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Spatio-Temporal Trends in Major Food Crop Yields in Rwanda

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Received: 13 December 2013 Accepted: 2 January 2014 Published: 15 January 2014

Abstract

This study uses various statistical techniques in an attempt to quantify the magnitude and to determine the significance of trends in the yields major food crops at seasonal and annual timescales over Rwanda for the period 2000-2010. The magnitude derived from the slopes of the regression lines is presented spatially in the form of maps. A steady rise in major food crops yields was registered. There was a higher non-significant increase in beans yields in the east, northern and southwestern regions; and a higher nonsignificant decrease in the southern and northwestern regions. A significant increase in cassava yields was observed in the central region. The east southern and southwestern regions had significant decreases in cassava yields in 2000-2005. The same was witnessed in the northwestern region in 2006-2010. The central and northwestern regions had a significant increase in Irish potato yields, especially in 2000-2005 and a significant reduction was registered over the southwestern, western and eastern regions. However, the southeastern region recorded a decrease in 2000-2005, and an increase in 2006-2010. A significant decline in maize yields was observed in the western region in 2000-2005, while the rest of country had an increase especially during the period 2006-2010. A significant decrease in sweet potato yields was recorded in the southwestern and western regions in 2000-2005; and in the western, northwestern and southeastern regions in 2006-2010. A significant increase in sweet potato yields was recorded in central Rwanda. These spatio-temporal trends in the yields major food crops may be influenced by the variability in precipitation intensity and frequency observed recently over Rwanda in combination with the agricultural reforms undertaken since 2007.

Index terms— food crops, yields, trends, Rwanda.

working population makes their living from rain-fed agriculture (ILO, 2007; Mary and Majule, 2009).

Although smallholder farmers in sub-Saharan Africa dedicate most of their time to growing food crops, their farm productivity is too low to meet their food needs. They spend most of their income on food rather than other goods or savings **??**UNDP, 2012). This can be attributed to minimal use of agricultural inputs (e.g. fertilizers, quality seeds, use of pesticides and insecticides, etc.), land degradation, significant food crop losses both pre-and post-harvest, seasonal climatic fluctuations with their adverse effects (Bart, 1993).

It is predicted that the future of agricultural production in Africa is likely to experience difficulties from factors other than the impact of climate change and variability. The situation will get much worse when the two factors mentioned above are put into the equation (Mendelsohn et al., 2000b;Tiffen, 2003;Arrow et al., 2004;Desta andCoppock, 2004 and **??**egurson, 2006). The rapid population growth prevailing in many sub-Saharan African countries, rapid urbanization and off-farm increases all contribute to a reduction in farm sizes and ultimately to low food crops production (Bryceson, 2002). This precisely is the case for Rwanda **??**NIRS, 2010).

Increase in temperatures and rainfall fluctuations coupled with weather extreme events (droughts and floods) have had negative effects on livelihoods and crop productivity in Rwanda. The eastern, southern and central lowlands have experienced frequent droughts, while the wet western and northwestern highlands have been

stressed by landslides, landslips and floods, (Bart, 1993; **??**INITERE, 2006; MINERENA, 2010 and David et al., 2011) which cause failure and destruction of crops and infrastructure. Since 1902, a number of famines following prolonged drought episodes have been registered in Rwanda (David et al., 2011) notably in the eastern, southeastern and central parts of the country (e.g. Umutara and Kibungo to the east,Bugesera to the southeast, Mayaga, Nyaruguru, Muhanga in the central regions) (CAMCO, 2011 and David, 2011). Previously, prolonged droughts were reported in 1910 (accompanied by a famine called "Kazuba"); 1917-1918 (accompanied by a famine called "Rumanurimbaba"); 1925-1926 (accompanied by a famine called "Gakwege"); 1928-1929 (accompanied by a famine called "Rwakamigabo"); **??**942-1944, 1962-1963, 1981-1984, 1989-1992 (accompanied by a famine called "Ruringaniza") **??** 1996, 1998-2000 and 2004-2005 respectively (Bart, 1993 and **??**INITERE, 2006). It is worth noting that although all these droughts have been associated with famines, there is no published scientific evidence linking the impact of droughts on food crop productivity in Rwanda.

Flooding has been reported mainly in the western and north-western highlands of the country. The floods that occurred in the region in May 2002 led to the death of 108 persons and the destruction of many hectares of crops together with infrastructure **??**MINITERE, 2006). Later in 2007, floods caused the displacement of more than 456 families and destruction of large areas under crops in Bigogwe sector in Nyabihu District. The heavy rainfall witnessed in September 2008 accompanied with strong winds affected eight of the 12 sectors of Rubavu District. In total, 500 families were displaced; about 2,000 hectares of land under crop cultivation as well as infrastructure were destroyed. The most recent floods were experienced in September 2012 in Nyabihu, Rubavu and Kirehe Districts, which saw more than 1,000 families displaced and their crops completely submerged (NIRS, 2012) to result into decline in crops production.

Landslides and landslips occurred in the north (Gakenke, Cyeru, Rulindo, and Gicumbi Districts) and in the west (Nyamasheke, Nyamagabe, Karongi and Ngororero Districts, etc.) regions of the country in , 2002 **??**David, 2012)). Despite these repeat episodes, no scientific interrogation has been carried out in the last decade to establish the total loss in food crops production that is caused by these extreme weather events (droughts and floods). The same could also be said on research into the impacts of the agricultural reforms undertaken in Rwanda (since 2007) on food crops productivity. It is in this regard, therefore, that a study on spatio-temporal trends in major food crop yields in Rwanda has been carried out to establish the country's potential agricultural productivity during the last decade to facilitate future projections in further studies. The increase in food crops production observed recently in Rwanda (figures5, 6 and 7)is the result of the agricultural reformsin place since 2007. These reforms include the use of agricultural inputs like improved seeds and fertilizers; land use consolidation policy, which encourages farmers in adjacent lands to grow the same crop; marshland irrigation; one cow per family programcalled "GIRINKA program" which sets out to integrate livestock keeping in agriculture by increasing the use of manure to increase soil fertility;the erosion control programs by constructing progressive and/or radical terraces **??**MINAGRI, 2008). It should be noted that in spite of these reforms, the use of practices such as mulching, planting trees, digging trenches, destumping or green fencing are used on a low scale in Rwanda (Karangwa, 2007). variability observed recently over the East African region (Mutai et al., 1998;Mutai and Ward, 2000;Funk and Brown, 2006;Anyah and Semazzi, 2007). Although a general increase in food crops production has been observed, all crops did not register the same rate of production (figure **??**).

1 Figure 6 : Evolution of total annual production (103tons) of key food crops in Rwanda

It is clear from figure **??** above, that bananas, cassava, Irish potatoes, sweet potatoes, vegetables and fruits, beans and maizegave the highest production(in'000 tons) respectively for the period 2000-2010. The greatest increase in food crop production was registered between 2008 and 2010. For this study, cassava, Irish potatoes, sweet potatoes, beans and maize have been selected for investigation because they are grown overlarger areas in most parts of the country during the agricultural seasons "A" and "B".

The annual mean yields (kg/ha)vary from one crop to the next due to their productivity capacity (figure 7) and suitability to the agro-ecological conditions present in Rwanda. Agricultural recordsper districtwereobtained from the National Institute of Statistics of Rwanda (NISR) and the Ministry of Agriculture and Animal Resources (MINAGRI) based at Kigali. Five major crops, namely, beans, cassava, Irish potatoes, maize, and sweet potatoes were selected for investigation. This was as pointed out above, because they are grown over large areas in most parts of the country during the two agricultural seasons (A and B).

Completeness of records wasthe basic criteria used to select the food crop yields to be investigated so as to satisfactorily cover most of the country during the two agricultural seasons. The food crop yields trend analysiswasdone for the period 2000-2010 using the raw seasonal values (food production and cultivated areas) from 11 provinces for 2000-2005 and 30 districts for 2006-2010, from which annual food crop yield trends were derived.These two periods were purely determinedon the basis that the administrative reforms of 2006 arbitrarily subdivided the country into 30 districts without taking into consideration the existing provincial boundaries. Thus the harmonization of data for the whole study period was rather difficult and this constitutes the limitations of this study.

Statistical techniques (linear and nonparametric tests) were applied on agricultural data used in this study to determine the magnitude and significance of trends in food crops yields at seasonal and annual resolutions

(Parry et al., 2004;Agustin, 2006;Rodrigo and Trigo, 2007;Kizza, 2009; **??**el Rio et al., 2012). The linear trend values represented by the slope of the simple least-square regression line showed the rise/fall in selected food crops yields (Sharad and Kumar, 2012).

The magnitude of the trends derived from linear regression analysis **??**Sen, 1968) and their statistical significance at 95% level were calculated **??**Horton et (Christopher, 2011). The trends were considered significant if P was ? 0.05. A geographical information system (GIS) was used to represent the spatial variations in food crop yields trends on the maps.

Analysis of major food crops yields in Rwanda for the period 2000-2010 helps to establish crop productivity across the country with a view to coming up with recommendations for the future. Crops productivitywas bound to have been impactedbythe agricultural reforms undertaken in Rwanda since 2007 (MINAGRI, 2010) together with the recent climate variability along with their adverse effects (Mutai et al., 1998;Mutai and Ward, 2000;Funk and Brown, 2006;Anyah and Semazzi, 2007). However, the impact of these reforms and variability in climate are to be realized after a long period though.

Therefore, the following spatial representation of yield magnitude trendsfor major foodcrops in Rwanda (figures 8-12) may serve as a key reference point for further investigations on the impact of climate change and variability on food crops productivity. Although the statistical significance of trends was not represented graphically, most of the crops showed either decreasing or increasing patterns in different parts of the country. It is on this ground that studies on spatial food crop productivity across Rwanda with regard to projected climatechange and variability should be founded. a) Beans yields trends Dry beans, (Phaseolus vulgaris L.) which are a major source of proteins for the poor in sub-Saharan Africa were grown in Rwanda in areas covering between 333.2 and 347.03 (103ha) for the period 2000-2009, and reduced to 316.4(103ha) in 2010. With a total production of between 215,346.9 and 325,165 tonsof beans for the period 2000-2010,Rwanda was the fourth highest producer in Africa after Kenya, Uganda and Tanzania **??**FAO, 2008; **??**atungiet al., 2009). The average bean production in Rwanda is 0.78 ton/ha (NIRS, 2010) compared to Kenyan, which oscillates between 0.35ton/ha and 0.54 ton/ha; 0.5 to 0.77 ton/ha for Tanzanian and 0.36 to 0.75 ton/ha for Malawi **??**Katungiet al., 2009). The bushy type is the predominant type of beans that is grown not only in Rwanda but also in most of Africa (Buruchara, 2007). northeastern region for season A. However, the yields decreased by between 0 and 35 kg/ha in the central, western and southern parts of the country except in Gitarama Province where yields showed an increase pattern in season A. The magnitude in yields at annual resolution for the period 2000-2005 showed the same trends as it was in season B, with slight differences in the northeastern region where they increased by between 0 and 10 kg/ha. The central and southern areas showed a decreasing pattern of 25-35kg/ha per season.

An increasing trend in beans yields of between 100 and 140 kg/ha per year was observed in the eastern and southwestern regions of the country, while the adjacent regions showed an increasing pattern of between 0 and 50 kg/ha in season A for the period 2006-2010. The adjacent regions registered a rise of between 0 and 50 kg/ha during season B.

A high decreasing pattern in yields of between 70 and 116kg/ha was observed in the northern areas of Rwanda during season B for the period 2006-2010. This may be attributed to the destruction of the crop that was caused by increasedflooding episodes observed in these areasrecently **??**MINERENA, 2010).A decrease of between 0 and 70 kg/ha was registered in the southern and northwestern regions of the country especially during season B. At annual resolution, the trend in yieldsfor the period 2006-2010 was almost similar to that observed in season A with slight differences in the southern and northwestern regions.

It is clear thata higher increasing pattern was observed in the northeastern and southwestern regions, while a higher decreasing pattern was seen in the central and southern regions for 2000-2005, and in the northwestern region for the period 2006-2010. The southern and the northwestern areas showed a decreasing pattern for the whole study period.

2 b) Cassava yield trends

Cassava (ManihotesculentaCrantz) is a major food crop in Rwanda in particular and for the people living in the tropics in general(Plessis et al, 2009; NIRS, 2010; NIRS, 2011). The area under cassava cultivation in Rwanda ranged between 120.5 and 196.6 (103ha) for the period 2000-2010, compared to 2,190 (103ha)in the DRC, 590 (103ha) in Tanzania and 290 (103ha) in Uganda in 1991 **??**FAO, 2005). Rwanda produced between 820,992 and 2,292,533 tons of the crop between 2000 and 2010, with the yield oscillating between 6.8 and 11.7 tons/ha (NIRS, 2010, NIRS, 2011) compared to 14.7 tons/ha in Nigeria, 10.5 tons/ha in Tanzania and 10.6 tons/ha in Uganda in 1991 **??**FAO, 2005). The spatial distribution in cassava yield trends is shown in figure 9. The spatial distribution in cassava magnitude yield trends (figure 9) at seasonal timescale for the period 2000-2005 reveals that yields increased by between 300 and 580 kg/ha per season in the central region of the country during season A. An increase of between 150 and 300kg/ha was observed in the southwestern and northern regions (Ruhengeri Province) in the same season. A rise of between 0 and 150 kg/ha was registered in the northeast. However, a significant seasonal decline of 100-205kg/ha in yield was observed in the provinces of Kibungo (in the southeast), Byumba (in the north). Adeclining trend of 0-100 kg/ha was observed in Gisenyi Province (in the northwest) and Gikongoro (in the south).

A rise in yield of 0-300 kg/ha per season was registered in the central and western regions of the country,while a decreasing trend of 100-205 kg/ha was observed in the eastern region during season B for the A significant

decreasing pattern in yields of between 300 and 504kg/ha was registered only in the northern areas of the country,with the adjacent regions having a decline of between 0 and 300kg/ha in both seasons A and B for the period 2006-2010. This may be attributed to the destruction of crops by floods as was the case with beans. The rest of the country showed an increasing trend in yields. However, a higher increasing pattern of 200-300 kg/ha was registered in the central and eastern regions of the country. As the variability in yields during seasons A and B was very low, the yield pattern at annual resolution looks was similar for the two seasons. Overall, cassava had an increasing pattern in yields since 2006 for most of the study area. c) Irish potatoes yield trends Irish potatoes, (Solanumtuberosum) also known as "earth apple" arethe most important non-cereal crop, and are ranked fourth after wheat, rice, and maize (Hoffler and Ochieng, 2008; **??**AO, 2008;Muthoni and Nyamongo, 2009; **??**degwaet al., 2009). The area under Irish potatoes in Rwanda was between 108,982 and 151,049 ha for the period 2000-2010. Production stood at between 957,197.5 and 1,794,042 tons compared to Kenya's 790,000 tons in 2006. The yieldsper hectare in Rwanda varied between 8,783 and 11,877kg/ha for the period 2000-2010 compared to 7,500 to 9,500kg/ha in Kenya in 2006 **??**FAO, 2008 **??** NIRS, 2010, 2011).

3 (B)

Year 2014 central region showed an increasing pattern of 0-90 kg/ha for season A. However, the southwestern, southeastern and northern (Byumba Province) areas showed a decreasing trend of 0-120 kg/ha in season A.

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During season B for the period 2000-2005 (figure 10), a significant increasing pattern of 180 to 280 kg/ha was registered in the central region, while the adjacent (western) regions showed a rise in yields of 90-180 kg/ha. The southwestern and northern regions had an increasing pattern of 0-90 kg/ha in season B for the period 2000-2005. A declining pattern of 120-180 kg/ha was seen in the southwestern, western and northeastern parts of the country. The western and adjacent areas showed a decreasing trend of between 0 and 120 kg/ha in season B. The rise and fall in yields at annual resolution for the period 2000-2005 were observed in the same provinces in season B, with the only difference being the magnitude of trends where it was lower at annual resolution.

AlthoughIrish potatoes yield trends showed a high spatial variability for the period 2006-2010, an increasing pattern of between 0 and 200kg/ha was registered in the southeastern and southwestern regions for season A and in the southern regionfor season B. A similar trend was observed in isolated areas of the northeastern, central and northern regions (Gakenke District) for both seasons, and Burera and Ngororero Districts for season A. The remaining areas of the country showed a declining trend of 0-276 kg/ha for the two seasons for the period 2006-2010. The rise and fall in yield at annual resolution for the period 2000-2005 were observed in same district in season B with the only difference being the magnitude where it was lower at annual resolution. From this data, it is concluded that the decreasing pattern was more pronounced in the latter period **??**2006) **??**2007) **??**2008) **??**2009) **??**2010) compared to the earlier one **??**2000) **??**2001) **??**2002) **??**2003) **??**2004) **??**2005) especially in season A. This is attributed to increased flooding episodes in recent years.

5 d) Maize yields trends

Maize (Zea mays L.) also called "corn" is an important cereal crop in sub-Saharan Africa (IITA, 2002) and it is the staple food for over 50% of the sub-Saharan Africa population **??**FAO, 2008).That said, however, Africa produces only 7% of the world's maize compared to 39% by the United States of America (USA) in 2006 **??**IITA, 2002; **??**AO, 2008 **??** USDA, 2013). In the period 2000-2010, the area under maize cultivation in Rwanda wasannually between 89,052.5 and 177,268 ha. This gave rise to an annual produce of between 62,501 and 440,951tons of 48,908 (103tons) total production in Africa in 2006 **??**FAO, 2008). The average maize yield for theperiod2000-2010 was between 701.8 and 2,487.5kg/ha in Rwanda compared to the 4,255kg/ha world average; 8,600kg/ha in the USA; 1,730kg/ha in Africa and 2,000kg/ha in East Africa in 2006 **??**IITA, 2002 **??** FAO, 2008 **??** USDA, 2013). The spatial distribution of yield trends between1999and 2010 is as shown in figure 11.

The spatial distribution of maize magnitude yields trends (figure 11) at seasonal timescale for the period 2000-2005 reveals that yields increased by between 15 and 42kg/ha per season in the western, northeastern and central regions of Rwanda during season A. An increase of between 0 and 15 kg/ha per season was registered in the southern (Butare Province), the southeastern (Kibungo Province) and the northern (Byumba Province) regions for season A. A decline of 40-66 kg/ha during season A was observed in the northern area of the country (Ruhengeri Province), while a decrease of 20-40 kg/ha and 0 to 20 kg/ha were seen in the south (Gikongoro Province) and Central (Kigali Ngari Province) regions respectively.

A rise of between 30 and 42 kg/ha and 15 and 30 kg/ha were registered in the southeast (Kibungo Province) and the north (Byumba Province) respectively during season B. The rise stood at 0-15 kg/ha in the northeastern (Umutara), central (Gitarama and Butare), northwestern (Gisenyi) and southwestern (Cyangugu) regions for season B. A decline of between 40 and 66 kg/ha per season was observed in the western region (Kibuye Province) followed by Ruhengeri Province in the north, which registered a decline of 20-40 kg/ha. Kigali Ngari in the central region recorded a reduction of 0-20 kg/ha in season B. A fall of 0-40 kg/ha in yields at annual resolution for the period 2000-2005 was observed in Gikongoro, Kibuye, Kigali Ngari and Ruhengeri Provinces, while a rise of between 0-30 kg/ha per year was observed in the remaining regions of the country. The spatial representation

of trend magnitude in sweet potato yields (figure 12) at seasonal timescale for the period 2000-2005 reveals that yields increased by between 150 and 290 kg/ha per season in the central region for seasons A and B. An increase of between 100 and 150 kg/ha per season was registered in the northwestern region for season B, while it stood at 0-100 kg/ha in the southwest region for season A. The eastern and northern regions showed an increasing trend of 0-50 kg/ha. A decline of between 0 and 74 kg/ha was recorded in the southwestern and western regions during the two seasons between 2000 and 2005. The central region showed a significant rise of 150-250 kg/ha in annual yields while it ranged between 0 and 50 kg/ha in the eastern and northern regions. It was recorded at 50-100 kg/ha in the southwestern and western areas of the country.

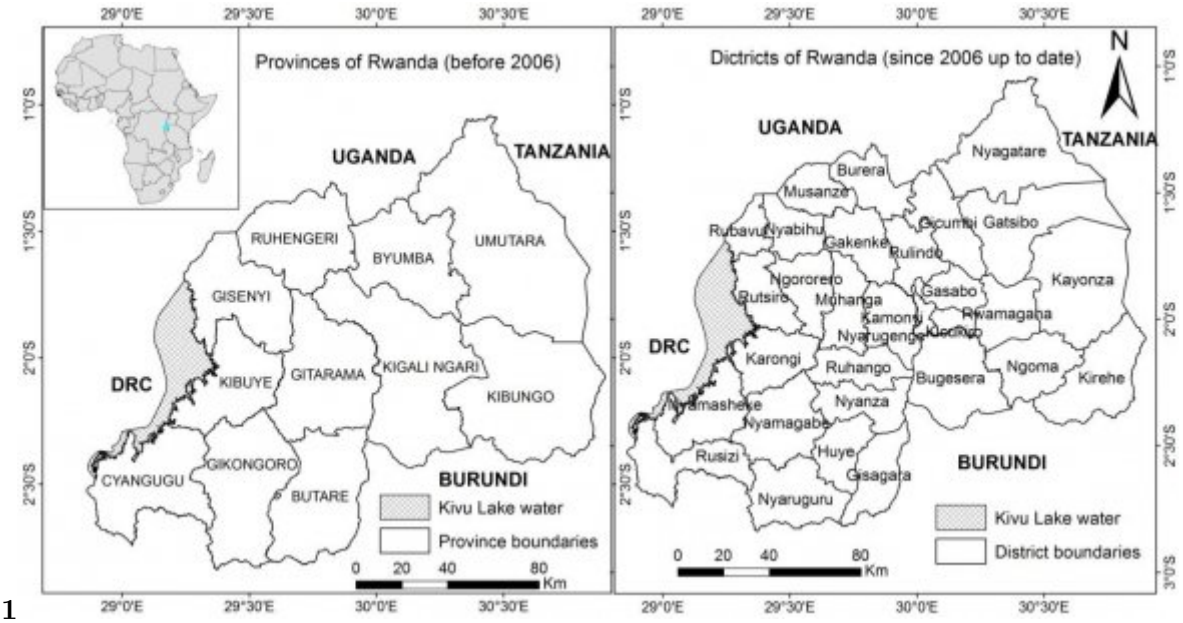
6 (B)

A rise in yield trends of between 100 and 290 kg/ha was registered in isolated areas of the eastern, central and southwestern parts of the country for season A between 2006 and 2010. An increase of 0-100 kg/ha per season was registered in small areas of the southern, western and northern regions of the country. The rest of the country showed an increasing trend in yields, ranging between 100 and 270 kg/ha over the western and northwestern regions and 0-100 kg/ha in the eastern region. The situation was different during season B for the period 2006-2010 where most of the regions showed an increasing trend except in Karongi, Kirehe, Musanze and Rwamagana Districts, which recorded a decline of between 0 and 200 kg/ha. Overall, season B registered a high increasing pattern in sweet potato yields. Arising from this, therefore, season B may be the most ideal to grow sweet potatoes. It was observed that on average, there was an increase in major food crops yields across the country. This may be attributed to the agricultural reforms undertaken by the government since 2007.

Althoughthe use of chemical fertilizers by smallscale farmers in Rwanda has emerged as a way of improving crop productivity, it has been reported to cause soil degradation. Further, soil degradation induced by erosion, chemical depletion, water saturation and solute accumulation, is touted as a major challenge **??**Oldemanet al., 1991) to agriculture because it contributes to the decline of the land's productivity. Irrigation projects that are designed to compensate the impact of recent climate variability in Rwanda (MINAGRI, 2008) may be seen to slow down productivity due to the degradation caused by water logging and salinization (Alexandratos, 1995). There could also be soil emanating from the pressure of a rapid population growth in Rwanda, which is among the highest in Africa (NISR, 2012).

In addition, it is anticipated that climate change and variability will have a big impact on food crops productivity in future if the recurrent flooding episodes especially in the northwestern regions of Rwanda are anything to go by. The southern and southeastern areas registered a decline in food crop yields perhaps due to an increase in aridity.Consequently, a study on the crop productivity in response to climate change and variability is recommended. [1]

Figure 1:



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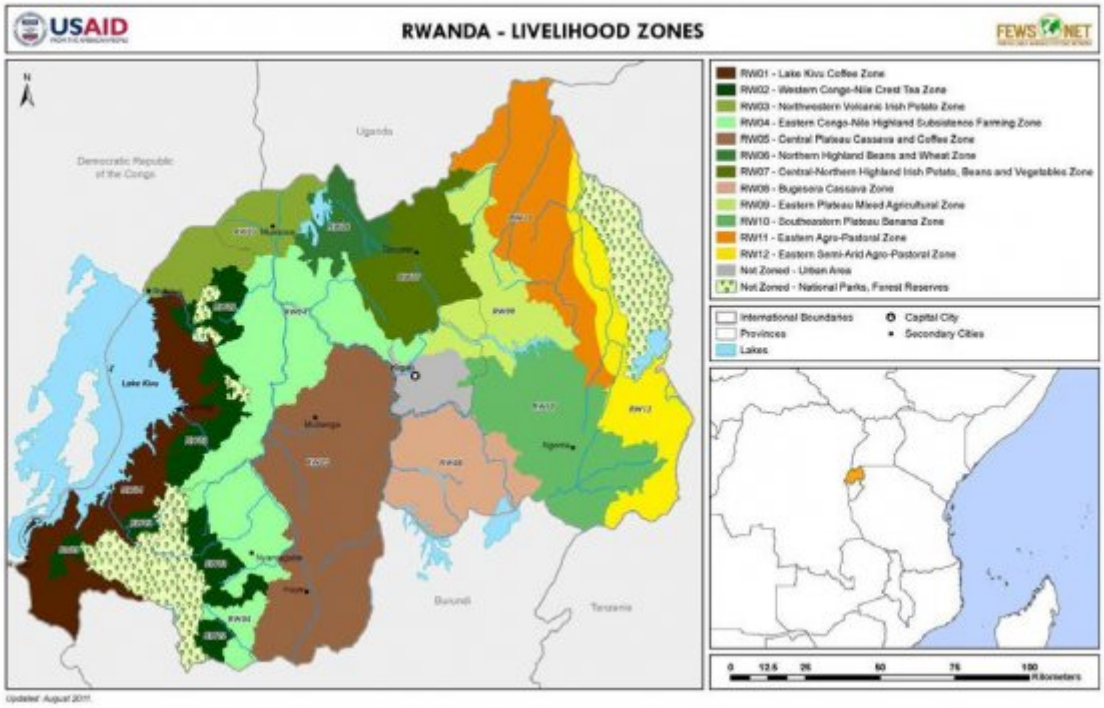

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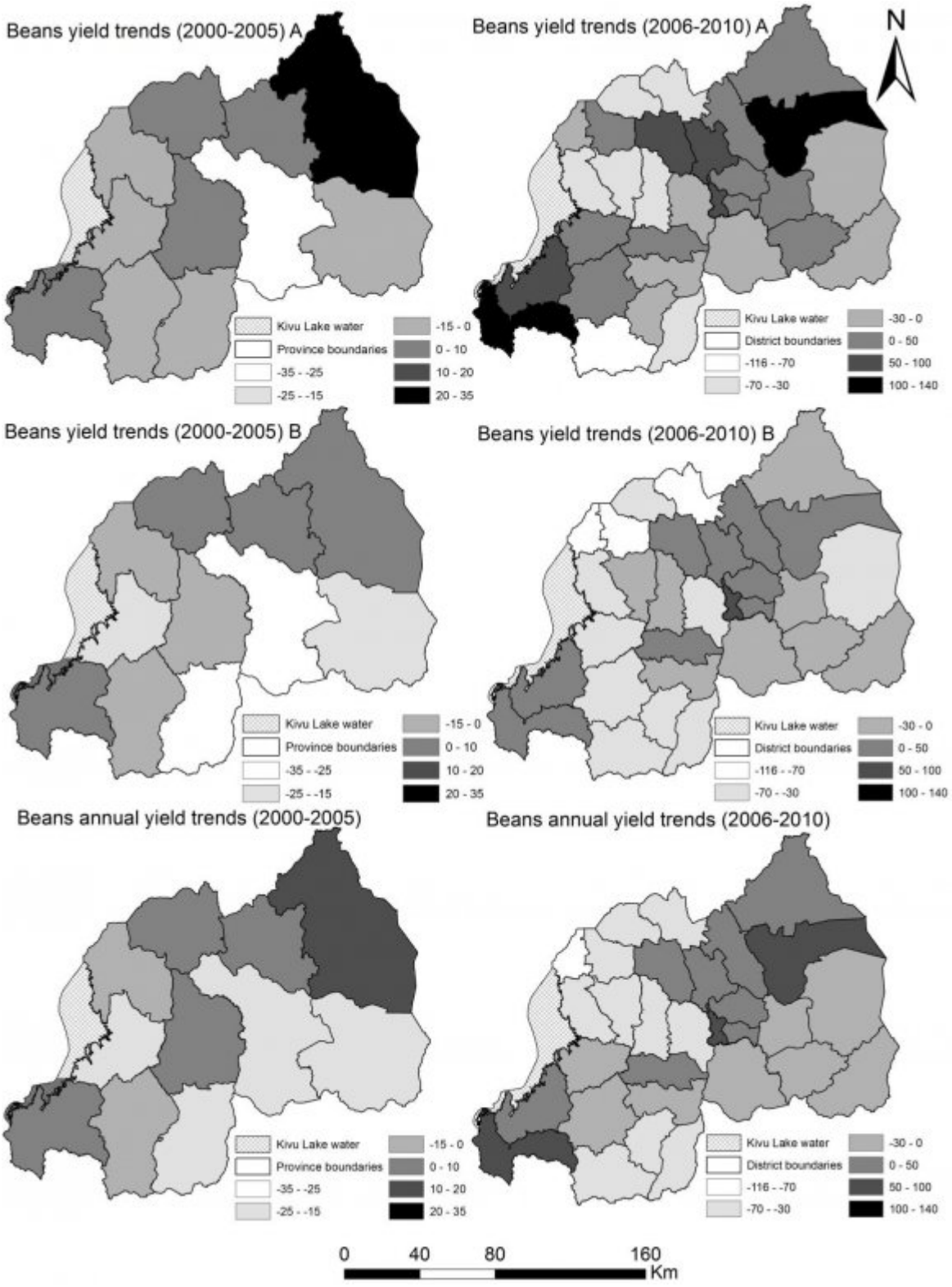
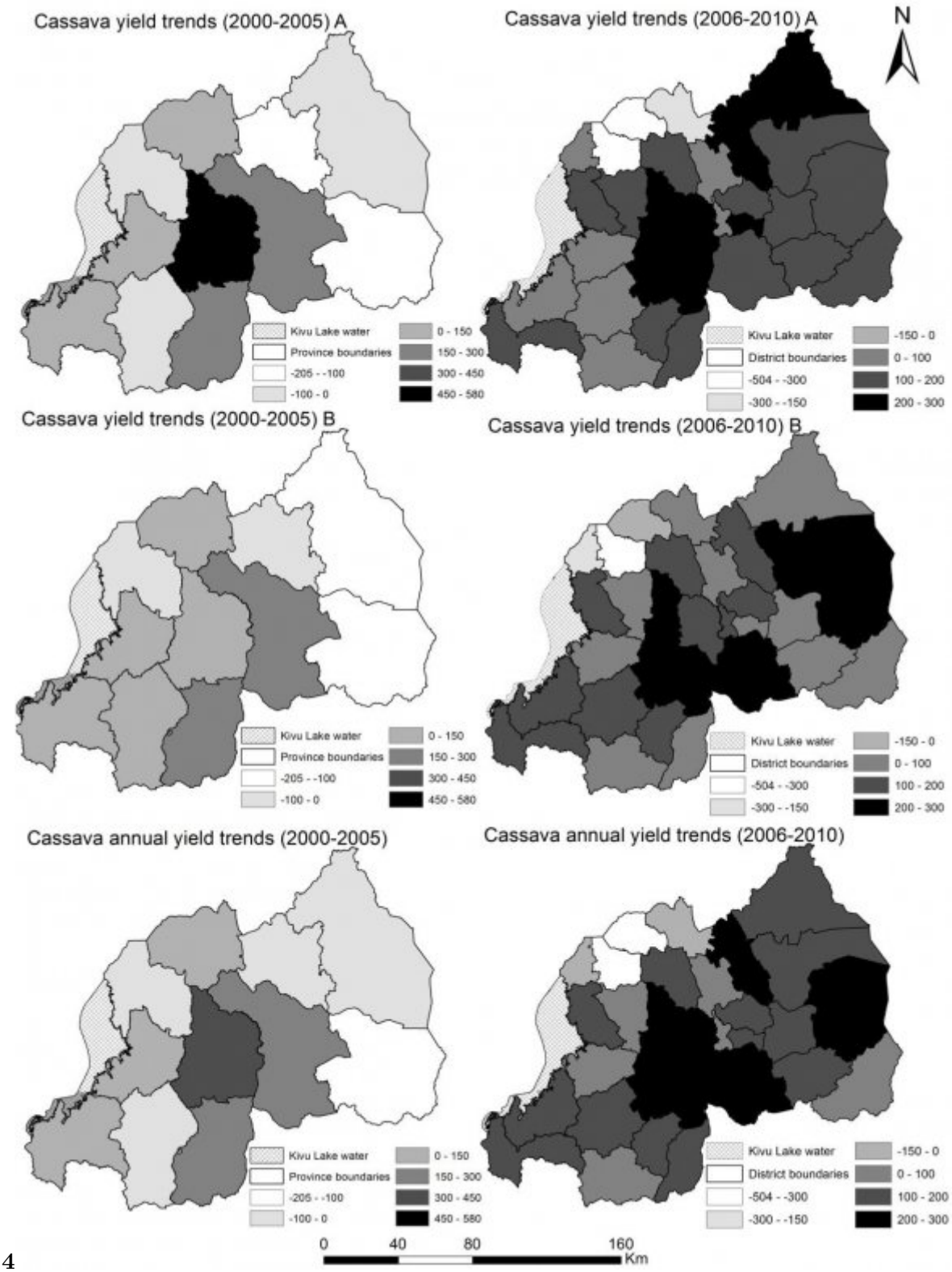


Figure 4: Figure



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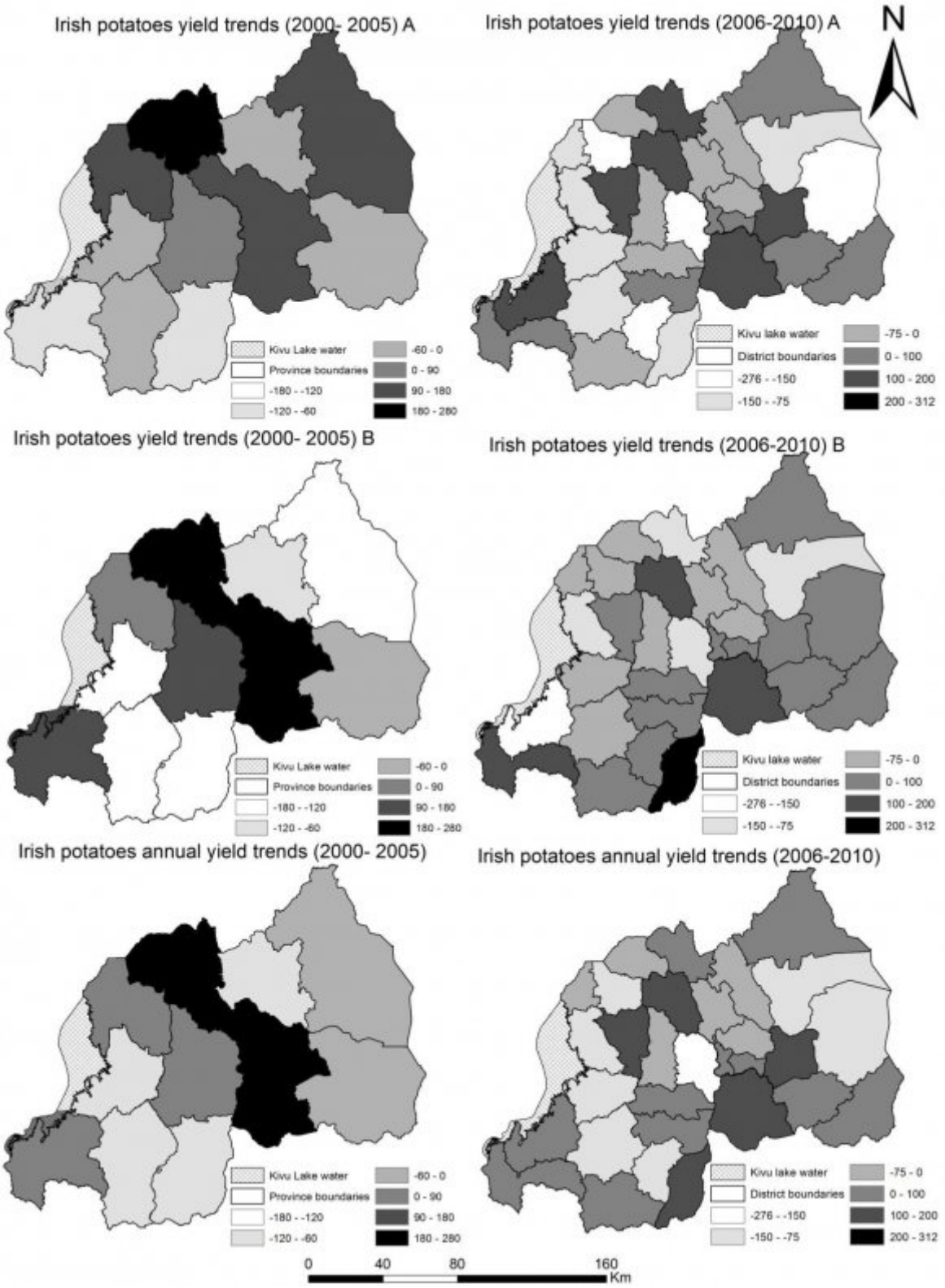

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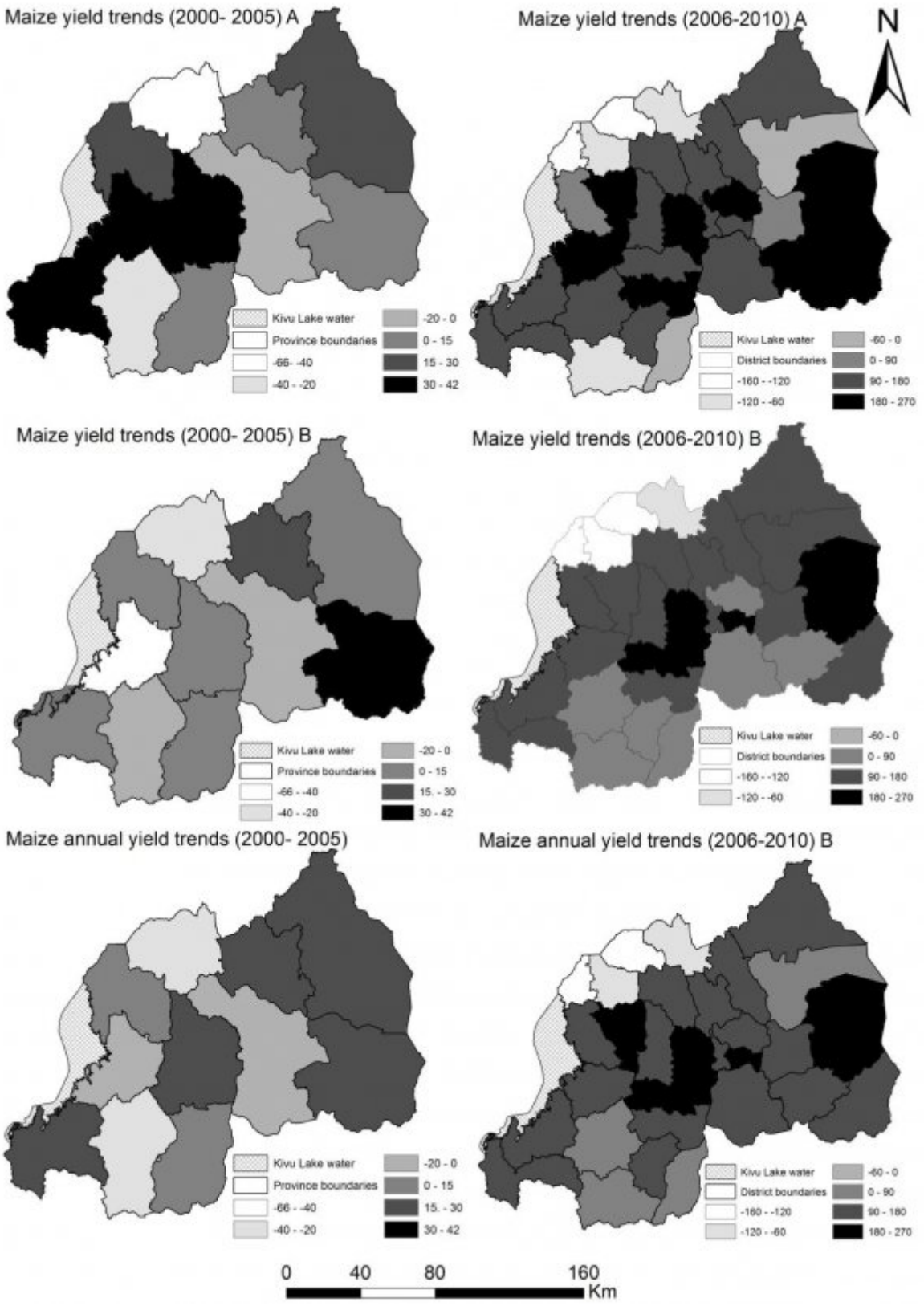

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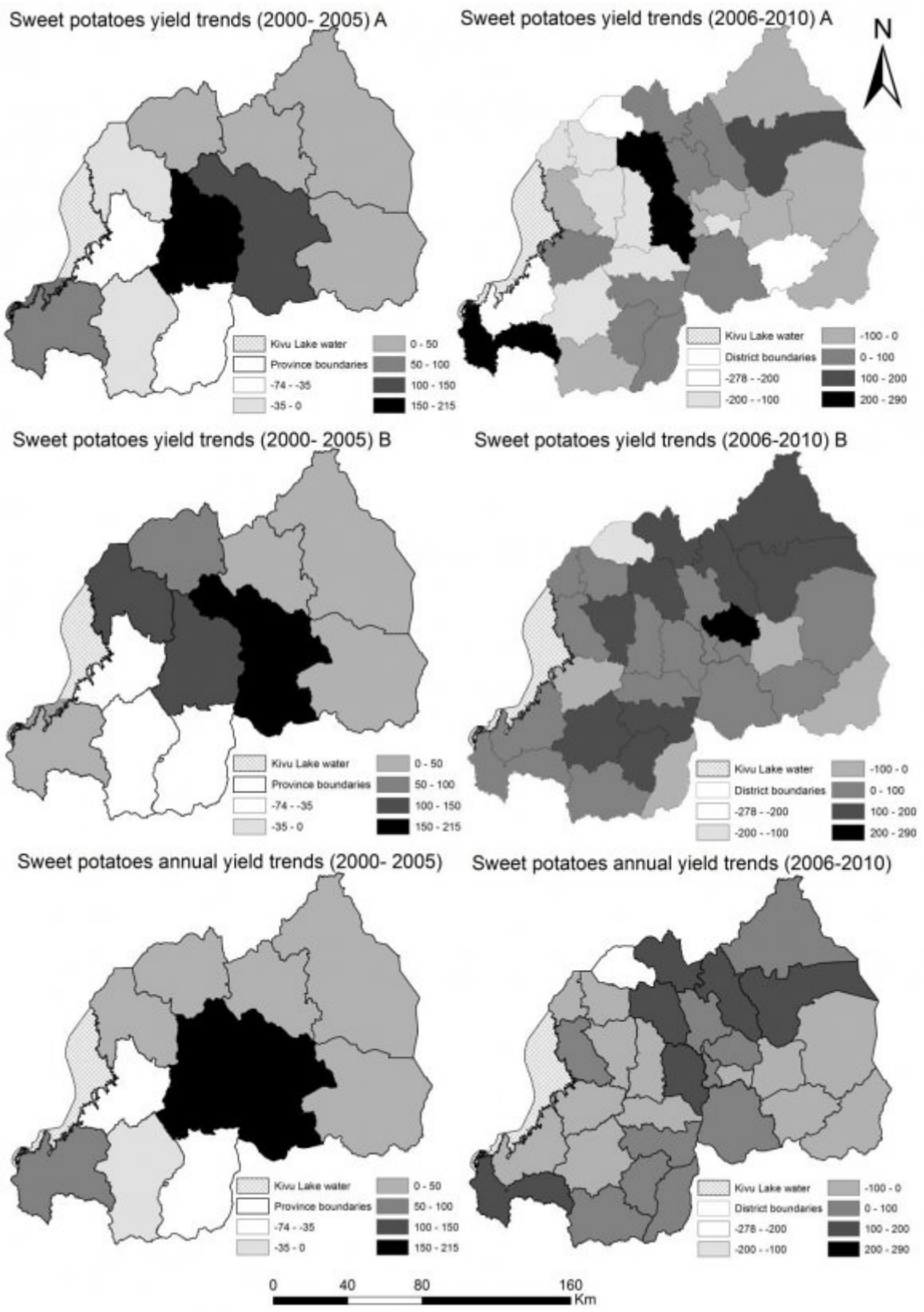

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Figure 8: Figure 8 :

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We wish to express our sincere gratitude to the Government of the Republic of Rwanda and the University of Johannesburg for the financial and other support they extended to Muhire Innocent while pursuing his PhD studies. We also feel greatly indebted to the Kigali Institute of Education (KIE) for unreservedly granting Muhire Innocent a study leave for the entire duration of study. The authors are grateful to the National Institute of Statistics of Rwanda (NISR) and the Ministry of Agriculture and Animal Resources (MINAGRI) for providing agricultural dataset used in the present study.

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