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The intersection between the dwelling environment and health and wellbeing in impoverished rural Puebla, Mexico☆

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ABSTRACT

This paper forms part of a major health needs assessment research project of small-scale subsistence farming households in three relatively impoverished villages located close to an active volcano (Popocatépetl) in the rural hinterland of the town of Atlixco, Puebla, Mexico. Our overarching research question is: how do housing conditions, the micro-environment of the lot and dwelling, air and water quality, patterns of food preparation and household behaviors impact health and wellbeing in each community? We use a mixed-methods strategy starting with a survey of almost 250 households to generate baseline data on the health status, treatment, and perceptions of health in each of the four communities. Our housing and health assessment also focusses upon the dwelling structure and perceived problems such as damp and pests; the use of rooms and yard space; and on-site environmental sampling of the water and air quality. In addition, we apply an intensive case-study methodology to five purposively selected farming households in order to highlight how different dwelling structures and conditions, room use, lot maintenance and organization, practices of animal husbandry, fertilizer and agrochemical storage, open fire cooking with wood, and other behaviors shape and impact health and wellbeing. Our findings and conclusions emphasize the need for further research to better understand the epidemiology of these and similar communities. We conclude by offering a series of policy actions to mitigate the risks and hazards that we identify, and argue that in these rural communities the intersections between housing, home, and yard management presents hazards and challenges to health outcomes that are more dynamic and more volatile, than those of most urban housing environments.

1. Introduction, context, and research goals

This paper forms part of a major research project about the health status, needs and treatment behaviors of households in Puebla, Mexico, and focusses primarily upon three agricultural villages (*pueblos*) located in the rural hinterland of the town of Atlixco. As one might expect the town of Atlixco, with its almost 100,000 population, is relatively well served in terms of public health providers, including a hospital and clinic, and we also include a low-income neighborhood as a fourth community of study which, we hope, will highlight health and treatment differences between poor households in both rural and urban communities.

The region lies in the shadow of Mexico's principal active volcano (Popocatépetl) which daily spews ash into the atmosphere. It is also a region subject to frequent earthquakes, one of which in September 2017 caused widespread damage, loss of life, and is an ongoing cause of

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trauma to the population. Working with local partner NGOs, and a university medical school from the city of Puebla, the study uses mixed-methods embedded in a community-based participatory research project in order to explore several overarching questions. First, we ask what is the health status of members of these communities, and given their relative poverty, to what extent are they able to leverage access to public and private medical treatment centers? A second goal, all too rarely explored in rural environments of Mexico, is to ask about mental health in these low-income populations, and specifically to measure levels of depression, anxiety, and stress, including specific additional markers to measure levels of ongoing trauma of the 2017 earthquake which even today remains fresh in people's minds. In addition, we are interested in community-wide perceptions about other arenas of behavior and addiction that affect health and wellbeing, such as domestic violence, and the consumption of drugs, tobacco, and alcohol. Our third major goal, and the focus of the present paper, is to evaluate rural housing conditions and to better understand how these impact health and wellbeing at the household level. Specifically, we address this research question in relation to the physical attributes of the dwelling structure itself, the indoor and patio air quality, the quality of domestic piped water supply, patterns of food preparation, diurnal behaviors and practices of family members within the micro-environment of the lot which, in these villages, is often shared in close proximity to farm animals. The hypothesis or proposition that undergirds our analysis is that these extremely poor residential structures and living arrangements carry intrinsic risks and hazards to the health and wellbeing of household members at different stages of the life course, whether these are young children playing barefoot on uneven surfaces in the farmyard, or exposed to woodsmoke from outdoor cooking on open wood fires, or are adults suffering from chronic disease and ailments, and in the case of the elderly also find their mobility around the home impaired.

Our findings on the two broader goals of health needs assessments are described fully elsewhere (Remmert and Mercer, 2020; Rojas and Ainslie, 2020; see also PAGL 2020), and are summarized here only as a backdrop to the dwelling and micro-level analysis that we offer. An initial household survey of almost 250 households indicates that around one-half report having a family member with a chronic illness such as diabetes, hypertension, and muscular-skeletal conditions such as arthritis and rheumatism; and a similar number have at least one family member with a major physical or mental disability. While most families in theory have access to public health care through *Seguro Popular*,[1] access to institutionalized service is perceived to be either "moderately difficult", or "very difficult", mostly because of the distance and transportation costs in travelling to the hospital clinic in the nearby town of Atlixco, the long wait times, and because prescribed medicines invariably have to be purchased out-of-pocket creating affordability problems for over two-thirds of respondents. Counter-intuitively, despite their poverty, one-third of villagers identify a private practitioner as their primary care provider: usually a doctor whom they know and have confidence, and with whom they can make an appointment, thereby saving wait times. Head of household perceptions are quite favorable regarding service provision for women's reproductive health, family planning, and cancer screening.[2] Mental health is considered to be a significant problem by almost one-third of respondents, and while the standard clinical measurement scales that we use to report depression, anxiety, and stress are more or less at average levels (i.e. "normal"), one-third have clinically significant higher scores. In addition, many also report one or more of these stressor symptoms tied to specific questions about the earthquake that occurred some two years' earlier.

Our analysis begins with an evaluation of the living conditions provided by the household survey and includes an assessment of the health implications of the dwelling structures, associated problems such as damp, pests, and natural lighting, the use of rooms and yard space, and the environmental water and air quality measurements that we gathered in each home. Next, we blend the survey data with insights gained from several focus group discussions that we undertook with residents, along with five intensive case studies through which we document the spatial organization and use of the micro dwelling environment: the lot and the house structure itself; rooms and their usage; yard space and proximity to livestock and farm animals; and ground and floor surface conditions that may affect mobility. In short, we ask what particular hazards or threats do these impoverished rural dwelling environments pose to health and wellbeing of household members, and what might be done to mitigate those risks and hazards?

2. Literature review: housing and health in low-income self-built homesteading communities of the Global North and South

While this study is primarily about rural Puebla, it is partly inspired by housing research in low-income self-built and self-managed settlements in Texas, especially those along the US-Mexico border, where they called *colonias*.[3] Informal settlement and self-help housing production have formed part of the mainstream thinking about urban growth in Latin America and the Global South for several decades, but recent research has begun to highlight parallels with housing and other forms of informality in the Global North (Ward, 1999; Harris 2017; Durst and Sullivan, 2019; Durst and Wegmann, 2017). Indeed, it is research about health and living conditions in Texas colonias that first led us to specifically explore the intersections between the dwelling environment and health outcomes in low-income informal peri-urban settlements in Central Texas (Bogolasky and Ward, 2018).

Colonias and informal subdivisions are low-density unincorporated settlements located in the rural hinterland of cities across the southern United States, and even more broadly across the USA (Durst and Sullivan, 2019). These neighborhoods are home to low- and very low-income (largely) Hispanic households, many of whom show high rates of chronic health problems and mobility challenges especially among the elderly, and who also have poor or limited access to health-providing institutions. This research parallels our discussion of housing and health in rural villages in Puebla and we hope that our study will lay the groundwork for future health and housing policy outreach to low income communities in both Mexico and the USA.

In the early 1990s, occasional outbreaks of Cholera, and the so-called "Third World" health and housing conditions in border colonias were a primary reason for state intervention (Davies and Holz, 1992; Ward, 1999). Rates of Shigellosis and Hepatitis A were found to be twice that of the national average, and Gastroenteritis and respiratory disease were rife (Ward, 1999; Anders et al., 2008; TWDB, 1995). These dramatic health deficits and the risks prompted Texas state government intervention and legislation in an attempt to prevent further colonia expansion, and then to extend basic infrastructure into existing border colonias. In 2006, after most state intervention had waned, Texas Senate Bill 827 established a three-level color-coded classification to identify border colonias exposed to severe public health risks: "Red" which poses the greatest health and safety risks due to a lack of piped water supply, and inadequate wastewater disposal; "Yellow" being those with adequate water and wastewater systems, but which lack street paving, and have inadequate drainage and poor solid waste disposal, and which still pose certain health risks; and "Green" colonias being those with adequate infrastructure that pose minimal health and safety risks (Durst

[1] Recast in January 2020 as INSABI (*Instituto Nacional de Salud Para el Bienestar*), The National Institute for Health and Wellbeing.

[2] 76% of the survey respondents were female which we regarded as entirely appropriate given that the goals of the survey were primarily to gather information about the health status of members of the household, perceptions of medical institutions and treatment, pre- and post-natal care, etc.

[3] In this paper we italicize the first occurrence of frequently used Spanish words such as *pueblo*, *colonia*, etc., and thereafter present in regular Roman font.

and Ward, 2014; Mier et al., 2008).

However, this classification applies only to early 1990s-designated colonias along the border, and ignores similar forms of informal settlements in Texas and elsewhere. While housing and health conditions in these widely found rural and unincorporated peri-urban neighborhoods are less impoverished than border colonias, many would also qualify for "Red" and "Yellow" classifications. Moreover, it is important to note that these health-risk classifications only measure the physical infrastructure of each settlement, and make no assessment of actual physical housing conditions. Paradoxically, some of the worst housing conditions that we have found along the border today are in newly unincorporated subdivisions which emerged after the ban on new colonia development, and after the introduction of State-legislated "model subdivision rules" which required developers to provide basic infrastructure (Durst 2015; Durst and Ward, 2015). The higher costs of buying a lot in legally serviced subdivisions means that would-be home owners have less cash to invest in the dwelling unit, with the result that trailer homes, campers, and rudimentary shacks remain in the long-term, and show little of the consolidation and improvement of their colonia counterparts in the border (Olmedo and Ward, 2016). Poor housing still leads to very poor health outcomes, even though basic infrastructure exists from the outset.

Furthermore, recent studies in border colonias are raising important questions about ongoing water quality, finding high levels of arsenic and bacterial contamination in drinking water supply networks (Rowles 2020; Rowles et al., 2020). As a result, many colonia and informal settlement residents purchase bottled drinking water – a luxury that villagers in Puebla can rarely afford, as we observe below.[4]

Although much of the extensive literature about the built environment and health comes from the Global North, there is a growing body of work that is beginning to explore these issues in urban informal settlements and in rural environments in the Global South (Unger and Riley, 2016; Rowles et al., 2018). It is especially in the Global South that inadequate levels of infrastructure (water and drainage), poor dwelling conditions, low-incomes and poor levels of nutrition, overcrowding and exposure to infectious diseases and other risks, all come together to exacerbate morbidity and mortality patterns, invariably in places where there is inadequate access to institutionalized health care.

Society has recognized for more than a century that improved housing generally leads to improved health (Jacobs et al., 2010), yet there is less consensus about the nature of the relationship. The independent effect of poor housing on health remains largely unknown, due to the many confounding factors that may apply (World Health Organization, 2005). Housing can affect health in a variety of ways, and Jacobs (2011) describes several general physical dwelling conditions that may contribute to adverse health effects: 1) physical conditions such as heat, cold, energy efficiency, light, ventilation, noise, etc.; 2) chemical conditions like carbon monoxide; 3) biological conditions such as rodents, house dust mites, cockroaches, humidity and mold; 4) building and equipment conditions; and 5), social conditions.

In terms of housing quality, the dwelling structure itself and the protection it provides against extreme weather and exposure to pests and disease, access to a secure potable water supply, and sufficient space to minimize overcrowding: all are important. Individually, and in combination, poor housing conditions increase exposure to infectious diseases, inhibit the capacity to cope with chronic illness, raise susceptibility to injuries from falls and accidents, reduce nutritional intake, and exacerbate mental disorders (Krieger and Higgins, 2002). Other elements that go beyond housing quality or structure also appear to exert an independent effect upon health and wellbeing; important ones being location, neighborhood characteristics, and the nature of social networks.

[4] See also Rowles et al. (2018) study of water quality and consumption patterns in three rural villages of Oaxaca, Mexico.

3. Methods: a health needs assessment of three rural *pueblos* and an urban *colonia popular* in the State of Puebla, Mexico

The research for this paper grew out of a University of Texas at Austin Presidential Initiative to fund a small number of interdisciplinary research experiences for three to four-person undergraduate teams working with faculty mentors and a graduate Research/Teaching Assistant. In the 2018-19 competition, which was the first round of the award, from among the proposals submitted for seven World regions, our Puebla project was the one selected for the Latin America, Mexico, and Caribbean region. The President's Award for Global Learning (PAGL) was embedded within the teaching curriculum of the University and offered students ten semester credit-hours to train, research, analyze, and write-up their findings over a twelve-month period during their junior and senior years (i.e. 2018-209).[5,6] The Final Report for our study was completed in March 2020, and may be found at www.lahn.utexas.org (Puebla Extension: "Health Needs Assessment").

Working with three faculty mentors and a graduate teaching assistant, the 2019 Spring semester was dedicated to training, cultural orientation, and preparation for immersion in the field which, in our case, took place over ten weeks (June through August), followed by analysis and report drafting during the Fall semester. Given the relative proximity to Mexico and to our fieldwork villages and research sites, we were able to make a return visit in October, in order to discuss the principal findings with the communities, with our NGO partners,[7] and with our collaborators at the Medical School of the Benemérita Universidad de Puebla (BUAP). We also provided an interim report to the State Health Ministry (Secretaría de Salud Estatal).

3.1. The study context: four communities

The metropolitan area of Puebla is located some 60 miles to the south-east of Mexico City in the state of the same name. The state is the fourth poorest in Mexico, with some two-thirds of the population living below the poverty line compared to around half that of the national population (OECD, 2016). Puebla State has systemic health inequalities being ranked 27th out of 32 states in access to healthcare, and it has the highest rate of infant mortality in the country (OECD, 2016). Mexico has one of the highest population levels of people living with non-communicable diseases (NCD), which account for 47% of premature deaths from all causes in men, and more than 67% of premature deaths in women (Córdova-Villalobos et al., 2008).

Table 1 presents the background data relating to the four communities that we studied in depth. The villages are located East and South of

[5] The team comprised four undergraduate students Christina Ciburri, Claire Stephenson, Andrea Sandoval Flores, and team leader Veronica Remmert. Mr. Alfonso Rojas Álvarez was the Research Assistant, and three faculty mentors were: Ricardo Ainslie (PhD); Tim Mercer (MD); and Peter M. Ward (PhD). All were intimately engaged in data collection and the household survey and their contributions are warmly acknowledged. Writing the Final Report was undertaken by Remmert, Ward, Ainslie, Mercer and Rojas, and separate papers are authored separately: The current paper is one such example.

[6] For more details on the PAGL see https://presidentsglobalaward.utexas.edu/. See also the production video that was made about the Puebla study at https://vimeo.com/393352303.

[7] The Fundación Comunitaria Puebla (FCP) and the Fundación Mónica Gendreau (FMG – part of the FCP). We are extremely grateful to our partners for their support, enthusiasm and for allowing us to engage with their principal extension workers – Patricia Vargas Espinosa and Alejandro Luna López—whose close knowledge and familiarity with community leaders and households facilitated our introductions and opportunities to conduct surveys in each of the three agricultural communities. We are also very grateful to Dr. Adriana Pacheco Roldán (then Chair of UT's International Board of Advisers) and herself a *Poblana*, for supporting us throughout the project, and indeed, for participating in several of the community meetings during fieldwork.

Table 1
Overview of demographics in each community.

Pueblos and Sites	San Fco. Xochiteopan N = 81	Colonia Agrarista N = 55	Santa Ana Coatepec N = 60	Colonia Flores Magón N = 46
Total Population[a]	984	306	1147	4500[b]
Classification	Rural	Rural	Peri-Urban	Urban
Average Household Size - Persons	3.9	3.7	4	4.4
% of Extended Family/More than one family on the lot	42%	33%	28%	32%
% of Households with One House on Lot	56%	65%	72%	67%
% of Households with Two Houses on Lot	28%	22%	22%	17%
% of Households with Three or more Houses on Lot	14%	11%	7%	15%
Average Tenure of Family in Home (years)	27	33	25	34
% of Female Respondents	73%	82%	70%	80%
Average Age of Respondent (years)	49	53	49	52
% of Respondents who Completed Secondary School	25%	29%	35%	54%
% in Possession of Vehicle	35%	20%	52%	46%
Primary Economic Activity of Community	Agriculture	Agriculture	Agriculture	Services
Primary Agricultural Cash Crop (in addition to corn and beans)	Amaranto (47%) Chia (36%)	Chia (69%) Amaranto (49%)	Corn (80%) Beans (47%)	NA
Distance from Center of Atlixco (kms.)	38.5	41.5	11.5	1.5

N = Number of household surveys completed in each community.
[a] = Taken from 2015 Census data.
[b] Approximation in February 2020.
Source: Household Survey PAGL Report Chapter 1.

the town of Atlixco with its almost 100,000 residents (Fig. 1). Atlixco has a hospital and other medical facilities and is the primary provider of health care for the region. It is also the center for weekly provisioning, and most households go to the market in Atlixco at least once a week (usually on Saturdays). Three of the communities are poor agricultural pueblos: San Francisco Xochiteopan, Colonia Agrarista Emiliano Zapata, and Santa Ana Coatepec. The first two are relatively remote and isolated (see Fig. 1), while we classify Santa Ana as a "peri-urban pueblo" given the relatively close proximity to Altixco. It was also perceived to be slightly better off, with better infrastructure such as paved streets, regular public transport, and higher vehicle ownership (Table 1). One also observes some difference in the primary products grown in the two other pueblos compared to that of Santa Ana, which also engages in some services (Table 1). Atlixco is a popular weekend tourist town for visitors from both Puebla and Mexico City, some of whom also have summer and weekend homes in surrounding villages, although this was not a feature in any of the three surveyed pueblos.

We also included an established and relatively consolidated low-income neighborhood (*colonia popular*) called Colonia Flores Magón,[8] where services rather than agriculture offer the primary source of employment. This research design allows us to analyze and compare the health profiles and treatment patterns of the agricultural pueblos to those of urban residents such as Colonia Flores Magón (see also Corburn and Sverdlik, 2016). We also anticipated that such a research design would allow us to draw interesting comparisons with health profiles that we have conducted and studied for Texas colonias.

This part of the State falls under the shadow of the active volcano Popocatépetl, with its often multiple-daily eruptions. Depending upon the wind direction, Atlixco and the three *pueblos* are periodically affected by light ash deposits and poor air quality, both of which feature in our housing survey and analysis. In the same vein, the area is subject to regular seismic activity, and a violent earthquake in September 2017 caused major structural damage to Atlixco and to dwellings in the three *pueblos*, especially in San Fco. Xochiteopan where the iconic Church and symbol of the community was destroyed.[9]

The volcanic soils are very fertile and form the basis of mostly small-scale subsistence farming on parcels of land owned or worked by the *ejidatario* households whom we interviewed. *Ejidos* were established after the Mexican Revolution 1910-20, from the previous extensive haciendas and were considered social property with use-rights rather than full ownership, at least up until 1992 when further reforms allowed for full ownership. Under the post-revolution land reform program *ejido* plots were handed out to small-scale subsistence farmers who, as members of the *ejido,* were permitted to bequeath their use rights of the plots to male and female heirs.[10] Farming in the *ejido* is an individual operation, albeit under a clear collective governance structure. The pueblo itself was deemed an *ejidal* "urban" zone in which each household, and others who served the *ejido* such as blacksmiths and bakers, were assigned homesteading lots which they owned outright. Under the *ejidal* regime, most families were assigned several small parcels of land of different quality around the village, and given that most do not have a tractor, farmers spend an hour or more walking and driving their animals to the parcels upon which they are working. Corn (maize) and beans are the staples grown for subsistence, complemented with a small cash crop such as *chia* and *amaranto* (Table 1).

This is rain-fed agriculture that starts with planting at the onset of the rainy season in July, and harvesting takes place three or four months later. Both spouses and other family members are involved in the busy period of planting and harvesting, while men tend to the parcels and maintenance throughout the rest of the year. Corn and beans are stored for family consumption throughout the year, and cash crops provide the income to purchase vegetables and produce. Some families grow produce and keep animals in their yards, and in the rainy season there is some "gleaning" (collection) of wayside plant leaves and herbs for household use.

As Table 1 indicates, actual average family size is not excessive – usually three to four persons –since most households have adult children who have left the nest and live nearby (the case with girls especially). However, many lots to have two or more families sharing living space either in "compound" arrangements, defined as those cases in which two

[8] In Mexico *colonias* are neighborhoods. *Colonias populares* are working class neighborhoods that began informally and embody self-building. In Texas, the border colonias are named for their counterparts on the Mexican side of the border.

[9] The PAGL paper on mental health explores the ongoing anxiety and stress related to that event (see Ainslie and Rojas 2020).

[10] Interestingly, Colonia Agrarista "Emiliano Zapata" spun off from Xochiteopan after a dispute about the management and assignment of the *ejido*. It is a more radical and mobilized community (Chapter 3, PAGL, 2020).

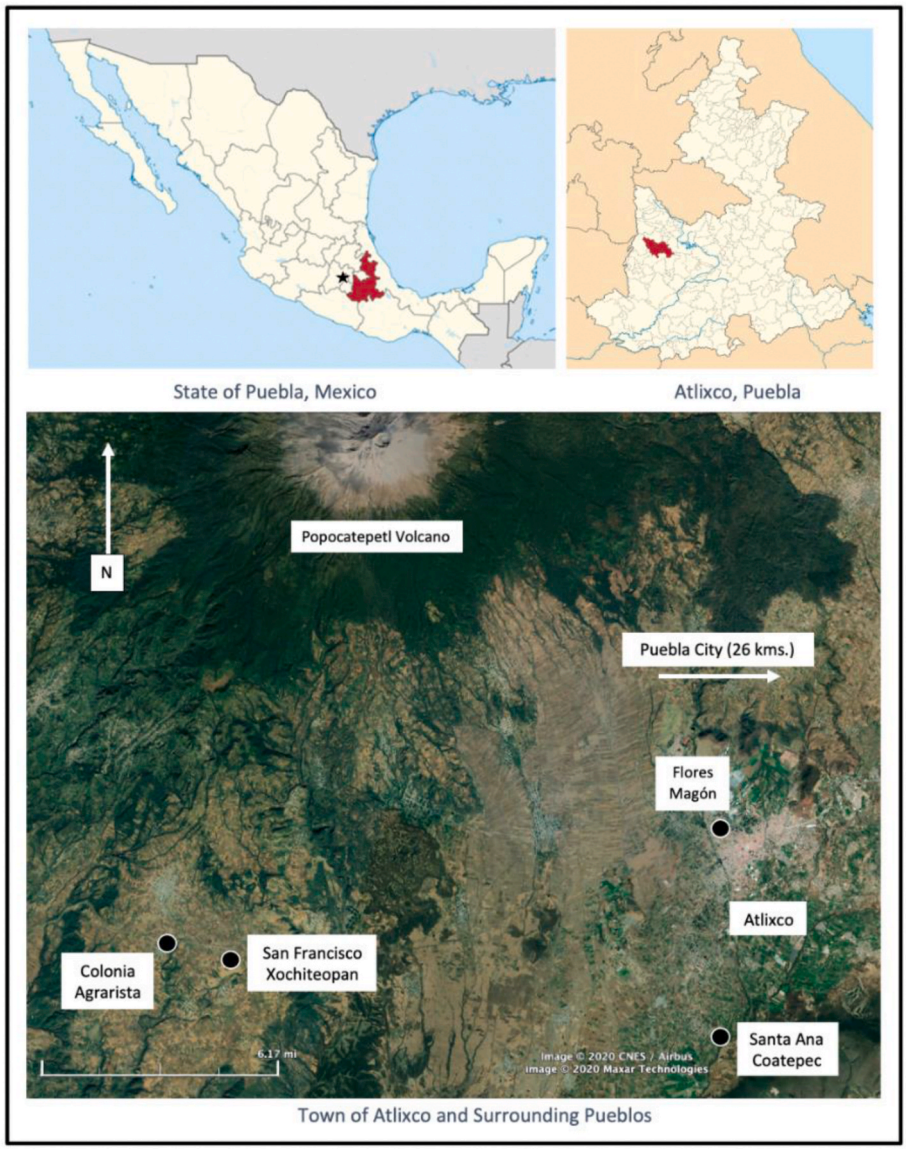


Fig. 1. Map showing locations of Puebla State, the town of Atlixco, and the four study. communities (marked by dots). Popocatépetl is the active volcano that regularly sheds ash and smoke across the region.

or more close kin-related households live in separate dwelling/spaces,[11] or as extended households comprising parents, adult children, and grandparents etc.[12] Thus many lots have eight or ten family members living together. Smaller nuclear families are also widespread, especially in the more established communities such as Santa Ana and Flores Magón, but even in these cases compound and extended arrangements are commonplace. Lot sharing among close kin-related households is an important mechanism of reciprocal support, poverty alleviation, and sharing the farming tasks in the rainy season. Even those households who do not share their lot invariably have close kin living nearby in the community.

3.2. Research strategy: a mixed methods approach

We adopted a mixed-methods strategy starting with an analysis of secondary data such as the census, relevant government and NGO reports and archives, and health system data. While the secondary data provided a good foundation to prepare for conducting the research in Mexico, we utilized a community-based participatory research strategy adapted to the individual challenges and patterns presented by each community. Once in the field, and after being introduced to members of each community in open meetings to explain the purpose of the study, we conducted surveys, focus groups, key-informant interviews and intensive case studies.

3.2.1. Household surveys

We began with a purpose-designed household questionnaire survey conducted in Spanish on electronic tablets using Qualtrics software. Our ability to engage household participation across the three pueblos would have been impossible without personal real-time introductions to residents from local agricultural extension workers – a married couple, Paty and Alejandro from the *Fondo Mónica* as it is affectionately named by

[11] An example is provided in https://lahn.utexas.org See "Puebla Extension" Appendix 4: Case Studies #1 & 2 San Fco. Xochiteopan where households share the lot in separate dwellings: 1) Nuclear family of parents and children and 2) the nuclear family of the eldest son. But both households share the "kitchen" and often eat together.

[12] Ibid. Appendix 4: Case # 2.

community members. To the extent that they first introduced us to families and encouraged their participation in the survey, household selection was "purposive" rather than randomized as we had originally intended. However, the relative socio-economic homogeneity and economic activity of households in these pueblos, combined with the common experience agricultural cycle described above, allows us to believe that the data we collected are quite representative of each *pueblo*. The survey covered demographics, health needs and access to healthcare, mental health and wellbeing in the communities, as well as health-impacting behaviors and related housing data. Household demographics focused on understanding the household structure and its dynamics, and included information about education, employment, and access to public and private transportation. Data were collected about family health profiles, access to healthcare institutions, types of medical attention for chronic as well as other illnesses, and individual opinions and perceptions of the quality of attention that family members received. The housing section of the survey gathered data about the physical structure of the dwelling, as well as environmental sampling of air and drinking water quality on each lot.

In order to gain access and a good response from residents in the urban colonia neighborhood of Flores Magón (where we did select households randomly), we relied upon a local contact who had close ties to the Town Council (*Ayuntamiento*). Thanks to him we were successful in getting cross-party political support to work in the urban colonia, including the offer of public police accompaniment while we were interviewing. This we politely declined, and the police patrol just made occasional "beat" checks to verify that we were OK. Ultimately though, we were obliged to abort after having conducted 46 interviews when, what we presumed were drug gang members, started making enquiries about the team's activities and movements. In total, 242 surveys were conducted across the four communities (Table 1).

3.2.2. Focus groups and key informant interviews

Six focus groups were conducted to expand on themes we found to be important to each community, and the topics included cooking practices and air quality in the home, diet and nutrition, immigration and remittances, chronic illnesses, problems with street dogs, and alcoholism. Participation was voluntary and encouraged by our NGO colleagues, and we did provide modest compensation for participation. We also interviewed several key informants[13] as a means of gathering additional data and understanding around topics beyond the materials captured in the survey.

3.2.3. Intensive case studies

In addition to the household survey on housing, we use an intensive case-study methodology that we had developed earlier as part of the Latin American Housing Network (https://www.lahn.utexas.org/) study of consolidated barrio and working-class (colonia) neighborhoods in nine Latin American countries, including the Mexican cities of Guadalajara, Mexico City and Monterrey (Ward et al., 2014).[14]

In the three rural communities five intensive cases were purposively selected in order to explore in greater detail the health challenges presented by: 1) hazardous air quality in homes and kitchens; 2) mobility impediments and the risks of accidents associated with different types of dwelling structures and lot organization; 3) health risks associated with life in very close proximity to farm animals (goats; chickens, cows); 4) disease and poor health linked to dirt floors, flimsy housing structures, storage of agrochemicals and fertilizers, ingress of pests, etc.; and 5), the utilization of new dwelling units that had been provided to households who lost their homes in the 2017 earthquake. It is important to underscore that the cases studies were not selected with the goal of generalization, but rather were designed to gain more detailed insights into the intersection between housing and health outcomes. Thus, intensive case studies are often "outliers": for example, dwellings where we identified particularly high levels of poor air quality; and in another rather anomalous case of single-person household where the owner was severely disabled from the waist down: how did he cope, we wondered?

Once a case study had been identified from the survey for possible inclusion, we returned to the lot to explain our objectives, and to explore the family's interest in participation and to request permissions. We offered a modest payment of 500 *pesos* (then about US$25) to compensate for the fact that five or six team members would all be on site for several hours, and because this would be represent a considerable intrusion into the innermost parts of their dwellings, as well calling upon their valuable time when they needed to be in the fields planting. We also committed to return in the Fall to provide each family with a copy of their lot and dwelling plans. Of the six households whom we approached, only one family declined.[15] A mutually convenient time and date was arranged for the site visit. Once on site, we undertook a number of data-gathering activities: 1) detailed measurements of the lot and dwelling structures in order to prepare lot and building plans; 2) photographs, aerial photos from a drone, and video recordings of all buildings and features on the lot; 3) air quality readings in all or most of the rooms, water quality readings; and 4), one-on-one interviews with additional family members, as well as follow-up discussions with the original interviewee(s).[16,17]

An integral element in subsequently building-out our notes and plans for each case study was to create a set of lot and dwelling diagrams that would pinpoint locations that presented particular health risks to household members. These risks included poor or dangerous air quality; poor building materials; living and sleeping in close proximity to farm animals such as turkeys, goats, cows; the presence of uneven or dangerous surfaces; hose pipes, high entry lintels on doors, all of which could cause falls and impede mobility especially for the elderly; rooms with high humidity; and garbage or dump areas on the lot which attracted flies and offered breeding sites for mosquitos and other insects.

4. Findings: housing and health in the three agricultural *pueblos* and in the urban *colonia popular*

Earlier in the paper we gave a summary showing that fifty percent or more of the households have at least one household member with a chronic illness, with similar percentages reporting a member with a major disability. Colonia Agrarista was an exception, where it dropped to just below 40 percent (See PAGL Report, 2020; Remmert and Mercer, 2020). Moreover, the three principal chronic illnesses reported were diabetes, hypertension and musculoskeletal conditions such as bone and muscle pain and arthritis, and although the actual rankings varied between the communities, diabetes was always either first or second most

[13] Clinic personnel, community leaders, extension workers, NGO staff, and in Santa Ana the community resident responsible for chlorinating the water supply.

[14] This methodology had also been used with good effect in a study of lot sharing and dwelling sub-division among family members in Texas *colonias*. https://www.lahn.utexas.org/lahn-extensions/texas-housing-database/ford-foundation-housing-study/.

[15] And that was when we tried to go it alone without a personal introduction from Alejandro or Paty: our bad!.

[16] We are indebted to UT School of Architecture undergraduate student Ms. Melannie Ruiz who turned our sketches and measurements into the final plans, as well as creating 3D sketch-ups of each building. We returned in October 2019 and delivered the plans to each of the five families, usually after an open community meeting convened so that we could present our initial broad-brush findings.

[17] Subsequently we drew up the specific house plans with lot and photos and these are available on-line at https://www.lahn.utexas.org/lahn-extensions/puebla/appendices/(See Appendix 4, Case Studies 1a-5a), as well as detailed dwelling construction plans and 3-D sketch-ups.

Table 2
Household fuel sources for cooking, practices for obtaining potable water, perceptions and measures of water and air quality.

Pueblos and Sites	San Fco. Xochiteopan %(N = 81)	Colonia Agrarista % (N = 55)	Santa Ana Coatepec % N = 60)	Colonia Flores Magón % (N = 46)
Sources of Cooking Fuel (may use more than one)				
Wood (Leña) % who use	98%*	87%*	78%	20%
Charcoal (Carbón) % who use	77%	78%	73%	26%
Gas tanks propane % who use	35%	44%	77% *	98% *
* = principal				
Drinking water - household usage always or very frequently				
Tap (*llave*) often via storage tank	83%	60%	60%	98%
Well (Pozo)			49%	9%
Tap & Bottled (purified)	0	4%	43%	76%
Believe that tap water is chlorinated	83%	53%	98%	96%
Regularly boil water before drinking	15%	31%	40%	50%
Felt strongly that water needs to be improved)	43%	55%	58%	70%
Mean chlorine concentration (ppm)	0.0307	0.0393	0.1151	0.1461
Air Quality in Kitchen				
Mean Carbon dioxide (CO2) concentration (ppm)	792.48 (Moderate)	760.71 (Moderate)	812.44 (Moderate)	987.91 (Moderate)
Mean PM2.5 (smoke particles) concentration (ppm)	44.58 (Unhealthy for Sensitive Groups)	70.91 (Unhealthy)	38.14 (Unhealthy for Sensitive Groups)	12.68 (Moderate)
Mean PM10 (smoke and ash) concentration (ppm)	58.75 (Moderate)	87.97 (Moderate)	48.36 (Good)	16.5 (Good)
Measures of Air Quality PM 2.5; Pm10; and CO2				
Poor levels of PM2.5 (N)	67% (9)[a]	57% (42)	71% (42)	55% (33)
Unhealthy levels of PM 2.5	33.30%	2.38%	2.38%	3.03%
Hazardous Levels of PM2.5	0%	7.14%	2.38%	0%
Poor levels of PM10	33%	5%	2%	3%
Unhealthy levels of PM 10	0%	0%	0%	0%
Hazardous Levels of PM10	0%	8%	2%	3
Poor levels of CO2 (N)	33% (33)	50% (42)	41% (42)	54.55% (33)
Unhealthy levels of CO2	8%	0%	14%	16%
Hazardous levels of CO2	0%	0%	2.38%	0%
Air Quality in the Home and Community				
Very satisfied air quality in home (N)	79% (64)	75% (41)	73% (44)	76% (35)
Yet also believe that are significant problems of air quality in the home (N)	49% (40)	36% (20)	30% (18)	46% (21)
Very satisfied air quality in the Community (N)	64% (52)	72% (40)	57% (34)	30% (14)

[a] Low N of cases here due to sample collection and data uploading errors.
Source: Household Survey, 2019

important. This is important for our discussion since both diabetes and musculoskeletal conditions are likely to be exacerbated in poor housing conditions, and on lots where mobility may be impaired by uneven surfaces.[18] In the following section we drill-down on the specific findings related to housing and infrastructure that impact health and wellbeing.

4.1. Drinking water sources and patterns of consumption

All three of the communities have access to piped water supplies direct into the home or into on-site storage tanks. The service is provided by the municipality and by community officials, and is chlorinated at the pumping station in the pueblo (although many respondents in Agrarista complained that it was inadequate). Residents pay a flat rate fee based upon the number of household members (including new born babies), and in both Agrarista and San Fco Xohiteopan for cost reasons the supply is only turned on twice a week (Sundays and Wednesdays), and sometimes only once, as occurred in the week that we were doing fieldwork. Supply in Flores Magón is good and provided by the town.

This tap water supply is used both for drinking and for daily household uses and is usually piped into the home via a storage tank or cistern. In the three pueblos the same water is used for all purposes: for drinking, washing, cleaning, and for the animals. In Santa Ana the topography allows for most households to also have their own well, used for animals and household use rather than drinking. In the rainy season some households also capture rainwater into these storage tanks, but in the remainder of the year the water supply comes via the network. Given that we were interviewing in the rainy season the original source was not always clear and this further compromised our water sampling which sought to measure chlorine levels. The problem was that tap water drawn via a storage tank was likely to register lower levels of chlorine than that directly taken off the network.

That caveat aside, in the two most rural pueblos (Xochiteopan and Agrarista), the level of chlorine is very low, on average about one-tenth of the prescribed minimum concentration of 03 ppm, suggesting that insufficient chlorine is being introduced into the distribution system. Table 2 shows that some families regularly boil the water that they drink, although the practice is notably much lower in Xochiteopan, and with the exception of the better-off urban and peri-urban communities of Flores Magón and Santa Ana, few families regularly purchase bottled drinking water, largely because they cannot afford to do so.

[18] Two of these chronic conditions – Hypertension and Diabetes – are also considered high risk factors for COVID-19, as are respiratory illnesses (poor air quality, asthma, etc.). However, our subsequent enquiries suggest quite low infection rates in these three pueblo communities as a result of low population density; outdoor living, and physical fitness born of agricultural work.

Fig. 2. Typical wood fire in outdoor "kitchen".

4.2. Patterns and perceptions of household air quality

In the three rural *pueblos* the majority of the households utilize wood as the primary cooking fuel over propane gas or electricity (Table 2). In urban Flores Magón 98% use gas, although residents also occasionally use charcoal (*carbón*) and wood (*leña*) for cooking. In Xochiteopan and Colonia Agrarista most families do not have a formal "kitchen" but prepare food in a space set aside from the house and main living areas (see Figs. 2 and 3). Structures are especially likely to be made of corrugated bitumen cardboard (*lámina*), sometimes open on one side and giving out onto the patio (see website photos at Appendix 4: Case 5a),[19] and if good ventilation is not assured then very poor or even hazardous air quality may ensue as we describe below (see also the website https://www.lahn.utexas.org/lahn-extensions/puebla/appendices/ See Appendix 4 Case 1a & 1c).

Fig. 3. At the rear is a large bowl set above a wood fire (to cook *mole* in this case), and small charcoal burning stoves (foreground) for warming *tortillas*.

During the household survey we took air quality measurements in several rooms, prioritizing the kitchen and cooking areas, and the aim was to better understand the impact of indoor air quality on health (for details on each of the measures and the instrumentation that we used see https://land.utexas.org/Puebla/App3.html).[20] We used a handheld instrument which provided detailed readings of particulate matter PM2.5 and PM10, largely smoke and ash particles respectively, as well as levels of carbon dioxide, humidity, and the temperature.[21] Most households gave us permission to take air quality samples in at least two areas of the dwelling, and we focused mostly on the kitchen/cooking area and the patio/yard which is where people spent much of their time. Sometimes we obtained readings for bedrooms, and less frequently for bathrooms, since few dwellings had a dedicated bathroom.

Our analysis focusses upon carbon dioxide (CO2) and air-borne particulates primarily PM2.5 as it consists of finer particles that are widely known to be detrimental to health. Long-term exposure can lead to the development of heart and lung disease and premature mortality. More importantly, perhaps, short-term exposures to particulate matter can aggravate asthma leading to poor respiratory health. This can be

[19] Note that all diagrams and commentary are reported in Appendix 4 of the Report and may be viewed (and accessed) at https://lahn.utexas.org. They are located in the Puebla Extension. For each of the five case studies we provide: a) a lot plan with photos; b) the same plan but with photos relating to health hazards; and c) a short description of the case. To the extent possible identifiers are redacted and pseudonyms are used for family names.

[20] The standards for quality ("Good, Moderate, Unhealthy for Sensitive Groups, Unhealthy, Very Unhealthy, Hazardous") are standard EPA measures for air quality and health.https://www.epa.gov/wildfire-smoke-course/wildfire-smoke-and-your-patients-health-air-quality-index.

[21] Temtop Model M2000C https://www.temtopus.com/.

especially harmful to young children who spend so much of their time alongside their mothers. Some women reported having to carry their toddlers while they cooked, sometimes for up to three hours at a time. Children are more prone to developing acute or chronic respiratory diseases when exposed to CO2 and to particulate matter in poorly ventilated dwellings. Adverse health effects of poor indoor air quality include low birth weight, tuberculosis, asthma, and the development or worsening of other respiratory illnesses. Cooking with wood and charcoal, without adequate ventilation, is associated with an even higher increased risk for asthma.[22] In San Fco. Xochiteopan for example, asthma is the third highest chronic illness reported, and we suspect that this is linked to the high levels of PM2.5 and CO2 in the home. As the World Health Organization shows, poor respiratory health outcomes among children in low-income settings can be aggravated by a combination of inadequate ventilation, crowded unsanitary conditions, and by the lack of resources to adopt safer fuel alternatives (WHO, 2005).

Vehicle emissions, agriculture, and dust from unpaved roads are additional sources of particulate matter, as are the frequent volcanic ash discharges from Popocatépetl: all exacerbate poor air quality in the communities.

The limited or poor ventilation observed in many kitchens/cooking areas and homes can increase the exposure to toxic pollutants emitted by solid fuels (Pérez Maldonado et al., 2011). We also observed plastic bottles and cups being used as an accelerant to start the wood fire,[23] and even though cooking fires were often placed away from the house, often in lean-tos, the partial exposure to wind meant that smoke often blew back into one's eyes and face. Where cooking was done in a single room with limited ventilation, the air quality readings were often hazardous and toxic. Cooking with wood, and the associated discomforts of eye and skin irritation and coughs that come with it, have become the norm in rural communities largely due a lack the resources to opt for safer fuel alternatives. Awareness of the hazards of such practices was often voiced; however, people reiterated that wood was simply more affordable and accessible, and that food tasted better.

4.2.1. Particulate matter (smoke and ash)

In the three rural *pueblos*, concentrations of PM2.5 show averages ranging from 38 to 71 μg/m3 (for equivalent in ppm see Table 2). By comparison, EPA's annual air pollution standard for PM2.5 is 12 μg/m3. The levels in the rural communities studied are considered "unhealthy" as Table 2 shows. While these are average levels, if one disaggregates the upper "tail" of the distribution it can be seen that a significant proportion of households are regularly exposed to unhealthy and very unhealthy particulate and CO2 readings across each of the three communities (Table 2).

4.2.2. Carbon dioxide (CO2)

In all four communities, the mean CO2 concentrations range from 760 to almost 1000 ppm falling into the "moderate" health-risk category. Although in our discussions with residents CO2 did not figure as such a significant issue as did particulate matter, we find some alarming levels within the homes, particularly in the kitchen spaces. An added hazard of CO2 is that, unlike smoke and ash, it is invisible, and is likely to be high in bedrooms with poor ventilation and where there is overcrowding of sleeping space. Unclean bedding, bug infestations can also compromise health and wellbeing.

While designing our survey, we were alerted by our NGO collaborators that we should include some questions about the use and storage of fertilizers and specific agrochemicals such as aluminum phosphide which households use to fumigate and protect their maize crop. Fertilizers, pesticides, and other agrochemicals that are not properly stored can have adverse effects on human health. Acute illnesses such as skin rashes, headaches, dizziness, and nausea have been linked to contact with pesticides, and in more serious cases chronic illnesses such as prostate, lung, and breast cancer have been correlated to the use of agrochemicals (Biswas et al., 2014). Our study reveals that the majority of households understand some of the dangers of chemical storage, although awareness is significantly lower in Agrarista, (only 44% of households were aware). Most households have a dedicated storage space (*almacén*) in which they keep agrochemicals although this was somewhat lower in Xochiteopan (48%). During the survey we also observed that a minority of homes had sacks of these chemicals in living spaces and sometimes even in bedrooms or cooking areas.

In these agricultural communities most yards have a range of farm animals and livestock such as goats, cows, chickens, donkeys, all of which can impact the quality of air in and around the home. In some cases, chickens are left to roam loose and were observed climbing onto beds and other furniture.[24] This close interaction between humans and animals is very commonplace in the three pueblos and can be problematic for health since domestic and non-domestic animals can shed or spread allergens, biological particles, and sometimes gases. Building materials and household furniture can also be a source of indoor air pollution: formaldehyde and volatile organic compounds (VOCs) can be emitted from wood products and paints, and earthen floors can allow radon to be introduced into the atmosphere, as well as generating higher levels of suspended particulate matter (dust).

4.2.3. Perceptions of air quality

Despite these findings, more than half of the households in the three rural pueblos report being very satisfied with the air quality within their homes, even while almost a third of them simultaneously recognize that there are significant health problems associated with poor indoor air quality. As for the quality of air outdoors, a lower percentage of people report being satisfied, and blame most of this discomfort on (the volcano) Popocatépetl's regular discharge of ash. We found it surprising that most people believe that the periodic light dusting of ash across their village poses a much greater risk on their health than the smoke and pollutants generated by the daily wood-and-plastic-burning in their cooking spaces. However, cooking with wood and charcoal are the norm in these villages, and few people view it as a hazard.

4.3. Baseline dwelling structures and post earthquake reconstruction

Traditional building and dwelling arrangements in these pueblos require a sizable lot for dwellings, animals, and for storage of wood, fertilizers, grain, and farm equipment. Unlike respondents to the survey in Flores Magón who receive property tax bills and know the size of their lots, in the pueblos few could tell us or estimate the actual size.[25] However, our intensive case study measurements and diagrams show lot sizes of 1000 m^2 or more are the norm, and are almost double that size in Colonia Agrarista (Table 3). Most are smallholder farmers who as *ejidatarios* have both a homestead in the *ejidal* urban zone, as well as several small land parcels for cultivation outside of the pueblo.

In the past, dwellings were traditionally built with *adobe* bricks made from compacted earth and straw. This rarely allowed for a second story, and the absence or limited use of lintels over doors and windows means that rooms often lack natural lighting, or have very small window openings. More recent building practices use concrete block (*tabique*) which does allow for upper floors provided that there is some sort of steel reinforcement, and that the first-floor ceiling is made of reinforced concrete. Otherwise roofs are of laminated (corrugated) iron or

[22] *From* <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2760246/>).

[23] The focus group confirmed that this practice was widespread.

[24] https://www.lahn.utexas.org/lahn-extensions/puebla/appendices/Appendix 4: Case # 3b & 3c.

[25] 500+m^2 is actually quite large for informal settlements in urban Mexico where 200 m^2 is the norm, but Flores Magón began with illegal sales of *éjidal* land, and parcels were often quite large, even if they were later subdivided.

Table 3
Characteristics of dwelling structures, building materials, bathing & toilet facilities.

Pueblos and Fieldwork Sites	San Fco. Xochiteopan	Colonia Agrarista	Santa Ana Coatepec	Colonia Flores Magón
Lot size – "trimmed" mean (5% values removed top and bottom)	1015m2 (37)	2377m2 (26)	917m2 (31)	566m2 (22)
Dwelling Number of Rooms Excluding Kitchen and Bathroom				
One or two	53% (43)	46% (25)	35% (21)	33% (15)
Four or more	16% (13)	27% (15)	30% (18)	28% (13)
Construction Materials Used in the Various Rooms. Floors[a]				
Tierra/earth	42% (16)	22% (12)	2% (1)	7% (3)
Concrete	86% (70)	91% (50)	83% (50)	71% (33)
Tile/mosaic/*Loseta*	5% (4)	11% (6)	20% (13)	35% (16)
Walls[a]				
Adobe	25% (20)	42% (23)	5% (3)	–
Block/*tabique*/concrete	96% (79)	87% (48)	113% (87)	113% (52)
Wood/lamina/plastic etc. throwaways	9% (7)	9% (5)	–	2% (1)
Roof[a]				
Concrete	79% (64)	67% (37)	88% (53)	91% (42)
Zinc corrugated etc.	33% (27)	50% (28)	25% (15)	27% (12)
Lamina de carton/asbestos	14% (11)	22% (12)	10% (6)	11% (5)
Type of wc/toilet/connection				
Pit latrine; septic tank Latrina/fosa septica	40.73% (33)	43.64% (24)	5% (3)	2.1% (1)
WC connected to drainage system	57% (46)	51% (28)	95% (12)	98%
Type of Bathing				
Ducha/Shower	26% (21)	22% (12)	62% (37)	61% (28)
Tina/bathtub	14% (11)	–	–	–
Tazón (bowl)	41% (33)	71% (39)	37% (22)	40% (28)
Jicarazos (gourd)	17% (14)	4% (2)	2% (1)	–
% households reporting rooms without natural lighting	28% (12)	14% (7)	9% (2)	8% (2)
Primary room where there is no natural lighting	Bedrooms	Bedrooms	Kitchen & bedroom	Bedrooms

[a] Readings may be of mixed materials and thus percentages can add up to more than 100%.
Source: Household Surveys

bituminized cardboard (*lámina de cartón*).

In both new and old dwellings most of the interior space is used largely for sleeping and/or for storage, and we were struck that households made little effort to furnish rooms, not surprising perhaps since most of the daily activities are conducted in the patio/yard, and in the kitchen or cooking areas.

As one can observe in Table 3, excluding kitchen and bathroom spaces the number of rooms in Xochiteopan and Agrarista homesteads is quite small, with around half of the dwellings comprising just one or two rooms. This leads to higher rates of overcrowding in these two communities, which can have important negative health outcomes such as Tuberculosis, other respiratory illnesses, skin infections etc., especially when several members are sleeping in the same room (Pemberton et al., 2007). While many homes have walls and floors made of permanent materials such as concrete and bricks, others have rooms, or sections of rooms, made of flimsy materials which diminishes their physical integrity, heightens vulnerability to earthquakes, and increases the likely problems of damp and pest ingress. Xochiteopan and Agrarista are particularly vulnerable in this respect, with a significant proportion of dwellings having a dirt floors in one or more rooms (42% and 22% respectively);[26] walls made of traditional adobe (25% and 42%); and sometimes walls made from lamina sheets, wood, and plastic.[27]

Roofing materials are where one observes greater variation in the quality of construction materials. A large minority of homes have one or more rooms roofed in zinc or other laminated materials. Concrete roofs are preferable and important not only because they provide better conditions for heating and cooling, but are also easier to keep clean and reduce pest infestations. They also allow for a second story to be added. Santa Ana Coatepec and Flores Magón have more consolidated and larger dwellings (Table 3).

Fig. 4. Earthquake damage to consolidated adobe walled house (Image taken by Alejandro Luna López).

Toilet and bathing facilities vary, the former especially being predicated upon the existence of, and connection to, some form of formal drainage network which is the case in Santa Ana and Flores Magón. Both Xochiteopan and Colonia Agrarista rely heavily on pit latrines of one sort or another (above 40% of cases); and only around one-quarter of the dwellings have a formal shower/bathroom facility, the majority making do with a *tazón* (bowl) or gourd to splash water over themselves. One focus group mentioned that lice infestations (*piojos*) were a serious problem among children, and to the extent that hair washing is less frequent among those families without showers, this exacerbates the problem.

Natural lighting and windows are important both for their own sake as well as to enhance ventilation, and while relatively few homes have rooms without a window and no natural light, a modest number do – in Xochiteopan especially (28% of dwellings), twice that of Agrarista, and three times as high as Santa Ana and Colonia Flores Magón.

The 2017 September earthquake hit both Colonia Agrarista and Xochiteopan very hard, especially the latter where the Church was

[26] Important since several important diseases and parasitic infections are often related to dirt floors.
[27] https://www.lahn.utexas.org/lahn-extensions/puebla/appendices/Appendix 4: Case # 3a.

destroyed, as were many homes especially those made of adobe (Fig. 4). Its impact was less severe in Agrarista, even though it, too, has many homes built of adobe (42%). Fortunately, the earthquake saw relatively few casualties since most people were out in the fields when the quake struck at 1:00pm. However, so bad was the damage especially to many of the adobe structures, that a major rebuilding effort was put in place to provide new homes through Mexico's Natural Disasters Fund (FONDEN - 3 bedroom homes), and by our NGO collaborators (the Fundación Comunitaria Puebla, FCP) with a two-bedroom prototype.

Two of the selected intensive case studies included both the FONDEN dwellings and the FCP's L-shaped homes with an open section that was designed to include a small open patio for cooking. However, despite some expectation on the part of both the FCP and FONDEN that cooking in the new dwellings would take place within the designated kitchen spaces, households continue to cook in spaces and lean-tos outside, since few could afford gas propane tanks, and most continue to have a strong preference to cook with wood or charcoal.

4.4. Intensive case studies: housing & poor health & exposure to hazards

The five intensive case studies were selected purposively, and together they provide detailed insights into various aspects of the intersection between the dwelling and lot environment and poor health outcomes and health hazards. In this section of the paper our discussion and analysis will draw upon the household survey and all five case studies, but for reasons of article length, we offer observations on two of the cases as an illustration of how we went about gathering and presenting materials that contributed our better understanding of the intersections between the built environment of the home and lot and health. The other three intensive case studies upon which we draw our conclusions will not be presented here, but each is available as a set of appendices and case study descriptions in the Final Report at https://www.lahn.utexas.org/lahn-extensions/puebla/publications-final-report/url.

Those cases are not presented in detail here, but they include an extended household who live on a large lot and whose home is a large single room with a dirt floor. That room is used for all functions (sleeping, eating, cooking), and animals – especially the chickens – roam free, jumping on and off beds and kitchen tables.[28] Another case is from Colonia Agrarista, and is in many respects an extreme outlier since it involves a single male who is a disabled (paralyzed) from the waist down. He is unable to walk or use a wheelchair to move around the house and lot, but he has developed various ingenious ways of continuing an active life, moving around the lot, and hauling himself up onto his donkey. This particular case is of interest since it provides insights about how the physical dwelling structure and the lot environment have been adapted to allow for some level of mobility. It also highlights social interaction from neighboring kin, and the importance of remittances from a daughter living in the USA, with whom he is in weekly contact via internet (using a satellite dish on his roof).[29] The Santa Ana Coatepec case has the most substantial and consolidated dwelling of the five, with good lot space organization and animal husbandry. The house is set to the front, and there is an orchard and animals at the rear with good separation between corralled sheep and the actual dwelling area. The respondent lives with her elderly mother who has mobility problems, and they have a small store at the front giving onto the street. As in the previous disabled man's case, remittances from family members in the USA have greatly impacted the family's survival, and allowed them to substantially improve their living conditions and to mitigate health hazards and poor wellbeing.[30]

In the following section we offer insights drawn from two of the intensive studies. The plans and diagrams that we created provide a visual representation of the micro-lot environment, three-dimensional structures, air-quality readings for different structures/rooms, together with selected on-site photographs. Taken together these help us to depict behaviors and spatial arrangements that present health risks and hazards within, and across the dwelling environment. In order to enhance readability, the plans for each of the two cases is split into a left- and right-hand sections. In all cases the family names have been changed, although local members of the community may be able to identify the sites from the photographs.[31]

4.4.1. Intensive case study # 1. San Fco. Xochiteopan

This case[33] is selected for three reasons. First, our survey had identified extremely poor air quality and the burning of plastic as a starter fuel accelerant in the kitchen area, so much so that the smoke problem in the "*cocina*" was off the charts – hazardous – on both pm.10 = 928 and pm2.5 = 230.1. Second, it was a good example of two dwellings and two family-related households (parents and adult son and his family), so we wished to explore lot sharing arrangements and the organization of space: namely that of two households living in close proximity to their various farm animals. Third, the homes had been severely affected by the 2017 earthquake, and the family was recipient of targeted support from both FCP and from FONDEN – with two prototype dwellings. Fig. 5 provides a detailed lot plan (see the footnote url to link to the full lot layout with photos).

4.iv.a.i Lot description. At almost 1500 m^2 (Fig. 5) the lot is quite large, and prior to the earthquake the original adobe house fronted the street with a space for the truck alongside. It was destroyed by the earthquake, and there are now two new dwelling units (the pink and green houses). The other purple-colored unit is partly made of adobe and concrete block and was also one of the original dwellings, but today the rooms are used for storage. The pink structure above the purple house is made of wooden materials given to the family as disaster relief, and provided partial temporary shelter after the quake. It has now been adapted to create an additional room on the roof that is used for storage of household belongings, access to which is both very awkward and somewhat dangerous (Fig. 6b top photo). The kitchen is a single room made of bitumen corrugated laminate, with no windows and little light, except for the doorway and a small gap below the roof that provides some ventilation (see photo at Fig. 6a).

The rest of the lot working space and areas are dedicated to animal husbandry. It comprises a lower section including a shed (also made from materials provided after the earthquake), which is used as a breeding area for chickens and turkeys. There is a penned area for the smaller fledglings, and the larger birds roam free in the daytime. This lower part also has a small orchard (*huerta*) area with two pomegranate trees and bananas. The middle section of the lot has a tractor "port" for their two tractors – signaling that they are better off than most in the community. This is also the area where the larger animals are tethered (see photos): specifically, they have five cows and a calf, three horses, and a donkey which they take to the fields each day either to work the fields or to let them forage. They also have 30 sheep (see photos Fig. 6b).

4.iv.a.ii Health Hazards Commentary. The boxes on the figures show the air quality readings for each room, and highlight where poor or hazardous readings were registered. Upon our return to undertake the case study the earlier hazardous air quality readings were confirmed in

[28] https://www.lahn.utexas.org/lahn-extensions/puebla/appendices/Appendix 4: Case # 3.
[29] Ibid: Appendix 4: Case # 4.
[30] Ibid: Appendix 4: Case # 5.
[31] In which case, please respect the privacy of the families who volunteered to be part of the study.
[32] https://www.lahn.utexas.org/lahn-extensions/puebla/appendices/Appendix 4: Case # 1 a & 1c.
[33] https://www.lahn.utexas.org/wp-content/uploads/2020/08/Case1a.pdf.
[34] See also https://www.lahn.utexas.org/lahn-extensions/puebla/appendices/Appendix 4: Case 1a-1c.

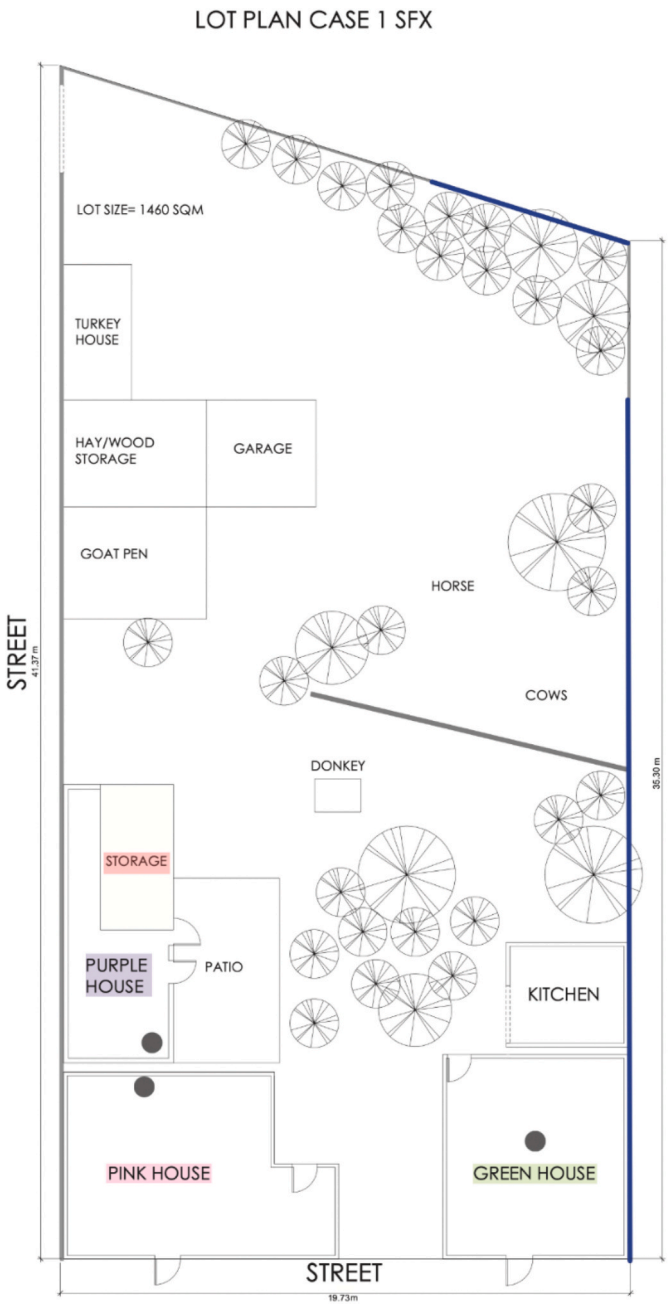


Fig. 5. Lot Plan of Case Study #1 Xochiteopan: Home of Doña Victoria and family.[32]

the kitchen, where both families also eat. We asked Doña Victoria if using plastic as an accelerant to lite the fires was common practice in the community, and a tad embarrassed, she nodded and said "yes, for most" (families). This suggest that there is some awareness of the danger, but that they do it anyway. Clearly there is little apparent cultural interest in cooking indoors since most people prefer wood and cannot afford gas and gas stoves. We were surprised to find that rooms in the two new dwelling units (pink and green in the figure), also record poor air quality – either at the "moderate" or "unhealthy for sensitive groups", which we explain as being caused by poor ventilation, since the windows were kept closed.

This is a serious working farm unit, and fertilizers are stored in the purple-colored building unit, so they do not present a health risk to the two households. The cows and horses are corralled very close to the house and may pose health risks, especially from their defecating close to the water tank. The sheep are corralled away from the dwelling space, as were the chickens and turkeys. The multiple stacks of wood, while set aside, are a possible fire risk, and could harbor pests and animals such as scorpions and snakes.

The water cistern in the center of the lot is fed from the network supply and is used both for drinking and for watering the animals. While not fetid, the water clearly is not fit for human consumption and if used as a potable source is a health hazard. The pipes and hoses leading to and from the cistern impede mobility and can cause falls. Although no-one in the family is yet elderly, mobility is impeded by the high lintel to the purple house, the multiple hose pipes straddling the yard, and an uneven climb to the kitchen and main dwelling units. And climbing up onto the second-floor temporary storage room above the purple house was dangerous – the two students team members had to climb up off of a chair (Fig. 6b, top inset photo).

4.4.2. *Intensive case study # 2. San Fco. Xochiteopan*

We selected this case primarily because the household survey showed that there were three households living on the lot (Website Appendix 4 Case 2a-c). It was also of interest since it included one of the FCP's-designed (Fundación Comunitaria Puebla) post-earthquake's core houses, which we had first seen and photographed on an initial reconnoiter visit a year earlier (March 2018). By the time of the survey the lot had seen lots of building activity. This included the enclosure of the open patio area on the FCP-dwelling which had been designed as an open kitchen and patio, and two new, but as yet unfinished, dwelling structures (see Website Appendix 4. Case 2a).

The first survey was conducted with Lidia, a 30-year-old mother who reported that she has lived on the lot all of her life and today lives in the FCP-built dwelling with her son (aged 9) and daughter Lupe (aged 4). As we began to gather the data for the intensive case study it became apparent that these were not three households but one, and comprised a mixed compound/extended household structure, actually headed by Lidia's mother (Doña Francisca) the matriarch, whose son Marco and daughter (Noemí) also live on the lot. Marco has some mental health issues, and he sleeps in the blue wooden room, while Noemí who is studying at the local High School (*preparatoria*) sleeps with her mother (Francisca) in the small two-roomed building (Fig. 7 house # 2. See also Website Appendix 4 Case 2a). Francisca has two other adult children who live elsewhere, and her elderly parents, who are also *ejidatarios,* live nearby in the same pueblo.

4.iv.b.i Lot Description. The incomplete constructions shown on Fig. 7 comprise two future dwellings: one is destined to be for Francisca and Noemí,[35] while the redbrick dwelling will be for Erik (another son).[36] The lot is relatively large (1141 m^2), and has two pig pens at the rear; as well as a plastic greenhouse provided by the FCP/Fondo Mónica Gendreau which Francisca attends to year-round, watering from the two large tanks (see Fig. 7). These tanks were originally designed to capture rainwater, but she fills them from the tap. She grows a variety of vegetables largely for home consumption. There is also a dilapidated storage shed and kitchen area adjacent to Marco's room alongside a small corral for sheep (not marked on the plot map). Most of the cooking is done in this kitchen with wood, and there is also a baking oven on the corner of Lidia's house (see photos). In the entrance to the newly enclosed area of Lidia's house which is used as a dining area, they have a small charcoal stove on which they warm tortillas, and close to the sink is an electric blender.

4.iv.b.ii Health Commentary: As one may observe on the plans

[35] It seems that Francisca's house is also being built – at least in part – using earthquake reconstruction funding from FONDEN, but which are insufficient to complete the job.

[36] Marco will move into Francisca's two room dwelling when she and Noemí move into the spacious new house. There are also plans to build two more homes at the back of the site for her other children.

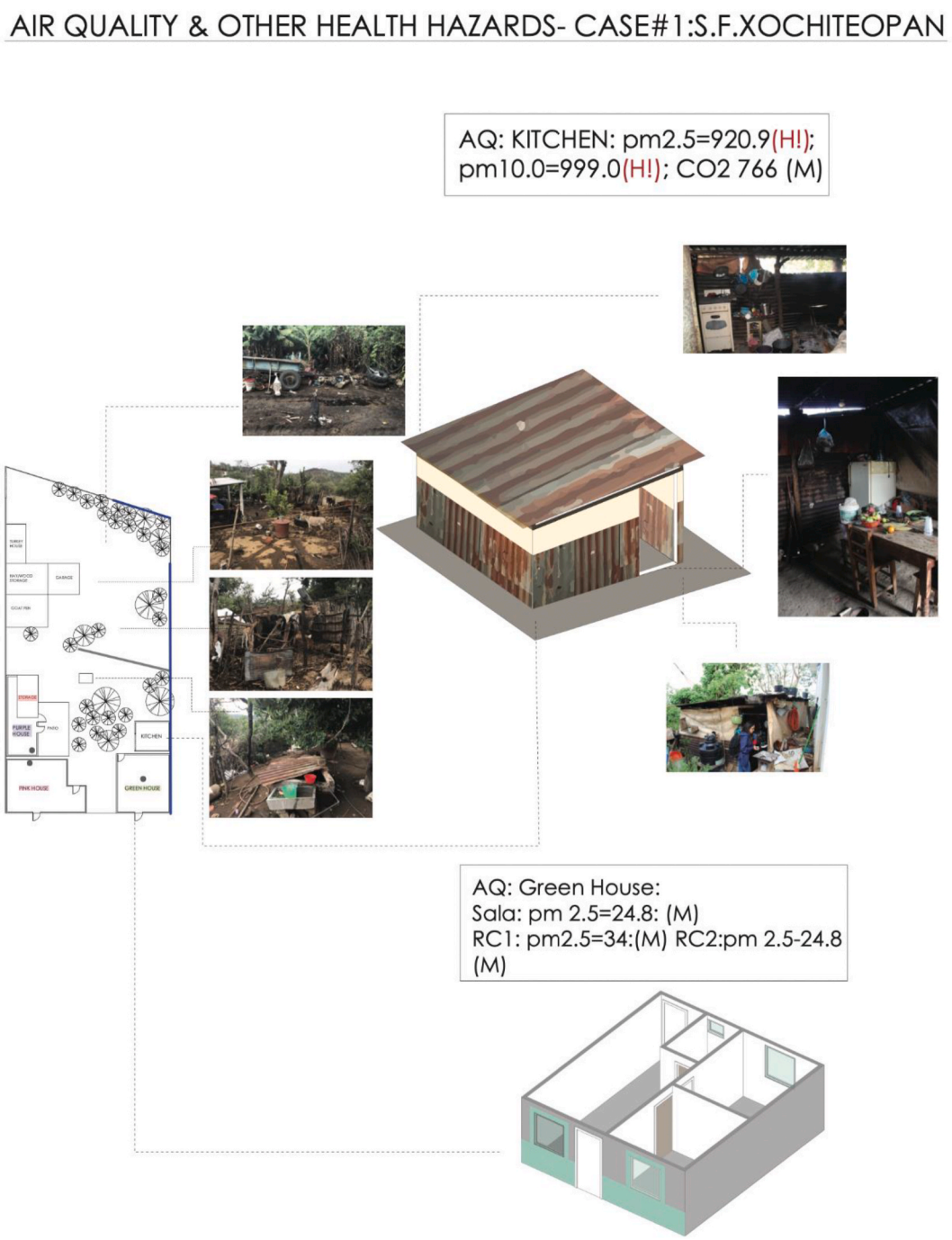


Fig. 6. 6a. Top section: Right-hand side of lot plan with health hazards. Intensive Case Study # 1 Xochiteopan: Home of Doña Victoria and family.[34] 6b. Bottom section: Left hand side of lot plan with Health Hazards. Intensive Case Study # 1 Xochiteopan: Home of Doña Victoria and family (see also website Appendix 4 Cases 1a-1c).

(Fig. 8a–c, "Health Hazards" [see also Website Appendix 4 Case 2b]), many of the rooms have poor air quality. Lidia's house is classified as "Unhealthy" in all rooms with particulate and CO2 readings at "unhealthy" or "moderately unhealthy" levels. We also noticed some damp in the ceiling at the entrance to one of the bedrooms (Fig. 8b photo inset). The poor air quality in the two bedrooms and in the bathroom are almost certainly the result of some dampness and inadequate ventilation. Even with an open doorway and a gap above the new block (*tabique*) walls, the room which is the now the enclosed former patio space shows "unhealthy" air quality levels, resulting from the use as a dining area and the small cooking stove located at the entrance.

Marco sleeps in the wooden box room which has fertilizer bags stacked up at one end (Fig. 8c photo inset), and this, too, has very poor air quality – actually "hazardous" on both particulate counts, almost certainly due to the poor ventilation and to the smoke from the adjacent kitchen area. The latter was also "very unhealthy" on the pm2.5 readings. Francisca's house is actually just bedrooms (for her and daughter Noemí), and again the poor air quality that we see is due to a lack of adequate ventilation in the bedrooms rather than from any cooking area. (All the cooking is done in the kitchen and in the entry to Lidia's house.) Photos reveal that they also share a bed in one of the rooms. Improving air quality would be a relatively easy fix through increasing ventilation

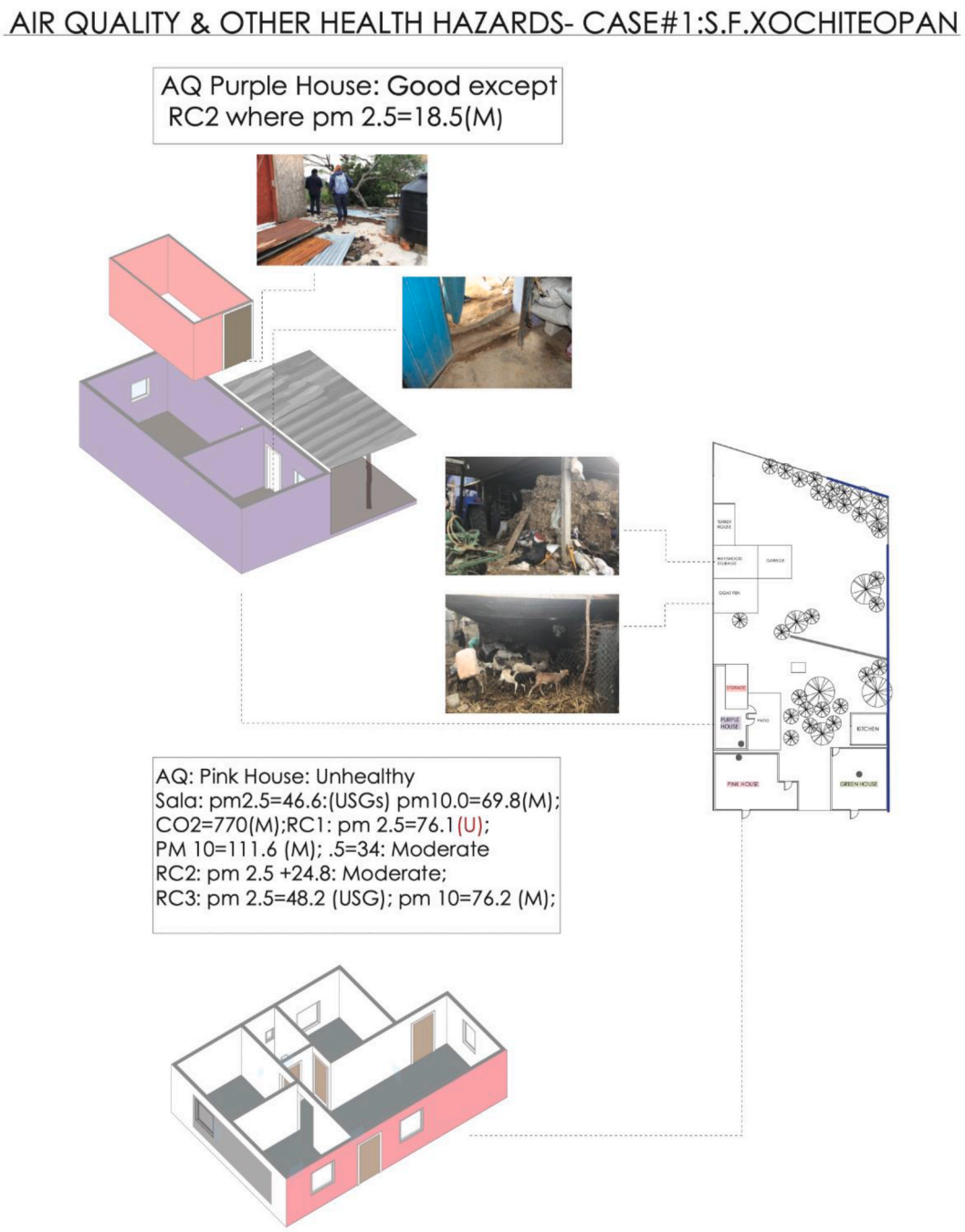


Fig. 6. (*continued*).

by opening the windows. We also advise that the household deter from using plastic as a "starter accelerant" fuel in the kitchen.

Somewhat unexpectedly the two buildings in construction also showed poor air quality measures in one or more of the room spaces (Fig. 8b). We suspect that this is a result of construction dust, and proximity to the road and associated vehicle fumes. The rubble and building materials lying around are a health hazard, especially for the Lidia's youngest daughter.

In addition to the air quality problems that this case presents, we can point to several other health issues observed in this micro-environment and which are highlighted in the photos. Uneven surfaces, the hose pipes, and the building materials lying around the front half of the lot all impede mobility and are especially hazardous for young children as well as anyone with poor mobility such as Lidia who is heavily overweight and appears to be poor health from diabetes. The uneven ground and entrance to Doña Francisca's house is also dangerous. The kitchen area is bare earth, and in combination with the dirty lot areas especially at the rear, are harbors for insects and pests. Drinking water comes from the piped supply, and hoses are used to move water around the lot and to fill the two cisterns (for the greenhouse). Although chlorinated at source, these storage on-site usage practices almost certainly lead to poor or contaminated water.

The rear part of the lot is strewn with garbage (plastic etc. – see Fig. 9c & d), and also smells foul – in part due to the pig pens. While there is some separation from the residential areas, this part of the lot is a locus for flies, mosquitos and their breeding grounds, and other pests

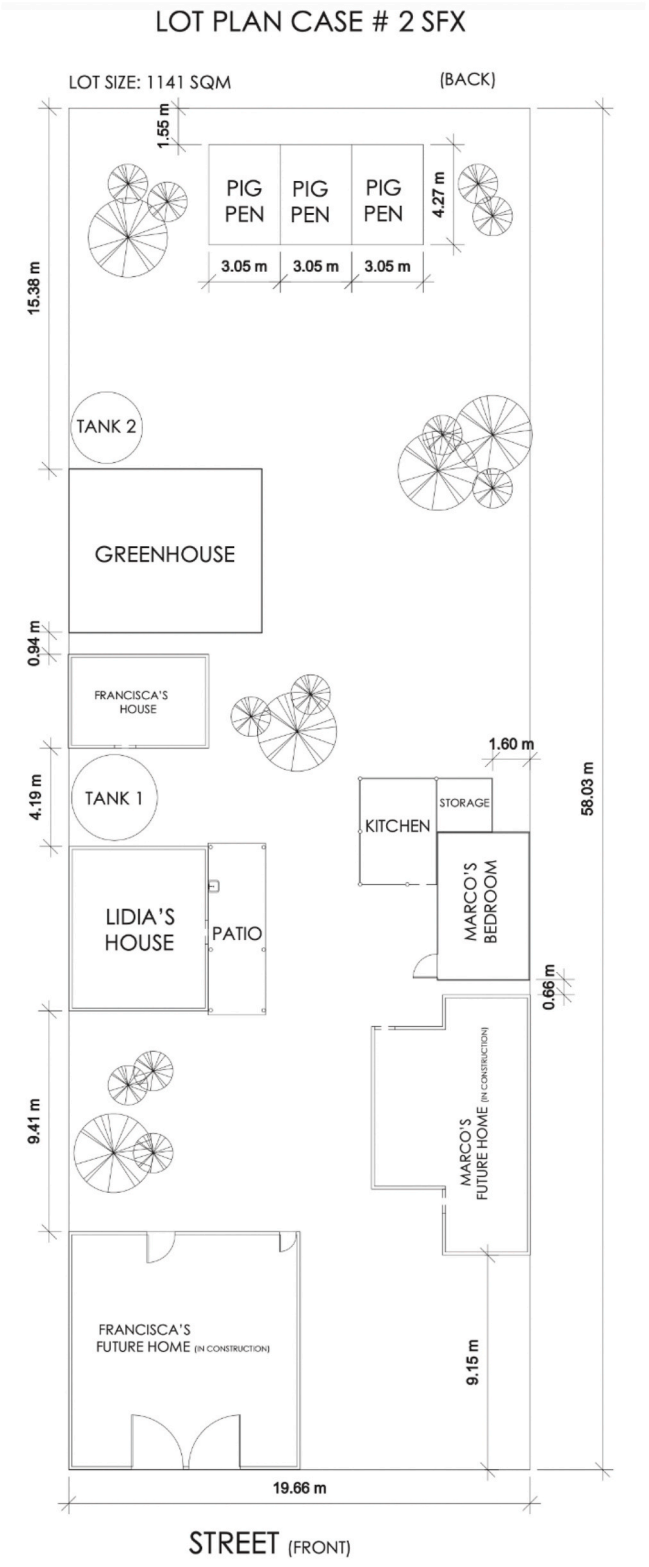


Fig. 7. Lot Plan of Case # 2. Xochiteopan: Home of Lidia and Doña Francisca, Extended Family (see also Appendix 4 Case 2b & 2c).

and disease carriers. Better yard care and cleanup would undoubtedly help reduce the health risks in this micro environment.[37]

5. Housing and health: discussion and overall policy implications

The wider survey, our interviews and focus group discussions, together with the insights informed by our five intensive case studies provide detailed evidence of the ways in which interaction between the physical fabric and the immediate environmental context may negatively shape and impact people's health and wellbeing. In addition, household and individual behaviors can mitigate or accentuate risks. Moreover, we were able to observe how such challenges change over the life course: the dwelling structure, lot conditions and behaviors that impact young children and adolescents are likely to be significantly different to those affecting the middle-aged and elderly. The principal chronic health challenges, along with commonplace "lighter" illnesses such as diarrhea and gastroenteric diseases, and respiratory illnesses such as asthma, are all examples of the ways in which the immediate home environment can exacerbate adverse health outcomes (Unger and Riley, 2016). In this paper we have documented many similar outcomes, but our research has also complemented the literature by providing a more nuanced understanding of the physical and behavioral interactions in poor agricultural pueblos in Mexico. Below we summarize our findings, and offer priority policies and actions that we believe would help to mitigate the negative effects of the intersection between housing and poor health and wellbeing.

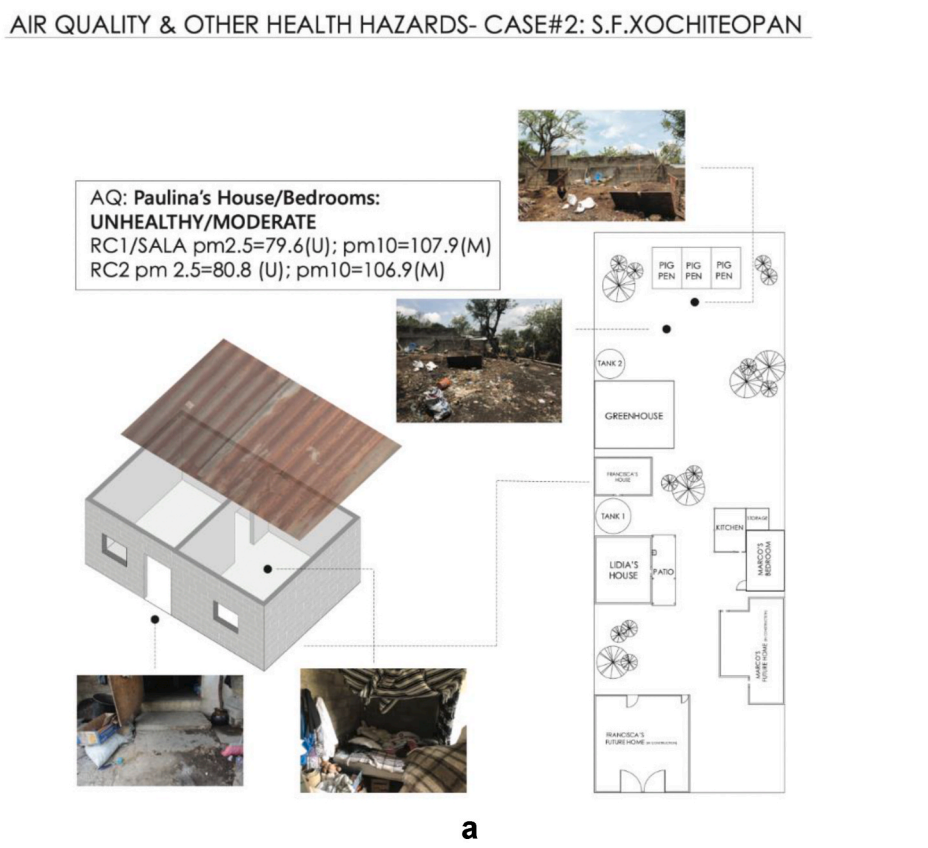
5.1. Water and drainage infrastructure

Access to safe drinking water is essential, and our study highlights several action items that would help to improve health and wellbeing in these pueblos (CDC, 1996). While there is chlorination of the water supply at source, it appears that the levels of chlorine are poorly measured. Our water quality measurements and interviews indicate that there is under-chlorination in the two most rural pueblos, and likely over-chlorination in Santa Ana.[38] In the two poorest pueblos, the costs of household water supply are assessed on a flat-rate per capita basis, and the cost mitigates against supply more than twice a week. This means that water must be stored in tanks for use on the non-supply days, and this leads to dissipation of the chorine level. Where other (non--chlorinated) water is captured through rainwater collection systems or wells (as in Santa Ana), and where tap water is proven to be inadequately chlorinated, then water should be systematically boiled and/or filtered, and wherever possible, should be refrigerated before drinking. Cleanliness practices should be enhanced when scooping or drawing water from storage tanks. Bottled drinking water consumption is rare in the poorer pueblos, and was only widely observed in the better off peri-urban pueblo of Santa Ana Coatepc, and in urban colonia neighborhoods in Atlixco. Affordability is the primary mitigating factor, but in both the rural pueblos we also noted widespread cynicism about the veracity of bottled water actually being pure! If untrue, such suspicion and lack of confidence should be addressed.

In short, as in so many facets relating to health and wellbeing, poverty is the primary factor shaping unhealthy water consumption in the poorest pueblos. Policies to promote more regular (daily) supply and to ensure adequate water treatment at source before delivery to

[37] We discussed this mess with Doña Francisca in October, and she said that she was planning on clearing it up in the dry season – now everything was too wet. She is also planning on building two more homes at the rear of the lot for her other two children, at which time she will get rid of the pig pen and the tree.

[38] In Santa Ana Coatepec people often complained of the smell of chlorine, and in an interview with the engineer community resident responsible for adding chlorine, he expressed concerns that he was over chlorinating.



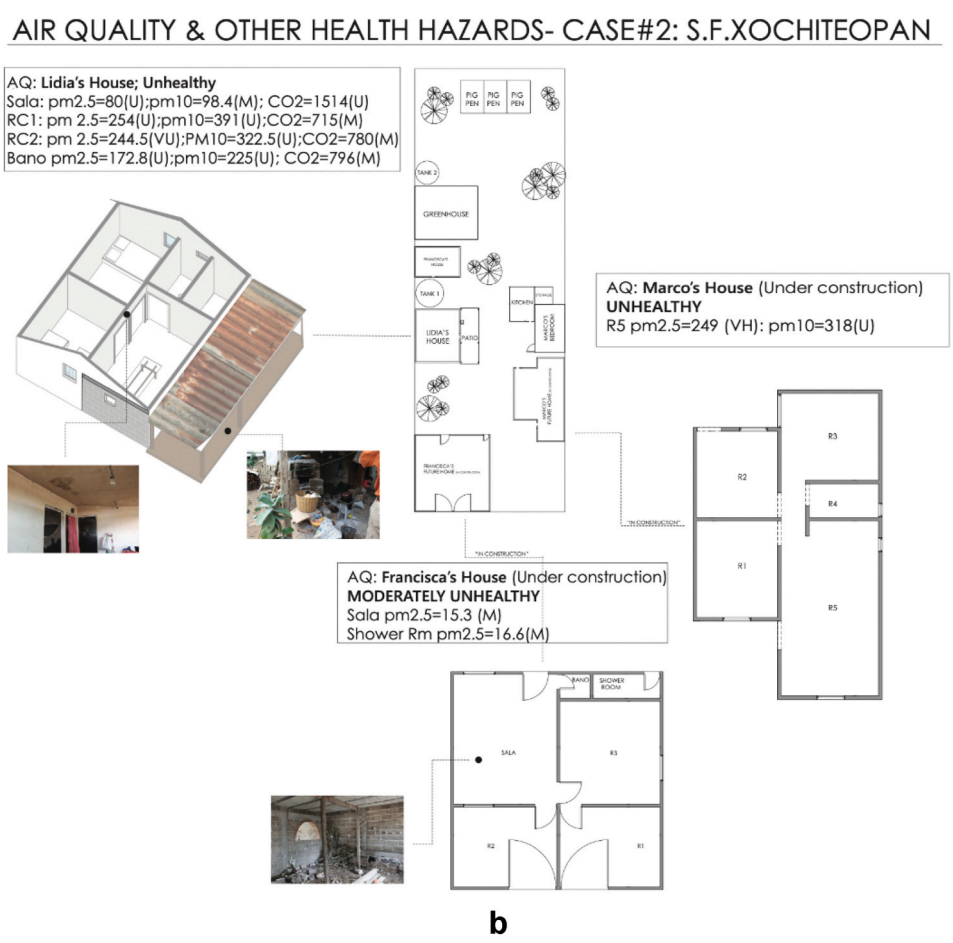


Fig. 8. a: Top. Rear of lot plan and views with Health Hazards. Case # 2. Xochiteopan: Home of Lidia and Doña Francisca, Extended Family. (see also Appendix 4 Case 2b & 2c). b: Middle left and bottom (street) views of lot plan with Health Hazards. Case # 2. Xochiteopan: Home of Lidia and Doña Francisca, Extended Family (see also Appendix 4 Case 2b & 2c). c: Middle right views of lot plan with Health Hazards. Case # 2. Xochiteopan: Home of Lidia and Doña Francisca, Extended Family (see also Appendix 4 Case 2b & 2c).

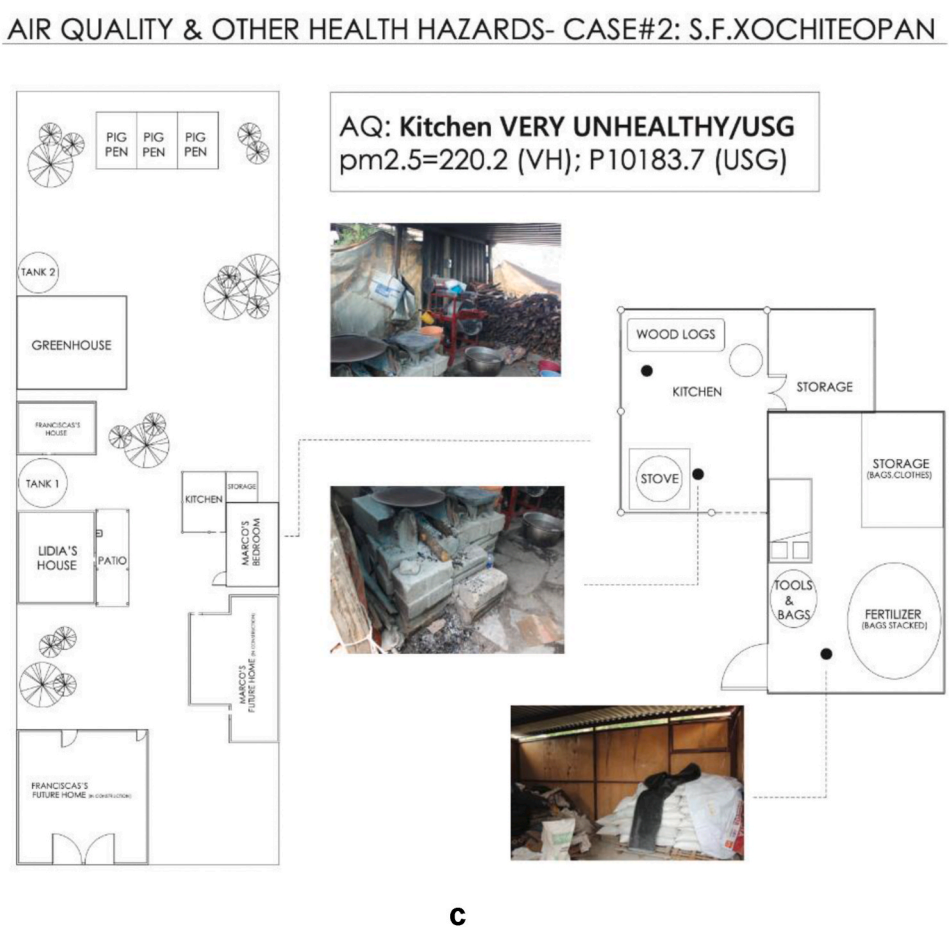


Fig. 8. (*continued*).

homesteads should be explored. These may include subsidies to the costs of pumping, this being the major cost that prevents daily supply, and the feasibility of installing photo-voltaic (solar) panels to generate energy for pumping should be evaluated. Both would require municipal or state support. Greater transparency about the levels of chlorination would be helpful, as would assurance of the purity of bottle water for those that can afford it. Tied to this, information campaigns to improve intra-lot behaviors relating to the storage and purification of water would help reduce water-borne illness and poor health.

Sanitation is often through pit latrines and septic tanks and we have little information about whether or not this contaminates water sources (wells especially). However, it seems certain that close proximity to farm animals and animal feces are a likely to be direct or indirect contaminants of water tanks, and will compromise health through household water usage such as washing, bathing, and cleaning. Tapeworm and other infections can be absorbed from well and other water sources without actually being drunk.

5.2. Air quality

There is little that can be done to mitigate the periodic effects of volcanic dust emissions from Popocatepétl, except perhaps to encourage indoor sheltering, although as we have observed this is largely unrealistic and anathema in rural pueblos. But in several other arenas behavioral changes could have important positive health outcomes, especially for young children. Actions here include greater or more adequate ventilation around wood burning stoves and ovens. This might include openings that would encourage breezeway removal of smoke, extractors or other fans, and the promotion of low cost "hoods" and chimneys above cooking spaces. NGOs that are respected locally are interested in organizing workshops that would offer technical advice and promote affordable solutions for the retro-installation of hoods, chimneys, and the use of other more efficient wood burning systems.

The promotion of safer fire-lighting procedures, and specifically alternatives to using plastic as an accelerant, would greatly reduce toxic air quality. This, and associated informational programs to encourage the separation between cooking and family eating sites, and to keep children away from the smoke and cooking area – not least since their lungs are less capable of resistance to damage, and smoke can exacerbate asthma and other respiratory diseases in younger children. Similarly, it is important to increase awareness about CO2: how it is a product of human exhalation and car exhaust, and to highlight our findings of widespread poor air quality due to unseen CO2 levels in the home. Ventilation is the key here, especially in bedrooms and in enclosed spaces. Windows should be opened and bedding aired daily. Agrochemicals and fertilizers should not be stored or kept in rooms and spaces used for sleeping or dining since these make for poor or even hazardous air quality.

5.3. Dwelling structures and lot management

Poverty, by its very nature means that many on-site dwelling constructions are of very poor quality and offer inadequate protection from the elements, and in some instances harbor threats to poor health and wellbeing. Unlike in the USA and in most urban areas where people spend a large part of their daily lives indoors, rural populations such as those with whom we engaged in Puebla, spend most of their time outside – either in the fields, or in the outside patio – cooking, playing, relaxing, and eating. They use the indoors far less, and rarely for cooking unless they have electric or gas stoves and purpose-built kitchens. The design of

Fig. 9. a–d: Images from Case 2 showing garbage and mobility hazards (uneven surfaces etc.) See also Appendix 4. Case 2b.

the modern prototype homes built after the earthquake appear to have been wrongly premised upon what are non-rural lifestyles and cultural understanding, and our observations and the videos that we shot revealed that rooms in these new homes are primarily used for sleeping, as a place to mount their religious altar and candles, keep their clothes, and for storage, rather than as safe areas for play, food preparation and for relaxation. Indeed, the relative lack of even affordable furnishings in the home demonstrate clear differences with most urban households' use of room and residential space.

Our surveys were largely conducted in people's homes and patios, so we observed a wide range of housing conditions described in Table 3, ranging from well-built homes and new post-earthquake replacement dwellings, to one-room hovels. Our five intensive case studies broadly cover that span and offer many insights about actions that would enhance better health outcomes. While earth floors are no longer as common as in the past, they are difficult to keep clean, and present a serious risk to disease and infection especially to children (Chargas disease and Malaria for example). Small-scale loans or grants to provide a concrete floor in living spaces would help. This is also important in non-living spaces to which children have access. Concerted efforts should be made to minimize damp and high humidity, especially in sleeping spaces; to improve ventilation and air circulation by ensuring that windows and openings provide for a throughflow of fresh air; and to increase availability of natural lighting in all rooms, especially where none currently exists. Similarly, it is important to ensure safe storage of foodstuffs and to maintain a level of external surface hygiene that will minimize pests and the disease dangers and infections that they pose.

Both within the dwelling, and especially outside, uneven floors and walking areas impede mobility and pose a threat to falls. Wherever practical, actions should be taken to ensure level the floor and ground levels are more or less level making for greater safety for young children and the elderly. Easier to implement in some respects, households should be encouraged to undertake efforts to maintain yard space clear of items that impede mobility and cause tripping and falls such as hoses and pipes, etc., and to clear garbage and other items (tires for example) that provide harborage for pests and disease. Farm households should be encouraged to maintain a healthy level of separation between livestock and household spaces used for sleeping, eating, and food preparation. Given their cultural awareness of plants, families should be encouraged to create and maintain tree and shrub foliage close to the dwellings in order to provide shade, and to improve air quality through plant absorption of CO2. Paradoxically, perhaps, our observations suggest that such planting is located away from the house, rather than adjacent to it. Thus, while several of these actions require new resources, many are also behavioral and imply little or no costs in implementation other than that of communication, information dissemination, and sensitive technical support ideally from trusted extension workers such as Paty and Alejandro in the case of the Fondo Mónica.

Returning to our original overarching research question, we asked how poor rural housing conditions impact health and wellbeing at the household level in each community? We hypothesized that these extremely poor dwelling structures and living arrangements carry intrinsic risks and hazards to the health and wellbeing of household members. And that this varies with different stages of the life course, whether these are young children playing barefoot on uneven surfaces in the farmyard, or exposed to woodsmoke from outdoor cooking on open wood fires, to adults suffering from chronic disease and ailments, and the elderly who are often also mobility impaired. And so it has proven: our detailed discussion in this paper, and the summary overview in this conclusion emphasize the need not only to better understand the epidemiology of these low-income communities and the ways in which health care is sought and received, but also the ways in which the micro-level environment of housing and home are inextricably bound-up with behaviors and practices that impact upon health and wellbeing. Indeed, we venture to suggest that even though more modern urban living environments also face health risks both inside and outside of the home,

the interactions that we have described between housing, home, and good health outcomes in rural Puebla, are more dynamic, and more volatile, than they are in urban and purportedly more "safe" housing environments.

Authorship and collaboration

Ward led the design and the application of the intensive case-study methodology, and oversaw the analysis and the preparation of the detailed diagrams undertaken by Ruiz. Ward wrote and edited the paper and Sandoval contributed sections relating to water and air quality. Sandoval led the team's household collection of air and water quality samples. Rojas, Sandoval, and Ward conducted the focus groups. Rojas was the graduate research assistant and coordinator on the ground throughout the period of fieldwork; he oversaw the fielding of the household survey; led the teams in gathering the materials for the intensive case-study interventions, and assisted with data analysis and editing.

Declaration of competing interest

None.

Acknowledgement of Other Contributors

The PAGL team comprised four undergraduate students Christina Ciburri, Claire Stephenson, Andrea Sandoval Flores, and team leader Veronica Remmert. Mr. Alfonso Rojas Álvarez was the Research Assistant, and three faculty mentors were: Ricardo Ainslie (PhD); Tim Mercer (MD); and Peter M. Ward (PhD). Writing the Final Report was undertaken by Remmert, Ward, Ainslie, Mercer and Rojas, and separate papers are authored separately: The current paper is one such example.

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