Land **2014**, *3*, 239-259; doi:10.3390/land3010239

OPEN ACCESS

land

ISSN 2073-445X

www.mdpi.com/journal/land/

Article

Assessment of Spatial-Temporal Expansion of Built-up and Residential-Commercial Dwellings with Some Economic Implications: A Case Study in the Lower Hunter of Eastern Australia

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Received: 21 November 2013; in revised form: 17 December 2013 / Accepted: 17 February 2014 / Published: 11 March 2014

Abstract: Built-up areas have been expanding throughout the world. Monitoring and prediction of the build-up is not only important for the economic development but also acts as sentinels of environmental decline important for ecologically sustainable development of a region. The aim of this paper is to model the growth of built-up and residential-commercial dwellings over the recent past and thus predict the near future growth for a popular tourist destination of the Lower Hunter of New South Wales, Australia. The land use and land cover change analysis, based on classification of Landsat imageries from 1985 to 2005 at a 5-yearly interval, indicates that built-up areas increased steadily; it was 2.0% of the total landscape in 1985 but increased to 4.2% by the year 2005. If this trend continues, the built-up area will have grown to over 6.5% by 2025—which is equivalent to growth of over 325% from the 1985 base. In order to further evaluate the residential and commercial growth, orthorectified aerial photographs of nearby periods of 1985, 1995 and 2005 were utilized to manually delineate residential/commercial dwellings, and thereby dwelling densities were derived. The results indicate that the mean dwelling density has more than doubled within a decade.

Keywords: dwelling density; economic development; Land use and land cover change; modeling; prediction; multi-resolution validation; null resolution; wine tourism

1. Introduction

By the early 2000s, urban areas occupied only about 2%–3% of the Earth's land surface; however, they sheltered nearly half the world's population [1]. The rapid expansion of urban areas, in the form of built-up or paved-over areas, is dramatically changing the landscape of the urban-rural fringe, clearly highlighting the intensity of the ecological footprints of cities [1–7]. The ecological footprint is defined as "*the total area of productive land and water required continuously to produce all the resources consumed and to assimilate all the wastes produced, by a defined population, wherever on Earth that land is located*" [8,9]. The wealthy quarter of the world's population consume over three-quarters of world's resources, and of the total global resource depletion and pollution, contribution from cities is probably 70% or more [8]. For example, the per capita ecological footprint of North Americans is 4–5 ha/capita, which accounts three times their fair share of the Earth's bounty. Similarly, Japan's footprint is about 2.5 ha/capita and the Netherland's is 3.3 ha/capita, accounting for about eight and 15 times greater than the areas of total domestic territories respectively [8]. Lenzen and Murray [10] found Australia's ecological footprint to be about 13.6 ha/capita, if determined in terms of actual land use on all types of land. These footprints are associated with the provision of non-farm job opportunities, shifts to higher-valued farm enterprises (such as vegetables, fruits, or livestock) to meet the demands of urban consumers. On the other hand, the provision of environmental services and landscape amenities place heavy demands on the ecological system in terms of resource extraction, disposal of waste, and discharge of pollutants [3]. Urbanization is mostly taking up agricultural lands and it is estimated that one to two million hectares of cropland are being taken out of production every year in developing countries to meet the land demand for housing, industry, infrastructure, and recreation [1]. The 20th century witnessed some of the most dramatic urban transformations in the history of Earth's terrestrial environments [11].

In Australia, land use change has accelerated dramatically since the first European settlers arrived in 1788. The initial phase of human-induced development was mainly commercial livestock ranching, which fed the colony's economy through export of beef, mutton, and wool to Europe and North America. Late in the 19th century, the increased market demand for commodities led to large-scale wheat farming. As a consequence, it is estimated that 69% of the vegetation in Victoria and 50% in New South Wales have been modified since 1780s [12]. Another contributing factor to landscape conversion in Australia was the rapid growth in population in the later part of 20th century. The national population was reported to have more than doubled in the last five decades from 9.2 million in 1955 to 20.3 million in 2005 [13] and it is expected to further increase to 35 million by 2050 [14]. This increase has led to rapid growth in urbanization, posing a significant threat to ecosystems on urban fringes, which is home to more than 50% of Australia's nationally listed threatened species [4]. The characterization and understanding of the changing patterns of urban growth is critical, given that urbanization will continue to be one of the major processes to transform the environment in the foreseeable future.

Besides the sheer significance of these developments, the physical process of build-up and residential-commercial development in the urban and semi-rural regions of Australia, and their underlying economic dynamics that result in certain spatial configurations are relatively understudied. The aim of this study, therefore, is to investigate recent trends in the growth of the built-up area, including residential and commercial dwellings in Hunter Wine Country Private Irrigation District (HWCPID), and to relate those changes to the underlying economic dynamics. This is particularly pertinent because the district is one of the rapidly growing and well-known tourist destinations in New South Wales [15].

2. Materials and Methods

2.1. Study Area and Background

The study area is the HWCPID district of the Lower Hunter Valley of New South Wales Australia (Figure 1). The Lower Hunter is a home to the sixth largest urban area in Australia with a diverse land uses and landscapes, consisting of coastline, mountains, lakes, floodplains and a river, and also includes the world's largest coal exporting port, the port of Newcastle. Mining and industrial manufacturing have been the source of the strong economic growth in the region [16]. The regional planning strategy of the Lower Hunter is focused on the provision of sufficient new urban development and employment to meet the demands of expected strong population growth from 515,000 in 2006 to the estimated 675,000 by 2031 [16].

Figure 1. Location of the study area in New South Wales (NSW) and astride the two local government areas, and the study area draped with the 2005 Landsat TM image.

HWCPID, which is characterized by an undulating plain of the Lower Hunter Valley, covers approximately 379 km^2 and is centered by Pokolbin—a little town known for its excellent wineries and resorts. The main attractions of HWCPID, especially as a tourist destination, are the fine wineries, aesthetic views of stretching grape vineyards, and the numerous golf courses. However, its image of a bucolic rural landscape with its varied mosaic of vineyards, pastures, scattered woodlands and wineries has been threatened by the prospects of overdevelopment [17]. This has led to concern among the public, which have invoked the inevitable yearning for tradeoffs between development and economic growth on one hand, and environmental sustainability on the other. Politically, the district is situated astride on two local government areas (LGAs): Cessnock local government area and Singleton local government area. There are a number of suburbs within each local government area, with some almost wholly contained within the study area, while others only partially so.

2.2. Data

For the purpose of this study, a series of LULC maps produced for multi-temporal steps in 1985, 1991, 1995, 2000 and 2005, as described in [18], were utilized. There are six delineated LULC categories for the earlier four maps, and seven categories for the 2005 map (Table 1). The overall classification accuracy of final classified maps was fairly high, *i.e.*, 91.3%, 91.0%, 89.5%, 88.5%, and 86.6% respectively for 1985, 1991, 1995, 2000 and 2005 maps. These levels of accuracy are considered adequate for this type of study [19]. The focus of this study is on the built-up land use category, which was compared across time in terms of proportion of the landscape it occupies. In order to observe where changes had occurred, the built-up layer of each year was overlain on the political sub-division map of the study area.

Table 1. Land use and land cover (LULC) categories delineated for the classification.

LULC Category	Description
Woodland	Forest covers including tree cover along the creeks
Pasture/scrubland	Natural and cultivated pastures, and scrubs with partial grassland
Vineyard	Irrigated and non-irrigated vineyards
Build-up	Commercial, and residential areas, and other areas with man-made structure; roads, railway lines
Water-body	Farm dams, sewage ponds
Mine/quarry	Mining areas
Olive	Olive groves (for 2005 only)

Additionally, appropriate high-resolution orthorectified aerial photographs—acquired sometimes between 2004 and 2006—were procured from a company called Plateau Images, Alstonville, New South Wales Australia. These photographs were of high spatial resolution of approximately 0.35m within the Cessnock photo tile and 1 m for all other tiles. Also, the following data were procured from two government sources: black and white aerial photographs acquired in 1984, colour aerial photographs acquired between 1976 and 1977, in 1991, 1998 and 2000 (from the New South Wales Department of Land), and the Singleton Land Use Geodatabase (currency: 2000–2007) and digital elevation model (DEM) (from then Department of Natural Resources, now renamed as Department of Environment, Climate Change and Water, New South Wales Government). The aerial 1:25,000 scale aerial photographs that were procured from the Department of Land were at the orthorectified using the above-mentioned already orthorectified aerial photographs (procured from Plateau Images acquired in 2004 to 2006). The aerial photographs for each period were mosaicked and transformed to projected coordinate system using ERDAS Imagine Ver. 8 [20]. Then all of the orthorectified aerial photographs were re-sampled to 2 m spatial resolution. While the photographs were mainly used as reference data, the Singleton land use geodatabase and DEM were utilized as ancillary data for the knowledge-based post-classification correction.

2.3. Testing for Performance of the Simulation Model and Prediction of Built-up to 2025

The prediction of build-up was done using the Land Change Modeler of IDRISI Andes, Version 15 software [21]. However, before predicting onto the future, it was important to know the validity of the simulation model in terms of its predictive power. The performance of the simulated model was tested using the methodology recommended by Pontius et al [22]. This method (a) budgets sources of agreement and disagreement between the prediction map and the reference map, (b) compares the predictive model to a null model that predicts pure persistence, (c) evaluates the goodness-of-fit at multiple-resolution to see how scale influences the assessment. Therefore the following steps were performed for predicting built-up areas for 2025: (i) prediction of built-up areas for the year 2005 (as the 2005 reference map was available for validation purpose) (ii) testing the performance of simulation (prediction) model (iii) prediction of built-up areas for the year 2025.

The prediction of built-up areas depends on past land transition information and on environmental variables that might drive or explain such a change. Based on this information, a layer expressing the transition potential—the likelihood that a LULC will be subjected to transition in the future, is produced. Each transition was modeled using a multilayer perceptron neural network. One of the main advantages of perceptron neural network is that it is distribution-free, *i.e.*, no underlying model is assumed for the multivariate distribution of the class-specific data in a feature space. The multi-layer perceptron uses back-propagation (BP) learning, which involves two major steps: forward and backward propagation, to accomplish its modification of the neural state. During training, each sample is fed into the input layer and the receiving node sums-up the weighted signals from all nodes to which it is connected in the preceding) layer. Formally, the input that node receives is weighed according to Equation (1) [23]:

$$net_j = \sum_{i=1}^{m} w_{ij} o_i \tag{1}$$

where w_{ij} represents the weight between node i and node j, and o_i is the output from node i. The output from a given node is then computed as shown in Equation (2):

$$o_i = f(net_j) \tag{2}$$

The function, f, is usually a non-linear sigmoidal function that is applied to the weighted sum of inputs before signal passes to the next layer.

All training pixels must go through the network before the error and weights are determined and propagated. This error is then propagated backward with weights for relevant connections corrected *via* a relation. The forward and backward passes continue until the network has "learned" the characteristics of all the classes. The purpose of training the network is to get the proper weights both for the connection between the input and hidden layer, and between the hidden and output layer for the classification of the unknown pixels.

The quantity of change was then modeled using a Markov chain analysis. In short, Markov model provides no information on the spatial distribution of occurrences; however, the spatial component is obtained from multilayer perceptron neural network. One basic assumption of the Markov chain is to regard land use and land cover change as a stochastic process, and the different categories are the states of a chain [24–26]. This stochastic process assumes that the value of the process at time t, X_t, depends only on its value at time $t - 1$, X_{t-1}, and not on the sequence of values X_{t-2}, X_{t-3}, X_0, and that the process passes through in arriving at X_{t-1}. The transition probability from a state i to state j, P_{ij}, is an element in a transition probability matrix, where the sum of the elements in each row is equal to 1 (Equation (3)):

$$\sum_{j=1}^{m} P(i,j) = 1 \tag{3}$$

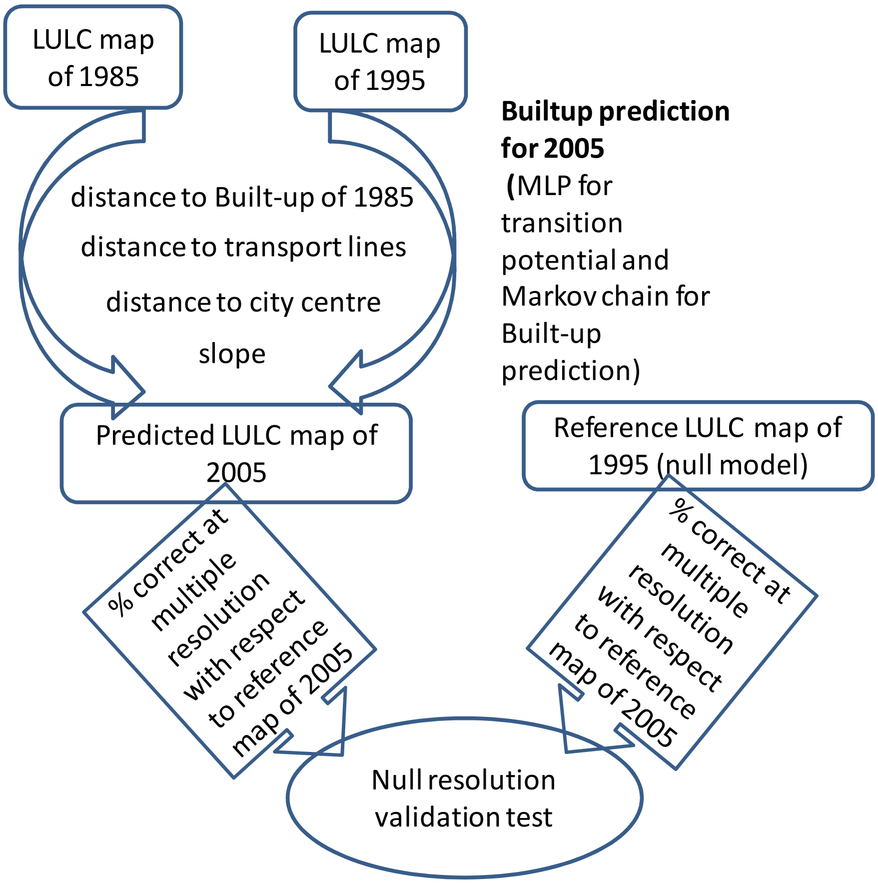
Using bi-temporal land cover data at specified periods, the Markov chain analysis can be used to figure out exactly how much land would be expected to transit from period t to period $t + 1$, which in turn can be used to project into the future by using the calculated transition potentials. This is not a simple linear extrapolation since the transition potentials change over time as various transitions in effect reach an equilibrium state. The Markov chain algorithm assumes that for every specified period, e.g., 10 years into the future, the proportion of land that transits from one category to another is the same for land that made that particular transition during the preceding 10 years calibration period [27].

In this study, the 1985 and 1995 LULC maps were used for calibration of the simulation model which was used to predict built-up areas for 2005, as the 2005 reference map was available for validation purpose. The prediction variables include distance to built-up areas of the 1985 map (considered dynamic variable), distance to transport lines, distance to city center (Cessnock), slope (derived from DEM of the area), and LULC map of 1985, as these variables were considered to have most influence on future expansion of the built-up area.

To test the performance of the simulated model, the following steps were performed (Figure 2): (i) percent correct at multiples of base resolution at geometric sequence was determined for the simulated map of 2005 with respect to the reference map of 2005 using a validate module of IDRISI Andes [21]. (ii) percent correct at multiples of base resolution at geometric sequence was determined for the null model map (reference map of 1995) with respect to the reference map of 2005 in the same way; (iii) the results of the two comparisons were plotted against the multiple resolutions to see a null resolution, *i.e.*, to determine if the resolution at which the accuracy of predictive model is equal to the accuracy of the Null model.

After testing the performance of the simulation model, prediction of built-up areas was done for 2025. For this purpose, LULC maps of 1985 and 2005 were used for calibration. All other variables used were the same as those used for the prediction of 2005 map. They include: distance to the build-up of the 1985 map (considered dynamic variable), distance to transport lines, distance to city center (Cessnock), slope, and LULC map of 1985. Similar to the way the prediction for 2005 was conducted, transition potential was derived using multilayer perceptron neural network, and thereafter built-up areas were predicted for 2025 using the Markov-chain algorithm.

Figure 2. Procedure for testing the performance of the simulated model in comparison to null model using null resolution procedure.



2.4. Extraction of Residential and Commercial Dwelling Density

As the study area is largely non-urban residential area with predominance of vegetation, the Landsat images were found too coarse to derive dwelling density. Therefore ortho-rectified aerial photos acquired in 1976–1977, 1984, 1990–1991, 1998, 2000, and 2004–2006, were respectively used to manually delineate dwellings for 1985, 1995, and 2005 in an ArcMap panel (ArcGIS Vers. 9.2: Product of ESRI, Redlands, CA, USA). The kernel densities were derived using a moving window of 500 m by 500 m. The maps of dwelling densities were classified to elucidate the spatial-temporal patterns of densities. They were overlain on the suburb map of the study area to assess the growth of residential and commercial dwellings in relation to the suburbs.

2.5. Relating the Economic Information with the Growth in Residential and Commercial Dwelling Density

To enable the interpretation of the economic implications of the spatial patterns of residential/commercial dwelling density, secondary data were collected from various publications, by the Australian Bureau of Statistics (ABS), Australian Bureau of Agricultural and Resource Economics (ABARE), Tourism NSW, Cessnock City Council and the Hunter Valley Research Foundation. The data collected include population, family income, employment, wine and grape production and their contribution to tourism as it was hypothesized that these variables may be related to the built-up areas and residential-commercial development. It is worth noting that these data were available at the suburban division level for the year 2006 only, but were available at a greater level of spatial aggregation, *i.e.*, local governmental area level for the years 1996, 2001, and 2006. Because of this limitation, detailed statistical analysis could not be performed, but the available data are used to illustrate certain economic dynamics across the suburbs and across time in the Cessnock local governmental area. It is also envisaged that the income data for NSW and for whole of Australia could serve as a proxy for a driver of growth of tourism in the region.

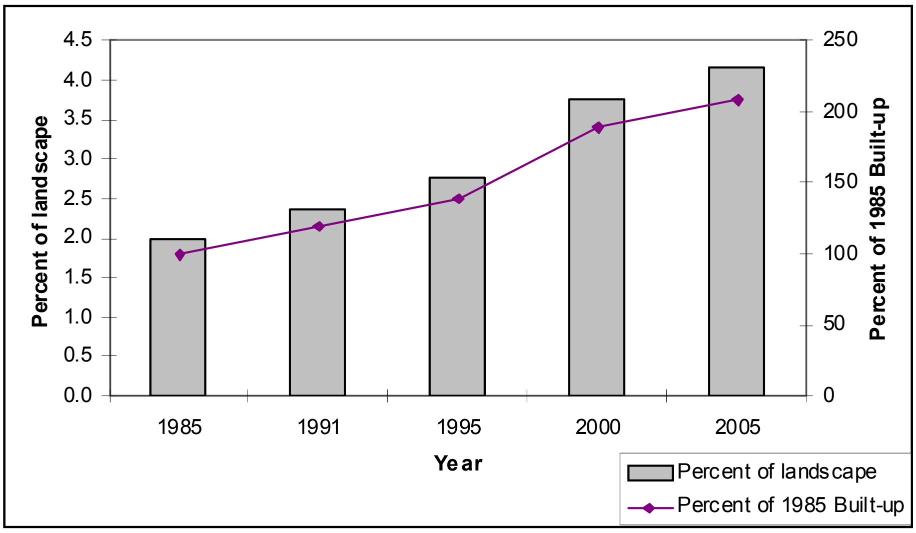
To enhance the visualization, GIS maps were constructed delineating the suburb divisions which are characterized by the following variables: population density, median income for people over 15 years of age, the proportion of workers employed in grape-wine tourism industry (for this purpose, number of workers employed in fruit growing, beverage manufacturing, accommodation, restaurants, and special food services were added up and divided by the total employment in a suburb) and the proportion of workers employed in mining. We assume that the household income level in NSW and in Australia are expected to have positive impact on tourism industry and consequently on the demand for services that require increase in the built-up area. Therefore, the relationship between state/national income parameters and build-up were also explored.

3. Results and Discussion

3.1. Trend in Built-up Area from 1985 to 2005

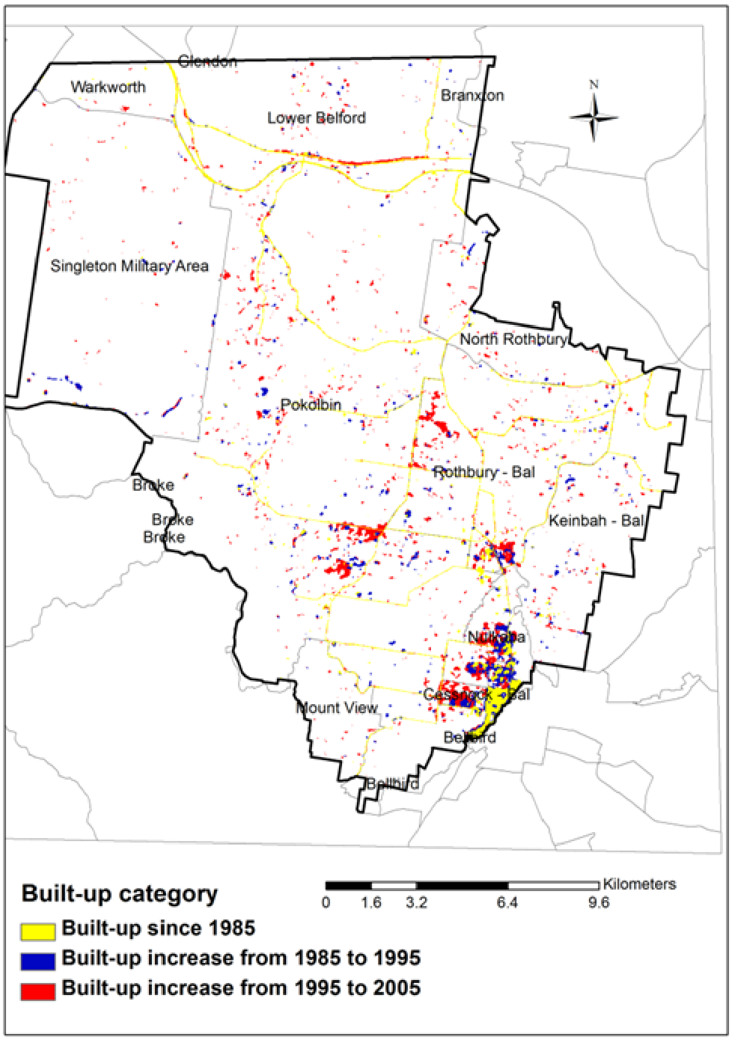
Built-up land was found to be 2% of the landscape in 1985 and then increased to 2.4%, 2.8%, 3.8% and 4.2% by the years 1991, 1995, 2000, and 2005, respectively. Thus, built-up areas had increased to more than double by 2005 in comparison to that of 1985 (Figure 3).

Figure 3. Trend in the proportion of built-up land from 1985 to 2005.



In overlaying the built-up layers of 1985, 1995 and 2005 on the suburb map (Figure 4), the expansion of built-up areas was observed to be mainly in the outskirts of the 1985 build-up and along the road corridors in the suburbs of Cessnock-Bal, Pokolbin, Nulkaba and Rothbury-Bal. Bigger patches of increased Built-up after 1995 in Pokolbin and Rothbury-Bal are associated with the large-scale hotel and resort developments in the area.

Figure 4. Built-up areas as distinguished by time intervals, overlain on the suburb map. Note: Thick black line is the study area boundary while thinner black lines are the suburb boundaries.

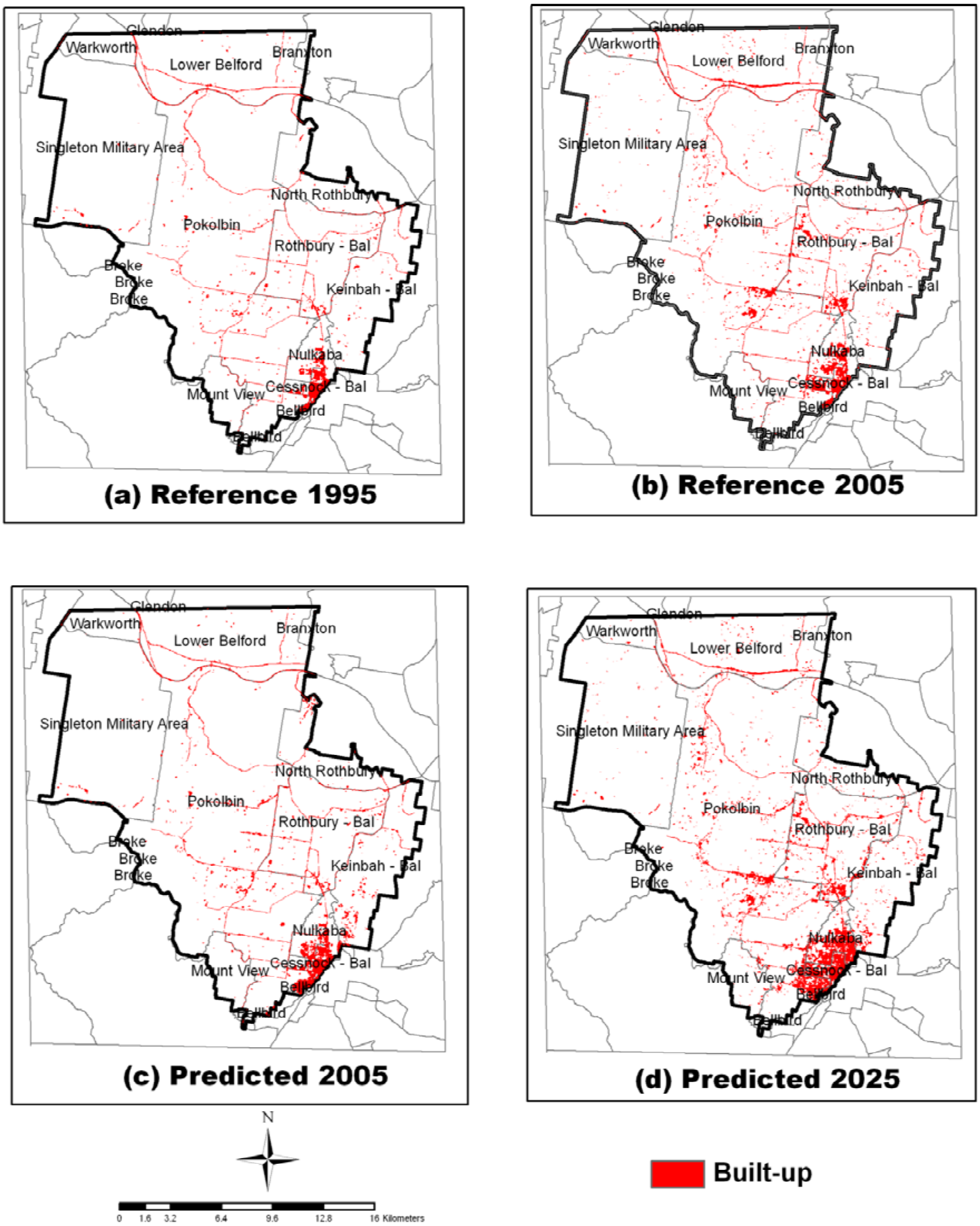


3.2. Model Validation and Prediction of Built-up to 2025

The reference maps of 1995 and 2005 along with the result of the prediction to 2005 and 2025 are shown in Figure 5. When the predicted map of 2005 was compared with the reference map of 2005 (Figure 5b), the area of Built-up observed in the middle of Pokolbin and south-east corner of Rothbury (as seen in the reference map) were found to be absent in the predicted map (Figure 5c). This shows the limit of LULC prediction based on historical information alone, as there could have been various other factors such as policy intervention and other events influencing the change. Though the prediction did not conform fully to the reality, this modeling has predicted a business-as-usual scenario (*i.e.*, a scenario showing if the pattern of the development remains same as that of calibration period).

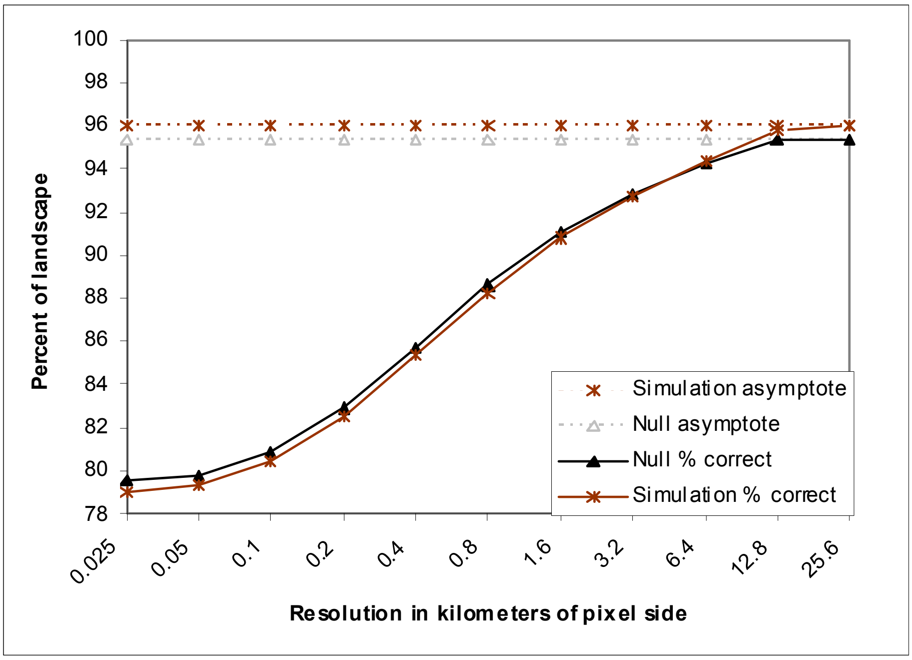
It is not particularly useful to attempt to crown a model as valid, or to condemn a model as invalid based on the validation results [28], as all models are wrong though some are useful [29]. It is more useful to state carefully the degree to which a model is valid [28]. More importantly, the relevant question is whether we can learn from our models, and whether that learning may contribute to improving human welfare and the sustainability of our natural resource base [28–30]. We evaluate our model in this light.

Figure 5. Distribution of Built-up area: (**a**) Reference map of 1995, (**b**) Reference map of 2005, (**c**) Predicted map of 2005, and (**d**) Predicted map of 2025.



When the percent correct of simulation model was compared with the percent correct of the null model at multiples of base resolutions (Figure 6), it was found that the null resolution of simulation model is at 3.2 km pixel side, meaning that the predictive model is more accurate than the null model at resolution coarser than 3.2 km resolution, while less accurate than null model at resolution finer than 3.2 km pixel side. The accuracy of the model is not particularly good, however when compared with other models of this type in the literature such as Pontius *et al.* [31], this can be considered as an average in level of accuracy.

Figure 6. Percent correct of reference map of 2005 *vs.* null and simulation model.

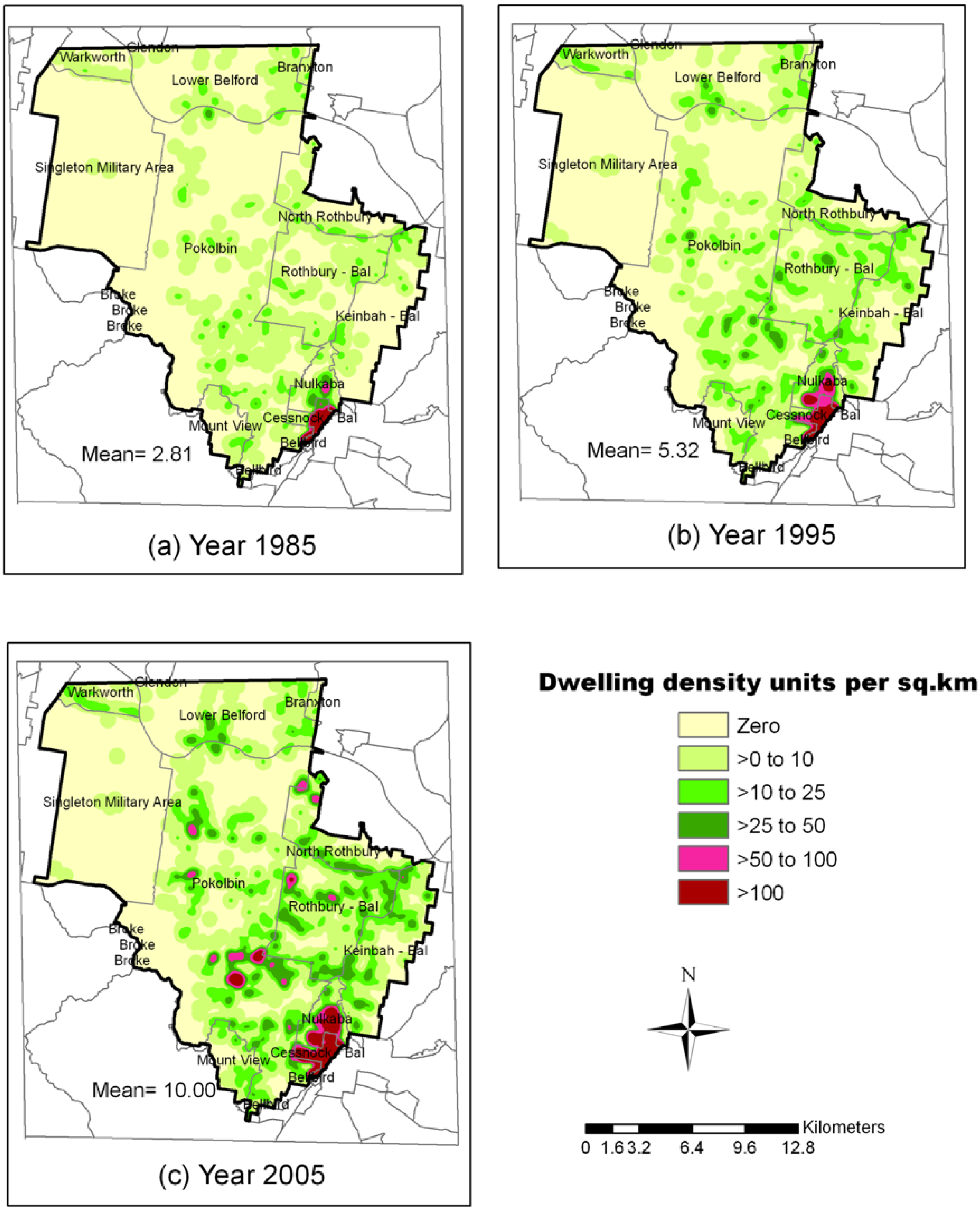


The model predicted Built-up for 2025 to about 2470 ha, which is 6.5% of the landscape, an increase of 327% from that of 1985. This is found under the business-as-usual scenario when the nature of future development remains the same as it has been in the past. The predicted Built-up, as overlain over the study suburb-map to illustrate where the expansion of Built-up will likely occur is shown in Figure 5d. This outcome illustrates the fact that the modeled expansion of Built-up is more likely to occur in the vicinity of the pre-existing developed areas than is the case with rural dwellings.

3.3. Residential and Commercial Dwelling Density Derived from Aerial Photos

The analysis of residential and commercial dwelling density indicates that the dwelling sprawl is mainly of very low density, which meant that its detection from Landsat images was difficult partly due to coarse spatial resolution of the Landsat images and partly because of the predominance of vegetative cover in the region [32]. This justifies the manual delineation of dwellings from orthorectified aerial photos. The delineation was followed by the derivation of residential/commercial densities. The results show that the mean density for the whole of the study area was 2.8 units/km^2 in 1985, increasing to 5.3 units/km^2 in 1995 and 10.00 units/km^2 in 2005, *i.e.*, almost doubling within a decade. Figure 7 shows that in 1985, the dwelling density above 50 units/km was only around the high-density suburb of Cessnock. However, by 2005, the higher density area has increased both in intensity as well as in area, expanding to other parts of the study area: the suburbs of Pokolbin and Rothbury.

Figure 7. Residential and commercial dwelling density derived from aerial photos for the time steps: (**a**) year 1985, (**b**) year 1995 and (**c**) year 2005.



Overall the proportion of areas of between zero to 10 unit/km^2 declined from 95% in 1985 to 86% in 1995 and then to 76% 2005 (Table 2). In contrast, the proportion of the landscape characterized by more than 10 units/km^2 increased commensurately from 5% in 1985 to 14% in 1995 and 24% in 2005. Moreover, the proportion of the landscape that exhibited dwelling density greater than 50 units/km^2 was 0.6% in 1985 increasing to 1.3% and 2.9% in 1995 and 2005 respectively. This increase in density is probably due to increase in wine-tourism activities, especially in the southern half of the study area in Cessnock LGA (Figure 7).

Table 2. Percent of landscape under different dwelling densities in a decadal time step.

Year	Dwelling Density (units/km^2)					
	0	0–10	10–25	25–50	50–100	>100
1985	59.0	35.7	4.2	0.5	0.2	0.4
1995	47.0	39.3	11.0	1.3	0.6	0.7
2005	40.0	36.0	15.6	5.5	1.2	1.7

3.4. Economic Implications

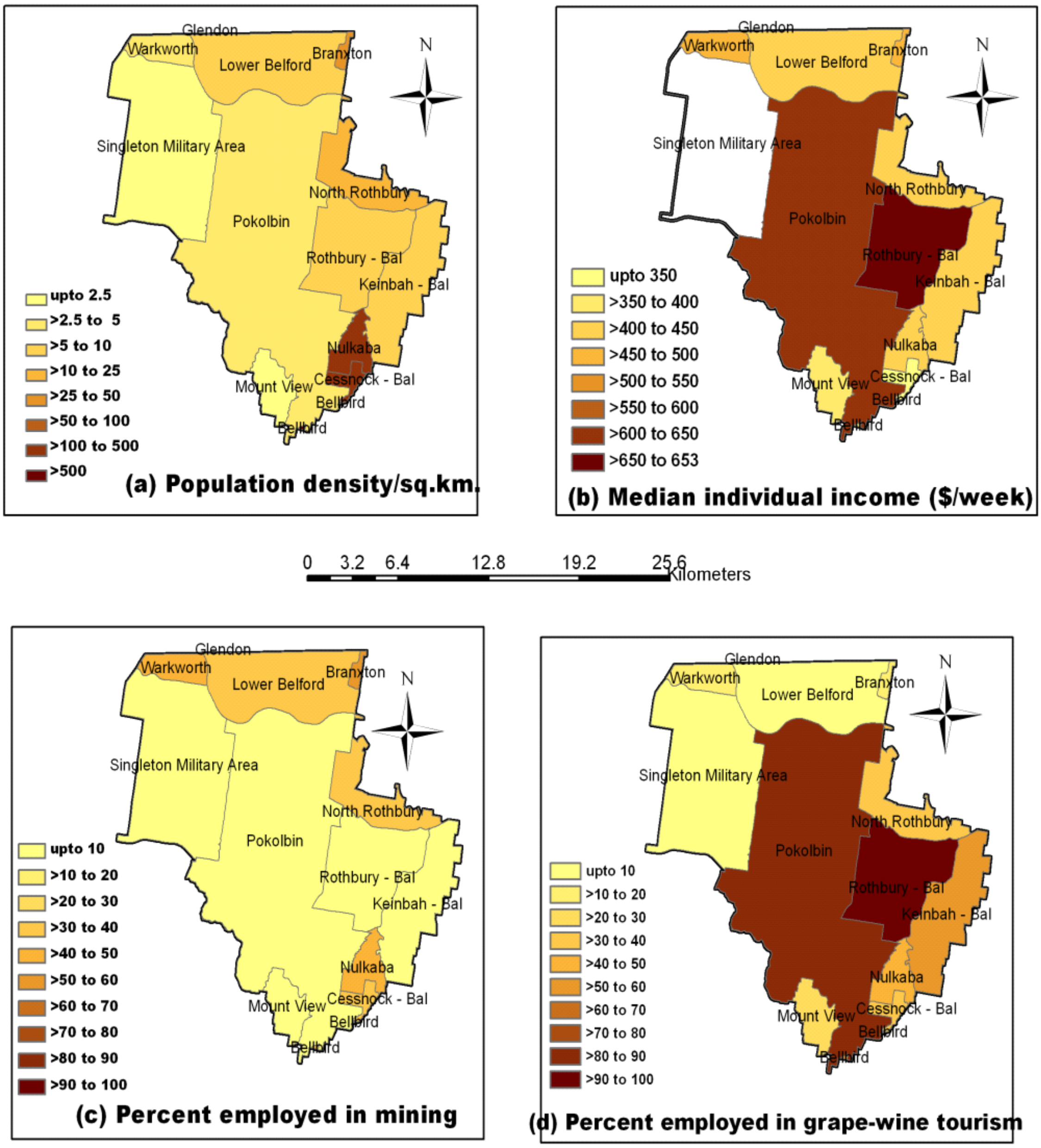
The HWCPID is an important tourism destination in New South Wales, and especially renowned for wine tourism. Prior to the development of wineries, mining was the principal industrial base and source of employment until the first half of 20th century. However, the decline in mining activities by the second half of the century was paralleled by the growth of tourism due to the introduction and consequent expansion of wineries, vineyards, and the associated recreational facilities. The relative proximity of HWCPID to the metropolitan Sydney aided to this process of transforming the HWCPID to a prime weekend tourist destination. It is therefore envisaged that economic factors have been the main driving force behind the growth of residential and commercial dwellings in the study area.

The 2006 population density, median income, and some labor statistics are presented in Figure 8 at suburb level of aggregation. The population density was very high in Bellbird, Cessnock-Bal and Nulkaba. As the data were averaged across each suburb, the spatial pattern within a suburb could not be visualized. In comparing the population density of a suburb (Figure 8) with the residential and commercial dwelling density of 2005 (Figure 7), it is clear that the higher dwelling density for Bellbird, Cessnock-Bal and Nulkaba coincide with the higher population density.

It is interesting to note that the high-density suburbs such as Cessnock and Nulkaba have lower (median) individual income in comparison to less densely populated and lower dwelling-density suburbs; Rothbury-Bal and Pokolbin. It might be hypothesized that this reflects the differences in asset ownership: the residents of more sparsely populated and low dwelling-density areas are likely to own valuable assets in terms of land, vineyards, and other farm related assets, and to derive most of their income as returns on their asset ownership, whereas the residents of more densely populated urban and semi-urban areas are likely to own assets of lower value, and to derive most of their income from employment. Another interesting observation is that generally, the higher the employment in the grape-wine tourism sector in a suburb, the higher is the median individual income in that suburb. So, the suburb of Rothbury has highest percentage of employment in grape-wine tourism as well as the highest median individual income, and is followed in both indicators by Pokolbin.

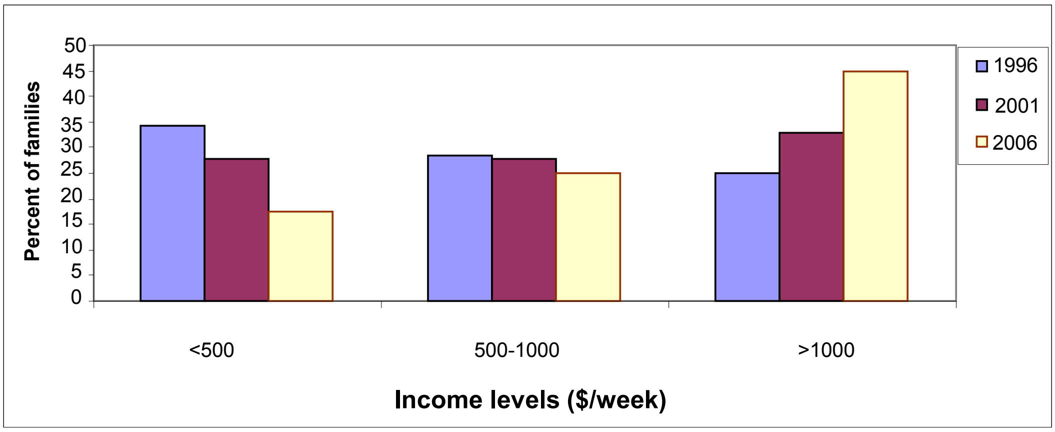
We note that the study area is situated astride two local government areas (LGAs): Cessnock LGA and Singleton LGA. Of the two, the study area within the Cessnock LGA (Figure 1) has significantly greater wine-tourism activity in comparison to Singleton LGA. Increase of residential and commercial dwelling density by 2005 was clearly observed especially in the study area belonging to Cessnock LGA (Figure 7).

Figure 8. Economic information across the suburbs in the study region: (**a**) population density/km^2, (**b**) median individual income $/week, (**c**) percent employed in mining and (**d**) percent employed in grape-wine tourism (Derived from ABS [33]).



A temporal comparison of the level of income of families in Cessnock LGA in 1996, 2001 and 2006, reveals a clearly increasing trend of income (Figure 9). In 1996, 34% of the families earned less than $500/week and only 25% of families were earning more than $1,000/week. By the year 2006, only 18% families had earned $500/week, but 45% families earned more than $1,000/week. This would be a little less if inflation rate had been considered, *i.e.*, $1 in 1996 is equivalent to $1.12 in 2001 and $1.29 in 2006 [34].

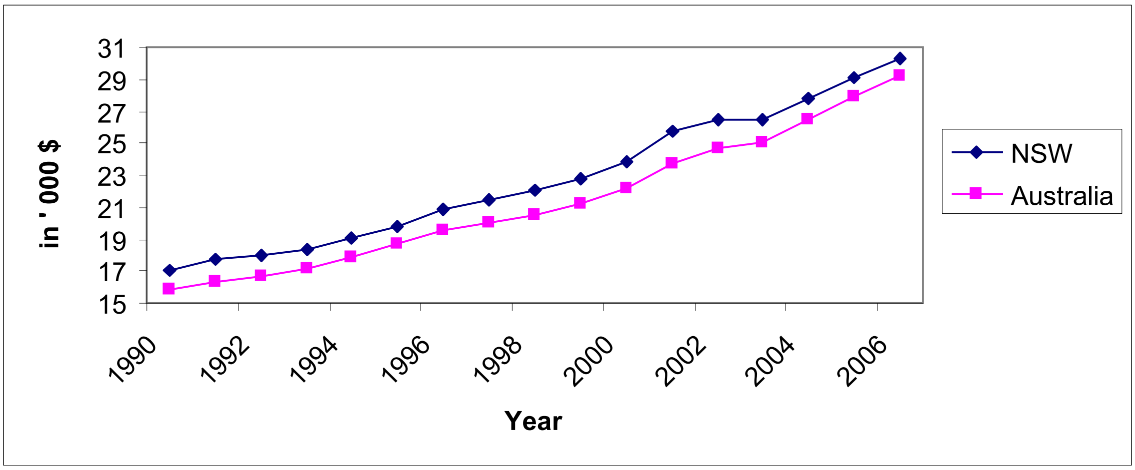
Figure 9. Percent of families with different levels of income in Cessnock LGA [35].



3.5. Linking the Built-up Increase with Economic Development

The tourism industry has been steadily growing in Australia. One of the main reasons is the strong economic growth that the country has experienced. Figure 10 shows steady increase of disposable household income per capita over the 16 years from 1990 to 2006 in NSW and in Australia. One can hypothesize that the higher the per capita income, the greater the expenditure on leisure and holidaying [36].

Figure 10. Time series of disposable household income per capita for NSW and Australia [37].

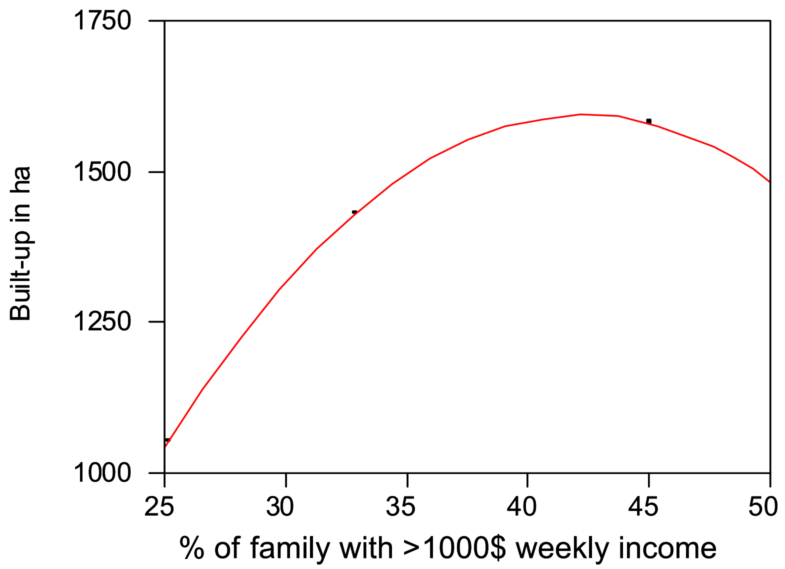


HWCPID is the main tourism center outside Sydney in NSW and is gaining popularity as a wine tourism center due the proximity of the district to Sydney. The greater the influx of tourists to the area, the greater is the demand for accommodation and other amenities such as golf courses and restaurants. This increased demand lures investors to invest in building these amenities in the area, which consequently results with increased Built-up and residential-commercial density. In addition the newly built hotels, golf courses and other various commercial venues create jobs, which then feed into overall economic growth of the local economy and associated increase in family incomes (Figure 9).

In order to observe the association between build-up expansion and family incomes, the correlation between the Built-up in hectares in the study area, and the proportion of families with different levels of income in Cessnock LGA were calculated. The correlation coefficient between the build-up and proportion of families with income higher than $1000/week was found to be 0.93. In contrast, the correlation coefficient between the build-up and the proportion of families with less than $500/week was found to be −0.93. This gives a clear indication of a positive correlation between the Built-up expansion and family income. This correlation can also be conformed visualizing the Figures 3 and 9. Figure 9 shows higher rate of increase of proportion of families with more than $1000/week from 2001 to 2006, which can be related to higher rate of build-up increase from 1995 to 2000, as evident in Figure 3.

Although Built-up growth may be associated with the growth of the local economy in terms of creation of employment and increased income levels, it may also be seen as having significant impact on the environment through its ecological footprints [2,4,5]. The Environmental Kuznets curve (EKC) hypothesis is a relatively recent concept in environmental economics [38,39] that encompasses some aspects of the relationships between economic development and environmental degradation. According to this hypothesis, environmental degradation increases with income in the initial stages of economic development, but the rate of this increase gradually slows down, and after reaching a turning point, environmental degradation decreases as income continues to rise. This hypothesis proposes an inverted U-shape relation between environmental degradation and per capita income. In the context of the present study, considering Built-up as the manifestation of environmental degradation, we could plot the EKC in terms of Built-up acreage against the proportion of families with more than $1000/week during 1995–1996 and 2005–2006 in Cessnock LGA. This is presented in Figure 11, where one can observe a continual increase in the Built-up within a range of between 25% and 40% (corresponding to the period 1995–2000) of families earning more than $1000/week. Acreage of Built-up starts to decline once the proportion of families on relatively high income goes beyond 40%–45% (corresponding to the period 2000–2005).

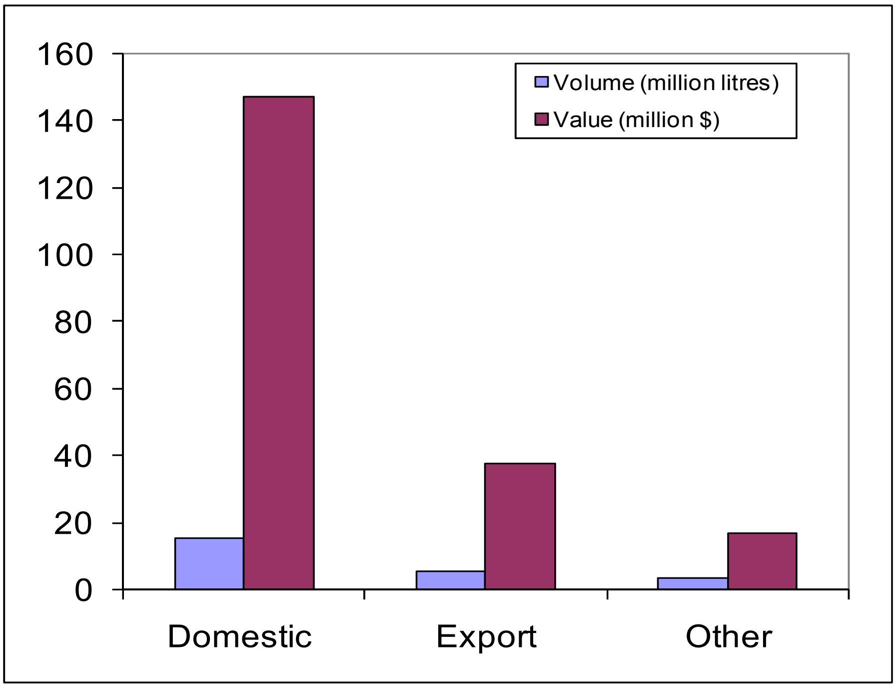
Figure 11. Environmental Kuznets curve with build-up *vs.* percent of family with higher level of income (more than $1000/week).



3.6. Contribution of Wine Tourism to the Economy of the Region

One of the key reasons for the rising incomes and rising employment in the tourism industry in the study region is the rapid rise to prominence of the Australian wine industry and the associated tourism activities. Wine tourism is defined as: "*visitation to wineries and wine regions to experience the unique qualities of contemporary Australian lifestyle associated with the enjoyment of wine at its source including wine and food, landscape and cultural activities*" [40]. Wine tourism has a separate and recognizable identity in the Australian economy. An overview of the wine and grape business in Australia indicates that the total production of grapes in 2005–2006 was a little above 2 million tonnes, of which more than 90% was used for wine making [41]. Of the total grape crushed for wine in 2006, NSW/Australian Capital Territory accounted for 34.6% after South Australia, which accounted for 47.3%. Though the total grape area in the lower Hunter is only just above one-tenth of the state total in 2008 [42], it is significant in terms of tourism industry. About 25 million liters of grape wine are produced in this region for which more than 40% of the grapes are imported from other regions [42], due to insufficient supply from the internal production. As wine business in the region is tourism based, the region has a larger share of the produced wine domestically sold (Figure 12). This is unlike the picture at a national scale in which larger share of the wine produced is exported.

Figure 12. Wine sale in the Lower Hunter in 2003–2004 [42].



According to CRC Tourism [43], the Hunter Valley's position is third among the wine-producing regions in Australia after Barossa Valley and Adelaide Hills in terms of number of tourists that visited each wine region. At the state level, the Lower Hunter alone contributed more than 70% cellar door visits in New South Wales [44]. The total turnover from the wine industry, including flow-on effect, was estimated to be $594 million in 1998/1999, and tourism in the area generated further $560 million (including flow-on effect) in the same year [45]. The total direct employment generated was 4700, and further 2100 jobs were created by the flow-on effects.

4. Conclusion

HWCPID is a rapidly growing regional area with built-up and residential-commercial building densities on the upward trend in recent decades. The built-up area was 2% of the study area in 1985 whereas it has increased to 4.2% by the year 2005. Build-up growth is expected to continue with 6.5% of the landscape built-up by 2025. Similarly, residential-commercial dwelling densities were found to almost double in a decade; from 2.8 units/km^2 in 1985 to 10.00 units/km^2 in 2005. The denser dwelling area (*i.e.*, above 50 units/km^2) has not only expanded nearby 1985 build-up but also in the center of HWCPID. When suburb-wise (median) individual incomes were compared, high density suburbs were found to have lower (median) individual incomes, which may be attributable to the lower asset ownership in those suburbs. On the other hand, the higher median individual income was observed in the suburbs with higher employment in the grape-wine tourism sector. Build-up increase as well as residential and commercial dwelling densities is likely to be associated with the growth of wine tourism which is generating more employment in wine tourism and increasing family income. Contribution of wine tourism to the local, regional and national economy is significant. Therefore, assessment of the spatio-temporal expansion of built-up areas, linking them to their underlying economic drivers provides important insights that are useful for developmental planning of the region.

Acknowledgments

We acknowledge the support of the Australian Government for providing an Endeavour International Postgraduate Research Scholarship to the first author to pursue this study and the Ministry of Agriculture Development of Nepal for granting her study leave.

Author Contributions

This is to confirm that all authors contributed to the research conceptualization, data analysis and writing of this paper.

Conflicts of Interest

The authors declare no conflict of interest.

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