Modeling the Causes of Urban Expansion

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Presentations and papers available at
http://www.williams.edu/Economics/UrbanGrowth/HomePage.htm

Urban Expansion

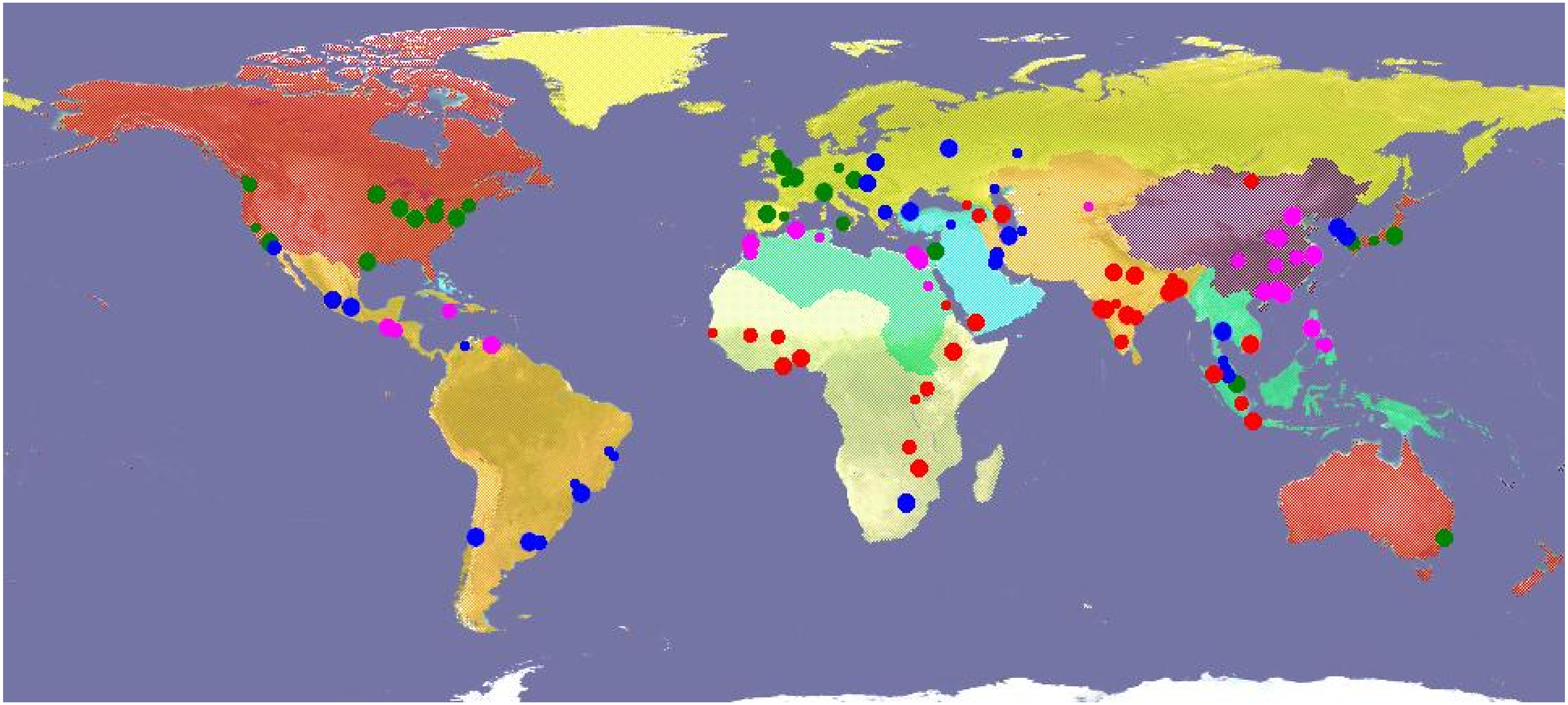
- Urban expansion taking place world wide
  - Rich
    - Evolving from transportation choices - “car culture”
    - Failure of planning system?
  - Poor
    - Rural to urban migration
    - Urban bias?
- Policy challenges
  - Environmental impact from transportation
  - Preservation of open space
  - Pressure for housing and infrastructure provision
- Policy response
  - Land use planning
  - Public transport subsidies & private transport taxes
  - Rural development
- Surprisingly few **global** studies of this **global** phenomenon
- Limited data availability

Data

- To address the lack of data, we construct a sample of urban areas
- The sample is representative of the global urban population in cities with population over 100,000
- Random sub-sample of UN Habitat sample
- Stratified by region, city size and income level

	Urban Pop.	Cities	Sample Population		Sample Cities	
Region	in 2000	in 2000	Population	%	N	%
East Asia & the Pacific	410,903,331	550	57,194,979	13.9%	16	2.9%
Europe	319,222,933	764	45,147,989	14.1%	16	2.1%
Latin America & the Caribbean	288,937,443	547	70,402,342	24.4%	16	2.9%
Northern Africa	53,744,935	125	22,517,636	41.9%	8	6.4%
Other Developed Countries	367,040,756	534	77,841,364	21.2%	16	3.0%
South & Central Asia	332,207,361	641	70,900,333	21.3%	16	2.5%
Southeast Asia	110,279,412	260	36,507,583	33.1%	12	4.6%
Sub-Saharan Africa	145,840,985	335	16,733,386	11.5%	12	3.6%
Western Asia	92,142,320	187	18,360,012	19.9%	8	4.3%
Total	2,120,319,475	3,943	415,605,624	19.6%	120	3.0%

Data – a global sample of cities



Regions

- East Asia & the Pacific
- Europe
- Latin America & the Caribbean
- Northern Africa
- Other Developed Countries
- South & Central Asia
- Southeast Asia
- Sub-Saharan Africa
- Western Asia

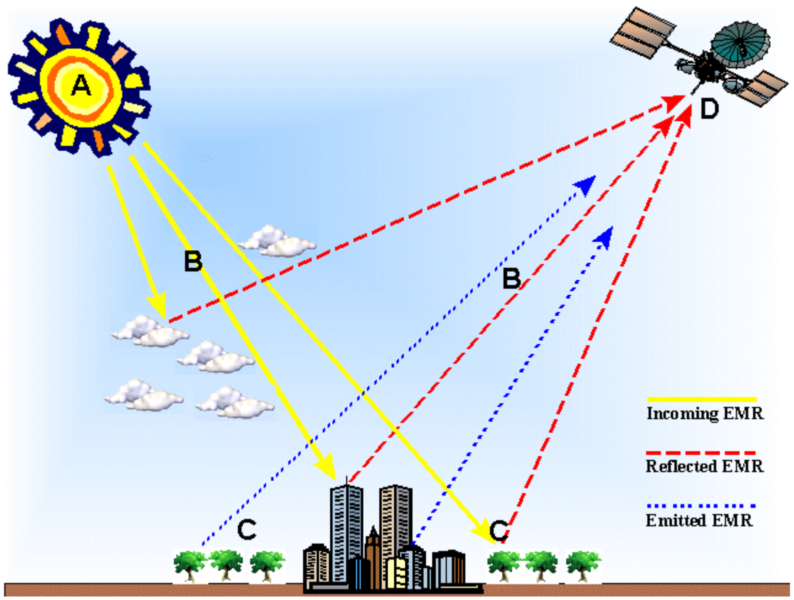
Population Size Class

- 100,000 to 528,000
- 528,000 to 1,490,000
- 1,490,000 and 4,180,000
- > 4,180,001

Income Class (annual per capita GNP)

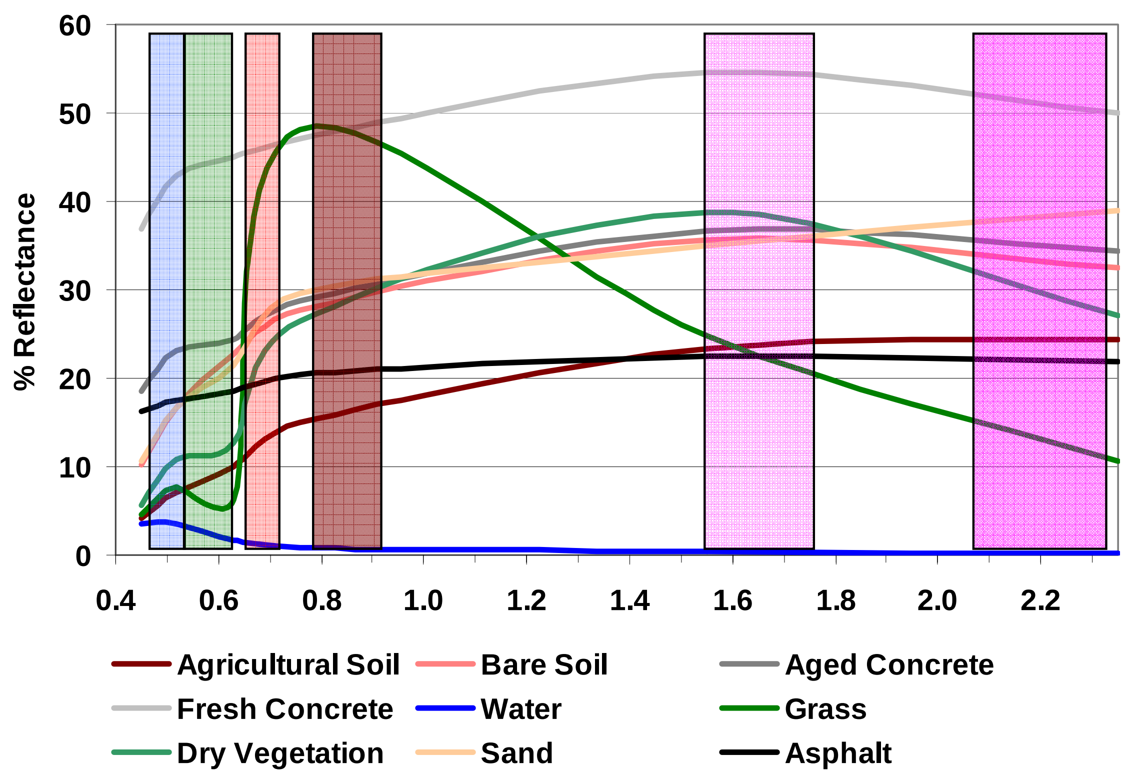
- < $3,000
- $3,000 - $5,200
- $5,200 - $17,000
- > $17,000

Remote Sensing



The relative brightness in different portions of the spectrum identify different types of ground cover.

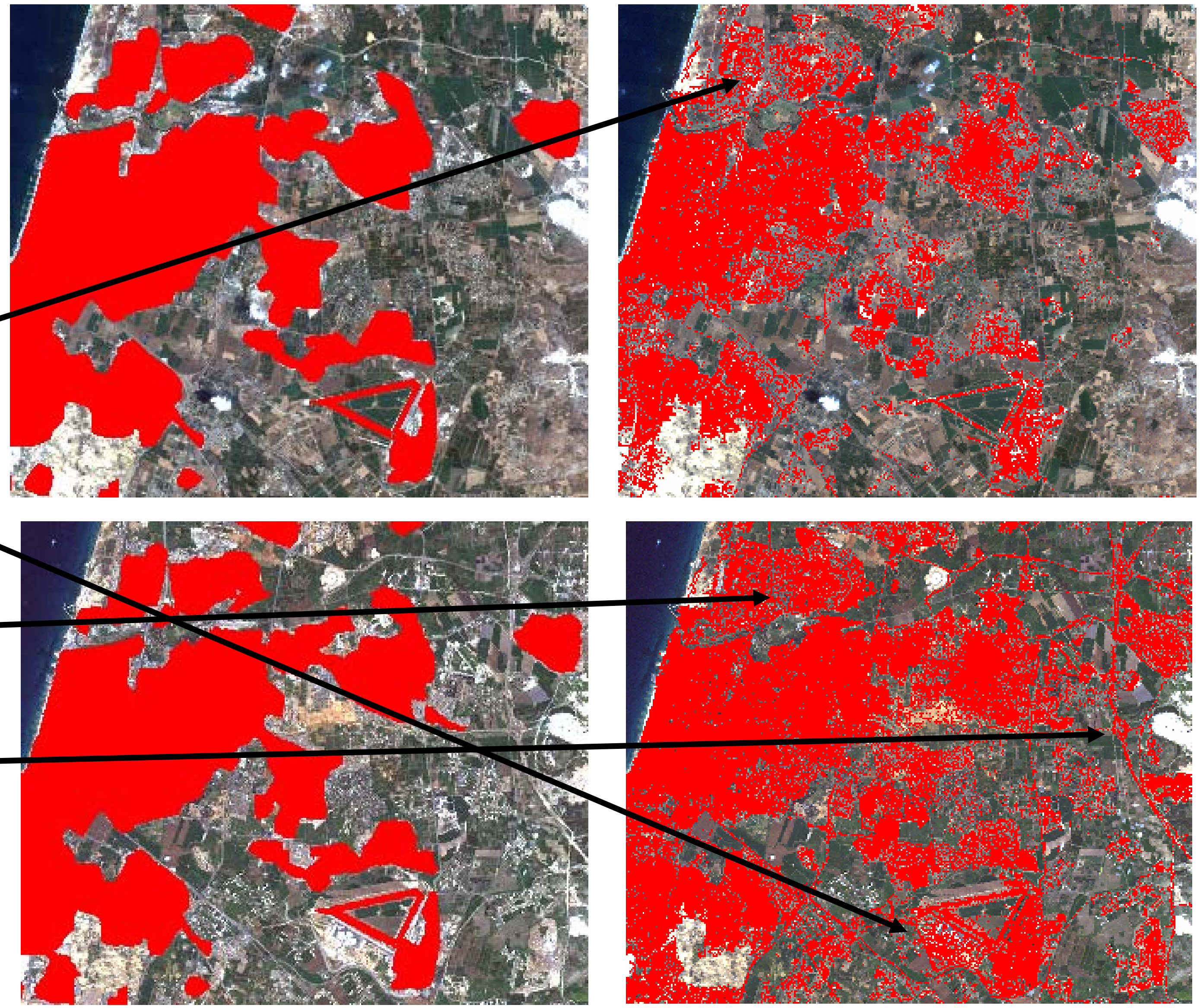
Satellite (Landsat TM) data measure – for pixels that are 28.5 meters on each side – reflectance in different frequency bands



Measuring Urban Land Use

Contrasting Approaches:

1. Open space within the urban area
2. Development at the urban periphery
3. Fragmented nature of development
4. Roadways in “rural” areas



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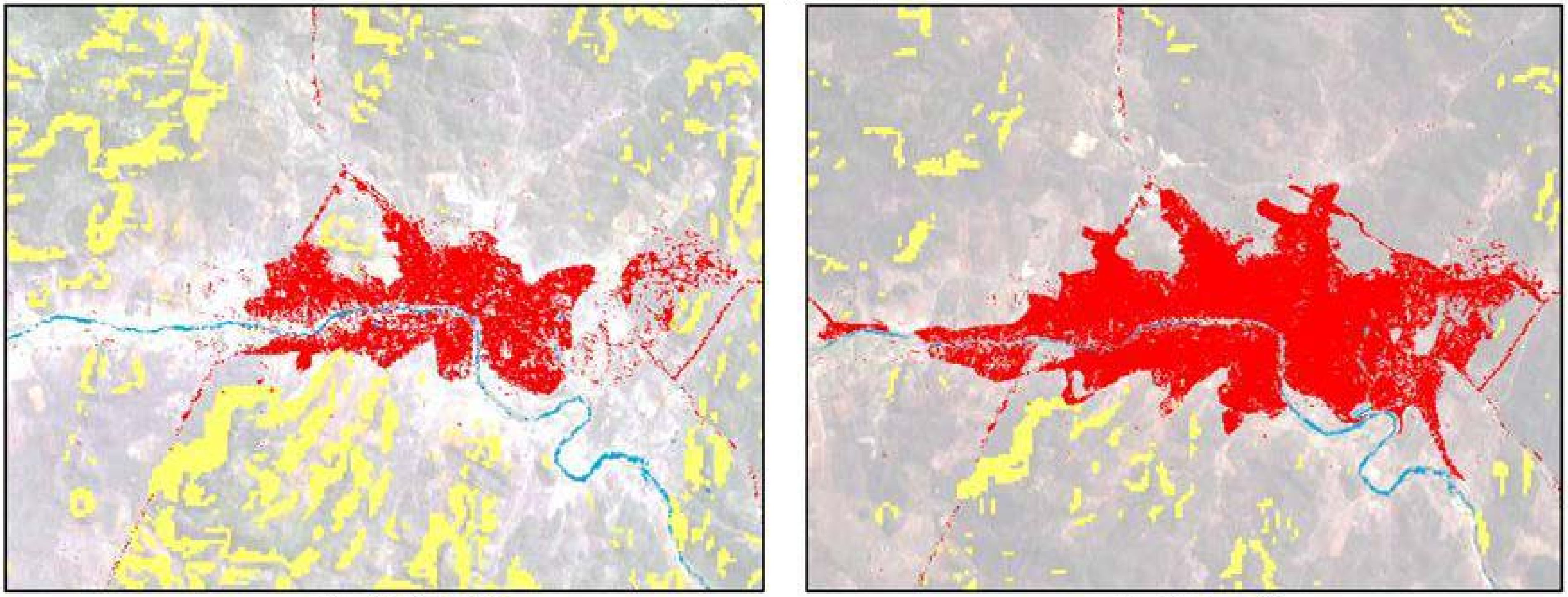
2000

EarthSat Geocover

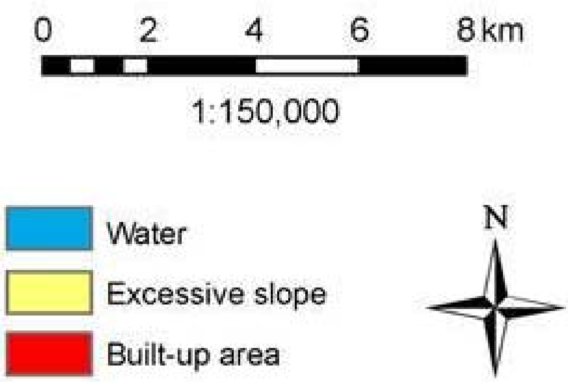
Our Analysis

Change in urban land use

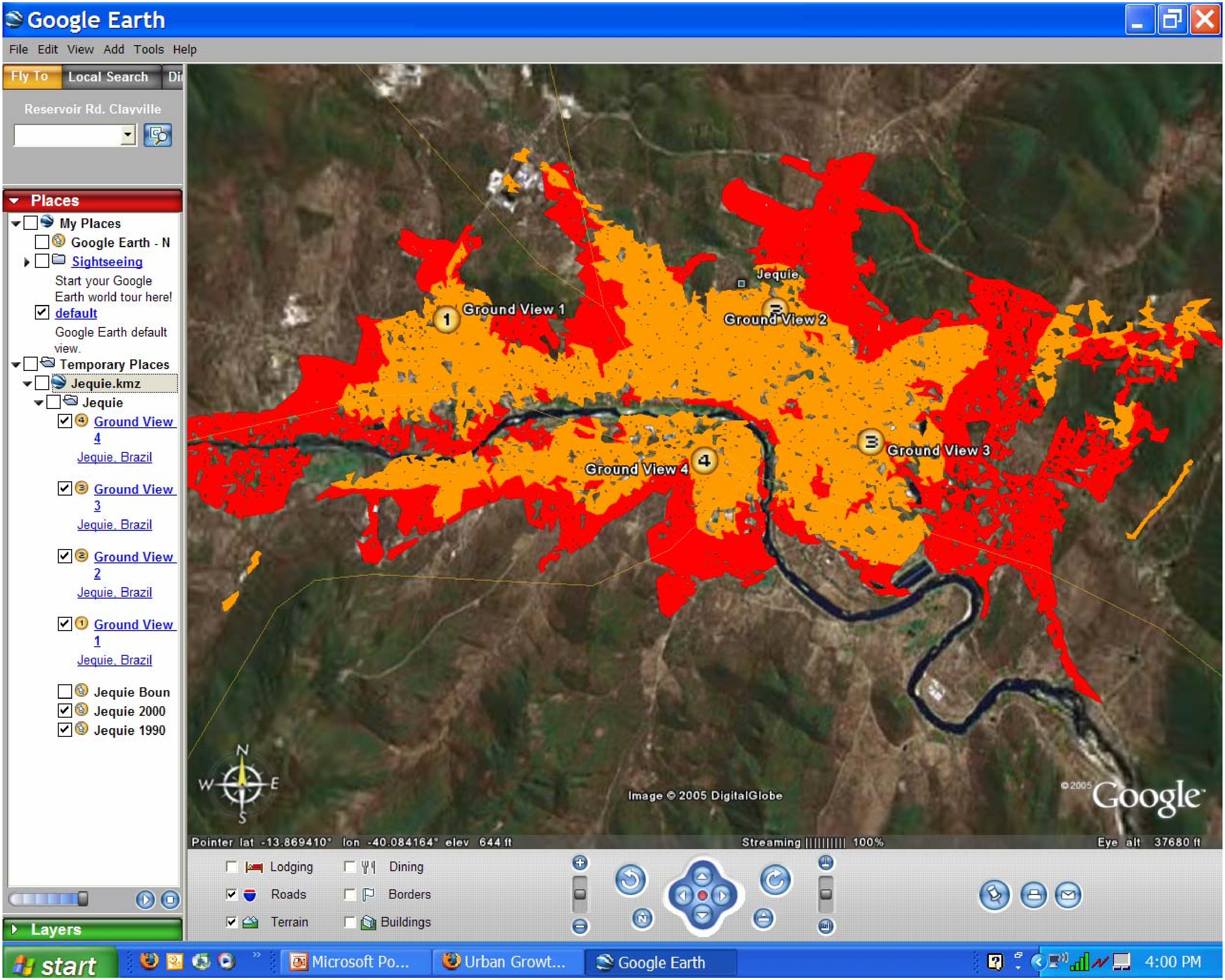
Jequié, Brazil



T_1: 22-Aug-88 — T_2: 12-Apr-01



Measure	T_1	T_2	Annual % Change
Population	144,030	147,439	0.19%
Built-Up Area (sq km)	18.23	36.55	5.66%
Average Density (persons / sq km)	7,899.18	4,033.64	-5.18%
Built-Up Area per Person (sq m)	126.60	247.91	5.46%
Average Slope of Built-Up Area (%)	5.79	7.86	2.46%
Maximum Slope of Built-Up Area (%)	31.58	43.05	2.48%
The Buildable Perimeter (%)	0.86	0.87	0.05%
The Contiguity Index	0.95	0.98	0.20%
The Compactness Index	0.36	0.25	-2.83%
Per Capita Gross Domestic Product	$5,823.89	$6,857.49	1.30%



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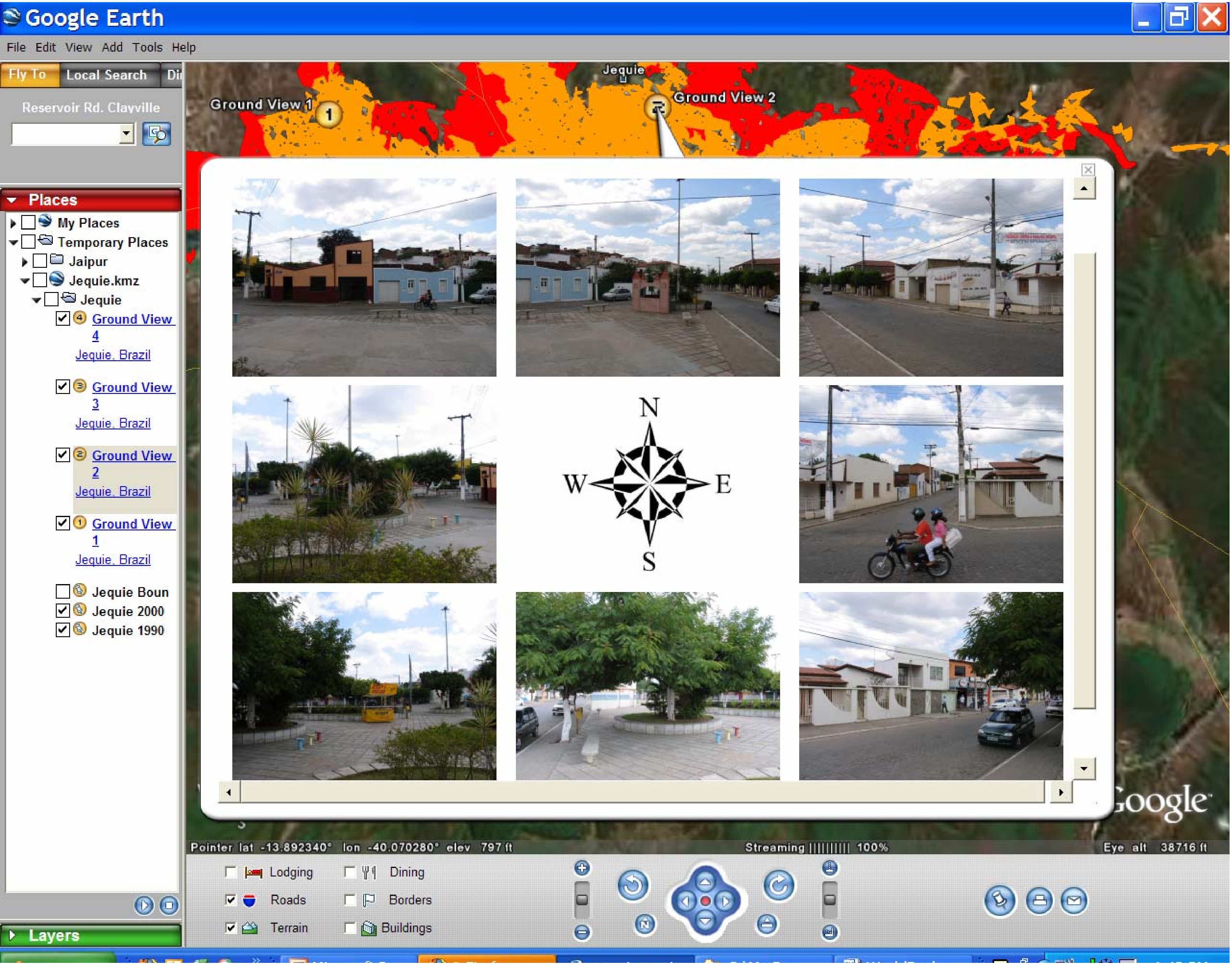
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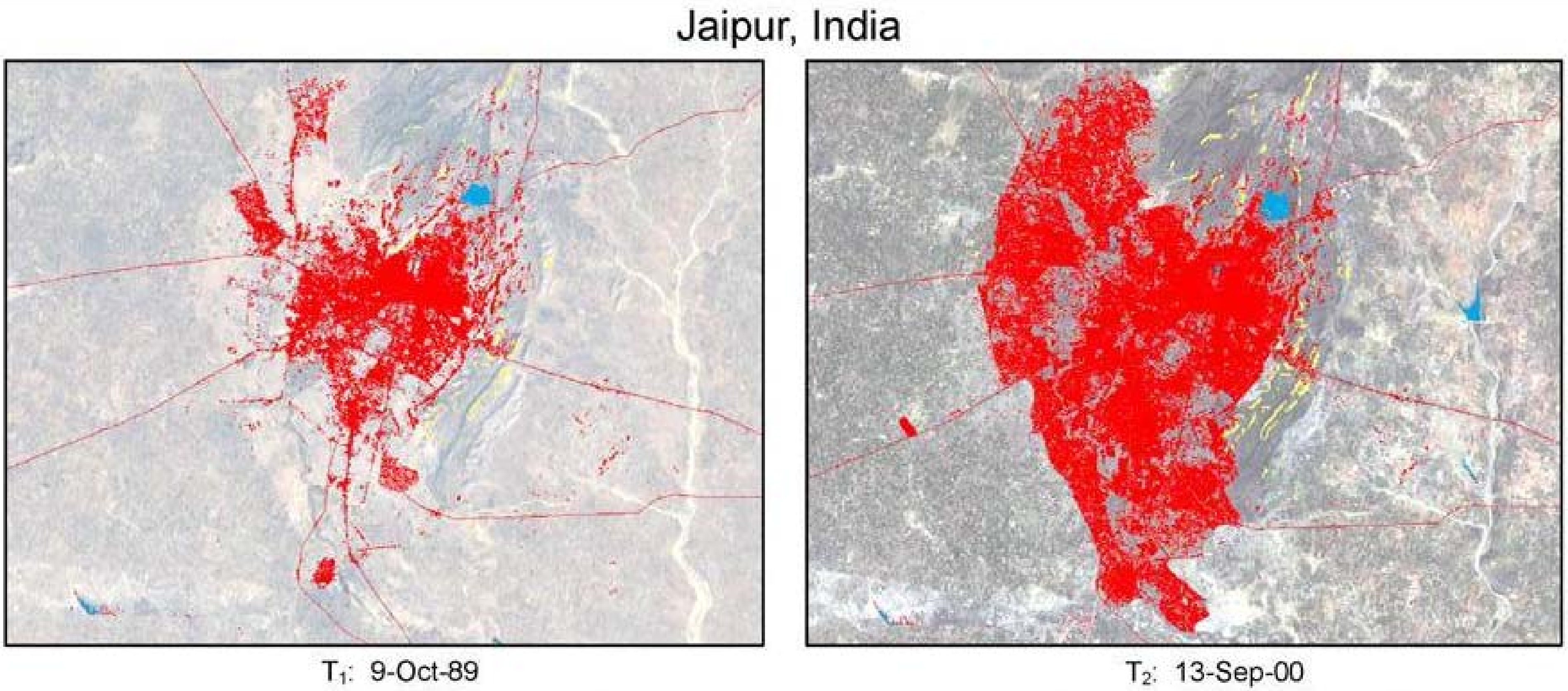
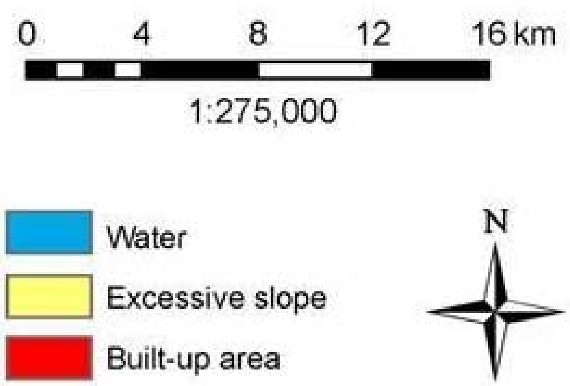
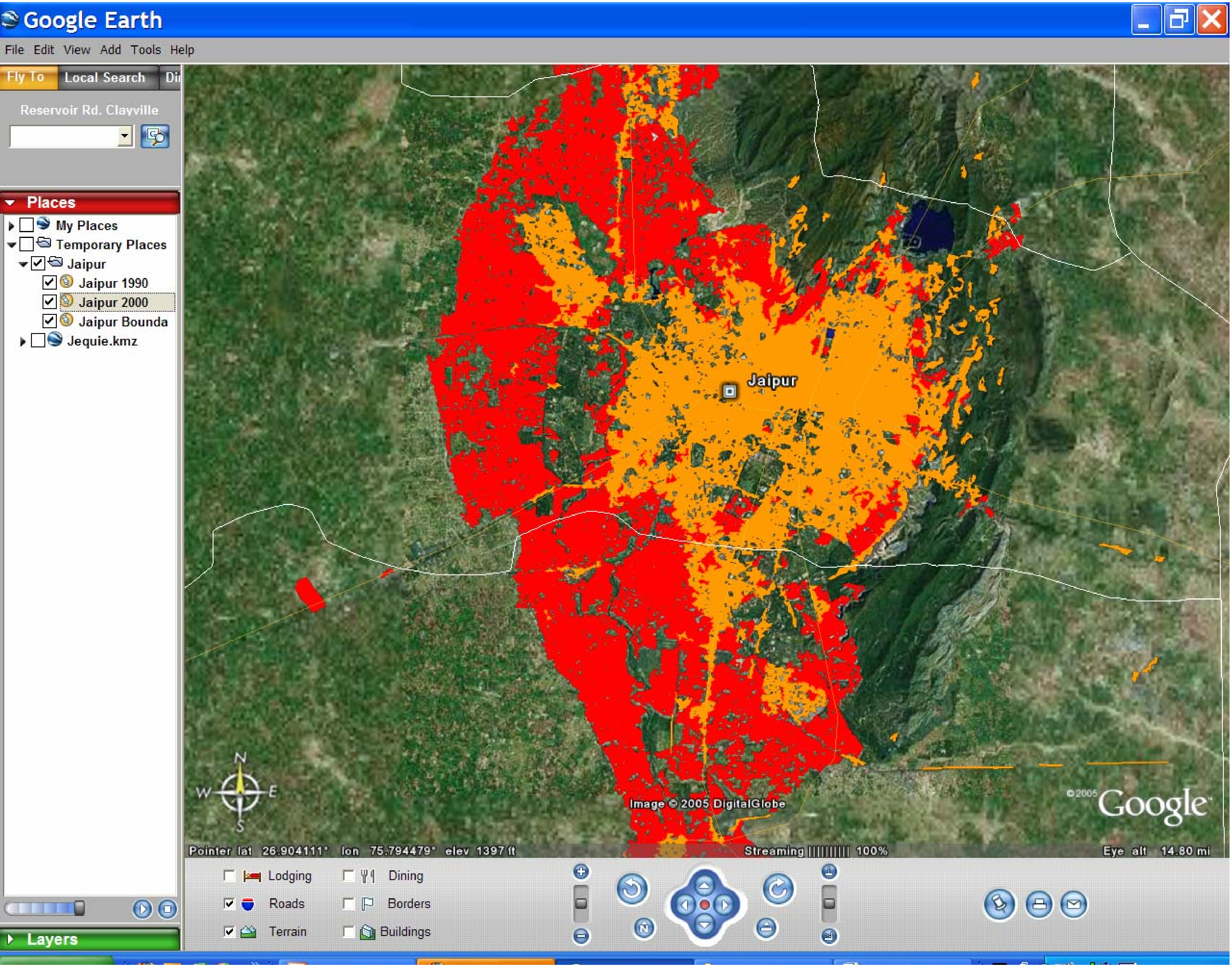
Change in urban land use: Jaipur, India





Measure	T_1	T_2	Annual % Change
Population	2,115,566	2,779,119	2.53%
Built-Up Area (sq km)	58.69	140.84	8.34%
Average Density (persons / sq km)	36,044.00	19,732.56	-5.36%
Built-Up Area per Person (sq m)	27.74	50.68	5.67%
Average Slope of Built-Up Area (%)	3.56	3.35	-0.56%
Maximum Slope of Built-Up Area (%)	49.66	43.86	-1.13%
The Buildable Perimeter (%)	0.94	0.93	-0.10%
The Contiguity Index	0.81	0.99	1.86%
The Compactness Index	0.42	0.35	-1.54%
Per Capita Gross Domestic Product	$1,535.18	$2,252.37	3.57%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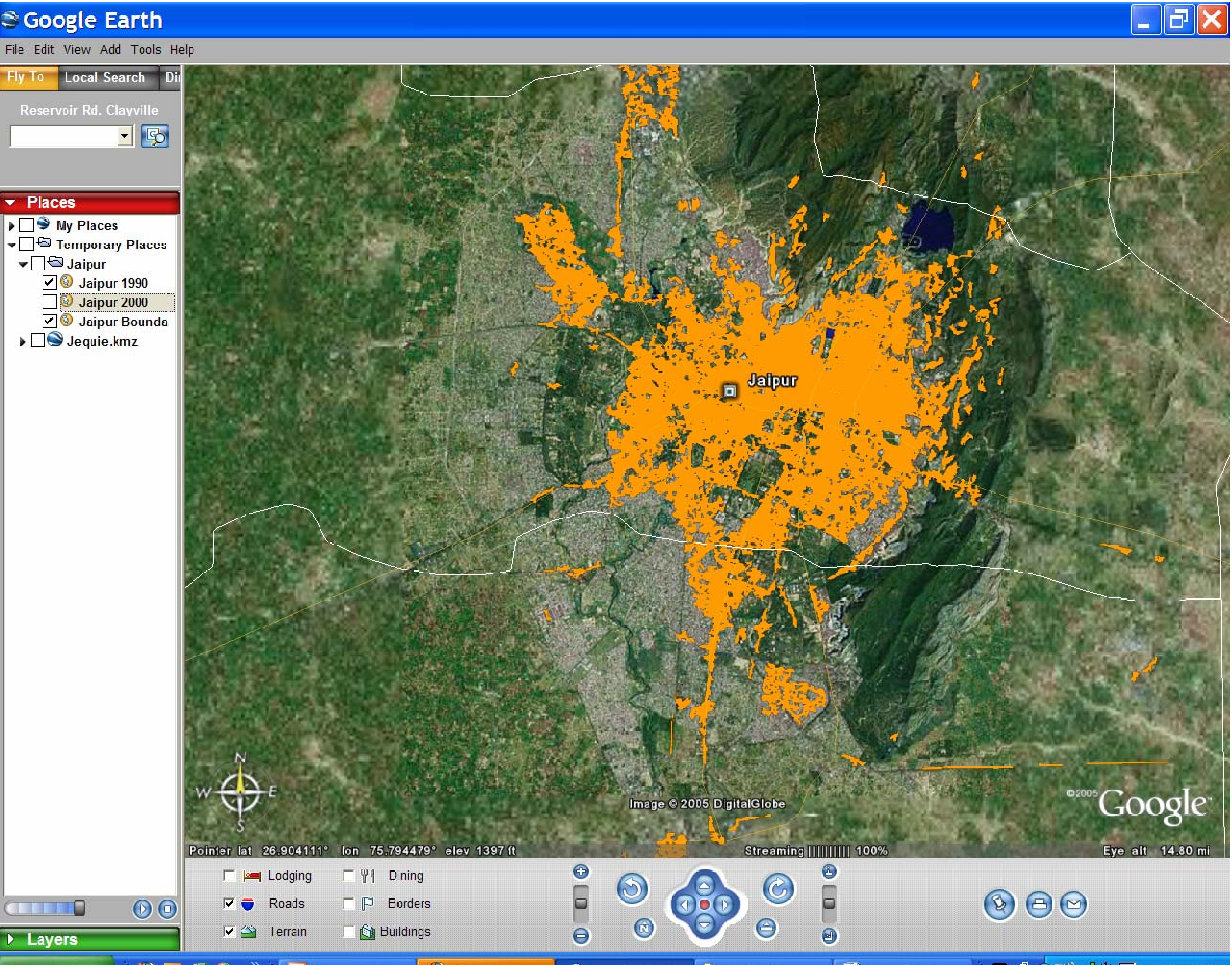
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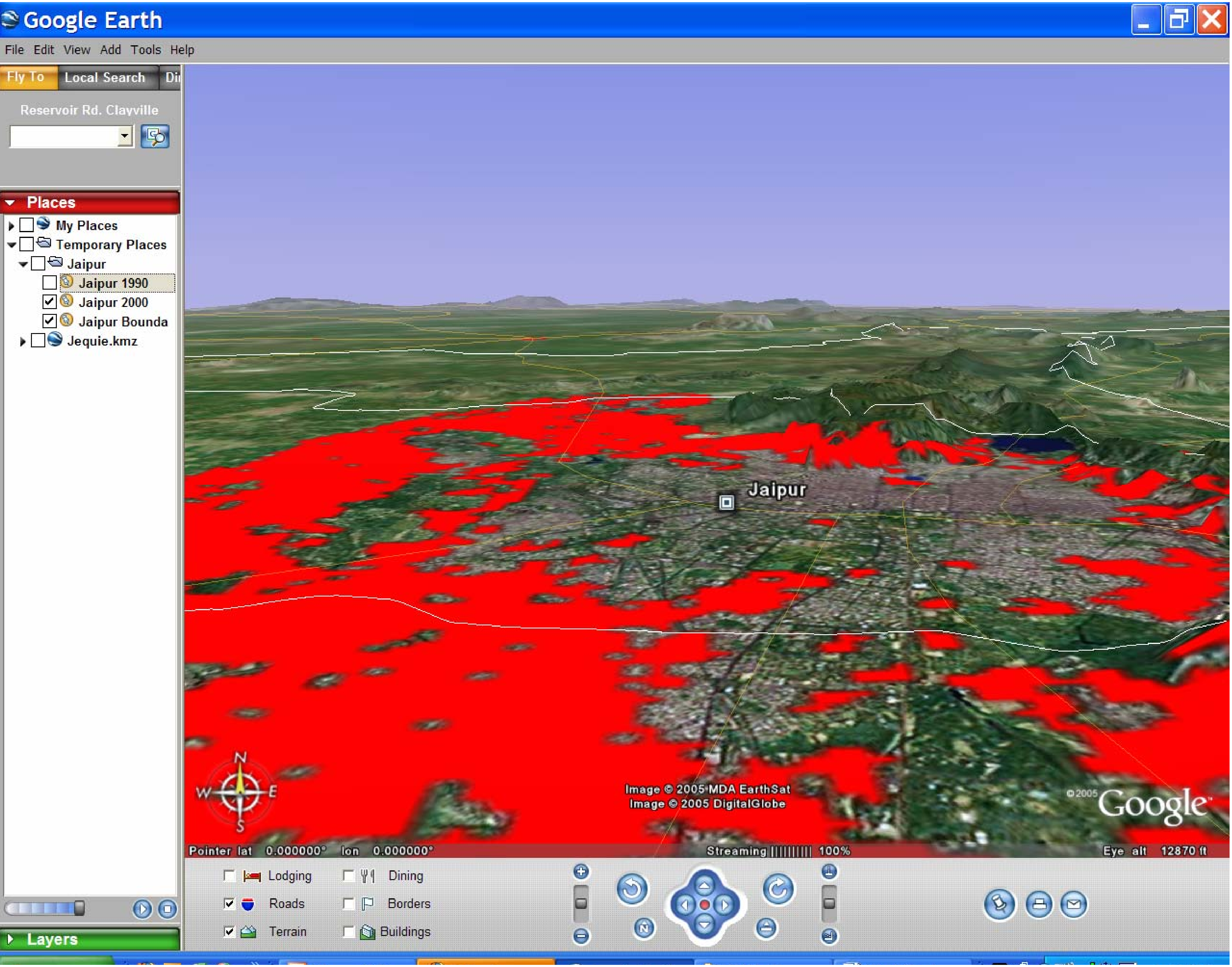
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Modeling urban land use

- Households:
  - *L* households
  - Income *y*
  - Preferences v(c,q)
    - composite good *c*
    - housing *q*.
  - Household located at x pays annual transportation costs
- In equilibrium, household optimization implies:

$$\max_q v\left(y - t \cdot x - q \cdot p\left(x\right), q\right) = u$$

for all locations x

- Housing q for consumption is produced by a housing production sector

Modeling urban land use

- Housing producers
  - Production function *H(N, l)* to produce square meters of housing
    - N = capital input, l=land input

  - Constant returns to scale and free entry determines an equilibrium land rent function *r(x)* and a capital-land ratio (building density) *S(x)*

$$\frac{\partial r(x)}{\partial x} < 0 \quad and \quad \frac{\partial S(x)}{\partial x}$$

  - Land value and building density decline with distance
  - Combining the *S(x)* with housing demand *q(x)* provides a solution for the population density *D(x,t,y,u)* as a function of distance t and utility level u
- The extent of urban land use is determined by the condition:

$$r\left(\bar{x}\right) = r_A$$

Modeling urban land use

- Equilibrium requires:

$$\int_0^{\bar{x}} 2\pi \cdot \theta \cdot x \cdot D\left(x, t, y, u\right) dx = L$$

- The model provides a solution for the extent of urban land use as a function of

Population	Agricultural land values
Income	MP of land in housing production
Transport costs	Land made available for housing

- Generalize the model to include an export sector and obtain comparative statics with respect to:
  - MP of land in goods production
  - World price of the export good

Hypotheses

	Result	Description
1.	$\frac{\partial \bar{x}}{\partial L} > 0$	An increase in population will increase urban extent and urban expansion.
2.	$\frac{\partial \bar{x}}{\partial y} > 0$	An increase in household income will increase urban extent and urban expansion.
3.	$\frac{\partial \bar{x}}{\partial t} < 0$	An increase in transportation costs will reduce urban extent and limit urban expansion.
4.	$\frac{\partial \bar{x}}{\partial r_A} < 0$	An increase in the opportunity cost of non-urban land will reduce urban extent and limit urban expansion.
5.	$\frac{\partial \bar{x}}{\partial H_l} > 0$	An increase in the marginal productivity of land in housing production will cause urban expansion.
6.	$\frac{\partial \bar{x}}{\partial \theta} > 0$	An increase in the share of land available for housing development will increase urban extent and urban expansion.
7.	$\frac{\partial \bar{x}}{\partial f_l} > 0$	An increase in marginal productivity of land in production of the export good will increase urban extent and urban expansion.
8.	$\frac{\partial \bar{x}}{\partial w} > 0$	An increase in the world price of the export good will increase urban extent and urban expansion.

Model estimation

- We consider three classes of empirical models
  - Linear models of urban land cover
    - “Models 1-3”
  - Linear models of the change in urban land cover
    - “Models 4-6”
  - Log-linear models of urban land cover
    - “Models 7-11”

- Each approach has different relative merits
  - Linear models – simplicity and sample size
  - Change in urban land use – endogeneity
  - Log linear – interaction and capture of non-linear impact

Linear model variables

Variable	Mean	σ	Min	Max
Urban Land Use (km^2)	400.6871	533.7343	8.91769	2328.87
Total Population	3,287,357	4,179,050	105,468	1.70E+07
Per Capita GDP (PPP 1995 $)	9,550.217	9,916.317	562.982	32,636.5
National share of IP addresses	0.085741	0.193696	3.50E-06	0.593672
Air Linkages	88.78808	117.6716	0	659
Maximum Slope (percent)	25.34515	14.55289	4.16	72.78
Agricultural Rent ($/Hectare)	1,641.608	3,140.596	68.8372	19,442.1
Cost of fuel ($/liter)	0.581498	0.328673	0.02	1.56
Cars per 1000 persons	144.7495	191.4476	0.39	558.5
Ground Water (1=shallow aquifer)	0.281518	0.451022	0	1
Temperate Humid Climate	0.077395	0.267979	0	1
Mediterranean Warm Climate	0.005109	0.071499	0	1
Mediterranean Cold Climate	0.017234	0.130515	0	1
Sampling Weight	0.011168	0.010542	0.000834	0.068174

Linear model estimates

Variable	Model 1	Model 2	Model 3
Population	**0.000077**	**0.000075**	**0.000073**
Income	**0.0295**	**0.0355**	**0.0260**
IP Share	529.3747	606.6442	639.3068
Air Link	0.3207	0.3633	0.4040
Maximum Slope	-0.7247	-0.3551	-0.8658
Agricultural Rent	**-0.0182**	**-0.0207**	**-0.0190**
Fuel Cost			64.0541
Cars/1000		-0.4750	
Shallow Ground Water	83.5832	85.3899	82.3103
Fixed Effects	Biome	Biome	Biome

Models of change in urban land

Variable	Mean	σ	Min	Max
Change in Built-Up Area	125.8202	163.3169	-322.559	527.368
Change in Total Population	751827.3	1474634	-470586	5.40E+06
Change in Per Capita GDP	1566.28	2156.812	-4552.33	6722.88
Air Links in 1990	88.03663	124.1801	0	659
Maximum Slope in 1990	25.03812	14.3309	4.16	70.63
Agricultural Rent in 1990	1589.797	3396.454	84.9003	19442.1
Fuel Cost in 1990	0.436883	0.247924	0.02	1.18
Cars per 1000 in 1990	130.7622	182.7599	0.39	489.2
Sampling Weight	0.011168	0.010573	0.000834	0.068174

Change in urban land model estimates

	Model 4	Model 5	Model 6
Population Change	**0.000083**	**0.000085**	**0.000084**
Income Change	**0.02169**	**0.01813**	**0.020129**
IP Share	**237.1614**	**279.7229**	**270.6102**
T_1 Airlink	0.1383	0.1154	0.1301
T_1 Maximum Slope	**-1.2954**	**-1.1688**	**-1.2267**
T_1 Agricultural Rent	-0.0011		
T_1 Fuel Cost		21.0234	
T_1 Cars/1,000			-0.0199
Shallow Ground Water	**36.0570**	**35.8025**	**36.5591**
Constant	24.2468	10.6364	20.8378
Fixed Effects	Biome	Biome	Biome
Number of observations	88	90	90
R-squared	0.8207	0.816	0.8154
Root MSE	73.515	74.035	74.154

Log-linear models

Variable	Mean	σ	Min	Max
Ln(Urban Area)	5.217764	1.302409	2.18804	7.75314
Ln(Total Population)	14.26064	1.243901	11.5662	16.6682
Ln(Per Capita GDP)	8.596582	1.099758	6.33325	10.3932
Ln(Share IP Addresses)	-5.249607	3.012159	-12.5592	-0.52143
Ln(Air Links+1)	2.923513	2.21341	0	6.49224
Ln(Maximum Slope)	3.065746	0.595572	1.42552	4.28744
Ln(Agricultural Rent)	6.757474	0.980555	4.23174	9.8752
Ln(Fuel Cost)	-0.71369	0.640135	-3.91202	0.444686
Ln(Cars Per 1,000)	3.399618	2.1609	-0.941609	6.32525
Sampling Weight	0.011168	0.010542	0.000834	0.068174

Log-linear models

	Model 7	Model 8	Model 9	Model 10	Model 11
Population	**0.7412**	**0.7667**	**0.8040**	**0.7453**	**0.7919**
Income	**0.5674**	**0.6166**	0.0707	**0.5552**	0.0931
IP Share		-0.0364	-0.0261	-0.0219	-0.0220
Air Links	**0.0880**	**0.0754**	0.0385	**0.0790**	0.0431
Maximum Slope	-0.0568	-0.0492	-0.1127	-0.0519	-0.1074
Agricultural Rent	**-0.2323**	**-0.2578**	**-0.2069**	**-0.2693**	**-0.2165**
Fuel Cost				**0.1670**	0.0680
Cars/1000			**0.2907**		**0.2671**
Shallow Ground Water	**0.2920**	**0.2729**	0.2183	0.2600	0.2163
Fixed Effects	Biome	Biome	Biome	Biome	Biome

Note: all variables except Ground Water enter as natural log

Hypotheses tested

	Expected	Result of Test
1.	$\frac{\partial \bar{x}}{\partial L} > 0$	**Strongly confirmed** – doubling population increases urban land cover by 74 to 80 percent.
2.	$\frac{\partial \bar{x}}{\partial y} > 0$	**Confirmed** – doubling national income increases urban land use by 55 to 60 percent – further investigation warranted on income and transport mode
3.	$\frac{\partial \bar{x}}{\partial t} < 0$	**Unclear –** increasing fuel cost associated with increased urban land use; doubling cars per capita increases urban land use by about 26 to 29 percent in log-linear model, but decreases urban expansion in linear model – colinearity and endogeneity?
4.	$\frac{\partial \bar{x}}{\partial r_A} < 0$	**Strongly confirmed** – doubling the value added per hectare in agriculture decreases urban land use by 20 to 26 percent
5.	$\frac{\partial \bar{x}}{\partial H_l} > 0$	**Confirmed** – less steeply sloped land and easy access to well water increases urban land use in all models
6.	$\frac{\partial \bar{x}}{\partial \theta} > 0$	**Confirmed –** less steeply sloped land increases the share of urban land available for development and increases urban land use
7.	$\frac{\partial \bar{x}}{\partial f_l} > 0$	**Confirmed** – increased accessibility to global markets increases urban land use in all models – doubling the share of global IP addresses increases urban land use in linear and differenced models – increasing the number of direct international flights increases urban land use in all models
8.	$\frac{\partial \bar{x}}{\partial w} > 0$	

Policy Implications

- Policies designed to limit urban expansion tend to focus on a few variables
  - Transportation costs and modal choice
    - Combat “car culture”
    - Provide mass transit alternatives
    - Limit road building
  - Rural to urban migration and population growth
    - Enhance economic opportunity in rural areas
    - Residence permits for cities
- Considerable urban expansion occurs naturally as a result of economic growth
- Limiting migration could be effective but ...
  - Economic misallocation costs
  - Problems where free mobility considered an important right
- Land use planning policies?
- Land taxation?

Need for improved data

- To improve model estimates tests we require more data
- Field researchers
  - Local planning data
  - Local taxation data
  - House prices and land values
  - Transport congestion and fuel prices
- Income data at local level
  - Big problem – explore alternative data sources

Conclusions and future directions

- Continuing progress
  - Field research to collect data on planning policies, taxes, housing conditions and prices
  - Evaluation of classification accuracy
  - Separate modeling of infill versus peripheral expansion
  - Modeling at micro-scale –
    - transition from non-urban to urban state
  - Interaction with nearby local development

Conclusions and future directions

- Issues to address going forward
  - Endogeneity issues
    - Income
    - Transport costs
    - Links to global economy
  - Effect of planning and tax policies
  - Impact on housing conditions and affordability
  - Availability of housing finance
  - Evaluation of impacts of urban expansion
- With global data we are developing a deeper understanding of the urban expansion that affects virtually every local area