Introduction: While developing countries continue to cope with the problem of malnutrition, overweight/obesity is emerging as a new burden of disease, particularly in large urban areas. Unlike the pattern observed in developed countries, the literature shows a postive association between overweight and socio-economic status (SES) in developing countries. This paper takes the research one step forward by examining the effect of SES in association with geographic access to green spaces, land-use type and urban sprawl on body mass index (BMI) among the adult population in the Delhi Metropolitan area, which has reported the highest prevalence of overweight/obesity among adult women in the country.

Historically, public health has been linked with "healthy places" such as contact with nature and urban forms. The recent literature in the context of western countries demonstrates this relationship empirically (Frumkin, 2003; Lopez, 2004; Saelens, Sallis, Black, & Chen, 2003). The major emphasis of obesity/overweight research in this area has been on certain land use/cover types that either promote or discourage physical exercise, particularly walking. While high-density mixed land-use with street connectivity, safety and an aesthetic look encourages walking and is linked with a low prevalence of overweight (Leyden, 2003; Saelens, Sallis, Black et al., 2003), urban sprawl, characterized by low density land-use and increasing dependency on car/sports utility vehicles and longer commute times, discourages physical activity and is often described as one of the most important causes of obesity/overweight (Jackson, 2003; Lopez, 2004). A recent study in the U.S. demonstrates that the risk of being obese increases by 0.2% with each point increase in urban sprawl (Lopez, 2004). Since moderate physical activities, such as walking, can prevent weight gain (Morabia & Costanza, 2004), urban planners recommend modern urban designs that facilitate walking in order to counter health problems, including the obesity epidemic in the U.S. (Leyden, 2003).

In the context of developing countries, few studies have addressed the increasing influence of land-use/cover and urban sprawl in the context of the prevalence of under- and overweight/obesity. Our ability to pursue research in this area is restricted by the limited geo-referenced BMI and land-use/cover and urban sprawl data. Advances in satellite remote sensing, however, can be exploited to compute land-use/cover and urban sprawl data, and geo-coded individual level data can be linked with different locational settings. This paper begins to fill the gap in the literature by examining the effects of the location of residence, geographic access to green places and urban sprawl along with the conventional (individual and household level) measures of SES (used in the literature) on BMI in the Delhi Metropolitan area, a rapidly growing urban area of a developing country.

Data and Methods: A household survey was administered between January-April 2004 to collect the data used in the analysis. The survey covered 1576 households that were spread across Delhi and its surroundings. Since a household sampling frame was unavailable, a spatial sampling design was adopted to select the households. In the first phases, residential areas were identified using satellite imageries and topographic sheets, and then 2000 random locations were generated within the residential areas. These locations were transferred to global position systems (GPS) to identify the households at these locations and acquire their consent to participate in the survey. Finally, of the identified households, 1576 participated in the survey.

Regression analysis was used to model BMI as a function of covariates including conventional measures of SES, household location characteristics, access to green spaces and urban sprawl. In an ordinary least square regression model (OLS), BMI (y_{ij}) of the i^{th} individual living in the j^{th} household can be expressed as a function X covariates as:

$$y_{ij} = \alpha + \beta X'_{ij} + \varepsilon_{ij} \qquad (1)$$

Where

y_{ij} = body mass index of the i^{th} individual in the j^{th} household.
X'_{ij} = a matrix of X covariates by 1
β = X by 1 vector of regression coefficients
ε_{ij} = unobservable or error term with a probability distribution $N(0,\sigma^2)$

Because the household level variables, such as social group and expenditure per capita, will be the same for all individuals of a household and introduce bias in the error term resulting the distribution of $\varepsilon_{ij} \neq N(0,\sigma^2)$, a household level random effect that controls for intra-household correlation structure in the data was introduced in the equation (1) to compute household independent estimates.

$$y_{ij} = \alpha + \beta X'_{ij} + (\delta_j + \varepsilon_{ij}) \qquad (2)$$

Where δ_j = error caused by intra-household correlation

Using the regression equation (2), three set of analyses were performed. In the first set, BMI was regressed on per capita monthly expenditure on food and non-food items and total expenditure after controlling for age, sex and smoking habits. In the second, BMI was examined as a function of the final set of covariates identified above by the location of residence (within Delhi and Outside Delhi), and in the final set, the effect of the same covariates on BMI was assessed for different land-use types. Analysis was carried out in Stata (Ver 8.0) software.

Main Findings: The average value of BMI (22.5±0.18) for this sample was in a normal range (between 18.5 and 24.9). However, BMI varied significantly by gender, age and location of residence; 34% of women and 25% of men were overweight/obese (BMI ≥ 25) and women in all age groups except children (between 5 and 15 years) were more likely to be overweight/obese than men (Table 1). The analysis of BMI by location of residence suggests that 32.8% of subjects living outside Delhi were in obese/overweight category as compared to 29% for those in Delhi and these differences were significantly higher for men than for women. The literature suggests an elevated risk of obesity among those who spend a longer duration of time commuting (Frumkin, 2002). Similarly, longer commuting hours could be one of the potential explanations for the high prevalence of overweight/obesity among men who work in Delhi but live outside Delhi.

Three different sets of regression analyses were performed, and their results are presented in Table 2, 3 and 4. In the first set, BMI was regressed on per capita monthly expenditure on food and nonfood items, separately and the total of both categories after controlling for age, smoking habit and gender. Although per capita monthly household expenditure on both food and non-food items showed a statistically significant positive association with BMI for the adult population across all ages, expenditure on non-food items, which can be considered as an indicator of material lifestyle, access to services and physical activity, recorded a stronger association with BMI than the expenditure on food items. Because both categories of expenditures observed a significant association with BMI, the total per capita monthly expenditure was included in the subsequent regression analyses.

In the second and third sets, BMI was analyzed by location of residence (inside or outside Delhi) and by neighborhood types, respectively. In the analysis by the location of residence, six and three of the selected eight covariates showed a statistically significant relationship with BMI in Delhi and outside Delhi, respectively (Table 3); and by neighborhood types six, five and two variables registered a statistically significant association with BMI in residential, commercial/industrial and others types of neighborhoods, respectively. As discussed earlier, household expenditure was positively associated with BMI and a similar association was observed in both residential and commercial/industrial neighborhoods as well, but not in the neighborhood under the other category (Table 3). In the aggregate analysis, a one percent change in expenditure explained a 0.055 ± 0.018 and 0.054 ± 0.017 increase in BMI for adult men and women (15y+), respectively, other variables being constant. This association was much stronger for the subjects living outside Delhi. These outcomes are contrary to what is observed in Western Countries (Kuczmarski, Flegal, Campbell et al., 1994).

Geographic access to open green spaces for men living in Delhi and in the residential neighborhoods was inversely correlated with BMI. The male specific access to open green spaces, which encourage walking and exercise, and its inverse association with the BMI, clearly reflects socially acceptable differential roles of men and women in the Indian Society. More often than not, women do not have the same access to recreational facilities due to cultural reasons that create separate gendered spaces making it culturally inappropriate for women to exercise in public spaces. In contrast, men can take advantage of public spaces, such as those found in Delhi, and exercise thereby reducing their risk of obesity.

The distance from the city center, used as an indicator of urban sprawl in the context of this article, was positively associated with BMI for all adult subjects (Table 3) and for men and women living in the residential neighborhood (Table 4), which means that the subjects, who live in predominantly residential neighborhoods located farther from the city center, are more likely to observe a higher value of BMI than those who live in the residential neighborhoods located closer to the city. This relationship, however, was statistically insignificant when analyzed by the location of residence (inside or outside Delhi) separately. It suggests that the locations of commercial/industrial activities do not follow a distance decay pattern from the city center and its association with BMI, while residential neighborhoods do.

Conclusions: There is an increasing interest in the (indirect) causal mechanism behind the health effects of urban sprawl in western countries, in general, and in the U.S., in particular. Obesity/overweight has drawn particular attention. For example, research in the U.S. shows 0.2 percent increase in the risk of obesity with one point increase in the measure of urban sprawl (Lopez, 2004). The results of our analysis demonstrate a similar relationship, but this relationship is stronger for the subjects living in a residential neighborhood, which constitutes more than half of the sample size, as compared to those living in commercial and other non-commercial and non-residential neighborhoods.

The results of our analyses are in agreement with the existing literature. The percentage of underweight men is significantly higher than that that of overweight/obese men and the trend is the reverse for women. Based on the comparison of our data with that of NFHS II data, it was clear that the prevalence of overweight/obesity among women is on rise. While the measures of SES observe a positive association with BMI, male specific access to open green spaces reflects the importance of cultural contexts for research on under- and overweight in India. In addition, urban sprawl has begun to show a significant relationship with BMI. These results, however, must be used with caution because due to data limitations distance from the city center was used as a crude measure of urban sprawl which may not reflect the same meaning as it does in developed countries.

In the wake of the globalization of the Indian economy, improvements in education, physical infrastructure and the booming service sector, the effect of urban sprawl on overweight/obesity is likely to trickle down to medium and small cities in the country. Therefore, it is critically important to adopt necessary public health measures before the obesity/overweight epidemic extends to medium and smaller cities.

Table 1: Distribution of Body Mass Index by Age and Sex

BMI Category	Male Age Group (Years)				Female Age Group (Years)				Age Group (Year)			
	<15	15-49	49+	All	<15	15-49	49+	All	<15	15-49	49+	All
Underweight (<18.5)	350 (73.68)	143 (15.65)	35 (10.26)	528 (30.52)	309 (69.75)	165 (12.38)	14 (3.69)	488 (22.65)	659 (71.79)	308 (13.71)	49 (6.81)	1016 (26.15)
Normal (18.5 to 25)	98 (20.63)	510 (55.8)	159 (46.63)	767 (44.34)	115 (25.96)	696 (52.21)	122 (32.19)	933 (43.29)	213 (23.2)	1206 (53.67)	281 (39.03)	1700 (43.76)
Overweight (25 to 30)	18 (3.79)	202 (22.1)	107 (31.38)	327 (18.9)	12 (2.71)	327 (24.53)	150 (39.58)	489 (22.69)	30 (3.27)	529 (23.54)	257 (35.69)	816 (21)
Obese (30+)	9 (1.89)	59 (6.46)	40 (11.73)	108 (6.24)	7 (1.58)	145 (10.88)	93 (24.54)	245 (11.37)	16 (1.74)	204 (9.08)	133 (18.47)	353 (9.09)
Total	475 (100)	914 (100)	341 (100)	1730 (100)	443 (100)	1333 (100)	379 (100)	2155 (100)	918 (100)	2247 (100)	720 (100)	3885 (100)

Table 2: Body mass index among adult population by expenditure type and gender

Covariates	Food Items			Non-Food Items			Total		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
Expenditure	0.062	0.036	0.045	0.037	0.034	0.037	0.058	0.057	0.059
	(4.88)**	(3.30)**	(5.04)**	(6.94)**	(6.70)**	(9.60)**	(5.88)**	(6.26)**	(8.42)**
0=Others, 1=Housewives	0	-0.001	0.029	0	0.009	0.034	0	0.01	0.036
	(.)	(-0.08)	(3.84)**	(.)	(-0.68)	(4.46)**	(.)	(-0.77)	(4.73)**
Type of place before the current residence 0=urban place, 1=rural or less urbanized	-0.011	-1.85	0.014	-0.006	-1.79	0.014	-0.21	0.03	0.02
	(-0.65)	(0.027)	(-1.23)	(-0.37)	(0.027)	(-1.27)	(0.003)	(2.02)*	(-1.79)
Caste Dummy	0.077	0.041	0.058	0.042	0.013	0.026	0.055	0.014	0.032
	(5.96)**	(3.20)**	(6.29)**	(2.86)**	(-0.95)	(2.53)*	(3.89)**	(-1.09)	(3.25)**
Age (years)	0.001	0.005	0.003	0.001	0.004	0.003	0.001	0.004	0.003
	(4.15)**	(12.26)**	(10.94)**	(3.71)**	(11.38)**	(10.12)**	(3.88)**	(11.47)**	(10.29)**
Smoking Habit	-0.036	-0.112	-0.059	-0.032	-0.09	-0.051	-0.035	-0.092	-0.054
	(3.21)**	(2.70)**	(5.57)**	(2.89)**	(2.21)*	(4.83)**	(3.15)**	(2.25)*	(5.13)**
SQRT(Distance to the closest vegetated area (decimal Degree)	0.285	0.313	0.309	0.266	0.27	0.271	0.281	0.272	0.279
	(2.08)*	(2.60)**	(3.19)**	(2.00)*	(2.27)*	(2.89)**	(2.12)*	(2.28)*	(2.96)**
(Distance to the Center of the City)^0.5)	0.013	0.073	0.045	0.051	0.08	0.065	0.051	0.083	0.067
	(-0.24)	(-1.44)	(-1.13)	(-0.92)	(-1.61)	(-1.64)	(-0.93)	(-1.66)	(-1.69)
Constant	2.5	2.6	2.563	2.803	2.719	2.746	2.594	2.513	2.532
	(24.63)**	(28.65)**	(35.28)**	(69.30)**	(65.95)**	(91.25)**	(36.70)**	(37.37)**	(49.19)**
Observations	1128	1579	2707	1128	1578	2706	1128	1579	2707
R-squared	0.11	0.15	0.13	0.12	0.17	0.15	0.11	0.17	0.15

Absolute value of z statistics in parentheses* significant at 5%; ** significant at 1%

Table 3: Body Mass Index by Location of Residence and Gender

Covariates	Delhi			Outside Delhi			Inside and Outside Delhi		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
ln(Monthly expenditure per capita (Rupees))	0.044	0.047	0.047	0.092	0.074	0.084	0.058	0.057	0.059
	(3.56)**	(4.34)**	(5.39)**	(5.14)**	(4.34)**	(6.73)**	(5.88)**	(6.26)**	(8.42)**
0=Others, 1=Housewives	0	0.01	0.032	0	-0.001	0.043	0	0.01	0.036
	(.)	(-0.72)	(3.72)**	(.)	(-0.04)	(2.77)**	(.)	(-0.77)	(4.73)**
Type of place before the current residence (0=urban place, 1=rural or less urbanization)	-0.006	-1.39	-1	-0.91	-1.65	0.037	-0.21	0.03	-1.79
	(-0.34)	(0.025)	(0.014)	(0.029)	(0.042)	(-1.95)	(0.003)	(2.02)*	(0.02)
Caste Dummy	0.066	0.016	0.039	0.017	0.015	0.012	0.055	0.014	0.032
	(4.14)**	(-1.08)	(3.47)**	(-0.55)	(-0.56)	(-0.58)	(3.89)**	(-1.09)	(3.25)**
Age (years)	0.001	0.004	0.003	0.001	0.005	0.003	0.001	0.004	0.003
	(3.48)**	(9.12)**	(8.41)**	(-1.74)	(7.69)**	(6.13)**	(3.88)**	(11.47)**	(10.29)**
Smoking habit	-0.046	-0.122	-0.066	-0.008	0.09	-0.022	-0.035	-0.092	-0.054
	(3.56)**	(2.88)**	(5.43)**	(-0.37)	(-1.06)	(-1.04)	(3.15)**	(2.25)*	(5.13)**
SQRT(Distance to the closest vegetated area (dd)	0.344	0.239	0.288	-0.417	0.711	0.316	0.281	0.272	0.279
	(2.38)*	-1.84	(2.79)**	(-0.92)	(2.05)*	(-1.07)	(2.12)*	(2.28)*	(2.96)**
(Distance from the Center of the City)^0.5	-0.019	0.019	-0.005	0.269	0.188	0.203	0.051	0.083	0.067
	(-0.23)	(-0.26)	(-0.08)	(-1.61)	(-1.23)	(-1.62)	(-0.93)	(-1.66)	(-1.69)
Constant	2.708	2.621	2.647	2.328	2.265	2.273	2.594	2.513	2.532
	(30.22)**	(32.18)**	(41.27)**	(15.24)**	(16.50)**	(21.30)**	(36.70)**	(37.37)**	(49.19)**
Observations	835	1191	2026	293	388	681	1128	1579	2707
R-squared	0.11	0.15	0.13	0.15	0.26	0.2	0.11	0.17	0.15
Robust t statistics in parentheses (* significant at 5%; ** significant at 1%)									

BMI for subject 18 years or older

Table 4: Body Mass Index by Location of Neighborhood Type and Gender

Covariates	Residential			Commercial			Rural + Others		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
ln(Monthly expenditure per capita (Rupees))	0.059	0.056	0.059	0.06	0.08	0.069	0.079	0.034	0.043
	(5.12)**	(5.11)**	(7.04)**	(2.87)**	(4.18)**	(4.78)**	(-1.42)	(-0.9)	(-1.24)
0=Others, 1=Housewives	0	0.005	0.026	0	0.04	0.051	0	-0.047	0.095
	(.)	-0.36	(2.96)**	(.)	(-1.33)	(3.20)**	(.)	(-0.99)	(2.81)**
Type of place before the current residence 0=urban place, 1=rural or less urbanization	0.001	-1.59	0.018	-0.011	-0.02	-0.1	-0.6	0.088	-1.21
	(-0.03)	(0.027)	(-1.4)	(-0.28)	(-0.001)	(0.003)	(0.027)	(-1.42)	(0.05)
Caste Dummy	0.041	-0.011	0.013	0.063	0.046	0.057	0.045	0.07	0.05
	(2.25)*	(-0.7)	(-1.01)	(2.44)*	(-1.75)	(3.06)**	(-0.71)	(-1.41)	(-1.23)
Age (years)	0.001	0.004	0.003	0.002	0.005	0.004	0	0.003	0.002
	(2.90)**	(9.42)**	(8.20)**	(2.54)*	(7.14)**	(6.52)**	(-0.06)	(-1.94)	(-1.69)
Smoking habit	-0.035	-0.129	-0.055	-0.051	-0.069	-0.056	0.041	0.014	-0.019
	(2.69)**	(2.08)*	(4.33)**	(2.12)*	(-1.46	(2.67)**	(-0.98)	(-0.12)	(-0.47)
SQRT(Distance to the closest vegetated area (dd)	0.373	0.233	0.307	-0.636	0.182	-0.124	0.405	-0.078	-0.103
	(2.48)*	(-1.61)	(2.77)**	(2.38)*	(-0.73)	(-0.67)	(-0.64)	(-0.16)	(-0.26)
(Distance from the Center of the City)^0.5	0.077	0.115	0.098	-0.165	-0.096	-0.131	0.374	-0.195	-0.028
	(-1.32)	(2.05)*	(2.31)*	(-1.02)	(-0.74)	(-1.18)	(-0.89)	(-0.86)	(-0.13)
Constant	2.597	2.539	2.547	2.761	2.395	2.554	2.2	2.79	2.609
	(31.39)**	(30.34)**	(40.92)**	(16.69)**	(18.09)**	(23.68)**	(5.48)**	(11.03)**	(10.86)**
Observations	814	1127	1941	250	350	600	64	102	166
R-squared	0.09	0.16	0.12	0.17	0.25	0.21	0.11	0.11	0.13
Robust t statistics in parentheses (* significant at 5%; ** significant at 1%)									

BMI for subject 18 years or older