ADDIS ABABA UNIVERSITY

COLLEGE OF HEALTH SCIENCES SCHOOL OF PUBLIC HEALTH

VALIDATING $PM_{2.5}$ CONCENTRATIONS MEASURED BY PATS+ RELATIVE TO UPAS DEVICE IN HOUSEHOLDS IN ADDIS ABABA

BY:

MULUGETA AYALEW ESHETE (BSc.)

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By: MULUGETA AYALEW (BSc) **Signature** __________________ **Date**____________

Approved by the examining board

Advisors:	**Signature**	**Date**
Abera Kumie (Ph.D)	________________	_______________
Worku Tefera (Ph.D. candidate)	________________	________________

Internal Examiner:

1. ______________________ ________________ ________________

External Examiner:

1. _____________________ _____________ ________________

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Acronyms and Abbreviations

AQGs Air Quality Guidelines

BAIRS Berkeley Aerosol Information Recording System

EDHS Ethiopia Demographic and Health Survey

FEM Federal equivalent Method

FRM Federal Reference Method sampler

EPA Environmental Protection Agency

GEOHealth: Global Environmental and Occupational health

GPS Global Positioning System

HAP Househould Air Pollution

HME Household micro-environments

IAP Indoor Air pollution

LED Light-emitting diode

LIC Low-income countries

LPG Liquefied petroleum gas NGOs non-governmental organizations

MIC Middle-income countries

PANDA Portable and Affordable Nephelometric Data Acquisition PICA

PATS+ Particle and temperature sensor plus

PEM Personal Environmental Monitor

PICA Platform for Integrated Cook stove Assessment software

PM Particulate Matter

$PM_{2.5}$ Particulate matter with an equivalent aerodynamic diameter less than or equal to 2.5 µm

QRE Health Questioners Requirement

RH Relative Humidity

SOP Standard operating procedure

TEOM Tapered Element Oscillating Microbalance

UCB-PATS University of California, Berkeley—Particle and Temperature Sensor

UPAS Ultrasonic Portable Air Sampler

Ab stract

Background; - $PM_{2.5}$ is an indicator of household air pollutants to measure the risk of air pollution. UPAS and PATS+ PM measuring instruments are portable monitors that were used to measure particulate matters in the households of Addis Ababa in a GEO Health for Eastern Africa. The validity of the measurements using these two instruments is a concern for exposure assessment as they use different principles of measuring $PM_{2.5.}$

Objective: This study aims to validating $PM_{2.5}$ concentrations measured by PATS+ relative to UPAS device in households in Addis Ababa and explore factors affecting the level of UPAS $PM_{2.5}$ concentration.

Methods: The study was cross-sectional, involving 150 households. The study used two instruments with different technologies: the light scattering method in PATS+ and the gravimetric in UPAS. Fifteen households were randomly selected from each sub-city from the source population that it used GEO Health project for Children's Health Study. Different statistical tools were used to explore the consistency and validity of the measured $PM_{2.5}$ by the two tools used to monitor for 24 hours for each household: paired t-test, and Bland-Altman scatter plot analysis were performed to evaluate the extent of agreement. P-Value <0.05 and 95% CI of parameters were used for statistical significance.

Results: There wasno agreement and had a proportional bias between PATS+ and UPAS measured $PM_{2.5}$ concentrations. Child room located in the kitchen and household had highpollution levelwere affected UPAS $PM_{2.5}$concentration. We recommend the need of a correction factor for $PM_{2.5}$concentration measured by PATS+.

Conclusion and Recommendations

There is difference in PATS+ and UPAS measured $PM_{2.5}$ concentration and has no agreement. The location of child room and the pollution category of the household had an effect on the measurments of $PM_{2.5}$concentration. Generating a correction factor for PATS+ monitor using UPAS as a gold standard is suggested.

***Keywords*:**

Indoor $PM_{2.5}$ concentration, PATS+, UPAS, light scattering PM sensor, validation

1. INTRODUCTION

1.1. Background of the study

Portable direct-reading instruments by light-scattering method are increasingly used in airborne fine particulate matter ($PM_{2.5}$) monitoring (1). However, there are limited studies on the validity of these of such instruments relative to gravimetric method as reference method (1).Study results showed that light scattering technology tends to overestimate particulate levels when compared with the gravimetric method, especially under higher RH (1,2). Personal monitoring provides a more detailed picture of indoor air quality, which is important since people spend a large part of their time in indoor (3).

Globally over 3 billion people are exposed to high levels of household air pollution (HAP) from burning solid (biomass and coal) and low-quality liquid fuels (kerosene) that are used for cooking, heating and lighting (4,5).Exposure to household air pollution (HAP) from cooking with dirty fuels is a leading health risk factor inAsia, Africa and Central/South America (6). A large body of research work has conclusively shown that HAP levels in homes in LIC (low income country) and MIC (middle income country) are typically many times above the world health organization (WHO) air quality guidelines (AQGs) (6).WHO Air quality guidelines provides forparticulatematter,$PM_{2.5}$annual mean of 10 $\mu g/m^3$and 25mg/m^3 24-hour mean personal exposure limit (7).These high levels of IAP (Inddor Air pollution) are prevalent in the homes of Addis Ababa, largely as a result of the burning of solid biomass fuels and kerosene for cooking (8). The result of the study conducted in Addis Ababa using UCB PATS measured data show 24 h geometric mean of 24-h indoor $PM_{2.5}$ concentration isapproximately 818 mg/m^3(Standard deviation (SD=3.61) (5,9).$PM_{2.5}$concentration it is above the limit of WHO daily personal exposure 25 mg/m^3 24-hr average concentration (10,11).

1.2. Statementof problem

Gravimetric PM measurement is the gold standard in air pollution exposure assessment (12). Its use is limited to show the hourly temporal variability if it measures say for 24 hours (12). This shortcoming is alleviated by using relatively cheap real time monitors operating in different principle such as light scattering methods. However, the validity of these instruments was not well explored in literature to handle the possible biases due to under or over estimation relative to the gold standard monitors (13,14). Frequent calibration of the instruments and keeping the stability of this adjustment are critical concerns of these instruments to provide viable data (15).

GEO Health project has used both gold standard and light scattering instruments by co-locating them to measure $PM_{2.5}$ in households. They are represented by UPAS and PATS+ $PM_{2.5}$measuring monitors, respectively. The measurements by PATS+ is required to be validated against UPAS measurements to get reliable data. This master's study aims to evaluate the performance of the two types of monitors to have measured valid data and an agreement between them that can be used assessing child health research managed by GEOHealth in Ethiopia.

1.3. Rationale of Study

Airborne particulate matter with the aerodynamic diameter equal to or less than 2.5μm ($PM_{2.5}$) has been linked to respiratory or cardiovascular diseases and all-cause mortality in epidemiological studies worldwide including developing countries (16).

Portable direct-reading instruments by light-scattering method are increasingly used in airborne fine particulate matter ($PM_{2.5}$) monitoring. However, there are limited calibration studies on such instruments by applying the gravimetric method as a reference method in field tests. This help to be unavoidably with potential exposure misclassification. The lack of on these validations $PM_{2.5}$ instruments, their accuracy and reliability are often unknown which limit their application in scientific research.

Gravimetric methods are used as a gold Standard but burdensome, expensive, need skill personnel for long- term sampling a collocation with the low-cost device for the shortest time possible to get an on-site correction factor (13). However Light Scattering methods Such as PATS+ sensor has small physical form, cheap, easy to handle and its relatively low power requirements (14). However Indoor Air monitoring studies are prone to measurement error. Data losses or invalid data because of equipment failure, human error, and other factors. Those missing data leads to a variety of complications including reduced project efficiency, incomplete data sets, potential incomparable data sets, and potential data bias (i.e. unrepresentative data) that may result overestimation or underestimation of exposure. This study address to generate cleaned data and undertake validation of the two instruments whose true exposure will be linked to child health.

1.4. Significance of the study

This study was used to validate the PATS+ monitor measuring $PM_{2.5}$ concentration for 24 hours relative to UPAS as the gold standard. This study also addressed the agreement of both instruments measured PM concentration data used as an exposure variable for children's respiratory health in Addis Ababa. Identify contributing factors affecting the UPAS $PM_{2.5}$ concentration measured data variability. The true $PM_{2.5}$ exposure data were use for the analysis of the temporal and spatial relationships of PM in households found in Addis Ababa.

2. LITERATURE REVIEW

2.1. Methods of Indoor Particulate matter ($PM_{2.5}$) concentration level measurements

Poor air quality remains a challenge in many urban areas of worldwide. Because of the complex relationships between humans and their environments it is necessary to integrate contextual factors such as environmental, socioeconomic and behavioral, into exposure assessment, which covers all aspects of estimating or measuring exposure (3). Berkeley Air Monitoring Group, and other academic institutions have developed a relatively inexpensive, sharp, battery-operated, microchip-based devices to quantify air pollutants related to household air pollution. Theses instrument collect PM data to understand of the household air pollution (HAP) concentrations and factors influencing them. Assessing particulate matter with a focus of $PM_{2.5}$ is the current practice to assess the risk of exposure to indoor air pollution. $PM_{2.5}$ monitors using a light scattering method requires to be verified by a gold standard method to provide a valid data. In addition, PM sensors must be calibrated against a gravimetric sample, requiring careful filter handling and significant, if occasional, and laboratory support (15).

The portable and direct-reading $PM_{2.5}$ instruments are generally based on the light-scattering and particle absorbance theories. Real-time monitors overestimate particulate levels when compared with the gravimetric method, especially under higher (1,17).
Direct measurement of personal exposure to $PM_{2.5}$ mass is considered the “gold standard” in epidemiologic studies for exposure assessment.$PM_{2.5}$ is measured using both the gold standard gravimetric method (Ultrasonic Portable Air Sampler (UPAS), Access Sensor Technologies, Fort Collins, CO) and a real-time light scattering method, using a particle and temperature sensor (PATS+, Berkeley Air monitoring group, Berkeley, CA). In the gravimetric method, the particle mass concentration is determined by weighing the filters before and after the sampling period (18) . Light scattering sensor it’s important for biomass cooking related study setting due to their a wide dynamic sensing range, as mass concentrations of $PM_{2.5}$ can vary between lower limits of 10 $\mu g/m^3$ and up to more than 30,000 $\mu g/m^3$(19).

The UPAS monitor is a time-integrated filter sampler that uses a quiet solid-state piezoelectric micro pump, and features a suite of onboard environmental sensors integrated with the pump to measure and record mass airflow [at between 0.5 and 3.0 l per minute (lpm) (±5%)], temperature, pressure, and relative humidity. It is also equipped with global positioning system (GPS) tracking capability, which can be disabled depending on study/user requirements. In addition to being quiet and energy efficient, the mass flow sensor enables the device to maintain a constant sampling flow rate and measures changes in pressure drop across the filter media, giving the UPAS the advantage of having reliably steady flow rate over time. Sampling parameters UPAS are programmable, collected a user defined at 1- 100% duty cycle, to avoid overloading operate, conserving battery life during sampling (4).

2.2. Advantage of Gravimetric PM filter based sampling methods

The Gravimetric filter based UPAS sampling methods is its simple, reliable, has the ability to provide PM sample further chemical analysis. It's also used as a gold standards for PATS $PM_{2.5}$ concentration sampled data validation and data quality. The UPAS was also evaluated relative to two commercial technologies: an equivalent federal reference method (FRM) for $PM_{2.5}$ monitoring (URG cyclone model URG-2000-30EGN-A; URG Corp., Chapel Hill, NC) and a personal environmental monitor (PEM) for assessing Personal exposure to $PM_{2.5}$ (PEM 761-203; SKC, Inc., Eighty Four, PA). The FRM sampler was operated at 16.7 L/min, per U.S. EPA guidelines, and served as the reference instrument. The UPAS and PEM both operated at 2.0 L/min(12). Additionally, the ability to program duty cycles into the UPAS monitor would significantly extend the effective sampling time capabilities of the device, making longer term sampling possible without the need to use an external battery pack.

2.3. Limitation of using gravimetric UPAS $PM_{2.5}$ sampling method

The higher failure rate for personal samples seems to be due to most failed samples involved a sharp drop in airflow rates, from which the monitor did not recover. This was most likely due to the intake of the UPAS being blocked by clothing or some other object. Other samples were lost due to damaged filters or contamination from insects drawn into the UPAS. Some samples were lost when a UPAS monitor sucked up small insects into the analytical filter chamber, others were likely lost when clothing from personal exposure participants covered the air intake, causing un recoverable interruption in airflow (20). The UPAS has not incorporated the direct-reading , provided multiple exposure type measurement at time (12). This shortcoming cannot provide real data by time and peaks of increased concentration as needed within the measured 24 hrs. In addition, gravimetric has a potential to introduce errors due to task related to lab preparation such as weighing filters. Seasonal change (spring vs. summer) is not controlded gravimetric sampling is considered the "gold standard," in the summer, semivolatile compounds collected on filters may evaporate before weighting in the lab. Higher RH will shift sulfate and nitrate particles into the higher response sizes for the PATS+ (21).

2.4. Real-time Light Scattering sensor PM concentration sampling methods

The PATS is a light-scattering, passive sampler that measures and logs $PM_{2.5,}$ temperature, humidity, and movement data real-time. The detection limit of $PM_{2.5}$ is 10 $\mu g/m^3$, while the upper particulate matter detection limit is 30,000 to 50, 0000 $\mu g/m^3$.PATS logs particulate concentration, temperature, humidity, movement, and battery voltage. PATS+ is usually deployed to measure the dynamics of air pollution in a given sampling duration to capture both low and high concentrations. PATS+ is the second generation after UCB-PATS, which performs more on-board processing via a multicore propeller microcontroller (Parallax, Inc., (Rocklin, CA, USA). PATS+ uses a modified version of the commercially available Sharp GP2Y1014 sensor (19). The light sensor is used primarily for detecting the presence of a UV signal, which is indicative of the sampler being outdoors. The accelerometer is used to gauge participant activity level, which, in addition to confirming user compliance (i.e., that the sampler is physically worn), can also be used to infer daily behavioral patterns. As a mass-based, time-integrated monitor, the UPAS is geared primarily towards assessing one's cumulative risk from PM exposure (12).

2.5. Advantage of Real-time Light Scattering sensor (PATS+) for $PM_{2.5}$ sampling methods

For PATS+, were settled on the Sharp GP2Y1014 optical sensor due to its small physical form factor, its linear response to particulate matter, and its relatively low power requirements. It is similar to a standard photometer, looking at IR light scattered at a 300 forward angle within a relatively open particle path between lenses facing the LED and the photodiode. It's very important where biomass cooking occurs is a wide dynamic sensing range, as mass concentrations of $PM_{2.5}$ can vary between lower limits of 10 mg/m^3 and up to more than 30,000 mg/m^3. The PATS+ incorporates precision control over the current and timing that drives the LED in the Sharp GP2Y1014 in order to extend the measurement range beyond its standard specification (15). It provides real data to evaluate the temporal variability of the air PM during the sampling time

2.6. Disadvantage of PATS+ Sampling $PM_{2.5}$ level

$PM_{2.5}$ collected data using PATS have limitation on related to data validity and reliability and also have undergo from drift and precision issues. By these methods loss of signal at sub-micron particle sizes, humidity effects, the variation of Mie scattering intensity with size and refractive index and insensitivity to differences in particle density (19). PATS+ output did consistently underestimate actual concentrations, but this can be addressed with in-field calibration (19). It requires frequent calibration overtime launching is needed. They requires intensive preparation before sampling to insure the data quality.

2.7. Sampling $PM_{2.5}$ concentration by PM sensor

This PM sensor is also a light scattering based technology that requires calibration against a gravimetric sample, requiring careful filter handling and significant, if occasional, and laboratory support (15).PM sampling by light scattering method, often affected by water vapor or droplets in the air which can be assessed by measuring the high relative humidity

(RH). Other factors such as the particle size distribution, particle morphology and chemical constituents also influence the measurements of $PM_{2.5}$, of which the influence magnitude may vary by different pollution sources (1). In addition, this PM sensor has short battery life and does not integrate real time monitoring.

2.8. Different studies used personal PMmonitormeasuring $PM_{2.5}$ concentration

The Dylos Air Quality Monitor (DC1100 and DC1700), Portable and Affordable Nephelometric Data Acquisition (PANDA) system, Shinyei PPD42NS, DS-01D-V1 and UCB-PATS have been used in different studies (22). $PM_{2.5}$ monitors Dylos (DS-01D-V1) an infrared light emitting diodes at 650 nm is used as the light source and a photodiode detector for scattered lights at a scattering angle of 90^0degrees.It detects large particle of 2.5 and 10 micrometers (µm). Small particles have diameters from 0.5 µm up to 2.5 µm(1). UCB-PATS which utilizes an optical chamber with two LEDs of different wavelengths (IR and blue visible light) at forward scattering angles of 45 degrees (15).

The validation of a light-scattering $PM_{2.5}$ sensor study conducted in China Shanghai with three different the real-time QT-50 and MicroPEM sensor instrument validate by gold standard by the gravimetric method SKC pump showed that QT-50 measurements were significantly higher than MicroPEM and the gravimetric method. PM measured data with those instrument were 47.8 $\mu g/m^3$ (19.2±135.1$\mu g/m^3$), 36.7$\mu g/m^3$ (11.7±142.3$\mu g/m^3$) and 39.7 $\mu g/m^3$ (10.4±95.8$\mu g/m^3$) respectively. The study concluded that light-scattering measurements of $PM_{2.5}$ by QT-50 instrument overestimated the concentration levels and were affected by temperature and RH (1).

2.9. Measurement errors in PATS+ and UPAS measured $PM_{2.5}$ mass concentration

There exist different sources of measurement errors when using UPAS and PATS+ that emanate from the skill of the technician, microbalance weighing, air flow calibrating procedures, stability of the energy flow in a battery, and the micro-environment of the lab room (temperature, RH). Measurement error from lab technician during pre-and post-weight filter in laboratory, such as the pre- weight is greater than post weight, or power outages, flow rate calibration error during UPAS sampling. Errors in measurement can occur as systematic or as random errors it occurs, for example, when a calibration procedure is based on a false standard. Random errors can occur at all stages of measurements (e.g. for particle measurements: during weighing, air flow variability, and mistaken use of exposure time) (23). Measurements error from data collector's instrument placement at study participant , invalid data coding during lunching PATS+ deployment inappropriate date and time calibration , during initial zero and final zero time,PM concentration should be between 10 to 50 mg/m^3. To address all those measurement error use both gravimetric and light scattering methods must be used HAP Study SOPs and Protocol properly.

2.9. Challenges of using UPAS and PATS+ indoor PM concentration study in developing countries

In developing countries, the range of household air pollution is high because of the use of biomass fuel in poorly ventilated space. Accurately measured personal PM exposure in the developing world seems limited, particularly for quantify the exposure risk to child health's(24). There is no adequate ambient air quality monitoring sampled data to estimate outdoor air pollution contribution for indoor PM concentration exposure estimation (25). The study conducted in Ghana showed those constraints of available technology and funds. PM exposure data remains indescribable because personal sampling devices remain heavy, expensive, and battery-limited (26). Conducting HAP study in developing countries is a challenge due to the costof the instrument is not affordable, the technology need trained skill manpower for Data collection, calibration and maintenances of instruments.

2.10. Factor Affecting Indoor PM concentration measured variability

2.10.1. PM Concentration level diffrece by fuel source used

The study conducted in Accra, Ghana using UPAS and PATS+ assessed personal exposure for four fuel user groups: LPG-only, LPG and charcoal, charcoal only, and wood use alone or in combination with any other fuel show that the wood user group demonstrated significantly higher $PM_{2.5}$ exposure than the other three user groups. The fuel and stove type used for cooking are major determinant factors in $PM_{2.5}$ concentration measured value in households.

Combustion indoors will cause elevated levels of $PM_{2.5}$ during and for some time after the end of burning. Depending on the frequency and intensity of domestic burning activities, indoor air pollution levels can have PM concentration viability (27).

2.10.2. Cooking Fuel and Stove type relation in households $PM_{2.5}$concentration level

The gravimetric analysis study on $PM_{2.5}$ concentration measurement show that High $PM_{2.5}$ concentration difference observed due to high relative humidity (RH) and seasonal variation (1). The study done Addis Ababa indoor air pollution measurments show that 24-h mean $PM_{2.5}$ concentration between fuel types differed statistically ($P < 0.05$), there is no significant difference in mean concentration of $PM_{2.5}$ between improved biomass stoves and traditional stoves (P=> 0.05) (5).

2.10.4. Micro –environment variability affecting on PM concentration

Study conducted in rural South Africa on Variation of Indoor Particulate Matter Concentrations (PM_4) by using Photometric light scattering instruments was shown that the concentration of PM in homes is dependent on various factors including building structure, types of human activities, the opening and closing of doors and meteorological factors such as temperature, wind, rainfall and humidity.

Differences in temperature indoors temperature influence natural ventilation through the movement of air. A higher rate of air exchange dilutes the concentration of PM generated indoors. Changes in temperature also affect PM by influencing the change of chemical reaction rates and atmospheric mixing heights that affect the vertical dispersion of pollutants and modifying local wind and flow patterns that control the transportation of pollutants (28).

2.10.5. Temperature and RH correlation on PM concentration

Study conducted in South Africa conducted revile that positive correlation between indoor PM4 and indoor temperature in spring and summer. There is positive relationships between PM and temperature. This occurs because warm weather induces the formation of secondary fine particles, therefore increased temperatures result in increased PM. A significant negative correlation between humidity and PM when assessing indoor air quality. This could have been caused by low relative humidity increasing particle deposition of fine particles and high relative humidity decreasing particle deposition (28).

2.10.6. Seasonal PM Variability in 24 hours sampling duration in winter season.

Study show that indoor 24-hour-averaged PM concentrations were significantly higher in winter than in summer, by as much as 50%. a strong seasonal variability in PM, with variability being highest in winter (28).PM in homes increased during cold seasons, when heating is common and ventilation is reduced, because doors and windows are typically closed, thus trapping PM inside.

Analytical framework

The level of household air pollution depends on many factors such as the type of fuel and stove, cooking episodes and housing characteristics as indicated in the analytical framework (Figure 1). Three PM monitors were used in each household to measure the temporal and spatial variability of PM in the household. PATS+ and UPAS were used to measure the potential exposure of a child. They were placed around the waist of a child when he was expected to be at home, and placed on his usual place in the house when sleeping and leaving home.

The task of this study was to compare the measured PM data by two PM monitors assuming the presence of other factors affecting the level of concentration during the sampling time. The study has also addressed what factors affecting the UPAS $PM_{2.5}$ concentrations level.

2.11. Analytical framework

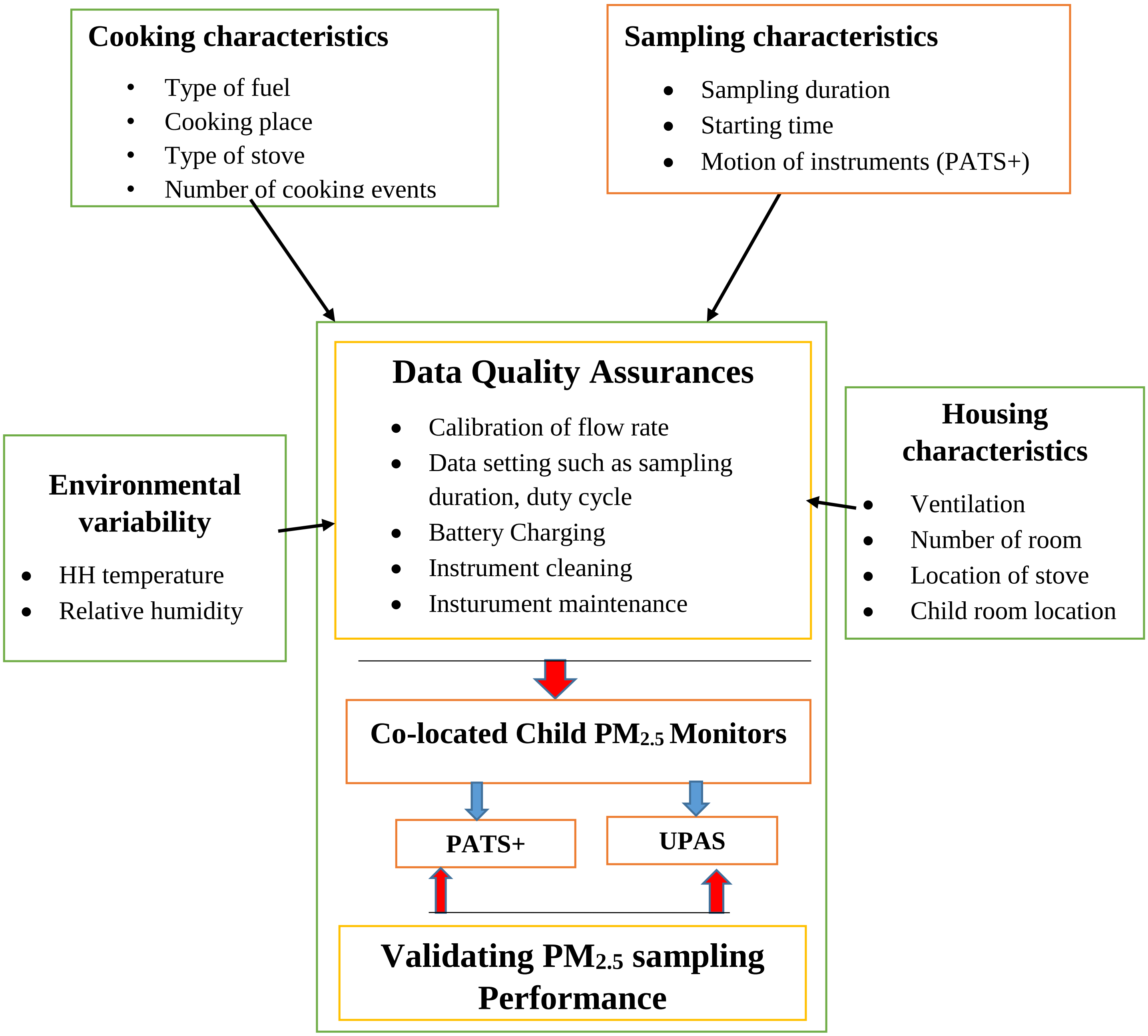

Figure 1: Analytical framework adjusting variability to evaluate the performance of PATS+ colacated with UPAS

3. OBJECTIVES

3.1.General Objective

Validating the measurements of $PM_{2.5}$ concentration level using PATS+ measured household data relative to the gold standard of UPAS in Addis Ababa city.

3.1.Specific Objectives

3.2.1 To validating the measured data of $PM_{2.5}$ concentration by PATS+ co-located with UPAS device.

3.2.2 To examine factor affecting UPAS $PM_{2.5}$ concentration measured data.

4. METHODS AND MATERIALS

4.1. Study Area setting

Addis Ababa is the capital city of Ethiopia. The city has recently years population counts as in 2015 were 3, 273, 000 in 2017 are growing closer to4 million (29).Addis Ababa lies at an elevation of 2,200 meters (7,200 ft) and is a grassland biome, located at 9°1′48″N 38°44′24″E. From its lowest point, around Bole International Airport, at 2,326 meters (7,631 ft) above sea level in the southern periphery, Addis Ababa rises to over 3,000 meters (9,800 ft) in the Entoto Mountains to the north. In Addis Ababa, the climate is warm and temperate. The summers are much rainier than the winters. The average annual temperature is 16.3 °C. Precipitation here averages 1143mm (30). The City has over 500,000 households with an average family size of 5An estimated 80% of the population in Addis Ababa lives in poor districts, (5).

GEO Health East Africa Hub, Children's Health Study (CHS), collected data in 1000 households represented in ten schools using a questionnaire and measuring household particulate matter in 150 households using UPAS and PATS+ instruments to evaluate the air pollution exposure and children's respiratory health.

4.2. Study Design

The design was a cross sectional study involving households with children attending primary school for the period ofJuly 24, 2018 to December 14, 2018.

4.3. Source and study Population

Households with children attending primary schools in 10 sub-cities of Addis Ababa were source population. One thousand school children attending 4-5th grades age of (10-13 years old) were part of Children's study for the GEO Health Ethiopia. These students had lung function testing measured in school premises. 150 households had PM measurements in inorder to develop a model to estimate the exposure to all children in the study population. Those households with changed address, not having the child under concern, losing the address were excluded from the study

4.4. Househould sampling methods

GEO Health child study completed 969 households out of the targeted 1000 households. Overall 150 householsr were planned for the HAP study. Fifteen households were randomly selected from each sub-city from the source population. Exposure was categorized with high-high (HH), high (H) and low (L) with a ratio of 2:2:1. Exposure level of these categories was based on fuel type and cooking area. Households using biomass fuel and cooking taking place indoor of the same space where children spent most of their time were labeled as HH, while households with biomass fuel and cooking outside labeled as high (H). Households using clean energy sources (electricity and LPG) were in low exposure categories. The source of information for the randomization was extracted from the previous HH QRE survey data. Based on the above sampling ratio, we had 60:60:30 HH, H, L, respectively.

Sampling Techniquesflow chart.

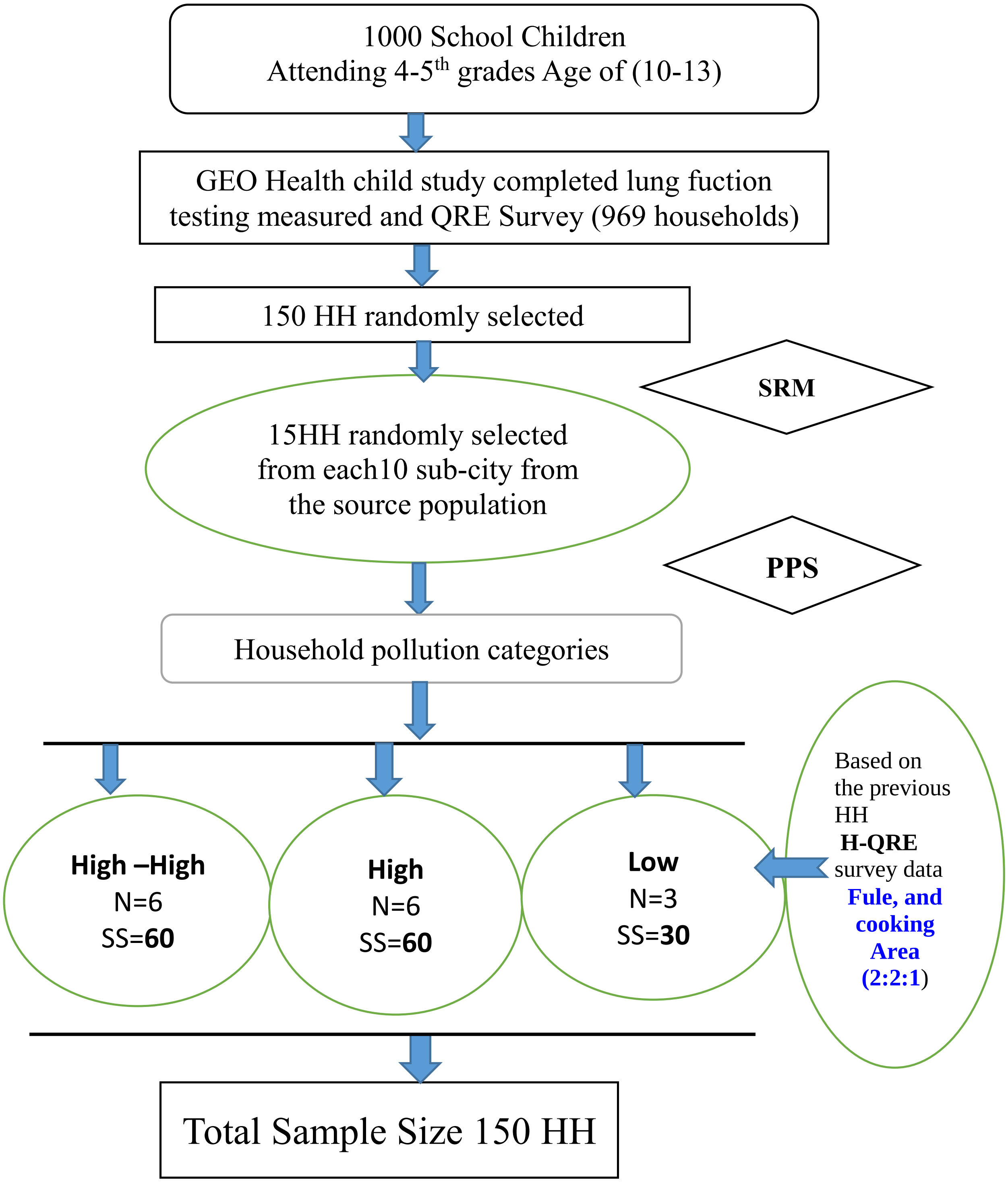

Figure 2: Study Household Sampling flow chart for $PM_{2.5}$ measurments.

4.5. Sample Size Calculation

We used to calculate the sample size using the study conducted in Addis Ababa during January and February, 2012 (5). The concentration of fine particulate matter ($PM_{2.5}$) in 59 households were measured using the University of California at Berkeley Particle Monitor (UCB PM) result was considered. The study showed that the geometric mean of 24-h indoor $PM_{2.5}$ concentration is Approximately 818 µg/m^3 (SD=3.61). The highest 24-h geometric mean of $PM_{2.5}$ concentration observed were 1134 µg/m^3 (SD= 3.36), 637 µg/m^3 (SD= 4.44), and 335 µg/m^3 (SD =2.51), respectively, in households using predominantly solid fuel, kerosene, and clean fuel (5).

Using a formula$n = \frac{(Z*SD)^2}{e}$with this formula using the above assumption59households were obtained. The final sample size calculated after considering design effect is considered and non-response rate is 144 househould.

$$n = \frac{(Z * SD)^2}{e}$$

$$\mathrm{e} = \mathrm{Z}_{\alpha/2}\,\frac{\delta}{\sqrt{n}}$$

e = 1.96x 3.61/√59 = 1.96x3.61/7.7 = **0.92**

n= $(1.96*3.61/0.92)^2$ = 60

Design effect: 2 x 60 = 120

Non response rate (20%) = 120 + 24 = 144

Calculated total Sample size for 10 sub-city for PM measurement will be **144**

Whereas;

d= margin of error between the sample and population (0.05)

$Z\alpha/2$ = critical value at 95% certainty (1.96)

e = margin of error

S= Standard deviation

So the HAP study used **150** sample size is adequate and representative for personal PM exposure level study.

It was believed this sample size is adequate enough to cover the 2nd specific objective of this study.

4.6. Data Collection Tools and Personnel

Four trained data collectors were involved in handling PM sampling in households. The data collectors had completed online based training on ethical issues involving human subjects (31). The field supervisor (the current PI of this study) and the research administrator of the GEO Health project had facilitated the logistic and transport support to ensure data quality.

4.7. Methods of $PM_{2.5}$ measurement

The PM measurement followed the procedures that was developed for this purpose. The detail description of the sampling activities are found in respective sampling protocol.

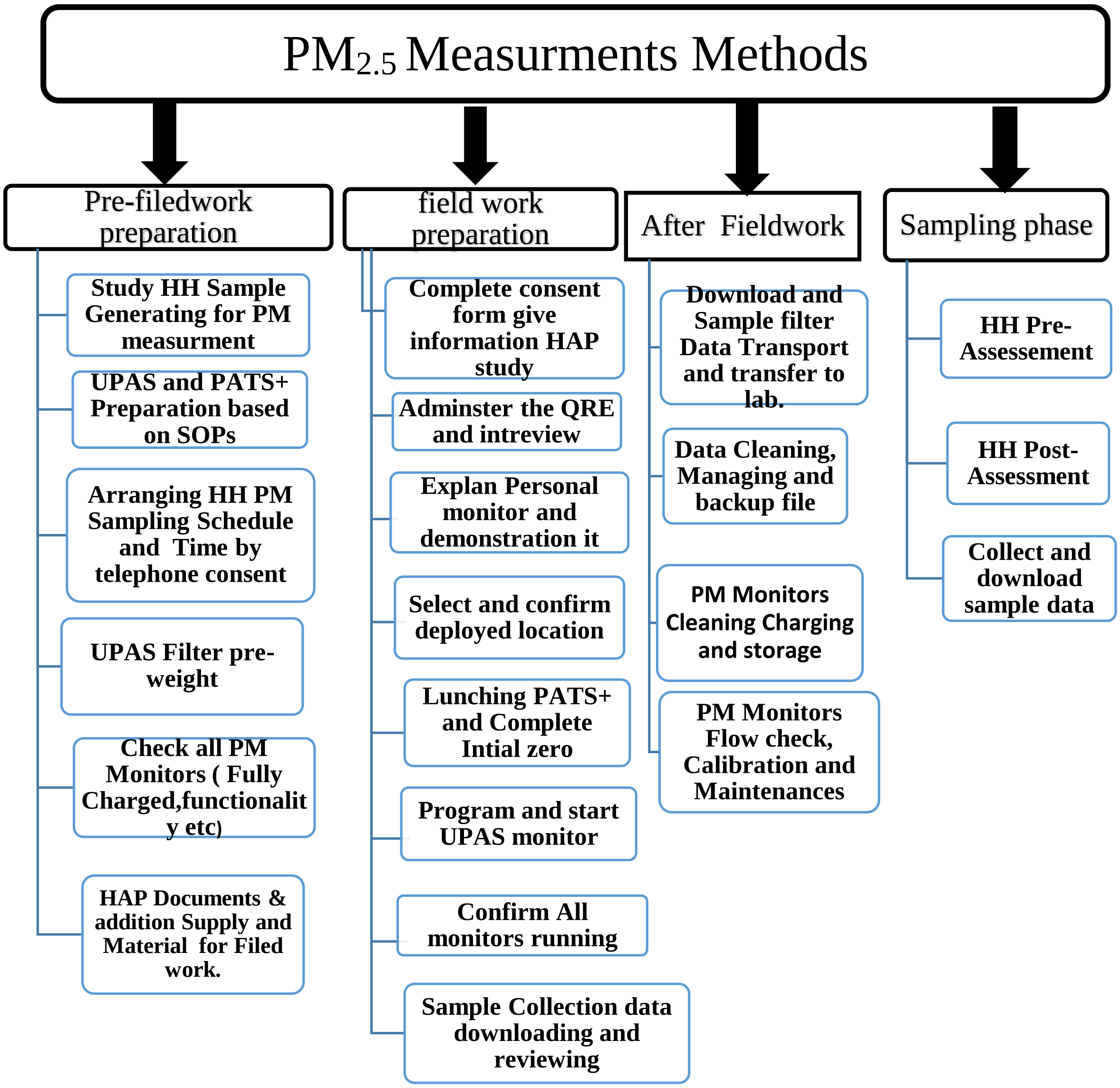

Figure 3. Flow Chart of $PM_{2.5}$ sampling procedure

4.7.1 Pre -field work preparation

This briefly involved the identification of actual study households by calling them on a phone and a preliminary visit to check the sampling placement. In addition, instrument preparation such as filter pre-weight, checking instrument charging and software (PICA and firmware) were part of this activity. All filter was pre-weight measurements chain of custody form are filled and the post weight form attached on it for gravimetric filter lab measurements. Mettler Toledo XS3DU microbalance accurate to ±1 µg was used to weigh the filters.

4.7.2. PM Sampling Procedure

One UPAS and one PATS+ were collocated on a waist band that was worn by the child when he was at home. The instruments were placed in the child's sleeping area when the child is not at home, when he was sleeping, or at any other time when it was not feasible to wear the monitors safely on the waist.

The instruments were placed in the child's sleeping area meeting the following criteria to the extent possible:

- Off the ground-units should not be placed directly on the ground
- Finding unobstructed air flow: ideally placed on a freestanding structure (like a bed or side table) 30-60 centimeters from the nearest wall or large obstacle (furniture etc). And not hung on a wall to allow for adequate airflow representative of household levels.
- Safety: The location should be safe and dry. The UPAS and PATS+ must always be worn outside clothing.

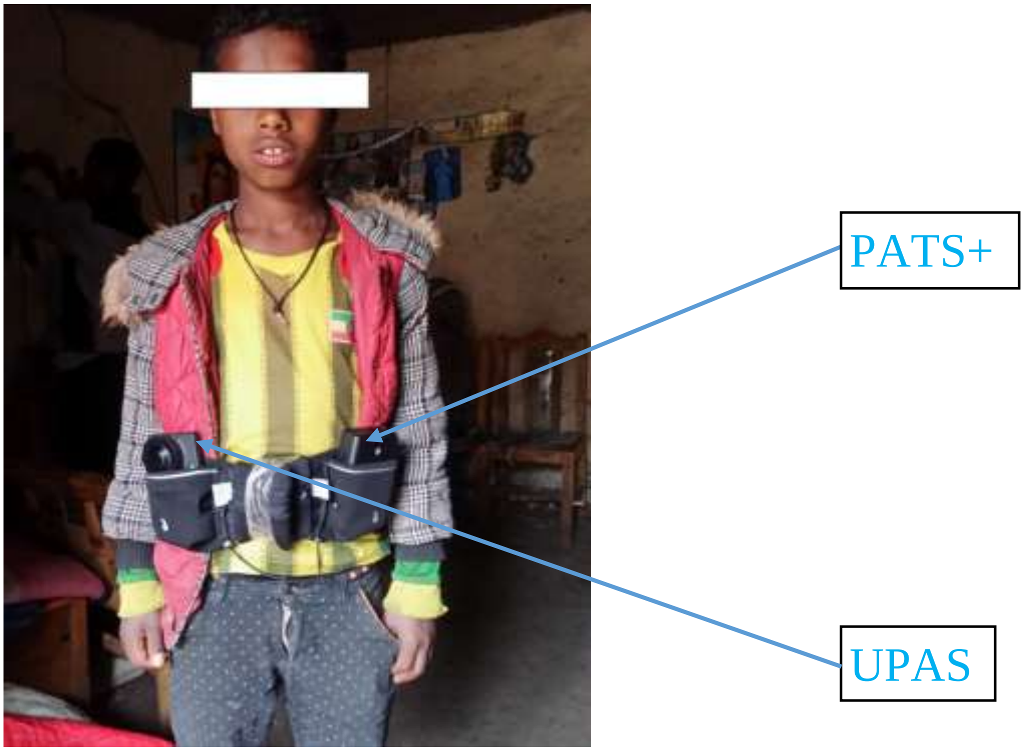

Figure 4: Personal PM Exposure measurment Childworn UPAS Co-located with PATS+ when he was at home. (Photograph by Mulugeta A.) 08/12/2018.

4.7.3. Downloading sampled data from PATS+ and UPAS

Electronic data was recorded in the micro memory SD card. The necessary data for both monitors were downloaded from the respective memory cards in a form of CSV and text formats. These data files were transformed into first excel file and then to SPSS file formats that can be used for data analysis.

4.8. Study variables:

4.8.1. Dependentvariable

$PM_{2.5}$ concentration measured by PATS+

$PM_{2.5}$ concentration measured by UPAS

4.8.2. Independent variable

Study Housing Character

- Number rooms
- Child room location
- Indoor Ventilation (door and window left open time)

Cooking Characteristics

- Stove type used for Cooking
- Fuel type used for Cooking
- Cooking place in the study househould.
- Number of cooking event (Frequency)

Environmental variability

- Temperature
- Relative humidity

4.9. Operational Definition

Clean stove: These are stoves using energy sources from electricity and gas fuels (LPG)(10).

Duty cycle: - percent of time the pump is operating fixed at 15 seconds sampling time. This is equivalent to the use of 66% of the battery life.

Sampled Volume: - Cumulative air volume sampled by UPAS.

Field blanks are conditioned, clean unexposed filters that are used to determine whether contamination occurs during sample transport, setup and recovery.

Laboratory blanks are conditioned, clean and unexposed filters that are kept in the lab and used to determine any weight change between pre- and post-sampling weighing due to contamination in the microbalance environment.

High-High pollution categories: - The study househould used dirty fuel (Biomass and LPG) and cooking in the main house or salon in the living room.

High pollution categories: - The study househould used fuelwood, charcoal, kerosene and cooking mostly done outside or in a separate structure rather than the main living area.

Low pollution categories: - The study househould used clean fuel and stove (Electricity, solar energy) and Cooking is mostly done in either the main living area or outside in a separate structure.

Child Room Location: - The child sleeping area located in the study household

Cooking frequency: -The frequency of cooking at Breakfast, Lunch, Dinner, Injera and Coffee Ceremony (in household within 24 hours during sampling period.

4.10. Data Quality Assurance

Data was collected by trained field enumerators who were supervised in a field setting during the sampling time. Downloaded data from UPAS and PATS+ were cleaned based on the following requirements as set in the instrument's SOP:

- Completing of 24 hrs. Samples were accepted if the duration is more than 22 hrs (Completingof 90% of sampling duration).
- Log interval for UPAS 30 seconds and for PATS+ 1 minute of sampling interval. This is to adjust the filter overloading of PM and the factory's default value, respectively that ensured the accuracy of measuring $PM_{2.5}$ concentration.
- Battery voltage > 3.75V to ensure the constant power flow in monitors.
- Checking the setted factory mass coefficient is equal to temperature coefficient for PATS + to verify the internal validation of the instrument as a specific charactersitcs.
- Checking the consistency of labels and IDs between PATS+ and UPAS
- Checking the duty cycle to be about 66% for UPAS. This parameter is useful to save the battery life of UPAS for the 24 hrs of measurement.
- Checking the range of sampling temperature (acceptable 1-40 ^{o}C) and RH (acceptable 10-80%) for PATS+
- Checking the default calibrated flow volume to be 1 litre per minute for both monitors
- UPAS Flow rate were checked by rota meter 2.1 devation for factorty caliberation.
- Checking the measured concentrations were expected: initial and final zeroing expected to be 10µg/m^{3}for the PATS+
- Excluding $PM_{2.5}$ concentration > 30,000 µg/m^3(14).
- Checking if weekly for PATS+ and UPAS external and internal cleaning

4.11. Data Management

We had 1 UPAS and 1 PATS+ used for PM measurements in each household. Data was downloaded from these instruments after 24 hours of sampling period. We download personal child wearable PATS+ logged data at the field from the device using complementary PICA software to save as the data as Excel data file. The post sampling interview was administered to the head of the household to verify the peaks of PM relative to the cooking events. Finally, the data was cleaned as indicated above. The cleaned data in excel was converted into the SPSS file format that was used for the analysis.

To check the normality assumption test the data was not normaly distributed and rightly skewed so we used natural log transformed data for analysis.

4.12. Data Analysis

For specific objective 1

The average daily mean (SD) GM (SD) concentrations were calculated for each PATS+ and UPAS Child using the excel spreadsheet. $PM_{2.5}$ data was transformed using a natural log scale to fulfill the normality distribution assumption. The geometric mean (GM) with its standard deviation (SD) was used to describe particulate matter concentration.

The following statistical tools are used based on the specific objective:

1. **Paired t-test** was performed for the collocated (PATS+ against UPAS) to examine the consistency in the measurements of the overall mean PM concentration. We concluded the measurements are similar if p-value was >0.05, H_0 =0 were accepted.
2. **Bland and Altman scatter plot analysis** was done to examine the complete agreement between the co-located (paired sampling) two data sets measured by the two instruments (PATS+ Vs UPAS). Bland-Altman plot analysis was performed using SPSS V.23 and NCSS statistical software release in 2019. Bland and Altman analysis helps to evaluate a fixed bias which isthe mean difference in PM concentration as measured by the two different instruments. The data was plotted using the mean difference Y-axis and the UPASdata on the X axis. The upper and lower limits of 95% CI were indicated for each scatter plot. The scatter plot was analyzed by observing any pattern if the scatter plots were within 95% CI limits and if the mean difference was about 0 or not. We labeled the two instruments agree in measuring PM concentration if mean difference is about 0 in the absence of any pattern. The use of Bland and Altman analysis was indicated in different literature(32–34).

For Specific objective 2

3. **Multivariable linear regression analysis** was used to assess which factor affecting the UPAS $PM_{2.5}$ concentration level. UPAS PM Concentration was taken as the dependent variable, while household related factors were considered as independent variables. A dummy variable was created for all categorical variables to fit in the bivariate linear regression model. All independent variable was fitted one by one in bivariate linear regression. Variables with $P < 0.25$ from the bivariate linear regression were included in the multivariable linear regression module. The natural log scale of PM concentration of

UPAS was used to compare which factor affecting the PM concentration using p values and 95%CI of the bet coefficients.

4.13. Ethical considerations

Ethical clearance and support letter was taken from the Institutional Research Review Board of Addis Ababa University. The average PM concentration data of household was disclosed to the participant by inquiry. Complete information using the participant's information sheet was communicated to each study participant, on the basis of which written informed consent was obtained during the initial stage of the study. Inconveniences for refusals was respected. The household PM data was permitted by GEO Health project in which the MPH candidate was trained to collect the data. The data confidentiality, was protected no other personal or third party had access to the HAP collected raw data and other HAP study information.

5. RESULTS

5.1. Household characteristics

It included 150 households in this study. From the sampled households 59(39.66%) were high-high regarding their pollution level categories, while 54(36%) and 37(24.7%) were High and low respectively (Table 1). Fifty-three percent of the household had only one room. From the sampled households, 79(52.7%) Cookes in the main house, while 38(25.3) and 33(22%) Cooks in a kitchen located in the main house and kitchen separated from the main house, respectively. Fifty-Six percent of the child room located in the household were in Bedroom and Salon only 12 (8%) of the child room located inside the kitchen room (Table 2).

Table 1: Study Household characteristics (n=150)

Characteristics	**Number (%)**
Pollution category	
High -High	59 (39.3)
High	54 (36.0)
Low	37 (24.7)
Number rooms	
One room	80 (53.3)
Two room	51(34.0)
3 & above room	19 (12.7)
Household size	
1-5	99 (66)
5 and above	51 (34)
Cooking place	
Main house	79(52.7)
Kitchen located in the main house	38(25.3)
Kitchen separated from the main house	33(22. 0)
Child room location in the household	
Bedroom	33(22.0)
Salon	21(14.0)
Kitchen	12(8.0)
Bedroom and Salon	84(56.0)

Among the total of the study households sixty-nine percent of households used mixed (charcoal and electricity stove) only thirty-nine percent used an electric stove. Forty percent of the house used charcoal 36(24%) of them used electric city 59 (39.3%) of the household was used mixed fuel as energy sources for cooking purposes. (Table 2)

Table 2: Stove and Fuel type used for cooking (n=150)

Cooking Characteristics	Number (%)
Stove Type	
Traditional stove (3 stone)	6 (4.0)
Kerosene Stove	9 (6.0)
Charcoal stove unimproved	3 (2.0)
Electric stove	39(26.0)
LPG	24(16.0)
Mixed type Charcoal and Electric stove	69(46.0)
Fuel Type	
Charcoal	40(26.7)
Electricity	36(24)
Kerosene Stove	11(7.3)
Wood	4(2.7)
Mixed Fuel (Charcoal) &Electricity)	59(39.3)

One hundred thirty-three (88.67%) of the household cooked three or more times within the 24 hours sampling duration. Only 17 (11%) cooked less than three times in 24 hours of sampling duration. Forty-three percent of the household opens a door or a window above 12 hours while cooking (Table 2).

Table 3: Twenty four hours of sampling time study the household frequency of cooking and indoor ventilation time (n=150)

Cooking frequency and Indoor ventilation	Number (%)
Frequency of Cooking(number of cookig event)	
2&<2 times a day	17(11.3)
Three times a day	50(33.3)
Four times a day	50(33.3)
Five times a day	33(22.1)
Door and Window left open(indoor ventilation)	
Open in 0-6 hrs./day	22(14.7)
Open 7-12 hrs./day	63(42.0)
Open above 12 hrs./day	65(43.3)

5.2. Household PM Concentration measured by PATS+ and UPAS

In, HAP study $PM_{2.5}$ measurements were performed in child personal exposure level measured by PATS+ and UPAS. The geometric mean (GM) and geometric standard deviation (GSD) were used as descriptors of central tendency and variability.The mass PM2.5 concentrations measured by both PM measuring instruments are indicated in the table below (Table 5).

Table 4: Mass $PM_{2.5}$ Concentration level of PATS+ and UPAS measured data units: (mg/m^3) (n=150).

PM Monitor	*(Min, Max)*	*1^{St} Q*	*3^{rd} Q*	*Geometric Mean (GSD)*
PATS+, *mg/m^3*	(13.81, 470.48)	43.62	178.70	88.07 (11.50)
UPAS, *mg/m^3*	(10.43, 1147.07)	54.98	187.53	102.73 (8.99)

5.3. Paired t-test analysis

The difference in PM concentrations measured by PATS+and UPAS was not significant (p=0.102). (Table 5).

Table 5: Paried t-test anlysis of LN_UPAS and LN_PATS+, $PM_{2.5}$ concentration, n = (150)

Pair	Paired Differences			
	Mean	SD	95%CI	Sig
LN_PATS Vs LN_UPAS	-0.15	0.094	(-0.34,0.031)	0.102

5.4. Bland-Altman plot analysis UPAS and PATS+

We managed the Bland and Altman plot analysis for the paired sampled co-located PATS+ and UPAS. A paired t-test of UPAS and PATS+ indicated the mean difference was zero (P-value = -0.15. This suggested undertaking to check the Bland- Altman plot analysis to explore any visual pattern or trend in the plots and estimate proportional bias between the two measurements.

When the plotted differences represent the light-scattering method Vs Gravimetric methods the established method, the bias quantifies how much higher its negative bias values are with the PATS+ with the UPAS. The standard deviation (SD) of all the 150 HH differences is calculated as a measure of variability (repeatability) from which the limits of agreement are determined. The 95% confidence limits of the normal distribution are used (mean difference ± 1.96 SD). The limits of agreement represented the range of values in which agreement between methods will lie for approximately 95% of the UPAS and PATS+ measured $PM_{2.5}$ concentration level. Three percent (5 of 150) of the data points are outliers and exceed the upper limit of agreement. Two percent (3 of 150) of the data points are outliers, and below the lower limit of agreement. The bias (SD) of PATS+Vs UPAS was 1.15 (± 0.16), indicating that the PATS+ measured lower $PM_{2.5}$ concentration than the UPAS. Bland and Altman plot showed that there is proportional bias between the UPAS and PATS+ measured $PM_{2.5}$concentration (Figure 5).

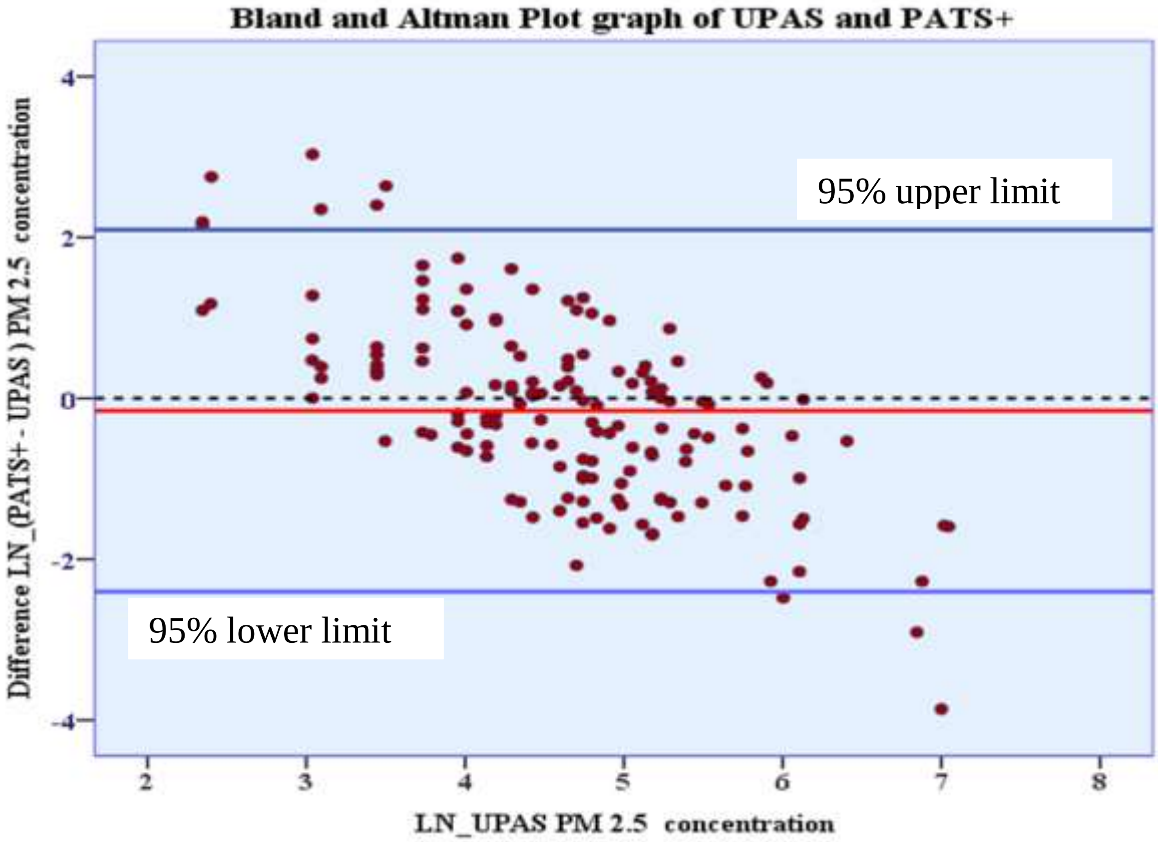

Figure 5: Bland and Altman Plot graph of PATS+ and UPAS

Note: - ***1.*** Upper Limit of Agreement (2.095), ***2.***The red line indicate that Line of biased agreement, Y=-0.15; ***3.***The broken line indicated that line of perfect agreement, Y=0; 4**.** Lower limit of agreement (-2.40)

The overall mean difference in values obtained with the two methods of the difference was -0.15. The mean (± SD) $PM_{2.5}$ concentration of PATS+ was 4.47 (±0.87), compared with 4.63 (±0.97) for the UPAS (data in log scale). The bias difference of the PATS+ and UPAS was (-0.15 (95% CI = -0.34, 0.03) The Bias (Difference) of -0.15 with 95% CI (2.09, -2.40) (Table 7).

Table 6: UPAS and PATS+ Bland –Altman Plot Analysis (n=150)

Variable	Mean	SD	95 % CI
Difference LN_ PATS+-UPAS	4.47	0.87	(4.34-4.62)
LN_UPAS	4.63	0.97	(4.48-4.79)
Difference	-0.15	1.15	(-0.34-0.03)
Parameter	**Value**	**SD**	**95% CI**
Bias (Difference)	-0.15	1.15	(-0.34-0.03)
Lower Limit of Agreement	-2.40	0.16	(2.09- 2.40)
Upper Limit of Agreement	2.09	0.16	(1.78-2.41)

Bias and Limits of Agreement for LN_ PATS+- UPAS and LN_ UPAS. Limits of Agreement = Diff ± 1.96 x (SD of Difference)

5.5. $PM_{2.5}$ concentration measured by UPAS

We had used 3 UPAS there is no statistically significant difference between them. (Table 7).

Table 7:$PM_{2.5}$ concentration measured by UPAS serial number

UPAS ID	n	Geometric mean	Std.Deviation
151	47	92.53	88.48
159	56	101.79	137.04
176	45	111.92	312.16
Total	148	101.65	200.55

One way ANOVA indicated the absence of significant difference among UPAS serial numbers grouped by PATS serial numbers, indicating the measured concentrations were similar (F=0.496, p value=0.48) that allowed us to use this concentration for a paired t-test with a corresponding concentrations measured by co-located PATS+serial number. Serial numbers indicate the variants of PATS+ that were manaufcatured by a company to meaure $PM_{2.5}$at at a factory context.

5.6. Paired t-test of PM concentration by PATS serial number Vs UPAS Concentration

This is indicated in Table 8. All PATS serial numbers except 7244 and 7295 had significant differences in PM concentrations relative to UPAS concentrations.The largest sample size has large PM mean concentration.

Table 8. Pared t-test of PATS+ and UPAS by serial number

PATS+ Serial Number	UPAS $PM_{2.5}$ concentration		PATS+ $PM_{2.5}$ concentration		Sample size	Paired t-test P-Value
	Mean	SD	Mean	SD		
7207	4.75	1.07	4.25	0.82	28	0.00
7244	4.47	4.41	4.41	0.63	25	0.73
7295	4.53	0.98	4.92	0.70	15	0.07
7322	4.45	1.05	5.15	0.81	35	0.01
7618	4.94	0.81	4.14	0.70	11	0.00
7620	4.58	0.95	3.96	0.82	20	0.052
Total	4.63	0.97	4.48	0.87	150	

NB: *Only Serial numbers 7244, 7295, 7620 required Bland & Altman Plot Analysis*

5.7. Bland and Altman Plot of PATS+ by their serial number

The Paired t-test result of PATS+ by serial number P.7244, P.7295, and P.7620 not significant P value of (0.73, 0.07, and 0.052) respectively. We plot Bland and Altman plot for those PTAS+ considering the three UPAS serial number. The Plot showed that there were a few outliers observed in 95% CI upper and lower limits (Figure 5, 6, 7).

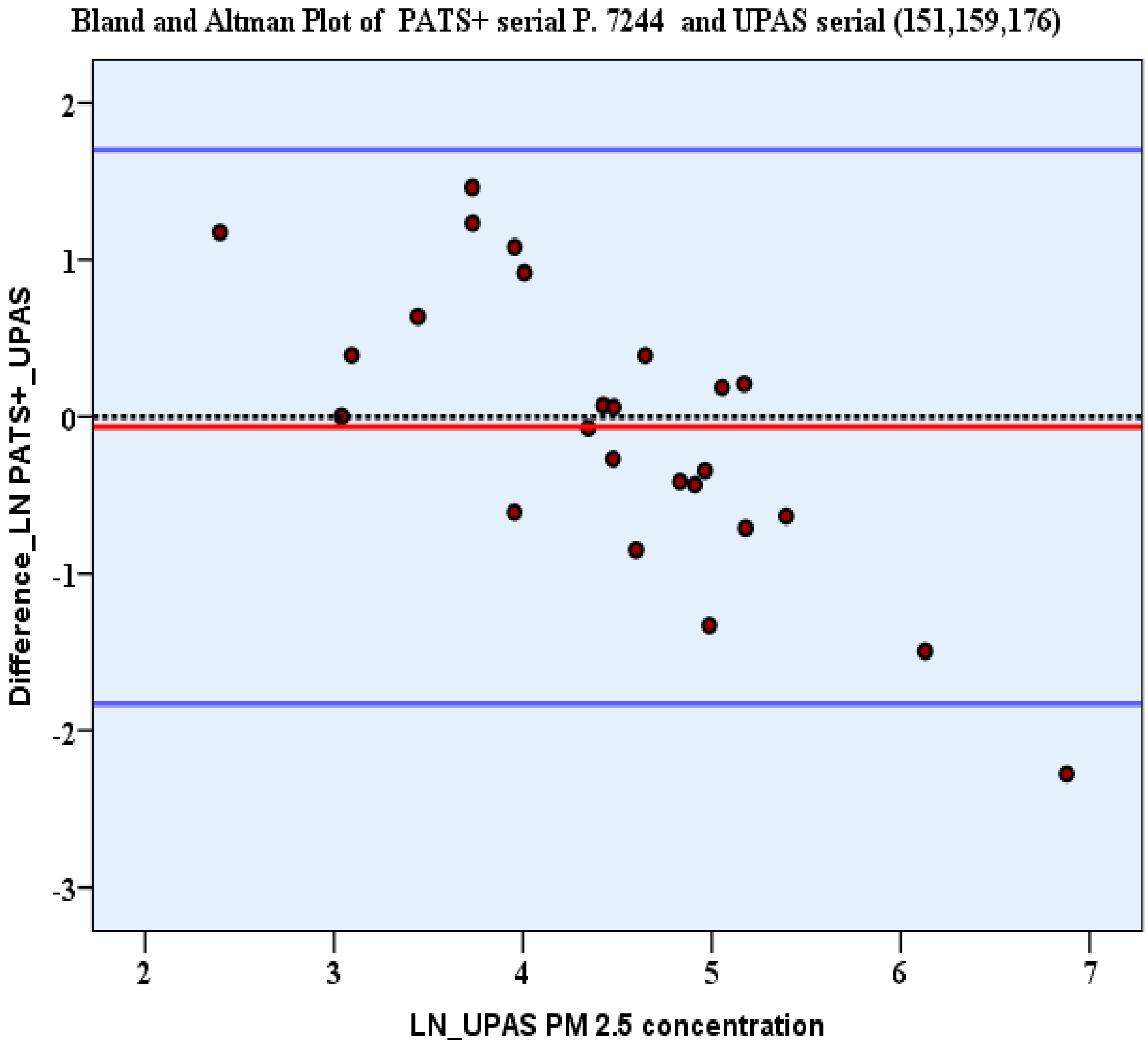

Figure 6. PATS+ serial number P.7244 and UPAS serial number (151,159,179)

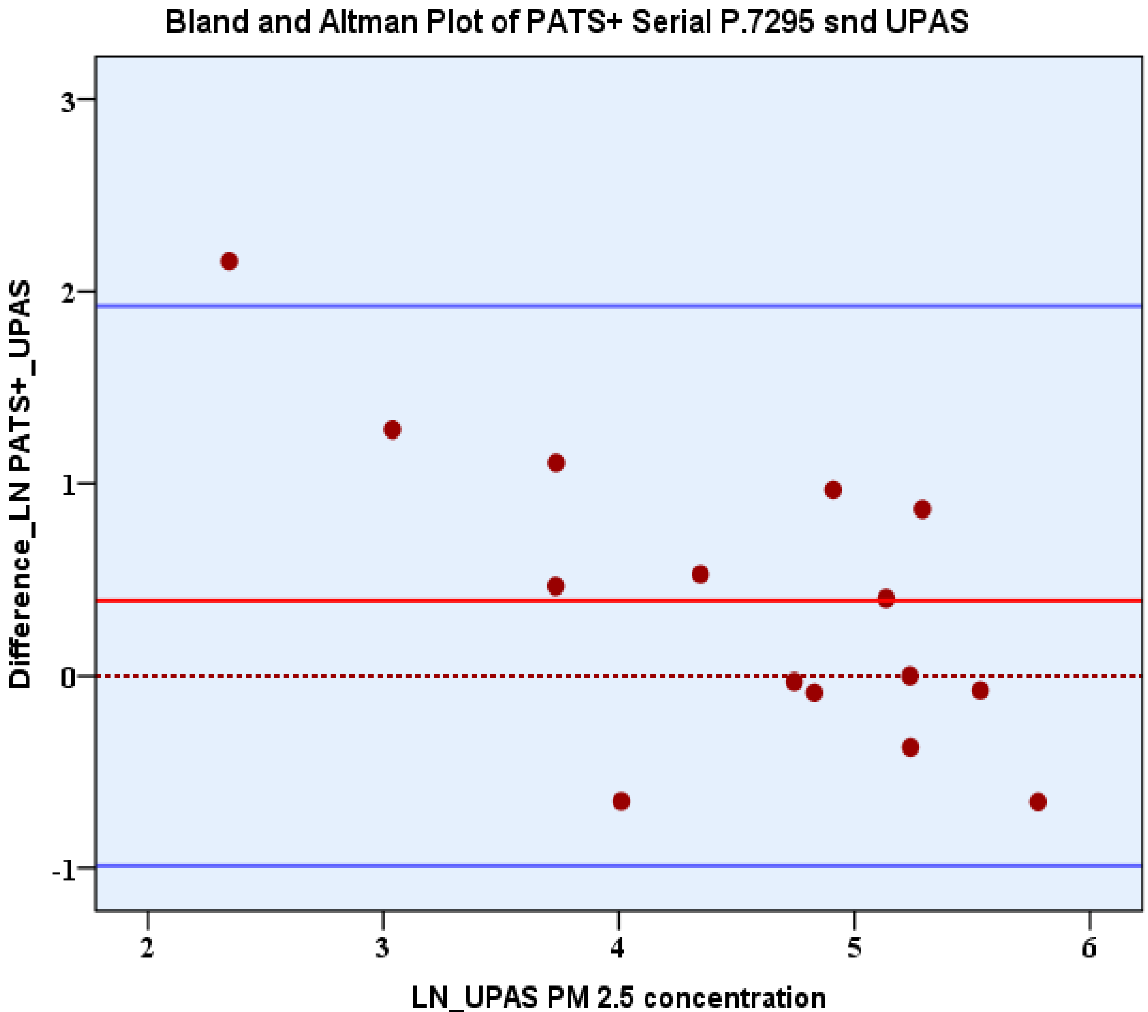

Figure 7: PATS+ serial number P.7295 and UPAS serial number (151,159,179)

The Bland and Altman Plot analysis of PATS+ serial number P.7295 showed that there is only one and 7 outlier in 95%CI upper and lower limit respectively. There is also a proportional biased.

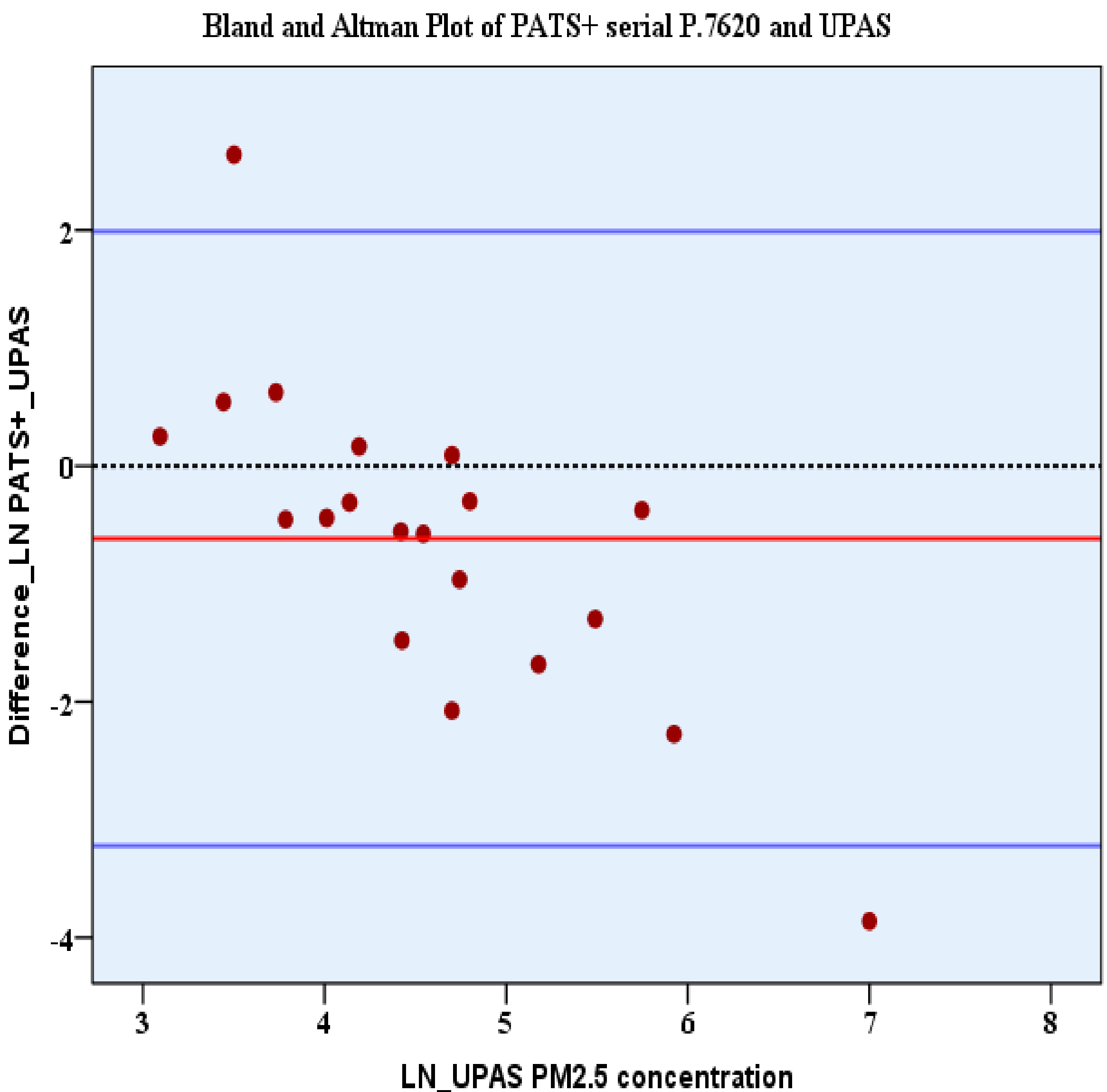

Figure 8.PATS+ serial number P.7620 and UPAS serial number (151,159,179)

The Above three PATS+ serial number P.7244, P7295, P.7620 shows a significant PM measurement difference if PATS+ used a single wise collecting PM measurement. However, the overall 9 PATS+ measured data has differences comparing to UPAS.

5.8. Sub-Analysis of PATS+ $PM_{2.5}$ concentration by serial number

5.8.1 Mean $PM_{2.5}$ concentration

The largest sample size has large PM mean concentration. Higher GM concentration were observed UPAS serial number 176 co-located PATS+ (Table: 9).

Table 9. $PM_{2.5}$ concentration measured by PATS+ serial number

PATS+ ID	n	Geometric Mean	Std. Deviation	Frequency of Co-located by UPAS serial number		
				151	**159**	**176**
7207	28	69.90	106.13	9	10	9
7217	7	41.28	10.28	6	1	-
7244	25	82.16	53.52	10	10	5
7295	15	136.87	117.78	3	7	5
7322	35	171.63	128.65	10	12	13
7525	4	151.14	51.13	1	2	1
7618	11	63.02	46.81	5	3	3
7619	5	34.99	13.8	2	1	2
7620	20	52.57	101.56	9	5	6
Total	150	88.07	112.78	55	51	44

5.9. Factors affecting the variability of UPAS measured $PM_{2.5}$ concentration

Bivaraible linear regressionanalysis were performed .A significant level of P= < 0.25 value were used for multivariable linear regression.

5.9.1 Multivariable linear regression

Multivariable linear regression were used which variables are associatedwith UPAS PM Concentration. The result showed that in househould pollution categories of High=High wereP= 0.03 and Child room located in the kitchen were statistically significant P-value 0.01 while,child room located inside bedroom, and salon were not significant.The stove type and cooking frequency results shows that it's not statistically significant difference at P<0.05(Table 10)

Table 10: Multivariable linear regressionof UPAS $PM_{2.5}$ concentration n= (150)

Model	β	Std. Error	95% CI	Sig.
(Constant)	4.93	0.20	(4.54, 5.32)	0.001
The household pollution categories				
High-high	-0.41	0.18	(-0.78, -0.05)	0.03
Low	0.24	0.21	(-0.17, 0.66)	0.25
Child room location in the household				
Bedroom	-0.35	0.20	(-0.75, 0.04)	0.08
Salon	-0.34	0.23	(-0.80, 0.12)	0.15
Kitchen	-0.83	0.30	(-1.43, -0.23)	0.01
Stove type used for cooking				
Traditional stove (3 stone)	-0.10	0.40	(-0.89, 0.69)	0.80
Kerosene Stove	0.13	0.33	(-0.53, 0.79)	0.70
Charcoal stove unimproved	-0.96	0.56	(-2.07, 0.15)	0.09
Electric stove	0.30	0.20	(-0.09, 0.69)	0.13
LPG	-0.24	0.23	(-0.69, 0.21)	0.29
Cooking Frequency				
2 &< 2 times a day	-0.12	0.27	(-0.66, 0.41)	0.65
3 times a day	0.00	0.19	(-0.38, 0.38)	0.99
5 times a day	-0.06	0.21	(-0.48, 0.36)	0.78

6. DISCUSSION

The Bland and Altman plot analysis showed significant differences, despite the mean concentrations measured by PATS+ Vs UPAS did not differ significantly in paired t-test. We understand that paired t-test statistically looked for the overall or aggregated mean difference without much accounting the pattern of differences. Bland Altman analysis instead looked for the paired plots in X and Y axis visually to examine any pattern or trend. It provided a possibility of testing if the mean difference is differing from 0 or not. The combination of visual inspection of the pattern of plots and statistical testing provided a good tool to settle the test made by the paired t-test. The technique of Bland and Altman plot analysis for a paired data was used in several medical and social literature to check the agreement of two measurements (34–36).

PATS+ had 9 different serial numbers labeled by a manufacturing company. The nature of light scattering technique to measure PM concentration by such devices had internal inherent differences that depended on measurement context such as temperature, relative humidity, loginterval. Having this issue in mind, our analysis verified the source of differences by analysising separately each serial number PM concentration with that measured by UPAS.

The paired t-test result showeds that there is a variation in PM concentration measured in the 9 PATS+ deployed in a 150 study household measured data. We observed the highest mean concentration in the PATS+ serial number of P.7525, while the lowest mean $PM_{2.5}$ concentration was also observed in P. 7618. However, we got three PATS+ serial number (P7244,P7295,P7620) among the total of 9 PATS+ had measure largest and least PM measuring difference comparing the with three UPAS. This might be each 9 PATS+ have a different factory temperature and factory mass coefficients and user temperature and user mass coefficients calibration value *(HAP Study Protocol V7 P- 13*).

There could be variations because of the co-location status was not equally treated. The child hadthe belt with the two monitors when he was at home and left them on agreed location when sleeping and attending school. There were uncertainties beyond our control that would affect the measurments. Example, we did not have control or observation to ensure the sampling inlets and outlets were not covered by an obstructing object that would have affected the flow of air to the instruments. Such challenges were documented in similar studies (4).The Bland Altman plot analysis of UPAS Co-located with PATS+ showed that there were few outliers observed beyond 95% CI of upper and lower limit of agreement. Sources of errors could be as well from the measurments of filters (pre and post) and recording errors emanated from the lab work. We could have missed such observation despite we had strict SOPs and supervisions on every single events that required lab intervention. We had forexample SOPs for filter weighing, book logs that were available for inspection, the weighing lab is organized in a way to manage the entrance of dust from the outside. These factors might affect the measured data have a proportional bias and poor agreement between both measured $PM_{2.5}$ concentrations.

The internal calibration of both UPAS and PATS+ were similar calibrated to measure the same particle size of $PM_{2.5}$ concentration level by the manufacturer. In a different study finding showed that many potential factor may affect the calculation of $PM_{2.5}$ mass concentration, such as collection efficiency, the stability of sampling flow rate, filter types, and weighing accuracy (37). Those factors might affect the mass PM concentration sampling variability. Statistical analyses showed that UPAS and PATS+ $PM_{2.5}$ measured data were not reasonably correlated with each other. In some range, PATS+ overestimates and UPAS underestimates the PM measurements. We can speculate the measured concentrations are different either because of the inherent characteristics of each individual PATS+ (by serial number) or because of uncertainties the emanated from the lab procedures and sampling handling. The burden of evidence informed us that the individual specific characteristics played the major role. This was demonstrated by very clear and similar plots pattern as demonstrated separately. The overestimation of PM concentration by PATS+ and its under-estimation at a certain cut-off is consistent to each plot analysis demonstrated by PATS serial number. Our analysis clearly showed PATS+ overestimates in the lower values, while UPAS did at higher concentrations.

It was important to explore the factors affecting the PM concentrations as measured by the gold standard monitor. We understand that the volumetric unit of measurements (mg/m^3) could be affected by the nature of fuel, type of room, type of cooking activity, and type of housing ventilation.

In our study, the micro-environment variability of (temp, RH) has no effect on $PM_{2.5}$ concentration variation of both instrument r^2 of 0.018. The study results showed that RH and temperature did not affect the PATS+ measured $PM_{2.5}$ concentration. The RH of PATS+ measurement of minimum and maximum were (37.27%, 76.40%) on average 51.76%. This might be because of fans inside PATS+ of each serial allowed air to flow to the inlet and outlet in a very similar way by having control over internal temperature and relative humidity. However, the studies conducted a similar light scattering methods with different instruments showed that $PM_{2.5}$ concentration level measurementwere affected by temp and RH (1). The validation study done in light scattering instrument showed that light-scattering devices underestimated PM at low relative humidity (RH) (< 40%) and overestimated PM at high RH (> 60%) (13).

Child room location in the kitchen and the household pollution level of High_High categories showed statistically significant results on UPAS $PM_{2.5}$ concentration. Our physical observation during the sampling showed either kitchen was in proximity to the child spending space that hopefully allowed the entrance of smoke to this space. Rooms in households usually had shared roofs that were not made air tight. The relative effect of a household labeled as HH pollution level was very clear due to the increased use of biomass fuel that intended to generate increased level of smoke.

A recent study also showed household air pollution derived from cooking is highly variable both spatially and temporally in village settings, where air pollution concentrations can vary by orders of magnitude within a few meters, with large daytime variations because of daily cooking patterns, and large seasonal variations. Household air pollution levels also have a high degree of intra-household variability, even over a few days, because of differences in stove use, ventilation, and time-activity patterns (14).

Therewere studies conducted in Addis Ababa city on PM_4 and $PM_{2.5}$ concentrations in households using traditional fuel and homes without separate kitchens and poorly ventilated rooms.Geometric mean of PM_4 concentration of >1000 mg/m^3, the highest $PM_{2.5}$ concentration were 911mg/m^3 ,(SD 4.22) measured (5,38).

The 24-hours GM $PM_{2.5}$ concentration measured in the households using traditional biomass stoves was 1357 µg/m^3, (SD 5.21) were observed in the study (5). In households they use where improved biomass stoves, $PM_{2.5}$ concentration increased to 1694 µg/m^{-3}, (SD=2.88). In households using kerosene stoves, $PM_{2.5}$ concentration was 743 µg/m^3 (SD=4.35) (5).
In summary, the existing difference in PM concentration as measured by the two monitors varied statistically calls to generate a correction factors for PATS+ based on the measured values of UPAS.

7. STRENGTHS AND LIMITATIONS OF THE STUDY

Strengths of the study

The study used recent advance technology of personal indoor air pollution using gravimetric filter-based method (UPAS) it'sthe only method that gives real concentration(39).Standard and instrument placement SOPs were also used to ensure the data quality. We used relatively large sample size when compared to other similar indoor personal PM exposure measurement studies. The use of PATS+ provided to record cooking events that were matched with the level of peaks of pollution. The measurement of PM concentration in relatively large sample size was an opportunity to estimate the exposure of a child to indoor air pollution which would be used as an input for the larger children's health study in GEOHealth project.

Limitations of the Study

We placed UPAS in proximity to PATS+ in child that affect the $PM_{2.5}$ sampling exposure position because of the inherent obstruction that could happen at the time of sampling. The child motion data within 24 hours of sampling duration was not included to compare the variability of PM concentration. PATS+ has motion sensor that could allow to evaluate the placement variability of the monitor Vs fixed position

We did not have adequate coverage of sampling during the wet season understanding the variations of indoor pollution by season. We had sampling interruption of about two week's rains days due to security challenges.

8. CONCLUSION AND RECOMMENDATION

CONCLUSIONS

We conclude the following:

1. There is difference in $PM_{2.5}$concentration measurments deployed between two monitors: PATS+ and UPAS.
2. PATS+ had higherconcentrations at low values, while UPAS had increased measurement at higher values.
3. The child room location and category of household pollution had an effect on PM concentration.

RECOMMENDATION

While PATS+ is an important monitor to record the pattern and trend of $PM_{2.5}$ level by time, it requires a correction factor against UPAS that will be useful for the epidemiological evaluation of an exposure to indoor air pollution.

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Annexes

Annex I: Questionnaires (English Version)

ADDIS ABABA UNIVERSITY, COLLEGE OF HEALTH SCIENCES, SCHOOL OF PUBLIC HEALTH

I. PARTICIPANT INFORMATION SHEET

Introduction: Greeting; this is ________________________________ and I am here for collecting information for the study which is conducted by the School of Public health of Addis Ababa University. This study was being carried out in HAP data collected by GEO Health randomly selected elementary schools in Addis Ababa. Validating indoor $PM_{2.5}$ Concentration measured data using PATS+ and UPAS. The study has approval of Institutional Review Board of the College of Health Sciences of AAU.

Title of the study: validating $PM_{2.5}$ concentrations measured by PATS+ relative to UPAS device in households in Addis Ababa, Ethiopia.

Objective: The objective of the study was to validating $PM_{2.5}$ measured data using PATS+ Co-located with a gold standard UPAS.

Components of the study: The present study conducted HAP indoor PM Concentarion Personal exposure level PM measuring instrument for 24 hours in the household.

Whom to contact: If you will have any question about the research please contact Dr. Abera Kumie (PI), at the School of Public Health of Addis Ababa University, 0911-882912;e-mail aberakumie2@yahoo.com. M.r Worku Tefera ,at the School of Public Health of Addis Ababa University, at 0913620514,e mail workutefera2000@ yahoo.com , M.r Dawit Siraw (MPH) Hub Manager GEO Health Research and Training Hub for Eastern Africa +251924662066, e-mail dawitsiraw33@yahoo.com and M.r Molla Mekashaw (MPH) Research Administrator-GEO Health Eastern Africa Research & Training Hub School of Public Health, Addis Ababa University molmreserch@gmail.com +25913611435 and Institutional Review Board of the College of Health Sciences: +251 11115513099

Annex II: QRE Questionnaire

Household Assessment and Instrument Placement Form

GENERAL INFORMATION

Date of visit (Day/Month/Year): ___________/Time of visit (hour: minute): _________

Participant study ID: _____________ Weather conditions: ____________________

HOUSEHOLD

1. When cooking, are doors and windows generally left open? □Yes□ no (if no skip to #3)

If yes, for how about many hours a day? ______ including the child, how many people currently live in the home? ______________

SN	Question	Response	Skipping
2	Which best describes the home in which this child currently lives? (MARK ONE THAT APPLIES; OBSERVE)	1. A stand-alone house 2. A shared compound 3. An apartment building or condominium. 4. Others, specify:	
3	Do the walls of the child's home connect to the ceiling without a gap?	1. No 2. Yes	
4	How many rooms does your child's home have, excluding kitchen?	____Room/s	
5	Which rooms are available? (Observe and circle that apply)	1. Bed room 2. Saloon 3. Kitchen 4. Bedroom and salon 5. Other, specify: _______	

COOKING

SN	Questions	Breakfast	Lunch	Dinner	Injera	Coffee Ceremony
6	Do you USUALLY cook at home/compound?	0. No →Finshed 1 Yes	0. No → Finshed 1 Yes	0. No → Finshed 1Yes	0. No → Finshed 1Yes	0. No → Finshed 1Yes
7	Is (child's name) USUALLY home while cooking?	No Yes	No Yes	No Yes	0.No Yes	No Yes
8	What type of stove do you use? (MARK ALL THAT APPLY)	1.Traditional stove (3 stone) 2.Improved stove "Injera" 3.Improved stove "Wett" 4.Kerosene stove 5.Charcoal strove 6.Unimproved 7.Electric 8.LPG 9.Other, Specify:	1.Traditional stove (3 stone) 2.Improved stove "Injera" 3.Improved stove "Wett" 4.Kerosene stove 5.Charcoal strove 6.Unimproved 7.Electric 8.LPG 9.Other, Specify	1.Traditional stove (3 stone) 2.Improved stove "Injera" 3.Improved stove "Wett" 4.Kerosene stove 5.Charcoal strove 6.Unimproved 7.Electric 8.LPG 9.Other,	1. Traditional stove (3 stone) 2. Improved stove "Injera" 3. Improved stove "Wett" 4. Kerosene stove 5. Charcoal strove 6. Unimproved 7. Electric 8. LPG 9. Other,	1.Traditional stove (3 stone) 2.Improved stove "Injera" 3.Improved stove "Wett" 4.Kerosene stove 5.Charcoal strove 6.Unimproved 7.Electric 8.LPG 9.Other,

9	Where do you normally cook?	1.Main house/ salon 2. Outdoors 3.Kitchen in main house 4.In the Kitchen 5.Separate from the main house	1. Main house/ salon 2. Outdoors 3.Kitchen in main house 4.In the Kitchen 5.Separate from the main house	1. Main house/ salon 2. Outdoors 3.Kitchen in main house 4.In the Kitchen 5.Separate from the main house	1. Main house/ salon 2. Outdoors 3.Kitchen in main house 4.In the Kitchen 5.Separate from the main house	1.Main house/ salon 2. Outdoors 3.Kitchen in main house 4.In the Kitchen 5.Separate from the main house
10	What fuel do you most commonly use in the dry season to cook? (CIRCLE ONE THAT APPLIES)	1, Charcoal 2, Electricity 3,Kerosene 4,stove 5,Gas stove 6,Wood 7,Animal dung 8,Solar 9,Biogas 10,Crop residue 12,Leaves	1, Charcoal 2, Electricity 3,Kerosene 4,stove 5,Gas stove 6,Wood 7,Animal dung 8,Solar 9,Biogas 10,Crop residue 12,Leaves	1, Charcoal 2, Electricity 3,Kerosene 4,stove 5,Gas stove 6,Wood 7,Animal dung 8,Solar 9,Biogas 10,Crop residue 12,Leaves	1, Charcoal 2, Electricity 3,Kerosene 4,stove 5,Gas stove 6,Wood 7,Animal dung 8,Solar 9,Biogas 10,Crop residue 12,Leaves	1, Charcoal 2,Electricity 3,Kerosene 4,stove 5,Gas stove 6,Wood 7,Animal dung 8,Solar 9,Biogas 10,Crop residue 12,Leaves
11	What fuel do you most commonly use in the wet season to cook? (CIRCLE ONE THAT APPLIES	1,Charcoal 2,Electricity 3,Kerosene 4,stove 5,Gas stove 6,Wood 7,Animal dung 8,Solar 9,Biogas 10,Crop residue 11, Leaves	1,Charcoal 2,Electricity 3,Kerosene 4,stove 5,Gas stove 6,Wood 7,Animal dung 8,Solar 9,Biogas 10,Crop residue 11, Leaves	1,Charcoal 2,Electricity 3,Kerosene 4,stove 5,Gas stove 6,Wood 7,Animal dung 8,Solar 9,Biogas 10,Crop residue 11, Leaves	1,Charcoal 2,Electricity 3,Kerosene 4,stove 5,Gas stove 6,Wood 7,Animal dung 8,Solar 9,Biogas 10,Crop residue 11, Leaves	1,Charcoal 2,Electricity 3,Kerosene 4,stove 5,Gas stove 6,Wood 7,Animal dung 8,Solar 9,Biogas 10,Crop residue 11, Leaves

INSTRUMENT PLACEMENT

Description and location of the child's sleeping area: ______________________________

II .Post-Sampling Household Assessment and Interview Form

GENERAL INFORMATION

Date of visit (Day/Month/Year): _________Time of visit (hour: minute): ___________

Participant study ID: ___________________Weather conditions: __________________

INSTRUMENT PLACEMENT

Instructions to interviewer: Read each of the questions and record response.

1. When the child was not wearing the UPAS and PATS+, was it placed in the designated location?
   a. □ yes □ no (If no, skip to 3)
2. If no, where was it placed? _____________________________________
3. Were doors and windows left open when cooking during the last 24 hours?
   A. □ yes B,□no (If no, move to next section)
4. If yes, when did you open the doors or windows? ______

CHILD'S ACTIVITY

Instructions to interviewer: Administer the following questionnaire regarding the child's activity in the 24-hour sampling period. Read each of the questions and record response.

5	Think about the last 24 hours. Which of the statements best describes how much time your child spent inside the home? **(CHOOSE ONE MOST RELEVANT; READ THE OPTIONS)**	NONE - not any; my child spent all of his/her day outside the home SOME - a part of my child's day was spent inside the home, but most was spent outside the home HALF - half of my child's day was spent outside the home and half was spent inside the home MOST - more than half, but less than all of my child's day, was spent inside the home ALL DAY-My child spent all day inside the home

COOKING INTERVIEW

Instructions to interviewer: Administer the following questionnaire regarding cooking practices in the 24-hour sampling period. Read each of the questions for each of the 5 cooking times beginning with breakfast and record response.

SN	Questions	Breakfast	Lunch	Dinner	Injera	Coffee Ceremony
6	Did you cook ______ at home/compound during the last 24 hours?	0. No → finshed 1. Yes	0. No → 1. Yes	0. No → 1. Yes	0. No → 1. Yes	0. No → 1. Yes
7	Was (child's name) home while cooking	No Yes	No Yes	No Yes	No Yes	0.No 1.Yes
8	At around what time did you cook _______?	Date: day/mo/yr ___/___/___ Time:---- hour:---- min— __:___ AM/PM	Date: day/mo/yr ___/___/__ Time:---- hour:-- ------ min-_: ___AM/PM	Date: day/mo/yr ___/___/__ Time:---- hour:--- min--_: ___AM/PM	Date: day/mo/yr ___/___/__ Time:---- hour:--- min__: ___AM/PM	Date: day/mo/yr ___/___/__ Time:---- hour:--- min___: ___AM/PM
9	Did you open doors or windows while cooking _______during the last 24 hours?	0. No → 1. Yes	0. No → 1. Yes	0. No → 1. Yes	0. No → 1. Yes	0. No → 1. Yes
10	At around what time did open doors and/or windows during__?	Date: day/mo./yr. ___/___/___ Time: hour: min __:___AM/PM	Date: day/mo./yr. ___/___/__ Time: hour: min___: __ AM/PM	Date: day/mo./yr. ___/___/__ Time: hour: min_: ___AM/PM	Date: day/mo./yr. ___/___/__ Time: hour: min _: ___AM/PM	Date: day/mo./yr. ___/___/__ Time: hour: min _: ___AM/PM

11	What type of stove did you use? (CIRCLE ALL THAT APPLY)	1.Traditional stove (3 stone) 2. Improved stove "Injure" 3. Improved stove "Wett" 4. Kerosene stove 5. Charcoal stroveunimproved 7. Electric 8. LPG 9. Other, Specify:___	1.Traditional stove (3 stone) 2. Improved stove "Injera" 3. Improved stove "Wett" 4. Kerosene stove 5. Charcoal strove unimproved 7. Electric 8. LPG 9.Other, Specify: ___	1.Traditional stove (3 stone) 2. Improved stove "Injera" 3. Improved stove "Wett" 4. Kerosene stove 5. Charcoal strove unimproved 7. Electric 8. LPG 9.Other, Specify: ___	1.Traditional stove (3 stone) 2. Improved stove "Injera" 3. Improved stove "Wett" 4. Kerosene stove 5. Charcoal strove unimproved 7. Electric 8. LPG 9.Other, Specify: ___	1.Traditional stove (3 stone) 2. Improved stove "Injera" 3. Improved stove "Wett" 4. Kerosene stove 5. Charcoal strove unimproved 7. Electric 8. LPG 9.Other, Specify: __
12	Where did you cook ______ during the last 24 hours? (CIRCLE ALL THAT APPLY)	1.Main house/ salon 2.Outdoors Kitchen in main house 3.Kitchen separate from main house	1.Main house/ salon 2.Outdoors Kitchen in main house 3.Kitchen separate from main house	1.Main house/ salon 2.Outdoors Kitchen in main house 3.Kitchen separate from main house	1.Main house/ salon 2.Outdoors Kitchen in main house 3.Kitchen separate from main house	1. Main house/ salon 2.Outdoors Kitchen in main house 3.Kitchen separate from main house
13	Which fuel(s) did you use to cook _______ during the last 24 hours? (CIRCLE ALL THAT APPLY)	1.Charcoa 2.Electricity 3.Kerosene stove 4.Gas stove 4.Wood 5.Animal dung 6.Solar 7.Biogas 8.Crop residue 9.Leaves	1.Charcoa 2.Electricity 3.Kerosene stove 4.Gas stove 4.Wood 5.Animal dung 6.Solar 7.Biogas 8.Crop residue 9.Leaves	1.Charcoa 2.Electricity 3.Kerosene stove 4.Gas stove 4.Wood 5.Animal dung 6.Solar 7.Biogas 8.Crop residue 9.Leaves	1.Charcoa 2.Electricity 3.Kerosene stove 4.Gas stove 4.Wood 5.Animal dung 6.Solar 7.Biogas 8.Crop residue 9.Leaves	1.Charcoa 2.Electricity 3.Kerosene stove 4.Gas stove 4.Wood 5.Animal dung 6.Solar 7.Biogas 8.Crop residue 9.Leaves

Annex VIII: Questionnaires (Amharic Version)

I አማርኛ ቅጂ የተሳታፊዎች መረጃ መሰጫ ቅጽ

የጥናቱ ርዕስ፡- በ ቤት ውስጥ የሚገኙ ጥቃቅን ብኛኝ የሚለኩ ፓትስና ዩፓስ የተባሉ መሳሪያዎችን የለኩትን መረጃ ማመሳከርና መገምገም.

የጥናቱዓላማ፡- የዚህጥናትትዓላማየቤት ውስጥ ጥቃቅን አየርብክለትበፓትስ መሳሪያ የተለኩ መረጃዎችን ትክክለኝነት ከዩፓስ ጋር በማመሳከር መረጃውን ማረጋገጥና.

የጥናቱጠቀሜታ፤- መረጃውን ላሰባሰበውና የጥናቱ ባለቤት ለሆነው (GEO Health project) በዩፓስ የተሰበሰበውን መረጃ ከ ዮፓስ ጋር በማስተያየት የጥቃቅን ብኛኝ መጠን መረጃውን በማስተካከል ለፕሮጀክቱ ዓላማ እና የፓትስ መሳሪያ የሰበሰበውን መረጃ በሚጠቅም መልኩ ማቅረብ ነዉ፡፡

የበለጠ መረጃ ካስፈለገዎ

እባክዎ ጥናቱን በተመለከተ ምንም ዓይነት ግልጽ ያልሆኑ ጥያቄዎች ካልዎት፤-

ዶ/ር አበራ ቁሜን (ዋና የትናቱ ተማማሪ) በአዲስ አበባ ዩኒቨርስቲ የህብረተሰብ ጤና ትምህርት ቤት የስልክ ቁጥር 0911882912 ፣ወይም አቶ ዳዊት (GEO Health project) ስራ አስኪያጅ በስልክ ቁጥር 0924662066 ደውለው ማነጋገር ይችላሉ፡፡በአዲስ አበባ ዩኒቨርስቲ የጤና ሳይንስ ኮሌጅ የጥናትና ምርምር ስነ-ምግባር ገምጋሚ ተቋም ምክር ቤት የስልክ ቁጥር +2511115513099፡፡ የአሁን የመጠይቅን ዓላማና ይዘት በተመለከተ እኔን መጠየቅ የሚፈልጉት ጥያቄ ካልዎት በስልክ ቁጥር 0913142555 መጠየቅ ይቻላል፡፡

<u>የህጻኑን የቤት ውስጥ አየር ብክለት ለመለካትና ህጻኑ ቤት በማይኖርበትና ሲተኛ መሳሪያው አቀማመጥ ሁኔታ፡</u>

ከዉጭ የሚመጣ አየር ተጽዕኖን አስወግድ፡ ከበርና ከመስኮት አርቀህ አስቀምጥ ከአንድ ቦታ የሚነሱተጽኖዎችን ተቆጣጠር፡ከምድጃና እሳት ከሚነድበት በቅርበት አታስቀምጥ ጥንቃቄ፡ የተቀመጠበት ቦታ አስተማማኝና ደረቅ መሆን አለበት በልጁ የሚለበሱት/ የሚያዙት ዩፓስና ፓትስ ልጁ ቤትበማ ይሆንበት፣ በሚተኛበት ወይም በማንኛዉም መያዝ በማይችልበት ጊዜ ልጁ በሚተኛበት ስፍራ መቀመጥ አለባቸዉ፡፡መሳሪያዎቹ ልጁ በሚተኛበት ስፍራ ሲሆኑ የሚከተሉት መስፈርቶች መሟላት አለባቸዉ፡፡

የተቀመጠበት ቦታ አስተማማኝና ደረቅ መሆን አለበት አንድ ጊዜ የአየር ጥራት መለኪያ መሳሪያዎቹ እኛ ልጁ ከሚይዘው መሳሪያና የሚቀመፍበት ቦታ ውጭ እባክዎ አይንኳቸዉ እዩአቸው ፤በጨርቅም ሆነ በሌላ ነገር አይሸፍኗቸዉ ወይም በማንኛዉም ነገር አይጋርዷቸዉ፡፡

የአየር ጥራት መለኪያ መሳሪያዎቹ ከወደቁ ፣ከተከፈቱ ወይም እርጥበት ካገኛቸዉ ሊበላሹ ይችላሉ፡፡ ስለዚህ እባከዎ እንዳይነካኩ ጥንቃቄ ያድርጉ፡፡ ዛሬ የምግብ አዘገጃጀት (የአበሳሰል) ልምዳችሁን በተመለከ ተጥቂት ጥያቄዎች እጠይቀዎታለሁ፡፡ነገ ስመለስ ደግሞ በ24 ሰዓት ዉስጥ የነበረዎትን የምግብ አዘገጃጀት (የአበሳሰል) ሁኔታ እጠይቀዎታለሁ፡፡ እባከዎ የሰሯቸዉን በማስታዋሻ ለመያዝ ይሞክሩ፡፡ ለመሰብሰብ የፈለግነዉ መረጃ በማንኛዉም ቀን የምታደርጉትን ነዉ፡፡ ስለዚህ ከዚህ በተለየ ማንኛዉም ነገር (ከፍተኛ ንፋስ፣ በቤትዎ ዙሪያ ቆሻሻ ከተቃጠለ) እባክዎ ማስታዎሻ ይያዙልን፡፡

I.የመጀመሪያ ቀን የቤት ውስጥ ብናኝ መሰብሰቢያ እናቃለ-መጠይቅ ቅጽ

አጠቃላይ መረጃ የጉብኝትቀን (ቀን/ወር/ዓመት) :---------/---------/------------

የጉብኝት ጊዜ (ሰዓት፡ደቂቃ) :------------/-----------------/--------------

የአየር ፀባይ ሁኔታ

1	ቤት ዉስጥ ምግብ በሚበሰልበት ጊዜ በርና መስኮቶችተ ከፍተዉ ይታዋሉ?	1. አዎ 2. አይደለም (አይደለም ወደ 3 ዝለል)
2	አዎ ከ ሆነ በቀን ለስንት ሰዓት	ሰዓት-------ደቂቃ -------
	ልጁን ጨምሮ በአሁኑ ጊዜ በዚህ ቤት ስንት ሰዎች ይኖራሉ?	የቤተሰብ ብዛት------(በቁጥር)
3	በአሁኑ ወቅት ልጅዎ የሚ/ምት/ኖርበትን ቤት በትክክል የሚገልጸው የቱ ነው? (አንዱን ብቻ ምረጥ፤ተመልክተዉ ይሙሉ)	1.ራሱን የቻለ ግቢ ቤት (ቪላ አይነት) 2. የጋራ ግቢ ያለዉ ቤት 3.አፓርታማ ወይም ኮንዶሚኒየም 4.ሌላ ካለ ይግለፁ________

4	የልጅዎ የመኖሪያ ቤት ግድግዳ እና ጣሪውያለ ክፍተት የተያያዘ ነዉ?	0. አይደለም 1. አዎ
5	የልጅዎ መኖሪያ ቤት ስንት ክፍሎች አሉት? /ኩሽና ሳይጨምር/	___________ክፍል
6	በልጅዎ መኖሪያ ቤት የትኞቹ ክፍሎች ይገኛሉ? (ተመልክተህ ከአንድ በላይ ማክበብ ይቻላል)	1. መኝታክፍል 2. ሳሎን 3. ኩሽና 4. መኝታክፍልናሳሎን 5.ሌላካለይግለፁ_______

የምግብ አበሳሰል ሁኔታ

ተ.ቁ	ጥያቄዎች	ቁርስ	ምሳ	እራት	እንጀራ	የቡና ስነ-ስርዓት
7	ብዙ ጊዜ ምግብ ቤት/ግቢ ዉስጥ ታበስላላች?	0.አይደለም 1. አዎ	0.አይደለ ም 1. አዎ	0. አይደለም 1. አዎ	0.አይደለ ም 1. አዎ	0.አይደለ ም 1. አዎ
8	ብዙ ጊዜ (የልጁን ስም ጥራ) ምግብ በሚበሰልበት ሰአት ከቤት ውስጥ ይገኛል?	0. አይደለም 1. አዎ	0.አይደለ ም 1. አዎ	0. አይደለም 1. አዎ	0.አይደለ ም 1. አዎ	0.አይደለ ም 1. አዎ
9	ምን አይነት ምድጃ ነዉ የምትጠቀ ሙት? **(ከአንድ በላይ መመለስ ይቻላል)**	1.ባህላዊ ምድጃ / በ3 ጉልቻ/ 2.የተሻሻለ ምድጃ (የእንጀራ ምጣድ) 3.የተሻሻለ ምድጃ (ለወጥ) 4.ነጭ ጋዝ	1.ባህላዊ ምድጃ / በ3 ጉልቻ/ 2.የተሻሻለ ምድጃ (የእንጀራ ምጣድ) 3.የተሻሻለ ምድጃ (ለወጥ) 4.ነጭ ጋዝ	1.ባህላዊ ምድጃ / በ3 ጉልቻ/ 2.የተሻሻለም ድጃ (የእንጀራም ጣድ) 3.የተሻሻለም ድጃ (ለወጥ) 4.ነጭ ጋዝ 5.ከሰል	1.ባህላዊ ምድጃ / በ3 ጉልቻ/ 2.የተሻሻለ ምድጃ (የእንጀራ ምጣድ) 3.የተሻሻለ ምድጃ (ለወጥ) 4.ነጭ ጋዝ	1.ባህላዊ ምድጃ / በ3 ጉልቻ/ 2.የተሻሻለ ምድጃ (የእንጀራ ምጣድ) 3.የተሻሻለ ምድጃ (ለወጥ) 4.ነጭ ጋዝ

		5.ከሰል 6.ኤሌትሪክ 7.ሲሊንደር ጋዝ 8.ሌላካለይጠ ቀስ	5.ከሰል 6.ኤሌትሪ ክ 7.ሲሊንደር ጋዝ 8.ሌላ ካለ ይጠቀስ-	6.ኤሌትሪክ 7.ሲሊንደር ጋዝ 8.ሌላ ካለ ይጠቀስ--	5.ከሰል 6.ኤሌትሪ ክ 7.ሲሊንደር ጋዝ 8.ሌላ ካለ ይጠቀስ--	5.ከሰል 6.ኤሌትሪ ክ 7.ሲሊንደር ጋዝ 8.ሌላ ካለ ይጠቀስ--
10	በመደበኛነት የት ነዉ የምታበስሉ ት? (ከአንድ በላይ መመለስ ይቻላል)	1.ሳሎን ውስጥ 2.ከቤት ውጪ 3.ማድ ቤት በመኖሪያ ቤት ውስጥ 4.ማድ ቤት ከመኖሪያ ቤት የተለየ	1.ሳሎን ውስጥ 2.ከቤት ውጪ 3.ማድ ቤት በመኖሪያ ቤት ውስጥ 4.ማድ ቤት ከመኖሪያ ቤት የተለየ	1.ሳሎን ውስጥ 2.ከቤት ውጪ 3.ማድቤት በመኖሪያ ቤት ውስጥ 4.ማድ ቤት ከመኖሪያ ቤት የተለየ	1.ሳሎን ውስጥ 2.ከቤት ውጪ 3.ማድ ቤት በመኖሪያ ቤት ውስጥ 4.ማድ ቤት ከመኖሪያ ቤት የተለየ	1.ሳሎን ውስጥ 2.ከቤት ውጪ 3.ማድ ቤት በመኖሪያ ቤትውስጥ 4.ማድቤት ከመኖሪያ ቤት የተለየ
11	በበጋ ወራት በአብዛኛዉ ምን አይነት የማብሰያ ዘዴ /ነዳጅ/ ማገዶ ነዉ የሚጠቀሙ ት? (የሚጠቀሙ ትን አንዱን ብቻ አክብብ)	1. ከሰል 2.ኤሌትሪክ 3. ነጭ ጋዝ 4.የሲሊንድር ጋዝ 5. እንጨት 6. ኩበት 7. ሶላር 8. ባዮ ጋዝ 9.የአዝርትተ ረፈ ምርት 10. ቅጠሎች	1. ከሰል 2.ኤሌትሪ ክ 3. ነጭ ጋዝ 4.የሲሊን ድር ጋዝ 5.እንጨት 6. ኩበት 7. ሶላር 8. ባዮ ጋዝ 9.የአዝርት ተረፈ ምርት 10.ቅጠሎ ች	1. ከሰል 2.ኤሌትሪክ 3. ነጭ ጋዝ 4.የሲሊንድር ጋዝ 5. እንጨት 6. ኩበት 7. ሶላር 8. ባዮ ጋዝ 9.የአዝርት ተረፈ ምርት 10. ቅጠሎች	1. ከሰል 2.ኤሌትሪ ክ 3. ነጭ ጋዝ 4.የሲሊን ድር ጋዝ 5.እንጨት 6. ኩበት 7. ሶላር 8. ባዮ ጋዝ 9.የአዝርት ተረፈ ምርት 10.ቅጠሎ ች	1. ከሰል 2.ኤሌትሪ ክ 3. ነጭ ጋዝ 4.የሲሊን ድር ጋዝ 5.እንጨት 6. ኩበት 7. ሶላር 8. ባዮ ጋዝ 9.የአዝርት ተረፈ ምርት 10.ቅጠሎ ች
12	ለክረምት ወራት	1. ከሰል 2.ኤሌትሪክ	1. ከሰል	1. ከሰል 2.ኤሌትሪክ	1. ከሰል	1. ከሰል

	በአብዛኛዉ ምን አይነት የማብሰያ ዘዴ ነዉ የሚጠቀሙት? (የሚጠቀሙትን አንዱን ብቻ አክብብ)	3. ነጭ ጋዝ 4.የሲሊንድር ጋዝ 5. እንጨት 6. ኩበት 7. ሶላር 8. ባዮ ጋዝ 9.የአዝርት ተረፈ ምርት 10. ቅጠሎች	2.ኤሌትሪክ 3. ነጭ ጋዝ 4.የሲሊንድር ጋዝ 5.እንጨት 6. ኩበት 7. ሶላር 8. ባዮ ጋዝ 9.የአዝርት ተረፈ ምርት 10.ቅጠሎች	3. ነጭ ጋዝ 4.የሲሊንድር ጋዝ 5. እንጨት 6. ኩበት 7. ሶላር 8. ባዮ ጋዝ 9.የአዝርት ተረፈ ምርት 10. ቅጠሎች	2.ኤሌትሪክ 3. ነጭ ጋዝ 4. የሲሊንድር ጋዝ 5.እንጨት 6. ኩበት 7. ሶላር 8. ባዮ ጋዝ 9.የአዝርት ተረፈ ምርት 10.ቅጠሎች	2.ኤሌትሪክ 3. ነጭ ጋዝ 4.የሲሊንድር ጋዝ 5.እንጨት 6. ኩበት 7. ሶላር 8. ባዮ ጋዝ 9.የአዝርት ተረፈ ምርት 10.ቅጠሎች

II. በሁለተኛው ቀን የቤት ውስጥ ብናኝ መሰብሰቢያ እና ቃለ-መጠይቅ ቅጽ

የልጁ ምኝታ ስፍራ መገኛ ገለጻ አጠቃላይ መረጃ

የጉብኝትቀን (ቀን/ወር/ዓመት)፡_______________________

የጉብኝትጊዜ(ሰዓት፡ደቂቃ)፡__________________

ለጠያቂዉ ማስታዎሻ፡እያንዳንዱን ጥያቄ አንብብና መልሱን ጻፍ

1.ልጁ ዩፓስና ፓትስ ያልያዘዉ/ችው መች ነበር፤በታቀደለት ቦታ ተቀምጦ ነበር
2. አይደለም ከሆነ የት ነበር የተቀመጠዉ?
3. ባለፉት 24 ሰዓት ምግብ በሚበሰልበት ሰዓት መስኮትና በሮች ተከፍተዉ ነበር
4. አዎ ከሆነ መስኮትና በር የከፈቱት መቼ ነበር ?

መረጃ መሰብሰቢያ መሳሪያዎችና መረጃ ክለሳ

የልጁ ፓትስ የመጨረሻ ዜሮ ከሆነ በኋላ ከእያንዳንዱ መረጃዉን ፒካ ሶፍትዌር በመጠቀም ማዉ ረድና በፓትስ መተግበሪያ በመመሪያ (ቅጥያ) መሰረት የብናኞችን ጥርቅም መጠን እና የመሳሪያዉን እንቅቃሴ ማየት፡፡ የልጁ ፓትስ ናሙና በሚወስድበትጊዜ መደበኛ የሆነ እንቅስቃሴ እንደ ሚኖረዉ ሲጠበቅ ቋሚ ቦታ ላይ የተቀመጠዉ ፓትስ በመጀመሪያና መጨረሻ ላይ ይኖረዋል፡፡ በተቻለ መጠን ዘርዘር ያሉ መረጃዎችን በሚከተለ ዉሳጥን ሙላ

መሳሪያ	መለያ ቁጥር	የሚታይ ጉዳት	መረጃዉየሚሳየዉ ያልተጠበቀ እንቅስቃሴ ወይም መዛባት	ሌላ አስተያየት
ዩፓስ (ልጅ)				
ፓትስ (ልጅ)				

የልጁ እንቅስቃሴ ለጠያቂዉ ማስታዎሻ፡-
በ24 ሰዓት የናሙና መዉሰጃ ጊዜ ዉስጥ የህፃኑ እንቅስቃሴን በተመለከተ በሚከተለዉ መጠይቅ ሙላ

5	ከመስከረም ወር ጀምሮ ስላለው ስለ ልጅዎ የትምህርት ዘመን እስኪ ትንሽ አስታውሱ፡፡ ልጅዎ በአብዛኛው ጊዜ ከትምህርት ቤት ስት/ሲ/መለስ ከሰዓት በኋላ ባለው ጊዜ ከቤት ውጪ በ/ምታ/ ሚያሳልፋቸው ጊዜያት የልጅዎን ሁኔታ የሚገልፀውን ከተዘረዘሩት ውስጥ ይምረጡ፡፡ (በአበዛኛዉ የሚጠቀምበትን አንዱን ብቻ ምረጥ) አማራጮች ይነበቡ	1.**ምንም** =ምንም የለም; ሙሉውን የከሰዓት ጊዜው/ዋ/ን ከቤት ውስጥ ማሳለፍን ይገልጻ 2.ጥቂት የተወሰነ የከሰዓት ጊዜ ው/ዋ/ን ከቤትውጪማሳለፍ ነገር ግን በአብዛኛው ከቤት ውስጥ ማሳለፍን ይገልጻል 3.**ግማሽ በግማሽ** የሚሆነውን የከሰዓ ጊዜው ከቤት ውጪ እና ግማሽ የሚሆነውን ጊዜ ደግሞ ከቤት ውስጥ ማሳለፍን ይገልጻል 4.**በአብዛኛው ከግማሽ በላይ** የሚሆነውን ጊዜ ከቤት ውጪ እና ትንሽ ጊዜ ከቤት ውስጥ ማሳለፍን ይገልጻል 5.**ሁሉንም**=ሁሉንም የከሰዓት ጊዜውን ከቤት ውጪ ማሳለፍን ይገልጻል

የምግብ ማብሰል ቃለ መጠይቅ ለጠያቂዉ ማስታዎሻ፡- በ24 ሰዓት ናሙና መዉሰጃ ጊዜ ዉስጥ ምግብ ማብሰል ተግበራትን በተመለከተ የሚከተለዉን መጠይቅ ሙላ፡፡ከቁርስ ጀምሮ 5ቱን የማብሰያ ጊዜያት ለእያንዳንዱ ጥያቄ በማንበብ መልሱን መዝግብ፡፡

ተ.ቁ	ጥያቄዎች	ቁርስ	ምሳ	እራት	እንጀራ	የቡናስነ-ስርአት
6	ባለፉት 24 ሰዓታትም ግብ ቤት/ግቢ ዉስጥ	0.አይደለም →ጨርስ 1. አዎ	0.አይደለም →ጨርስ 1. አዎ	0.አይደለም → ጨርስ 1. አዎ	0.አይደለም→ ጨርስ 1. አዎ	0.አይደለም→ጨርስ 1. አዎ

	አብስላች ኋል?					
7	ባለፉት 24 ሰዓታት (የልጁን ስም ጥራ) ምግብ በሚበሰል በት ሰአት ከቤት ውስጥ ይገኛል?	0. አይደለም 1. አዎ	0.አይደለም 1. አዎ	0. አይደለም 1. አዎ	0.አይደለ ም 1. አዎ	0.አይደለ ም 1. አዎ
8	በምን ጊዜ አካባቢ አበሰሉ?	ቀን፣ወር፣ዓ/ም ---/---/--- ጊዜ፡- ሰዓት፡ደቂቃ ---፡---- ጠዋት / ከሰዓት	ቀን፣ወር፣ዓ/ ም ---/---/--- ጊዜ፡- ሰዓት፡ደቂ ቃ ---፡---- ጠዋት / ከሰዓት	ቀን፣ወር፣ዓ/ ም ---/---/--- ጊዜ፡- ሰዓት፡ደቂቃ ---፡---- ጠዋት / ከሰዓት	ቀን፣ወር፣ ዓ/ም ---/---/--- ጊዜ፡- ሰዓት፡ደ ቂቃ ---፡---- ጠዋት / ከሰዓት	ቀን፣ወር፣ዓ/ ም ---/---/--- ጊዜ፡ሰዓት፡ ደቂቃ ---፡---- ጠዋት / ከሰዓት
9	ባለፉት 24 ሰዓት ዉስጥምግ ብ በሚያበስ ሉነት ጊዜ በር ወይም መስኮት ከፍተዋል	0.አይደለም 1. አዎ	0.አይደለም 1. አዎ	0.አይደለም 1. አዎ	0.አይደለ ም→ 1. አዎ	0.አይደለ ም→ 1. አዎ
10	በስንት ሰዓት አካባቢ በሮችና/ ወይም	ቀን፣ወር፣ዓ/ም ---/---/--- ጊዜ፡- ሰዓት፡ደቂቃ	ቀን፣ወር፣ዓ/ ም ---/---/--- ጊዜ፡ሰዓት፡ ደቂቃ	ቀን፣ወር፣ዓ/ ም ---/---/--- ጊዜ፡- ሰዓት፡ደቂቃ	ቀን፣ወር፣ ዓ/ም ---/---/---	ቀን፣ወር፣ዓ/ ም ---/---/---

	መስኮቶች ተከፍተዉ ነበር?	---:---- ጠዋት / ከሰዓት	---:---- ጠዋት / ከሰዓት	---:---- ጠዋት / ከሰዓት	ጊዜ:- ሰዓት:ደቂቃ ---:---- ጠዋት / ከሰዓት	ጊዜ:- ሰዓት:ደቂቃ ---:---- ጠዋት / ከሰዓት
11	ምን አይነት ምድጃ ነዉ የምትጠቀሙት? (ከአንድ በላይ መመለስ ይቻላል)	1.ባህላዊምድጃ / በ3 ጉልቻ/ 2.የተሻሻለምድጃ (የእንጀራምጣድ) 3.የተሻሻለምድጃ (ለወጥ) 4. ነጭጋዝ 5. ከሰል 6. ኤሌትሪክ 7.ሲሊንደር ጋዝ 8.ሌላ ካለ ይጠቀስ	1.ባህላዊ ምድጃ / በ3 ጉልቻ/ 2.የተሻሻለ ምድጃ (የእንጀራምጣድ) 3.የተሻሻለ ምድጃ (ለወጥ) 4. ነጭጋዝ 5. ከሰል 6.ኤሌትሪክ 7.ሲሊንደር ጋዝ 8.ሌላ ካለ ይጠቀስ	1.ባህላዊምድጃ / በ3 ጉልቻ/ 2.የተሻሻለ ምድጃ (የእንጀራ ምጣድ) 3.የተሻሻለ ምድጃ (ለወጥ) 4.ነጭጋዝ 5. ከሰል 6. ኤሌትሪክ 7.ሲሊንደር ጋዝ 8.ሌላ ካለ ይጠቀስ	1.ባህላዊ ምድጃ / በ3 ጉልቻ/ 2.የተሻሻለምድጃ 3.ኤሌትሪክ 4.ባዮጋዝ 5.ሌላ ካለ ይጠቀስ	1.ባህላዊምድጃ /በ3 ጉልቻ/ 2.የተሻሻለ ምድጃ(ለእንጀራ) 3.የተሻሻለ ምድጃ (ለወጥ) 4.ነጭጋዝ 5. ከሰል 6.ኤሌትሪክ 7.ሲሊንደር ጋዝ 8.ሌላካለይጠቀስ
12	ባለፉት 24 ሰዓታት የትነዉ የምታበስሉት? (ከአንድ በላይ መመለስ ይቻላል)	1,ሳሎን ውስጥ 2.ከቤት ውጪ 3.ማድ ቤት በመኖሪያ ቤት ውስጥ 4.ማድቤት ከመኖሪያ ቤት የተለየ	1,ሳሎን ውስጥ 2.ከቤት ውጪ 3.ማድ ቤት በመኖሪያ ቤት ውስጥ 4.ማድቤት ከመኖሪያ ቤት የተለየ	1.ሳሎን ውስጥ 2.ከቤት ውጪ 3.ማድ ቤት በመኖሪያ ቤት ውስጥ 4.ማድቤት ከመኖሪያ ቤት የተለየ	1.ሳሎን ውስጥ 2.ከቤት ውጪ 3.ማድ ቤት በመኖሪያ ቤት ውስጥ 4.ማድ ቤት ከመኖሪያ ቤት የተለየ	1.ሳሎን ውስጥ 2.ከቤትውጪ 3.ማድ ቤት በመኖሪያ ቤት ውስጥ 4.ማድ ቤት ከመኖሪያ ቤት የተለየ

13	ባለፉት 24 ሰዓታት ምን አይነት የማብሰያ ዘዴ/ነዳጅ/ ማገዶ ነዉ የተጠቀ ሙት? (የሚጠቀ ሙትን አንዱን ብቻ አክብብ)	1. ከሰል 2.ኤሌትሪክ 3. ነጭ ጋዝ 4.የሲሊንድ ር ጋዝ 5. እንጨት 6. ኩበት 7. ሶላር 8. ባዮ ጋዝ 9.የአዝርት ተረፈ ምርት 10. ቅጠሎች	1. ከሰል 2.ኤሌትሪክ 3. ነጭ ጋዝ 4.የሲሊንድ ር ጋዝ 5.እንጨት 6. ኩበት 7. ሶላር 8. ባዮ ጋዝ 9.የአዝርት ተረፈ ምርት 10.ቅጠሎች	1. ከሰል 2. ኤሌትሪክ 3. ነጭ ጋዝ 4.የሲሊንድር ጋዝ 5. እንጨት 6. ኩበት 7. ሶላር 8. ባዮ ጋዝ 9.የአዝርት ተረፈ ምርት 10. ቅጠሎች	1.ኤሌት ሪክ 2.የሲሊን ድር ጋዝ 3.እንጨ ት 4. ኩበት 5.ባዮ ጋዝ 6.የአዝር ት ተረፈ ምርት 7.ቅጠሎ ች	1. ከሰል 2.ኤሌትሪ ክ 3.ነጭ ጋዝ 4.የሲሊን ድር ጋዝ 5.እንጨት 6. ኩበት 7. ሶላር 8. ባዮ ጋዝ 9.የአዝርት ተረፈ ምርት 10.ቅጠሎ ች

ተጨማሪ በግራፉ መሰረት ዳታውን በማየት የሚታዩ ከፍተኛ የብናኝ መጠን ካለ ይመዝግቡ

ጊዜ	የነበሩ ድርጊቶች (ቁርስ፣ ምሳ፣ እራት ወዘተ)	የበሰሉ ምግብ ዓይነቶች (ቡና፣ሻይ ወዘተ)	የነዳጅ አይነት (እንጨት፣ከሰል፣ኤሌትሪክ ወዘተ)

አ መ ሰ ግ ና ለ ሁ

Annex IV: Assurance of investigator

I, the undersigned, MPH student declare that this thesis is my original work, has not been presented for a degree in any other university and that all resources of material used for this thesis have been fully acknowledged.

Mulugeta Ayalew   Signature__________________Date of submission __________

Place: Addis Ababa University School of Public Health

This thesis has been submitted for examination with my approval as University

Name of the primary advisor: Dr. Abera Kumie (Ph.D.)

Signature_____________________________________

Date:_______________________________________