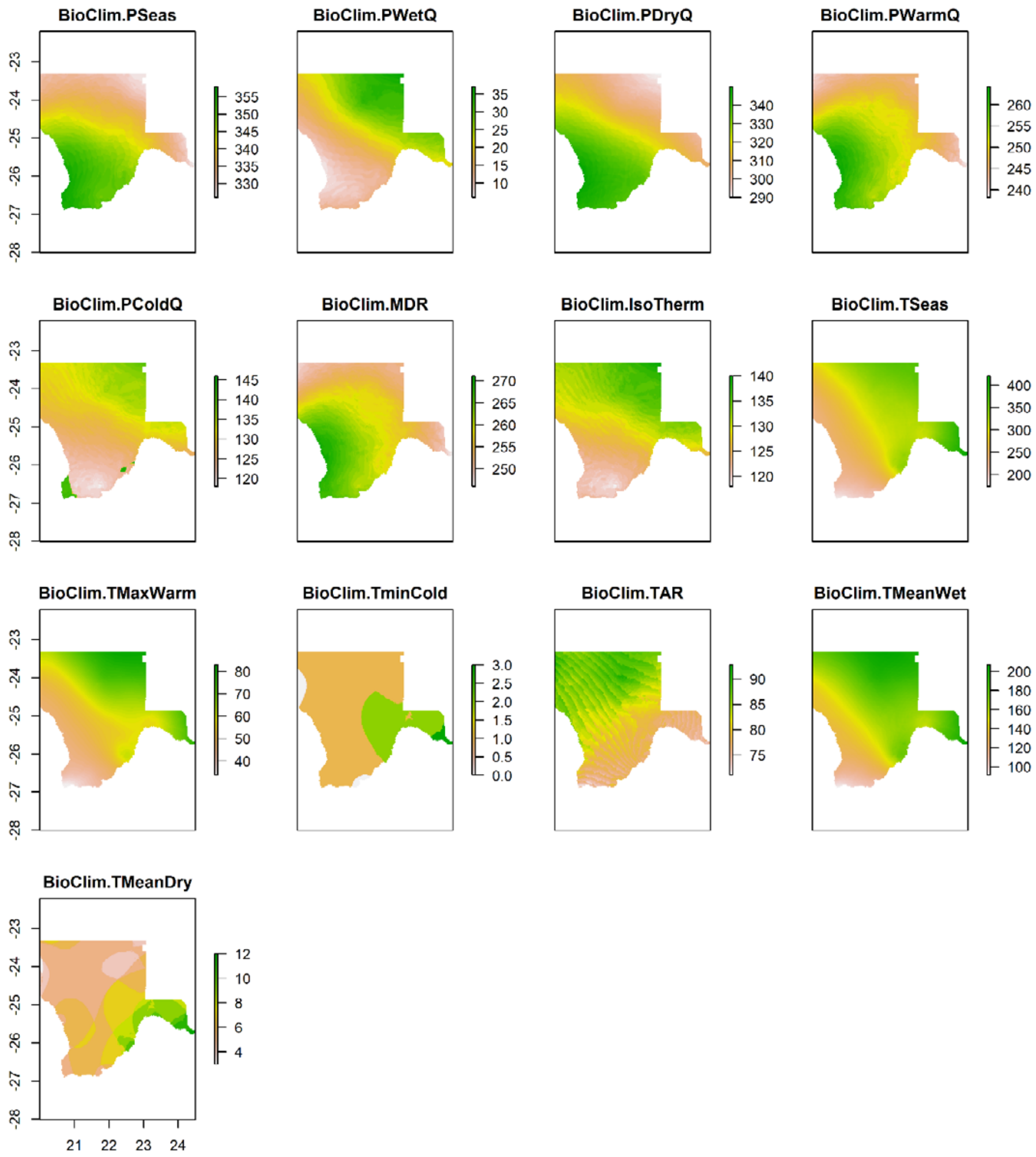

Figure 58. Abiotic covariates for Kgalagadi used to train the soil carbon prediction maps (continued).