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Chapter 7

Estimates of carbon sequestrated by the *Jacaranda mimosifolia* street trees in the City of Tshwane, South Africa

Abstract

In 2003 approximately 17% of the City of Tshwane's urban street tree forests (195 789 trees) were populated with Jacaranda trees (33 630 trees). However, the National Department of Agriculture declared *Jacaranda mimosifolia* as a Category 3 alien invader and consequently Jacaranda street trees may not be replaced. This will eventually result in the total loss of the Jacaranda population of the City of Tshwane.

The City of Tshwane Metropolitan Municipality requested that monetary values be determined for the trees with the aim of determining the value of the Jacaranda urban street tree forest to the City of Tshwane. The aim of this report was therefore to calculate the estimated quantity of carbon contained in the Jacaranda street tree population and its related monetary value. It is hoped that this quantifiable environmental benefit in terms of carbon that has been sequestrated and its associated monetary value will provide some motivation for the preservation of the Jacaranda urban forest.

Stem circumference measurements were taken from 1525 Jacaranda street trees in 73 suburbs. Tree volume was determined from the measurements and tree volumes were converted to biomass and thence into carbon and from there into CO_2. A per tree mean of 0.378 tonne carbon (t C) was estimated for all the suburbs in which trees were measured. The calculated percentage error in this per tree mean carbon quantity for all of the Jacaranda street trees in Tshwane was 3.59%. Mean carbon per suburb, standard deviation and total carbon in each suburb were determined. The total quantity of carbon in all the suburbs of Tshwane (114 suburbs) that have Jacaranda street trees is estimated at 12 709.241 t C. It is suggested due to discrepancies of approximately 10% between the numbers of trees observed during fieldwork and municipal tree census data, that an adjusted carbon quantity be assumed. An adjustment of -10% is therefore suggested, yielding a total estimated carbon quantity for Tshwane's Jacaranda street trees of 11 438.317 t C. A per tree mean of 1.387 t CO_2 equivalent (CO_2eq) was estimated for all the measured suburbs, and an adjusted total of 41 978.625 t CO_2eq was estimated for the Jacaranda street trees in Tshwane. Assuming a hypothetical market related price of US$10 tonne^{-1} CO_2, the total value of all the Jacaranda street trees in Tshwane based on the suggested adjusted carbon value could be estimated at US$419 786 and has an estimated value of R2 766 391 (R6.59 = US$1.00; 17/08/2004).

The carbon captured by the trees cannot be traded. The above carbon quantities and monetary values provide preliminary estimates. More robust estimates will be obtainable once a locally derived allometric biomass equation has been developed.

The carbon sequestration value of Jacarandas is but a portion of the total environmental, social and economical contribution made by the Jacaranda street trees of Tshwane's urban forest. The Jacaranda urban forest has been a part of the city's natural, cultural, and historical heritage for more than a century and it should thus be appreciated that such an asset outweighs monetary benefits and values.

Keywords: carbon sequestration, carbon trade, *Jacaranda mimosifolia*, street trees, urban forest

Introduction

The first two *Jacaranda mimosifolia* trees arrived in Pretoria (currently the City of Tshwane) in 1888 from Rio de Janeiro and were planted by a Cape botanist, Mr Templeman, in the garden of Myrtle Lodge owned by Mr J.D. Celliers. These trees are currently on the Sunnyside school campus. The first official Jacaranda street trees were planted in 1906 in the current Bosman and Arcadia Streets when Mr James Clark donated a number of these trees to the Municipality of Pretoria. Mr Clark kept a nursery in the suburb of Groenkloof for the Transvaal Colony government. The seeds for these trees had been imported from Australia (Department of Environment Planning and Energy, 1980).

Since 1906 the Municipality of Pretoria planted Jacarandas to such an extent that in 2003 approximately 17% of the City of Tshwane's urban street tree forests were populated with Jacaranda trees (Mr Bertie Dry, Deputy Manager: Urban Forestry, Nursery and Training of the City of Tshwane Metropolitan Municipality, personal communication, 27/10/2003). Due to the fact that the street trees were planted from early in the twentieth century there is a strong association between the Jacaranda trees and the City's history. In spring and early summer Jacarandas create such a display of colour and splendour throughout the city that the City of Tshwane has become known as the Jacaranda City of South Africa. Many of the Jacaranda trees are older than architectural and public infrastructure in the city. These trees have become synonymous with the city and could be viewed as an integral part of the city's cultural, natural and historical heritage.

The City of Tshwane Metropolitan Municipality is however concerned about the future of the Jacaranda population. In 2001 the National Department of Agriculture declared *Jacaranda mimosifolia* as a Category 3 alien invader according to the amended regulation 15 of the Conservation of Agricultural Resources Act (No 43 of 1983) (Urban Green File, 2002). Category 3 invaders may not be propagated or established in any part of South Africa except for the biological control reserves. As a consequence the Jacaranda street trees may not be replaced where these trees have to be removed due to for example disease or other unavoidable circumstances. This will eventually result in the total loss of the Jacaranda population of the City of Tshwane.

In a quest to preserve the Jacaranda population, the City of Tshwane Metropolitan Municipality requested that monetary values be determined for the trees. Because the Jacarandas store carbon they ameliorate global warming and the greenhouse effect. A part of the Jacaranda's value to society can be determined by calculating its carbon storage and converting that to a monetary value. The aim of this report was therefore to calculate the estimated quantity of carbon contained by the street tree population and its related monetary value. It is hoped that the quantifiable environmental benefit in terms of carbon that has been sequestrated and its associated monetary value will provide further motivation for the preservation of the Jacaranda urban forest.

Methodology

The Deputy Manager of Urban Forestry, Nursery and Training of the City of Tshwane Metropolitan Municipality (hereafter referred to as Municipality), Mr B. Dry, provided data (27/10/2003) containing suburb and street names with the number of *Jacaranda mimosifolia* trees in each street. (This was the only data provided by the Municipality.) This database was compiled from a census conducted in the late 1990s as well as from a tree-planting database initiated in 1995.

A total of 73 suburbs of the 114 suburbs that have Jacarandas planted as street trees in the Pretoria area of the City of Tshwane, were measured for stem circumference. Overbark stem circumference was taken at breast height i.e. at 1.37 m above ground level. The stem circumferences were measured in February and early March of 2004. A total of 116 streets were investigated and 1525 trees were measured in total. Forty-one suburbs that had less than 50 trees were not measured (Table 7.1).

To determine the mean stem circumferences of the Jacaranda street tree population in each suburb, a test sample was conducted to establish the number of trees that had to be measured per suburb. The stem circumferences of 20 trees per suburb for 13 different suburbs were measured. The low percentage error as calculated from the aforementioned 13 suburbs (see Results and Discussion sections below) showed that 20 trees per suburb provided a statistically representative sample of the mean stem circumference of *Jacaranda mimosifolia* trees in a suburb.

Table 7.1. Total number (n) of *Jacaranda mimosifolia* trees in descending numerical order growing in each suburb in the City of Tshwane. The total number of trees includes the various extensions of the different suburbs. The data were obtained from the City of Tshwane Metropolitan Municipality (27/10/2003)

Suburb	n
Pretoria Central	2853
Brooklyn	2535
Arcadia	1929
Sunnyside	1836
Waterkloof Ridge	1509
Waterkloof	1412
Villeria	1207
Rietfontein	1028
Hatfield	977
Proclamation Hill	896
Pretoria North	840
Pretoria West	702
West Park	622
Muckleneuk	559
Lisdogan Park	531
Lynnwood	514
Eastwood	499
Annlin	492
Riviera	465
Rietondale	454
Garsfontein	449
Valhalla	447
Eersterust	442
Ashlea Gardens	409
Pretoria Industrial	396
Constantia Park	393
Menlo Park	378
Moreletta Park x 1	348
Claremont	344
Lukasrand	323
Kwaggasrand	310
Colbyn	308
Mamelodi	304
Nieuw Muckleneuk	284
Laudium	281
Atteridgeville	268
Waltloo	248
Kilner Park	235
Meyers Park	235
Erasmusrand	227
Wonderboom South	227

Suburb	n
Faerie Glen	223
Queenswood	215
Saulsville	208
Waterkloof Park	189
Florauna	168
Silverton	166
Elardus Park	159
Eloffsdal	159
Hillcrest	155
Waterkloof Glen	155
Mountain View	153
Capital Park	144
Pretoria Gardens	132
Trevenna	128
Lynnwood Ridge	108
Dorandia	103
Lynnwood Glen	102
Alphen Park	96
Samkor Park	95
Montana	93
Wingate Park	92
Salvokop*	87
Deerness**	82
Sinoville	82
Hazelwood	77
Erasmuskloof	70
Asiatic Bazaar	67
Clydesdale*	67
Danville	67
Jan Niemand Park	61
Newlands	60
La Montagne	59
Menlyn x 4	58
Philip Nel Park	56
Monument Park	54
Maroelana	50
Gezina	48
Prinshof	48
Die Wilgers	45
Koedoespoort	45
Lyttleton Manor	42
Mayville	42
Murrayfield	42
Weavind Park	42
Pierre van Ryneveld	41
Groenkloof	40
Ekklesia	39
Pretoria	38
Hermanstad	37

Suburb	n
Eastclyffe	33
Bailey's Muckleneuk	32
Erasmia	28
East Lynne	22
Brummeria x 2	20
Lydiana	18
Nellmapius x 3	17
Bellevue	16
Hennopspark	13
Les Marais	12
Zwartkop	12
Maroelana x 3	10
Doringkloof	9
Eldoraigne	9
The Reeds	9
Lynnwood Manor	8
Rooihuiskraal	8
Waverley	8
Booysens	6
Bryntirion	6
Heuweloord	6
Irene	5
Val-De-Grace	5
Moregloed	4
Waterkloof Heights	4
Highveld	2
Die Hoewes	1
Salieshoek	1
Wierda Park	1
Total	**33630**

* Not indicated on Figure 7.1, Figure 7.2, and Figure 7.3.
** Not taken into account in calculating the mean stem circumference.

Not all streets had 20 trees that could be measured and in such instances additional trees in other streets in the same suburb were measured to obtain the required 20 circumference values. In some suburbs less than 20 trees were available for measurement (Table 7.1). In some streets, the number of trees encountered differed from the data provided by the municipality. Where possible, these discrepancies were noted. It was, however, not part of the study to conduct a tree census and therefore these differences were not rigorously observed, but were rather noted in passing.

To determine the possible effect of local environmental conditions on the variation in stem circumference two transects, of varying length, were surveyed in the same street. For this statistical test two sets of 20 large trees were measured at opposite ends of Milner Street in the suburb Waterkloof. In the first set the trees at the western end of the street were measured consecutively and for the second set, every second tree was measured at the eastern end of the street. When measuring the trees consecutively, measurements were taken on both sides of the street in a zigzag manner in order to minimise the transect length (approximately 150 m long). In the second case, every alternate tree only on the northern side of the street was measured, in order to maximise the transect length. In this particular case there were a number of damaged trees that were not measured and the transect length was approximately 1 km.

Apart from the above *intra*-street stem circumference variation, *inter*-street variation in stem circumference within a suburb was also analysed. This was done to determine whether larger stem circumference distributions would be found in different streets of the same suburb rather than in only one street of that suburb. If this were the case more than one street would need to be measured in each suburb. The *inter*-street analysis was done by measuring 20 trees in each of two streets in Brooklyn, Hatfield and Sunnyside and showed that taking measurements in one street per suburb is sufficient for obtaining statistically satisfactory representative measurements.

Anticipating an urban to rural gradient in this study, Church Square was used as the focal point because Church Square was the location of the first settlements in the Pretoria region of the City of Tshwane from which the city developed in all directions. Church Square is currently in the Pretoria Central suburb. At any given location where tree measurements were taken, the trees in the street were measured starting from the point closest to Church Square and working further away from it. In all instances where the street runs in an east west direction the trees were measured on the northern side of the street or the side closest to the north. When a street runs in a north south direction, the trees on the eastern side of the street were measured. However if these selected sides did not have 20 trees available for measurement trees were measured on both sides of the street. In these instances trees on both sides of the street were measured starting from the tree closest to Church Square in that particular street.

The measurement methodology had to be adapted under specific conditions depending on the physical conditions in the street. It must be emphasized, though, that these were the exceptions to the norm and were enforced by practical considerations:

- In some instances where there were very few trees in a street, the trees were measured on both sides parallel to the centre line of the road – starting in one direction and coming back in the opposite.
- In some instances where there were very few trees, the first 20 trees from a designated point were measured regardless of which side of the street it stood.
- In Government Avenue in Eastwood and Lisdogan Park there were two rows of trees on either side of the street. Here both rows on only one side of the street were measured. These trees were measured in a zigzag method starting with the northernmost tree closest to Church Square of the particular street block.

Longitude and latitude were recorded with a global positioning system (Garmin, eTrex, Venture GPS) at the start and end of each transect in a street. The reading was taken as close as possible to the tree stem without jeopardising accuracy of the reading. Often this resulted in the reading being taken on the street corner, to avoid interference with satellite reception by the canopy. The name of the closest street that crosses the street in which the first tree was measured, as well as that of the closest street crossing it after the last tree measured, were noted for future reference (Table 7.2).

Table 7.2. Suburb names, streets in which measurements were made, direction in which the trees were measured in the street, closest cross street to first and last trees measured and GPS co-ordinates for first and last trees in each street (trees in more than one street were measured in some suburbs (see Methodology)) for the Jacaranda street trees that were measured for stem circumference in February and March 2004 in the City of Tshwane. The suburb and street names in which Jacarandas grow were obtained from the City of Tshwane Metropolitan Municipality (27/102003)

No	Suburb	Street name	Direction	Closest cross street to first tree	Closest cross street to last tree	Start GPS South			Start GPS East			End GPS South			End GPS East		
						Degree	Minute	Second	Degree	Minute	Second	Degree	Minute	Second	Degree	Minute	Second
1	Alphen Park	Dely	SE	Nuwe Hoop	Club	25	47	4.164	28	15	37.008	25	42	23.976	28	15	41.616
2	Alphen Park	Garsfontein	E	Selati	Nuwe Hoop	25	46	57.504	28	15	49.680	25	46	58.116	28	15	42.084
3	Annlin	Zambesi	E	Veldkornet	Parsley / Elizabeth	25	40	36.984	28	11	49.956	25	40	41.088	28	12	9.252
4	Arcadia	Schoeman	E	Beckett	Eastwood	25	44	50.388	28	13	35.400	25	44	48.768	28	13	19.560
5	Ashlea Gardens	Garsfontein	W	Matroosberg	Selati	25	47	4.812	28	16	0.876	25	46	57.504	28	15	49.680
6	Ashlea Gardens	Matroosberg	NE	Dely	Garsfontein	25	47	23.208	28	15	53.136	25	47	4.812	28	16	0.876
7	Asiatic Bazaar	Boom	W	7th Street	DF Malan	25	44	24.252	28	10	35.976	25	44	26.988	28	10	22.584
8	Atteridgeville	Maunde	W	Khoza	Monoa	25	46	29.028	28	5	22.344	25	46	31.980	28	4	59.664
9	Brooklyn	Brooks	E	Hay	Duncan	25	45	31.104	28	14	8.160	25	45	34.596	28	14	14.784
10	Brooklyn	Mackenzie	E	Duncan	Pienaar	25	45	50.472	28	14	13.524	25	45	54.504	28	14	28.860
11	Claremont	Diamond	N	Dead end of st	Weir	25	43	37.956	28	7	55.632	25	43	21.792	28	7	58.260
12	Clydesdale	Kirkness	S	Park	Jorrison	25	45	3.672	28	13	19.704	25	45	18.432	28	13	17.760
13	Colbyn	Amos	E	Douglas	Glyn	25	44	21.372	28	14	14.460	25	44	21.876	28	14	32.784
14	Constantia Park	Anton van Wouw	NW	Beethoven	Langenhoven	25	47	57.012	28	17	5.460	25	48	5.904	28	17	12.372
15	Danville	Wrentmore	W	Paul Roos	Ferdie Berg	25	44	9.996	28	8	9.204	25	44	7.440	28	7	58.98
16	Eastwood	Government	E	Becket	Herbert	25	44	24.468	28	13	1.380	25	44	24.072	28	13	7.428
17	Eersterust	Hans Coverdale North	E	Spitfire	Neon	25	42	8.244	28	18	0.468	25	42	1.332	28	18	20.520
18	Elardus Park	Boeing	S	Hans Strijdom	Allandale/ Ebenhaezer	25	49	20.964	28	15	20.268	25	49	52.500	28	15	19.440
19	Eloffsdal	Franzina	E	Mansfield	Avril	25	42	46.116	28	11	12.444	25	42	47.412	28	11	26.556

No	Suburb	Street name	Direction	Closest cross street to first tree	Closest cross street to last tree	Start GPS South			Start GPS East			End GPS South			End GPS East		
						Degree	Minute	Second	Degree	Minute	Second	Degree	Minute	Second	Degree	Minute	Second
20	Erasmuskloof	Lois	S, SW	Peak (Place)	Hans Strijdom	25	48	32.760	28	16	13.188	25	49	9.192	28	16	18.588
21	Erasmusrand	Rigel	S,E	Neptune	Buffelsdrift	25	48	27.720	28	14	54.312	25	48	29.340	28	15	19.584
22	Faerie Glen	Olympus	SE	Skukuza	Kromdraai	25	47	23.460	28	19	46.164	25	47	45.780	28	19	50.088
23	Garsfontein	Serene	E	Beatrix Mare	Isie Smuts	25	47	17.988	28	17	3.948	25	47	48.840	28	17	36.960
24	Hatfield	Park	E	Hilda	Grosvenor	25	44	56.724	28	14	6.252	25	44	56.040	28	14	17.232
25	Hatfield	Prospect	E	Hilda	Duncan	25	45	7.452	28	14	7.620	25	45	6.084	28	14	23.352
26	Hazelwood	Dely	SE	Albert	Highlands	25	16	40.080	28	15	20.844	25	46	49.224	28	15	26.712
27	Hestea Park	Daan de Wet Nel Dr	NW	President Steyn	Waterbok	25	40	24.204	28	9	51.588	25	40	12.000	28	9	29.196
28	Hillcrest	Duxbury	W	Duncan	-	25	45	20.124	28	14	21.192	25	45	17.820	28	14	11.616
29	Jan Niemand Park	Uil	E	Meeu	Voetpadnek	25	42	7.920	28	17	7.008	25	42	11.304	28	17	33.396
30	Kilner Park	C.R. Swart	N	Soutpansberg	Webb	25	43	55.452	28	15	32.220	25	43	40.620	28	15	31.428
31	Kwaggasrand	Reier	NW	Waterbok	Digteby	25	45	44.424	28	7	6.096	25	45	39.420	28	6	57.204
32	La Montagne	Catharina	E	Trevor	Margarita	25	44	46.644	28	18	29.124	25	44	46.500	28	18	33.516
33	La Montagne	Kandelaar	E	Shirley Ave East	Waggellaan	25	45	4.320	28	18	49.104	25	45	4.500	28	19	8.976
34	Laudium	Emerald	W	6th Street	13th Street	25	47	8.232	28	6	20.916	25	47	8.736	28	6	7.848
35	Lisdogan Park	Government	W	Dumbarton	Balmoral	25	44	25.080	28	13	28.488	25	44	26.448	28	13	25.248
36	Lukasrand	Sibelius	E	Arnoldi	Lingbeek	25	45	58.392	28	12	35.784	25	45	55.548	28	12	59.040
37	Lynnwood	Elizabeth Grove South	S	Kings Highway	Dead end of street	25	45	35.316	28	15	47.592	25	45	43.884	28	15	45.108
38	Lynnwood Glen	Glenwood	S, SE	Alcade	-	25	46	3.144	28	16	46.128	25	46	21.432	28	16	51.636
39	Lynnwood Ridge	Freesia	E	Insignis	Hibiscus	25	46	0.840	28	17	23.496	25	46	0.480	28	18	1.836
40	Mamelodi	Denneboom	E	Dobolwane	Dumsa	25	43	5.592	28	20	42.432	25	43	5.808	28	20	54.204
41	Mamelodi	Tsamaja	E	Kgomo	Hinterland	25	43	9.192	28	21	36.756	25	42	50.976	28	22	28.380
42	Maroelana	Maroelana	S	Hazelwood	Elandslaagte	25	46	36.444	28	15	42.840	25	46	47.064	28	15	35.712
43	Maroelana	Nuwe Hoop	S	Koelman	Roeline	25	46	48.720	28	15	47.988	25	46	52.752	28	15	44.496
44	Mayville	Mansfield	N	Fred Nicolson	Van Rensburg	25	42	26.784	28	11	12.840	25	42	5.472	28	11	15.576
45	Menlo Park	Brooklyn	S	Bariton	6th Street	25	45	42.228	28	14	45.168	25	46	0.156	28	14	56.976
46	Meyers Park	Pretoria	E	Waltloo	Battery	25	44	5.100	28	18	59.076	25	44	8.160	28	19	13.224
47	Montana	Zambesi	E	-	-	25	40	51.744	28	13	57.972	25	40	43.716	28	14	50.352
48	Moreleta Park	Rubenstein	W	Stander	Helios	25	49	8.580	28	17	32.640	25	49	10.560	28	16	51.888

No	Suburb	Street name	Direction	Closest cross street to first tree	Closest cross street to last tree	Start GPS South			Start GPS East			End GPS South			End GPS East		
						Degree	Minute	Second	Degree	Minute	Second	Degree	Minute	Second	Degree	Minute	Second
49	Mountain View	Daniel	N	Ivor	Daphne	25	42	6.876	28	9	22.212	25	41	58.308	28	9	24.552
50	Muckleneuk	Bourke	S	Walker	Berea	25	45	32.616	28	12	25.308	25	45	41.688	28	12	23.544
51	Newlands	Dely	SE	Lois	Matroosberg	25	47	43.584	28	16	9.732	25	47	25.116	28	15	51.732
52	Nieuw Muckleneuk	Dey	S	Nixon / Cameron	Middel	25	46	16.968	28	13	50.088	25	46	4.008	28	13	44.616
53	Philip Nel Park	Staatsartillerie	W	Technikon oord	Rebecca	25	44	19.284	28	9	32.652	25	44	20.220	28	9	25.344
54	Pretoria Central	Bloed	E	Bosman	Andries	25	44	26.448	28	11	6.828	25	44	25.404	28	11	22.308
55	Pretoria Central	Visagie	W	Paul Kruger	Andries	25	45	8.136	28	11	19.140	25	45	7.668	28	11	31.092
56	Pretoria West	Servaas	W	Zeiler	Rosetta	25	45	6.012	28	9	26.856	25	45	7.056	28	9	9.468
57	Pretoria Gardens	Bornman	N	Willies Hill	Hanny	25	43	35.148	28	8	32.964	25	43	12.900	28	8	36.276
58	Pretoria Industrial	Staal	NE	Bessemer	Industrial	25	45	57.096	28	7	44.580	25	45	45.972	28	7	57.792
59	Pretoria-North	Brits	W	Koos de la Rey	Danie Theron	25	40	50.664	28	10	47.424	25	40	49.044	28	10	27.876
60	Proclamation Hill	Acacia	W	Tungsten	Mica	25	45	4.608	28	8	38.760	25	45	5.868	28	8	17.304
61	Queenswood	Soutpansberg	E	Gordon	Kilnerton	25	43	57.720	28	14	47.472	25	43	56.532	28	15	17.568
62	Rietfontein	19th Avenue	N	Swemmer	Haarhof	25	42	50.796	28	13	10.452	25	42	37.404	28	13	8.076
63	Rietondale	Nuffield	N	Soutpansberg	-	25	43	58.872	28	13	11.244	25	43	49.620	28	13	10.092
64	Riviera	Annie Botha	E	Union	Blacke	25	43	58.548	28	12	30.420	25	43	58.188	28	12	42.372
65	Salvokop	Skietpoort	W	Koch	Potgieter	25	45	35.388	28	11	12.120	25	45	36.072	28	10	59.484
66	Samcor Park	Simon Vermooten	N	Alwyn	Waltloo	25	43	42.564	28	19	56.856	25	43	21.072	28	19	57.900
67	Saulsville	Makaza	NW	Maunde	Mngomezulu	25	46	48.036	28	3	12.348	25	46	41.952	28	3	4.752
68	Saulsville	Masopha	N	Makaza	Mesa	25	46	39.972	28	3	5.148	25	46	32.196	28	3	5.184
69	Silverton	Fakkel	S	Jasmyn	Joseph Bosman	25	43	54.192	28	17	46.608	25	44	10.464	28	17	45.096
70	Sinoville	Zambesi	E	Miriana	Aldo	25	40	42.456	28	12	15.732	25	40	46.956	28	12	43.812
71	Sunnyside	Bourke	S	Water	De Kock	25	45	7.596	28	12	37.620	25	45	19.584	28	12	31.536
72	Sunnyside	Jorrison	E	Troye	Vos	25	45	16.740	28	12	13.788	25	45	24.372	28	12	39.348
73	Trevena	Meintjie	N	Kotze	Esselen	25	45	7.416	28	12	2.196	25	45	4.824	28	12	2.088
74	Valhalla	Fjord	S	Paul Kruger	Angvick	25	47	45.960	28	9	32.796	25	47	58.200	28	9	27.468
75	Villiera	Pierneef	E	29th Avenue	31th Avenue	25	43	19.056	28	14	5.280	25	43	19.128	28	14	17.952
76	Waterkloof	Milner (both sides)	E	Kloof	Rautenbach	25	46	46.100	28	13	51.000	25	46	18.800	28	14	16.400
77	Waterkloof	Milner (one side)	W	Heloma	Crown	25	46	36.400	28	15	4.500	25	46	40.100	28	14	36.200

No	Suburb	Street name	Direction	Closest cross street to first tree	Closest cross street to last tree	Start GPS South			Start GPS East			End GPS South			End GPS East		
						Degree	Minute	Second	Degree	Minute	Second	Degree	Minute	Second	Degree	Minute	Second
78	Waterkloof Glen	Anton van Wouw	SE	Beethoven	Mendelsohn	25	47	57.012	28	17	5.460	25	47	45.168	28	16	59.808
79	Waterkloof Park	Drakensberg	S	Outeniqua	Matroosberg	25	47	21.732	28	15	37.152	25	47	33.180	28	15	42.516
80	Waterkloof Park	Matroosberg	E	Outeniqua	Dely	25	47	29.688	28	15	43.416	25	47	25.872	28	15	49.320
81	Waterkloof Ridge	Delphinus	NE	Rigel	Dorado	25	47	36.816	28	14	23.964	25	47	21.012	28	14	32.100
82	Watloo	Mundt	E	Dead end of st	Watloo	25	43	18.588	28	19	9.192	25	43	19.344	28	19	25.428
83	Wes Park	Iscor	SW	Cordelfos	Bosbok	25	45	6.480	28	7	50.304	25	45	20.880	28	7	39.936
84	Wingate Park	Delmas	S	Barnard	Hans Strijdom	25	49	35.040	28	15	40.104	25	49	17.652	28	15	37.620
85	Wonderboom South	De Beer	E	9th Street	12th Street	25	41	54.996	28	12	4.824	25	41	53.340	28	12	17.496

When there were sufficient trees in a street, trees on the street corners were not measured. Trees with scars at breast height that could influence the stem circumference measurement were discarded, nor were trees measured that branched at or below 1.37 m. However, if there were no other suitable trees that could be measured, these trees were measured at an appropriate level with respect to the scar or just below the branch swelling. If forking occurred at or just above breast height, the tree was not measured. However, if the tree had to be included due to a shortage of trees in the street, the measurement was taken below the fork swelling. If a tree had an indentation on the one side, steps were taken to avoid skewing the measurement. The measurements were taken perpendicularly to the central vertical axis of the tree stem. If a tree was leaning sideways, the measurement was taken on the portion where the side of the tree stem that had the acute angle to the ground was at a vertical height of 1.37 m from the ground.

Trees that were overgrown with ivy (*Hedera sp.*) were not measured since the ivy could not be removed to obtain an accurate stem circumference. In some suburbs this caused a substantial number of trees to be skipped, resulting in longer transects.

If a tree obviously differed in size from the majority of the trees in the street, it was not measured. Often these trees were smaller than the other trees in the street, indicating that they were possibly replacements for trees that had died. When a continuous variation in tree stem circumference sizes was encountered, a representative sample was taken, ensuring that most of the different sizes were represented in the sample. In some instances discontinuous size classes were obvious and identifiable, in which case the trees were randomly measured in informal visually identified, size classes. The method involved visually judging tree stem circumferences when first moving along the street. Size classes were then identified from these visual observations. Sampling was stratified by measuring trees within each of the identified size classes. For example, if four classes were identified, measurements would be taken of five trees in each class to amount to 20 trees in that street. In cases where there were many trees with a large variation in stem circumference size, no stratification and size class subdivision were done and the trees were measured, as was the norm for the other streets.

Trees that had been damaged by fire at the base of the stem, by people presumably making fire for cooking or for heating, were not measured. In Laudium some trees had termite or ant nests at their base. These trees were still measured because there was no indication that the growth of these trees had been affected. Where trees were dead, showed signs of dieback or re-growth, they were excluded from measurement.

The statistical methodology and analysis in this report was conducted under the instruction and guidance of Professor F. Steffens (Statistician) formerly from the University of South Africa. The data were captured and analysed in Microsoft® Excel. The mean circumference and the standard deviation of the stem circumferences were calculated for each suburb (Table 7.3). The following equation (Pillsbury *et al.*, 1998) was used to estimate the volume of each tree:

$$V(cf) = 0.036147(dbh)^{2.486248} \quad (1)$$

where $V(cf)$ is the volume of the aboveground woody parts (excluding leaf volume) of the tree in cubic feet, and dbh is the stem diameter at breast height in inches. Following from the above, equation (1) was converted to metric units as follows:

$$V(m^3) = 3.29118 \ . \ 10^{-7}(dbh(mm))^{2.486248} \quad (2)$$

where $V(m^3)$ is the volume of the aboveground woody parts in cubic metres and $dbh(mm)$ is the stem diameter in millimetres at breast height. Because the stem circumference of the trees were measured, the circumferences were converted to diameters for application in equation (2). After the volume of each tree was calculated its biomass was determined as:

$$Biomass = density \ . \ V(m^3) \quad (3)$$

where $Biomass$ is calculated in kilograms (kg) and $density$ is a given value. In this report the density of 520 kg/m^3 was used which was determined from sampling stem wood derived from a *Jacaranda mimosifolia* tree that grew on the University of Pretoria campus. The wood was oven dried to a constant mass and the density was calculated.

Fifty percent of the dry biomass per tree is allocated to carbon (McPherson *et al.*, 1994; McPherson & Simpson, 1999; Gifford, 2000; McPherson *et al.*, 2001; IPCC, 2003) and this value was converted to metric tonnes. The mean aboveground carbon quantity per suburb as well as the standard deviation of aboveground carbon per suburb were calculated. The standard error was calculated for the aboveground carbon of each suburb in the following manner:

$$SE = \frac{SD}{\sqrt{(n)}} \quad (4)$$

where SE is the standard error, SD is the standard deviation and n is the sample size. The standards deviation (SD) is a measure of the variability of individual trees within the suburb. The standard error (SE) is a measure of the accuracy of the estimated mean for the suburb. A correction factor was applied to the standard error and was derived from the following equation:

$$c = \sqrt{\frac{W_i - n}{W_i - 1}} \quad (5)$$

where c is the correction factor, W_i is the total number of trees in the suburb and n is the sample size in the particular suburb.

The correction factor was applied to the SE as follows:

$$SE(c) = SE \ . \ c \tag{6}$$

where $SE(c)$ is the corrected standard error. The mean quantity of aboveground carbon per Jacaranda tree in Tshwane can be calculated as:

$$X = \frac{\Sigma(W_i \ . \ X_i)}{\Sigma W_i} \tag{7}$$

where X is the mean quantity of aboveground carbon per Jacaranda tree in Tshwane, W_i is the total number of trees in each suburb and X_i is the mean aboveground carbon per tree for each suburb. The total quantity of aboveground carbon that has been sequestrated by all the Jacaranda trees in Tshwane (C_{agt}) can be calculated as:

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$$C_{agt} = X \ . \ N \qquad (8)$$

where N is the total number of Jacaranda trees in Tshwane.

The carbon standard error per tree $(SE_{pertree})$ was calculated as follows:

$$SE_{pertree} = \sqrt{\frac{\Sigma W_i^{\,2} SE(c)_i^{\,2}}{(\Sigma W_i)^2}} \qquad (9)$$

From equation (9) the standard error for the aboveground carbon of the total quantity of trees follows:

$$SE_{total} = N * SE_{pertree} \qquad (10)$$

where SE_{total} is the standard error of the aboveground carbon for the total quantity of trees. The percentage error ($\%Err$) follows as:

$$\%Err = \frac{SE_{total}}{C_{agt}} \ . \ 100 \ . \ 2 \qquad (11)$$

To determine the belowground biomass of the Jacarandas a root : shoot ratio of 22:78 was used (McPherson *et al.*, 2001) and Equations (4) to (11) were repeated to determine the total carbon quantities that include the root carbon. The percentage carbon of the root was also taken as 50% of total biomass (McPherson *et al.*, 2001; IPCC, 2003).

Results

The total number of trees on which the calculations were based, were 33 630 according to the data provided by the municipality. The difference between the number of trees per street as provided by the municipality and that obtained from informal field observations indicated that there were approximately 10% fewer trees in the streets in which stem circumferences were measured than was indicated by the municipality's data. Figure 7.1 gives an indication as to the numbers of trees found in various suburbs as per the data provided by the municipality (27/10/2003). Pretoria Central, Brooklyn, Arcadia, Sunnyside, Waterkloof Ridge, Waterkloof, Villeria and Rietfontein (darkest colour) have between 1001 and 2853 Jacaranda street trees.

A 2.17% error was obtained from the test sample conducted by measuring stem circumferences of 20 trees per suburb for 13 different suburbs to establish the number of trees that had to be measured per suburb. This low percentage error suggested that 20 trees per suburb provided a sufficiently acceptable statistically representative sample of the mean stem circumference of Jacaranda trees in a suburb. The percentage error calculated for all of the Jacaranda trees in Tshwane was 3.59%.

Table 7.3. Suburbs with mean stem circumferences (mm) of trees in descending order of magnitude as well as the standard deviation (mm) in stem circumference for each suburb. Mean circumference and standard deviation are based on measurements that were taken of Jacaranda street trees in February and March 2004 in the Pretoria region of the City of Tshwane

No	Suburb	Mean circumference (mm)	Standard deviation (mm)
1	Asiatic Bazaar	1687	320
2	Laudium	1671	245
3	Claremont	1644	316
4	Colbyn	1616	263
5	Mountain View	1587	298
6	Wonderboom South	1552	297
7	Waterkloof	1538	288
8	Sinoville	1532	251
9	Riviera	1497	206
10	Pretoria Gardens	1471	297
11	Muckleneuk	1467	341
12	Brooklyn	1446	187
13	Rietfontein	1430	196
14	Pretoria Central	1420	342
15	Villiera	1410	271
16	Eloffsdal	1403	402
17	Rietondale	1400	340
18	Menlo Park	1400	311
19	Lynnwood	1395	486
20	Salvokop	1392	342
21	Pretoria-North	1389	277
22	Sunnyside	1383	227
23	Pretoria West	1381	205
24	Nieuw Muckleneuk	1347	250
25	Proclamation Hill	1345	170
26	Hatfield	1332	171
27	Lisdogan Park	1331	338
28	Trevena	1312	385
29	Arcadia	1302	199
30	Kwaggasrand	1286	166
31	Samcor Park	1272	361
32	Valhalla	1256	270
33	Silverton	1233	261
34	Annlin	1218	417
35	Clydesdale	1216	236

No	Suburb	Mean circumference (mm)	Standard deviation (mm)
36	Pretoria Industrial	1193	193
37	Wes Park	1159	196
38	Danville	1129	254
39	Lynnwood Glen	1108	187
40	Waterkloof Ridge	1102	176
41	Eastwood	1098	288
42	Lukasrand	1089	252
43	Watloo	1063	215
44	Ashlea Gardens	1060	389
45	Eersterust	1049	257
46	Queenswood	1039	404
47	Hillcrest	1027	264
48	Meyers Park	1021	219
49	Alphen Park	913	258
50	La Montagne	898	310
51	Constantia Park	848	175
52	Maroelana	843	158
53	Waterkloof Park	824	224
54	Garsfontein	818	191
55	Atteridgeville	814	119
56	Kilner Park	810	207
57	Waterkloof Glen	805	170
58	Erasmusrand	773	204
59	Mamelodi	736	174
60	Jan Niemand Park	669	273
61	Lynnwood Ridge	626	156
62	Moreleta Park	624	173
63	Hazelwood	523	347
64	Faerie Glen	522	124
65	Montana	522	200
66	Philip Nel Park	520	112
67	Mayville	419	176
68	Erasmuskloof	390	162
69	Saulsville	340	85
70	Elardus Park	323	91
71	Hestea Park	278	85
72	Newlands	213	110
73	Wingate Park	195	64

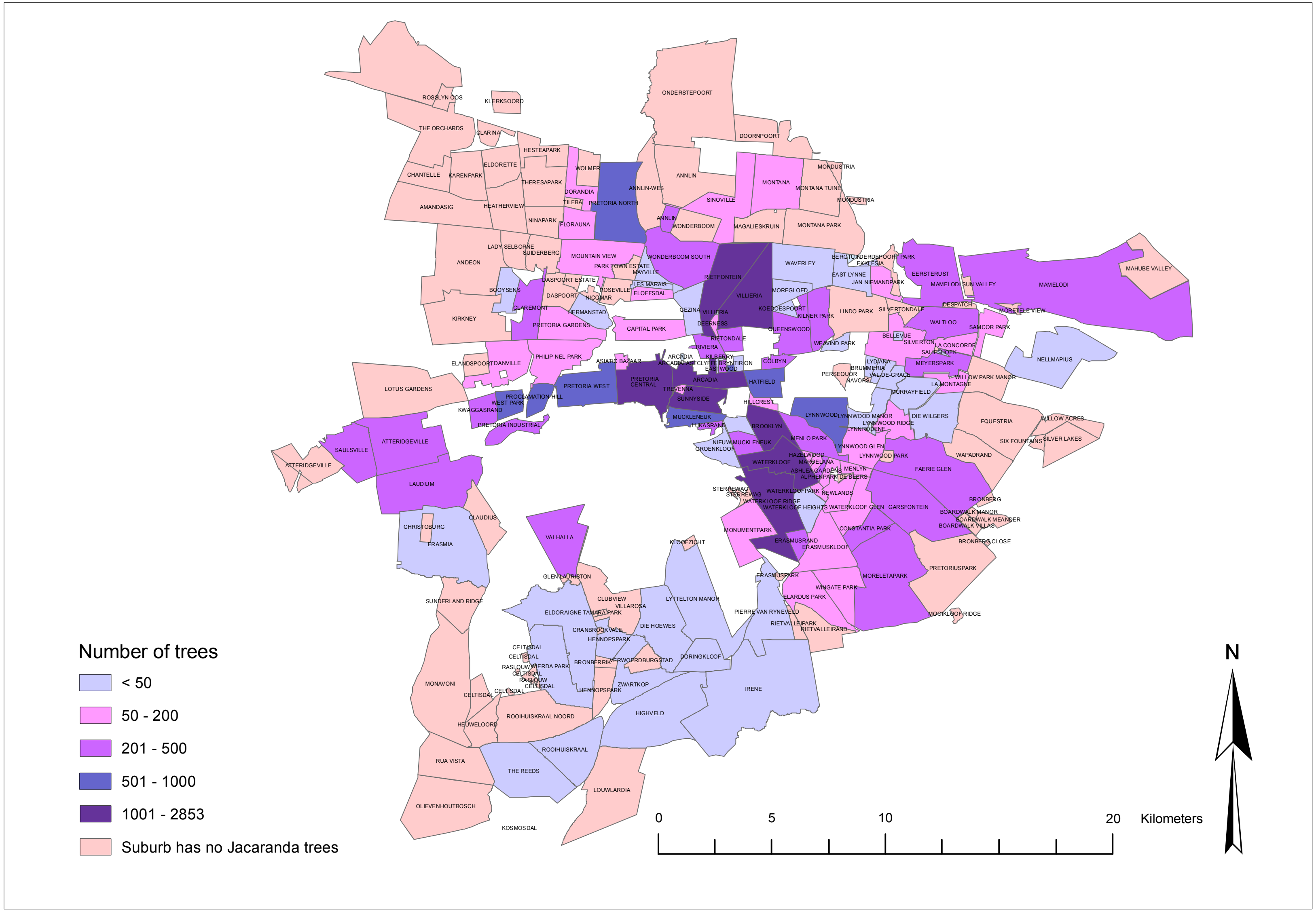

Figure 7.1. The number of Jacaranda street trees in Tshwane on 27 October 2003 based on the data provided by the City of Tshwane Metropolitan Municipality. The darker colours represent suburbs with larger numbers of trees.

An *intra*-street variation test conducted in the suburb of Waterkloof showed no significant difference between a long and short transect (ANOVA, Alpha = 0.05, p = 0.362). *Inter*-street variation showed no significant difference for trees measured in two different streets in the same suburb (ANOVA, Alpha = 0.05, Brooklyn p = 0.164; Hatfield, p = 0.394; Sunnyside p = 0.884).

After the statistical test sample analysis was conducted, it became clear that there was no definite urban to rural gradient in stem circumference size. Suburbs with their associated mean stem circumferences as well as the standard deviation for the circumferences are shown in Table 7.3. Figure 7.2 illustrates the stem diameter distribution in the different suburbs of the City of Tshwane as measured in this study. The trees with larger stem diameters tend to occur in the older suburbs. However, a clear urban to rural gradient is not deducible, which may be due to the city's morphological development since establishment in 1855 in combination with the planting regime of the Urban Forestry division of the municipality.

Suburb names, number of Jacaranda street trees per suburb, mean carbon per tree per suburb, standard deviation and total carbon in each suburb are shown in Table 7.4. The carbon calculations were based on the total number of trees in the suburbs in which trees were measured (73 suburbs) and amounted to 32 302 trees. The highest mean carbon quantities per tree occurred in Asiatic Bazaar, Laudium and Claremont with an estimated 0.713 tonne carbon (t C), 0.680 t C and 0.670 t C per street tree respectively (Table 7.4). The lowest mean carbon quantities per street tree occurred in Hestea Park, Newlands and Wingate Park with an estimated 0.009 t C, 0.006 t C and 0.004 t C per tree respectively (Table 7.4). Figure 7.3 shows the Jacaranda street tree carbon quantities for each suburb. The darkest rendered areas on the map indicate those areas with large carbon quantities. When calculating the sum of the total amount of carbon that the areas rendered in the darkest two colours contain it amounts to 5 425.980 t C, which indicates that 44.448% of the total quantity of carbon that is stored in the Jacaranda street tree population occurs in these suburbs (Pretoria Central, Brooklyn, Waterkloof, Sunnyside, Arcadia and Villieria).

Pretoria Central, Brooklyn, and Waterkloof had the highest total quantity of carbon with an estimated 1 379.037 t C (11.297% of the total quantity of carbon), 1 195.351 t C (9.792% of the total quantity of carbon), and 801.359 t C (6.565% of the total quantity of carbon) respectively. Hestea Park, Newlands and Wingate Park had the lowest total carbon quantities with an estimated 0.913 t C (0.007% of the total quantity of carbon), 0.346 t C (0.003% of the total quantity of carbon), and 0.344 t C (0.003% of the total quantity of carbon) respectively.

The total carbon quantity of all the street trees of all the suburbs in which trees were measured (73 suburbs) and on which the calculations are based, is estimated at 12 207.372 t C. A per tree mean of 0.378 t C was estimated for all the suburbs in which trees were measured. The total quantity of carbon for all the street trees in all the suburbs of Tshwane (114 suburbs) is estimated at 12 709.241 t C. Due to discrepancies observed in the quantity of trees it is suggested that an adjusted carbon quantity be assumed. Based on the aforementioned observations an adjustment of -10% is suggested and results in a total estimated carbon quantity for Tshwane's Jacaranda street trees of 11 438.317 t C.

Emission reductions are often reported as the full molecular mass of CO_2 rather than the atomic mass of carbon. The molecular mass of CO_2 can be obtained by multiplying the atomic mass of carbon by 3.67 (McPherson & Simpson, 1999). When applying this conversion factor the abovementioned trees will result in a per tree mean of 1.387 t CO_2 equivalent (CO_2eq) for all the measured suburbs, an estimated total of 46 642.916 t CO_2eq and an adjusted total of 41 978.625 t CO_2eq for all the Jacaranda street trees in Tshwane. Assuming a hypothetical market related price of US$10 tonne^{-1} CO_2eq (www.pointcarbon.com accessed 31 May 2005), the total value of all the Jacaranda street trees in Tshwane based on the suggested adjusted carbon value could be estimated at US$ 419 786. At the time of writing the carbon dioxide value of all the Jacaranda street trees in the City of Tshwane could thus be estimated at R2 766 391 (exchange rate of US$1.00 = R6.59 (http://www.finance24.co.za/Finance/Sake/Home/, accessed 17/08/2004)).

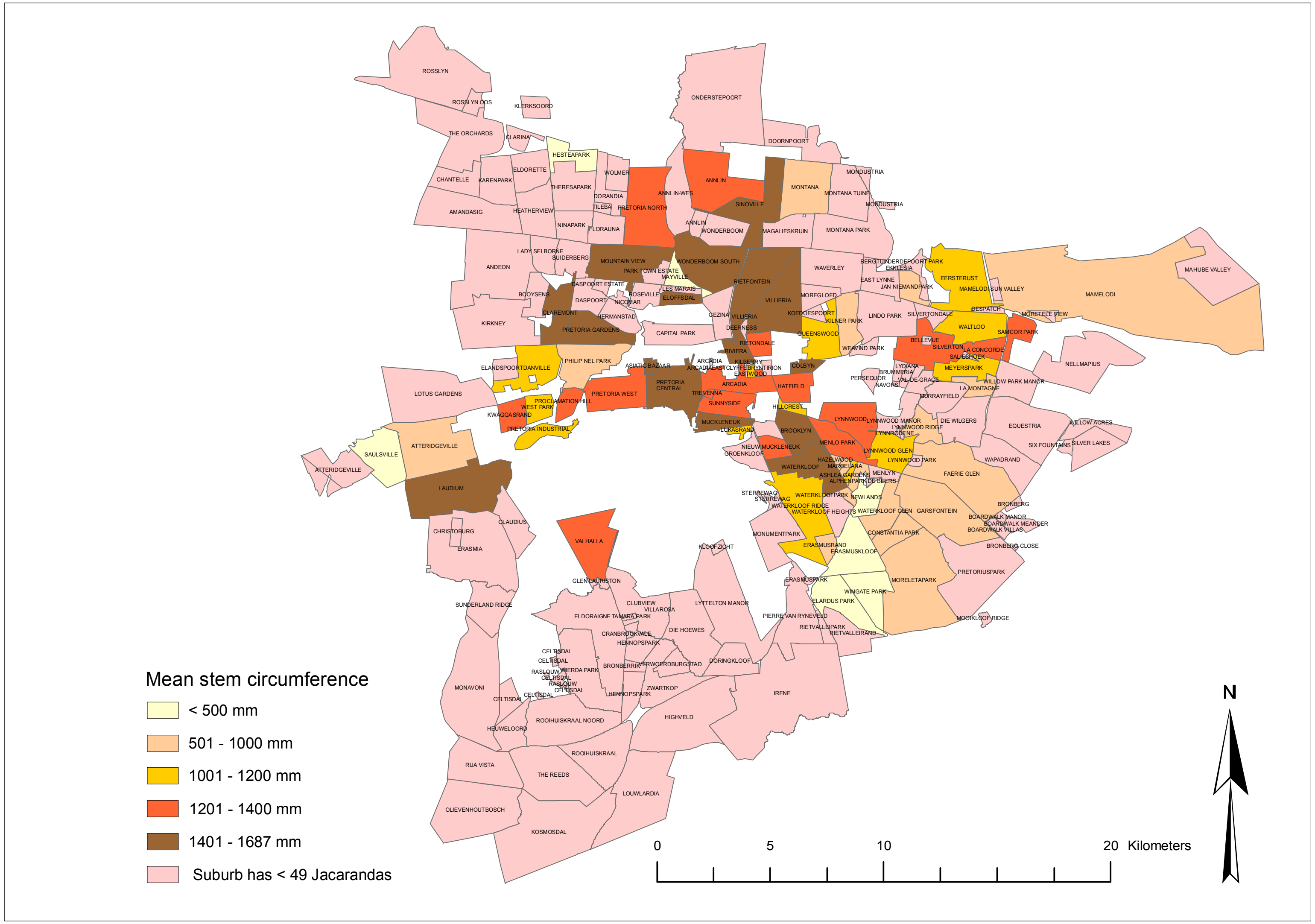

Figure 7.2. The mean stem circumference of Jacaranda street trees in the City of Tshwane as measured in February and March 2004. The darker colours represent suburbs with larger trees.

Table 7.4. Suburb names, number of Jacaranda trees per suburb (n), mean carbon (tonne) per tree per suburb in descending order, standard deviation (t C) and total carbon (tonne) in each suburb as well as the percentage of total carbon per suburb. The calculations are based on stem circumference measurements taken of Jacaranda street trees in February and March 2004 in the Pretoria region in the City of Tshwane

No	Suburb	n	Mean t C per tree	Standard deviation t C	Total t C	%
1	Asiatic Bazaar	67	0.713	0.286	47.791	0.391
2	Laudium	281	0.680	0.237	191.184	1.566
3	Claremont	344	0.670	0.304	230.642	1.889
4	Colbyn	308	0.631	0.243	194.436	1.593
5	Mountain View	153	0.612	0.250	93.645	0.767
6	Wonderboom South	227	0.582	0.279	132.014	1.081
7	Waterkloof	1412	0.568	0.265	801.359	6.565
8	Sinoville	82	0.553	0.211	45.358	0.372
9	Muckleneuk	559	0.520	0.301	290.647	2.381
10	Riviera	465	0.516	0.170	239.763	1.964
11	Pretoria Gardens	132	0.511	0.226	67.445	0.552
12	Lynnwood	514	0.508	0.406	261.110	2.139
13	Eloffsdal	159	0.487	0.336	77.396	0.634
14	Pretoria Central	2853	0.483	0.277	1379.037	11.297
15	Brooklyn	2535	0.472	0.150	1195.351	9.792
16	Rietondale	454	0.467	0.273	211.941	1.736
17	Salvokop	87	0.462	0.287	40.159	0.329
18	Rietfontein	1028	0.460	0.156	473.021	3.875
19	Menlo Park	378	0.458	0.235	173.310	1.420
20	Villiera	1207	0.458	0.225	552.806	4.528
21	Pretoria-North	840	0.443	0.227	372.497	3.051
22	Sunnyside	1836	0.430	0.177	788.651	6.460
23	Pretoria West	702	0.424	0.148	297.842	2.440
24	Lisdogan Park	531	0.415	0.255	220.387	1.805
25	Trevena	128	0.415	0.324	53.111	0.435
26	Nieuw Muckleneuk	284	0.407	0.196	115.723	0.948
27	Proclamation Hill	896	0.393	0.118	352.157	2.885
28	Hatfield	977	0.385	0.129	375.986	3.080
29	Samcor Park	95	0.381	0.278	36.223	0.297
30	Arcadia	1929	0.367	0.139	708.776	5.806
31	Annlin	492	0.359	0.251	176.627	1.447
32	Kwaggasrand	310	0.352	0.105	109.051	0.893

No	Suburb	n	Mean t C per tree	Standard deviation t C	Total t C	%
33	Valhalla	447	0.348	0.171	155.683	1.275
34	Silverton	166	0.332	0.157	55.080	0.451
35	Clydesdale	67	0.317	0.148	21.265	0.174
36	Pretoria Industrial	396	0.297	0.119	117.623	0.964
37	Wes Park	622	0.277	0.116	172.483	1.413
38	Danville	67	0.269	0.148	18.051	0.148
39	Ashlea Gardens	409	0.263	0.224	107.491	0.881
40	Eastwood	499	0.259	0.154	129.201	1.058
41	Queenswood	215	0.253	0.183	54.314	0.445
42	Lynnwood Glen	102	0.248	0.096	25.311	0.207
43	Lukasrand	323	0.248	0.150	80.042	0.656
44	Waterkloof Ridge	1509	0.243	0.095	367.287	3.009
45	Watloo	248	0.229	0.119	56.683	0.464
46	Eersterust	442	0.228	0.126	100.602	0.824
47	Hillcrest	155	0.218	0.134	33.859	0.277
48	Meyers Park	235	0.208	0.103	48.855	0.400
49	La Montagne	59	0.170	0.148	10.047	0.082
50	Alphen Park	96	0.165	0.085	15.823	0.130
51	Constantia Park	393	0.131	0.068	51.386	0.421
52	Waterkloof Park	189	0.127	0.082	24.096	0.197
53	Maroelana	60	0.127	0.059	7.619	0.062
54	Garsfontein	449	0.122	0.072	54.670	0.448
55	Kilner Park	235	0.121	0.073	28.406	0.233
56	Waterkloof Glen	155	0.115	0.057	17.824	0.146
57	Atteridgeville	268	0.114	0.041	30.545	0.250
58	Erasmusrand	227	0.109	0.078	24.692	0.202
59	Mamelodi	304	0.094	0.056	28.549	0.234
60	Jan Niemand Park	61	0.088	0.093	5.375	0.044
61	Hazelwood	77	0.067	0.109	5.197	0.043
62	Moreleta Park	348	0.065	0.049	22.452	0.184
63	Lynnwood Ridge	108	0.063	0.038	6.856	0.056
64	Montana	93	0.045	0.031	4.195	0.034
65	Faerie Glen	223	0.040	0.022	8.889	0.073
66	Philip Nel Park	56	0.039	0.021	2.182	0.018
67	Mayville	42	0.028	0.023	1.156	0.009
68	Erasmuskloof	70	0.023	0.025	1.625	0.013
69	Saulsville	208	0.014	0.009	2.900	0.024
70	Elardus Park	159	0.013	0.009	2.007	0.016
71	Hestea Park	103	0.009	0.007	0.913	0.007
72	Newlands	60	0.006	0.007	0.346	0.003
73	Wingate Park	92	0.004	0.003	0.344	0.003

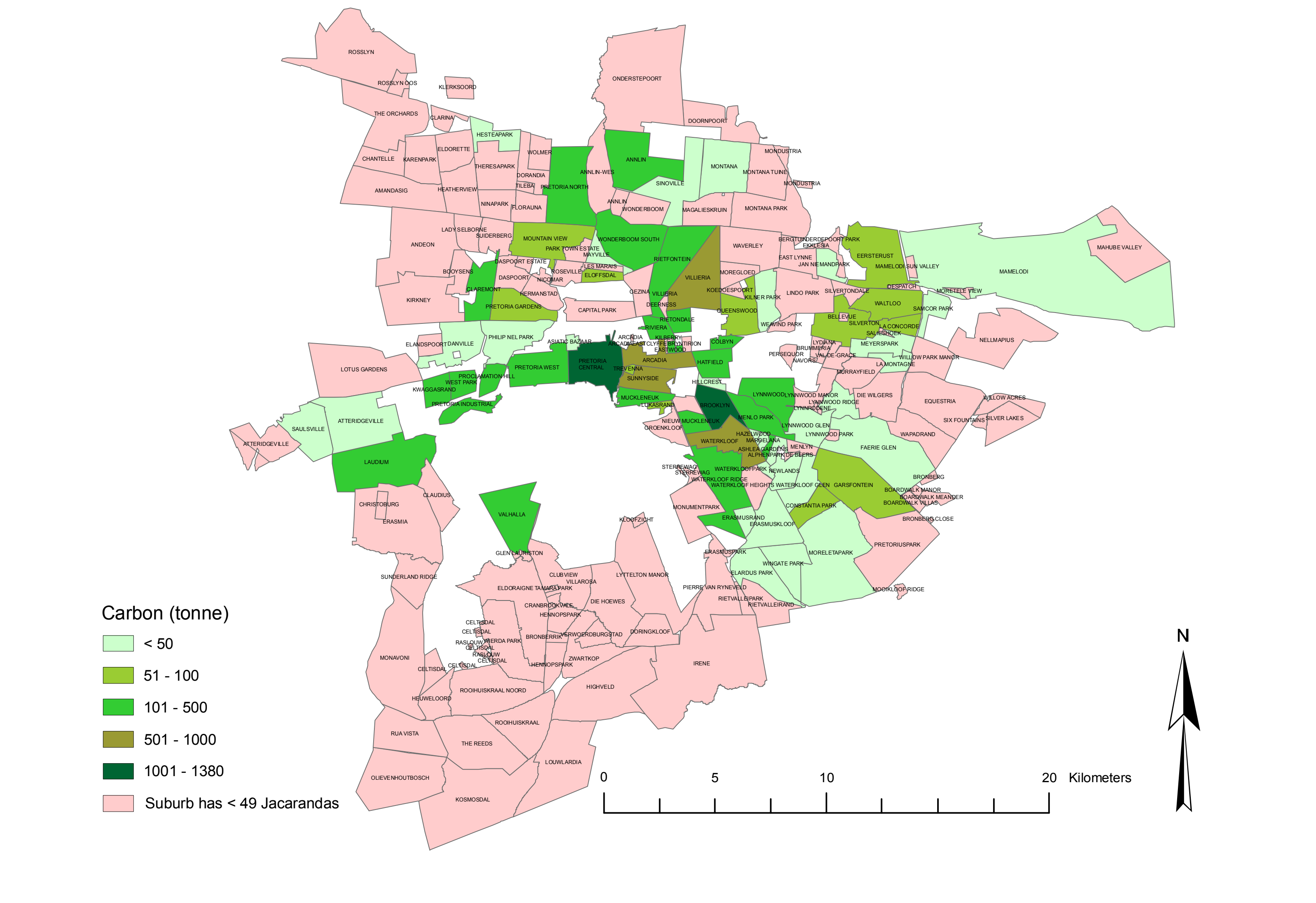

Figure 7.3. The estimated carbon quantities in each suburb for Jacaranda street trees in the City of Tshwane as determined in 2004. The darker colours represent suburbs with larger quantities of carbon.

Mean carbon per tree in a suburb, mean CO_2 per tree and the associated monetary values of the carbon dioxide equivalent in US dollars and Rand are shown in Table 7.5. The estimated mean value of a Jacaranda tree in the City of Tshwane is US$13.87 or R91.40. The estimated carbon dioxide equivalent (CO_2eq) stored in the above and belowground biomass of a mean tree in Asiatic Bazaar, Laudium, Claremont and Colbyn are 2.618 t CO_2eq, 2.497 t CO_2eq, 2.461 t CO_2eq, 2.317 t CO_2eq respectively and is worth an estimated R172.51, R164.55, R162.16 and R152.68 respectively (Table 7.5).

Total carbon per suburb, total CO_2 equivalent per suburb and the associated monetary values of the carbon dioxide equivalent in US dollars and Rand per suburb are shown in Table 7.6. The largest estimated total quantities of carbon dioxide equivalent that have been sequestrated at the time of measurements by all the Jacaranda street trees in a suburb are 5 061.067 t CO_2eq, 4 386.939 t CO_2eq, 2 940.988 t CO_2eq and 2 894.349 t CO_2eq and are of the suburbs Pretoria Central, Brooklyn, Waterkloof and Sunnyside respectively. The estimated monetary value of all the Jacaranda street trees in these suburbs is R333 524.29 (11.297% of the total value), R289 099.26 (9.792% of the total value), R193 811.08 (6.565% of the total value) and R190 737.60 (6.460% of the total value) respectively (Table 7.6).

Table 7.5. Suburb names, mean carbon (tonne) per Jacaranda tree in descending order, mean CO_2 eq (tonne) per Jacaranda tree and the associated monetary values of CO_2 eq in US$ and Rand per tree, based on trade value of US$10.00 per tonne CO_2 eq and an exchange rate of US$1.00 = R6.59 (http://www.finance24.co.za/Finance/Sake/Home/, accessed 17/08/2004). The calculations are based on stem circumference measurements taken of Jacaranda street trees in February and March 2004 in the Pretoria region in the City of Tshwane

No	Suburb	Mean t C / tree	Mean t CO_2eq / tree	US$	Rand
1	Asiatic Bazaar	0.713	2.618	26.18	172.51
2	Laudium	0.680	2.497	24.97	164.55
3	Claremont	0.670	2.461	24.61	162.16
4	Colbyn	0.631	2.317	23.17	152.68
5	Mountain View	0.612	2.246	22.46	148.03
6	Wonderboom South	0.582	2.134	21.34	140.65
7	Waterkloof	0.568	2.083	20.83	137.26
8	Sinoville	0.553	2.030	20.30	133.78
9	Muckleneuk	0.520	1.908	19.08	125.75
10	Riviera	0.516	1.892	18.92	124.70
11	Pretoria Gardens	0.511	1.875	18.75	123.57
12	Lynnwood	0.508	1.864	18.64	122.86
13	Eloffsdal	0.487	1.786	17.86	117.73
14	Pretoria Central	0.483	1.774	17.74	116.90
15	Brooklyn	0.472	1.731	17.31	114.04
16	Rietondale	0.467	1.713	17.13	112.90
17	Salvokop	0.462	1.694	16.94	111.64
18	Rietfontein	0.460	1.689	16.89	111.29
19	Menlo Park	0.458	1.683	16.83	110.89
20	Villiera	0.458	1.681	16.81	110.77
21	Pretoria-North	0.443	1.627	16.27	107.25
22	Sunnyside	0.430	1.576	15.76	103.89
23	Pretoria West	0.424	1.557	15.57	102.61
24	Lisdogan Park	0.415	1.523	15.23	100.38
25	Trevena	0.415	1.523	15.23	100.35
26	Nieuw Muckleneuk	0.407	1.495	14.95	98.55
27	Proclamation Hill	0.393	1.442	14.42	95.06
28	Hatfield	0.385	1.412	14.12	93.07
29	Samcor Park	0.381	1.399	13.99	92.22

No	Suburb	Mean t C / tree	Mean t CO_2eq / tree	US$	Rand
30	Arcadia	0.367	1.348	13.48	88.86
31	Annlin	0.359	1.318	13.18	86.82
32	Kwaggasrand	0.352	1.291	12.91	85.08
33	Valhalla	0.348	1.278	12.78	84.23
34	Silverton	0.332	1.218	12.18	80.25
35	Clydesdale	0.317	1.165	11.65	76.76
36	Pretoria Industrial	0.297	1.090	10.90	71.84
37	Wes Park	0.277	1.018	10.18	67.07
38	Danville	0.269	0.989	9.89	65.16
39	Ashlea Gardens	0.263	0.965	9.65	63.56
40	Eastwood	0.259	0.950	9.50	62.62
41	Queenswood	0.253	0.927	9.27	61.10
42	Lynnwood Glen	0.248	0.911	9.11	60.02
43	Lukasrand	0.248	0.909	9.09	59.93
44	Waterkloof Ridge	0.243	0.893	8.93	58.87
45	Watloo	0.229	0.839	8.39	55.28
46	Eersterust	0.228	0.835	8.35	55.05
47	Hillcrest	0.218	0.802	8.02	52.83
48	Meyers Park	0.208	0.763	7.63	50.28
49	La Montagne	0.170	0.625	6.25	41.19
50	Alphen Park	0.165	0.605	6.05	39.86
51	Constantia Park	0.131	0.480	4.80	31.62
52	Waterkloof Park	0.127	0.468	4.68	30.83
53	Maroelana	0.127	0.466	4.66	30.71
54	Garsfontein	0.122	0.447	4.47	29.45
55	Kilner Park	0.121	0.444	4.44	29.23
56	Waterkloof Glen	0.115	0.422	4.22	27.81
57	Atteridgeville	0.114	0.418	4.18	27.56
58	Erasmusrand	0.109	0.399	3.99	26.31
59	Mamelodi	0.094	0.345	3.45	22.71
60	Jan Niemand Park	0.088	0.323	3.23	21.31
61	Hazelwood	0.067	0.248	2.48	16.32
62	Moreleta Park	0.065	0.237	2.37	15.60
63	Lynnwood Ridge	0.063	0.233	2.33	15.35
64	Montana	0.045	0.166	1.66	10.91
65	Faerie Glen	0.040	0.146	1.46	9.64
66	Philip Nel Park	0.039	0.143	1.43	9.42
67	Mayville	0.028	0.101	1.01	6.66
68	Erasmuskloof	0.023	0.085	0.85	5.61
69	Saulsville	0.014	0.051	0.51	3.37
70	Elardus Park	0.013	0.046	0.46	3.05
71	Hestea Park	0.009	0.033	0.33	2.14
72	Newlands	0.006	0.021	0.21	1.40
73	Wingate Park	0.004	0.014	0.14	0.90

Table 7.6. Names of suburbs, total carbon (tonne) per suburb in descending order, total CO_2 eq (tonne) per suburb and the associated monetary values of the total t C and the total t CO_2 eq for each suburb in US$ and Rand, based on trade value of US$10.00 per tonne CO_2 eq and an exchange rate of US$1.00 = R6.59 (http://www.finance24.co.za/Finance/Sake/Home/, accessed 17/08/2004) as well as the percentages of the total amount. The calculations are based on mean per tree carbon values for each suburb that were derived from stem circumference measurements taken of Jacaranda street trees in February and March 2004 in the Pretoria region in the City of Tshwane

No	Suburb	Total t C	Total t CO_2eq	US$	Rand	% of total
1	Pretoria Central	1379.037	5061.067	50610.67	333524.29	11.297
2	Brooklyn	1195.351	4386.939	43869.39	289099.26	9.792
3	Waterkloof	801.359	2940.988	29409.88	193811.08	6.565
4	Sunnyside	788.651	2894.349	28943.49	190737.60	6.460
5	Arcadia	708.776	2601.208	26012.08	171419.59	5.806
6	Villiera	552.806	2028.797	20287.97	133697.70	4.528
7	Rietfontein	473.021	1735.988	17359.88	114401.63	3.875
8	Hatfield	375.986	1379.870	13798.70	90933.43	3.080
9	Pretoria-North	372.497	1367.064	13670.64	90089.54	3.051
10	Waterkloof Ridge	367.287	1347.944	13479.44	88829.53	3.009
11	Proclamation Hill	352.157	1292.418	12924.18	85170.32	2.885
12	Pretoria West	297.842	1093.082	10930.82	72034.08	2.440
13	Muckleneuk	290.647	1066.675	10666.75	70293.90	2.381
14	Lynnwood	261.110	958.273	9582.73	63150.16	2.139
15	Riviera	239.763	879.928	8799.28	57987.29	1.964
16	Claremont	230.642	846.457	8464.57	55781.49	1.889
17	Lisdogan Park	220.387	808.820	8088.20	53301.21	1.805
18	Rietondale	211.941	777.822	7778.22	51258.45	1.736
19	Colbyn	194.436	713.580	7135.80	47024.92	1.593
20	Laudium	191.184	701.647	7016.47	46238.51	1.566
21	Annlin	176.627	648.222	6482.22	42717.84	1.447
22	Menlo Park	173.310	636.049	6360.49	41915.60	1.420
23	Wes Park	172.483	633.014	6330.14	41715.62	1.413
24	Valhalla	155.683	571.358	5713.58	37652.52	1.275
25	Wonderboom South	132.014	484.493	4844.93	31928.06	1.081
26	Eastwood	129.201	474.168	4741.68	31247.70	1.058
27	Pretoria Industrial	117.623	431.676	4316.76	28447.47	0.964
28	Nieuw Muckleneuk	115.723	424.703	4247.03	27987.93	0.948

No	Suburb	Total t C	Total t CO_2eq	US$	Rand	% of total
29	Kwaggasrand	109.051	400.217	4002.17	26374.29	0.893
30	Ashlea Gardens	107.491	394.492	3944.92	25997.00	0.881
31	Eersterust	100.602	369.211	3692.11	24330.99	0.824
32	Mountain View	93.645	343.676	3436.76	22648.28	0.767
33	Lukasrand	80.042	293.753	2937.53	19358.31	0.656
34	Eloffsdal	77.396	284.044	2840.44	18718.52	0.634
35	Pretoria Gardens	67.445	247.524	2475.24	16311.82	0.552
36	Watloo	56.683	208.027	2080.27	13708.95	0.464
37	Silverton	55.080	202.144	2021.44	13321.29	0.451
38	Garsfontein	54.670	200.639	2006.39	13222.09	0.448
39	Queenswood	54.314	199.331	1993.31	13135.92	0.445
40	Trevena	53.111	194.918	1949.18	12845.08	0.435
41	Constantia Park	51.386	188.588	1885.88	12427.97	0.421
42	Meyers Park	48.855	179.296	1792.96	11815.62	0.400
43	Asiatic Bazaar	47.791	175.392	1753.92	11558.34	0.391
44	Sinoville	45.358	166.463	1664.63	10969.91	0.372
45	Salvokop	40.159	147.384	1473.84	9712.59	0.329
46	Samcor Park	36.223	132.938	1329.38	8760.63	0.297
47	Hillcrest	33.859	124.261	1242.61	8188.82	0.277
48	Atteridgeville	30.545	112.098	1120.98	7387.29	0.250
49	Mamelodi	28.549	104.775	1047.75	6904.64	0.234
50	Kilner Park	28.406	104.251	1042.51	6870.12	0.233
51	Lynnwood Glen	25.311	92.893	928.93	6121.64	0.207
52	Erasmusrand	24.692	90.618	906.18	5971.72	0.202
53	Waterkloof Park	24.096	88.432	884.32	5827.70	0.197
54	Moreleta Park	22.452	82.399	823.99	5430.12	0.184
55	Clydesdale	21.265	78.044	780.44	5143.09	0.174
56	Danville	18.051	66.247	662.47	4365.68	0.148
57	Waterkloof Glen	17.824	65.415	654.15	4310.88	0.146
58	Alphen Park	15.823	58.070	580.70	3826.79	0.130
59	La Montagne	10.047	36.874	368.74	2430.00	0.082
60	Faerie Glen	8.889	32.623	326.23	2149.86	0.073
61	Maroelana	7.619	27.963	279.63	1842.73	0.062
62	Lynnwood Ridge	6.856	25.161	251.61	1658.10	0.056
63	Jan Niemand Park	5.375	19.728	197.28	1300.05	0.044
64	Hazelwood	5.197	19.072	190.72	1256.82	0.043
65	Montana	4.195	15.395	153.95	1014.56	0.034
66	Saulsville	2.900	10.645	106.45	701.49	0.024
67	Philip Nel Park	2.182	8.007	80.07	527.65	0.018
68	Elardus Park	2.007	7.364	73.64	485.29	0.016
69	Erasmuskloof	1.625	5.963	59.63	392.95	0.013
70	Mayville	1.156	4.241	42.41	279.51	0.009
71	Hestea Park	0.913	3.352	33.52	220.87	0.007
72	Newlands	0.346	1.271	12.71	83.77	0.003
73	Wingate Park	0.344	1.261	12.61	83.10	0.003

Discussion

Methodological issues

Trees on street corners

Whenever there were sufficient trees in a street, trees on the street corners were not measured because they are exposed to more negative environmental factors such as:

- Pavements: There are larger impermeable surfaces on street corners than elsewhere in the road reserve.
- Pollution: Trees on street corners are exposed not only to the concentrated pollution associated with an intersection but also to that of the two intersecting streets.
- Pedestrian traffic: This is possibly double compared to that along a street.
- Hawking: This is associated with soil compaction and impermeable surfaces provided for hawkers.

These corner trees are in some instances smaller and / or are more vandalized than the other trees.

Tree volume equation

Equation (1) (see Methodology) is derived from measurements of *Jacaranda mimosifolia* trees in California USA conducted by the Urban Forest Ecosystem Institute at the California Polytechnic State University in San Luis Obispo in cooperation with the California Department of Forestry and Fire Protection in Riverside California (Pillsbury *et al.*, 1998). The largest stem circumference measured for the determination of equation (1) was 1844 mm (Pillsbury *et al.*, 1998). Errors could occur if equation (1) is used to estimate the volumes of trees with stem circumference values outside the sampling range from which equation (1) was derived (Pillsbury *et al.*, 1998). The stem circumferences of some of the trees measured in Tshwane exceeded 1844 mm and, therefore the results for these very large trees measured in Tshwane may be less accurate. The largest stem circumference measured for the determination of equation (1) (1844 mm) is however, larger than the largest mean stem circumference per suburb in Tshwane which was calculated for Asiatic Bazaar (1687 mm).

Trees used to determine equation (1) were trees with little or no defect but due to practical considerations the trees measured in the present study did in some instances have defects which could alter the biomass results. Pruning could also be a factor in the present study. No tree where the crown was excessively trimmed or pruned was included in the data from which equation (1) was derived (Pillsbury *et al.*, 1998). The Jacarandas of Tshwane are in some instances severely pruned to allow for overhead services. Biomass and carbon estimates calculated using equation (1) would be overestimates for these severely pruned trees. Furthermore, using equation (1) instead of a locally derived equation may result in discrepancies due to climatic, pedological and other environmental differences.

A literature search revealed no biomass or allometric equations for *Jacaranda mimosifolia* locally or internationally either in urban or natural settings. It is important to note that the volumetric equation used in this report provides only an *estimated* volume. Therefore all calculations derived from this equation are also estimates and thus all the resulting carbon calculations and the derived monetary values may only be quoted as *estimates* and should be viewed as *preliminary*.

The development of local biomass and allometric equations through destructive sampling could provide more accurate biomass estimates than those derived from equation (1). However, due to cost implications and because destructive sampling was not permissible in the urban environment (personal communication with Mr B. Dry, The Deputy Manager of Urban Forestry, Nursery and Training of the City of Tshwane Metropolitan Municipality) local equations were not developed.

Destructive sampling could be done by cutting down a number of Jacaranda trees ranging in sizes from small to large stem circumferences. The total mass of each tree should be determined and some samples should be dried to determine fresh : dry mass ratio and a mean wood density. The wood carbon content should also be determined. This process is very cumbersome, time consuming and costly. It would furthermore, mean that perfectly functional and healthy street trees would need to be destroyed. This technique, although very applicable, is not very well suited to the urban environment where every surviving tree is essential to the environmental urban well-being (Jim, 1989; McPherson *et al*., 1994; IPCC, 2000; Konijnendijk, 2000; Akbari *et al.*, 2001; Nowak & O'Connor, 2001; Akbari, 2002; Nowak *et al.*, 2002a; Nowak *et al.*, 2002b; McPherson, 2003). A future option would however be, for the municipality to go through this destructive sampling process for each tree that *by necessity* has to be removed, for example, for the widening of roads or similar infrastructural alterations. Through this procedure, a database could be built and regressions could be developed from which biomass could be more accurately calculated.

However, it is important to note that the Californian *Jacaranda mimosifolia* trees from which equation (1) was derived, were all urban trees and were therefore exposed to similar stressors that Tshwane's trees are exposed to. Furthermore, due to the limited availability of biomass equations for urban tree species, it is general practice to use those few equations that do exist for the urban and indeed natural environment in a generic manner (Goodman, 1990; McPherson *et al*.,1994; Nowak & Crane, 2002; Nowak *et al.*, 2002b). Equation (1) was also used by McPherson *et al.* (2001) for carbon sequestration calculations. This supports its applicability and appropriateness for such derivations.

Root to shoot ratio

Aboveground to belowground conversions (root : shoot ratios) are commonly used (Scholes & Walker, 1993; McPherson *et al.*,1994; McPherson *et al.*, 2001; Nowak & Crane, 2002; IPCC, 2003; Scholes, 2004), because it is difficult and therefore also expensive to determine belowground biomass. This is especially true of belowground biomass in urban environments. To determine root biomass, soil core samples could be taken (Scholes & Walker, 1993; Scholes, 2004). Other methods are to excavate the roots mechanically (with a backhoe or small excavator (Snowdon *et al.*, 2002)) or by excavating 1 m x 1 m x 1 m pits (Scholes & Walker, 1993) and then as in the case of the soil core and mechanical methods, to sieve, wash, oven dry, weigh and determine the carbon content of the roots and then to extrapolate to the whole tree's root system. This will have to be done for trees of various sizes to obtain a regression so that interpolation could be made.

The problems with these methods are that:

- roots of other plants may also be included in the sample
- the tree sampled may undergo crown dieback, growth retardation or in the case of smaller trees, they may even die
- it is likely that not all of the roots will be obtained because the larger trees have roots that enter private property or are beneath the road adjacent to the road reserve
- difficulty may arise in urban settings where concrete pavements may be encountered
- trenches may become hazardous to pedestrian and vehicle movement (parking) along road reserves
- this method is labour and time intensive
- the method is costly.

In the light of the above it was decided to use the root : shoot ratio (see Methodology) which was also used by McPherson *et al.* (2001) to determine urban carbon sequestration quantities for *Jacaranda mimosifolia* trees for Inland Empire Communities in California U.S.A..

Wood density

Carbon quantities of the trees measured are relatively low. This can largely be ascribed to the low wood density of *Jacaranda mimosifolia*. However, the density of 520 kg / m^3 measured for *Jacaranda mimosifolia* in Tshwane corresponds with the air dry density of 520 kg / m^3 for *Jacaranda acutifolia* given by J. Ilic (Email correspondence Dr Jugo Ilic, Commonwealth Scientific and Industrial Research Organization (CSIRO) Forestry and Forest Products, Private Bag 10, Clayton

South MDC, Victoria 3169, Australia. E-mail: Jugo.Ilic@csiro.au, (03/03/2004) who quoted Mainieri & Chimelo, (1989)). It also agrees well with the density of 550 kg / m^3 suggested by the Intergovernmental Panel for Climate Change (IPCC) for *Jacaranda* species in general (IPCC, 2003). A density of 590 kg / m^3 for *Jacaranda mimosifolia* in Argentina was cited by Lahitte & Hurrell (1999), but no indication could be found whether this density refers to oven-dried wood samples and it is possible that this density was that of either wet or air-dry wood.

Termites

Termites found at the base of Jacaranda trees in Laudium were not only concentrated at the trees but were often found elsewhere in the streets. Information received from the Institute for Commercial Forestry Research (Province of KwaZulu-Natal, South Africa) confirmed that the dead bark of Jacarandas are in some instances eaten by termites, but that they do not harm the live trees (Haigh, 1990). Therefore, the data gathered from Laudium could be included in the calculations.

***Intra*-street and *inter*-street comparisons**

The analysis of variance conducted for the *intra*-street and *inter*-street stem circumference variation showed no significant differences. This suggests that the socio-economic, cultural and environmental conditions within a suburb are relatively homogeneous. It could furthermore suggest that the trees in a street and suburb were planted at more or less the same time.

The standard deviations for various results are provided. These deviations should be borne in mind when using the results.

Calculated carbon quantities

The mean carbon per tree of some suburbs are amongst the highest calculated, yet some of these suburbs have lower total carbon quantities than suburbs with a relatively low mean carbon quantity per tree. The reason being that not only is a high mean carbon quantity per tree necessary to obtain a large total suburb carbon mass but a large number of trees is also necessary. For example, the Asiatic Bazaar has the highest mean carbon per tree (0.713 t C) but has only 67 trees and as a result has only the 43rd largest total quantity of carbon for all the suburbs (47.791 t C) (Table 7.4). On the other hand Pretoria Central is ranked 14th with regards to mean carbon per tree (0.483 t C), yet it is the suburb with the largest quantity of carbon stored in its street trees (1 379.037 t C). This can be attributed to the large number (2853) of Jacaranda street trees present in the suburb and its accompanying relatively high mean carbon quantity. The mean carbon quantity per tree is positively correlated to the mean stem circumference per tree. In the case of the three suburbs that have the lowest mean stem circumferences (Hestea Park, Newlands and Wingate Park) and therefore lowest mean carbon quantities per tree also have moderately low numbers of trees per suburb when compared with other suburbs. Consequently, these suburbs also have the lowest total quantity of carbon per suburb of all the measured suburbs.

The mean carbon per tree for the city's Jacaranda population was calculated as an estimated 0.378 t C while the highest mean carbon per tree for a single suburb was almost double this value (0.713 t C for Asiatic Bazaar). This suggests that the urban Jacaranda forest in Tshwane still has a large carbon sequestration potential. Therefore when street trees are removed (especially young trees) it should be appreciated that such a tree could have had a long life expectancy and therefore a relatively high carbon sequestration potential which is now lost. This loss should be considered when these removed trees are not replaced and can even be translated into monetary terms. However, when larger trees are removed monetary compensation may be required due to the destruction of green infrastructure but especially in context of these results, due to the release of carbon dioxide.

Carbon trading

It should be noted that the carbon that has been captured by the trees cannot be traded because amongst other reasons the trees were not part of a registered carbon sequestration project and most were planted before 1990 which is the Kyoto Protocol baseline year. It could furthermore be argued that the municipality would have planted the trees as a part of the normal day to day practice. This would indicate that there are no additionalities and that there is thus no extra carbon sequestrated over and above that which would have been sequestrated as part of the normal tree planting. Additionality is a prerequisite for carbon sequestration trading (see Chapter 9). Although the CO_2 price given is market related (Booth, 2003; McHale, 2003; www.pointcarbon.co.za accessed 31 May 2005) it still is hypothetical because as with other stock exchange commodities the value fluctuates and is exchange rate related.

Other benefits associated with street trees

Increase in property values

Increase in the value of properties can be used as an example of how street trees provide other monetary benefits. Well maintained trees on the road reserves increase the "curb appeal" of properties (McPherson *et al.*, 2001). McPherson *et al.* (2001) state the following:

"Research comparing sales prices of residential properties with different tree resources suggests that people are willing to pay 3% - 7% more for properties with ample tree resources versus few or no trees."

In a telephonic survey conducted with various estate agents (AEA, ERA, RE/MAX, 23/08/2004) that are responsible for sales of properties in the wealthy suburb of Brooklyn a lowest price of R750 000 and a highest price of R8 million were suggested for current house prices. A mean house price of R1.5 million was however suggested for a 3 bedroom, 2 bathroom and double garage residence.

Assuming that there are three Jacaranda trees in front of each house and assuming a conservative curb appeal of 3% of the property value, it would provide an additional value to these trees of R7 500 per tree, R15 000 per tree and R80 000 per tree for the lowest, mean and highest suggested house prices in Brooklyn respectively. Even when applying a conservative 1% curb appeal value to the lowest house price in Brooklyn the value of a single street tree related to the house would still amount to R2 500.

The above increase in the value of property could then be translated to the increase in revenue from property tax and possible capital gain tax. These tax aspects are already included in the current property tax system although it has currently probably been determined on a subjective and intuitive basis. The municipality is thus already receiving this curb appeal tax value of street trees. However, more street trees planted by the municipality could contribute positively to the income of municipalities and the national government.

The "curb appeal" of Jacarandas increases the value of the trees. Although this survey was done in an affluent suburb with large trees, similar results (proportional to house prices for that area) could be expected in other areas where trees provide sufficient "curb appeal". The percentages suggested by McPherson *et al.* (2001) are not based on research conducted in South Africa and caution should therefore be used when applying these values in a South African context. Yet, the suggested percentages provide ballpark figures and due to the lack of local information could be considered when applied to the value of street trees.

Environmental benefits

As is the case with other urban trees, Jacaranda trees hold numerous other benefits apart from their carbon sequestration value and the increase in the value of property. Many of the benefits mentioned below can be converted to monetary values. Some of the benefits that urban trees hold are amongst others:

- Energy savings in terms of the heating and cooling of buildings (Akbari, 2002; Nowak *et al.*, 2002c; Maco & McPherson, 2003)

- Reduction in soil erosion (McPhillips & Stone, 2003)
- Amelioration of the urban heat island effect (Rosenfeld *et al.*, 1998; Akbari *et al.*, 2001; Behm, 2003; January-Bevers, 2003)
- Amelioration of microclimatic conditions (Huang *et al.*, 1987; Jim, 1987; Simpson, 1998; Akbari, 2002; Nowak *et al.*, 2002a; January-Bevers, 2003)
- Air pollution reductions and air quality improvements (Rosenfeld *et al.*, 1998; Akbari, 2002; January-Bevers, 2003; Maco & McPherson, 2003; Nowak *et al.*, 2003)
- Positive impacts on human health and well being (Jim, 1987; Arnn & Svendsen, 2003; Buchner, 2003; Fowler & Hagevik, 2003; Grove, 2003; Wolf, 2003a; Wolf, 2003b)
- Rainfall interception and reduction in storm water runoff (Xiao *et al.*, 1998; McPherson, 1999; Xiao *et al.*, 2000; Gulick, 2003; Maco & McPherson, 2003)
- Wildlife habitat creation and increase in species diversity (Jim, 1987; Hosty, 2003),
- Reduced noise pollution (Jim, 1987; January-Bevers, 2003),
- Scenic beauty (Jim, 1987; McPherson, 1999; Abdollahi & Ning, 2003; Cremeens *et al.*, 2003; Hosty, 2003; January-Bevers, 2003)
- Recreation, environmental awareness and education opportunities (Jim, 1987; Coulter, 2003; de Vera, 2003; Fowler & Hagevik, 2003; Grove, 2003; Hosty, 2003; MacArthur, 2003; Malone, 2003; Roque, 2003)
- Contribution to the development of civic pride (Arnn & Svendsen, 2003; Fowler & Hagevik, 2003; Hosty, 2003)

- Reduction in the occurrence of crime (Hosty, 2003; MacArthur, 2003; Murray, 2003)
- Jacaranda flowering as tourist attraction

McPherson *et al*. (2001) determined the *annual* benefit of a 20 year old Jacaranda tree for Inland Empire Communities of California, U.S.A. According to their calculations the estimated net *annual* benefit from a public Jacaranda tree 12 m high and with a crown diameter of 10 m is US$37.44 (R246.72) (exchange rate of US$1.00 = R6.59, http://www.finance24.co.za/Finance/Sake/Home/, accessed 17/08/2004). In another study the compensatory value of an average U.S.A. urban tree was determined to be US$630 or R4 151.70 (Nowak *et al.*, 2002a). The compensatory value of urban trees represents the compensation to the owners for the loss of an individual tree and can be viewed as the value of the tree as a structural asset (Nowak *et al.*, 2002a). The Rand values of the above calculations do not take into account inflation, or other economic factors and variables since the date of publication. The above values, although not fully applicable to a South African context, do give an indication as to approximate estimated net annual benefits derived from a Jacaranda tree that is 20 years old and the compensatory value of an average urban tree.

Determining the local monetary value of the above benefits is beyond the scope of this study. However, a South African study is being undertaken to determine the value of a tree taking some of the above factors into account (personal communication, C. Marx, 2004, University of South Africa (formerly the Technikon of South Africa), cmarx@tsa.ac.za). Once the equations from that study are available the monetary value of some of the above factors could be incorporated into the estimated carbon sequestration benefits of Jacaranda trees as determined in this report.

Costs of urban forests and trees

Cognisance should be taken that there are also monetary and environmental costs involved with urban trees and forests (McPherson *et al*., 2002), for example:

- Propagation costs,
- Planting costs,
- Pruning costs,
- Tree and stump removal and disposal costs,
- Pests and disease control,
- Irrigation costs,
- Maintenance of infrastructure (e.g. sidewalks, storm and sewer systems and utility lines),
- Maintenance of leaf litter clean-up,
- Management of urban trees and forests,
- Administration costs,
- Carbon dioxide, other green house gas and pollutant emissions due to the above,
- Allergenic reaction to pollen,

Tree numbers

The numbers of Jacaranda trees in the city (Table 7.7), which were quoted by various media, provide a good illustration of the uncertainty as to the total number of Jacarandas in the city's public and private land. The calculations in this report are based on tree census data, which were the most accurate data obtainable from the municipality when the field work was executed. Caution should be applied when extrapolating the results provided in this report to Jacaranda tree quantities quoted elsewhere because the carbon quantities in this report are based on a street tree sample, which may not be representative of the total Jacaranda population, which includes park and private trees.

However, Table 7.7 indicates that an appreciably larger Jacaranda population than that of the street tree population exists. This implies that the total carbon quantities of the Jacarandas in Tshwane could be much larger than suggested by this report. An extensive tree census and corresponding stem circumference sampling of public and private trees would provide valuable data to estimate the total carbon value of all of the city's Jacarandas.

Table 7.7. The year of publication and the number of Jacaranda trees quoted for streets, parks or the Pretoria region in the City of Tshwane as a whole as well as the publication name and reference is shown. "Streets" refers to street trees, "parks" refers to trees planted in public parks and "city" refers to the total number of trees planted in the whole city

Year of publication	Number of trees	Location of trees	Publication	Reference
1978	60 000	Streets	South African Panorama	(Dellatola, 1978)
1978	55 000	Streets and parks	Beeld	(Van der Schijff, 1978)
1980	50 000	Streets	Omgewing / Environment RSA	(Department of Environment Planning and Energy, 1980)
1984	70 000	Streets	Pretoria News	(Boje, 1984)
1984	55 000 - 60 000	Streets	Beeld	(Reyneke, 1984)
1985	70 000	Streets	Beeld	(Robinson, 1985)
1985	50 000	Streets	Die Transvaler	(Botes, 1985)
1987	50 000	Streets	Pretoria News	(Uys, 1987)
1991	75 000	City	City Council of Pretoria Yearbook	(City Council of Pretoria, 1991)
1991	63 000	Streets	Pretoria News	(Gough, 1991)
1991	70 000	City	Record Moot	(Oberholzer, 1991)
1998	70 000	City (34 600 were planted by municipality)	Record East	(Marquart, 1998)
2000	50 000	City	Pretoria News	(Hlahla, 2000)
2000	35 000	City	Pretoria News	(Pretoria News, 2000)
2002	40 000	City	Record Central	(Linde, 2002)
2003	70 000	City (36 000 were planted by municipality)	Beeld	(Olivier, 2003)
2003	70 000	City	Beeld	(Williamson, 2003)
2003	40 000	City	Beeld	(Marais, 2003)
2003	70 000	City	Beeld	(Marais, 2003)
2003	40 000	Streets and parks	Record Central	(Record Central, 2003)

All trees sequestrate carbon

It should be appreciated that all trees sequestrate carbon albeit at different rates. The Jacaranda population is therefore not unique in this regard. However, due to the unique cultural importance of these trees as well as their integral part of the city's urban forest they are highly regarded by both the citizens and city urban forestry officials. It is however important to note that if *Jacaranda mimosifolia* and other trees maintain their Category 3 alien invader status it would eventually result in an establishment of a new urban forest that does not provide invasive threats. The issue of the inhabitants of Tshwane's emotional and affectionate association with the Jacaranda versus its invasive threat is however, one that can only be resolved with compromise.

Conclusion

Mean carbon per tree per suburb, standard deviation and total carbon in each suburb were determined. The highest mean carbon quantity per tree for a suburb occurred in Asiatic Bazaar and is estimated at 0.713 t C. The lowest mean carbon quantity per tree for a suburb occurred in Hestea Park with an estimated 0.009 t C. The percentage error calculated for the mean carbon quantity per tree for all of the Jacaranda trees in Tshwane based on stem circumference measurements of 20 trees per suburb for 73 suburbs was 3.59%.

Pretoria Central, Brooklyn, and Waterkloof had the highest total quantity of carbon with an estimated 1 379.037 t C, 1 195.351 t C, and 801.359 t C respectively. In contrast, Hestea Park, Newlands and Wingate Park had the lowest total carbon quantities with an estimated 0.913 t C, 0.346 t C, and 0.344 t C respectively.

The total carbon quantity of all the suburbs in which street trees were measured (73 suburbs) and on which the calculations were based was estimated at 12 207.372 t C. A per tree mean of 0.378 t C was estimated for all the suburbs in which street trees were measured. The total quantity of carbon for all the street trees in all the suburbs of Tshwane (114 suburbs) is estimated at 12 709.241 t C. Due to discrepancies casually observed in the number of trees it is suggested that an adjusted carbon quantity be assumed. Based on the aforementioned observations an adjustment of -10% is suggested and results in a total estimated carbon quantity for Tshwane's Jacaranda street trees of 11 438.317 t C.

A per tree mean of 1.387 t CO_2 equivalent (CO_2eq) was estimated for all the measured suburbs, an estimated total of 46 642.916 t CO_2eq and an adjusted total of 41 978.625 t CO_2eq for all the Jacaranda street trees in Tshwane. Assuming a hypothetical price of US$10 tonne^{-1} CO_2eq, the total value of all the Jacaranda street trees in Tshwane based on the suggested adjusted carbon value could be estimated at US$419 786. At the time of writing the carbon dioxide value of all the Jacaranda street trees in the City of Tshwane could thus be estimated at R2 766 391.

The largest estimated total quantities of carbon dioxide equivalent that have been sequestrated at the time of measurements by all the Jacaranda street trees in each of the measured suburbs are 5 061.067 t CO_2eq, 4 386.939 t CO_2eq, 2

940.988 t CO_2eq and 2 894.349 t CO_2eq and are for the suburbs Pretoria Central, Brooklyn, Waterkloof and Sunnyside respectively and have an estimated monetary value of R333 524.29, R289 099.26, R193 811.08 and R190 737.60 respectively.

It should be stressed that the carbon that has been captured by the trees cannot be traded since amongst other reasons the trees were not part of a registered carbon sequestration project and most were planted before 1990 which is the Kyoto Protocol baseline year. Although the CO_2 price given (US$10 per ton CO_2eq) is market related (McHale, 2003) it is still hypothetical because as with other stock exchange commodities the prices fluctuate and are exchange rate related.

The carbon sequestration value of Jacarandas is but a portion of the total possible value of a large tree. These results do, however, give a first approximation as to the monetary value of Jacarandas. However, the Jacarandas of Tshwane are more than just a carbon sink and have additional value related to their urban environmental attributes. Furthermore, they are a part of the city's natural, cultural, and historical heritage and it should thus be appreciated that natural, cultural and historical heritage far outweighs the monetary benefits and values described in this report. Once such a heritage is lost it can become irreplaceable. Permission from the Department of Agriculture to provide the municipality the right to propagate Jacarandas for replacement purposes to maintain the city's Jacaranda population would prevent the loss of our national heritage. Although carbon sequestration estimates in this report provide tangible monetary values, it would be tragic if it were the only premise used to determine the value of the capital city of South

Africa's cultural, natural and historical heritage, especially a heritage that had its origin more than a century ago.

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