Understanding Rural Productive Land Use Change in Canterbury and its Driving Factors

Samuel Cook, Dempsey Rose-Day, Thomas Sunderland, Jack Thorp, Sam Wong

GEOG309: Research for Resilient Environments and Communities

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1. Executive Summary

- The research aim was to map rural productive land use change in Canterbury over recent decades and identify key driving factors.
- Data was collected from government departments, peer-reviewed journals, satellite images, weather stations, and industry professionals.
- Economic factors were found to be the key driver of rural land use change.
- Local rainfall events found to be intensifying, but conditions drier overall, presenting a key consideration for land use decisions.
- Data and time availability were major limitations.
- Further research could aim to produce the required data to understand rural productive land use change at an individual farm level.

2. Introduction

In New Zealand, there is growing concern about the loss of farmland. Rapid urbanization and expanding infrastructure projects are encroaching on valuable agricultural land, reducing the country's capacity for food production. This trend has raised alarms about the need to balance urban development with preserving vital farmland. Efforts are underway to implement sustainable land-use policies and protect agricultural areas, ensuring a secure and thriving future for New Zealand's farming communities. For this report, we aim to investigate factors that are influencing rural land use change in the Canterbury region. We chose to focus on the Canterbury region, as a smaller scale allows us to more accurately map change as well as investigate the factors behind it.

The first part of this report offers a comprehensive analysis of how these factors influence rural productive land use change in the Canterbury region. We investigated four factors, consisting of: socio-economic, urban expansion, precipitation trends and extreme weather events. The second part of this report covers the formation of maps to highlight the change, and a rudimentary weather analysis to aid understanding of potential driving environmental factors.

During the project, we encountered limitations including data constraints, impractical data collection methods, and a constrained timeframe. These challenges prompted a shift in focus towards investigating the factors behind rural productive land use change in Canterbury, and less focus on the original brief of mapping actual change in land use such as sheep, beef or dairying.

As a farming nation, New Zealand's agricultural sector is the backbone of its economy and plays a crucial role in ensuring food security. The loss of farmland due to urbanization poses a significant threat to this vital industry. Preserving agricultural land is not only about safeguarding the livelihoods of farmers, but also about maintaining the country's ability to produce food for its population and contribute to global markets.

3. Literature Review

The following section delves into the four sub-themes that we have hypothesised to be drivers of rural productive land use change in Canterbury, in addition to mapping methodology. This review provided us with a necessary knowledge base, and identified gaps in current research to potentially be further explored throughout the project.

3.1 Socio-economic Factors

Socio-economic factors are influential in the way people interact with land, defining land use. These influences of land use change include profitability, with land being allocated to the most profitable use (Ustaoglu & Williams, 2017), population growth, and more. A higher income will influence people to keep using land the way it has been used, whereas a decline in profit will influence people to change land usage. This is evident in the boom of Canterbury's dairy industry, where from 1980 to 2014 the milk output of the region increased from 2% to 19% of New Zealand's total (Pangborn et al., 2015). This was a result of current land use not generating enough profit; therefore, land use was changed to a more financially viable option. Additionally, social factors such as population growth and migration are key influencers of land use change as urban centres continue to grow, this can encroach onto rural land, often leading to urban sprawl (Handavu et al., 2019).

3.2 Urban Expansion

Urban sprawl is transforming the Canterbury region, with communities such as West Melton experiencing a 167% increase in residents from 2013 to 2018 (Stats NZ, 2018). This increase is mirrored across once small farming towns such as Rolleston, Lincoln, and Darfield. The draw of these communities lies in their accessibility, as improved transportation networks make commuting from rural areas to cities more convenient. A Maryland study showed that highway construction was a key factor in growth (Heimlich et al., 2001). There is a growing desire for lifestyle blocks, offering individuals the freedom of a sizeable piece of land within commuting distance of urban centres. Affordability plays a pivotal role, with housing costs in urban centres often being more expensive than those in surrounding rural areas. This results in individuals seeking more budget-friendly options in nearby suburbs out of town such as West Melton. This increase in population leads to the conversion of rural productive farmland into urban developments.

3.3 Precipitation Trends

Changes in precipitation regimes can have a large influence on the suitability and profitability of many rural productive land use decisions. Statistically significant seasonal precipitation trends have been identified in Canterbury, with widespread negative trending in the summer, autumn and spring months, and some more localised positive trends over winter months (Caloiero, 2015). One process driving this change is a projected regional increase in rainfall-suppressing anticyclonic conditions, and a decrease in the conversely rainfall-promoting cyclonic conditions, with these shifts becoming more pronounced by the end of this century (Gibson et al., 2016). In addition to this, the positive phase of the Southern Annular Mode climate variable has become more common over recent decades, partly through increased atmospheric carbon dioxide (King et al., 2023). This phase produces easterly airflow anomalies which resist rain-bearing fronts approaching from the west of New Zealand, leading to drier conditions (Ummenhofer et al., 2009). As a consequence of these findings, the Canterbury Plains are predicted to be the most vulnerable region to increasing drought, spending 10% more time in drought conditions by 2050 under the most likely moderate emission scenario, with this value rising in the second half of the century (Clark et al., 2011).

3.4 Extreme Weather Events

Extreme weather events such as floods and droughts can be key drivers of land use change. Droughts can reduce the productivity of land by decreasing forage growth, which in turn can change the way land is used. Research by Wakelin et al. (2018) suggests that droughts occurring in 2007 and 2008 cost the New Zealand economy $2.7 billion, as they reduced earnings for primary industries. Along with reducing plant growth, droughts can result in the reduction of stock numbers on farms, in turn reducing the economic productivity of land (Pourzand et al., 2020). This can influence agriculture professionals to change the way the land is used. Like droughts, flooding can also impact land use change by reducing the productivity of rural land. This threatens food security and agriculture production, which can influence ways in which rural land is used (Blanc & Noy, 2023).

3.5 Mapping Methodology

Mapping rural land is a substantial and time-intensive task. To meet our project's schedule, we explored various remote sensing methods for land cover analysis. Among these methods, we found several that hinged on a common approach, leveraging the Normalized Difference Vegetation Index (NDVI) to extract valuable insights. NDVI, primarily used for assessing plant health through multispectral imagery, can also serve as a tool for land cover classification. Different surfaces reflect light in distinct wavelengths, and sensors measure the light's quantity in each. NDVI calculates a value within the range of -1 to 1 for each pixel in the image, based on light reflection in the near-infrared (NIR) and red bands. We deemed this method particularly beneficial, especially in the context of rural productive land, which is predominantly utilized for agriculture in the mid-Canterbury Plains. Its utility lies in its ability to discern and quantify land cover types. Several journals utilise NDVI to derive land cover classification, such as Johnson et al. (2016) and Tehrany et al. (2014). One concern with this method is its poor ability to differentiate urban land cover from dry/stressed vegetation. However, the effect of this on our results was minimal, due to the low population numbers in the townships which inhabit the mid Canterbury plains.

4. Methodology

4.1 Three-fold Approach

Due to the complex nature of our task, and our want to comprehensively answer the research question, our methodology took a threefold approach. We aimed to utilize official organisational data to gain insight into broad picture numbers, such as the total land area used for dairy farming in Canterbury, whilst also obtaining expert and local opinions into the drivers of rural productive land use change, and a land use map of the mid-Canterbury Plains. Data collection was straightforward, with the primary obstacle being locating and identifying publicly available data sources from various organizations, such as Stats NZ, Landcare research, and the Ministry of Primary Industries.

4.2 Questionnaire

Gaining a comprehensive understanding of the factors driving rural land use change requires first-hand insights and expert opinions. To achieve this, we developed a questionnaire for farmers and industry professionals. Below is a sample of two main questions:

- To your knowledge, what is the one key factor that drives land use change in the Canterbury region?
- To what extent do you think these factors play in land use changes within Canterbury: socio-economic, extreme weather events, precipitation trends, urban sprawl, and migration?

4.3 GIS Mapping

The process of creating the map involved multiple software, accessing Application Programming Interfaces (APIs) and performing land use classification. The key idea behind the methodology was to use satellites images of mid-Canterbury, calculate the NDVI of the area, and then classify land cover based on the resulting values. The satellite images were sourced from the Landsat satellite, which holds a catalogue of multispectral images of New Zealand dating back to 1982.

4.3.1 Sourcing Landsat Images

The Google Earth Engine library was used in Python to query the collection of Landsat images of the Canterbury plains, filtering to minimize cloud cover. The timeframe images were collected from was late November to early December. It was crucial to ensure that the satellite images were from similar or equal timespans to avoid seasonal disparity. These months were chosen as healthy vegetation cover would be more prominent, to minimize the amount of dry land that may be confused for urban land. The image had to be split into several smaller subsections due to restrictions on export sizes. We utilized images from 1999, 2010, and 2021 - although an exact decade gap would have been preferable, it could not be achieved due to significant cloud cover.

4.3.2 Remerge Tiles and NDVI

The subsets of the satellite images were initially remerged using ArcGIS. After remerging, the images were subsequently exported into ENVI. From there, the NDVI values were calculated for all the images. This involved the NIR and red bands, from the respective satellite data: $NDVI = (NIR - Red)/(NIR + Red)$. Following NDVI computation, the resulting datasets were re-exported into ArcGIS for further analysis and visualization.

4.3.3 Image Classification

Utilising the Image Classification tool within ArcGIS, every pixel across all three of the satellite images was then classified based off of their resulting NDVI values, as described in Table 1. Creating several distinct classes allowed us to gain a better understanding of the underlying land cover.

Table 1: Classification table with values between the bounds changed into new values with the real-world land cover.

Lower Bound	Upper Bound	Class Value	Classification
error	error	-128	To be ignored
-1	0	0	Rock
0.001	0.14	1	Other
0.15	0.27	2	No Data
0.28	0.20	3	Water
0.21	0.36	4	Dry Field
0.37	1	5	Irrigated field

4.4 Weather Analysis Methodology

In an effort to gain further understanding of the potential environmental factors influencing rural land use decision-making, we also examined precipitation and temperature data for the region in and around our mapping study area. Particular emphasis was placed on the seasonal timescale as farm management decisions such as crop rotation often align with these, comparing the distributions of average values between the late 20th and early 21st centuries to highlight any change in seasonal tendencies. Monthly total rainfall (mm) and mean air temperature (degrees Celsius) weather station data was sourced from the NIWA National Climate Database. Selected stations were both situated within a 40km radius of the approximate centroid of our mapping study area, and contained a record from 1970 (1980 for temperature due to scarce data availability) to 2020. 17 stations with rainfall data fit these requirements (see Figure 1 for locations), whereas only 5 with temperature data were available, presenting a considerable limitation. Within Microsoft Excel, data was sorted into monthly averages across the 40-year study period before being further converted to seasonal averages for visualisation. Some data gaps were present in the raw weather station data, but at a frequency low enough to be deemed negligible in the context of this limited analysis, as such, the decision was made to leave these blank.

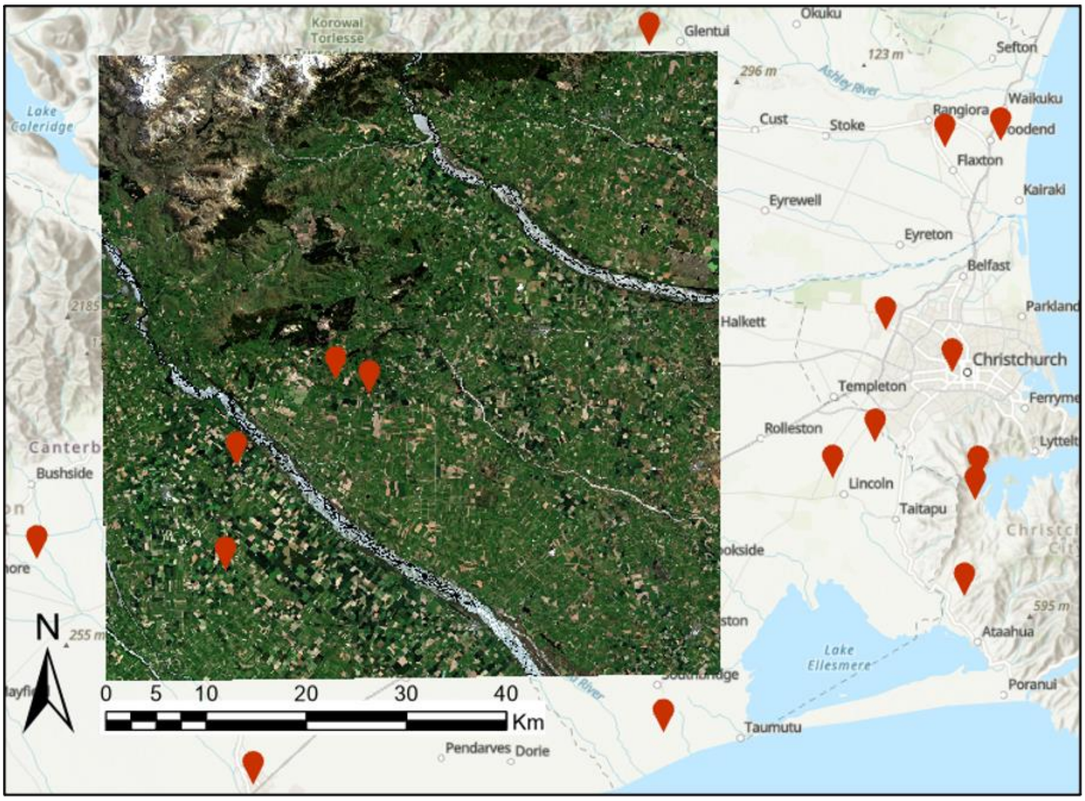

Figure 1: Locations of weather stations (red markers) from which monthly total rainfall data was sourced, in relation to the mapping study area (covered by Landsat satellite imagery).

5. Results and Discussion

5.1 Questionnaire Results

The most consistent response to our questionnaire for farmers and industry professionals was that economics had the biggest impact on land use decisions within their businesses and industries. For instance, a respondent stated:

- "From my perspective, the key driver appears to be economics."

Another respondent also emphasized the significance of economics in land use change, stating:

- "Profits are a key driver when deciding on rural land use."

Whilst the consensus was that economic considerations largely guided decisions surrounding rural land use in Canterbury, numerous respondents also indicated that our other three hypothesised factors played some minor role.

5.2 Statistics

5.2.1 Urban Land Cover

As shown in Figure 2, urban land cover in the Canterbury region has increased from 2002 to 2019. During the available data period, urban area expanded by 30,264 hectares, of which 25,248 hectares of exotic grassland was converted to urban area, whilst 2,602 hectares of cropland was converted (Stats NZ, 2021a). One of the main drivers in the increase of urban land cover in the Canterbury region is urbanization. Data from 2019 suggests the greater Christchurch population stood at 516,800 people and is expected to increase by 1.7% annually (Canterbury Wellbeing Index, n.d.). The Selwyn District Council (2023) suggests that several areas have and are continuing to experience significant increases in population, including Rolleston, Lincoln, and Darfield. Many of these areas have large amounts of highly productive rural land. The Ministry for The Environment & Stats NZ (2021) suggests that future urban expansion is to move outward from urban areas, making these areas more at risk of future land use change.

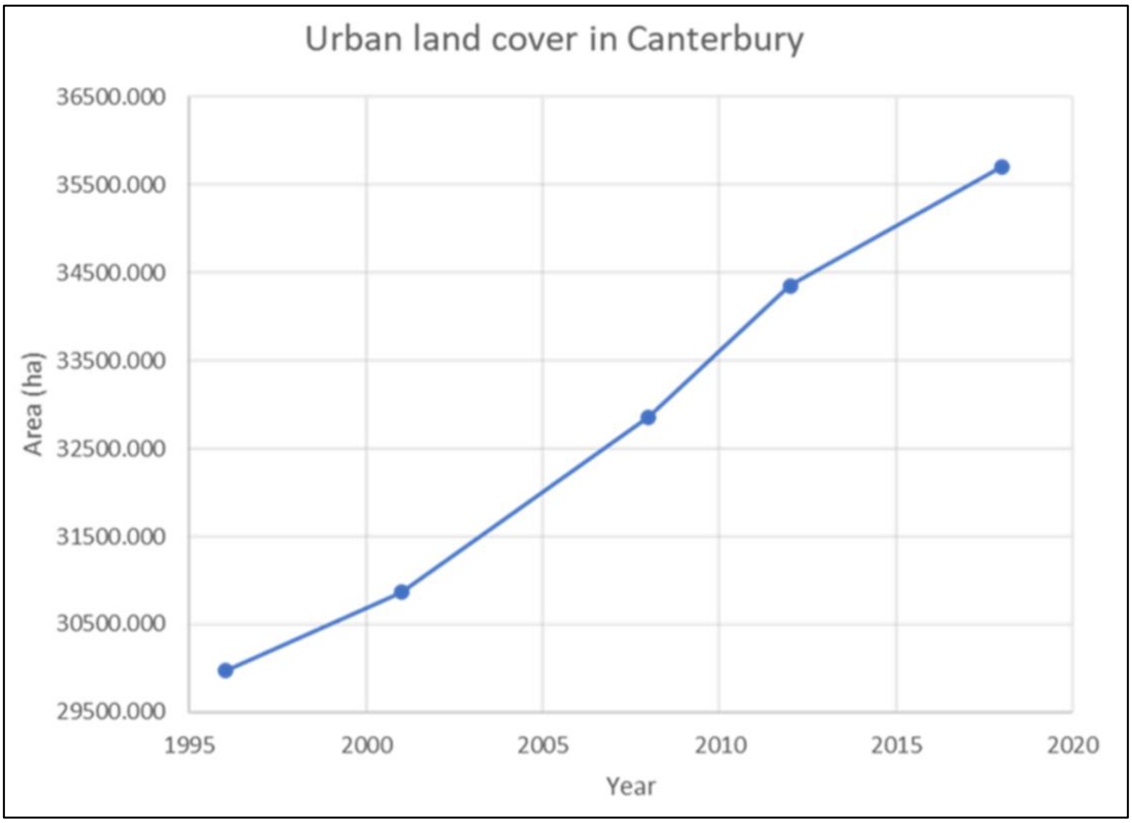

Figure 2: Canterbury urban land cover (2002-2019), exhibiting positive trend (Stats NZ, 2021a).

5.2.2 Farm Count and Size

Data derived from Stats NZ (2021b) show that between 2002 and 2019 the total area of farmland in Canterbury decreased from 3,150,891 hectares to 2,575,684 (by 18.3%). Coinciding with farm size decreasing, the total number of farms in the Canterbury region has also decreased from 10,185 farms to 7,161 (by 29.7%) between 2002 and 2019 (Figure 2) (Stats NZ, 2021b). Changes to farm size and counts can have implications for surrounding environments and communities. Decreasing farm size can result in agriculture intensification, which can then lead to contamination of water resources due to higher levels of agriculture activity on smaller parcels of land. Joy et al. (2022) suggests intensification of agriculture in the Canterbury region began in the 1990's which witnessed low intensity cropping and sheep switch rapidly to highly intensive dairying (Figure 3).

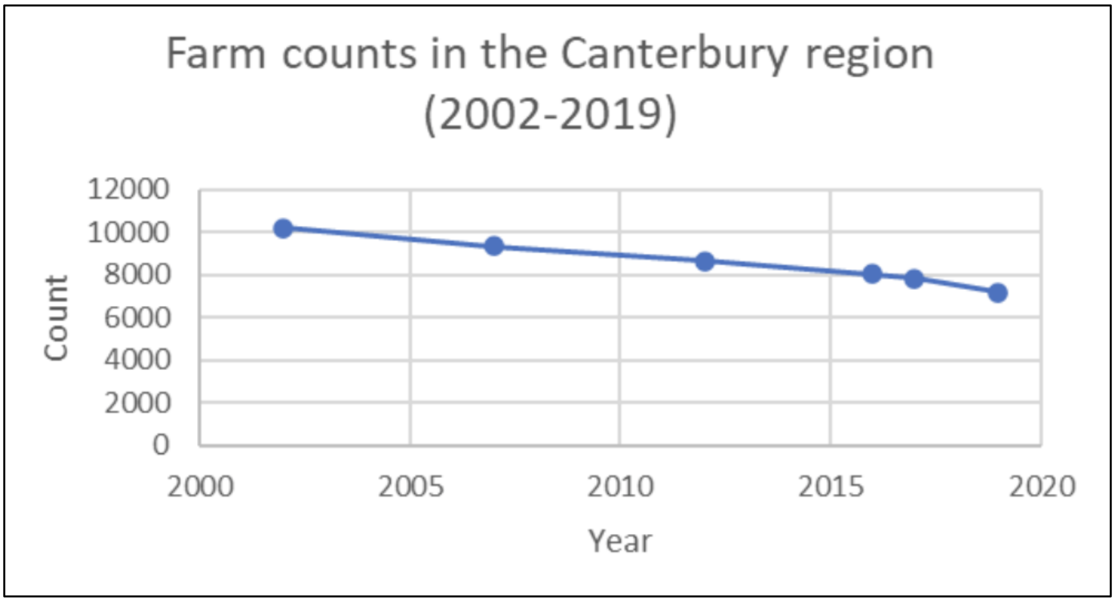

Figure 2: Farm counts in the Canterbury region (2002-2019), exhibiting decreasing trend (Stats NZ, 2021b).

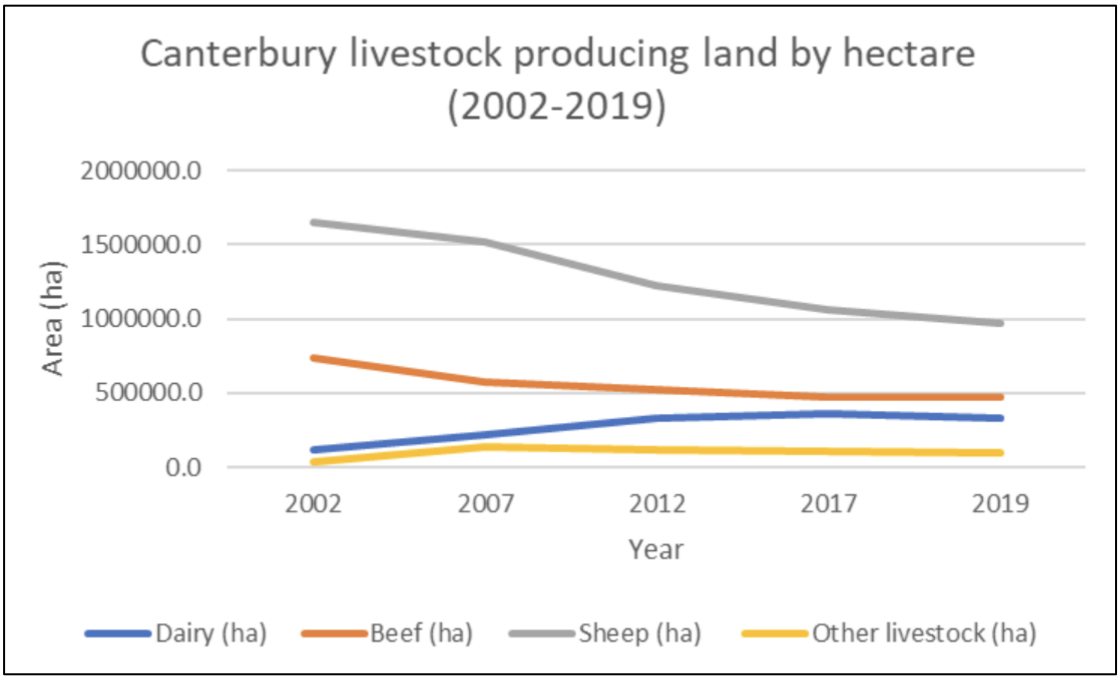

Figure 3: Different types of livestock producing land in the Canterbury region by hectare (2002-2019; Stats NZ, 2021c).

5.2.3 Livestock and Horticulture Land Use

Figure 3 shows livestock land use change in the Canterbury region from 2002 to 2019 - over this available data period, Canterbury had the biggest decline for livestock land use across New Zealand. According to Stats NZ (2021c), sheep farming declined by 683,000 hectares and beef farming declined by 256,000 hectares. In contrast to these considerable declines, dairy land use increased by 213,000 hectares over the same period (Stats NZ, 2021c). Our research suggests that there are several reasons for changes in livestock land use in the Canterbury region. These can include urbanisation, a conversion from sheep and beef to dairy, or a conversion to forestry to earn carbon credits (Figure 4). Brown and Mortimer (2014) suggest that dairying displaced sheep and beef as the dominant agricultural land use in the region as high demand from foreign markets made the dairy sector more profitable. Coinciding with dairy becoming a more profitable land use, reductions in sheep and beef farming can be accredited to several other factors. Brown and Mortimer (2014) further suggest that falling wool prices and droughts are key contributors to the decline in sheep numbers. Additionally, Beef + Lamb New Zealand (2017) indicate that the increase in dairy cow numbers have supplemented the need for beef cows as the dairy industry provides 24% of slaughter cattle.

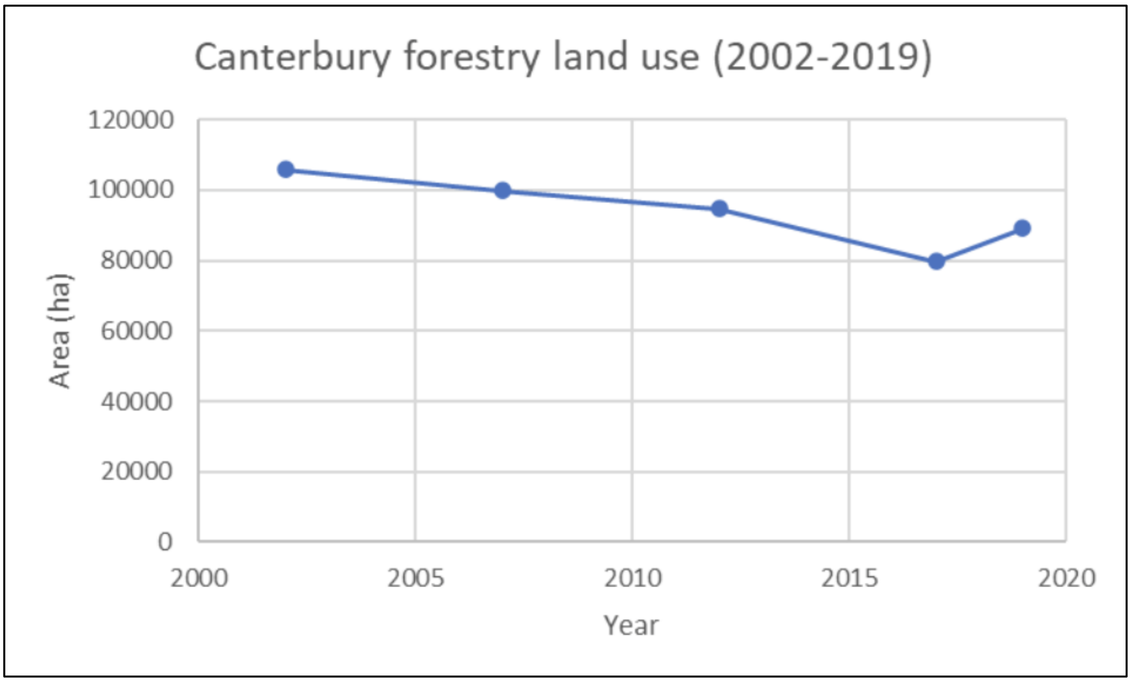

Figure 4: Changes in Canterbury land use for forestry (2002-2019; Stats NZ, 2021d).

Figure 5 shows horticulture land use in the Canterbury region over the period from 2002-2019. The available data suggests that horticulture land use in Canterbury has stayed relatively similar with slight increases over the data period. Horticulture is a popular use of land in the Canterbury region due to high levels of fertile soils and preferable climate conditions (Environment Canterbury, n.d.). However, a growing population may increase the amount of land needed for horticulture.

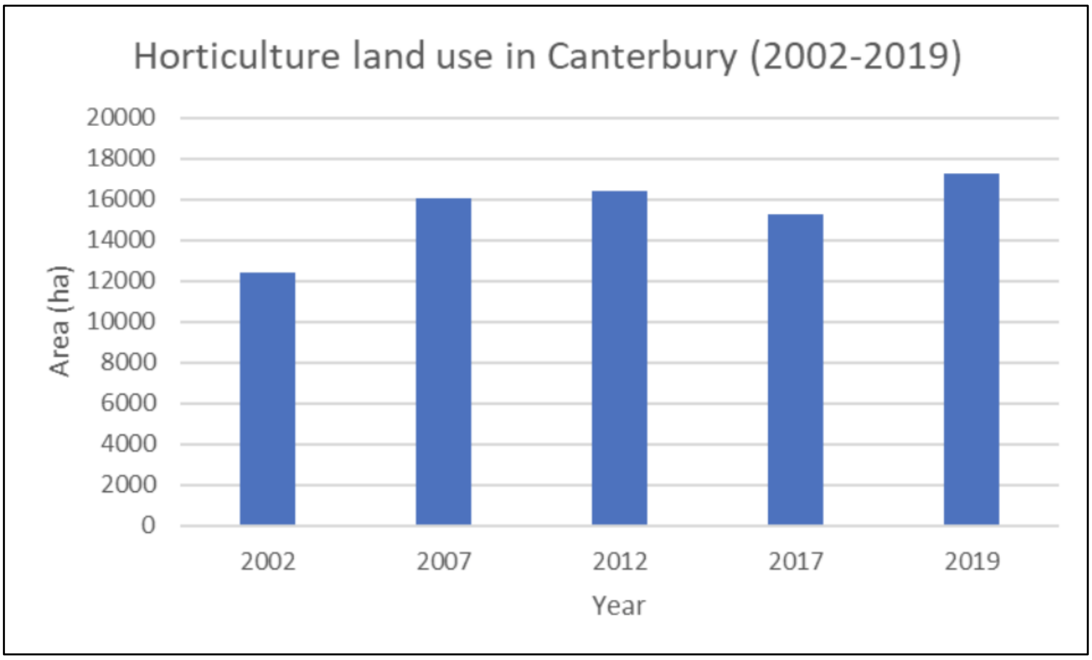

Figure 5: Horticulture land use in Canterbury in increments (2002-2019; Stats NZ, 2021d).

5.3 GIS Results

Prior to the discussion of GIS results, it is noteworthy that the 2010 results are heavily influenced by a major drought that hit the region during that summer, with an abundance of dry fields. An additional issue found was a form of sensor error in the same image, which saw some values erroneously measured. Both notes can be observed in Figure 7.

Smaller changes are often noticeable in the distribution of dry or stressed fields, constituting a significant portion of the visual alterations across the images (Figures 6, 7 and 8). However, these changes in distribution may not offer substantial insights into underlying land use patterns. Such alterations in the number or prevalence of dry fields are frequently attributed to individual farmer practices. These are not indicative of any consistent land use trends unless, for example, they result from an extreme weather event, as exemplified by the 2010 drought. While identifying significant changes in land use can be challenging through satellite images and NDVI classifications, subtle transformations are still observable. Over time, numerous small farming communities in the mid-Canterbury plains have expanded. Commercial forestry activities have emerged in the foothills, with fields extending further up the hills. These observations suggest that economic activity in the mid-Canterbury region is thriving, expanding, or adapting to meet evolving demands.

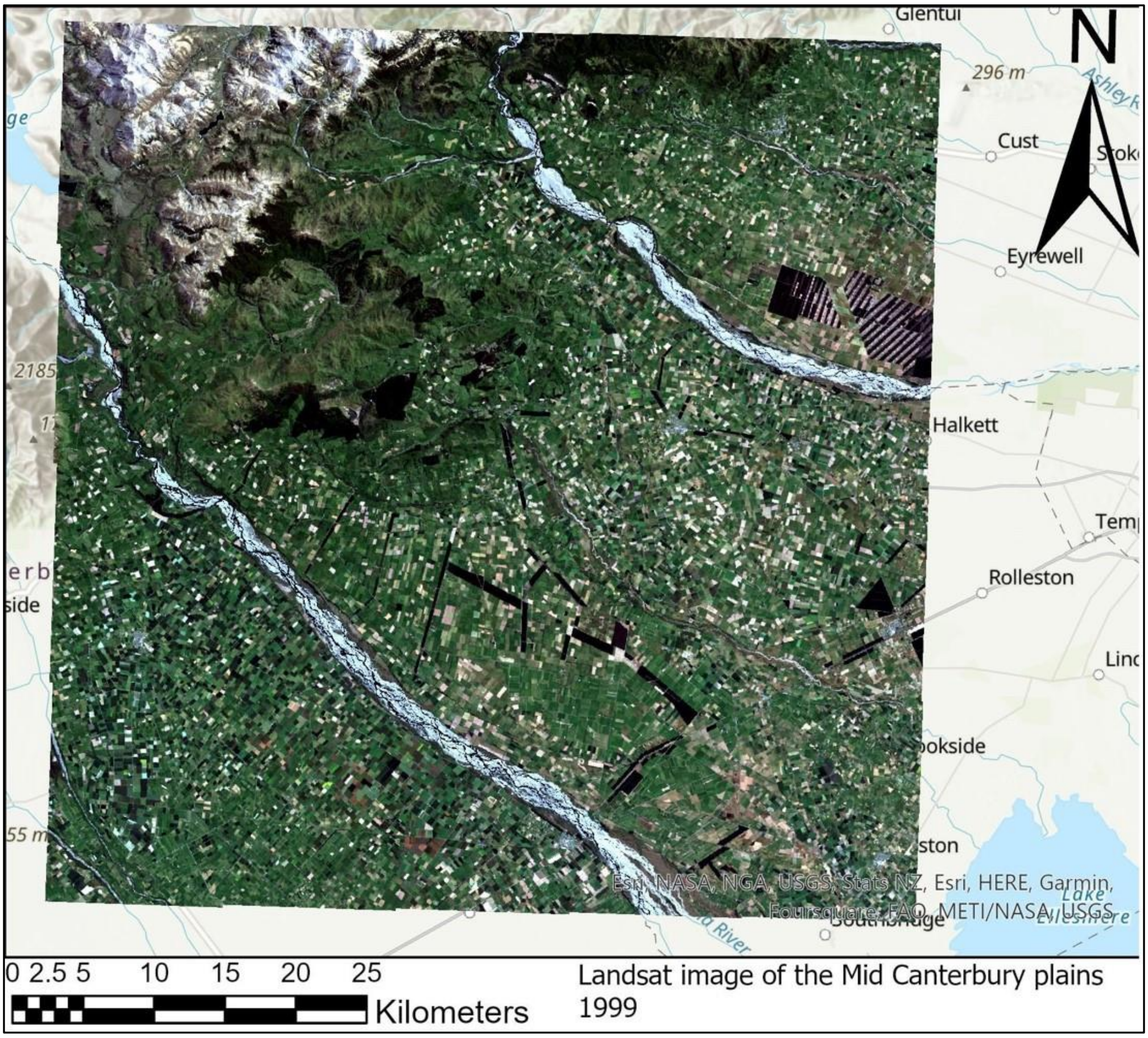

Figure 6: Landsat-7 satellite image of mid-Canterbury Plains, December 1999, for visual comparison purposes.

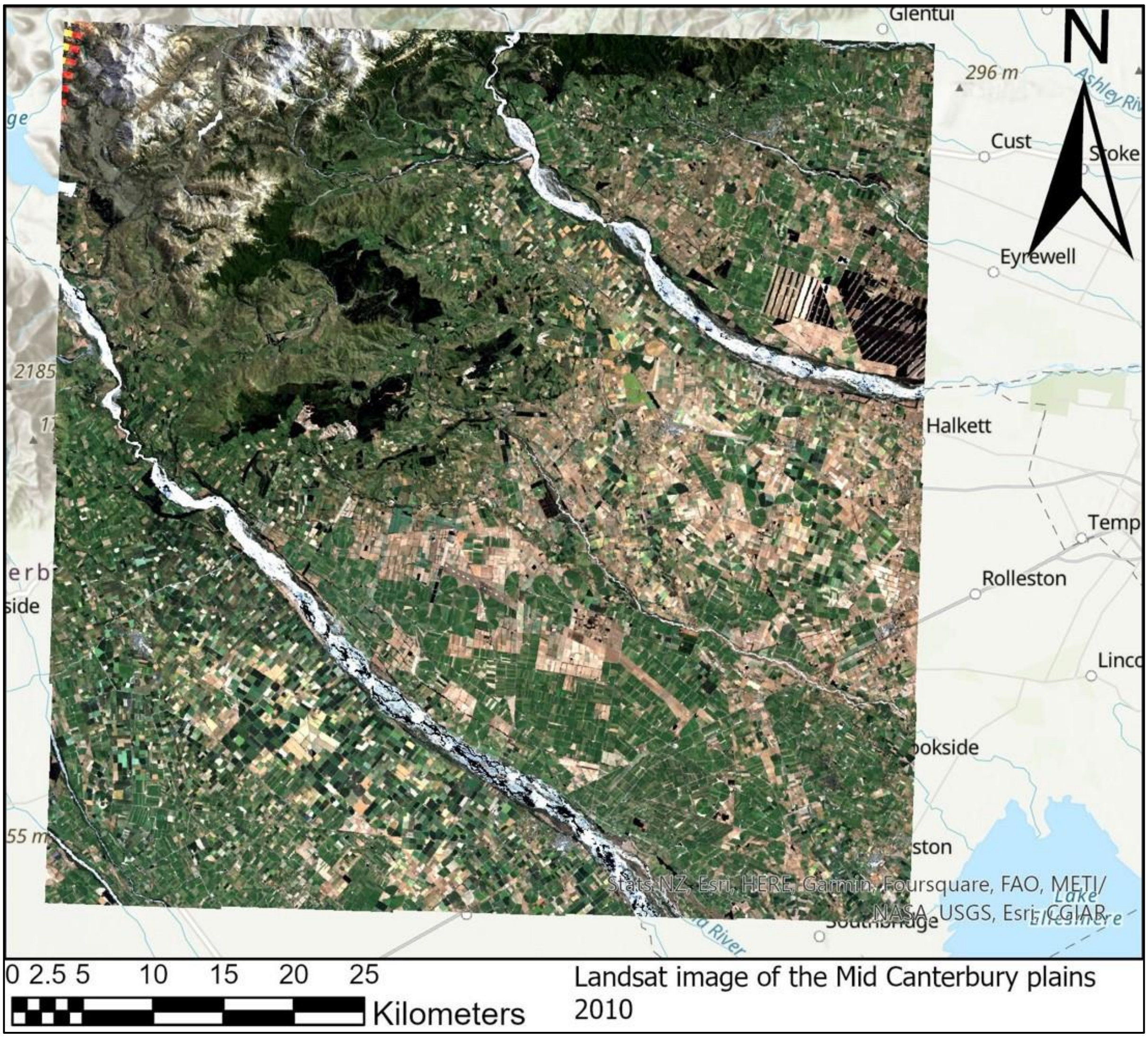

Figure 7: Landsat-7 satellite image of mid-Canterbury Plains, December 2010. Note the sensor error (yellow and red, top left).

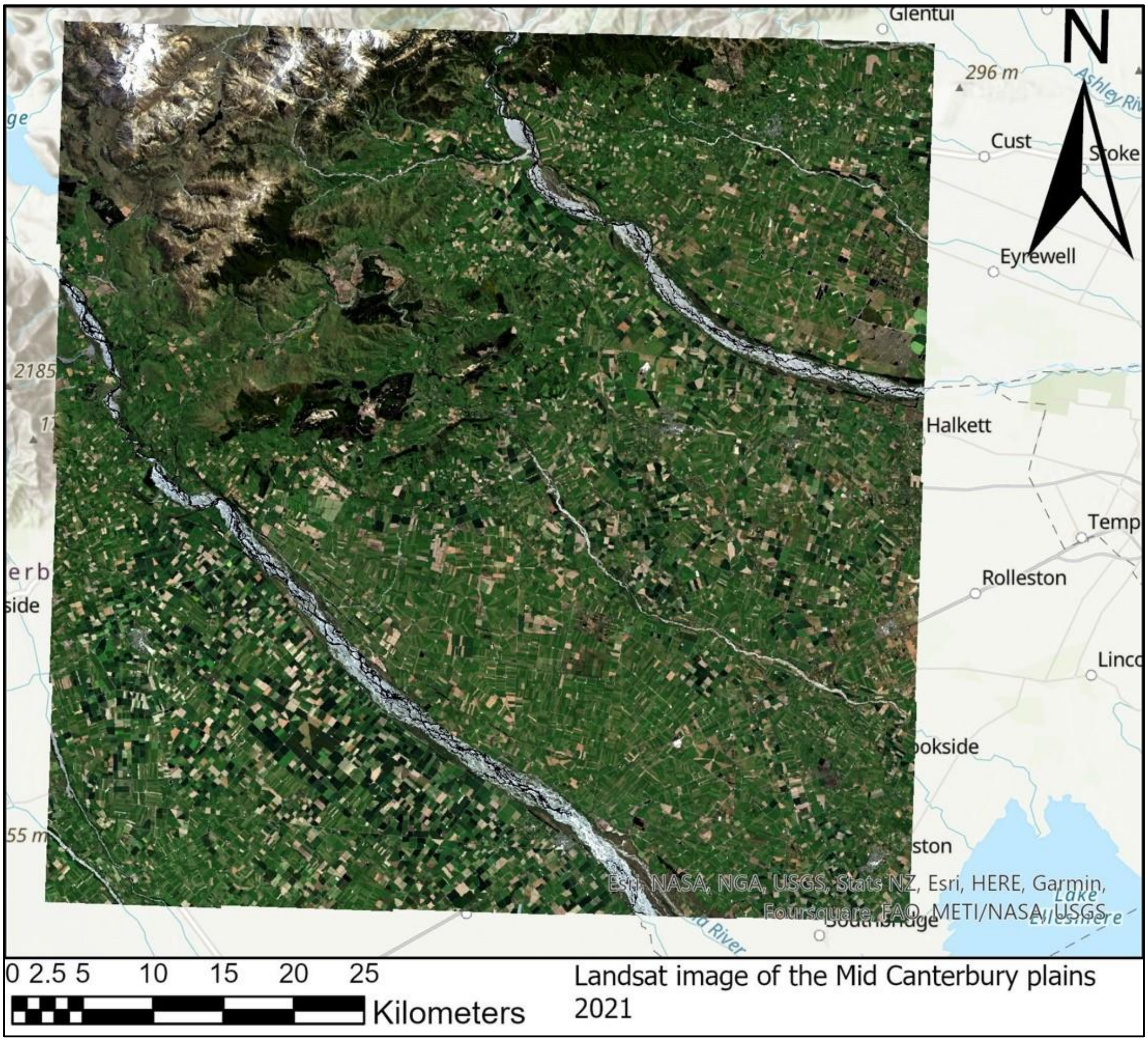

Figure 8: Landsat-8 image of the mid-Canterbury Plains, November 2021.

Comparing classification results across all three timeframes (Figures 9, 10, 11, 12, 13 and 14), with each pixel representing roughly 400 meters squared and considering the class guide (Table 2), we can observe minimal change between 1999 and 2021. As expected, a large jump in classes 3 and 4, which represent water and dry fields, can be observed in 2010. Yet, as many dry field pixels have been misclassified as water, the significant jump in the number of dry fields is not entirely represented in the graph. If we observe only class 4, it can be seen that the amount of dry field pixels increased by 500% in 2010.

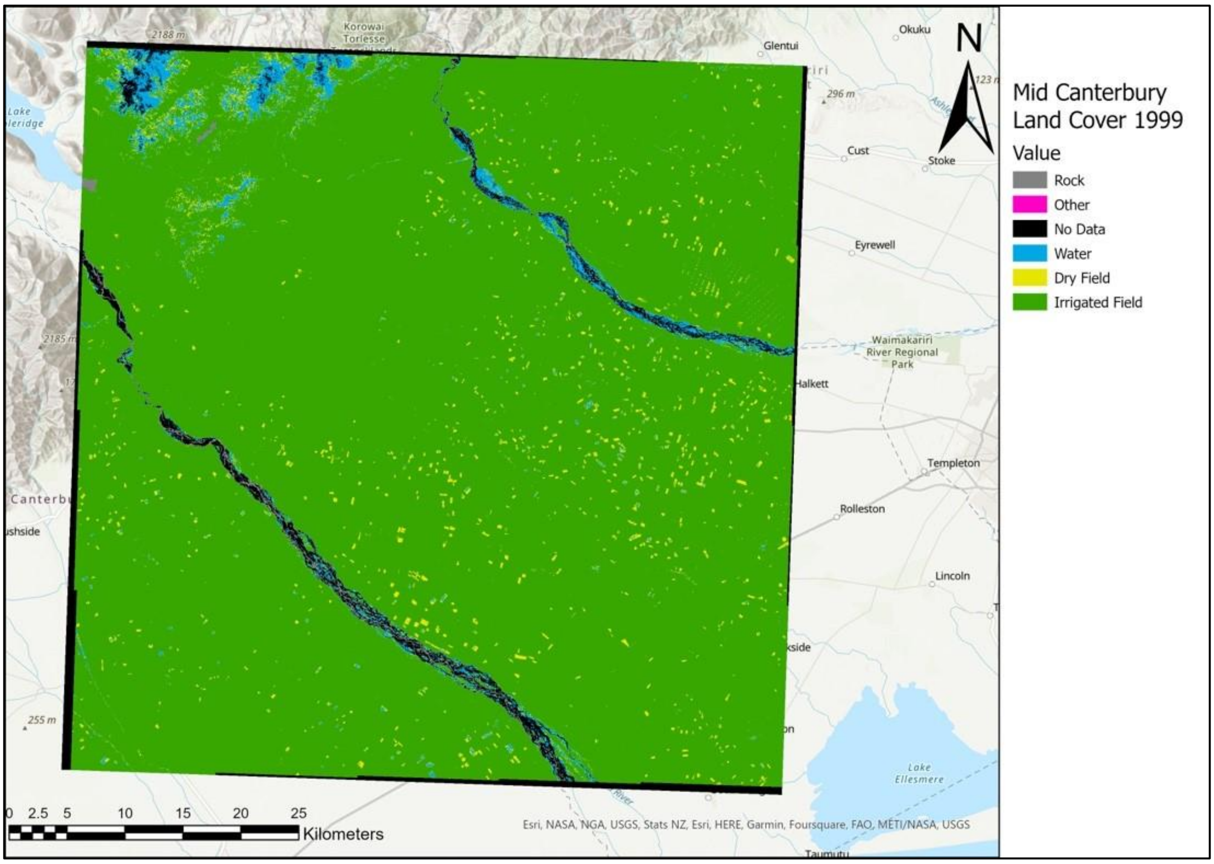

Figure 9: NDVI land cover classification map of mid-Canterbury Plains, December 1999.

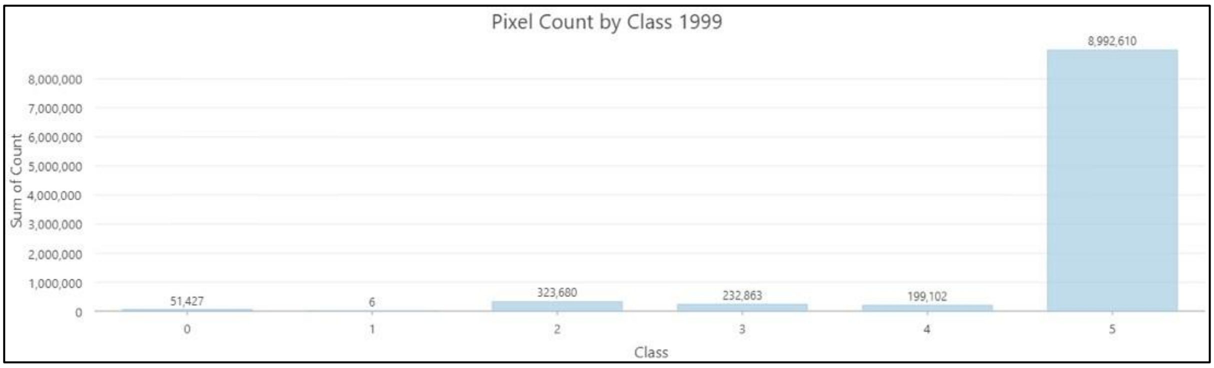

Figure 10: Bar graph depicting the distribution of pixels in set classes, from NDVI classification of 1999 mid-Canterbury Plains. Refer to Figure 9 for the conversion of classes into real-world land cover.

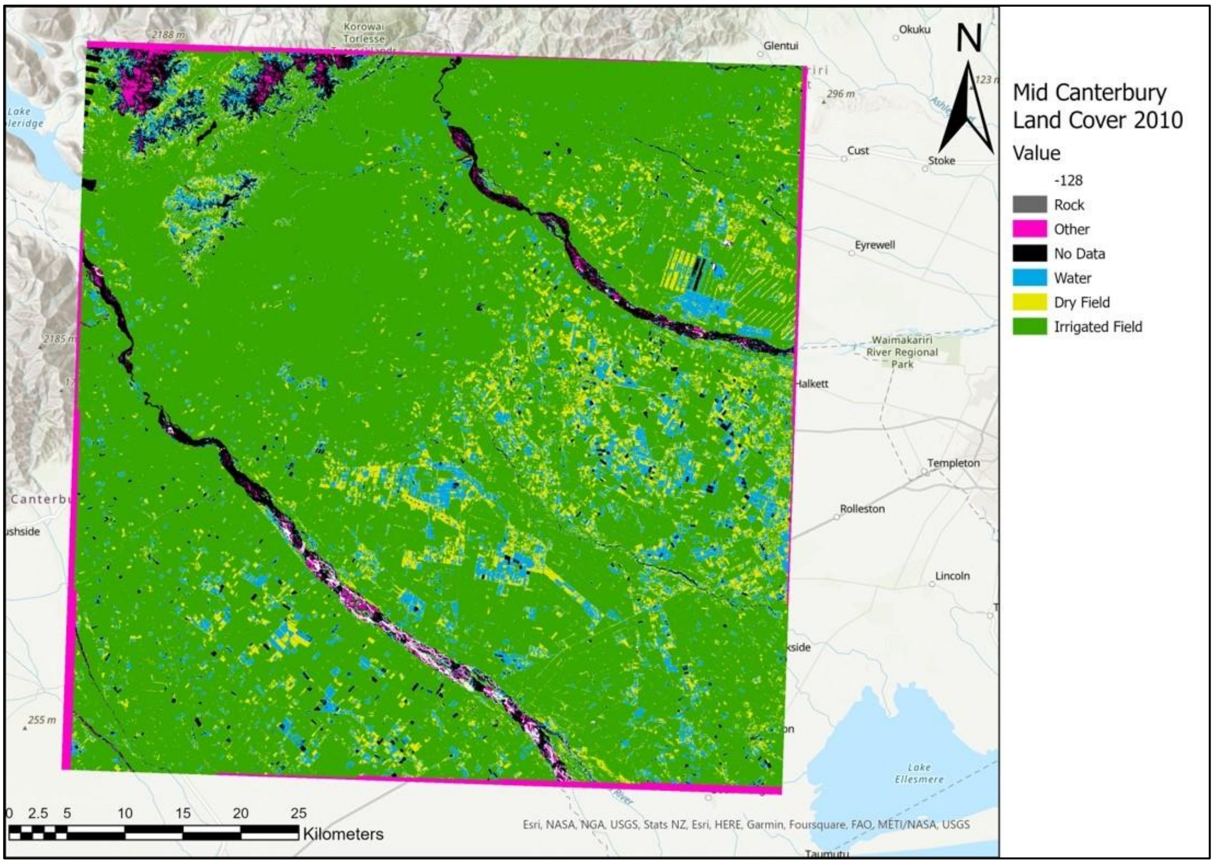

Figure 11: NDVI land cover classification map of mid-Canterbury Plains, December 2010.

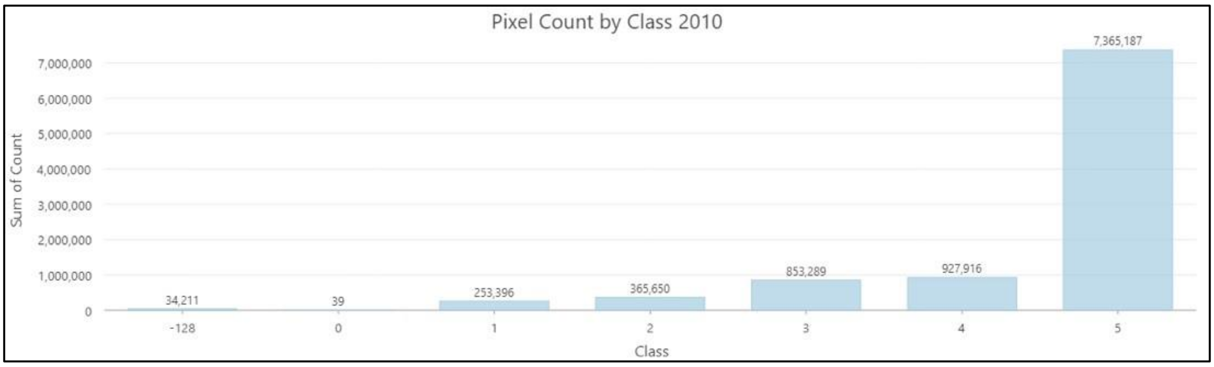

Figure 12: Bar graph depicting the distribution of pixels in set classes, from NDVI classification of 2010 mid-Canterbury Plains. Refer to Figure 11 for the conversion of classes into real-world land cover.

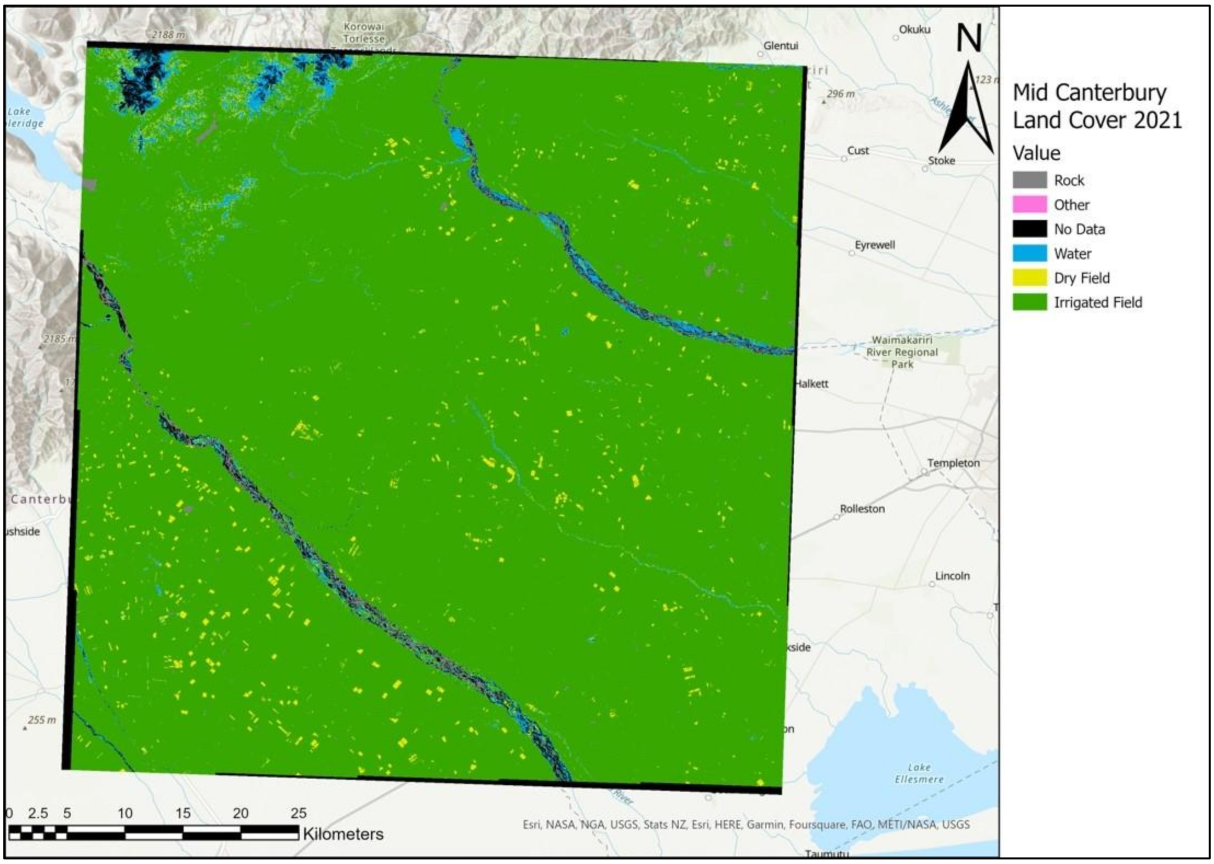

Figure 13: NDVI land cover classification map of mid-Canterbury Plains, November 2021.

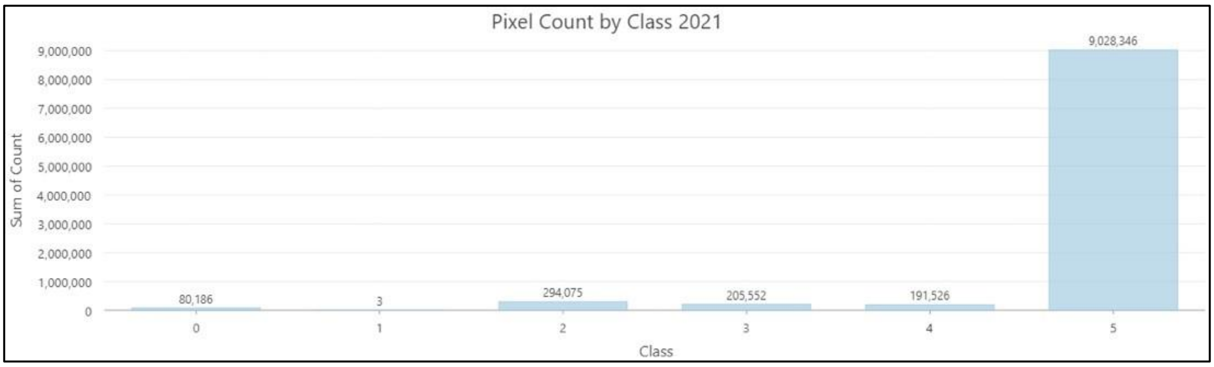

Figure 14: Bar graph depicting the distribution of pixels in set classes, from NDVI classification of 2021 mid-Canterbury Plains. Refer to Figure 13 for the conversion of classes into real-world land cover.

Table 2: Classification table for the translated pixel classification into real-world land cover.

Class Value	Classification
-128	To be ignored
0	Rock
1	Other
2	No Data
3	Water
4	Dry Field
5	Irrigated field

5.4 Weather Analysis Findings

Firstly, a plot of average annual rainfall values across our study area over the last five decades shows an overall decreasing trend consistent with studied literature (Figure 15). It is noteworthy, however, that significant fluctuations of relatively high and low precipitation can be observed between the years, an unsurprising feature given the numerous interrelated climate variables affecting New Zealand (such as El Niño-Southern Oscillation). Concentrating on the evolution of seasonal average rainfall distributions between the late 20th and early 21st centuries, whilst little change was observed in autumn and spring months, Figure 16 reveals an interesting shift in the summer and winter months. Those seasons post-2000 exhibit a shrinking of their lower quartiles and expansion of their upper quartiles, in addition to decreases in their median values, in comparison with their pre-2000 counterparts. This is indicative of intensification of rainfall events, but drier conditions overall, potentially making for a key consideration in rural land use decisions.

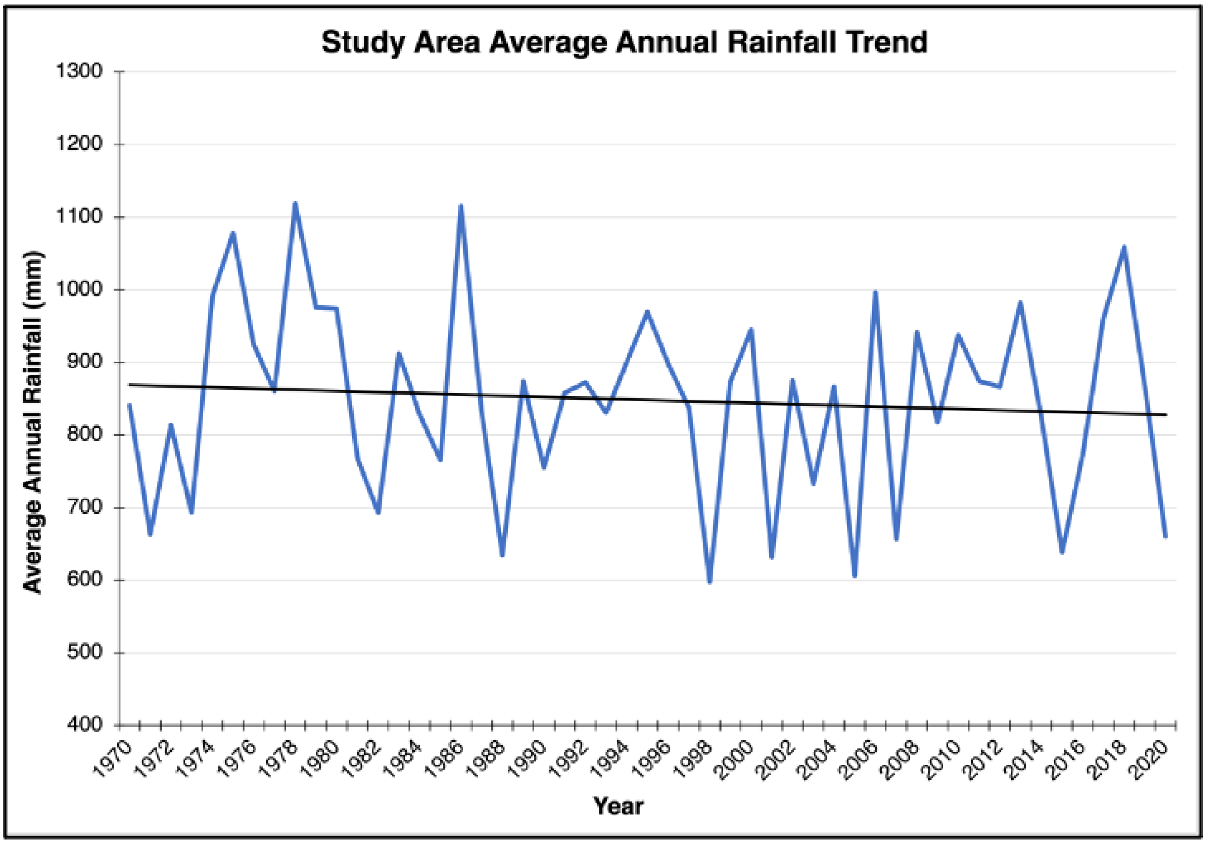

Figure 15: Overall decreasing average annual rainfall trend identified in study area between 1970-2020.

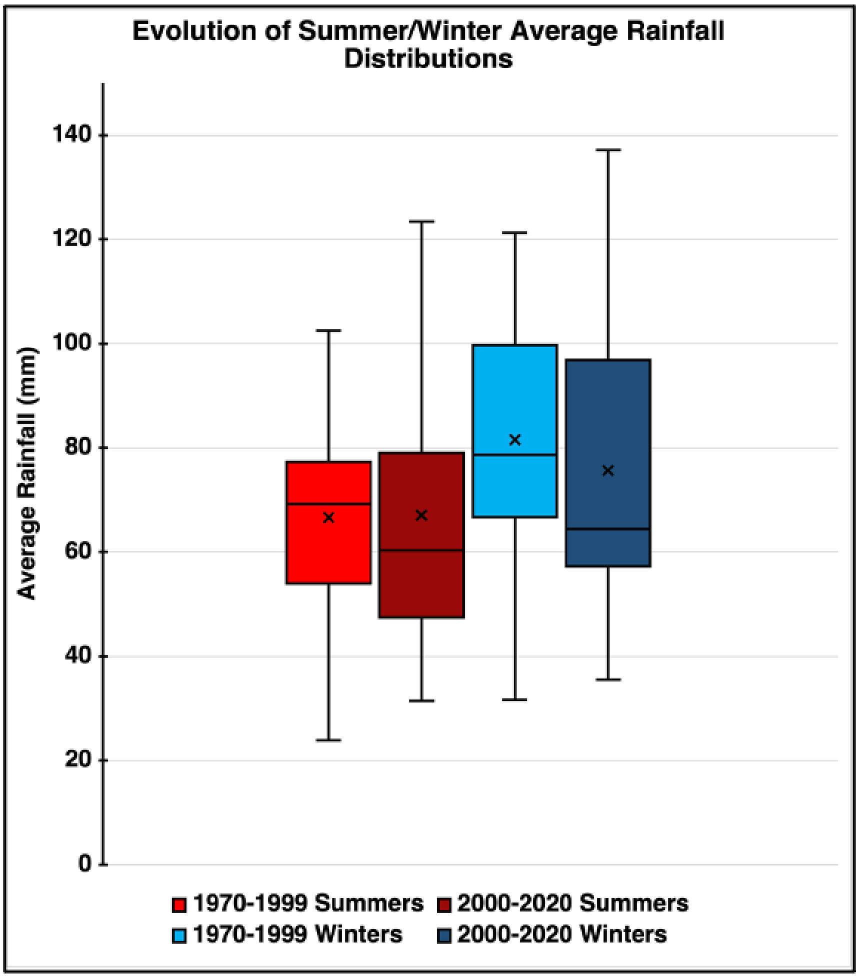

Figure 16: Comparison between late 20th century and early 21st century summer and winter months, exhibiting intensification of rainfall events but overall drier conditions.

As for mean air temperature, slightly increasing trends of a very similar gradient were identified across all four seasons over the previous four decades (Figure 17). There was little temperature separation between the autumn and spring data series (approximately one degree Celsius), whilst the summer and winter series exhibited an approximately ten-degree Celsius difference. Observing the distributions of mean seasonal air temperatures pre and post-2000 (Figure 18), all four seasons experienced a compaction – in other words, a lesser degree of variation in mean air temperatures over the past two decades. This change was found to be most pronounced in the winter and spring months, and less so in autumn months. This may be a welcomed finding for Canterbury farmers, indicating more predictable temperatures at a seasonal scale. However, it is important to reiterate that scarce data availability resulted in limited coverage of mean air temperature data, thus these findings should be interpreted with caution.

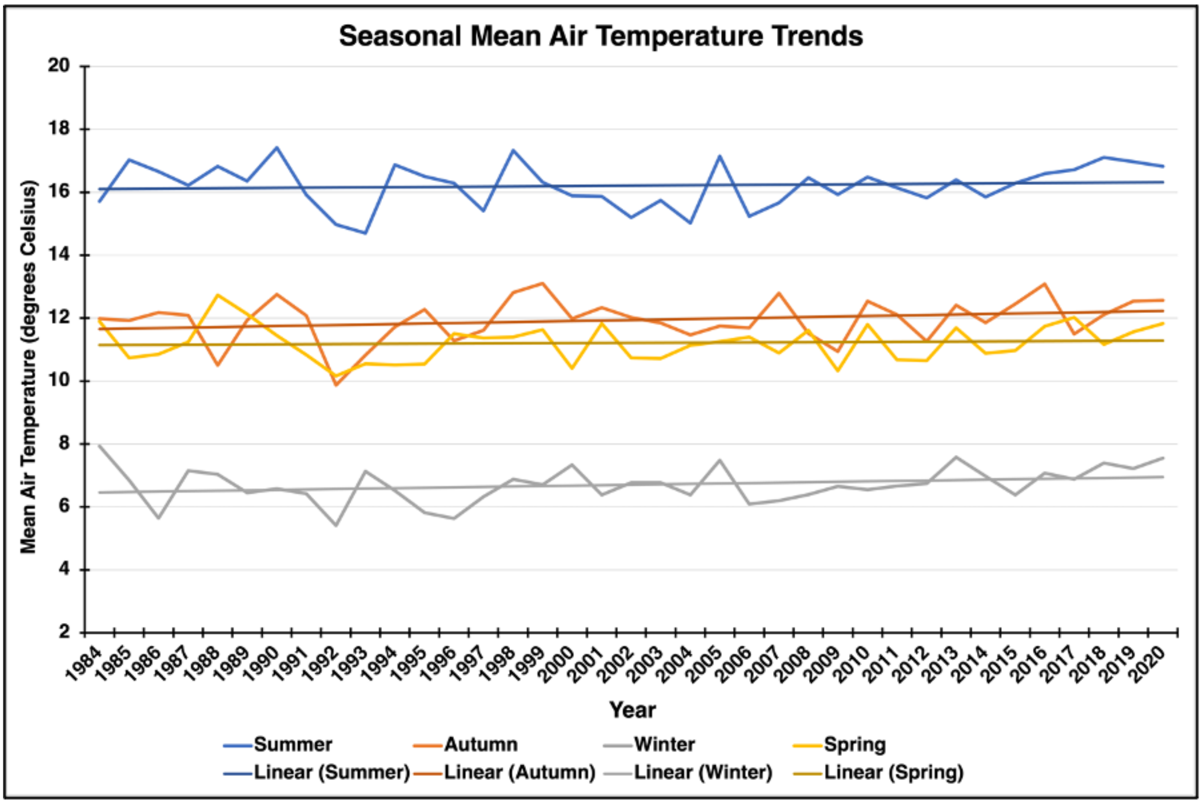

Figure 17: Small increasing trends in mean air temperature of a similar gradient identified across all four seasons in study area between 1980-2020.

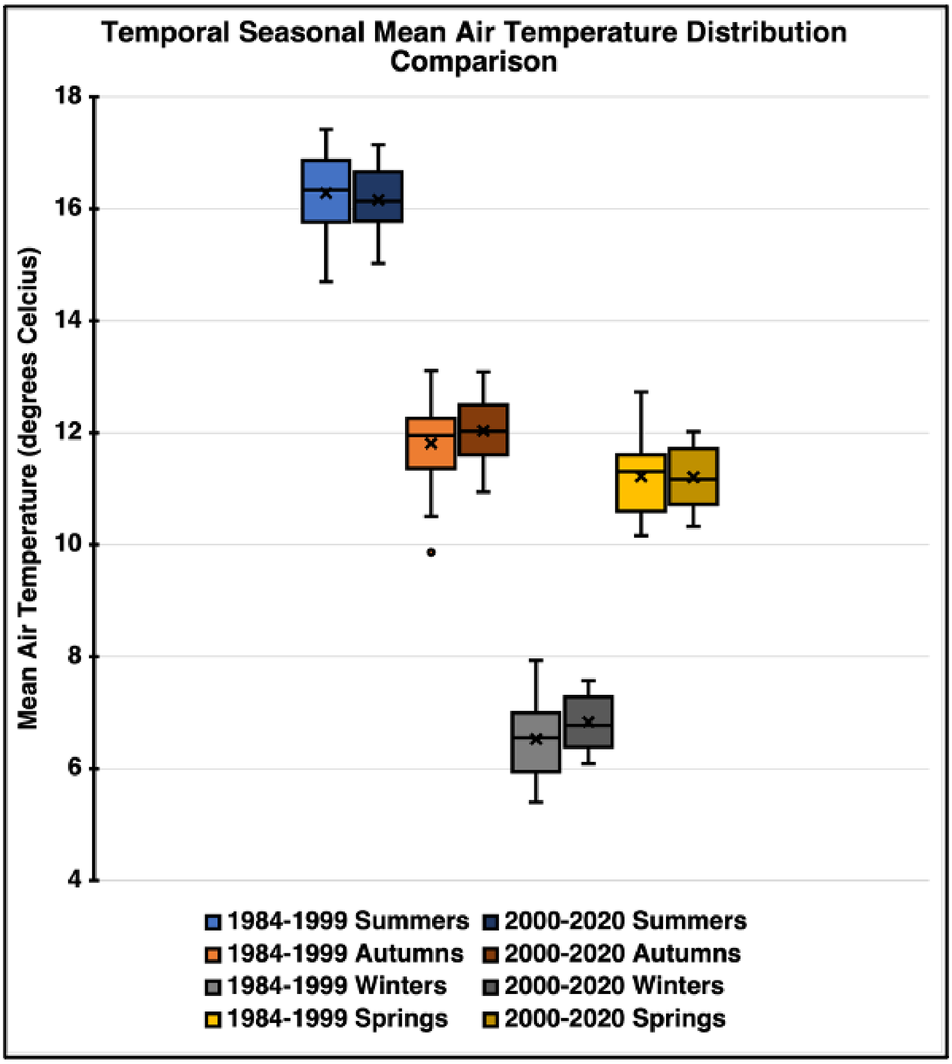

Figure 18: Comparison between late 20th century and early 21st century seasonal mean air temperature distributions in study area, all exhibiting compactions.

6. Limitations

The initial aim and research goals of the project proved to be highly difficult, due to various limitations affecting data, accuracy of GIS analysis, and map outputs. The scope and size of the project was initially too large for our time frame and available resources. We then changed the study area to the Canterbury region, but this still proved to be too great a task, with over 7,000 farms (Stats NZ, 2021b). Instead, we settled for the mid-Canterbury Plains between the Waimakariri and Rakaia rivers. However, as we neared the end of the project, we found that we could not truly represent rural productive land use change in the Canterbury region.

A major limitation of the project was the lack of necessary data. We were able to source statistics from Stats NZ regarding overall agricultural productivity in the Canterbury region, in the absence of the individual farm scale data required for the original project proposal. Another data collection method that we deemed unfeasible was door knocking for surveying. With the number of farms and size of our study area, this method would have taken too long to obtain representative responses and an accurate sample size. The questionnaire we sent to industry professionals, although providing us with useful information, also had limitations. Namely: response time (or lack thereof) and field of the professional.

7. Conclusion

The rural, productive areas of the Canterbury region are constantly changing. Our research shows that the quantity and extent of traditional rural land uses is continuing to decrease every year, while urban land coverage continues to rise. This was most apparent in areas such as West Melton, Darfield, and Rolleston. Initially, we hypothesised several factors that we believed were key drivers in rural land use change, being socio-economic, urban expansion, precipitation trends and extreme weather events. Of these, it is evident from our research that socio-economic is the main driver of rural land use change in Canterbury. Analysis of weather data, namely precipitation and temperature, revealed considerable changes over recent decades that point towards environmental factors also playing a fair role in influencing rural productive land use decisions. GIS methodology allowed us to visualize land cover change across multiple time periods. Although we identified limited changes in land cover, further research could expand upon our findings using higher resolution satellite images among other methods to potentially produce data at an individual farm scale. As this project focused on Canterbury, further research could also look into rural productive land use change on a national scale.

8. Acknowledgements

We wish to acknowledge all those that assisted in our research. We offer our thanks to our community partner Di Lucas for her support and generosity through providing us with maps, our project supervisor Marwan Katurji for his feedback regarding our data collection and methodology, and to all our questionnaire respondents who helped to guide us in the right direction of research and conclusions.

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