# Kernel Density Analysis of Active Transport to School Patterns in Dunedin Adolescents

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## Abstract

Geographical information science (GIS) is widely applied in the fields that analyse human activities, including public healthcare and transport planning. Active transport to school (ATS) is a convenient way for children to achieve the recommended daily physical activity level and develop life-long exercise habits. Understanding the factors that influence children's use of active transport is essential to inform the design of effective interventions to encourage active transport selection, such as the development pedestrian-friendly neighbourhoods and supportive infrastructure.

This research applied geospatial analysis methods to ATS to examine the relationship between ATS and its correlates over space. The results of kernel density estimation (KDE) indicate that gender, attendance at a co-educational school, distance to school and Neighbourhood Deprivation Index along with residential density and intersection density show associations with ATS over space, while body mass index, ethnicity and mixed land use entropy do not. The results of this research could be used as evidence to support future strategies and policies to increase the ATS rate.

**Keywords**: Active transport to school, GIS, Visual analytics, Kernel density estimation, Home-school distance

## 1. Introduction

Active transport to school (ATS) is a convenient way for children to achieve the recommended daily physical activity level and start developing life-long exercise habits (Davison, 2008). In recent years, studies regarding ATS among adolescents have been undertaken around the world. Understanding the factors that influence children's use of active transport is essential to inform the design of effective interventions to encourage active transport selection, which include but are not limited to developing pedestrian-friendly neighbourhoods and supportive infrastructure (Kerr, 2006).

Previous research reported that factors such as children's age (Pabayo, 2011; Yeung, 2008; Wong, 2011), gender (Hatamzadeh, 2017; Cooper, 2017), parental concerns (Rothman, 2015), socioeconomic status (Mehdizadeh, 2017), and car ownership (Cutumisu, 2014; Hatamzadeh, 2017) correlate with ATS. Distance from home to school is the strongest predictor of ATS in adolescents (Wong, 2011; Easton, 2015; Mackett, 2013), whereas evidence for the association between ATS and other built environment factors has been mixed. For example, Wong (2011) did not find land use mix and intersection density to be significant, whereas Pont (2009) and Rothman (2015) did.

In this paper, active transport only is defined as the transport method that adolescents used from home to school on walk or by cycle while motorised transport mode including taking school bus, riding cars and motorcycle. The combination of both active transport and motorised transport is considered as mixed transport mode. This research aims to establish whether the correlates of ATS in adolescents are related to adolescents' travel to school mode choices over space. By comparing the spatial distribution and pattern maps of ATS and its correlates, this paper presents an initial evaluation of which correlate(s) have an impact on adolescents' ATS choices, depending on whether the spatial patterns of the variables being mapped show any coincidence or overlay in terms of their kernel. The findings will provide evidence to support further results for local quantitative spatial analysis.


Figure 1 Dunedin districts and suburbs and 12 high schools

The Built Environment and Active Transport to School (BEATS) Study conducted in Dunedin, New Zealand, between 2013 and 2017 focused on 1) understanding the reasons for adolescents' choice of transport mode to school; 2) examining the interaction between the school transport mode and built environment and the physical activity level and body weight of adolescents, and 3) examining the policy factors, barriers or enablers of ATS in adolescents (Mandic, 2016). In Dunedin, New Zealand, the ATS choice is affected by home-to-school distance, topography, traffic safety, encouragement by peers and family, cycling skills, and availability of cycling infrastructure (Mandic, 2017). Based on BEATS Study data, the optimal threshold distance for walking to school among Dunedin adolescents is 2.25 km (Pocock, 2019). In addition, in New Zealand only adolescents living within 4.8 km from school were eligible to use the school bus (Ministry of Education).

This research was conducted in the city of Dunedin. To visualise and analyse the distribution of the adolescents' ATS and the correlates of the ATS, the city was described by using regional names based on Open Street Maps and a city map provided by Dunedin City Council, some important street names, and relative directions and positions to the areas and streets. The significant district names in the city area are specified in Figure 1.

# 2. Methodology

Kernel Density Estimation (KDE) (Silverman, 1986) is a spatial analysis and mapping tool to calculate the overall area density of point-located events based on the number of point events per unit of area (O'Sullivan, 2010). By assuming spatial patterns have density not only at the event point location, but also between those event point locations, KDE estimates the density of the area based on calculating the total count of events in an area or the centre of the location (kernel) (O'Sullivan, 2010).

The KDE spatial analysis tool (ArcGIS, 2017) requires a "POPULATION" field of each input data feature for calculation. Since the KDE distribution patterns show the density of adolescents per square kilometre, this field was to "NONE", where the individual sample was calculated as one time for all the variables. Many KDE bandwidths (search radius) were tried in the research, 500m is used to get the best KDE surface for all the variables to avoid the surface being either too smooth over the entire area or too sharp on individual event points.

# 3. Data and data preparation

The data used in this research was the surveying data of 1,480 adolescents collected from 12 Dunedin School by BEATS team. Each adolescent has a series of attributes (ATS correlates) showing detailed data from general information to thoughts of ATS gathered by BEATS team during surveying. The ATS correlates from the adolescents are generated into KDE maps to get spatial patterns. The patterns can reveal spatial features giving an idea of the relationship between ATS and its factors over space. However, the KDE patterns of one factor can only reveal distribution features of the factor over space. Therefore, by applying three transport modes to school for each group of factors as a second order, the KDE result can reveal the relationship between transport to school modes and factors over space at the same time (Table 1).

All the factors/variables was manually grouped by using querying to be divided into several groups. The grouping method for the KDE map display will be: 1) based on the categories defined during survey shown in table 1; 2) Variables with unique values for each record are divided into three levels based on the Jenks natural breaks classification method: residential density, intersection density, and mixed land use; 3) Distance to school was divided into three categories: up to 2,250 metres, between 2,251 and 4,800 metres, and over 4,800 metres. The home-school distance is the most significant variable affecting adolescents' transport mode selection. This research considered all the factors based on transport modes with distance range as a basic condition. Due to research sample size with only five adolescents using active transport over 4.8 kilometres, this home-school range was ruled out of the discussion in this paper.

Table 1 Two orders of KDE distribution factors

| 1st order | Number of each natural category (total adolescents) | 2nd order (under same home-school distance range) |
|---|---|---|
| ATS | Active transport=352; mixed transport=231; motorised transport=895 | |
| Gender | Male=663; female=815 | ATS & Gender |
| Ethnicity | NZ European=1074; Maori=160; Pacific=59; Asian=104; others=75 | ATS & Ethnicity |
| Body Mass Index | Underweight=59; normal weight=955; overweight=274; obese=88 | ATS & Body Mass Index |
| Co-ed Status | Co-ed school=594; girls' school=496; boys' school=388 | ATS & Co-ed Status |
| Deprivation | Less deprived=818; more deprived=342 | ATS & Deprivation |
| Distance | Within 2,250m=482; between 2,250m and 4,800m=414; over 4,800m=582 | ATS & Distance |
| Residential Density | | ATS & Residential Density |
| Intersection Density | | ATS & Intersection Density |
| Land Use Mix | | ATS & Mixed Land Use Entropy |

## 4. Discussion

KDE distribution maps of all ATS correlates in both 1st order and 2nd order were made while in this paper only those which show significate spatial features were displayed. This discussion interpreted the distribution of KDE patterns and the suburbs and school names addressed are referenced from figure 1. All 1st order KDE distribution maps of the above mentioned factors demonstrated notable spatial patterns but did not show any spatial relationship with the distribution of adolescents' transport mode until they were mapped under different transport mode choices and distances. Therefore, the only 1st order KDE figure was discussed in this paper is KDE distribution based on transport modes. The 2nd order KDE distribution based on body mass index and ethnicity did not show significant difference in terms of the distribution of spatial patterns relative to adolescents' transport mode to school over space. Therefore, this research argues that given the same home-to-school distance, body mass index and ethnicity are not significantly associated with adolescents' active transport choices over space. Therefore, body mass index and ethnicity will be excluded from the discussion.

The difference between the population using active transport and motorised transport is very large within the intermediate distance (between 2.25km and 4.8km). The difference became larger when applying the ATS correlates on top of intermediate distance and transport mode to generate 2nd order KDE maps, the difference became larger. Therefore, all the spatial patterns of the factors based on active transport are significantly overlapped by those of motorised transport and did not show any significance in density level against motorised transport in this distance range. This means that the relationship between transport mode factors within the intermediate distance cannot be detected.

Therefore, this paper will only discuss the relationship between ATS and ATS correlates with the condition of distance within 2.25km.

## 4.1. Distribution of transport modes

*Active transport* *Mixed transport* *Motorised transport*

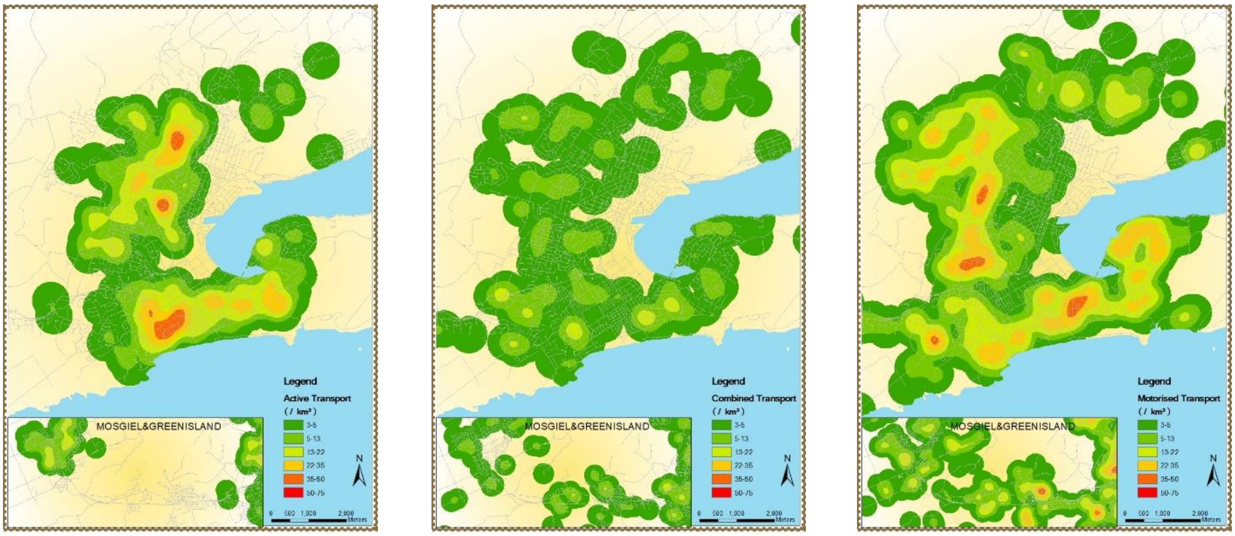



Figure 2 KDE distribution based on transport mode choices

The distribution of ATS (Figure 2) indicated that there are large differences in terms of locations and density level of KDE patterns among all three transport modes. For example, adolescents living in St Clair and Roslyn show a higher trend of using the active transport mode from home to school, while Waverley, Kenmure, Maryhill and Mornington show a stronger signal of using motorised transport than active transport. These distribution maps are general distribution maps of the transport modes which show difference in terms of the density level and locations of the KDE patterns. It means that transport mode in this case is sensitive to the locations and can be analysed by KDE.

## 4.2. Transport mode and distance

*Distance to school $d \leq 2.25km$* *Distance to school $2.25 < d \leq 4.8km$* *Distance to school $d > 4.8km$*

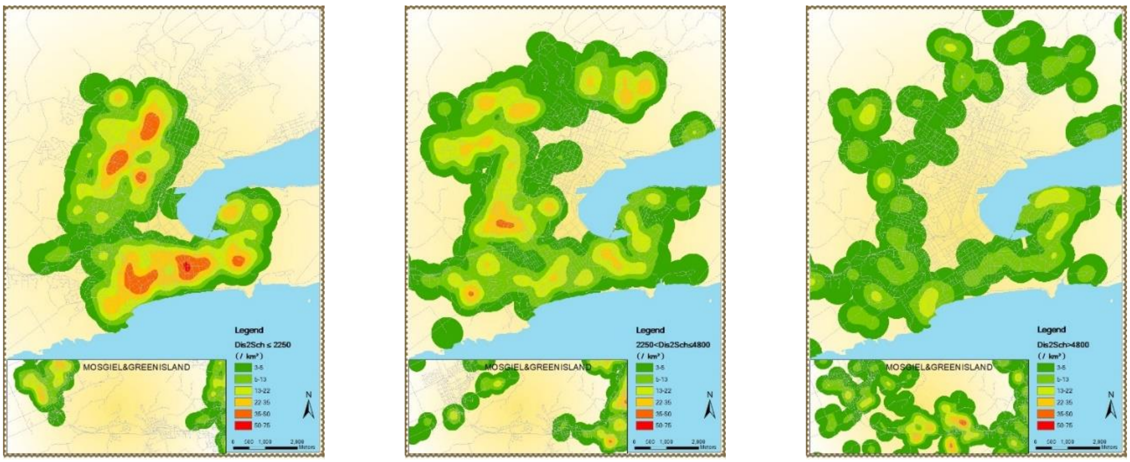



Figure 3 KDE of distance from home to school

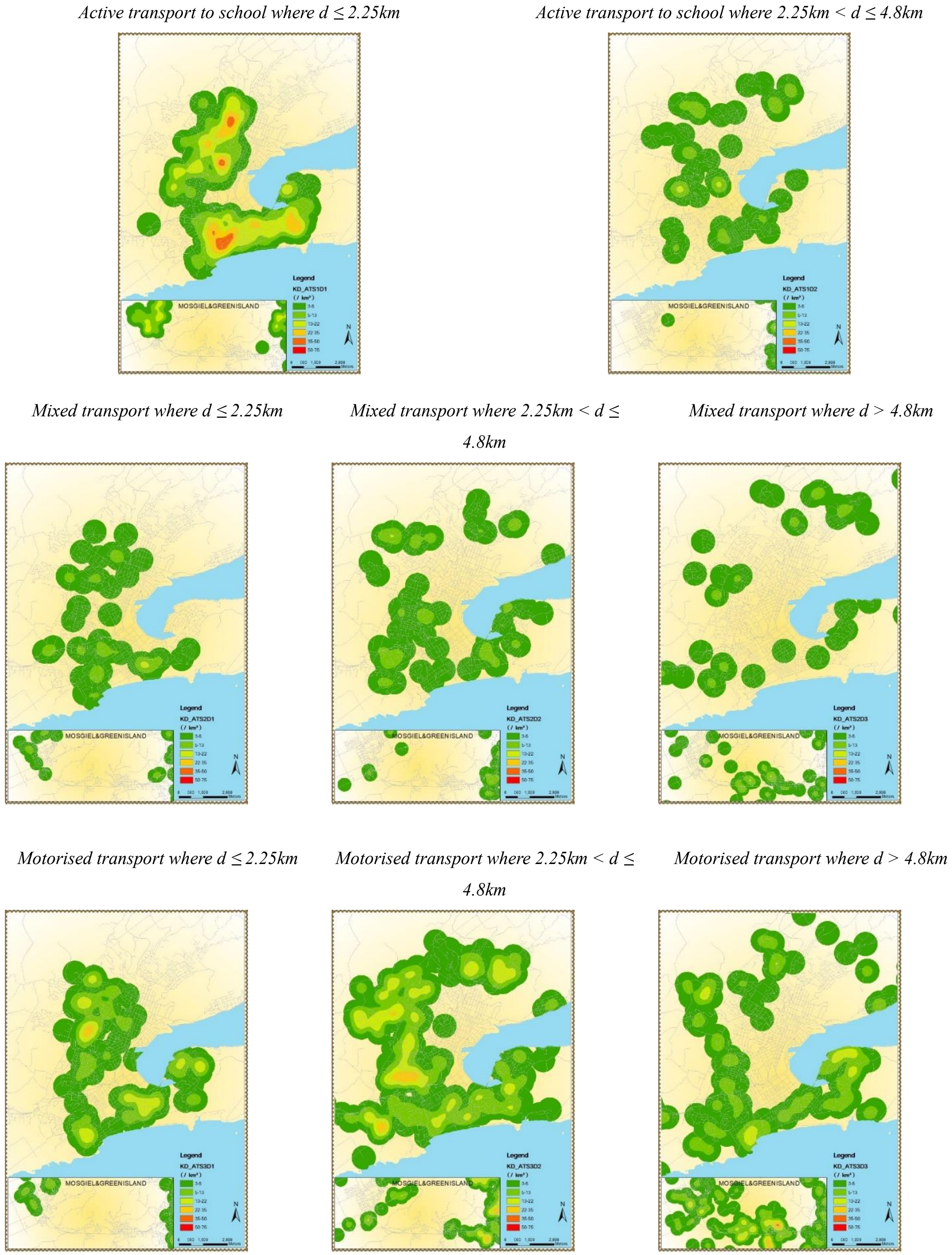



Figure 4 KDE distribution based on ATS and distance

The KDE based on ATS choices and distance range show clear difference in terms of pattern density level and distribution status. Clearly, adolescents living within walking distance can actively commute from home to school and the number of active transport user declines with the increase in distance between home and school. The usage of mixed transport did not show specific difference in terms of density, location and coverage of patterns between the three distance categories, meaning that there are always adolescents who use mixed transport to school regardless of the home-school distance. A clear increasing trend can be seen in terms of the density of the spatial pattern of motorised transport with the distance increasing, which means that the further the adolescents live from school, the more they are dependent on motorised transport to school. In conclusion, distance is a significant correlate that will affect adolescents' transport mode choices. The rate of active transport from home to school declines with the increase of distance. Therefore, the existence of schools in the neighbourhood is a positive factor that leads to more adolescents actively commuting to schools in the neighbourhood.

## 4.3. Transport mode and gender and co-educational school status

*Female active transport* | *Female motorised transport* | *Male active transport* | *Male motorised transport*

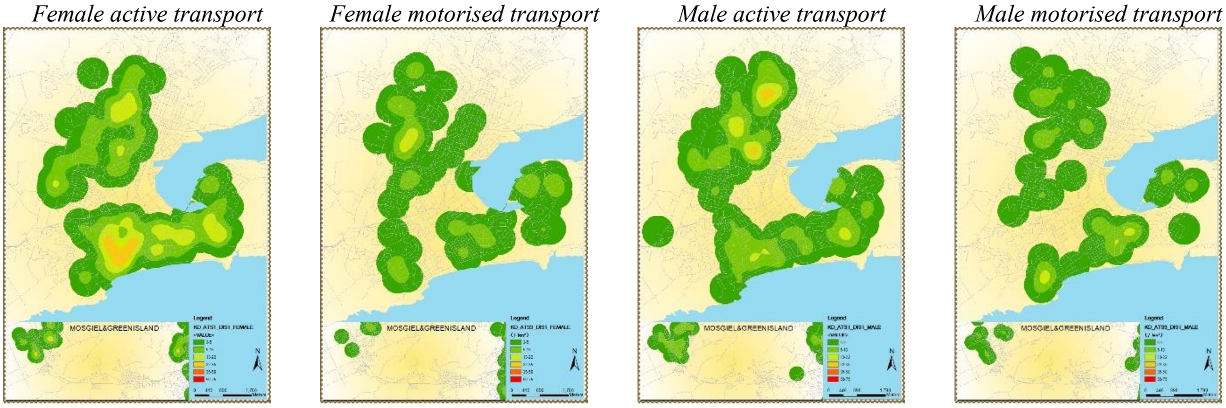
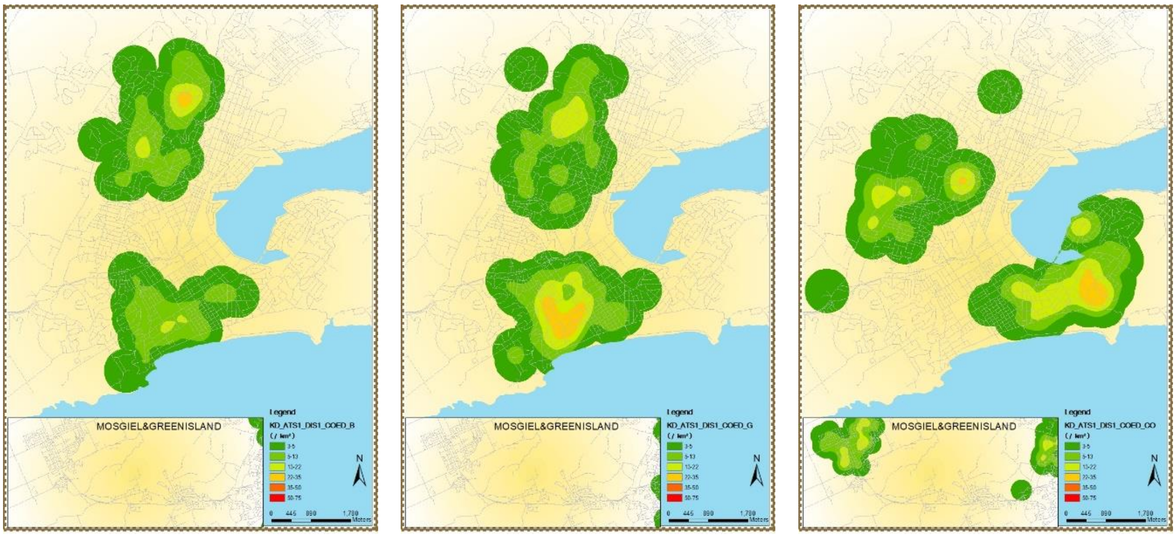



Figure 5 KDE distribution based on gender and distance

*Active transport and boys' school attenders* | *Active transport and girls' school attenders* | *Active transport and co-educational school attenders*



*Motorised transport and boys' school attenders* | *Motorised transport and girls' school attenders* | *Motorised transport and co-educational school attenders*

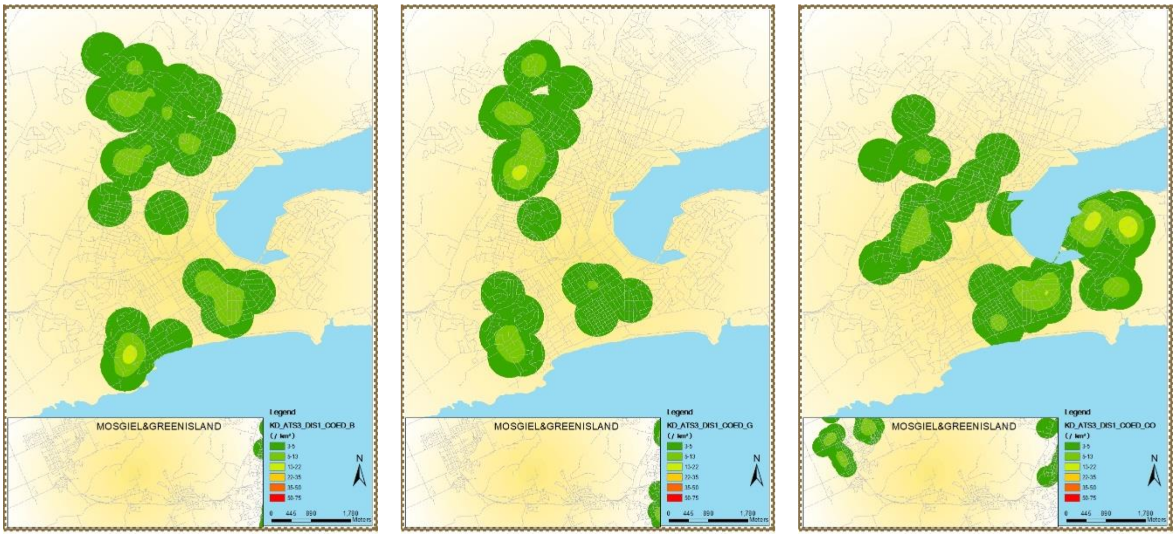


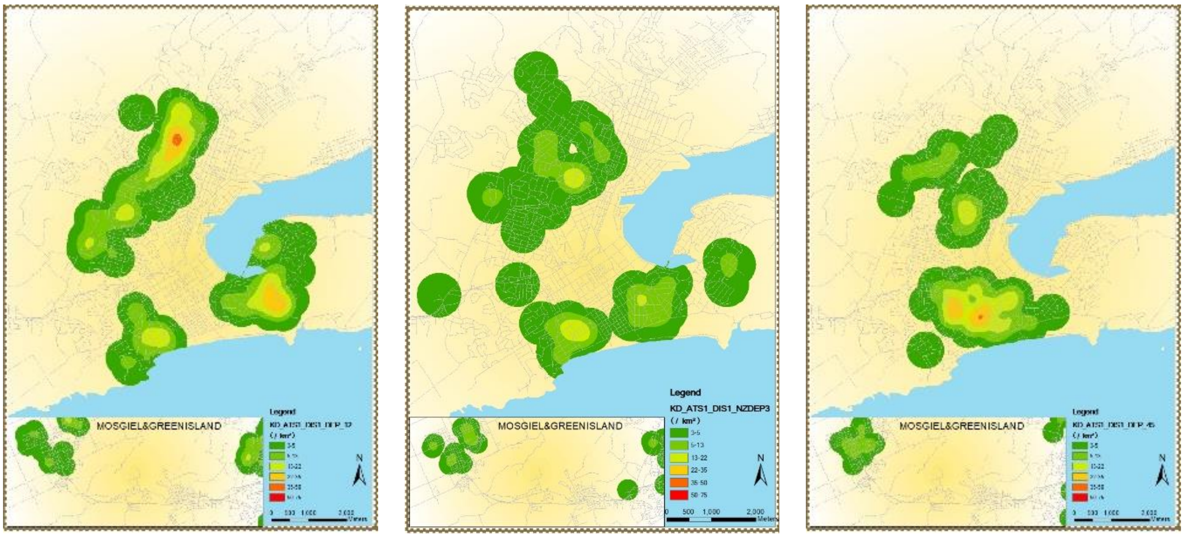

Figure 6 KDE distribution based on ATS and co-educational school attendance status within walking distance

The 2nd order KDE mapping based on transport mode in different genders and co-educational school attendance status based on walking distance should be considered together for discussion. By comparing the maps in Figure 5 and 6, the patterns revealed a significant relationship between gender and active transport choices. The reason for this is probably the location of the single-sex high schools in the neighbourhood: Queens High School (girls only) (a large number of girls participated in the BEATS study in this school) and King's High School (boys only) in the south of the city, and John McGlashan College (boys only) located in the north (refer to figure 1). High density patterns can be witnessed at St Clair for females and the second-lowest density pattern for males, indicating that female adolescents in this region tend to actively commute to school much more than females in other places, whereas males living in this area do not show the same trend even though both Queens high and the King's High are in the neighbourhood. Some area (such as the Andersons Bay area) show higher density of adolescents attend co-educational schools using active transport more than those living in neighbouring Waverley even though the closest school in the neighbourhood for both locations is the same school at Andersons Bay.

By comparing the results of KDE based on gender and co-educational school attendance, and with the fact that single-sex schools in the neighbourhood of some adolescents, this research can suggest that adolescents actively commute to single- gender schools more frequently when the single-sex schools are located in the neighbourhood. In conclusion, the direct result from the KDE patterns did show a relationship over space between transport mode selection and both gender and co-educational school attendance corresponding with home-school distance.

## 4.4. Transport mode and New Zealand Deprivation Index

*Active transport & less deprived* *Active transport & medium deprived* *Active transport & more deprived*




*Motorised transport & less deprived* *Motorised transport & medium deprived* *Motorised transport & more deprived*

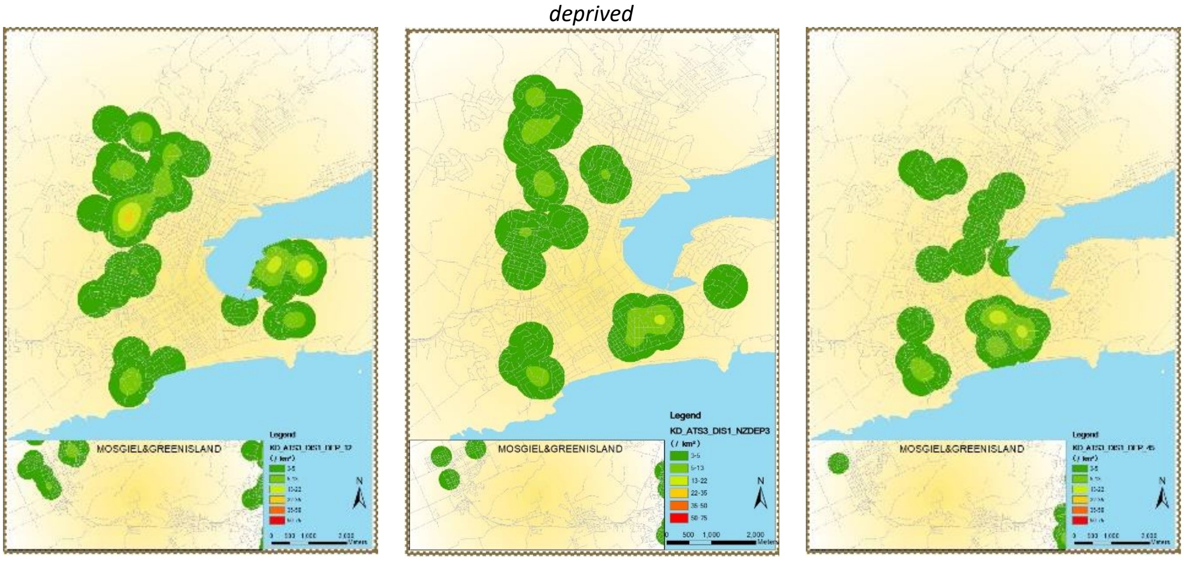



Figure 7 KDE distribution based on ATS and home deprivation within walking distance

The 2nd order KDE patterns based on ATS and home deprivation within walking distance revealed clear differences across the combination of two variations. With a less deprived neighbourhood, Maori Hill and Andersons Bay area show high density of active transport users, while adolescents living in Waverley and Belleknowes are more likely to have a motorised commute to school. With a more deprived neighbourhood, adolescents living in Forbury, St Clair and Mornington tend to actively commute to school more, while some adolescents in St Kilda prefer motorised transport. Therefore, this research assert that adolescents living in different places across the city with the same level of neighbourhood deprivation show clustering in terms of transport mode to school, and it can be concluded that neighbourhood deprivation is a factor that shows an association with adolescents' ATS over space.

## 4.5. Transport mode and intersection density within walking distance


Figure 8 KDE distribution based on ATS and intersection density

2nd order KDE distribution maps based on transport mode and intersection density within walking distance indicated clear patterns in terms of both location and density level between active transport users and motorised transport users. Adolescents living in St Clair, Andersons Bay, Roslyn and Mornington with medium-level intersection density tend to actively commute to school more, while locations such as Waverley and Bradford show higher density of motorised transport than other suburbs. Moreover, in St Kilda and Forbury adolescents with high intersection density around home use active transport more than those in other places. In this case, it can be asserted that intersection density is one of the factors that show an association with adolescents' active transport mode choices.

## 4.6. Transport mode and residential density within walking distance

*Active transport and medium ResD* | *Active transport and high ResD* | *Motorised transport and medium ResD* | *Motorised transport and high ResD*

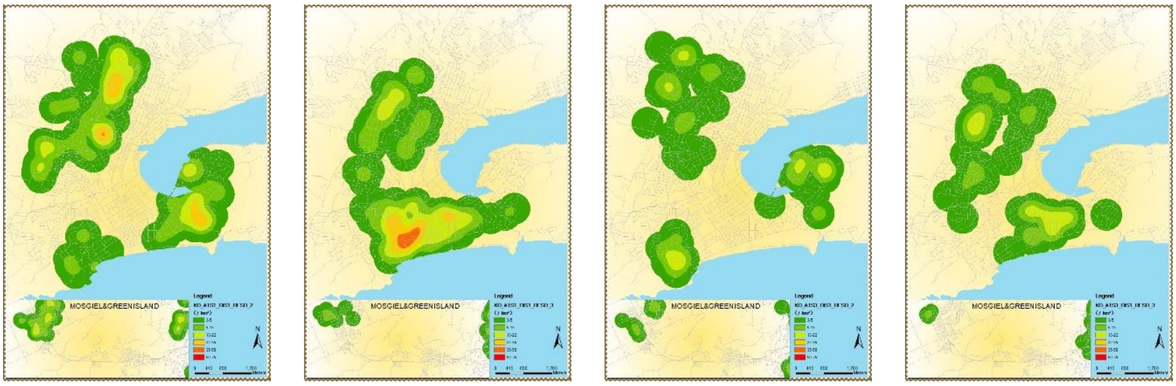
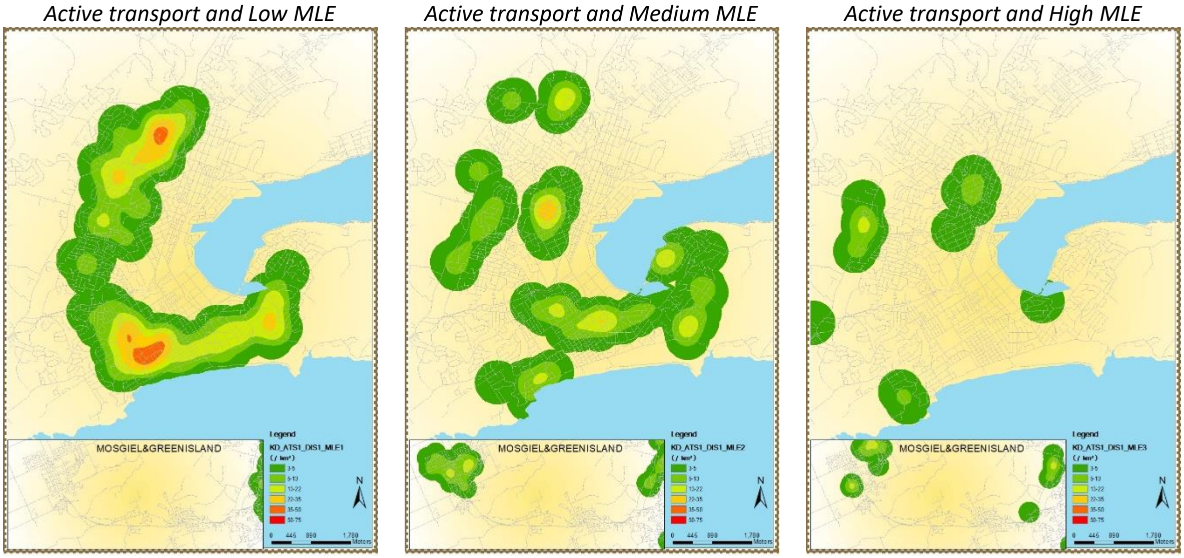



Figure 9 KDE based on ATS and residential density

The 2nd order KDE distribution of ATS based on residential density within walking distance presents some differences among locations across the transport mode and residential density. The research did not present low-level residential density adolescents as only a few adolescents belong to this group. For the medium-level residential density, Roslyn and Andersons Bay show a clear trend of using active transport, while Waverley and Corstorphine indicate that more adolescents use motorised transport. With high residential density, St Clair shows very high-density patterns of active transport, indicating the number of adolescents using the active transport mode, while this trend was not witnessed in terms of motorised transport. In this case, this research suggests that although the density levels of the patterns are different, the ATS of users under the same residential density level still changes based on different locations.

## 4.7. Transport mode and mixed land use entropy (MLE)

*Active transport and Low MLE* | *Active transport and Medium MLE* | *Active transport and High MLE*



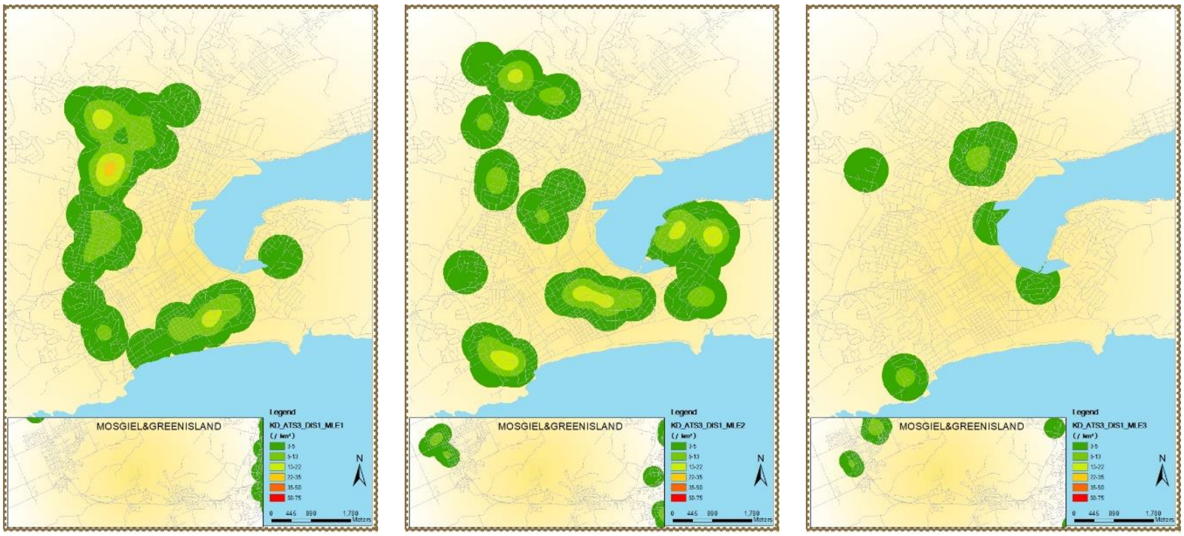


Figure 10 KDE based on ATS and MLE

KDE distribution based on mixed land use entropy (MLE) show a positive relationship to transport modes over space since most of the maps indicate that under the same level of both home-school distance and MLE, however, the patterns of motorised transport are overlapped by active transport patterns in terms of location, coverage and density level, which means that at most of the locations adolescents tend to use active transport more than motorised transport. In this case, it is clear to assert that with MLE is related to adolescents' ATS choices to some extend but it needs verification from other methods to confirm the extent of relationship.

## 5. Conclusion

In conclusion, adolescents' ATS choices in Dunedin show a significant association with distance to school, which is the strongest correlate of ATS, and location. Within walking distance, adolescents tend to actively commute from home to school more than those who do not have schools located in the neighbourhood. With the distance as a basic condition, other ATS correlates, including gender, co-educational status and home deprivation along with intersection density, residential density and MLE show associations with ATS over space, while body mass index and ethnicity are not applicable in terms of this result.

By way of limitation the use of KDE as a spatial analysis method to detect possible features from density maps is a visual method. Therefore, KDE result needs to be backed up by quantitative spatial analysis evidence to measure how and to what extent the factors would affect adolescents' ATS choices. Even though the results are verified and compared to the results generated from a local version of Moran's I which is local indicators of spatial association (Anselin, 1995) which created clusters and outliers for adolescents' showing the clustering status of active transport, the results of this paper alone are predictive visual analysis results, which will be verified and evaluated with quantitative spatial analysis methods such as geographically weighted regression (GWR) in the future.

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