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SOIL LEAD CONCENTRATIONS AND PREVALENCE OF HYPERACTIVE BEHAVIOR AMONG SCHOOL CHILDREN IN OTTAWA, CANADA

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This pilot study presents findings of a case study of the prevalence of hyperactive behavior among school children and soil lead concentrations in the urban environment of Ottawa, Canada. Preexisting data on the prevalence of hyperactivity were correlated with soil lead concentrations from soil samples collected in 1981. Soil lead concentrations of the samples were analyzed using atomic absorption spectrometry. Further, synagraphic mapping was done to facilitate spatial analyses of the topographical patterning of the prevalence of hyperactivity and soil lead concentrations. The two major trends in the prevalence of hyperactivity and soil lead data are overlapped and seen as topographical "ridges" running northeast - southwest in the central part of the city. Both trends are geographically bounded and parallel to the major thoroughfares of the city. The explained variability in prevalence of hyperactivity based on soil lead concentrations is 25% in areas of high concordance between the residence of the children and location of the sampling points. The results illustrate the effectiveness of soil lead as a significant indicator of the psychological effect of hyperactivity among urban children, and its importance as a monitor of ambient lead.

INTRODUCTION

In the United States, lead poisoning in children is so widespread that it has been referred to as a silent epidemic (Needleman 1973; Ross and Ross 1976). However, there has been considerable and continuing debate as to whether sub-acute levels of lead, i.e., levels below those inducing obvious symptoms, are associated with adverse effects on the brain (Needleman et al. 1979) or outright minimal brain dysfunction as described by several groups (Millichap 1975; NRC 1972). There seems to be a higher relative risk of bearing a retarded offspring in areas of higher lead concentration, when compared with controls matched on geography and socio-economic status (Beattie et al. 1972). Additionally, there is sufficient evidence suggesting a strong link between exposure to relatively low levels of lead and adverse effects on the brain and classroom behavior (Needleman et al. 1979). Since a number of other studies have already provided suggestive evidence linking hyperactive behavior with lead concentration levels in children as individuals (Silbergeld and Goldberg 1974; Yule and Rutter 1985), it was important to test the degree of correlation of the spatial patterns of soil lead and prevalence of hyperactivity on an urban scale.

This pilot study, using a one-group correlational research design, describes the association between the prevalence of hyperactive behavior among school children and soil lead concentrations in the urban environment of Ottawa, Canada. An earlier study of the prevalence of hyperactivity in Ottawa (Trites 1979) indicated a geographical anomaly having an east-west aspect in the northern half of the city, which parallels major thoroughfares and highways in the city. This study extends the work by Trites by using spatial analysis modeling techniques to associate the prevalence of hyperactivity with soil lead concentrations. It was not possible to consider confounding factors in this pilot study. Therefore, caution should be used in assessing its outcome.

LEAD AND HYPERACTIVITY

There is no clear definition of the hyperactive disorder. The American Psychiatric Association in its Diagnostic and Statistical Manual of Mental Disorders (APA 1980) has laid out diagnostic criteria for attention deficit disorder with or without hyperactivity. They include signs of developmentally inappropriate inattention, impulsivity, and hyperactivity disproportionate to the child's mental and chronological age. Due to an unclear definition, the true incidence in different age groups and across gender cannot be quantified. Consequently studies have given different estimates based on varying definitions, measures, statistical cut off, and the number of observers used to make a diagnosis (Trites 1979; Whalen 1989). Nevertheless, numerous studies have demonstrated an association between environmental exposure to high levels of lead and/or high body burden of lead in blood or tissues and cognitive psychological and behavioral dysfunctioning. For example, children living closer to a lead-emitting source and having blood lead levels greater than 40 µg/dL show significantly lower scores on intelligence and quantitative neurologic measures (Landrigan et al. 1975; Needleman 1979). The issue of a cause and effect relationship between hyperactive behavior and exposure to lead is still the domain of active research.

SOIL LEAD AS AN INDICATOR OF URBAN LEAD

Besides emissions from industrial sources automobile exhaust is currently the dominant source of soil contamination by lead (Lagerwerff 1967). Soil lead values should reflect auto emissions along the major transportation routes and facilities such as bus stations, truck stops, and garages. This process of high concentrations of lead in urban surface soils is seen in cities such as Los Angeles and San Francisco which have a relatively higher proportion of lead contaminated emissions from automobiles. For example, the surface level of lead in urban surface soil in MacArthur Park, Los Angeles is 3357 µg/g and that in Golden Gate Park, San Francisco is 560 µg/g as compared with only 194 µg/g in Balboa Park, San Diego (NRC 1972). Lead is incorporated into the soil in proportion to the amount of aerosol precipitation at a particular location (Nozaki et al. 1978). Hence, soil lead in the urban environment has importance as a monitor of ambient lead which in turn, has potential effects on the urban population. Thus, this paper determines the degree of correlation between soil lead concentrations with a known biological effect in children which is hyperactive behavior.

OTTAWA CASE STUDY

Ottawa as an urban environment was selected for study for two important reasons. As the capital city for the country of Canada, it is an administrative center without heavy industry. Thus, the major inputs of lead in the environment are from auto emissions. Secondly, an extensive study of the hyperactive behavior of school children (Trites 1979) was published without interpretation of probable factors involved in the demographic patterns of hyperactivity.

Hyperactivity pattern

The study on the prevalence of hyperactivity was based upon the Conners Teacher Rating Scale for a random sample of 14 083 elementary school children from Ottawa. The hyperactivity data was grouped by school and a total percent hyperactivity was calculated for each school. These values and the geographical locations of the schools were entered into a SYMAP program (Trites 1979). A definite anomaly of hyperactivity occurred with a east-west aspect through the city. The study also showed a remarkable consistency across age and teachers, and as expected, boys had a 3:1 higher ratio than girls surpassing the arbitrary cut-off scale of the Hyperactivity Factor.

Ottawa lead potential

There are many sources of lead in the urban environment. The dominant sources are combustion of leaded gasoline, iron and zinc smelters, foundries, coal burning power plants, and battery plants which create high levels of aerosol lead particulate matter. Ottawa, the capital city of Canada is situated on the southern bank of the Ottawa River and has little to no heavy industry located within its boundary. Although heavy industry is located to the north in Quebec where there are paper mills and other major industries, and to the south in nearby cities such as Nepean. Given the pervading west winds, lead-bearing aerosols are expected to be carried downwind away from Ottawa from these sources and precipitated from plumes at some distance from their sources.

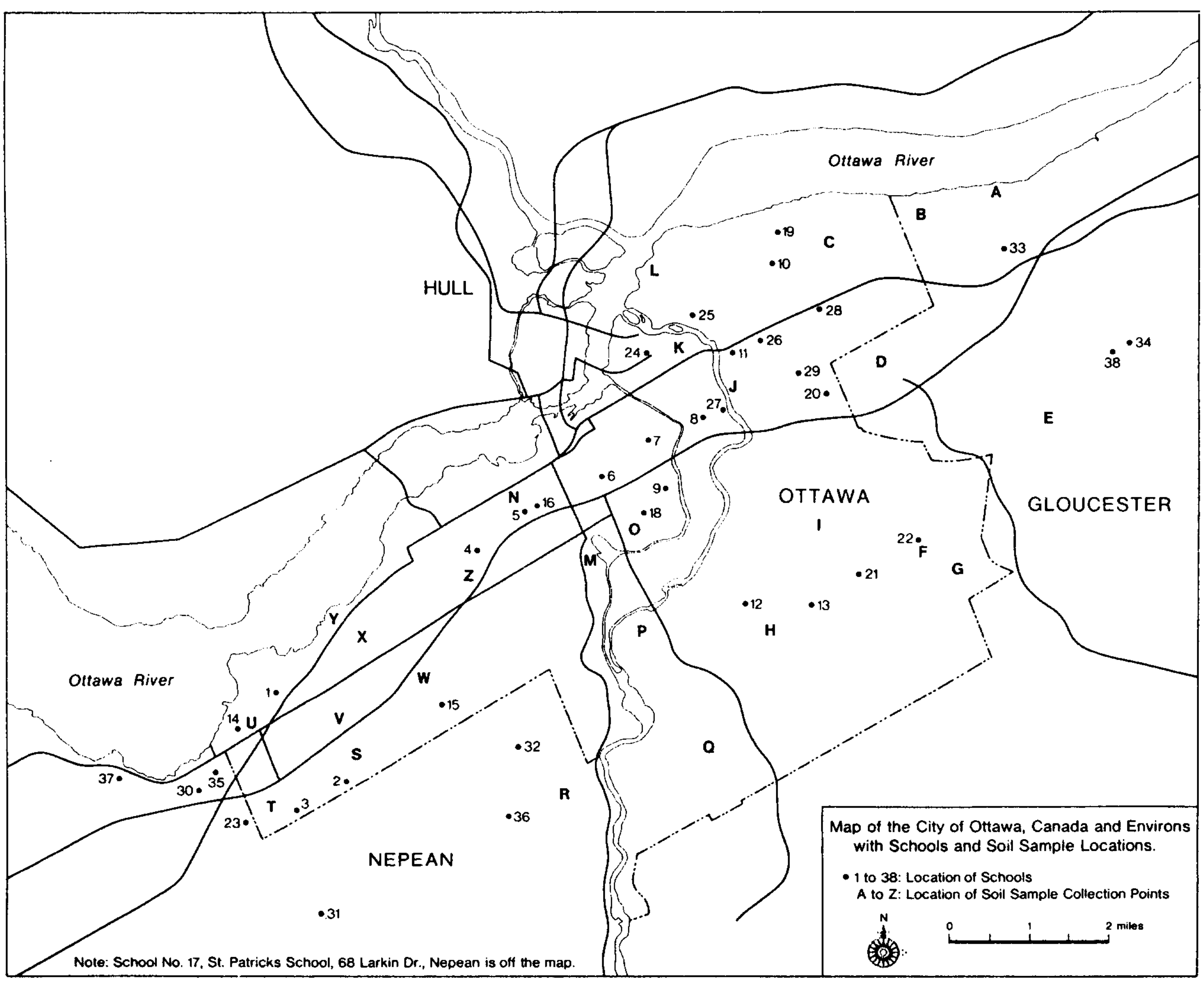
The Capitol is surrounded by administrative facilities and multiple storied dwellings in the older sections of the city, which are surrounded by suburbs of single dwellings constructed at various periods of development. Lead paint is unlikely to be a source of lead to the occupants as house exteriors are generally unpainted and constructed of brick or stone. The growth of the city began in the northeast corner and radiated in the south, east and southwesterly directions. There are several major auto transportation routes, such as Queensway which runs southwest to northeast, through the city (see Map).

The electric power plant located near Ottawa is hydroelectric, although occasionally coal is used as a supplementary fuel. The degree to which coal burning is used as a home heating fuel is not known. There is virtually no lead plumbing in use in Ottawa, with no more than 50 homes located in the Glebe or Sandy Hill areas of the city that still have lead plumbing.

Thus, given these environmental characteristics of Ottawa, the main source of ambient lead appears to be local automobile emissions. The average lead content in gasoline is approximately 2.1 and 1.5 g/gallon for premium and regular gasoline, respectively (Zimdahl and Hassett 1977). Of the lead in gasoline, only 25% is trapped in the car (Lagerwerff 1967), and the rest is emitted as a pollutant to the environment.

SOIL SAMPLING

The locations of the soil sample points, schools, and major transportation routes in Ottawa are presented in the map of Ottawa and its environs (see Map). The soil sampling criteria and soil sampling procedures are designed to be systematic thereby providing a first order approximation of the soil lead distribution in the urban environment of Ottawa. Soil was selected to monitor the cumulative lead precipitated from the air column above the soil sample unit, in lieu of long-term monitoring of that air column. This technique has been used to determine the atmo-



Map of the city of Ottawa and environs with schools and soil sample locations.

spheric flux of lead-210 (Nozaki et al. 1978). Basic procedures for sampling of soil lead have been presented by Skogerboe et al. (1977). Prior to entering the field, twenty-five sample points were preselected and placed on a map of Ottawa to provide an approximately equal array of points of the urban environment. Target locations were designated within the Greenbelt, which surrounds the city, and includes parks, and other uninhabited areas.

Field collection points were selected using a number of criteria: (1) the collection point had to be over 200 feet from an auto roadway or building, if possible; (2) the collection point had to be a flat area or slightly elevated so that drainage would not increase the net input of lead; (3) the collection point had to be a natural surface without major disruption. Vegetation, particularly the presence of large diameter trees, was used as a guide to judge the integrity of the collection point. The above on-site criteria were used to reduce the effects of local perturbations of auto emissions, lead from house paint, drainage, and surface disruptions. Snow dumps located at various locations around the city were avoided as they may contain anomalously high levels of lead due to entrapped road dust. At each collection point, field notes on the area and soil collection were recorded.

At each collection point, organic surface debris was cleared from the surface and the surface layer of vegetation was cut into a 10 by 10 centimeter square and peeled back to a depth of 2-4 centimeters. A level surface was then created by a distilled water-cleaned Marshalltown masonry trowel. The trowel was rewashed in distilled water and used to remove a 1-2 centimeter layer of soil (sample A) at a depth of 2-4 centimeters. This sample was sealed in a cleaned polyethylene bag which was tied with acid-washed rubber bands. The original sample bag was placed in a second clean polyethylene bag, labelled, and tied with rubber bands. On all occasions the excavator and assistant wore new sterilized polyethylene surgical gloves. The sample unit was further excavated to a depth of 10-12 centimeters from the surface. After rewashing the trowel a second soil sample (sample B) was removed using the above procedure. The backdirt and vegetation were replaced to restore the original surface. Soil profiles of most of the collection points had been naturally disturbed by the mixing action of the common earthworm (*Lumbricus terrestis L.*). In this way, two soil samples from 26 collection points of 25 target locations were obtained for analysis, shown in Map and described in Table 1. In addition, the soil lead concentration for 38 schools and the percent hyperactivity data from these schools are described in Table 2. Further precautionary measures to reduce external contamination were employed. Field notes were taken before or after completion of the soil sampling process. All tools and accessories were acid-cleaned and double-bagged to avoid contamination.

ANALYSES OF LEAD CONCENTRATION

Twenty-six soil samples excavated from the upper strata (sample A) were submitted for analysis by atomic absorption spectrometry. Each sample was removed from its double bag storage containers, oven dried at 85° C for 48 hours, and sifted through a 20-mesh screen. A 3 gram sample was removed and weighed into a clean 250 mL beaker, cleaned by refluxing in concentrated nitric acid and rinsing with deionized water. Twenty mL of sub-boiled concentrated nitric acid was added to the beaker and covered with a watch glass. The sample was heated for 2 hours with gentle boiling after which 20-30 mL of deionized water was added and reheated for 20 additional minutes. The sample was cooled, filtered using Whatman No. 541 filter paper, and diluted to 100 mL with deionized water.

The lead concentrations of the solutions were analyzed by atomic absorption spectrometry. Two techniques were used depending on the concentration value of the sample. Seven µg/g was used as a cut-off value between the flame or furnace technique. The high concentration above 7 µg/g were analyzed by flame atomic absorption spectrometry using a Perkin-Elmer Model 603AA equipped with an AS-1 autosampler. The sample detection limit for the flame atomic absorption spectrometry was 3 µg/g. The lower concentrations, with a detection limit of 0.3 µg/g, were analyzed by graphite furnace atomic absorption spectrometry, using a Perkin-Elmer Model HGA 2200. The results of these analyses are reported in Table 1.

Quality assurance of the lead concentrations determined by atomic absorption was maintained by the following analysis: one blank (all reagents), one blank (water) for atomic absorption instrument, two duplicates on unknown samples, two "spike" for recovery percent, one blind sample (NBS 1571 orchard leaves). A surrogate internal standard of 200 µg of lead (spike) was mixed with unknown matrix to correct for recovery. A 4 to 5 point calibration of in-house standards was used to calibrate concentrations in unknown samples.

Table 1. soil collection sites and lead concentrations in Ottawa and environs which are shown on map.

Map No.	Soil Sample No.		Lead Concentration (μg/g)
A.	1A	Beacon Hills: Shefford Rd. near Ottawa River	20.0
B.	2A	Rothwell Heights: Kindle Court	17.0
C.	3A	Stol Port: Hemlock Rd.	100.0
D.	4A	Castle Heights: Eastern Parkway (Greenbelt)	58.0
E.	5A	Innes Rd. Area: Anderson Rd.	7.8
F.	6A	Hawthorne Meadows: Joliffe and Tupper (Park)	13.0
G.	7A	Conroy Subdivision: Pussel Rd. (Greenbelt)	22.0
H.	8A	Walkey Park: Heron Rd. (Park)	33.0
I.	9A	Elmvale Acres: Smyth Rd. (Greenbelt)	25.0
J.	10A	Overbrook: Donald and River Roads (Park)	33.0
K.	11A	King Edward Area: Heney and Charlotte	87.0
L.	12A	Rockliffe Park: at lookout (Park)	43.0
M.	13A	Arboretum: near Dows Lake (Park)	37.0
N.	14A	McNaab Park: Gladstone (Park)	42.0
O.	15A	South Ottawa: Craig and Holmwood	54.0
P.	16A	Vincent Massey Park: near Rideau River	57.0
Q.	17A	Riverside Park South: McCarthy Rd. (Greenbelt)	7.5
R.	18A	Borden Farm: Colonade (Greenbelt)	16.0
S.	19A	Ridgeview: Woodruff and Iris (Greenbelt)	26.0
T.	20A	Draper near Christie (Park)	12.0
U.	21A	Brittania Bay: Brittania Park (Greenbelt)	37.0
V.	22A	Brittania Heights: Parkhaven and Rembrandt (Greenbelt)	29.0
W.	23A	Carling Park: Castle Hill and Maitland Ave.(Greenbelt)	61.0
X.	24A	Westwood Park: Sherbourne and Black Friar's Rd. (Park)	17.0
Y.	25A	Ottawa River Park: Northwestern and Pontiac (Park)	30.0
Z.	26A	Hampton Park: Parkview and Bluebell Rd.	23.0

SYNAGRAPHIC MAPPING AND SPATIAL CORRELATION

The SYMAP program calculates a contour map based on the nearest neighbor principle and the supplementary SYMVU program presents a three-dimensional topography of the data at preselected views of perspectives. In this study the percent hyperactivity data for 38 schools, and soil lead concentrations from 26 locations were entered into the SYMAP and SYMVU programs for spatial analysis.

RESULTS AND DISCUSSION

The results of these spatial analyses are presented in Figs. 1 through 6 which provide various perspectives of the topography of the prevalence of hyperactivity and soil lead concentrations in Ottawa. The 26 soil lead concentration values and their locations were entered in as data for the SYMAP program. The SYMVU option was used to produce the various perspectives presented in the figures. The hyperactivity patterns are identical to those presented by Trites (1979). The percent hyperactivity is a discrete variable rather than a continuous variable for the catchment area of each school. The students from each school were from the surrounding neighborhoods. In the case of ethnic or religious schools, the catchment areas were rather broad. Also, the catchment area of each school varied as did the distance between each school. All these factors must be considered when one assesses the prevalence of hyperactivity and its association with soil lead levels. A better topographical representation of the prevalence data would have been to use the proximal option of the SYMAP program resulting in each catchment area having its own hyperactivity value. In comparison to percent hyperactivity, the soil lead concentration is a continuous variable.

Table 2. School names, school addresses, percent hyperactivity and average soil lead in school catchment areas.

Map No.	School Name	School Address	% Hyperactivity*	Lead Concentration (μg/g)
1.	Regina	2599 Regina	16.9	35
2.	Parkway	Highgate and Westbury Rds.	11.1	25
3.	Pinecrest	1281 Pinecrest Rd.	22.6	15
4.	Elmdale	49 Iona	12.9	45
5.	Connaught	1149 Gladstone	20.7	35
6.	McNabb	160 Percy	7.4	45
7.	Elgin	310 Elgin	25.1	55
8.	Viscount Alexander	55 Mann Ave.	31.9	75
9.	First Ave.	73 First Ave.	11.8	45
10.	Manor Park	100 Braemar	12.7	65
11.	J.O. Swerdfager	307 Montgomery, Vanier	28.7	70
12.	Alta Vista	1349 Randall Ave.	13.8	35
13.	Featherston	1801 Featherston Dr.	14.5	25
14.	Dr. J.F. McDonald	2860 Ahearn Ave.	1.7	30
15.	St. Daniel	1160 Maitland	5.3	45
16.	Holy Rosary	35 Melrose Ave.	26.4	35
17.	St. Patrick	68 Larkin Dr., Nepean	16.1	nd
18.	Corpus Christie	157 Fourth Ave.	12.1	45
19.	Lady of Mt. Carmel	675 Gardenvale Rd.	16.0	65
20.	St. Michael	741 Bernard	15.3	50
21.	St. Mark	803 Canterbury	16.3	25
22.	St. Luke	2485 Dwight Cr.	14.8	15
23.	St. Remi	2844 Sprague	12.5	15
24.	Routhier	172 Guigues Ave.	18.4	55
25.	Barrette	50 Vaughan	17.6	55
26.	Ducharme	Begin & LaJoie Str.	19.6	65
27.	St. Pie-X	150 Mann Ave.	8.0	50
28.	Notre Dame	2810 Baycrest Dr.	10.4	65
29.	St. Paul	411 Seyton Dr., Nepean	21.2	50
30.	Bayshore Public	145 Woodridge Cr., Nepean	14.2	25
31.	Knoxdale	170 Greenbank, Nepean	13.3	nd
32.	Parkwood Hills	60 Tiverton Dr.	14.8	25
33.	L.D. Billings	2147 Loyola	18.6	nd
34.	Emily Carr	2681 Innes Rd., Blackburn	11.5	nd
35.	Bayshore Catholic	50 Bayshore Dr., Nepean	16.2	25
36.	St. Monica	2000 Merivale Rd., Nepean	8.7	15
37.	St. Thomas	9 Leeming Dr., Nepean	9.9	nd
38.	St. Marie	2599 Innes Rd., Blackburn	8.6	nd

* from Trites, 1979

The prevalence of hyperactivity is highest in north-central Ottawa as seen in Fig. 1A. The highest rates are around school numbers 7, 8, 11, and 16, which are geographically bounded by the major thoroughfares of Ottawa: Queensway to the south of the schools and the Scott-Wellington-Montreal roads to the north. The areas of lowest prevalence are along the western, southern, and eastern peripheries of Ottawa as shown in Fig. 1A. School numbers 14, 15, 36, 37 and 38 have the lowest percent hyperactivity.

The soil lead concentration values are highest in school numbers 8, 11 19, 26, 29 which are again bounded by the same major thoroughfares as seen with the highest prevalence of hyperactivity. Areas of lowest soil lead are near school numbers 13, 21, 30, 32, 35, 36, which are all located on the western, southern and eastern peripheries of the city.

The two major trends in the prevalence of hyperactivity and soil lead data are overlapped and seen as topographical "ridges" running northeast-southwest

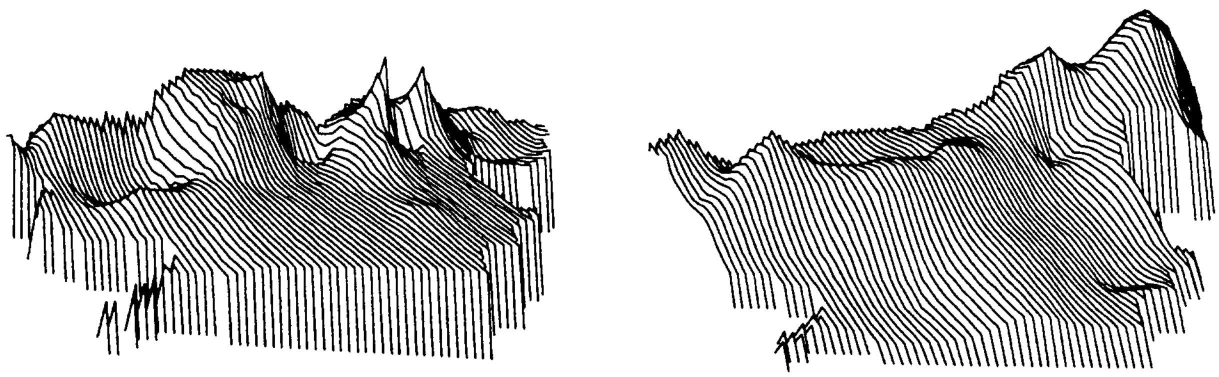


Fig. 1. South view of hyperactivity (1A) and soil lead concentrations (1B) in the city of Ottawa.

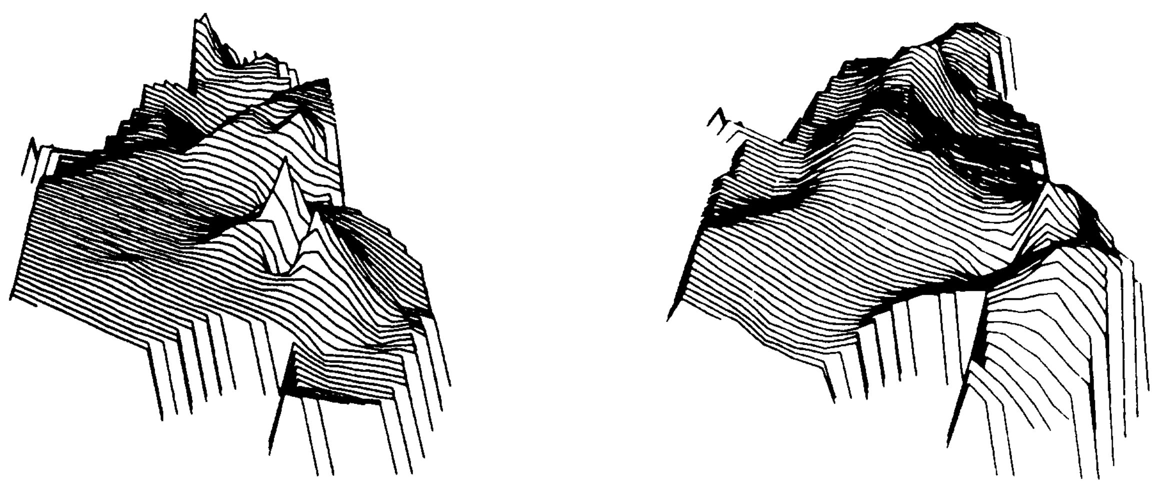


Fig. 2. East view of hyperactivity (2A) and soil lead concentrations (2B) in the city of Ottawa.

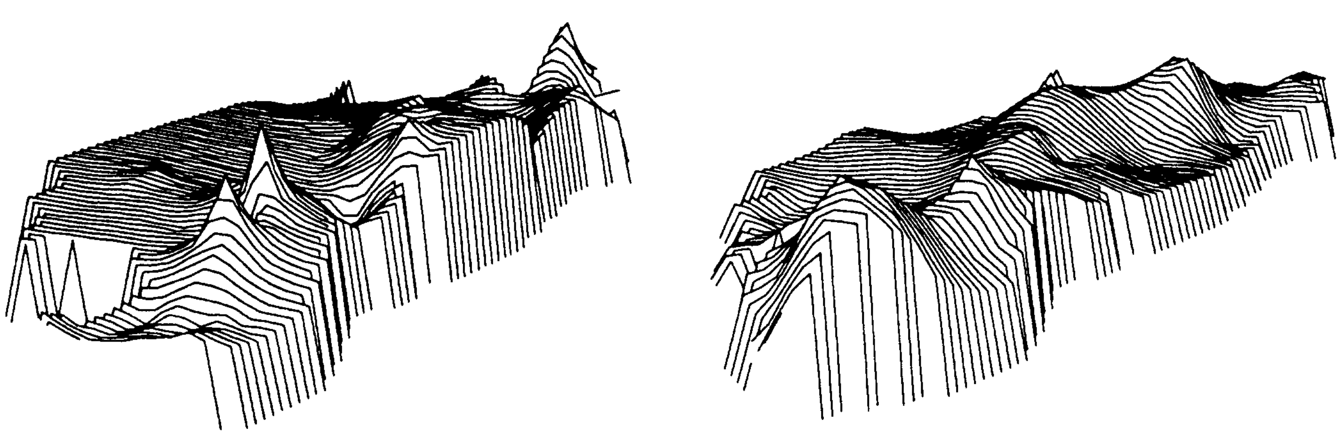


Fig. 3. Northeast view of hyperactivity (3A) and soil lead concentrations (3B) in the city of Ottawa.

in the central part of the city, shown best in Fig. 5. The "ridge" of prevalence of hyperactivity is north of the "ridge" of soil lead which can be explained by the operation of two major factors. One, aerosol lead from roadways tends to be distributed downwind or to the south in this case. Two, the lack of geographical concordance between the residences of the students and the locations of schools attended by them. The trends as seen in these figures are bounded by and parallel to the major roadways and thoroughfares through the city.

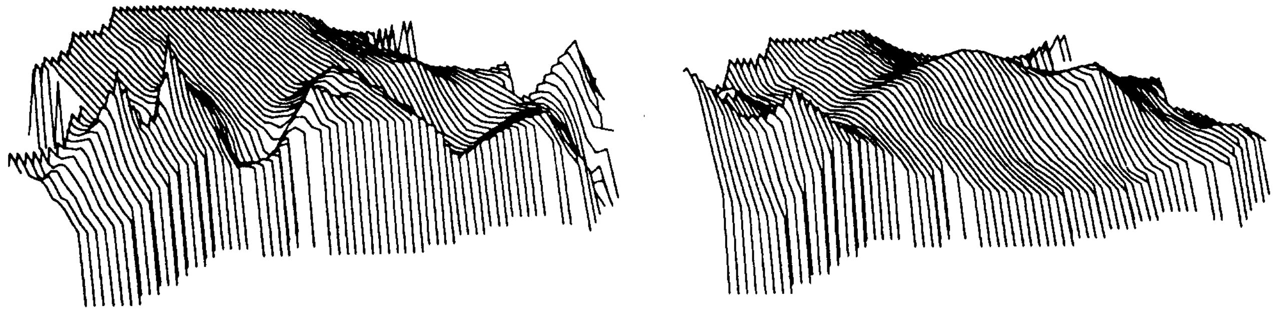


Fig. 4. North view of hyperactivity (4A) and soil lead concentrations (4B) in the city of Ottawa.

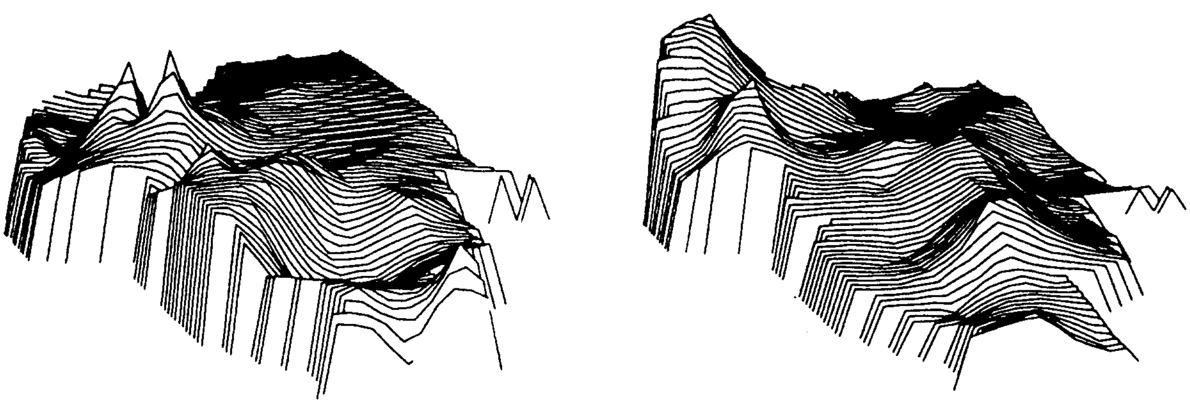


Fig. 5. Northwest view of hyperactivity (5A) and soil lead concentrations (5B) in the city of Ottawa.

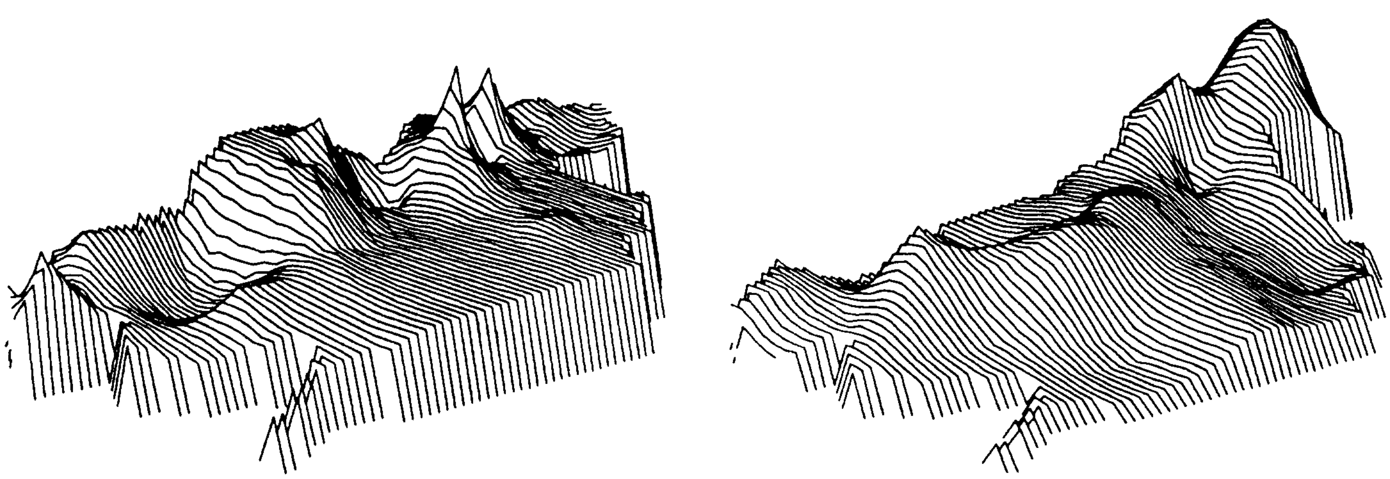


Fig. 6. Southwest view of hyperactivity (6A) and soil lead concentrations (6B) in the city of Ottawa.

To further support the above trends seen in the SYMVU figures, we undertook a statistical analysis of the two data sets. To compare spatial patterns and correlate the data the average soil lead concentration of each school catchment was calculated by summing the concentrations of lead of contours within a catchment weighed by their fraction of the catchment. The percent hyperactivity and average soil lead for each school zone was analyzed by linear regression. Since there are six different school boards in Ottawa, the catchment of each school is determined by the dispersion of the student population which is controlled by religion and ethnicity. The best concordance between student residence and school location was found to be in schools 1 - 13. This is mainly due to the fact that these schools have well-defined catchment areas. The correlation coefficient for schools 1 - 13 (excluding school 6 as an outlier) is 0.50, which is significant at the $p = 0.05$ level. Thus, the explained variability in percent hyperactivity based on soil lead concentrations in these schools with a high degree of concordance between student residence and school location is 25%. The regression equation for the two variables relevant to these schools is $y = 0.19x + 10.47$ where x is percent hyperactivity and y is soil lead concentration. The catchment areas for the remaining 25 schools are largely dispersed due to the fact that the students are drawn from many different areas, created by the six different school boards in Ottawa. The correlation coefficient between soil lead concentrations and percent hyperactivity for all the 38 schools is 0.32, which is significant at the 5% level. The regression equation for this data is $y = 0.12x + 10.66$. Thus, both the statistical correlations and the analysis of topographical trends within the data support the association of a set of demographic variables measured by soil lead and the psychological effect of hyperactivity of urban children.

Certain limitations of this study must be addressed. First, this being a one-group correlational research design, cause-effect relationships between the variables have not been demonstrated. Therefore, associations seen in this pilot study warrant further investigation. Second, the association between the variables could possibly be due to confounding factors. Some factors that need to be considered are those involving hyperactivity and environmental lead levels, independently. Factors involving hyperactivity are multi-causational and include biological variables such as genetic, neurotransmitters; nutritional variables such as intake of chemicals; and psychosocial variables such as socio-economic status (Whalen 1989). Factors involving environmental lead levels are as numerous as those for hyperactivity. Children ingest lead from urban-grown plants, especially if grown near a highway (Hoggan et al. 1978), from foods in soldered cans (Settle and Patterson 1980), and through road dust entrapped in snow (Grandstaff and Myer 1979). Furthermore, there can be interactive effects of these and other factors. For example, there is an inverse relationship of blood lead levels in children and parental education which could be indicative of the relative socio-economic status of the family, and the spatial distribution of their residence in a high to low lead polluted environment continuum (de la Burde and Choate 1972, 1975). Each source of lead is difficult to identify and monitor in terms of individual exposure and uptake. Nevertheless, soil lead reflects ambient air pollution which is one of the primary sources of environmental lead.

In summary, the effectiveness of soil lead as a significant variable must be viewed in a multivariate framework. In the above discussion of the variables promoting hyperactivity a number of variables were mentioned, including lead in food, lead in water, and lead in the home. The contributions of all these variables were not examined in this study. If they were it is likely that the explained variability of total lead intake would be much higher in terms of explaining the observed patterns of the prevalence of hyperactivity among school children of Ottawa.

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