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Author(s)	Jim, CY; Chen, WY
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Ecosystem service of air pollution abatement by urban forest

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Professor C.Y. Jim
Department of Geography
The University of Hong Kong
hragjcy@hku.hk

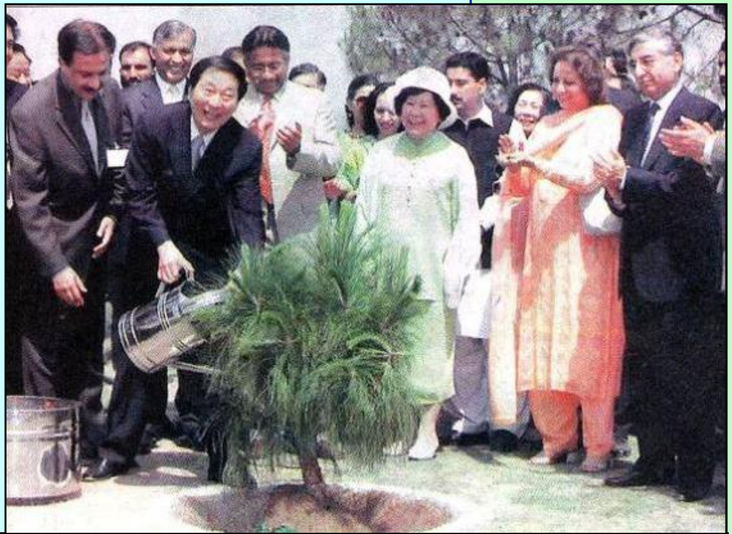
Dr Wendy Y. Chen
Department of Civil and Structural Engineering
Polytechnic University of Hong Kong
cewychen@inet.polyu.edu.hk

Outline of presentation

1. Introduction
2. Study objectives
3. Study area
4. Methods
5. Results and discussion
6. Implications and conclusion

1. Introduction

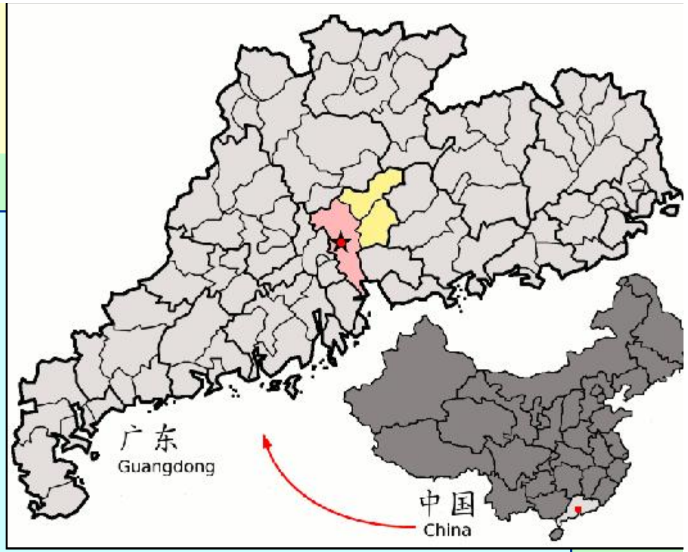
- China national urban greening status
  - 2007: average 33% of urban areas
  - 2010: ~8 m^2 per capita
  - 2050: target of 45% of urban areas
- National greening accolades
  - National Model City of Greening (19)
  - National Forest City (9)
  - National Garden City (>100)
- Rapid urbanization
  - Environmental quality
  - Quality of life
  - Rising expectations
  - Expanded roles of urban forests



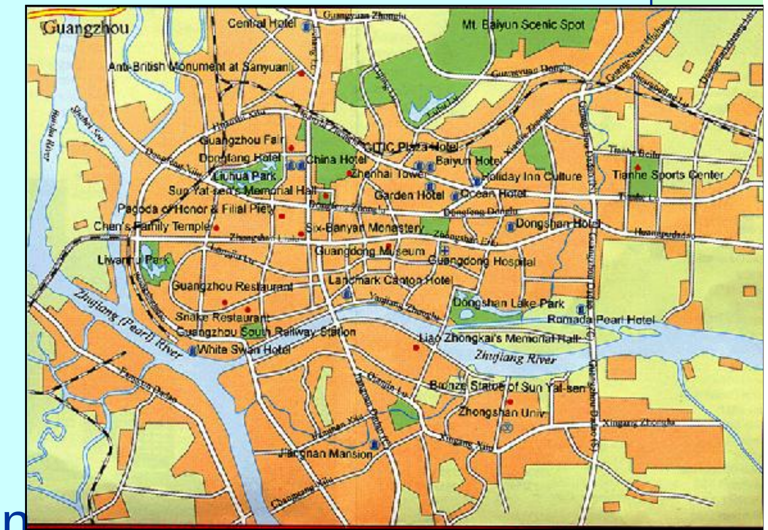
Study objectives

- Efficacy of air pollutant removal by urban forest
- Monetary value of this ecosystem service
- Alternative to technical solution to air pollution abatement
  - Cost-effective solution to urban environmental quality
  - Multiple collateral benefits of urban forest
  - Landscape and health implications
  - Sustainable development:
    indispensable ingredient

Study area



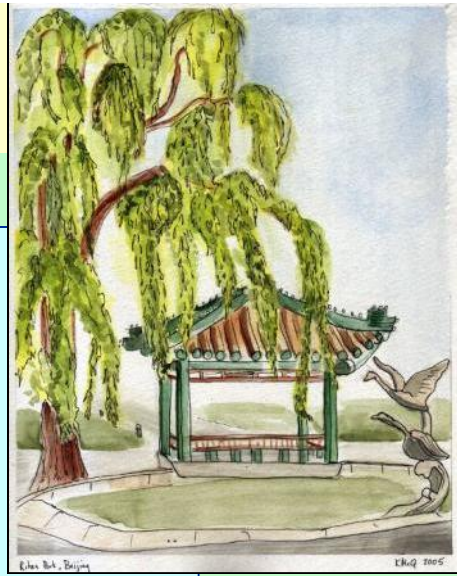
- Guangzhou: major city in south China
  - Humid-subtropical monsoonal climatic zone
  - Rapid urbanization and urban renewal
  - Development intensification in brown fields
  - Infilling of interstitial green fields
  - Sprawling into peri-urban green fields
  - Compact development mode
  - Aggravation of air quality
- Focus on central built-up part
  - Old districts (Liwan, Yuexiu and Dongshan)
  - Medium-age districts (Haizhu and Fangcun)
  - New districts (Tianhe and Baiyun)



Study area

- Guangzhou urban forest
  - One of the greenest cities in China
  - Green space system
    - 1.8M trees, 399 species, 67 families
    - 2.3M shrubs and 690 ha lawns
  - Pronounced spatial variations by land use
    - Parks 57.4%
    - Institutional 23.5%
    - Industrial 10.4%
    - Residential 4.8%
    - Roadside 3.9%

Study area



- Urban forest composition
  - Dominant: subtropical and pantropical
  - Minority: temperate components
  - Exotic species decline from centre to periphery
- Factors of urban forest structure
  - Natural, inherited, remnant
  - Cultural, cultivated
  - Ruderal, semi-natural
  - Imprints of human selection and unnatural selection

Study area

Table 1
Air quality and tree cover by land use categories in Guangzhou in 2000

Land use	Land area (ha)		Average pollutant concentration ($\mu g/m^3$)[a]		
	Whole district	Tree cover	SO_2	NO_2	TSP
Recreational	1973	875.5	39	58	131
Institutional	5548	548.2	45	59	165
Residential	6868	43.1	49	60	141
Transportation	5390	49.0	32	65	152
Others (industrial)[b]	3371	121.3	53	68	185
Total	23,150	1637.1			

[a] Yearly average concentrations of air pollutants were given.

[b] Separate data on green spaces in industrial grounds were not available in the study area; instead, industrial sites were mainly subsumed under the others land use category.

Study area

- Major air pollutants in Guangzhou
  - SO_2 Widespread use of fuels high in sulphur content
  - NO_x Rapid increase in vehicles and traffic jam
  - TSP Infrastructural and construction activities
- Sources of air pollutants
  - Industrial
  - Transport (mobile)
  - Residential
  - Service

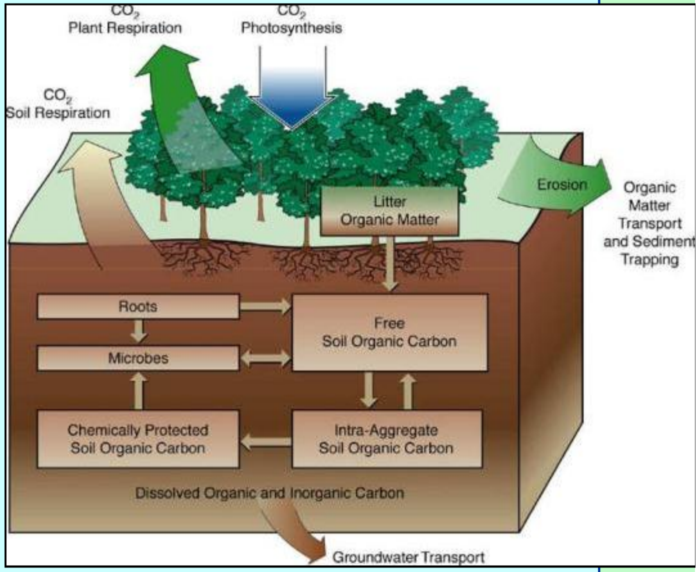
Study area

Table 2
Air quality and tree cover by administrative districts in Guangzhou in 2000

District	Fangcun	Yuexiu	Liwan	Tianhe	Dongshan	Haizhu	Baiyun	Total
District age (y)	20–30	1200–2500	800–1500	10	50–150	40–80	10–40	
Land area (ha)	1930	890	1180	5440	1720	3810	8180	23,150
Tree cover (ha)	69.3	71.9	25.1	442.6	93.2	112.7	822.3	1637.1
Population (person)	89,000	437,100	512,900	325,000	556,300	574,000	707,300	3,201,600
Population (person/ha)	46	491	435	60	323	151	86	138
Air pollutant concentration ($\mu g/m^3$)								
SO_2	39	41	38	33	19	34	12	30
NO_2	58	77	96	82	63	57	62	70
TSP	236	203	200	201	168	232	192	198

Methods

- Removal of air pollutants by vegetation (foliage)
  - Dry deposition (no precipitation)
    - Gravity sedimentation and impaction
  - Absorption of gaseous pollutants
    - Through stomata
    - Photosynthesis and respiration
  - Pollutant removal
    - Exterior and interior deposition
    - Both particulates and gaseous pollutants



Methods

- Pollutant flux (F_i)
  - Calculated as the product of the deposition velocity (*Vd*) and the concentration of air pollutant *i* (C_i):

$$F_i(\mathrm{g/cm^2/s}) = Vd_i(\mathrm{cm/s}) \times C_i(\mathrm{g/cm^3})$$

Methods

- Total flux into urban trees of air pollutant i (F_{it})
  - Estimated through multiplying F_i by tree cover (A) in a time period (T):

$$F_{it} = F_i \times A \times T$$

Methods

- The amount of air pollutants removed by urban trees (F)
  - Quantified by:

$$F = \sum_{i=1}^{3} F_{it}$$

Methods

Table 3
Typical range of deposition velocity for air pollutants on tree canopy and the average values adopted in the study

Air pollutant	Site of deposition	Deposition velocity (cm/s)	
		Range	Average[a]
SO_2	Exterior surfaces and interior of leaves	0.2–1.0[b]	0.55
NO_2	Primarily interior of leaves also exterior surfaces	0.1–0.5	0.37
Particulate	Exterior surfaces	0.5–2.0	0.64

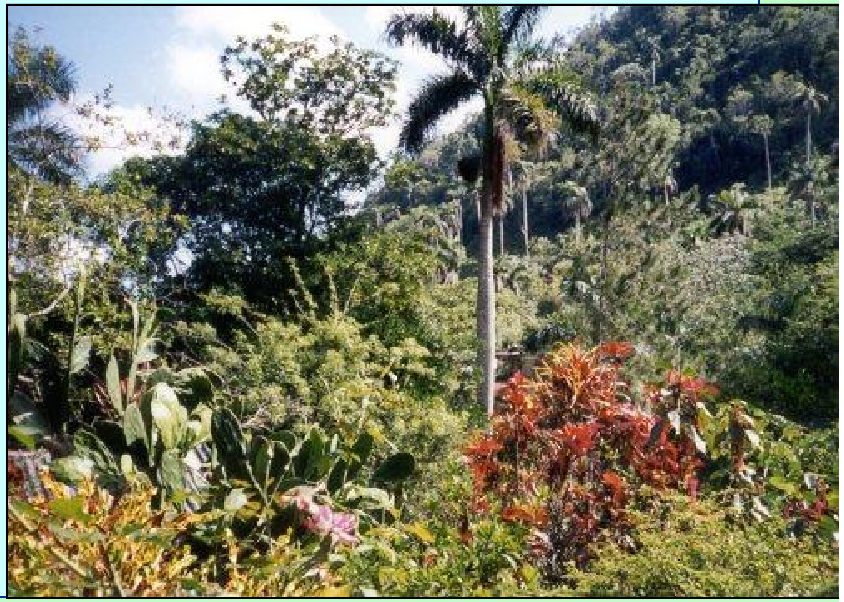
Sources: Lovett (1994), Nowak et al. (1998).

[a]The average deposition velocity were used in some studies on air pollutants removal in American urban areas.

[b]The value may be higher for wet surfaces.

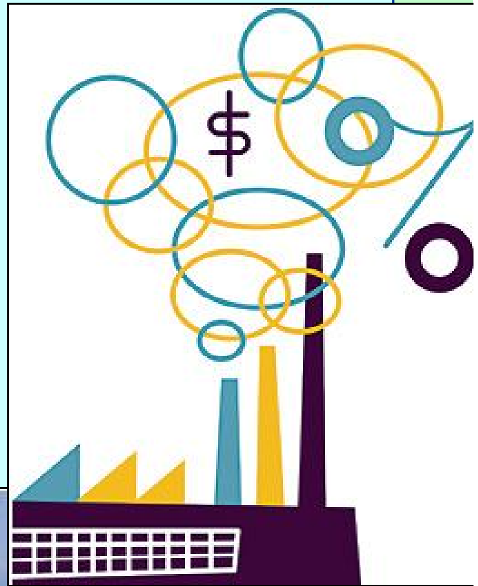
Methods

- Air pollutant removal calculation
  - Most trees are evergreen
  - Dry season growth rate sustained by irrigation
  - Whole year sampling period
  - 12 hours per day
  - Excluding days with rainfall
  - Pollutant concentration data from Environmental Protection Bureau of Guangzhou



Methods

- Valuation of air pollutant removal
  - Marginal cost: additional cost of producing one unit of output (= emission of one unit of air pollutant)
  - Data from State Environmental Protection Administration of China (2004)
    - RMB600/Mg for SO_2
    - RMB600/Mg for NO_2
    - RMB185/Mg for particulates



Results and discussion

Table 4
Monthly air pollutant removal by dry deposition (Mg)[a] and monetary value (RMB'000)[b] attributed to urban trees in Guangzhou in 2000

Pollutant	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total	Monthly average
SO_2														
Amount	4.45	1.68	4.28	2.29	2.10	1.85	1.52	1.56	2.15	1.96	2.50	3.92	30.25	2.52
Value	2.67	1.01	2.57	1.37	1.26	1.11	0.91	0.93	1.29	1.18	1.50	2.35	18.15	1.51
NO_2														
Amount	5.92	3.34	7.07	5.50	4.13	3.03	2.85	2.22	3.20	2.64	3.25	4.84	47.98	4.00
Value	3.55	2.01	4.24	3.30	2.48	1.82	1.71	1.33	1.92	1.58	1.95	2.90	28.79	2.40
TSP														
Amount	31.66	14.67	28.06	17.20	2.48	1.82	1.71	1.33	1.92	1.58	1.95	2.90	233.79	19.48
Value	5.86	2.71	5.19	3.18	16.75	13.42	15.08	14.48	20.64	16.44	19.16	26.23	43.25	3.60
Total														
Amount	42.03	19.69	39.41	24.99	22.98	18.30	19.45	18.26	25.99	21.04	24.91	34.99	312.03	26.00
Value	12.08	12.08	12.00	7.85	6.84	5.41	5.41	4.94	7.03	5.80	7.00	10.11	90.19	7.52

[a]The pollutant removal calculations were based on environmental quality data for the whole city.
[b]RMB stands for Renminbi which is the Chinese currency, at an exchange rate of US$1.00 = RMB8.26

- Peak removal month: January for all pollutants
- Pollutant with maximum removal: TSP
- Total removal: 312.03 Mg/year
- Monetary value: RMB90.19 x 10^3 or US$10.92 x 10^3

Results and discussion

- High removal in January, followed by March
  - Depression in February due to Chinese New Year with temporary stoppage of factories operations
  - Continuous removal throughout the year

- Contrast with North American studies
  - Peak removal in summer
  - Domination by deciduous trees
  - Little removal in winter

Results and discussion

Table 5
Annual air pollutant removal and monetary value[a] attributed to urban trees by land use categories in Guangzhou in 2000

Land use[b]	SO_2			NO_2			TSP			Total		
	Removal amount (Mg/y)	Removal rate (kg/ha/y)	Service value (RMB'000)	Removal amount (Mg/y)	Removal rate (kg/ha/y)	Service value (RMB'000)	Removal amount (Mg/y)	Removal rate (kg/ha/y)	Service value (RMB'000)	Removal amount (Mg/y)	Removal rate (kg/ha/y)	Service value (RMB'000)
Recreational	20.87	23.83	12.52	21.26	24.29	12.76	77.73	88.79	14.38	119.86	136.90	39.66
Institutional	15.42	28.13	9.25	13.65	24.89	8.19	63.14	115.18	11.68	92.21	168.21	29.12
Residential	1.32	30.55	0.79	1.09	25.30	0.65	4.28	99.31	0.79	6.69	155.16	2.24
Transportation	1.04	21.18	0.62	1.42	28.86	0.85	5.42	110.50	1.00	7.88	160.55	2.48
Others (industrial)[c]	3.97	32.74	2.38	3.51	28.90	2.11	16.11	132.78	2.98	23.59	194.42	7.47
Total	42.62		25.57	40.93		24.56	166.68		30.84	250.23		80.97

[a] RMB stands for Renminbi which is the Chinese currency, at an exchange rate of US\$1.00 = RMB8.26.
[b] The pollutant removal calculations were based on environmental quality data collected at monitoring stations in each land use category.
[c] Separate data on green spaces in industrial grounds were not available in the study area; instead, industrial sites were mainly subsumed under the others land use category.

- Maximum removal: recreational land (119.86 Mg, 47.9%)
- High removal: institutional land (92.21 Mg, 10.70%)
- Minimum removal: residential land (6.69 Mg, 2.67%)
- Maximum removal rate: industrial land (194.42 kg/ha/y)

Results and discussion

Table 6
Annual air pollutant removal and monetary value[a] attributed to urban trees by administrative districts in Guangzhou in 2000

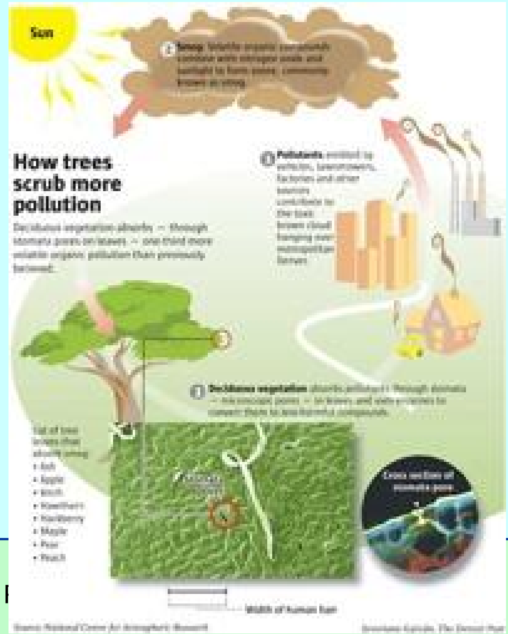
District[b]	SO_2			NO_2			TSP			Total		
	Removal amount (Mg/y)	Removal rate (kg/ha/y)	Service value (RMB'000)	Removal amount (Mg/y)	Removal rate (kg/ha/y)	Service value (RMB'000)	Removal amount (Mg/y)	Removal rate (kg/ha/y)	Service value (RMB'000)	Removal amount (Mg/y)	Removal rate (kg/ha/y)	Service value (RMB'000)
Fangcun	1.04	15.01	0.62	1.10	15.87	0.66	10.98	158.44	2.03	13.12	189.32	3.32
Yuexiu	1.83	25.45	1.10	2.29	31.85	1.37	10.35	143.95	1.91	14.47	201.25	4.39
Liwan	0.57	22.71	0.34	0.98	39.04	0.59	3.64	145.02	0.67	5.19	206.77	1.60
Tianhe	8.95	20.22	5.37	14.95	33.78	8,97	64.59	145.93	11.95	88.49	199.93	26.29
Dongshan	1.15	12.34	0.69	2.48	26.61	1.49	11.32	121.46	2.09	14.95	160.41	4.27
Haizhu	2.42	21.47	1.45	2.66	23.60	1.60	18.76	166.46	3.47	23.84	211.54	6.52
Baiyun	4.30	5.23	2.58	17.78	21.62	10.67	125.40	152.50	23.20	147.48	179.35	36.45
Total	20.26		12.16	42.24		25.34	245.04		45.33	307.54		82.83

[a] RMB stands for Renminbi which is the Chinese currency, at an exchange rate of US$1.00 = RMB8.26.
[b] The pollutant removal calculations were based on environmental quality data collected at monitoring stations in each district.

- Maximum removal amount and rate:
  - New Tianhe (47.95%) and Baiyun (28.77%)
  - High tree cover in recreational land
  - Maximum gaseous pollutant removal: Zhuhai due to heavy vehicular flow

Results and discussion

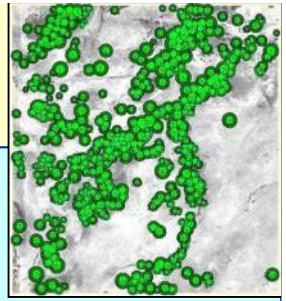
- Comparing with overseas studies
  - Relatively low marginal cost of pollution abatement in China using technical means
    - Use of less sophisticated technology in air pollution control
    - Lower labour and material costs
    - Reduces monetary value of this ecosystem service
  - Higher removal rate of TSP



Results and discussion

- Pivotal role of recreational spaces
  - Extensive green spaces in Baiyun and Tianhe
  - 44% and 31.7% respectively of total value
  - Large and continuous tree cover
  - Continued appreciation in value as the young trees grow bigger
  - High benefit-cost ratio

Implications and conclusion



- Green space planning implications
  - Planning for both landscape-amenity and ecosystem services; holistic sustainable development package
  - Integrate air pollution services into development process
  - Fine adjustment of green space factors to enhance air cleansing processes
    - Species assemblage: air pollution tolerance and abatement
    - Biomass structure: growth form, leaf area index, planting density
    - Seasonality: evergreen versus deciduous habit
    - Health and vigour: planting material and site quality, tree care
    - Green site geometry: spatial contiguity and connectivity
    - Location and orientation: upwind or downwind to built-up areas

Implications and conclusion

Table 7
Selected common urban tree species and their air pollution tolerance in Guangzhou

	Species	Growth form[a]	Family	Air pollutant tolerance		
				SO_2	NO_x[b]	Particulate
1	*Ficus microcarpa*	E	Moraceae	Good	Good	Good
2	*Cinnamomum camphora*	E	Lauraceae	Good	Good	Good
3	*Ailanthus altissima*	E	Simarubaceae	Medium	Medium	Good
4	*Fraxinus chinensis*	E	Oleaceae	Good	Good	Good
5	*Mimusops elengi*	E	Sapotaceae	Good	—	Good
6	*Morus alba*	E	Moraceae	Good	—	Good
7	*Platycladus orientalis*	E	Cupressaceae	Good	Good	Medium
8	*Sabina chinensis*	EC	Cupressaceae	Good	Good	Good
9	*Pittosporum tobira*	E	Pittoporaceae	Good	Good	Medium
10	*Lagerstroemia indica*	D	Lythraceae	Good	—	Good
11	*Magnolia grandiflora*	E	Magnoliaceae	Good	Medium	Good
12	*Gleditsia sinensis*	D	Caesalpiniaceae	Good	—	Good
13	*Celtis tetrandra*	E	Ulmaceae	Medium	Medium	Good
14	*Alstonia scholaris*	E	Apocynaceae	Medium	Medium	Good
15	*Hibiscus syriacus*	E	Malvaceae	Medium	—	Good
16	*Euonymus japonicus*	E	Celastraceae	Good	—	Medium
17	*Plumeria rubra*	D	Apocynaceae	Good	—	Good
18	*Sapium sebiferum*	D	Euphorbiaceae	Good	—	Good
19	*Livistona chinensis*	EP	Palmae	Good	—	Good
20	*Hibiscus tiliaceus*	E	Malvaceae	Good	Good	Good

Source: Gangzhou Green Planning Office (2002).
[a]D stands for deciduous, E for evergreen, C for conifer and P for palm.
[b]Blanks denote data not available.

Implications and conclusion

- Urban forest contribution
  - Mainly contributed by urban parks and other public recreational grounds
  - Main determinants of air cleansing
    - Urban forest cover
    - Pollutant concentration
  - Dry winter months with high pollutant concentration
    - Increases removal rate
  - Young districts with more green areas
    - Higher removal rate
    - Continued increase in efficacy with increase in vegetation biomass and cover

Implications and conclusion

- Opportunities for further research
  - Refine data and computation method
    - Acquire more detailed meteorological and air-quality monitoring data
    - Find data for accurate hourly computation of air pollutant removal
    - More elaborate assessment of the complex process of pollutant deposition velocity under local microclimatic conditions
  - Holistic assessment of urban forest benefits
    - Include ozone removal
    - Include the offset process and negative value of tree VOC emission
    - Include benefits of summer temperature reduction and amelioration of urban heat island effect
    - Include benefits of upstream pollutant avoidance
  - Both preservation and enhancement of urban nature

Implications and conclusion

- Urban forestry a fast developing domain in China
  - Continual adoption and adaptation of new concepts and practices
  - Integrating the latest research findings in cognate disciplines
    - Urban ecology, landscape ecology, community ecology, ecological economics, forestry, arboriculture, nature conservation
  - Rather fragmented with glaring gaps in knowledge and skill
    - Scope of urban forestry
    - Concepts and terminology
    - Research coverage
    - Management practice

The End
Questions and Comments are Welcome