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Human Scalp Hair: An Environmental Exposure Index for Trace Elements

I. Fifteen Trace Elements in New York, N.Y. (1971-72)

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May 1978

HUMAN SCALP HAIR: AN ENVIRONMENTAL EXPOSURE INDEX FOR TRACE ELEMENTS

I. Fifteen Trace Elements in New York, N. Y. (1971-72)

by

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DISCLAIMER

FOREWORD

The many benefits of our modern, developing, industrial society are accompanied by certain hazards. Careful assessment of the relative risk of existing and new man-made environmental hazards is necessary for the establishment of sound regulatory policy. These regulations serve to enhance the quality of our environment in order to promote the public health and welfare and the productive capacity of our Nation's population.

The Health Effects Research Laboratory, Research Triangle Park, conducts a coordinated environmental health research program in toxicology, epidemiology, and clinical studies using human volunteer subjects. These studies address problems in air pollution, non-ionizing radiation, environmental carcinogenesis and the toxicology of pesticides as well as other chemical pollutants. The Laboratory participates in the development and revision of air quality criteria documents on pollutants for which national ambient air quality standards exist or are proposed, provides the data for registration of new pesticides or proposed suspension of those already in use, conducts research on hazardous and toxic materials, and is primarily responsible for providing the health basis for non-ionizing radiation standards. Direct support to the regulatory function of the Agency is provided in the form of expert testimony and preparation of affidavits as well as expert advice to the Administrator to assure the adequacy of health care and surveillance of persons having suffered imminent and substantial endangerment of their health.

These data are provided for those researchers interested in developing a reliable and easily collected index of environmental exposure to certain trace elements, and as well, the data shed light on the influences of personal covariates on the trace element content of hair. These data are timely with regard to the current concerns regarding low-level environmental exposure to trace elements and their uptake by exposed populations.

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ABSTRACT

Previous studies have revealed that hair trace element concentrations can reflect exposure in cases of frank poisoning and deficiency. Correlations have been found also in some populations living in regions where metallurgic processes are conducted.

This study reports significant correlations between hair barium, chromium, lead, mercury, nickel, tin, and vanadium content and exposures (as measured by analyses for the corresponding elements in dustfall or housedust) within a single metropolitan area. Age, sex, hair color, and smoking habits were included in the statistical evaluation. Several metals showed a tendency to increase and decrease together in the hair specimens in agreement with trends reported for other human tissues.

It is acknowledged that hair has the capacity to adsorb and to release trace elements in certain situations. However, population studies can compensate for confounding influences by (1) a randomizing effect, by (2) an averaging effect, and (3) by statistical rejection of unrepresentative data values. The relationship of hair content to (a) content in other tissues and to (b) metabolic status are separate and complex issues that should not be confused with (c) exposure relationships.

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SECTION 1

INTRODUCTION

Human scalp hair has been shown to reflect increased environmental exposure to metals such as lead, mercury, cadmium and arsenic (1-6). Hair chromium and zinc concentrations have been reported to reflect deficiency conditions in humans (11,22,38,40-46). Similar trends for these and other elements have been found in animal studies (11,38,43,44 47). Scalp hair is an almost ideal tissue for population sampling in that it is painlessly removed, normally discarded, easily collected and easily stored (1,2,38). The CHESS* program of the United States Environmental Protection Agency (7) provided a means for community-wide sampling of scalp hair.

The purpose of this study was to evaluate further the utility of scalp hair as a method of environmental monitoring of humans for trace metals exposure. The relationship of scalp hair trace metal levels to important personal covariates such as hair color, age, sex, and socioeconomic level was also of concern. Since for some metals, smoking has been implicated as an important exposure covariate (8,9), it was included in this study. A knowledge of the effects of these personal covariates on scalp hair trace metal levels will permit a more accurate assessment of the quantitative relationships of hair trace metal levels to environmental exposure.

Dustfall has been used as an environmental index of trace substance exposure (19,48). More intimate indices of trace substance exposure such as household dust, soil and water from CHESS-participant homes have already been considered (9,10).

*CHESS stands for Community Health and Environmental Surveillance System.

The specific hypotheses tested in this study were:

1. Significant relationships exist between dustfall, household dust (housedust), and soil trace metal levels.
2. There are significant variations in selected scalp hair trace metal levels due to personal covariates such as age, sex, hair color, socioeconomic status and smoking habits.
3. Environmental exposure, as measured by one of the above media, has a significant effect upon selected scalp hair trace metal levels, even after adjusting for any effects due to personal covariates.

One covariate of great interest that could not be evaluated in this study was race. There were too few non-white respondents to make such an investigation possible. This covariate will be examined in later studies.

Other than the above specific hypotheses, it was of interest to establish the distributional characteristics of each scalp hair trace metal, including baseline levels, ranges, and skewness of the distributions.

Although measurements of nineteen (19) different scalp hair trace elements were attempted, only the following fifteen (15) will be dealt with in this report: barium (Ba), boron (B), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), lithium (Li), manganese (Mn), mercury (Hg), nickel (Ni), selenium (Se), silver (Ag), tin (Sn) and vanadium (V). Arsenic (As), beryllium (Be) and cobolt (Co) were excluded from consideration because many hair sample values were below detection limits for the sample sizes available. Zinc (Zn) was measured in all three environmental samples collected as well as in scalp hair, but the scalp hair concentrations were found to be low in comparison to most normal values in the literature (11,22). A report on this metal has therefore been postponed. Five metals (Cd, Cu, Pb, Mn and Ni) were measured in all the media (dustfall, housedust, and soil) and the remaining nine metals were measured in housedust only.

SECTION 2

METHODS

Environmental Monitoring

Three CHESS communities were selected in the New York City metropolitan complex: the Westchester section of Bronx, the Howard Beach section of Queens, and the town of Riverhead, Long Island. These communities were believed to exhibit a general pollution exposure gradient from low (Riverhead) to intermediate (Queens) to high (Bronx); this belief was based on previous observations of total suspended particulate levels and dustfall levels, as well as some preliminary examinations of levels of selected trace metals in dustfall (10,12). Atmospheric studies including dustfall collections, were made at CHESS air monitoring sites. These sites were located such that the families from each of the three communities of interest were within 2.5 km. of the respective sites.

Dustfall data were obtained monthly over a period of 22 months, from September, 1970 through June, 1972, at the central site within each community. Standard procedures of collection were followed (13). Four soil samples were obtained from each of 43 residences (14 each from Queens and Riverhead and 15 from Bronx). Two samples were collected from the front yard, and two from the back yard. All samples were taken to a depth of two inches with a stainless steel auger. Ninty-nine housedust samples (29 from Queens, 37 from Riverhead, and 33 from Bronx) were obtained by collecting the contents of vacuum cleaner dust bags from community homes.

Scalp Hair and Covariate Information

In March, 1971, letters giving information about the proposed trace metals study were sent to all active CHESS acute respiratory disease (ARD) families in the three communities. These letters included for each family member a return addressed postpaid envelope, with the individual member identification label affixed to the back, and instructions for the collection of the hair sample.

In the instructions it was stressed that the hair should be taken from the next normal haircut or trim, and that as much hair as possible should be collected. It was also stressed that there was no special need to wash or shampoo the hair before the haircut or trim, because it would be washed in the laboratory before analysis. Polyethylene bags for hair samples were sent with the letters and had an identification label on the back with each person's first name, family name and a space for the date of the haircut. During a scheduled ARD survey phone call, after allowing sufficient time for receipt of the letters, the color of each member's hair and the location of the haircut (barbershop or home) were ascertained. This information was then combined with the CHESS ARD background information questionnaire obtained at the start of the ARD study to make a complete covariate information file on each contributing family member. Collection of hair samples was terminated in July 1971. The hair samples were then stored from July 1971 until trace metal analyses were carried out in the Spring of 1973.

Chemical Analysis

Dustfall samples were acid extracted and the metals determined by atomic absorption spectrophotometry (13). Housedust samples were sieved through a 0.5 mm screen for 5 minutes at 260 oscillations per minute on a mechanical shaker, and extracted with 6N nitric acid at 50°C for 30 minutes. Soil samples were also sieved through a 0.5 mm screen. Twenty grams of soil was then extracted with 40 ml of 1N HCl. Hair specimens were washed with a detergent solution, rinsed and dried according to the procedure of Harrison et al. (14). Digestion was achieved by oxygen combustion for some elements and by dry ashing for others, as indicated in Table 1. To prevent any losses when volatile elements were to be analyzed, weighed portions of the washed and dried hair were prepared by the Schöniger Flask technique.

Analytical methods for each metal are also shown in Table 1. Standard laboratory quality control procedures were employed. In addition, recovery of all 19 elements added to a housedust sample and to a hair sample were evaluated using additions that were either twice the detection limit or twice the endogenous level, whichever was larger. Recovery rates were greater than 85 percent in all cases, and greater than 95 percent in most of the cases.

Statistical Analysis

The first step taken in preparation for statistical analysis of the hair data was the careful editing of the data for outliers, values so far removed from the main body of readings as to warrant their removal from the population for statistical analysis purposes.

A statistical procedure was developed for this process, so that all subjective tendencies toward removal of any values were eliminated. In this procedure the inherent population variability, as measured by the standard deviation of the logs of the values, was estimated from the central section of the sample. Limits were then obtained by taking ± 3 standard deviations from the mean of the logs of the sample. Histograms of the data were carefully examined to insure the effectiveness of this procedure, and to verify that a large number of seemingly valid observations were not being eliminated. No such problems were ever encountered. For the trace metals measured, the percent declared outliers varied from 0.2 percent for lithium up to 7.6 percent for selenium, with the median percent rejected being 1.5 percent.

Examination of the trace element values revealed a consistent tendency toward log-normality of the distribution (i.e. populations skewed to the right), so that logs of all values were employed in the subsequent statistical analyses. Standard statistical techniques of correlation and multiple linear regression were then used to discover the effects and interrelationships of all of the measured variables.

SECTION 3

RESULTS

Study Population Characteristics

Over 3000 subjects participated in the CHESS-ARD study (13); 426 families, comprised of about 1900 total members, responded to the hair study letter in some fashion. Family members who gave no hair, who gave an insufficient quantity of hair, or who had incomplete covariate information, were excluded from the study. Because responses were available from very few nonwhite families, these persons were also excluded. The resultant population consisted of 498 subjects with complete information. The distribution of subjects by age, sex and residence is shown in Table 2. The study population is seen to consist of two distinct age groups. This is a result of the method of contact in the ARD study, wherein only families having children in elementary schools were selected. This population division presents no difficulty, however, since subsequent analyses are made on children and adult populations separately. The distribution of the final group of participants with respect to smoking patterns and education for head of households (Table 3) was similar to the original ARD population (13).

Reported hair color by sex for children (15 years of age and less) and adults (over 15 years of age) showed significant differences in hair color distribution between male adults and male children, but not between female adults and female children (Table 4). The adult males showed a higher percentage of black and grey hair than male children.

Sample Hair Trace Metal Characteristics

The 15 trace metals in this study all have typical log-normal type of distribution usually displayed by trace metals in hair (15,16). Analytical hair values obtained generally agree with published values (3,11,15,16).

The interrelationships of scalp hair trace metal levels were examined separately for children (15 years of age or less) and adults (over 15 years of age), since children are in a rapidly developing stage of growth in contrast to adults who have reached a leveling off in growth and development. Some adults also are likely to have been exposed to some work-related sources of trace metals, and hence may display a good degree more variability from person to person in scalp hair trace metal burden than children.

It was found that adults have higher mean scalp hair levels than children in 10 out of the 15 metals (Table 5).

Pairwise correlation coefficients were computed separately for the adults and children groupings using the logs of scalp hair trace metals. There were 68 significant correlations for adults and 85 for the children out of the 120 correlation coefficients (Table 6). Selenium (Se) was the only element to consistently show significant negative correlations. In both adults and children Cd, Cu and Pb were highly inter-correlated.

The relation of hair trace metal levels to media indices of trace metal exposure and to personal covariates are considered in a later section of this report.

Pollution Media Trace Metal Characteristics

Arithmetic means of dustfall and geometric means of soil and housedust trace metal concentrations by community are presented in Tables 7, 8 and 9.

A previous study of pollution data from these same sites within these same communities established the fact that there were indeed statistically significant differences in trace metal levels between communities in dustfall, soil, and housedust for Cr, Cu, Mn, Ni, Pb and Cd, except that chromium was not analytically determined in the soil, and Cd was found to display no difference in the housedust levels across communities (10). Bar graphs of the means for dustfall and geometric means for housedust and soil by community are shown in Figures 1-3. These figures demonstrate the concentration gradients as well as the similarities and differences in trace metal patterns across these three media. Cd, Cr and Ni generally have much lower concentrations than Cu, Pb, Mn and Zn. There is apparently a higher percent of Mn in the soil than in housedust or dustfall, while dustfall seems to have relatively less Ni and Cu than the other two environmental media. For most of the trace metals the three media indices of exposure are quite similar, reflecting increased exposure in moving from Riverhead to Queens to Bronx. In order to more precisely assess the interrelationships of soil, housedust and dustfall, correlations of the respective trace metals across these media were computed (Table 10). Logs of the concentrations were used in this computation in order to normalize the data and make significance tests valid. One should keep in mind that all correlations with dustfall metals involve the pairing of housedust and soil metals within a community to a single dustfall value. However, this correlation produces the same results as one would obtain by a simple linear regression of the media metal on the dustfall metal. The housedust-soil correlation was obtained by first averaging the four soil values to obtain a single value per home, and using all houses for which both housedust and solid results were available in order to obtain the correlation coefficients. All of the correlation coefficients were found to be highly significant indicating a strong relationship between these measures of environmental trace metal levels for the six metals available for analysis.

The use of soil as an environmental index of trace metal burdens has several problems that have been mentioned in earlier reports (19,20, 21). The problems that must be considered are background levels in the soil, possible gradients in soil concentrations due to roadway traffic, and contamination from older homes on which a great deal of lead-based paint had been used. From an analysis of the logs of soil trace metal levels (Table 11), the strong relationship of dustfall levels to soil levels is seen, as well as the great variability between homes within the areas, and between the front and back yard measurements.

Hair Trace Metal Concentrations in Relation to Media Indices of Trace Metal Exposure and to Personal Covariates

One must take into account as many influences on scalp hair trace metal levels as possible in order to assess adequately its utility as an epidemiological personal exposure index. The first step in this process was the separate analysis of children ($\leq$15 years old) and adults ($\geq$16 years old). Within each of these groups, the following possible influences were assessed: age, sex, hair color, location of haircut (home or barbershop), socioeconomic level (as measured by education of head of household) and smoking patterns (in adults only). The relation of environmental exposure to hair trace metal levels, after adjusting for the effects due to these covariates, was then tested using a linear multiple regression model. The logs of both the scalp hair trace metal levels and the environmental exposure trace metal levels were used in the analysis to make the scalp hair values more closely fit a normal distribution and to help insure the fit of a linear model to the data.

The results of the statistical tests when monthly average trace metal dustfall rates were used are given in Table 12. Dustfall trace metals had a significant effect on hair levels for Pb, Cr, and Ni in children but only on hair levels of Pb in adults. All of these scalp hair metals show a marked increase in concentration with the media gradient (Table 13).

Housedust was used in place of dustfall as an environmental index in the above models by computing the geometric mean of the housedust trace metal readings obtained from contributing households within each community. The results of this substitution were essentially identical to those with dustfall in the model, except that housedust chromium was not indicated as having a significant effect on scalp hair chromium in children (Table 12).

By selecting the family members of households contributing housedust and computing the correlation of these scalp hair trace metals and the corresponding housedust trace metals, a more direct comparison of environmental exposure and scalp hair levels of trace metals is possible, although other covariates must of necessity be ignored. Significant correlations found were for Pb (r=0.27) and Ni (r=0.32) in children and for Cu (r=0.31) in adults. It is apparent that the housedust and dustfall trace metal values compared above can be used interchangeably as an exposure index.

There are nine metals in this study for which the only pollution index available is housedust: Ba, B, Fe, L, Hg, Se, Ag, Sn and V. The linear model analysis for these metals using housedust as an environmental index is shown in Table 12.

Selenium was found to show no differences in housedust trace metals across communities, so that the effect of selenium in housedust on scalp hair selenium levels could not be tested here. Ba, Pb, Hg and V were found to have a significant relationship between housedust and scalp hair levels for both adults and children, while Sn was significant for children only.

Significant trends of scalp hair Pb, Mn and Ba with age were found in children, while Cu and Ba in scalp hair were related to age in adults. In children, scalp hair Pb decreased with age while Mn and Ba showed an increase with age. In adults, both Ba and Cu decreased with age. A separate linear model including an age-sex interaction term was also examined in the belief that the concentration change with age might be different between sexes. This proved to be true for adult scalp hair Cu and Ba as well as for Ba, Pb and Mn in hair of children (Figures 4-8).

When examined separately by sex, the female adults were found to have rapidly decreasing Cu scalp hair levels, while male levels were fairly steady over age. These trends in Cu levels are in close agreement with the results of Schroeder et al. (15). The increased hair Ba and Mn values in females (but not males) at ages 12-13 is intriguing in reference to puberty. Mn does have a role in reproduction (39), but Ba has usually been considered nonessential (11). Ba is chemically related to calcium (Ca), and the higher concentration of Ba in female hair than in male hair may be associated with a similar differential observed for Ca (16,17,36,38).

For adults, significant differences in scalp hair trace metals between sexes were noted for all metals except Cr, B, Fe, Se, Ag and V. For children only Cr, B, Fe and Se were not significantly different by sex. Females levels were always higher than male concentrations wherever significant differences were found in children. In adults, females were higher than males except for cadmium and lead.

Fe levels in scalp hair were found to be significantly related to socioeconomic level as measured by education for both adults and children with the scalp hair levels following a negative gradient with increasing education level. That is, subjects with higher levels of education of the head of household had lower levels of Fe in their scalp hair. Fe in adult scalp hair was the only metal showing a significant relationship to hair color, with brown and black hair colors having less Fe, while gray hair had more.

Hair samples collected at barbershops as opposed to home collection were significantly higher for adults in Cd, Pb, Ba, B and V while in children Ni, Ba and V were higher. Selenium in children's hair collected in barbershops were significantly lower than found in hair from children who had home haircuts.

Smokers were found to have significantly higher hair Se and Fe. Hair Pb was higher for smokers than for nonsmokers, but was not quite statistically significant (p=0.06).

SECTION 4

SUMMARY AND DISCUSSION

While other studies have illustrated metal changes in hair when exposure differences have been dramatic, this report indicates that hair metal content can reflect exposure trends within a single metropolitan area. Several personal covariates were found to influence scalp trace metal levels strongly and must be taken into consideration if scalp hair is to be used as an environmental index.

In this study, the environmental exposure gradients of Pb, Ba, Hg and V (as measured by dustfall or housedust) were significantly associated with scalp hair trace metal levels in both adults and children, while the environmental exposure gradients of Cr, Ni and Sn were reflected in children's hair only. The seven other metals investigated (Cd, Cu, Mn, B, Fe, Li and Ag) displayed no such significant associations. Housedust and dustfall trace metal values proved to be usable interchangeably as an exposure index for the metals that were measured in both media.

Sex was found to be the most important covariate in the study, being significantly associated with 11 of the 15 trace metals examined in children and 9 of the 15 trace metals in adults. Female scalp hair values were higher than male values in all cases where differences were significant except for Cd and Pb in adults. The reversal of the general sex trend for Cd and Pb could be a reflection of work-related exposure of males to these nonessential metals, although this hypothesis was not examined in this study. Adult males reportedly have more kidney Cd than adult females (69,70) but Pb did not differ by sex in 33 tissues (70). However, blood Pb is reported (9) to be lower in women than in men in similar environments.

Other investigators have also found sex differences as observed in this study, with females most often higher than males (3,11,15-18,25,36). The tendency for female hair to be higher than male hair in several metals may be related to a higher inorganic content for female hair on the average (49). Additional studies may also investigate whether the sex difference might be explained by other factors such as hair length or shampoo frequency.

Scalp hair Pb values decrease rapidly with age in children. This decrease is probably a result of a proclivity to pica as well as a higher respiratory rate in the very young. Mn and Ba begin increasing in children's scalp hair around age 8; Ba displays peak values in women at age 11-12 and 31-35 while Mn does not change with age in adults. The causes of these age trends in Ba and Mn are not clearly understood. Cu was found to rapidly decrease with age in adult females. Other reports have shown a decreasing trend in hair copper with age (15,25,50).

Hair color and education of head of household both reflected a relationship only to scalp hair Fe. The hair color differences in Fe were significant only for adults. Over 90 percent of the hair in this study was either blond or brown, so other hair colors may not have been adequately sampled for the determination of any differences in trace metal content. Other investigators have reported differences with hair color (11,15,39).

The increased concentrations of Cd, Pb, Ni, Ba, B and V found for hair samples collected in a barbershop or beauty shop as compared to collection in the home may represent contamination. The concentration of Se, however, was found to be lower in hair collected in barbershops or beauty shops compared to the amounts found in children's hair from home haircuts.

Smokers were found to have higher Pb, Fe and Se scalp hair levels than nonsmokers in this study. Although these metals have been reported to be in cigarettes, the authors are unaware of any published studies in which the relationship between hair levels and smoking have been examined, although blood Pb values have been found to be higher in smokers than in nonsmokers (9).

The hair element intercorrelations (Table 6) show agreement with several element intercorrelations reported for other human tissues. Schroeder et al. (52) reported that Cr was significantly correlated with Ba, Mn and Ni in 14 to 18 of the 29 human tissues examined. Ba and Mn correlated in 15 of 28 tissues in another report (53). In our data, hair Ba, Cr, Mn and Ni were significantly intercorrelated in both children and adults. As found for a majority of human tissues (54), hair showed a significant correlation between Cu and Fe and (in adults) between Cr and Mn. Cr and Pb did not correlate significantly in hair (Table 6) nor in 20 out of 29 other human tissues (52). Although exceptions to these trends can be found between the data, hair does not appear to be unique among body tissues in its compositional variations.

The highly significant correlations in hair between Cd, Cu and Pb have been found by other investigators (16-18). As in another study (17), only hair Se, a nonmetal, showed a negative correlation with certain hair metals. The Fe - V correlation in hair is interesting in view of evidence that V, like Fe, is bound to transferrin in blood (65) and that hemoglobin and tissue respiration are decreased in Vanadium toxicity (72).

Hair growth in humans is a complex cyclic process involving non-growing and growing phases of variable duration for each fiber plus differences in growth rate depending on age and sex. In addition scalp hair grows faster and is retained longer in summer than in winter (51).

Metal concentrations are known to differ in hair from the same individual and even at different locations along single fibers or fiber bundles (4,22,23,30-38,40-47,50). These hair trace metal variations have been considered by investigators as evidence for

(a) external contamination

(b) body intake variations

(c) seasonal trends

The relatively large number (7.6%) of scalp hair Se values rejected as outliers may be related to the use of special shampoos containing Se (16). Exogenous Se on hair was shown by Bate (23) to be resistant to removal by a variety of washing procedures.

Complexity in interpretation of hair trace metal data is increased by evidence indicating that physiological uptake by hair of trace elements is not a simple growth phenomenon (36,44). For this study, hair was sampled without restriction as to location on the scalp or distance from the scalp. Consequently, effects observed in the covariate data could possibly be related to sampling technique such as differences in distance from the scalp between male and female samples. However, area differences would not be affected by these sampling techniques since variations in the sampling were randomized across all areas.

Laboratory washing of hair before metal analyses has been a point of contention (2,3,14,22-32,34-38). A recent report (36) indicates that the binding of certain metals to hair is not as strong as has been previously assumed by many investigators. After comparison testing of five techniques, the washing procedure described by Harrison et al. (14) was selected for use in this study. The detergent used in this procedure was demonstrated to be similar in effect to commercial shampoos, which agrees with the findings of another investigator for non-ionic detergents (24). In an earlier EPA hair study (1), a metal chelating agent (EDTA) was included in the hair washing procedure, but use of this reagent was not recommended in a follow-up report (2). Other investigators have subsequently concurred with the opinion that EDTA should not be used in washing hair before analyses for metals (33,34).

The relationship of hair content to tissue content and metabolic status are separate and complex issues that should not be confused with exposure relationships.

Some evidence indicates that hair trace element content can reflect whole body content (38,55,58,67) or content in specific tissues (3,38,40, 43-45,50,57,58,64,68). When hair content does not reflect other tissue values (15,38,66,71), hair can reflect the metabolic or health status (38, 43,47,64,68) while the blood and other tissue values do not (9,38,47,56,59-64, 66).

The absence of a demonstratable relationship between hair content and media values for some elements in this study is not definitive, but may simply indicate that:

(a) the exposure difference was not sufficient for a correlation effect on hair trace metal levels to be observed or

(b) that the media indices employed were not representative of the overall metal exposure for the population sampled.

Future hair trace element content reports from other geographic areas will help to clarify the utility of scalp hair as a community exposure monitor.

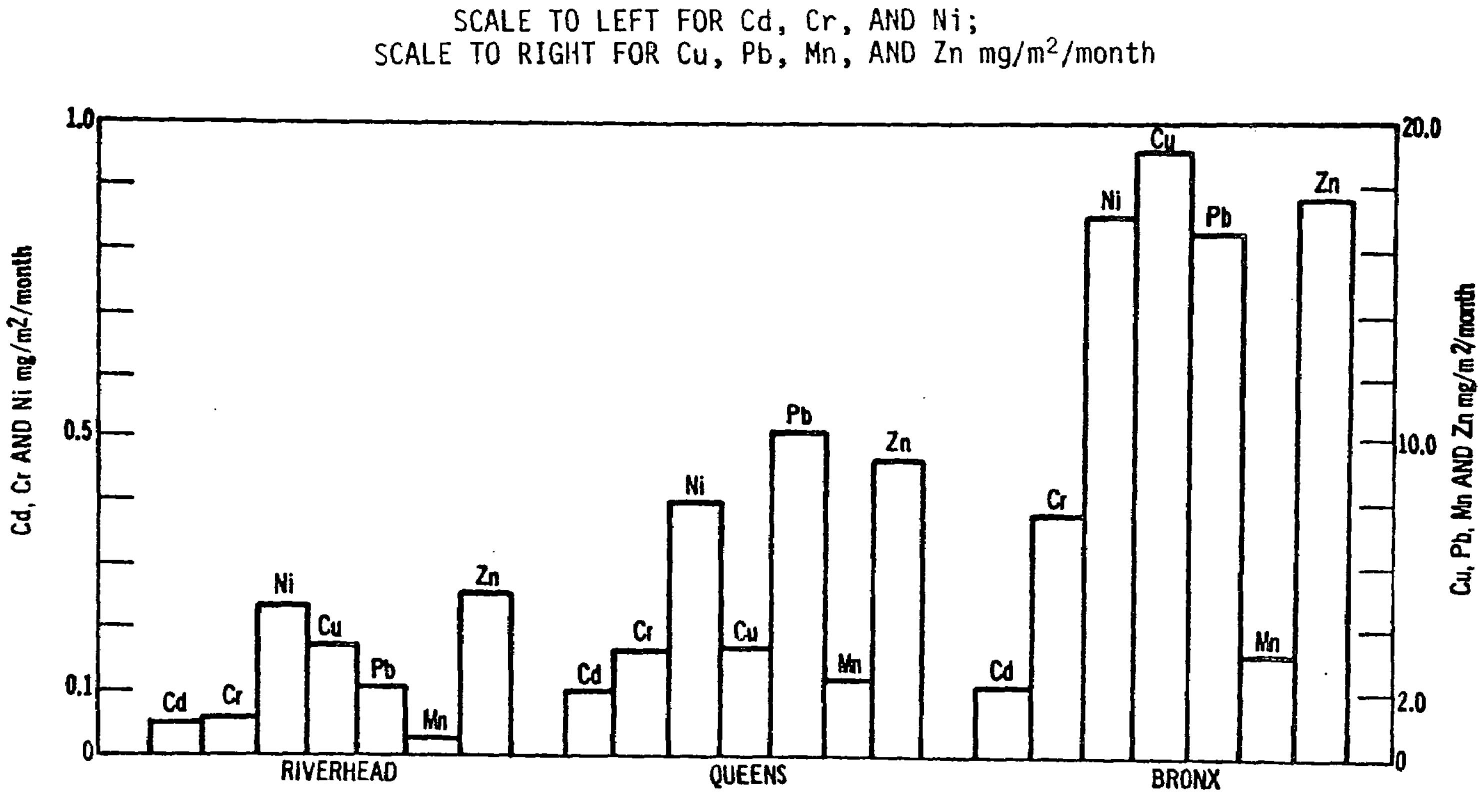


FIGURE 1. TRACE METAL LEVELS BY ELEMENT AND COMMUNITY FOR DUSTFALL

SCALE TO LEFT FOR Cd, Cr, AND Ni;
SCALE TO RIGHT FOR Cu, Pb, Mn AND Zn μg/g

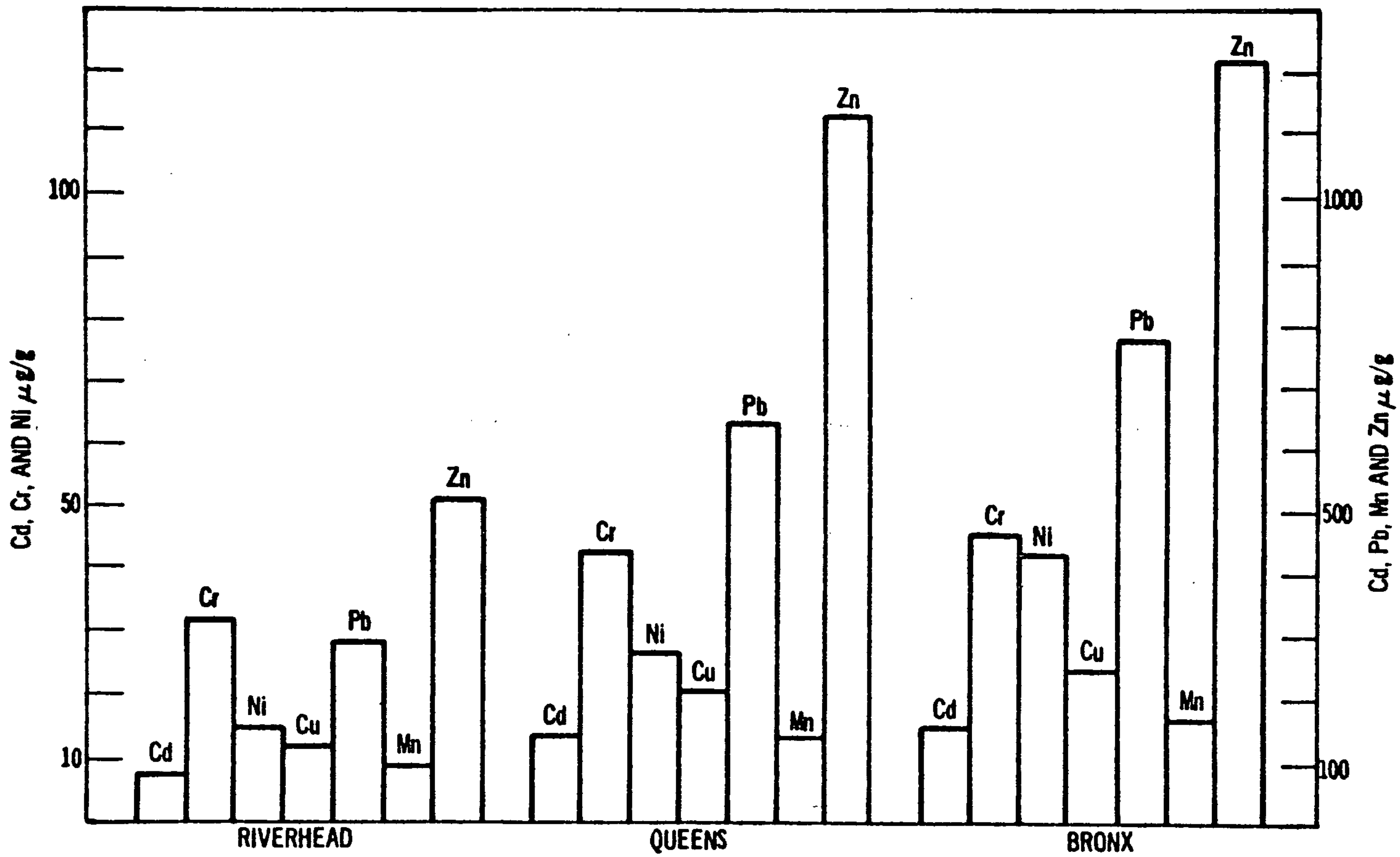


FIGURE 2. TRACE METAL LEVELS BY ELEMENT AND COMMUNITY FOR HOUSEDUST

SCALE TO LEFT FOR B, Li, Hg, Ag AND Sn
SCALE TO RIGHT FOR Ba, Fe X 10^{-2}, Se X 10^{3}, AND V µg/g

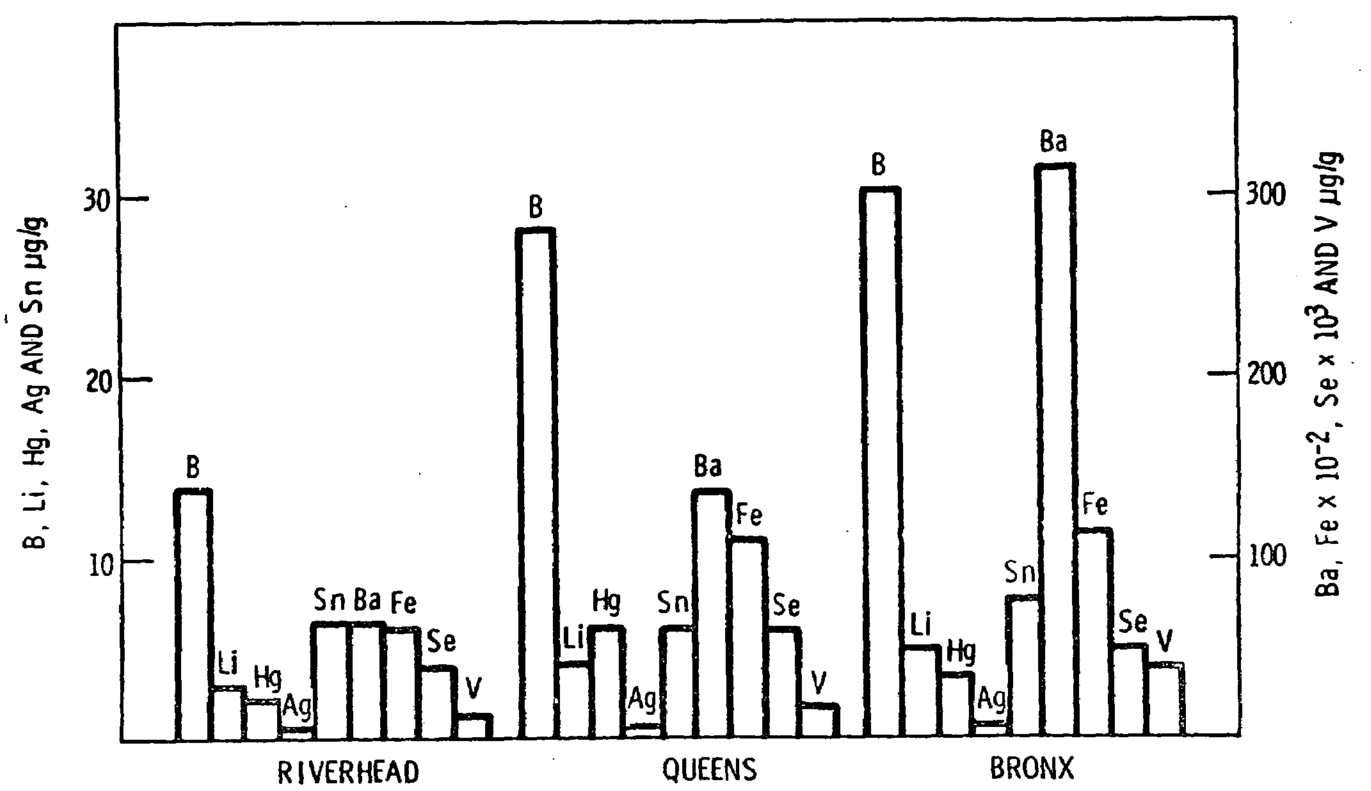


FIGURE 2. (continued).

SCALE TO LEFT FOR Cd AND Ni;
SCALE TO RIGHT FOR Cu, Pb, Mn AND Zn μg/g

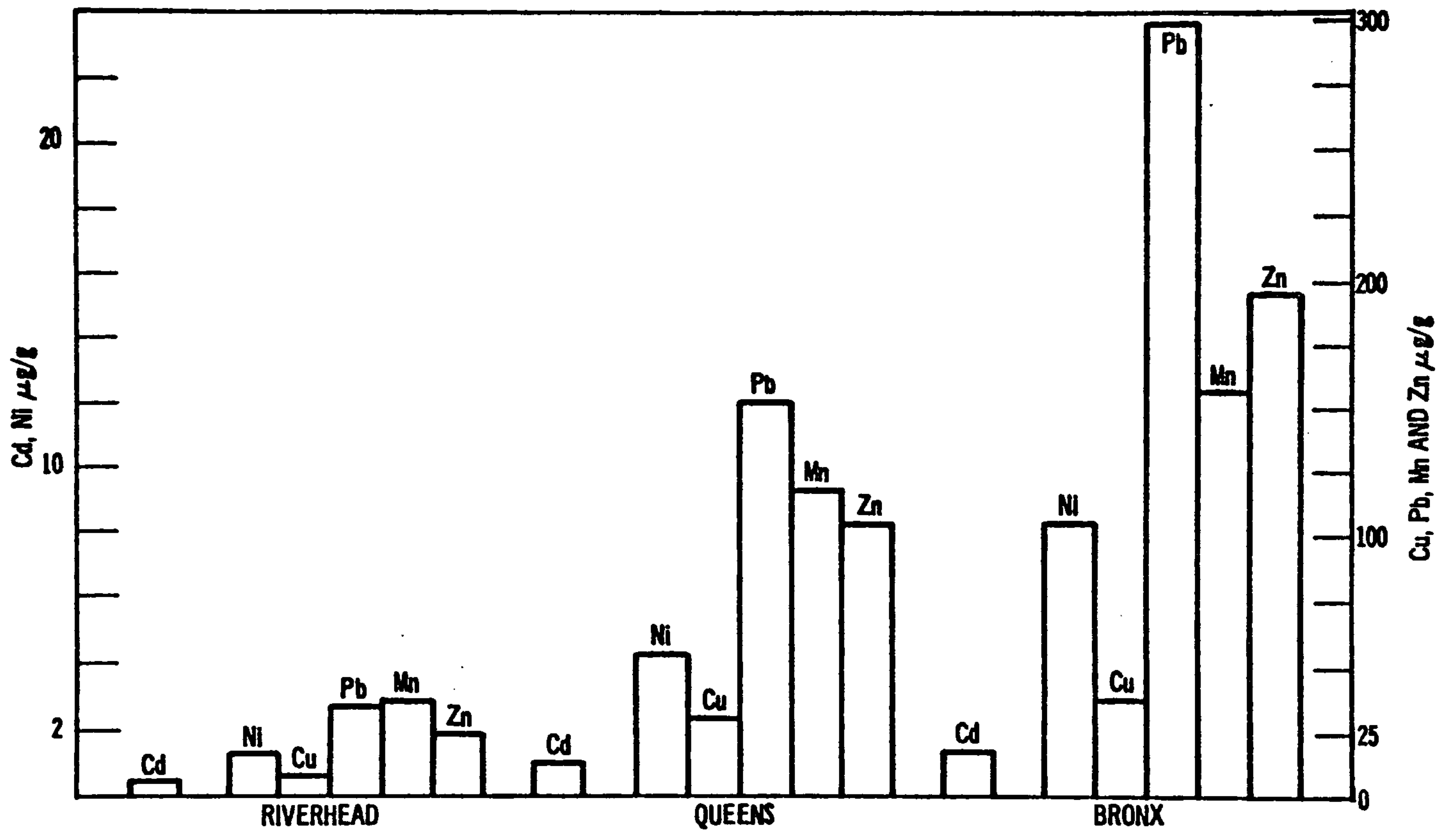


FIGURE 3. TRACE METAL LEVELS BY ELEMENT AND COMMUNITY FOR SOIL

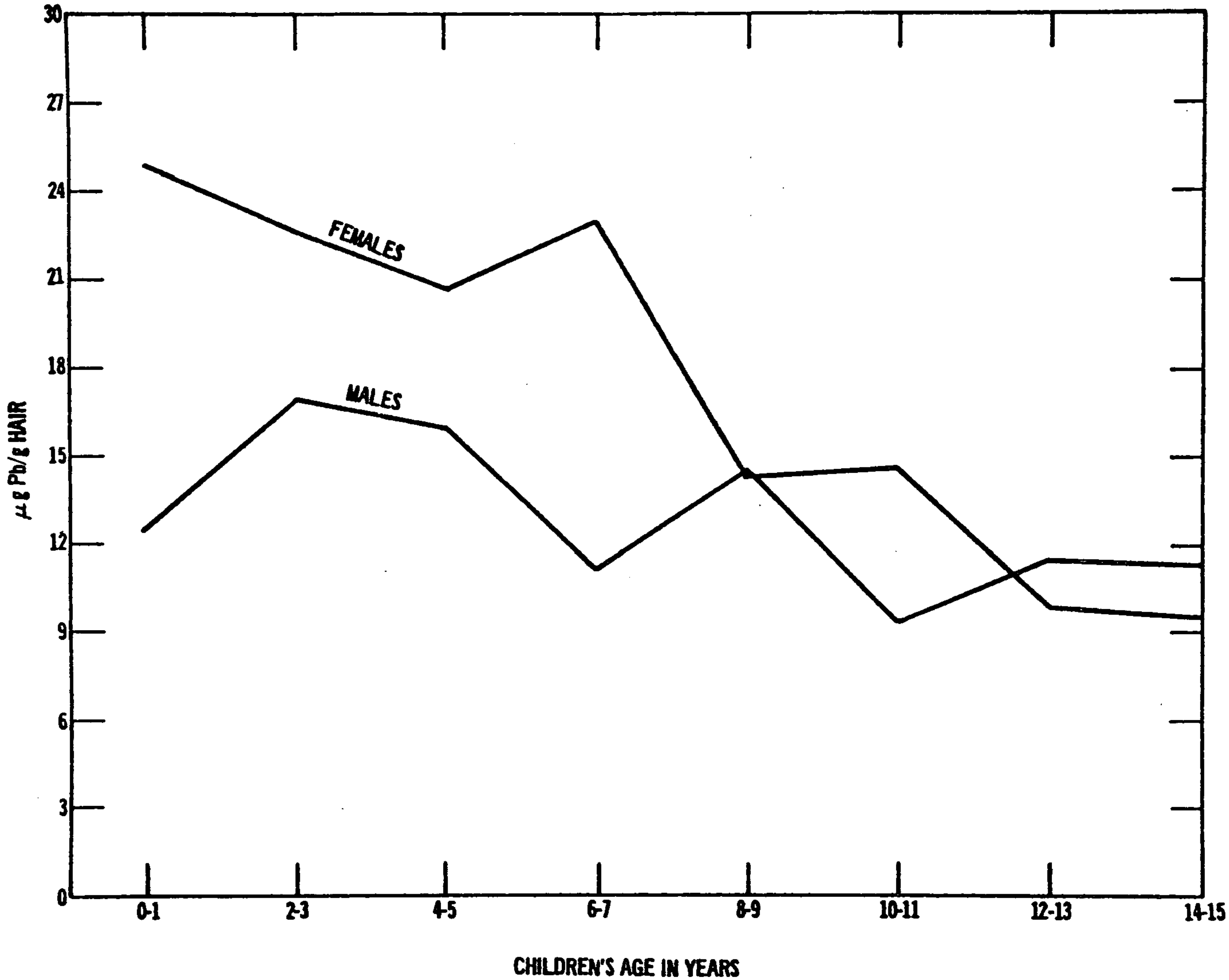


FIGURE 4. GEOMETRIC MEAN SCALP HAIR Pb FOR CHILDREN BY AGE AND SEX

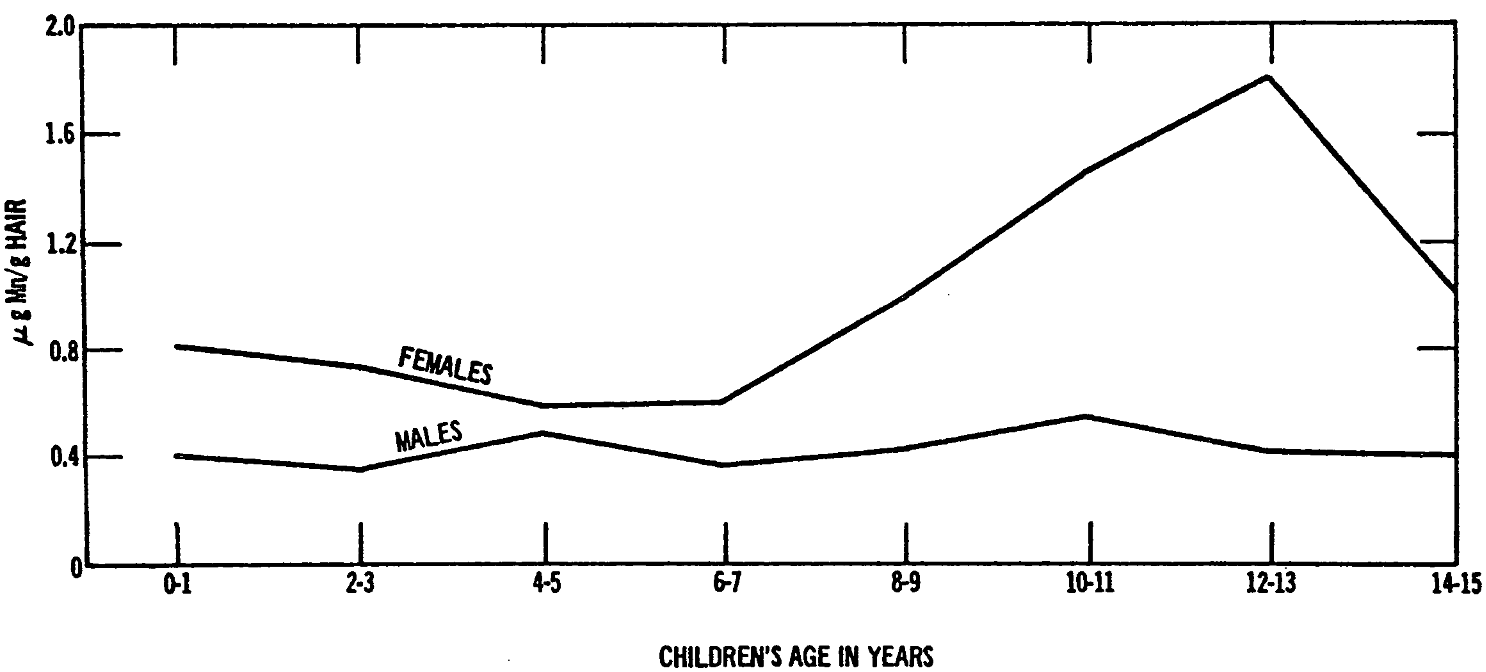


FIGURE 5. GEOMETRIC MEAN SCALP HAIR Mn FOR CHILDREN BY AGE AND SEX

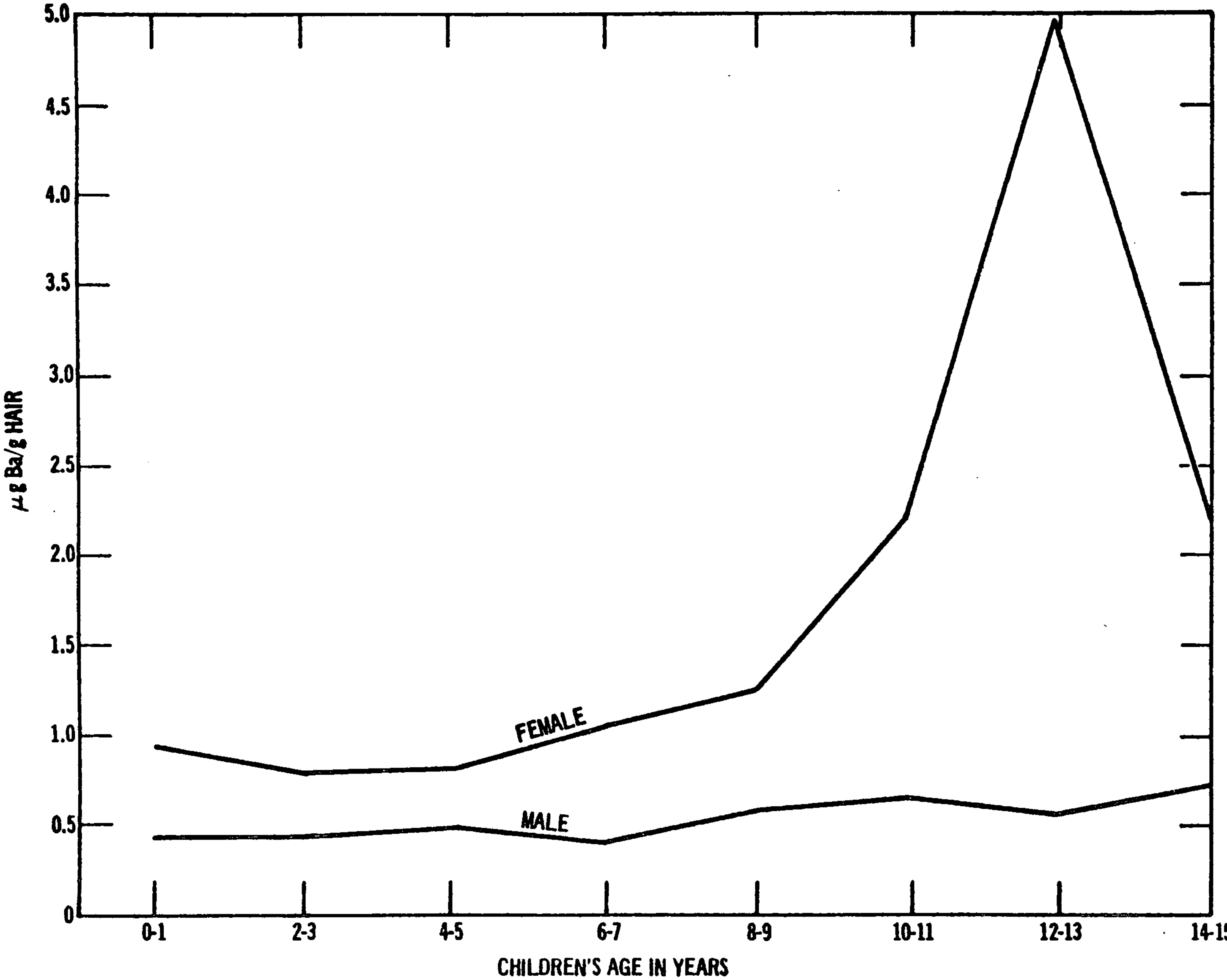
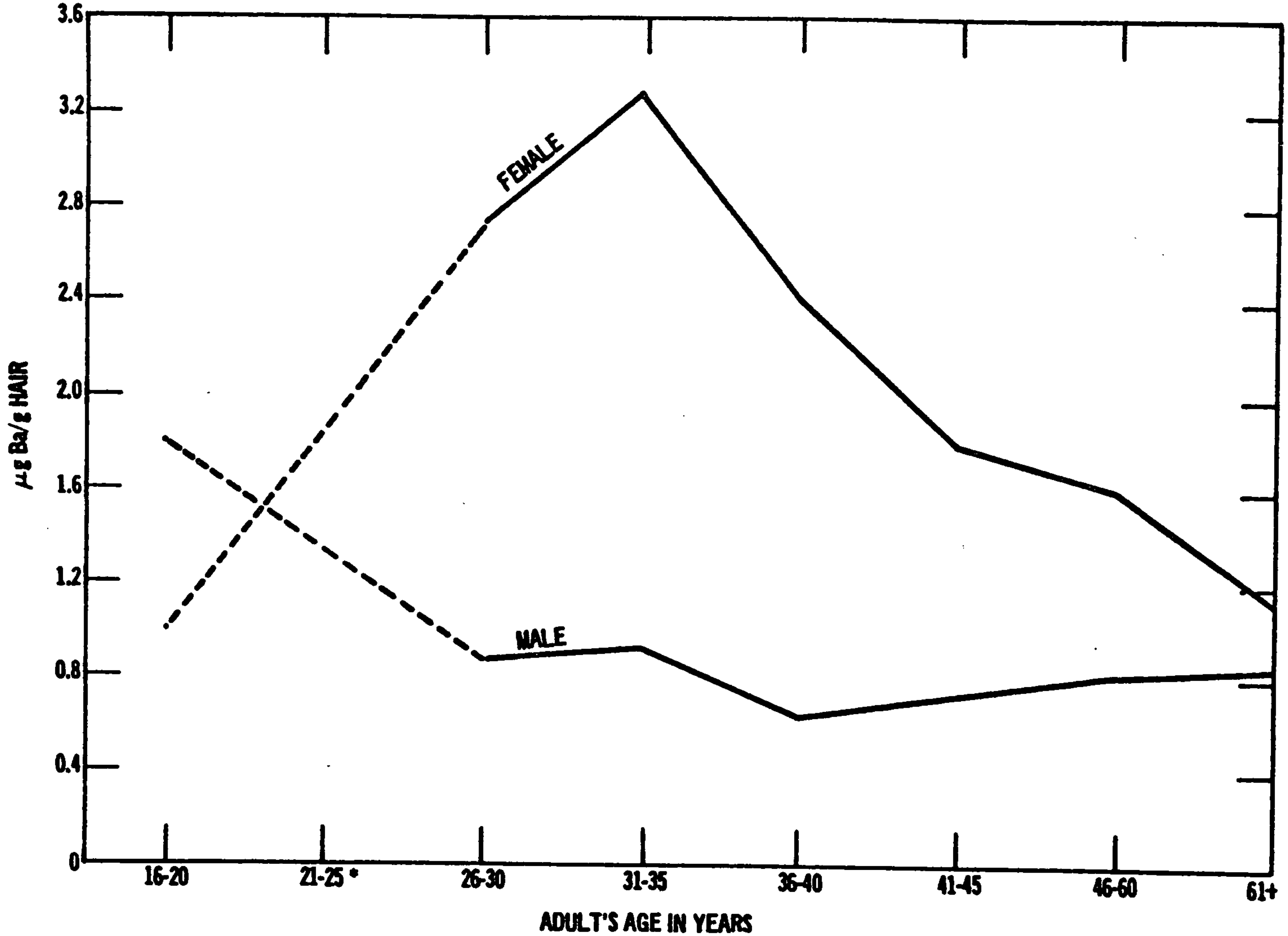
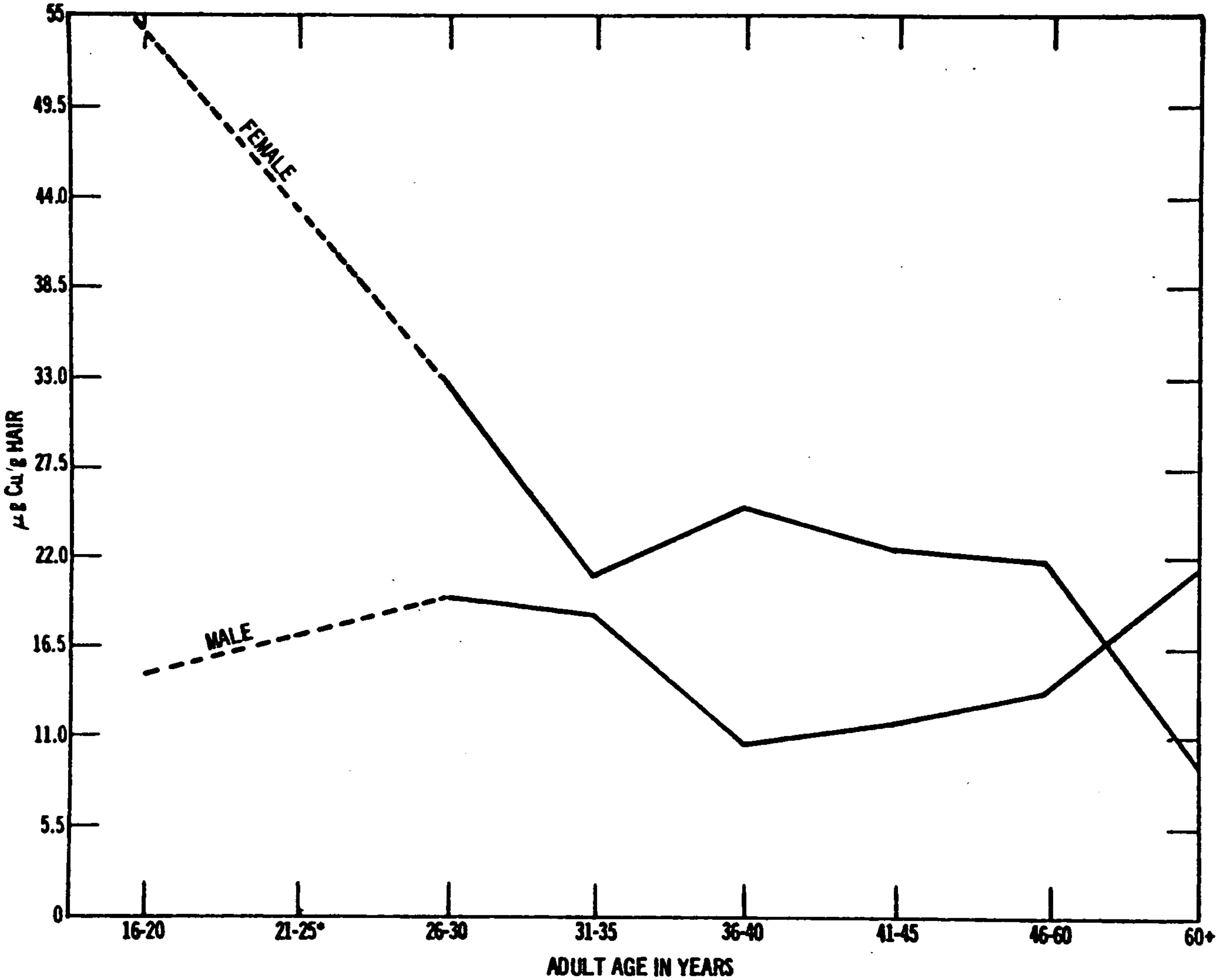


FIGURE 6. GEOMETRIC MEAN SCALP HAIR Ba FOR CHILDREN BY AGE AND SEX



*ONLY 1 MALE AND 1 FEMALE IN THIS CATEGORY, NO ACCEPTABLE MEAN VALUE IS AVAILABLE.

FIGURE 7. GEOMETRIC MEAN SCALP HAIR Ba FOR ADULTS BY AGE AND SEX



*ONLY 1 MALE AND 1 FEMALE WERE IN THIS CATEGORY,
SO NO ACCEPTABLE MEAN VALUE IS AVAILABLE.

FIGURE 8. GEOMETRIC MEAN SCALP HAIR Cu FOR ADULTS BY AGE AND SEX

TABLE 1. SAMPLE PREPARATION AND ANALYTICAL METHODS

Metals	Preparation	Analysis
Cd, Pb	Oxygen combustion	AA aspiration
Cu, Mn, Zn, Fe	Oxygen combustion	AA aspiration
As, Hg, Se	Oxygen combustion	AA on vapor
Li	Oxygen combustion	Flame photometry
Ag	Oxygen combustion	ES
Ba, Be, B, Cr	Dry ashing	ES
Co, Ni, V, Sn	Dry ashing	ES

Remarks:

1. Managanese in hair was evaluated from ES data when detection from AA was found to be inadequate.

2. AA = atomic absorption
   ES = emission spectroscopy

TABLE 2. NUMBER OF PARTICIPANTS BY AGE, SEX, AND AREA OF RESIDENCE

	Riverhead		Queens		Bronx	
	Males	Females	Males	Females	Males	Females
0-5	5	15	16	6	8	7
6-10	41	25	27	20	26	17
11-15	31	9	17	4	8	5
16-20	7	3	2	1	1	1
21-25	0	1	0	2	1	0
26-30	2	9	7	8	0	5
31-35	7	9	10	9	2	10
36-40	12	10	10	8	6	6
41-45	8	7	7	6	7	6
46-50	6	1	0	2	1	0
51+	1	2	2	3	3	0
Total	120	91	98	69	63	57
	211		167		120	

TABLE 3. DEMOGRAPHIC CHARACTERISTICS OF ADULTS BY AREA OF RESIDENCE

	Riverhead	Queens	Bronx
Smoking Patterns (%)			
Never	37.6	44.2	36.7
Ex	16.5	24.7	30.6
Current	45.9	31.2	32.7
Education of Head of Household (%)			
< High School	15.3	10.4	26.5
High School	48.2	50.6	44.9
> High School	36.5	39.0	28.6

TABLE 4. HAIR COLOR BY AGE CATEGORY AND SEX

	Adults			Children		
	Male	Female	Overall	Male	Female	Overall
Brown	67	76	143	122	76	198
Blond	10	17	27	43	21	64
Red	2	2	4	6	3	9
Black	15	8	23	6	6	12
Grey & White	7	4	11	0	0	0
Unknown	1	2	3	2	2	4
Total	102	109	211	179	108	287

TABLE 5. TRACE METAL LEVELS IN HUMAN HAIR IN CHILDREN* AND ADULTS*

Children	No. of obs.	geo. mean	min.	max.	±1 geo. std. dev.
Barium	267	0.762	0.054	9.29	0.271 - 2.135
Boron	265	0.881	0.030	22.00	.263 - 2.956
Cadmium	281	0.88	0.14	6.90	0.42 - 1.85
Chromium	261	0.56	0.076	4.80	0.26 - 1.22
Copper	279	12.11	1.01	144.0	4.97 - 29.48
Iron	282	20.83	2.70	152.00	10.52 - 41.24
Lead	284	13.47	2.12	100.0	6.07 - 29.91
Lithium	277	0.044	0.009	0.300	0.022 - 0.088
Manganese	267	0.56	0.05	12.0	0.22 - 1.45
Mercury	280	0.672	0.048	11.30	0.236 - 1.914
Nickel	265	0.51	0.036	11.0	0.20 - 1.30
Selenium	260	0.320	0.025	1.65	0.158 - 0.645
Silver	266	0.205	0.007	6.20	0.066 - 0.637
Tin	265	0.561	0.034	8.30	0.231 - 1.361
Vanadium	267	0.250	0.010	2.90	0.085 - 0.738
Adults					
Barium	197	1.41	0.121	29.00	0.419 - 4.77
Boron	197	0.981	0.037	25.00	0.297 - 3.23
Cadmium	201	0.76	0.08	8.73	0.33 - 1.74
Chromium	192	0.62	0.06	5.30	0.26 - 1.46
Copper	204	18.25	2.22	184.00	7.28 - 45.75
Iron	202	22.30	3.60	177.00	10.46 - 47.53
Lead	207	12.21	1.96	155.00	5.13 - 29.07
Lithium	206	0.056	0.009	0.228	0.025 - 0.083
Manganese	197	0.95	0.07	11.0	0.34 - 2.67
Mercury	203	0.774	0.050	14.00	0.276 - 2.17
Nickel	194	0.74	0.045	11.0	0.27 - 2.07
Selenium	188	0.303	0.025	1.58	0.140 - 0.653
Silver	198	0.165	0.007	4.30	0.049 - 0.550
Tin	191	0.785	0.048	12.00	0.283 - 2.17
Vanadium	193	0.182	0.009	2.20	0.056 - 0.588

* Children defined as ages 0 through 15, adults as ages greater than 15. All measurements in μg/g.

TABLE 6

A SIGNIFICANCE TABLE FOR HAIR ELEMENT/ELEMENT CORRELATIONS

ADULTS (above diagonal) / CHILDREN (below diagonal)

	Pb	Cd	Cu	Hg	Li	Se	Fe	Ba	B	Cr	Ni	Ag	V	Sn	Mn	Zn
Pb		+	+				+	+		+		+	+		+	
Cd	+		+		+		+			+			+		+	
Cu	+	+		+	+		+	+		+	+			+	+	
Hg	+	+	+		+			+		+				+	+	
Li	+	+	+	+						+	+				+	+
Se				-	-			-				-	-	-		
Fe	+	+	+	+	+			+		+	+		+	+	+	
Ba		+					+		+	+	+	+	+	+	+	
B								+			+		+	+	+	
Cr	+		+		+		+	+	+		+	+	+	+	+	
Ni	+	+	+	+	+		+	+	+	+		+	+	+	+	
Ag	+	+	+	+	+			+	+	+	+		+	+		-
V	+	+	+	+			+	+	+	+	+	+		+	+	
Sn	+	+	+	+	+		+	+	+	+	+	+	+		+	
Mn	+	+	+		+		+	+	+	+	+	+	+	+		+
Zn		+	+		+				-			-		-	+	

+ indicates significant positive correlation and
- indicates significant negative correlation, where significant means $p<0.05$.

TABLE 7. TRACE METALS IN DUSTFALL BY AREA*

	No. of months observed	Minimum	Maximum	Mean
Cadmium				
Riverhead	20	0.0	0.12	0.047
Queens	22	0.01	0.23	0.095
Bronx	22	0.0	0.22	0.103
Chromium				
Riverhead	4	0.02	0.11	0.048
Queens	5	0.0	0.38	0.156
Bronx	7	0.06	0.60	0.371
Copper				
Riverhead	8	0.32	13.41	3.338
Queens	8	0.69	11.12	3.216
Bronx	8	1.85	40.68	19.009
Lead				
Riverhead	20	0.30	4.38	2.005
Queens	22	1.10	23.28	10.119
Bronx	22	2.20	30.99	16.367
Manganese				
Riverhead	8	0.05	0.70	0.346
Queens	8	0.53	2.11	1.179
Bronx	8	0.68	4.57	2.860
Nickel				
Riverhead	8	0.0	0.96	0.212
Queens	8	0.03	0.78	0.384
Bronx	8	0.05	1.45	0.850

* Levels in mg/m^2/month.

TABLE 8. TRACE METALS IN HOUSEDUST BY AREA*

	No. of Samples	Minimum	Maximum	Geo. Mean
Cadmium				
Riverhead	37	0.1	32.0	7.6
Queens	29	4.0	34.0	13.3
Bronx	33	4.5	118.0	14.6
Chromium				
Riverhead	37	4.0	400.0	31.7
Queens	29	12.0	210.0	42.3
Bronx	33	28.0	230.0	45.0
Copper				
Riverhead	37	23.8	2250.0	109.3
Queens	29	50.4	900.0	196.9
Bronx	33	72.5	1250.0	233.7
Lead				
Riverhead	37	42.6	1630.0	278.9
Queens	29	188.0	3180.0	629.0
Bronx	33	124.0	2930.0	766.3
Manganese				
Riverhead	37	27.9	158.0	79.9
Queens	29	16.3	455.0	131.0
Bronx	33	37.0	275.0	153.4
Nickel				
Riverhead	37	1.0	95.0	14.6
Queens	29	2.0	200.0	26.1
Bronx	33	18.0	250.0	42.0
Barium				
Riverhead	37	10.0	430.0	65.2
Queens	29	32.0	4000.0	137.6
Bronx	33	75.0	13000.0	312.4

(continued)

* Levels in µg/g.

TABLE 8. (CONTINUED)

	No. of Samples	Minimum	Maximum	Geo. Mean
Boron				
Riverhead	37	1.0	110.0	14.1
Queens	29	2.0	370.0	28.5
Bronx	33	4.0	410.0	30.8
Iron				
Riverhead	37	2320.0	16900.0	6091.6
Queens	29	6650.0	92400.0	11195.4
Bronx	33	2500.0	41000.0	11431.2
Lithium				
Riverhead	37	0.9	5.8	3.0
Queens	29	2.5	8.7	4.3
Bronx	33	1.3	10.1	4.9
Mercury				
Riverhead	37	0.4	9.1	1.9
Queens	29	0.5	116.0	5.9
Bronx	34	0.5	19.8	3.6
Selenium				
Riverhead	37	0.005	0.255	0.038
Queens	29	0.005	0.234	0.062
Bronx	33	0.005	0.252	0.049
Silver				
Riverhead	37	0.1	7.0	0.4
Queens	29	0.1	7.0	0.5
Bronx	33	0.1	38.0	0.8
Tin				
Riverhead	37	2.0	270.0	6.4
Queens	29	2.0	76.0	6.2
Bronx	33	2.0	230.0	7.8
Vanadium				
Riverhead	37	1.0	170.0	14.3
Queens	29	1.0	77.0	18.8
Bronx	33	3.0	90.0	40.2

TABLE 9. TRACE METALS IN SOIL BY AREA*

	No. of Samples	Minimum	Maximum	Geo. Mean
Cadmium				
Riverhead	56	0.04	1.72	0.27
Queens	56	0.20	8.75	0.89
Bronx	60	0.11	5.82	1.28
Copper				
Riverhead	56	0.8	28.0	5.8
Queens	56	6.9	1020.0	29.3
Bronx	60	3.9	405.0	37.4
Lead				
Riverhead	56	4.8	407.0	32.6
Queens	56	33.2	1010.0	150.5
Bronx	60	37.0	1660.0	298.2
Manganese				
Riverhead	56	11.8	132.0	34.6
Queens	56	28.8	269.0	113.1
Bronx	60	91.5	283.0	161.0
Nickel				
Riverhead	56	0.4	2.7	1.2
Queens	56	1.2	37.4	4.3
Bronx	60	2.5	25.2	8.4

*Levels in μg/g.

TABLE 10. CORRELATION COEFFICIENTS OF LOGS OF MEDIA TRACE METAL LEVELS*

	Dustfall-Housedust (N=99)	Dustfall-Soil (N=172)	Housedust-Soil (N=36)
Cadmium	0.37	0.64	0.25
Chromium	0.23	-	-
Copper	0.30	0.43	0.52
Lead	0.56	0.73	0.77
Manganese	0.53	0.82	0.54
Nickel	0.40	0.80	0.41
Zinc	0.51	0.72	0.56

* All of the above correlation coefficients are significant at $p < 0.005$ except for chromium dustfall-housedust, with $p = 0.02$.

TABLE 11. TESTS OF SIGNIFICANCE OF THE EFFECT OF SELECTED FACTORS ON SOIL TRACE METAL LEVELS*

	Dustfall Levels	Homes Within Areas	Front Yard-Back Yard Differences
Cadmium	<0.0001	<0.0001	.0004
Copper	<0.0001	0.28	.99
Lead	<0.0001	<0.0001	.0059
Manganese	<0.0001	<0.0001	.0162
Nickel	<0.0001	0.0006	.0029
Zinc	<0.0001	<0.0001	.0705

* Values given are probabilities of no relationship of factors to soil trace metal levels given the observed differences in soil trace metal levels between factor categories. Logs of soil and dustfall levels were used in the analysis.

TABLE 12. TESTS OF SIGNIFICANCE OF THE EFFECT OF SELECTED FACTORS ON SCALP HAIR TRACE METAL LEVELS, USING (1) DUSTFALL AND (2) HOUSEDUST AS A MEASURE OF ENVIRONMENTAL EXPOSURE

(1) Dustfall

	Children						Adults						
Metal	Dustfall	Age	Sex	Educ.	Hair Color	Haircut Location	Dustfall	Age	Sex	Educ.	Hair Color	Haircut Location	Smoking
Cd	-	-	.0003	-	-	-	-	-	.0001	-	-	.004	-
Cu	-	-	.0001	-	-	-	-	.005	.0001	-	-	-	-
Cr	.006	-	-	-	-	-	-	-	-	-	-	-	-
Pb	.005	.005	.003	-	-	-	.01	-	.02	-	-	.02	.06
Mn	-	.02	.0001	-	-	-	-	-	.0001	-	-	-	-
Ni	.02	-	.0001	-	-	.04	-	-	.0001	-	-	-	-

(2) Housedust

	Children						Adults						
Metal	Housedust	Age	Sex	Educ.	Hair Color	Haircut Location	Housedust	Age	Sex	Educ.	Hair Color	Haircut Location	Smoking
Cd	-	-	.006	-	-	-	-	-	.0002	-	-	.005	-
Cu	-	-	.0001	-	-	-	-	.004	.0001	-	-	-	-
Cr	-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	.005	.005	.003	-	-	-	.01	-	.02	-	-	.02	.06
Mn	-	.03	.0001	-	-	-	-	-	.0001	-	-	-	-
Ni	.06	-	.0001	-	-	.04	-	-	.0001	-	-	-	-
Ba	.0001	.0001	.0001	-	-	.03	.0006	.01	.0001	-	-	.05	-
B	-	--	-	-	-	-	-	-	-	-	-	.04	-
Fe	-	-	-	.004	-	-	-	-	-	-	.04	-	.04
Li	-	-	.01	-	-	-	-	-	.003	-	-	-	-
Hg	.0001	-	.01	-	-	.06	.04	-	.001	-	-	-	-
Se	No Test	-	-	-	-	.02	No Test	-	-	-	-	-	.02
Ag	-	-	.0002	-	-	-	-	-	-	-	-	-	-
Sn	.0001	-	.0003	-	-	-	-	.0001	-	-	-	-	-
V	.0001	-	.0003	-	-	.03	.0001	-	-	-	-	.03	-

Values given are the probability of the observed difference in sample mean levels between factor categories assuming no difference in the original population. Only values of .06 or less are listed.

TABLE 13. DUSTFALL, HOUSEDUST, AND SCALP HAIR MEAN TRACE METAL LEVELS BY COMMUNITY FOR SCALP HAIR METALS WITH A SIGNIFICANT ENVIRONMENTAL EXPOSURE EFFECT

	Mean Dustfall ($mg/m^2/mo$)	Geometric Mean Housedust ($\mu g/g$)	Childrens' Geometric Mean Scalp Hair ($\mu g/g$)	Adults' Geometric Mean Scalp Hair ($\mu g/g$)
Chromium				
Riverhead	0.05	31.7	0.52	-
Queens	0.16	42.3	0.45	-
Bronx	0.37	45.0	0.80	-
Lead				
Riverhead	2.01	278.9	11.74	10.39
Queens	10.12	629.0	14.07	14.50
Bronx	16.37	766.3	17.13	12.88
Nickel				
Riverhead	0.21	14.6	0.50	-
Queens	0.38	26.1	0.40	-
Bronx	0.85	42.0	0.70	-
Barium				
Riverhead	-	65.2	0.64	1.11
Queens	-	137.6	0.63	1.36
Bronx	-	312.4	1.26	2.34
Mercury				
Riverhead	-	1.9	0.48	0.66
Queens	-	5.9	1.00	1.01
Bronx	-	3.6	0.73	0.67
Tin				
Riverhead	-	6.4	0.54	-
Queens	-	6.2	0.44	-
Bronx	-	7.8	0.83	-
Vanadium				
Riverhead	-	14.3	0.20	0.12
Queens	-	18.8	0.24	0.20
Bronx	-	40.2	0.40	0.35

TABLE 14. GEOMETRIC MEAN SCALP HAIR TRACE METAL CONCENTRATIONS BY SEX FOR CHILDREN AND ADULTS‡

	Children		Adults	
Metal	Males	Females	Males	Females
Cd	0.77	1.14	0.96	0.62
Cu	9.92	17.91	13.87	25.06
Cr*	0.52	0.62	0.57	0.63
Pb	11.86	17.52	13.95	10.97
Mn	0.43	0.88	0.64	1.34
Ni	0.39	0.79	0.47	1.14
Ba	0.54	1.30	0.82	2.41
B*	0.81	1.00	0.90	1.04
Fe*	18.9	23.4	19.8	24.0
Li	0.04	0.05	0.04	0.05
Hg	0.59	0.84	0.58	0.99
Se*	0.31	0.34	0.35	0.27
Ag	0.18	0.28	0.18	0.15
Sn	0.47	0.77	0.54	1.17
V*	0.20	0.37	0.18	0.19

* No differences by sex for these metals at the 0.05 level of significance.

‡ Levels given in μg/g.

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16 ABSTRACT

Previous studies have revealed that hair trace element concentrations can reflect exposure in cases of frank poisoning and deficiency. Correlations have been found also in some populations living in regions where metallurgic processes are conducted.

This study reports significant correlations between hair barium, chromium, lead, mercury, nickel, tin, and vanadium content and exposures (as measured by analyses for the corresponding elements in dustfall or housedust) within a single metropolitan area. Age, sex, hair color, and smoking habits were included in the statistical evaluation. Several metals showed a tendency to increase and decrease together in the hair specimens in agreement with trends reported for other human tissues.

It is acknowledged that hair has the capacity to adsorb and to release trace elements in certain situations. However, population studies can compensate for confounding influences by (1) a randomizing effect, by (2) an averaging effect, and (3) by statistical rejection of unrepresentative data values. The relationship of hair content to (a) content in other tissues and to (b) metabolic status are separate and complex issues that should not be confused with (c) exposure relationships.

17 KEY WORDS AND DOCUMENT ANALYSIS

a DESCRIPTORS	b IDENTIFIERS/OPEN ENDED TERMS	c COSATI Field/Group
trace elements hair indexes (ratios) environmental surveys		06, T, F

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