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Research paper

Comparing conventional and PPGIS approaches in measuring equality of access to urban aquatic environments

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HIGHLIGHTS

- Combines PPGIS and advanced spatio-temporal accessibility modelling techniques.
- Examines access to aquatic environments from environmental justice perspective.
- Inappropriate accessibility measures may return distorted or false interpretations.
- Differences in accessibility related to income status and car ownership was found.
- Waters should be included in environmental justice and equity of provision studies.

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ABSTRACT

Assuring equal accessibility to public outdoor and recreation services is important because of the potential health and social welfare implications. The focus has primarily been on parks and other green spaces but should be expanded to include also the aquatic environments and the numerous recreational opportunities they have to offer. As the accessibility standards and approaches on ensuring equal accessibility to green spaces are often based on purely spatial measurements, this research examined the equality of accessibility of aquatic environments by combining spatio-temporal dimensions of accessibility with person-based measures. Public Participation GIS (PPGIS) method used in the study provided multifaceted knowledge on the person-based accessibility patterns related to aquatic environments in Helsinki Metropolitan Area, Finland. This paper demonstrates how an advanced GIS-based analysis combining both objective and subjective measurements of accessibility can result in more detailed and even contradictory outcomes compared to traditional spatial measures. The results indicate that a common presumption of a nearest service available made in studies on accessibility and environmental justice may have notable impacts on results or even return unfounded interpretations. Results also indicate that there are significant ($p < 0.05$) differences in accessibility in the study region related to income status and car ownership. We conclude that PPGIS approaches can provide valuable information to accessibility research, studies on environmental justice and provide additional approaches for the planning and management officials of public recreation and outdoor services.

1. Introduction

Public recreation opportunities, such as those provided by parks and green spaces, are vital to the quality of life of urban residents. Access to green and other public spaces has been widely studied often in the context of environmental justice and equity of provision (Higgs, Fry, & Langford, 2012; Neutens, Schwanen, Witlox, & de Maeyer, 2010). While the concept of environmental justice as a whole is broad (Schlosberg, 2013), the leading spatial focus has been on the use of, and access to, parks and other elements of green infrastructure and their potential health effects (Barbosa et al., 2007; Boone, Buckley, Grove, & Sister, 2009; Sister, Wolch, & Wilson, 2010; Tyrväinen et al., 2014; Tzoulas & Greening, 2011; Wolch, Byrne, & Newell, 2014). Accessibility, usability and the related health effects of natural waters and other blue bodies of infrastructure have also evoked some interest (Cox, Morse, Anderson, & Marzen, 2015; Korpela, Ylén, Tyrväinen, & Silvennoinen, 2010).

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Spatial approaches, such as those associated with geographic information systems (GIS), are often used to study access to green spaces (Coutts, 2008; Wolch et al., 2014). Yet, residents' accessibility and usage related to aquatic environments has not gained as wide consideration as the green spaces in the literature. When determining the accessibility of an amenity, the requirements and preferences of individuals and their capacity to access and participate should be recognised. Within accessibility research however, non-spatial approaches have attracted less attention (Kwan & Weber, 2003; Wang, Brown, & Mateo-Babiano, 2013).

Developing a more realistic approach to questions of access and equality necessitates that we take into account individual and other non-spatial measures thus moving away from an over-reliance on spatial and temporal measures of accessibility (Ferreira & Batey, 2007; Kwan & Weber, 2003; Salonen, Toivonen, Cohalan, & Coomes, 2012; Spinney & Millward, 2013). Service provision and equality of access are often studied with a presumption of focusing on the nearest service available instead of examining the places people actually prefer to use (Boone et al., 2009; Comber, Brunsdon, & Green, 2008; Higgs et al., 2012; Lee & Moudon, 2006; Macintyre, Macdonald, & Ellaway, 2008; Oh & Jeong, 2007; Sister et al., 2010). We should not assume that it is only the proximity of a service that determines its usage, but also understand that individual preferences and other social-psychological factors may be factors in the use of certain places (Kaczynski, Potwarka, & Saelens, 2008; Wang, Brown, Liu, & Mateo-Babiano, 2015).

Public participation GIS (PPGIS) has not often been applied in accessibility studies (Salonen, Broberg, Kyttä, & Toivonen, 2014; Wang et al., 2015), though it can be used to provide an additional layer of individual, person-based experiences in respect of accessibility. The PPGIS method used in this study provided multifaceted knowledge on the person-based accessibility patterns and on the places people actually use for various activities by the water. The data offered an option to compare different accessibility measures. Euclidean distance is often used as a measure in environmental justice and accessibility studies and was here compared to alternative accessibility measures provided by a combination of PPGIS and spatial accessibility approaches. The objective was to examine different types of dimensions and measurements of accessibility and related effects on the resulting accessibility patterns. By combining these different dimensions we aim to shed a light on the ongoing discourse of accessibility and its measurements.

The research presented in this article examined the accessibility of aquatic environments, namely the sea, lakes, rivers, streams and ponds. It combined PPGIS data with an advanced accessibility modelling tool 'MetropAccess', that has been created to measure accessibility by different travel modes in a comparative manner. The study follows Geurs and van Wee (2004) in defining accessibility "as the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)" but studies accessibility with a person-based viewpoint.

The current study also aimed to examine whether access to aquatic environments was sensitive to differences among various socio-demographic groups and their preferences on accessing different places. Such comparisons offer an interesting equality point of view as the person who, for financial or other reasons, has to walk rather than drive a car or use a bike may face considerable difficulties in accessing services compared to a fellow citizen with a car or a bike (Salonen & Toivonen, 2013).

The study demonstrates how an advanced GIS-based analysis combining both spatial and person-based measurements of accessibility can result in more detailed and even contradictory outcomes compared to solely spatial measures. The study also demonstrates the relevance of the PPGIS approach in combining person-based and spatial measures when studying accessibility within the context of environmental justice.

2. Methods

2.1. Study area

The Helsinki Metropolitan Area (HMA) consists of four independent city units, Espoo, Helsinki, Kauniainen and Vantaa (Fig. 1). Helsinki is the capital of Finland and forms with its surrounding three cities the HMA region. The cities of Helsinki and Espoo border the Baltic Sea in the South. Vantaa is a city in the Northern part of the region extending across a large geographical area from East to West. Kauniainen is a small independent city entirely surrounded by the city of Espoo.

The Baltic Sea borders the southern part of the region. The river *Vantaanjoki* is a major river running through Vantaa and Helsinki and draining into the Baltic Sea. The largest lakes are located in the northwest portion of the city of Espoo, most are part of Nuuksio National Park. In addition, both Vantaa and Espoo are criss-crossed by numerous small lakes, rivers and streams. In Kauniainen there is only one lake, other waters are mainly wetlands. The majority of the sea shoreline and that of the HMA's inland waters is open to the public and thus suitable for various activities.

2.2. PPGIS methodology for a place-based study of residents' usage and access to aquatic environments

Forming an understanding of residents' accessibility to public services is not only a theoretical but also a methodological challenge: Research that takes into account the spatial and person-based variables of accessibility requires access to advanced methodological tools. Recent developments in GIS science, especially in accessibility modelling and public participation GIS (PPGIS) however offer new possibilities for GIS-based and other location-based studies, and particularly for accessibility studies.

The SoftGIS methodology developed at Aalto University is an example of the PPGIS method for the collection of experiential knowledge concerning different physical environments (Kyttä & Kahila, 2011). This methodological approach is an advanced example of PPGIS enabling a collection of large data sets with user-friendly online applications (Brown & Kyttä, 2014). SoftGIS methods have been developed in close cooperation with urban planners and other land use professionals. Prior to this research many different SoftGIS-based studies were conducted in Finland and in Japan, Australia, the USA, and Portugal. Other PPGIS studies and large scale data collections have also been performed around the world (Alessa, Kliskey, & Brown, 2008; Brown & Weber, 2011; Cox et al., 2015; Elwood & Ghose, 2001; White, Kingston, & Barker, 2010).

In this study, an internet-based PPGIS survey using the SoftGIS methodology was used to study HMA residents' access to aquatic environments. In the "By the Water" survey (Fig. 2) the respondents used an online interface to mark the locations of the aquatic environments they use and indicate the activities they engage in at those places. They also described how they access these places in terms of mode of transport and visiting frequency. In addition, the respondents were asked to mark their home, places they perceive as inaccessible, places that were particularly valuable for them indicating values related to cultural ecosystem services such as spiritual, historical and educational activities, and their preferences for future land uses within aquatic environments in the HMA. The respondents also answered questionnaires as regards their opinions on usage and planning in respect of sea shore areas. This study focused on the mapped activity points since they

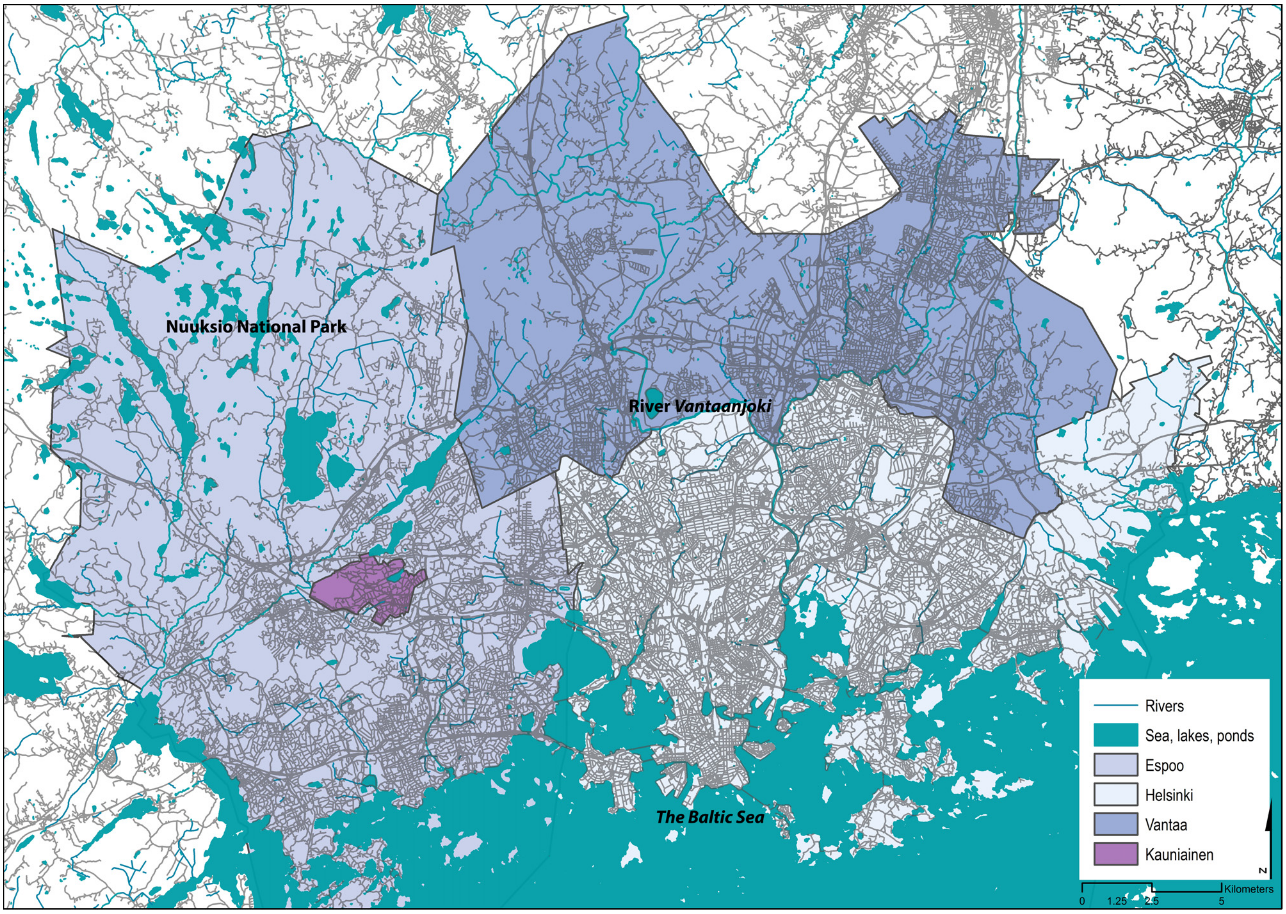

Fig. 1. Helsinki metropolitan area and the waters of the region.

represent the actual usage of different places and include knowledge on the mode of transport used to access them making them particularly valid for an analysis on accessibility. A more extensive analysis of the use preferences and other qualitative approaches to the data will be undertaken elsewhere.

The data was collected from across the entire HMA during late autumn of 2013. A random sample of 30 000 people aged between 15 and 75 years old was drawn from Finnish Population Register Centre. The 30 000 people were sent a letter by mail asking them to take a part in an internet survey. The mailing was carried out by an independent mailing company. Only a single mailing round was done. A total of 2151 full or partial online responses were received. Due to rather low response rate a random sample on 31 people from the original randomly sampled group was selected and contacted via telephone a few weeks after the original letters were sent. Of the 31 people 12 reported that they had received the letter, 7 said they did not remember receiving the original letter and a further 12 reported that they had definitely not received the letter. It subsequently emerged that the mailing company could not provide any proof of letter delivery.

The survey data was nevertheless representative of the HMA as a whole. Table 1 compares the self-reported socio-demographic characteristics of the survey respondents with those reported by the Statistics Finland, 2014. Sample results showed general consistency with the Statistics Finland HMA statistics on most socio-demographic variables (e.g., city of residence, age, gender, family type, income), however our sample had a greater number of people with an higher educational attainment level (Master's Degree: sample 31% *vs* Statistics Finland HMA 17%) while also consisting of proportionately less people living in apartment buildings (sample 62% *vs* Statistics Finland HMA 75%) and renting (sample 32% *vs* Statistics Finland HMA 42%).

2.3. Metropaccess-tool for modelling travel time

The Metropaccess-tool has been developed by a research group of the Department of Geosciences and Geography at the University of Helsinki (Accessibility Research Group, 2014; Salonen & Toivonen, 2013). The MetropAccess-tool has three different functions; the MetropAccess-Digiroad, the MetropAccess-Reititin and the MetropAccess-Travel Time Matrix, all of which have several features. All of the calculations and data used are based on open data sources.

The MetropAccess-Travel Time Matrix (M-TTM) was the tool used in this research. It is a dataset that consists of travel time and distance information of travel routes across the Helsinki Metropolitan Region. The routes have been calculated between all SYKE YKR grid cells (N = 13 230) by walking, public transportation and private car consisting, in total, of more than 175 million routes. The SYKE YKR grid is a spatial dataset including various socio-economic variables that are represented in cells of 250 × 250 m. The travel times and distances by private car are based on the MetropAccess-Digiroad tool using the door-to-door approach, i.e., walking, searching for a parking space, speed limits and traffic conditions etc., are all taken into account. Public transportation travel times and distances have been calculated using the MetropAccess-Reititin tool which also takes into account the whole travel chain from origin to destination. Walking times and distances are based on OpenStreetMap networks using the MetropAccess-Reititin tool by disabling all motorised transport modes in the calculations. The

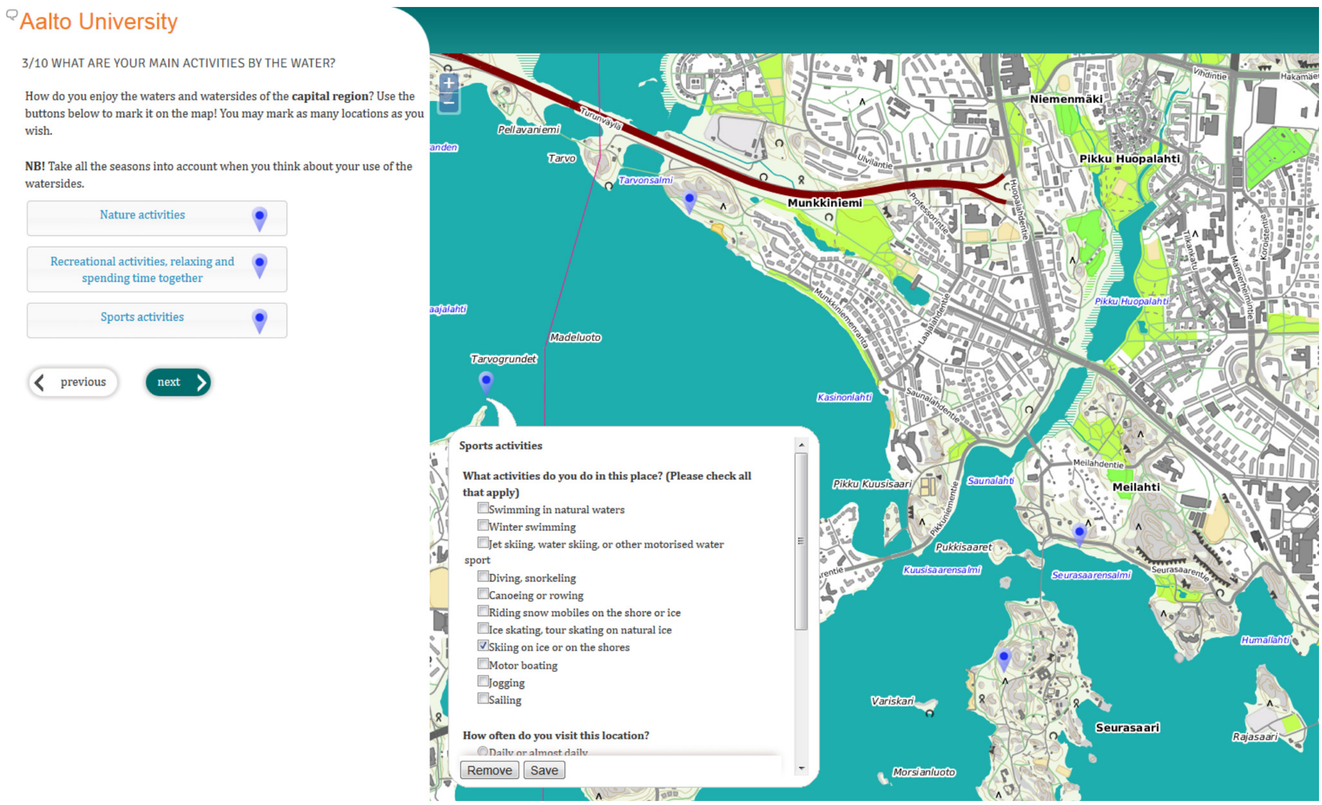

Fig. 2. Respondents were asked to map their main activities by the water (sports, nature and recreation activities). After each marking, a pop-up window opened and asked in detail what types of activities the respondent actually did there, how they accessed the place and how often.

walking speed in the matrix calculations is 70 m/min. While M-TTM does not include travel times for cycling, a defined factor (walking time divided by four) was used to simulate travel time data for this transport mode. Dividing the walking speed by four gives a cycling speed of 16.8 km/h which corresponds to the average cycling speed used in Helsinki region's transportation Journey Planner (17.0 km/h) (Accessibility Research and Group, 2014).

While M-TTM is a specific dataset for the HMA, it is also possible to do similar kinds of accessibility analyses with these tools in other city regions providing public transportation schedules in standard GTFS-format (Google GTFS, 2015). At the current time of writing, there were approximately 900 cities globally providing such GTFS data. Analysing accessibility by private car is also possible in various cities around the world by using specific Routing APIs provided for instance by *Nokia* (Nokia Here Routing, 2015) or *Google* (Google Directions API, 2015).

2.4. Accessibility analysis

Accessibility was analysed with the M-TTM and ArcGIS 10.2.2 tools using four different types of accessibility measures (Fig. 3) to compare whether different measurement types have an effect on the results in terms of equality of access. Accessibility measures for each respondent were calculated from respondents' home (origin point) to mapped activity points and for one measure to the nearest waters (destination points). Studies on environmental justice and equality of access often measure access based on the idea of nearest service available (Boone et al., 2009; Sister et al., 2010). Distance to a nearest service available is also a commonly used measure in accessibility studies as proximity to a service influences visitation frequency—the phenomenon known also as "distance decay"(Cohen et al., 2007; Eldridge & Jones, 1991; Spinney & Millward, 2013). To return similar measures, the Euclidean distance from respondents' home to the nearest waters was calculated (measure A). We also calculated Euclidean distance (measure B) and a road network distance (measure C) from the respondents' home to activity points marked by the respondents, both also often used as measures of accessibility to potential or actually used places (Higgs et al., 2012; Kyttä, Broberg, Tzoulas, & Snabb, 2013; Oh & Jeong, 2007; Wang et al., 2015) The road network distance was modelled with the M-TTM tool based on the knowledge of a mode of transport used by the respondent to access each activity point. The fourth access measure was an optimised travel time (measure D) along the road network to aquatic activity points from the respondent's home. For this measure the mode of transport used was also taken into account and modelled with the help of the M-TTM tool. All but measure D were calculated as metric distances; measure D was based on time distance.

Of the original 8763 activity points marked by the respondents 7360 were included in the further accessibility analysis. 1403 points were omitted because the activity point was located somewhere offshore and so was only accessible by private boat. If an activity point was located on islands accessible from the mainland by public transport ferries a destination point for these activity points was directed to the ferry dock on the mainland. From the ferry dock onward access to the island is equal for all no matter which transport mode was used to access the dock. Euclidean distance to the nearest water (measure A) was calculated from the respondents' home to the nearest waterscape. To determine the 'nearest waters' calculation a data set containing all water areas in the region from the topographical database provided by National Land Survey of Finland was used. Euclidean distance (measure B) calculations to the activity points were calculated for all of the marked points since those did not require knowledge of a mode of transport. Travel times (measure D) and distances (measure C) were calculated for all of the points where a mode of transport was reported by the

Table 1
Socio-demographic characteristics of survey respondents (N = 2031).

		By the water-survey (%)	Statistics Finland 2012 (%) © Statistics Finland, [StatFin database 2012], [2014,27.10]
City of residence	Kauniainen	1	1
	Vantaa	15	19
	Espoo	24	24
	Helsinki	60	56
Gender	Male	43	48
	Female	57	52
Age	15 – 24	12	15
	25 – 34	19	20
	35 – 44	15	17
	45 – 54	19	16
	55 – 64	20	14
	65 –	15	17
Native tongue	Other	5	12
	Swedish	7	6
	Finnish	88	82
Education	Basic	8	32
	Secondary Education	40	37
	Bachelor's Degree	22	14
	Master's Degree	31	17
Family type	Single	23	35
	Couple	41	32
	One adult + kids	5	5
	2 adults + kids	28	25
	other	3	3
Residential type	Detached house	15	15
	Rowhouse or semi-detached	23	9
	Apartment	62	75
Resident ownership	Housing cooperative	5	6
	Renter	30	42
	Owner	65	52
Car ownership	Yes	71	–
	No	29	–

respondent. Due to the nature of the data which has one origin but several destination points it was necessary to calculate an average value from multiple distance measures in order to create a single accessibility measure for each individual. This meant that to get a distance value for each individual an average value needed to be returned from all of the distance measures calculated between the respondent's home and the places he/she visits. Median travel time ($N = 1073$) and travel distance ($N = 1073$) were returned for each respondent who both marked their home onto the map and reported the mode of transport used to access the activity points. A median value was used instead of a mean value due to the nature of skewed data. Median value was also calculated for the Euclidean distance to activity points ($N = 1503$). For the Euclidean distance measure to the nearest water ($N = 1503$) there was no need to create an average value as there is only one origin and one destination point per person. As the Euclidean distance calculations do not require knowledge of the mode of transport used they could be returned to each respondent who had marked their home on the map.

3. Results

3.1. Access patterns to aquatic environments

As Fig. 4 shows, marked activity points are concentrated along the sea shoreline of the cities of Helsinki and Espoo as well as the river *Vantaanjoki* and around the largest lakes situated in the north-eastern and north-western parts of the metropolitan area. 60% of the points were marked along the seashore while the other 40% were marked on the shores of lakes, rivers, streams or ponds. Each respondent marked, on average, 5.6 activity points. Respondents in the main marked points located in the city of their residence: respondents from Espoo marked 83% of their points on the shores of Espoo, respondents from Helsinki marked 93% to Helsinki, respondents' from Vantaa marked 79% to Vantaa, while those from Kauniainen located 75% of their points within the borders of Kauniainen.

Each of the four different access measures provides a different impression of the accessibility patterns in the study region. Descriptive statistics of the different measures are shown in Table 2. Access to the nearest waters measured from the respondents' home, suggests that accessibility patterns are good: the median distance is less than 300 m while the maximum distance is only a little over 1 km. The water areas respondents actually visit are however often located much further away, on average, a little over 2.5 km measured as a Euclidean distance. The difference between the two Euclidean distance measures indicates that respondents do not necessarily utilise the nearest water areas or shorelines to their homes. The median travel distance (measure C), measured along transportation routes based on knowledge of the mode of transport used, is on average 1.83 times longer than the median Euclidean distance to the same places. Travel times to utilised places are also long: people travel more than 25 min to access their favourite places by the water. As the results in Table 2 suggest, the proximity of water areas to the respondent's home is actually very different from the respondents' real access patterns in terms of both travel distance and time.

A further examination of the similarity or correlation between the different distance and time measures corroborates previous results (Table 3). The statistical distribution of the computed distances and travel times was highly positively skewed, so Spearman's rank correlation coefficient was selected to test for the strength of relationship or dependence. There is only a very weak association between measures A and B as well as between measure A and C and measures A and D. High correlations between measure B and C and B and D as well as between C and D are however evident as the travel time naturally increases as distances increase.

3.2. Comparison of various respondent groups' access patterns to aquatic environments with different accessibility measures

In addition to previous inspection a comparison between different groups of individuals and different accessibility measures was conducted to test whether there were differences in accessibility patterns.

A set of commonly used socio-demographic background variables was chosen to examine the patterns of accessibility between different respondent groups. As the statistical distributions of the computed distances were all highly positively skewed we used a Mann–Whitney *U*-test to determine whether there were differences between the various socio-demographic groups described in Section 2. The continuous distributions for all of the test variables were similar for the two sub-groups as assessed by visual inspection. Thus, the median values are reported and used to compare the possible differences between groups.

Population sub-groups that showed significant differences in accessibility patterns are presented in Table 4. Level of education and language did not show any differences in accessibility with any of the measures and so are not reported.

While there are many significant differences, only one socio-demographic determinant shows significant differences across all

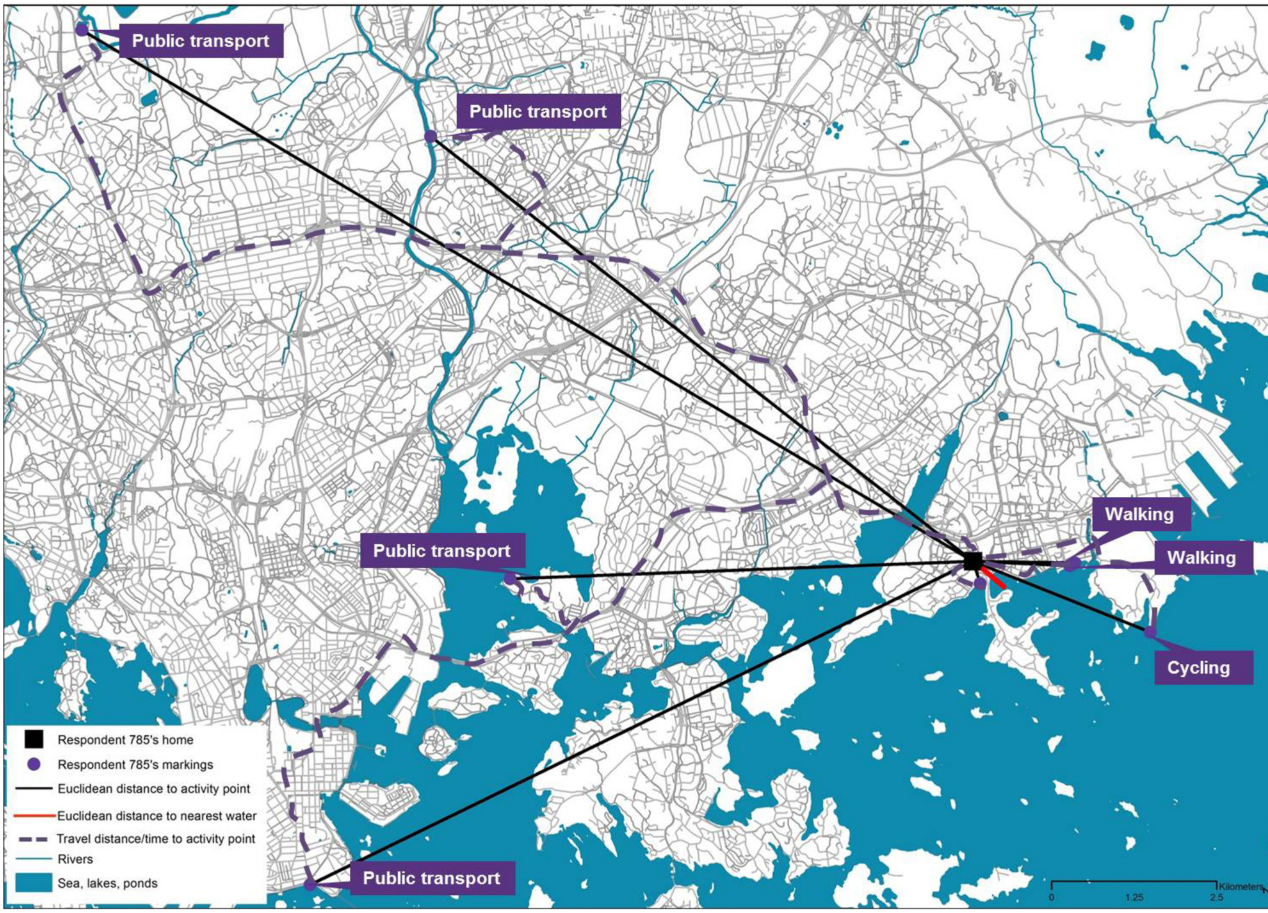

Fig. 3. Measures of accessibility used in the accessibility of aquatic environments analysis.

four accessibility measures: access differs for those who own and for those who do not own a car.

Travel time to aquatic environments was significantly shorter statistically for car owners than for non-car owners. In terms of travel distance, car owners access aquatic environments further away than those of non-car owners. However, the travel time differences are very small: the average travel time for people with a car is 26 min and only 4 min more for people without a car. The optimised travel distance was on average a little more than 5.5 km for those who drive a car and 3.8 km for those who do not. Euclidean distance to activity points demonstrates similar types of results only with shorter distances. As for the nearest waterscape available, accessibility in terms of distance was shorter for car owners than for non-car owners.

Respondents' income status showed a similar pattern. Access to water of those above the HMA median income level was statistically significantly better than for those below the median income level except in relation to measure B. In terms of travel time, access is shorter for those above the median income level than for those below it. In terms of travel distance, those above the median income level access aquatic environments further away than those below it. These differences were also statistically significant. Measuring the Euclidean distance to activity points provides similar results, but the differences were not statistically significant. In addition, the nearest waters were located much closer to respondents' homes for people above the median income level than for those below it.

Apart from the two above-mentioned socio-demographic variables, accessibility patterns to aquatic environments in terms of travel time (measure D) do not seem to differ statistically significantly related to age, gender, home ownership, type of residence, employment or family status. However, a Mann–Whitney *U* test run with the other accessibility measures (measures A, B and C) showed different results. When accessibility is measured with the presumption of a nearest available service or as network distance to activity points seven out of nine background variables show statistically significant differences between different socio-demographic groups. Where accessibility is measured with Euclidean distance to places actually used by respondents, five out of nine variables show statistically significant differences. There are clear differences in the results between different respondent groups when the measurement of accessibility changes. A good yet demanding way of measuring accessibility by travel time results in the least differences between different respondent groups. Travel distance to utilised places, shows a lot more variation in the level of accessibility between different respondent groups while the measure of a nearest available service shows similar patterns. Euclidean distance to utilised places also showed more differences than travel time.

3.3. *The geographical variation of accessibility*

Additional spatial aspect of accessibility was studied by running Mann–Whitney *U* tests related to the respondents' city of residence. The results indicate that accessibility patterns differ statistically significantly if a respondent lives in Espoo as compared to the rest of the region when measured with A, B and C, however not if measured with accessibility measure D (Table 5). This applies also to the case of Helsinki and Vantaa, but not to Kauniainen.

The statistical test leads us to surmise that accessibility is clearly related to a place of residence in the HMA. However,

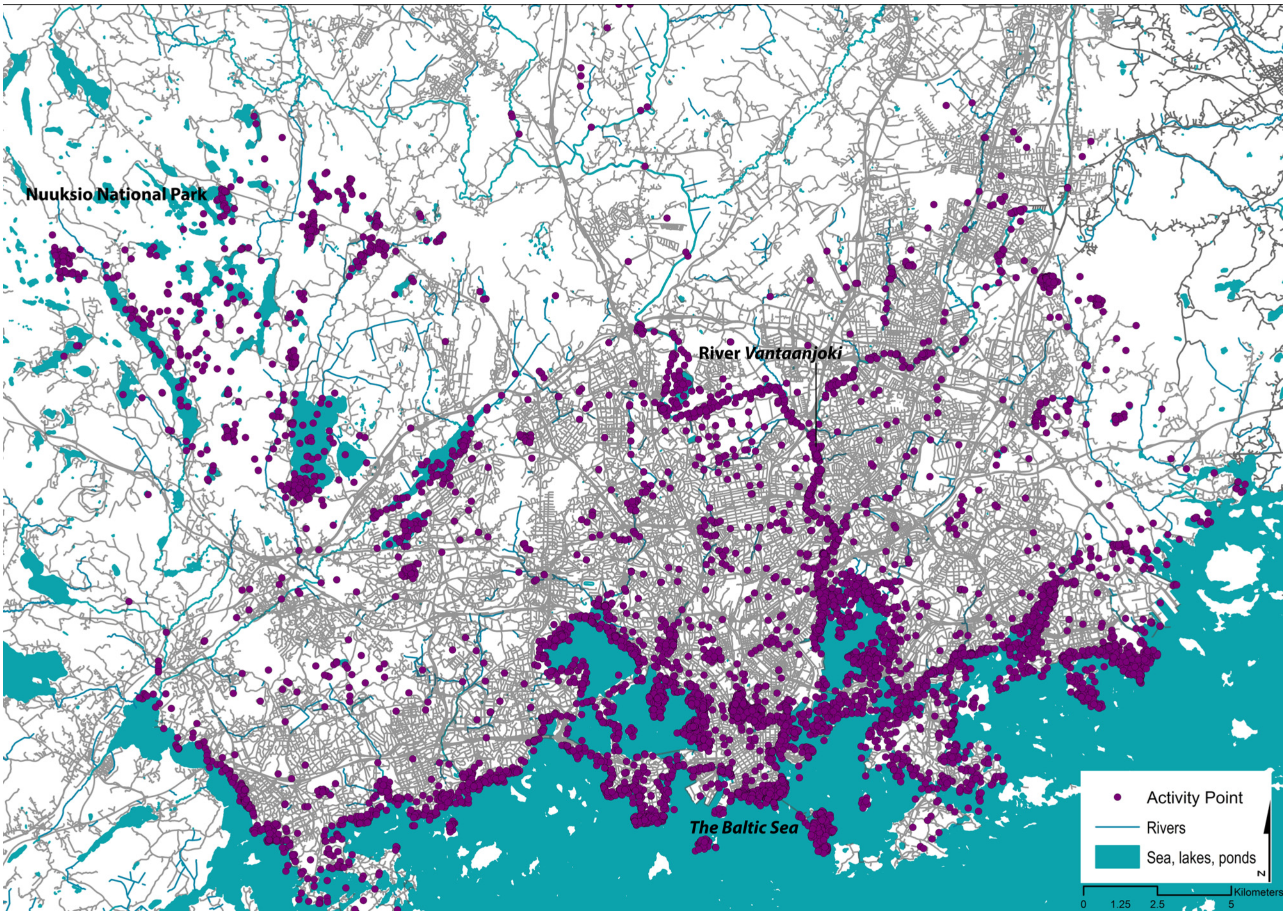

Fig. 4. Original activity points marked within the study area ($N = 8763$).

Table 2
Descriptive statistics of the different accessibility measures.

Descriptive statistics of the variables used in analysis						
	N	Median	Mean	Std. deviation	Minimum	Maximum
(A) Distance to nearest water (m)	1503	265.6	301	210.8	0.2	1,062.3
(B) Euclidean distance (m)	1503	2612.5	3971.6	3865.7	11.3	26,570.5
(C) Travel distance (m)	1073	4790.5	6294.6	5639.1	0	39,973
(D) Travel time (min)	1073	26.4	30.3	20.1	0	206

Table 3
Spearman's rank correlation coefficient testing for the strength of relationship or dependence of different accessibility variables.

The Spearman's correlation coefficients between respective distance measures.				
	(A) Distance to nearest water (m)	(B) Euclidean distance to AP (m)	(C) Travel distance to AP (m)	(D) Travel time to AP (min)
(A) Distance to nearest water (m)	–	0.049	0.14	0.068*
(B) Euclidean distance to AP (m)		–	0.884**	0.648**
(C) Travel distance to AP (m)			–	0.689**
(D) Travel time to AP (min)				–

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

as accessibility is in nature bounded to space, it is important to also include a spatial investigation to generate a distinct understanding of how accessibility patterns differ in relation to the place of residence in the HMA. A geographical map-based inspection was therefore undertaken in addition to the various statistical tests by aggregating each home point with knowledge of the median accessibility value to the YKR grid. As Fig. 5 shows, accessibility varies even within each city but also within very small geographical areas in each city. Moreover, there are clear spatial differences in accessibility even when measured with travel time regardless of the non-significant statistical evidence. The maps demonstrate that the geographical location of the specific residence as well as personal usage and travel patterns all have an impact on how easily aquatic environments can be accessed.

Comparing the differences between the four different accessibility measures, the novelty of taking into account the person-based

Table 4
Mann-Whitney U tests comparing different socio-demographic subgroups.

A) Distance to nearest water

Variable	Subgroup	*N*	MED[a]	Mean rank	*U*-test	*Z*-value	*p*-value
Age, young	Under 25	183	270	739,28		ns	
	25+	1243	266	709,7			
Age, old	65+	159	222	652,84	91081	−1.971	.049*
	Under 65	1267	270	721,11			
Gender	Man	640	266	749,23		ns	
	Woman	863	263	754,05			
Car ownership	No car	423	317	835,79	184095	−5.360	<.001***
	Car	1059	239	703,84			
Home ownership	Owner	917	247	616,79	190925	3.857	<.001***
	Renting/co-op	366	313	705,15			
Type of residence	Apartment	782	300	813,36	329892	5.708	<.001***
	Detached	721	216	685,45			
Employment status	Employed	892	271	764,26	247301	−2.227	.026*
	Unemployed, student, other	595	242	713,63			
Income	Less than HMA median	659	284	748,68	229544	−2.990	.003**
	More than HMA median	767	247	683,28			
Family status	Single	335	301	801,23	268412	2.355	.019*
	Couple, family w/kids, other	1168	253	737,88			

B) Euclidean distance

Variable	Subgroup	*N*	MED[a]	Mean rank	*U*-test	*Z*-value	*p*-value
Age, young	Under 25	183	2330	673,46		ns	
	25+	1243	2689	719,39			
Age, old	65+	159	2734	676,06		ns	
	Under 65	1267	2604	718,2			
Gender	Man	640	2769	777,84	259624	−1.987	.047*
	Woman	863	2526	732,84			
Car ownership	No car	423	2189	674,69	252239	3.798	<.001***
	Car	1059	2846	768,19			
Home ownership	Owner	917	2850	661,95	149519	−3.052	.002**
	Renting/co-op	366	2288	592,02			
Type of residence	Apartment	782	2450	722,21	258615	−2.771	.006**
	Detached	721	2952	784,31			
Employment status	Employed	892	2778	769,4	242712	−2.793	.005**
	Unemployed, student, other	595	2331	705,92			
Income	Less than HMA median	659	2479	698,9		ns	
	More than HMA median	767	2776	726,04			
Family status	Single	335	2633	741,82		ns	
	Couple, family w/kids, other	1168	2604	754,92			

C) Travel distance

Variable	Subgroup	*N*	MED[a]	Mean rank	*U*-test	*Z*-value	*p*-value
Age, young	Under 25	151	3298	459,69	57937	−2.396	.017*
	25+	874	4866	522,21			
Age, old	65+	95	3862	460,78		ns	
	Under 65	930	4814	518,33			
Gender	Man	448	5172	551,29		ns	
	Woman	625	4669	526,76			
Car ownership	No car	325	3840	465,09	140697	4.626	<.001***
	Car	735	5577	559,42			
Home ownership	Owner	651	5028	482,85	84728	−2.273	.023*
	Renting/co-op	287	4460	439,22			
Type of residence	Apartment	596	4343	508,42	125111	−3.377	.001***
	Detached	477	5712	572,71			
Employment status	Employed	632	4906	551,2	122795	−2.607	.009**
	Unemployed, student, other	429	4325	501,23			
Income	Less than HMA median	475	4132	480,65	144567	3.114	.002**
	More than HMA median	547	5212	538,29			
Family status	Single	245	4325	501,55	92745	−2.038	.042*
	Couple, family w/kids, other	828	4920	547,49			

D) Travel time

Variable	Subgroup	*N*	MED[a]	Mean rank	*U*-test	*Z*-value	*p*-value
Age, young	Under 25	151	25	511,80		ns	
	25+	874	27	513,21			
Age, old	65+	95	24	467,12		ns	
	Under 65	930	27	517,69			
Gender	Man	448	26	521,31		ns	
	Woman	625	25	548,24			
Car ownership	No car	325	30	574,72	105066	−3.127	.002**
	Car	735	26	510,95			
Home ownership	Owner	651	26	460,08		ns	
	Renting/co-op	287	29	490,88			
Type of residence	Apartment	596	27	553,54		ns	
	Detached	477	26	516,33			
Employment status	Employed	632	26	532,24		ns	
	Unemployed, student, other	429	27	542,43			
Income	Less than HMA median	475	28	531,98	120187	−2.067	.039*
	More than HMA median	547	26	493,72			
Family status	Single	245	28	560,80		ns	
	Couple, family w/kids, other	828	26	529,96			

* Statistical significance at the 0.05 level.
** Statistical significance at the 0.01 level.
*** Statistical significance at the 0.001 level.
[a] Median distance.

Table 5
Mann-Whitney *U* tests comparing respondents' accessibility between different cities of residency.

Variable	Subgroup	Distance to nearest water					Euclidean distance					Travel distance					Travel time				
		N	MED[a]	*U*-test	*Z*	*p*	*N*	MED[a]	*U*-test	*Z*	*p*	*N*	MED[a]	*U*-test	*Z*	*p*	*N*	MED[a]	*U*-test	*Z*	*p*
City of residence	Espoo	356	186	150294	−7.531	<.001***	356	3199	224638	2,862	.004*	248	6666	123873	5.041	<.001***	248	26	103413	.260	.795
	Other HMA	1147	293				1147	2490				825	4346				825	26			
City of residence	Helsinki	916	315	353885	10.359	<.001***	916	2345	223681	−5.502	<.001***	675	3978	102261	−6.539	<.001***	675	27	132724	−.327	.744
	Other HMA	587	189				587	3388				398	6660				398	26			
City of residence	Vantaa	214	191	108847	−4,945	<.001***	214	3923	163544	4,357	<.001***	136	6878	75113	3.375	.001***	136	26	65625	.565	.572
	Other HMA	1298	276				1289	2511				937	4588				937	27			

* Statistical significance at the 0.05 level.
** Statistical significance at the 0.01 level.
*** Statistical significance at the 0.001 level.
[a] Median distance.

variability in accessibility patterns is evident (Fig. 5). If accessibility is studied based on the Euclidean distance to the nearest waters available, the variation in accessibility is related to geographical patterns, namely, to how far from the shore a respondent lives. When, on the other hand, accessibility is studied in relation to person-based knowledge of actual usage it is evident that accessibility patterns are not as one-dimensional as the nearest water assumption leads us to believe. Map-based investigations then illustrated the variability in accessibility that is a result of combining the spatial and person-based components of accessibility.

4. Discussion

Empirical data on inhabitants' travel and usage patterns, related to aquatic environments in the HMA, was used to illustrate the sensitivity of the analysis on accessibility and related equality questions. The study presents an approach that combines the place based data produced by the PPGIS survey respondents with an advanced method for modelling spatial multimodal accessibility.

The results indicate how easily accessible aquatic environments in the HMA are when accessibility is measured as a straight line distances between respondents' homes and the nearest available waters. However, if respondents' true usage and travel patterns are taken into account the results change. As the results reflected in the following discussion show, the impressions related to equality of access generated are generally reliant on the measures and methods used to quantify accessibility.

4.1. Patterns of accessibility with different measures

Measuring accessibility to the nearest waters from respondents' homes suggests that the access to aquatic environments is good in HMA. This is however more a result of the spatial proximity of waterscapes to respondents' homes than of actual access patterns. Respondents tend to live close to aquatic environments because, as we can see from a detailed map of the region, the HMA is comprehensively covered by water areas be they sea shorelines, rivers, streams and lakes. As such, while measuring to the nearest waters provides a good overall impression of the spatial patterns of aquatic environments in the study region and the potentiality to utilise them, it fails to answer the question of actual accessibility. Undoubtedly the simplicity of the calculation of Euclidean distance to the nearest service available makes its use appealing (Shahid, Bertazzon, Knudtson, & Ghali, 2009; Sister et al., 2010). The limitations related to this measurement approach are, however, acknowledged in the literature (Salonen et al., 2012; Shahid et al., 2009) and as our results further demonstrate, it is a rather poor proxy for the studies on the spatial equity of the places actually used.

The PPGIS method made it possible to move beyond the presumption of the 'nearest service available' logic, by incorporating the actual utilisation and travel patterns into the study. As the results indicated, the proximity of the nearest water from one's home does not seem to have a clear influence on the actual usage or travel distances and times. Although all of the respondents live in close proximity to waters they still tend to utilise aquatic environments further away. Even though there would be nearby waters, they might not be interesting or desirable for people living next to them and thus never used.

Even though water is a dominant feature in most parts of the region, for various reasons people do not necessarily utilise their closest water body even though most marked their points to their home cities. While some parts of the region seem to be very well covered in terms of water features this does not automatically translate into good access which can often be the result of personal

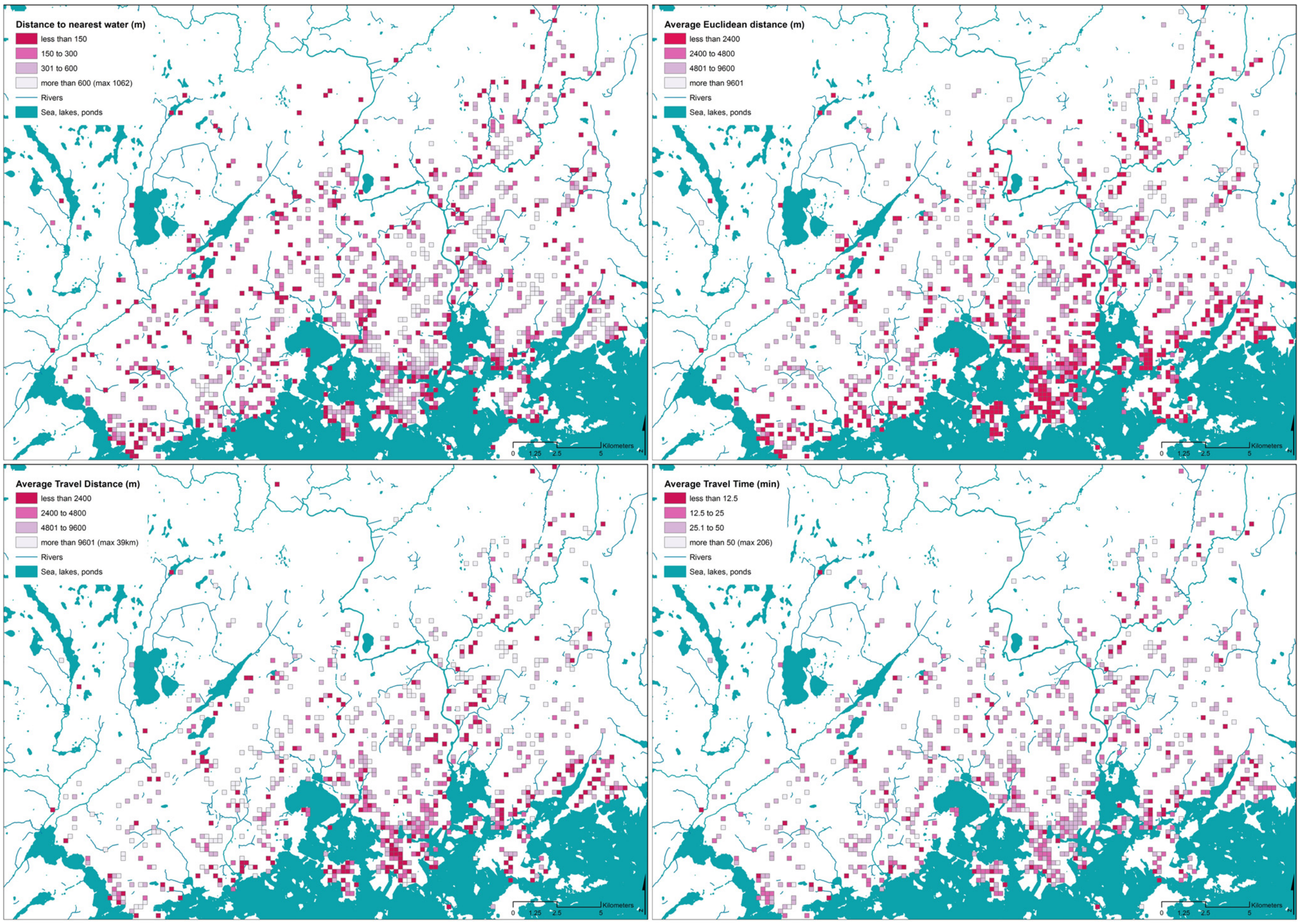

Fig. 5. Distance to respondents' nearest waters from their homes and average Euclidean, travel distance and travel time to the places they use by the water and in HMA aggregated to 250 × 250 m grid.

usage preferences or related to the existence of inaccessible areas and land ownership issues. A preference for visiting different shore types could explain some of the variance in the access patterns: There could be preference to visit the sea shore instead of inner land water. Further investigations on personal visiting preferences towards different types of aquatic environments could help verifying whether for instance a sea shore has a superior status compared to other shores.

The results indicate that measuring distance to the nearest service available alone is not enough to address the true multidimensional nature of the accessibility and equality of access concepts as it fails to incorporate any knowledge on the utilisation or perceptual patterns of accessibility. Previous studies have generated similar results on the importance of including non-physical variables in accessibility measurements (Lindsey, Maraj, & Kuan, 2001; Salonen et al., 2014; Wang et al., 2015).

Compared to the Euclidean distance to utilised places (measure B), the results on optimised travel distances (measure C) illustrate how long distances respondents actually travel, not only that how far such places are located from their homes. The advantage of this measure is that it calculates optimised travel distance along the actual transport route network based on the knowledge of the mode of transport used by the respondent. The novelty of the measurement is that it takes into account the different travel routes for different transport modes and calculates door-to-door journeys for each transport mode thus creating comparable accessibility measures. It is however a weak measure when the object of study is accessibility in terms of equality. Metric distances alone fail to capture the fluctuation of transportation caused by varying travel times with different modes of transport along the route network, something which the more robust accessibility measure, 'optimised travel time to utilised places', is able more easily to capture.

This study found that studying accessibility is not a straightforward process but rather one that needs to be thought thorough. Previous studies have also recognised that choosing a simple but easy to use measure can result in contradictory conclusions. As long as arbitrary travel thresholds (Boone et al., 2009; Lee & Moudon, 2006; Oh & Jeong, 2007), dissimilar accessibility measures (Ferreira & Batey, 2007; Salonen et al., 2012) and different presumptions on utilisation are incorporated into the studies on equality of accessibility and service provision, comparisons of findings and conclusions even within the same study area will remain problematic. As such, it is important to fine-tune the granularity of the spatial accessibility measures used and correctly calibrate their modal comparability (Salonen & Toivonen, 2013; Salonen et al., 2012). The commonly used and somewhat simplistic accessibility measure, 'Euclidean distance to the nearest service available', thus appears to be too simplistic if the goal is to understand equality of access to certain services. The study showed that this problem can however be easily overcome by using PPGIS methods.

While creating some new methodological opportunities, the data sources used in the study did however pose some limitations on the analysis. The low response rate in the survey was anticipated to some extent given the known drawbacks of using the Internet in this way. Other internet-based PPGIS surveys have shown similar patterns (Pocewicz, Nielsen-Pincus, Brown, & Schnitzer, 2012). In general however Finns are technologically well-oriented with the study region enjoying good access to the internet (Taipale, 2013). As such, concerns relating to datasets collected through computer-aided methods and whether they are representative enough due to the existence of a possible digital divide (Brown & Reed, 2009) should not be an issue here.

4.2. Equal access for all?

This study provided insights into multidimensional accessibility patterns in the HMA. No respondent would have to travel a distance of more than 1.3 km – measured as a straight line distance – from their home to the nearest waters. However, levels of accessibility differ statistically significantly when measured between several different socio-demographic groups, which suggests' that unequal accessibility patterns are found in the region. If accessibility is measured with knowledge of the waters actually used by the respondents, in this study measures B, C and D, the results and their interpretations change markedly.

The Euclidean distance to utilised places is computationally as simple a calculation as that to the nearest service available. The only difference is that it requires data on self-reported utilisation patterns from people of a certain region which can be easily collected with advanced yet easy to implement PPGIS survey methods. The identification of actual utilisation patterns and usage preferences in respect of different places not only offer a more sophisticated layer for accessibility analysis but can also produce important information for local planning, policy and decision making professionals. People in the HMA often choose to travel quite far to access aquatic environments: a little over 4 km at 25 min travel time, on average. This is however an approximation of all of the modes of transport used, so investigations into people's actual travel patterns relating to different modes of transport would benefit accessibility studies and the modal comparability of accessibility (Spinney & Millward, 2013).

The results showed that levels of accessibility differ statistically significantly between several different socio-demographic groups and with the various accessibility measures used so similar interpretations cannot be drawn from the comparison of different groups of individuals' accessibility with the different measurements used. Travel distance, Euclidean distance to utilised waters and Euclidean distance to nearest waters all showed statistically significant differences in accessibility thus giving a clear indication of the existence of inequality. However, all of these measures are based on distance calculations. The results of the metric calculations leads to interpretation of unequal situation due to lack of knowledge of the travel times with different modes of transportation that cause true differences between people in terms of easiness or uneasiness of access. Travel time showed statistically significant differences in accessibility related only to car ownership and income status. So there exists some inequality between the groups in the region even when accessibility is being measured with travel time. The differences in the results demonstrate how important it is to ensure that the chosen accessibility measure is finely tuned and also the importance of discussing thoroughly beforehand the possible effects of an overly simplistic measurement type.

In the HMA respondents who own a car travel further and faster to access aquatic environments than those without one. The HMA is well connected region in terms of the route network in general but also in terms of the public transportation network. That, and the large number of water areas in the region, probably explains the small differences in the travel times between car and non-car owners. Differences in travel distances were however greater for the car as opposed to non-car owners. This is understandable given that the car offers the most flexible and fastest way to access places, even those far from home, except within the Helsinki city centre area where parking conditions are challenging and public transport connections are at their best (Salonen & Toivonen, 2013). Having access to a car enables one to travel longer distances in less time in the HMA thus facilitating a broader selection of places to visit within a fixed timeframe compared to those without car.

Income status revealed similar results to that of car ownership. Respondents whose income is above the median level in the HMA also travel further and faster compared to those who earn less than the median income. A respondent has good access to aquatic environments in terms of travel time especially if their yearly income is above the median. This could be partly a result of access to more expensive housing next to the sea shore. However, as that is not the case within large areas in East-Helsinki it cannot be the only reason. The longer travel distances of the respondents who earn more could also result from the possibility of moving more easily around the region and away from the immediate vicinity of one's home compared to those earning less. Having a low wage does not directly equate to having poor access to aquatic environments rather it manifests itself by confining those to travelling shorter distances and longer times. However, it seems that earning less than the median income in the HMA and not owning a car may cause greater difficulty in accessing aquatic environments in the HMA compared to those with access to a private car and with bigger yearly income. This is an important point given the environmental justice perspective of the study and thus it should be of immediate interest for those planning and managing the shoreline areas in the region. As such, it would be fruitful if future research studied how to implement such findings in relation to planning and management practices and policies.

Even when the statistical analysis revealed differences in accessibility between cities in the region a visual inspection of the accessibility patterns on a map led to different conclusions. Geostatistical methods such as geographically weighted regression designed to study the issue of accessibility from a person-based point of view joined with an analysis on a preference for visiting different shore types could provide a better understanding of local accessibility patterns. More person-based research on usage preferences and accessibility would thus be beneficial for planning, management, policy and decision making professionals whose decisions impact transport networks and the provision of resources and in this way the overall accessibility of services in certain regions.

5. Conclusions

While it is widely acknowledged that accessibility is not a one dimensional concept and is by no means limited to geographical factors it is still often operationalised as such. This research demonstrated the multifaceted concept of accessibility and combined the spatio-temporal and person-based dimensions of accessibility to study the accessibility patterns of aquatic environments in the Helsinki Metropolitan Area. By combining PPGIS data and advanced spatio-temporal accessibility modelling techniques and using four common but different accessibility measures, the study illustrated how and to what extent overly simplistic or inappropriate measurements can have a detrimental effect on the results of accessibility. The research suggested that the common presumption of a 'nearest available service' may have a discernible impact on results even to the extent that interpretations are significantly distorted. The study showcases the relevance of person-based measures within accessibility studies and the importance of including such data when researching accessibility within the context of environmental justice. The study concluded that accessibility patterns to aquatic environments are rather equal in a Nordic Metropolitan along the Baltic Sea coast but although some clearly identifiable socio-demographic factors undoubtedly provide better levels of access for some people.

Although this study focused mainly on empirically testing the best ways to study accessibility it also highlights the importance of including water areas in studies of environmental justice and health (in)equalities especially where aquatic environments play a major role in the geographies of a certain region. Local planning, management and decision making professionals could gain valuable information from local residents on their preferences and utilisation patterns as they relate to different aquatic leisure amenities. This study has also identified the non-physical conditions that determine access to aquatic environments while the adoption of the findings herein could provide additional avenues of approach to traditional physical planning in respect of the ways in which management and planning officials address issues of public aquatic recreation and outdoor services.

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