Second LACCEI International Latin American and Caribbean Conference for Engineering and Technology (LACCET'2004)
"Challenges and Opportunities for Engineering Education, Research and Development"
2-4 June 2004, Miami, Florida, USA

Environmental Infrastructure and Socioeconomic Indicators in San Pedro Sula, Honduras

Daniel E. Meeroff, Ph.D., E.I.
Assistant Professor, Department of Civil Engineering,
Florida Atlantic University, Boca Raton, FL, USA

Helena Solo-Gabriele, Ph.D., P.E.
Associate Professor, Department of Civil, Architectural, and Environmental Engineering
University of Miami, Coral Gables, FL, USA

Richard Weisskoff, Ph.D.
Associate Professor, Department of
University of Miami, Coral Gables, FL, USA

Abstract
Access to safe drinking water and sanitation is a basic human necessity, but such access appears to be highly variable in the developing countries of Central America and the Caribbean. In this study, access to these basic needs was evaluated with respect to socioeconomic factors. The study site was San Pedro Sula, Honduras (SPS). It is believed that lessons learned from a detailed study of SPS will be invaluable in promoting transitional development of similar urban centers in other countries. Thus, to pursue this aim, data was collected from published literature, surveys, assessments, and water and wastewater documentation produced by a diverse variety of sources including global agencies, financial institutions, municipal governments, amplified by a site visit that included informal interviews with local residents, researchers, and both governmental and non-governmental organizations. A multidisciplinary integrated analysis was conducted to merge infrastructure information with socioeconomic indicators and spatial data in order to determine the nature and extent of any existing inequalities. This comparison was used to determine if higher income neighborhoods were experiencing less sewage contamination and a greater degree of water treatment in SPS. Findings indicated that access or socioeconomic status does not always correlate with quality of service.

Keywords
Water, Wastewater, Socioeconomic Indicators, Honduras

1. Introduction

SPS is the second largest city in Honduras and is located 230 km from the capital, Tegucigalpa. SPS is roughly double the size of Miami, FL stretching over an area of 1010 km^2 (Figure 1), containing 8 sectors. The city is designed in the colonial Spanish style with the first four sectors making up the urban shell. Beyond the first ring, radiating outward toward the lower valley are the suburban sectors 5, 6, and 7. The final sector, Cofradía (Sector 8), is a parcel of rural land located about 18-30 km southwest of the urban shell. Each of the sectors is subdivided into non-uniformly distributed neighborhoods (n = 433). Some are very large in size yet contain small populations, while others are small in size and are densely populated. Furthermore, the number of neighborhoods per sector is not equal (Sector 1 has 90 while Sector 6 has 35) (DIEM, 1999).

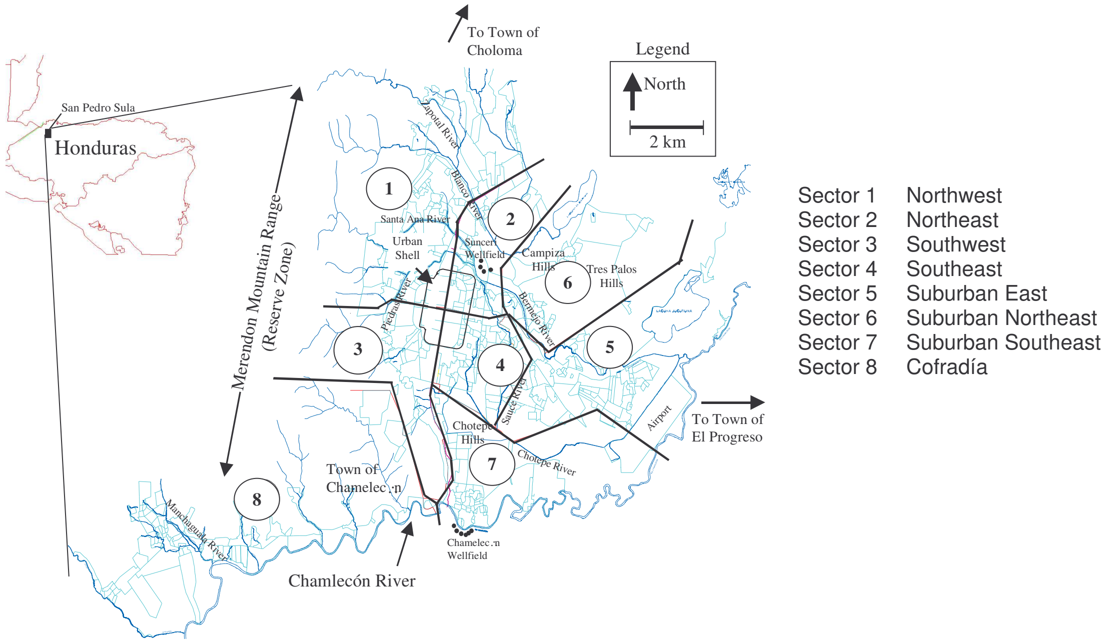

Figure 1: Map of the city of San Pedro Sula, Honduras showing locations of each sector

The population of SPS was approximately 546,000 in 1999 (DIEM, 1999) representing nearly 15% of the urban population of the country. Over the last decade, population has increased at an annual growth rate of 5-7% (Larrea et al., 2002), the highest population growth rate in Honduras (C. Lotti & Associati S.p.A., 2002). As a result of the economic and industrial development, this accelerated growth rate along with the high migration rate from the rural areas to the urban centers, has combined to increase demand for basic services including potable water, sanitary sewer, solid waste disposal, and energy needs.

2. Water and Sewer Service

For municipal potable water supply, several major surface water and groundwater sources are available. These include the two wellfields (Chamelecón and Sunceri) and the Santa Ana, Piedras and Zapotal Rivers, which serve the network within Sectors 1-7 and also the Manchaguala River, which is the primary source for Sector 8. During the dry summer months, the groundwater system provides the necessary demand. In 2002, groundwater systems met more than 70% of the total demand (Larrea et al. 2002).

The Chamelecón wellfield is located south of the urban shell along the banks of the river that bears the same name (Figure 1). The wells are situated in a zone of high population density, low economic characteristics, and high criminal activity. The Sunceri wellfield is located in an urban expansion zone within sector 6 dominated by agricultural and industrial activity, which has complicated source water protection of the vulnerable aquifer. As of the summer of 2003, none of the wellfields were equipped with disinfection capacity.

Major surface water sources used for potable supply include the: Santa Ana, Piedras, Zapotal, and Manchaguala rivers. Most of these originate within the Merendón mountain range and are enriched in organic content and minerals, particularly Fe and Mn, which impart an unpleasant taste and stain orange-brown. Turbidity typically rises during rainfall events, which transport a considerable sediment load. Also in winter during periods of high runoff, the pH can drop as low as 3-4 due to the accelerated erosion of exposed mineral-rich formations that occurred after Hurricane Mitch. The three main surface water sources (Santa Ana, Piedras, and Zapotal) combine to produce 18.6 MGD (814 L/s) of raw water to supplement the wellfields.

3. Contractual Obligations

Through the mid 1990s, the government of SPS administered potable water, sewer, and stormwater services through the *División Municipal de Aguas* (DIMA). However, after the Hurricane Mitch disaster of 1997, DIMA decided to solicit privatization of its water and sanitation services. Through financial backing from the Inter-American Development Bank, a 30-year concession contract was awarded to an Italian consortium called *Aguas de San Pedro S.A.* (ASP) beginning on February 1, 2001 (Larrea et al., 2002) covering a physical area of 837.6 km^2 (roughly the size of Dallas, TX) within SPS. At the start of the contract, the public water system covered about 85% of the population, and sewerage covered between 65-68% of the population. By the end of the third year, the coverage must reach 100% for water services and must achieve specified levels of service quality (i.e. adequate pressure of water and 24-hour continuous service). By the sixth year, sewerage coverage must reach 100%, and 25% of the connections should have some form of treatment. This value must increase to 50% by year eight and 85% by year 10 and be maintained at or above those levels for the life of the concession period.

Water supply coverage

The concession is required to achieve universal water supply coverage by 2004. According to census information available for 1999, the total coverage of the public water supply extended to 83% of the population, with an additional 7% connected to private water supply systems (DIEM 1999). Figure 2 clearly illustrates that public water access has not kept up with population growth over the past decade, as the separation between the two curves has grown more distant with time. As of 2001, 85% of the population (447,950) had potable water service (Larrea et al. 2002), and the total coverage was estimated at 94% overall (ASP 2002). However, revised coverage estimates using a more realistic value of 4.5 persons per connection instead of 5.0, resulted in a coverage value of 80% for 2002 (C. Lotti & Associati, S.p.A. 2001).

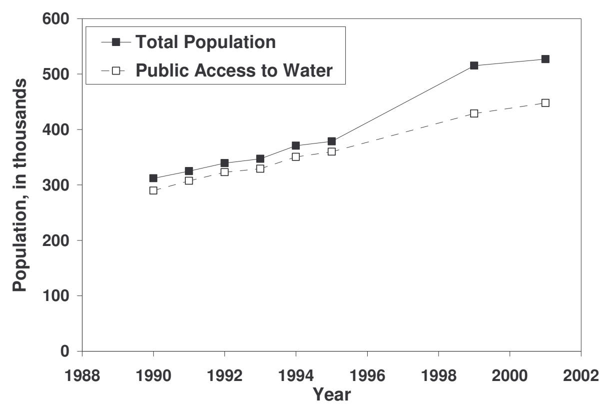

FIGURE 2. Coverage of public water access since 1990 in San Pedro Sula, Honduras, by population

In 2001, the concession added 6580 new public water service connections and an additional 2009 the following year, increasing the coverage by about 6-7% (Díaz 2003). However, the population increased at a similar rate during that same time interval, so to meet the 2004 contractual goal of 100% coverage, another 25,000 new connections are needed, considering population growth and capacity expansion issues. This number of new installations seems unlikely, particularly considering the rates of the previous two years.

Continuity of water service

DIMA was unable to provide 24-hour water supply coverage to its customers during the mid 1990s. In many neighborhoods, water service could only be supplied for a few hours of the day for only a few days of the week. In the EPIS'95 survey (DIEM 1996), an effort was made to quantify the extent of the problem, since an estimated 98% of the population of Honduras in 1995 had only intermittent access to water supplies. The results indicate that 71% of the population received 24-hour coverage. Unexpectedly, sectors 1 and 3 were included in the areas of most concern. These sectors are located within the urban shell and comprise primarily middle class residences, businesses, and shops. However, these are also two of the oldest sectors, and therefore are likely to be supplied by the oldest pipe networks. The first contractual goal of ASP was to achieve 100% continuous service to the integrated network customers. As of February 2003, the intermittent service issue was resolved (restoring flow from 6 hours to 24 hours a day) by over-saturating the distribution lines. In essence greater quantities of water were pumped through the distribution pipes to eliminate rationing within the urban shell. Furthermore, minimum pressure requirements for the integrated system have also been met in major distribution pipes (ASP 2002) as a result of the increased flow rates.

In terms of achieving the contractual goals for potable water treatment, the volume of water that received treatment was only 12-16% in 2001-2002. By 2005, this percentage is required to be 100%. Since nearly 60% of the water demand is supplied by two wellfields, the percentage of treatment will increase substantially by the end of 2003, if planned groundwater disinfection systems are brought online. The gap will then be closed even further when the Cofradía water treatment facility and the Zapotal River disinfection systems are completed. However, even if all these systems are operational by 2003, it is still unlikely that the 100% treatment goal can be achieved due to the 58 isolated wells and several smaller surface water systems, many of which are not treated, also contribute water to the distribution network.

Sewerage coverage

Sewage collection within SPS is in the form of either sanitary sewer networks (70-85%) or on-site disposal facilities (10-25%). Sanitary sewers transport collected sewage away from residential areas towards a discharge point (i.e. river, canal). Given the local topography, the majority of the sewage discharge points are located at the eastern end of the city. As of 2003, absolutely no treatment was available for collected wastewater. Therefore, receiving water bodies essentially serve as open sewers downstream of the discharge points. Raw sewage as well as industrial wastewater effluent is discharge directly into the Sunceri Canal, Bermejo River, and Sauce River. Discharge of wastewater is also practiced at the Chamelecón River in the vicinity of the wellfield.

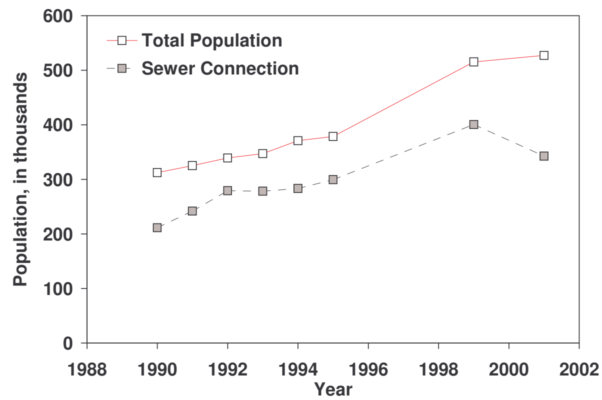

FIGURE 3. Coverage of sewer connections since 1990 in San Pedro Sula, Honduras, by population

With respect to expansion of the sewage collection system, 464 new connections were made in 2001 and an additional 518 were added the following year, increasing the coverage by approximately 1% (Díaz 2003). In 2001, the estimated coverage for sanitary sewer collection was 65% (342,550) (Larrea et al. 2002) with revised coverage estimates of 69% overall in 2002 (ASP 2002). Moreover, the existing system is also plagued with sewer overflow problems due to illegal connections and insufficient pipe diameters. In 2002, 4297 emergency work orders were filed for the sewage collection system alone, and many of the pump stations have reached their design capacity limits, requiring expansion upgrades (ASP 2002). Figure 3 shows how sewer coverage has evolved over the past decade and clearly illustrates how the number of sewer connections has not kept up with population growth. Furthermore, the recent trend is in the wrong direction. If it hopes to reach the contractual goals, ASP must increase its efforts considerably in this area.

Contamination issues

For the three largest surface water sources (i.e. Santa Ana, Piedras, and Zapotal) contamination results from nutrient loading from agricultural activity, raw sewage inputs, stormwater runoff, algal blooms, organic color issues, untreated industrial discharges, mine tailings, elevated levels of heavy metals, inadequate disinfection, discharge of water treatment plant residuals, and finally infiltration/inflow due to poorly maintained distribution networks. Furthermore, source water protection is generally inadequate since raw water intake systems are not patrolled and are not isolated from humans and animals to prevent fecal pollution.

For the Sunceri wellfield, major contamination issues arise from untreated industrial discharges into the adjacent Bermejo River, hazardous chemical transportation risks from industrial river traffic, and lack of disinfection. The Sunceri Canal, which is adjacent to the wellfield is a major receiving water for industrial and commercial wastewater directly discharged in that district. For the Chamelecón wellfield, contamination is caused by high population density in the vicinity of the wellfield, direct sewage discharge, lack of disinfection, and high levels of natural minerals in the subsurface, including Fe and Mn (Región Sanitaria 2003). Even though the Chamelecón aquifer has sufficient productivity to sustain nearly 100% of the present demand in terms of volume, its usage is limited by elevated levels of naturally occurring Fe and Mn above the recommended limits.

Receiving water quality

SPS is rich in water resources, some of which are blessed with pristine watersheds that produce clean drinking water of enviable quality. Furthermore, a productive aquifer with high quality raw groundwater is also available. However, the way in which the distribution networks and the sewage conveyance systems were designed has led to inevitable water quality impacts and noticeable deterioration. This issue requires immediate attention because while universal access to running water is a benefit to society, if that water is of poor quality, the entire community will still be at risk.

Water quality degradation is not restricted to the urban zones, however. Rural areas, such as Cofradía, have not been spared the rapid deterioration of surface water resources due to low pH, high turbidity, and high concentrations of heavy metals, such as Fe and Mn, as indicated by water quality testing shown in Table 1. Apart from health consequences of ingesting inorganic contaminants, Fe and Mn impart a color. Therefore, even if safe to drink from a chemical and microbial aspect, users may avoid this water in favor of another source of questionable quality.

TABLE 1. Surface water quality monitoring data, 01/2002-05/2002. Values listed are arithmetic means of up to 11 samples taken at different monitoring stations. Highlighted values indicate violation of local drinking water regulations.

Sample Site	pH	BOD (mg/L)	Turbidity (NTU)	Fe (mg/L)	Mn (mg/L)	Fecal Coliform (CFU/100mL)
Sunceri Canal	7.4	57.0	30.4	1.3	0.2	4.5E+06
Primavera – Bambu Stream	4.5	0.4	0.1	0.1	0.2	5.8E+01
Bermejo River	7.4	107.9	47.1	2.2	0.2	1.9E+08
Blanco River	7.5	3.9	8.3	0.9	0.1	2.2E+04
Chamelecón River	7.8	15.9	15.7	0.7	0.1	3.6E+05
Chotepe River	7.2	178.7	84.3	2.2	0.2	1.6E+07
Manchaguala River	7.5	4.6	17.8	1.3	0.3	1.8E+05
Piedras River	7.5	97.8	23.6	0.9	0.1	6.7E+06
Santa Ana River	7.0	382.3	46.5	1.1	0.2	9.8E+06
Sauce River	7.5	110.8	56.5	1.7	0.4	1.3E+07
Zapotal River	7.5	0.7	1.9	0.5	0.1	4.8E+02

In order to investigate the water supply network, selected surface water quality data (C. Lotti & Associati, S.p.A. (2002) (Table 1) were analyzed. In terms of microbiological quality, all sample locations were found to contain measurable levels of fecal coliform, an indicator of human excreta contamination. Some sites contained dangerously high colony counts in the range of 10^7-10^8 CFU/100 mL (a bacterial strength greater than that of raw sewage). The locations with the highest concentrations detected corresponded to receiving water bodies of domestic sanitary sewage and industrial wastewater (i.e. Bermejo River, Sauce River, Sunceri Canal, etc.).

Using this data, the major surface water sources were compared in terms of an empirical water quality score developed by ranking each of the locations by average BOD, turbidity, Fe, Mn, and fecal coliform concentration, from highest to lowest. The summation of rank orders for each parameter yields a water quality score. Higher values correspond to better water quality. According to Figure 4, the Zapotal has the highest ranking of the sources tested, which agrees with an assessment conducted by ASP (personal communication with Manuel López, Director of Strategic Planning, ASP) claiming that the finest quality water in the entire water supply network comes from Zapotal, until it reaches the Fesitranh Bridge. Beyond that point, the waters are contaminated with elevated BOD and low dissolved oxygen, measures of pollution. Coincidentally, the Zapotal services an area characterized by poorer neighborhoods. Because spatial averages could not be used, some of the river systems masked segments of severe contamination with data from pristine upstream reaches, like Chamelecón for example. The Chamelecón River had at least seven different sampling sections, and the water quality was observed to deteriorate in the easterly direction of flow, particularly after merging with the Chotepe River, due to agricultural activity (sugarcane) and raw sewage inputs from the Chotepe.

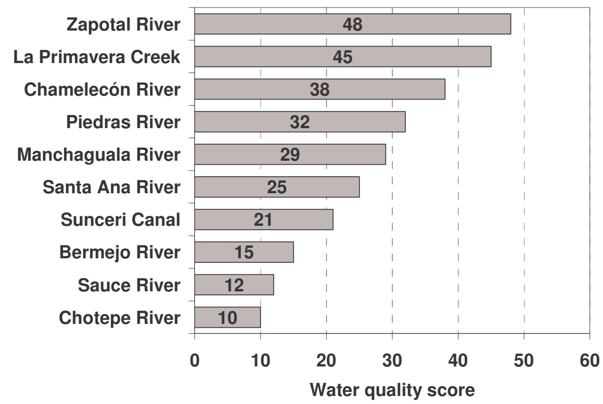

FIGURE 4. Comparison of aquatic water quality scores among the major surface water sources in San Pedro Sula. *Note higher scores signify higher quality and lower scores signify lower quality.

Conversely, the lowest water quality corresponds to the major receiving water bodies for untreated sewage and wastewater effluents (i.e. Bermejo River, Sauce River, Sunceri Canal, Chotepe River, etc.). Curiously, the Santa Ana, Piedras, and Manchaguala Rivers were not among the sources with the highest water quality scores. This was unexpected since these are the three most important sources of drinking water for the entire city, including the more affluent communities.

Analysis of socioeconomic factors

In SPS, the distribution of wealth is well delineated between sectors. However, it is important to keep in mind that poverty is also interspersed throughout the city in high-density informal housing alongside relatively well-to-do districts. This differs from the typical distribution in developed nations, where urban poverty is generally concentrated in certain areas. In conventional analyses of health and sanitation, informal settlements are often ignored, but their significance is clearly important because they are purposely located in areas where it is exceedingly difficult to provide basic infrastructure and services (i.e. steep hillsides, riverbanks, beneath bridges, and on the right-of-way of roads). This inaccessibility makes it more difficult to force the inhabitants from these areas and is one major reason why this portion of the population chooses to live there.

Non-conventional socioeconomic indicators were employed in this study, instead of traditional parameters such as income distribution. Socioeconomic indicators utilized included the indicator of homes with dirt floors on a per neighborhood basis. This indicator is expected to correlate closely with urban poverty, since even low income housing would be expected to have cement or wood flooring. Other surrogate measures included topographical elevation and spatial distributions of various indicators. Topographical elevations were considered to represent an indirect measure of ambient water contamination from sewage. Spatial distributions were of interest in evaluating whether or not geographic locations influenced availability of proper sanitary sewerage facilities.

Neighborhood analysis of socioeconomic indicators and sewer access

The percentage of homes with dirt floors was chosen to evaluate lack of access to adequate sewerage (i.e. no sewer pipes, no septic tanks, and no latrines) on a neighborhood basis. Data indicate that neighborhoods with a large percentage of homes with dirt floors are the only neighborhoods that do not have a large portion of the population (near 100%) served by sewer or septic tanks (Figure 5). However, it is noted that a considerable number of neighborhoods with a low percentage of homes with dirt floors (less than 20%) are also not served by septic tanks or sewer pipes. The general trend observed is for the fraction of homes lacking adequate sewerage to increase as the percentage of homes with dirt floors in that neighborhood increases. The correlation appears to be nearly 1:1 (r^2 = 0.65), for the non-zero data points.

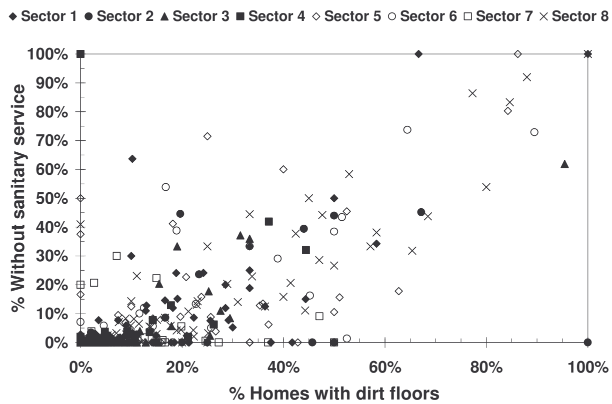

FIGURE 5. Percent of the population without sanitary service compared to the percent living in homes with dirt floors (1999 data)

The areas with the least sanitary sewer coverage are located in the extreme outer fringes of the city (i.e. Sectors 6 and 8), and also along the riverbanks of the Zapotal, Santa Ana, Piedras, Bermejo, Sauce, and Chamelecón (Figure 6). Conversely, the areas of greatest coverage correspond to the urban shell, which is highly residential and commercial. A similar pattern was observed using the percentage of households with dirt floors as the socioeconomic indicator. Interestingly, the shading pattern in Figure 6 matches the stream flow of the major surface waters, which is expected to closely follow topographical lines. Therefore gaps in sanitary sewer coverage are spatially correlated with locations of waterways in addition to being correlated with topographic elevation.

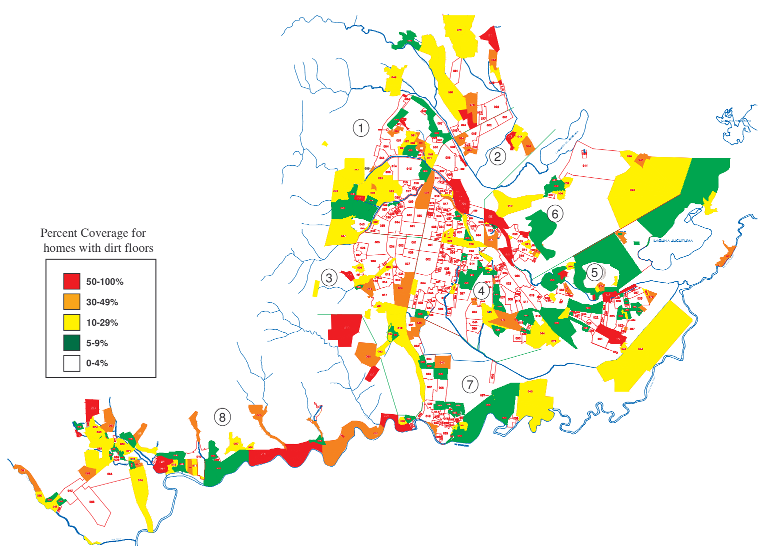

FIGURE 6. Spatial distribution diagram of households without sanitary service, by neighborhood (1999 data)

Topographical analysis

Since the treatment of domestic wastewater is basically nonexistent in SPS, the disposal of human excreta and the discharge of industrial wastes must generally follow the gradient of flow of the receiving waters. This was confirmed during a field visit to SPS, where the rivers generally become more contaminated towards the downgradient or eastern side of the city. Therefore, it was desired to evaluate topography as a surrogate for evaluating the impacts of sewerage discharges upon a particular sector. In SPS, much of the urban shell is about 80-100 m above sea level, while only the regions in the airport district (Sector 5) are located at low elevations. The overall gradient follows a west-to-east pattern from the Merendón watershed to the Sula Valley, and also the northern sections are located in hilly uplands that overlook the valley to the south.

Elevation differences taken from topographical maps (Instituto Geográfico Nacional 1983) were compared against monthly expenditures to evaluate the relationship between topography and socioeconomic status. Sector 8 was not included in the analysis since it is detached from the urban center and thus its topographic elevation would be independent of sewage impacts from the remainder of the city. From Figure 7, it is evident that average monthly expenditures follow the average topographical distribution of the city. Judging from the pattern, it seems that elevation differences for the contiguous areas of SPS can be used to test for spatial distributions of inequalities. In general sectors characterized by higher monthly expenses are located at higher elevations, which receive little sewage from upstream areas. Those sectors with lower monthly expenses are located at predominantly lower elevations, which receive sewage discharges from areas at higher elevations in addition to local impacts from inadequate sewerage.

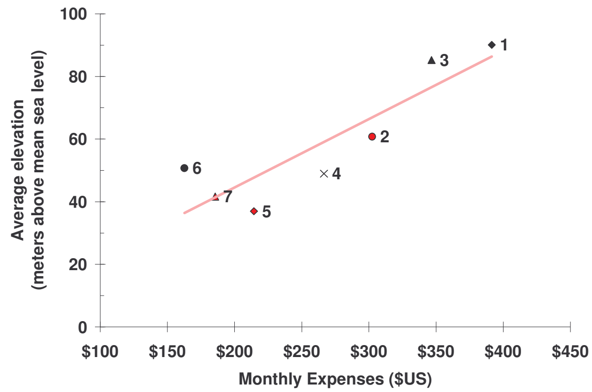

FIGURE 7. Household monthly expenditures versus average topographic elevation

Conclusions

Notable relationships observed between sanitary infrastructure and socioeconomic indicators indicate that the fraction of the population without any access to sewerage disposal correlates with the fraction of the population living in homes with dirt floors. In general, the disposal of human excreta and the discharge of industrial wastes follows the gradient of flow of the receiving waters as indicated by an observed relationship between topographic elevation and socioeconomic level, with wealthier sectors found at high elevations (or upstream) of poorer sectors. In essence, the poorer sectors receive sewage impacts from wealthier upstream sectors on top of devastating local impacts from inadequate sewage conveyance and disposal within their own communities. Neighborhoods with a larger fraction of the population without sewage service were found to border river systems, further contributing to the contamination of water resources. Basically, the poorest areas within SPS are found along sewage-contaminated riverbanks, and children from low-income families who play, swim, and bathe in those waters are particularly at risk from a public health perspective.

References

ASP (2002). Clausula 75 contrato de concesion, periodo del 1 de enero al 31 de diciembre del 2002. Aguas de San Pedro S.A. (ASP). San Pedro Sula, Honduras.

C. Lotti & Associati, S.p.A. (2001). Estudio de abastecimiento de agua potable de la comunidad de Cofradía por medio de agua subterranea: Informe final. Aguas de San Pedro, San Pedro Sula, Honduras.

C. Lotti & Associati, S.p.A. (2002). Estudio para la protección ambiental del acuífero del valle de sula y de las fuentes de agua de la reserva forestal del merendón. Aguas de San Pedro, San Pedro Sula, Honduras.

Díaz, J. (2003). La participacion del sector privado en los servicios de agua y saneamineto en San Pedro Sula, Honduras. Interamerican Development Bank, Department of Sustainable Development, Washington, DC.

DIEM (1996). Encuesta estandar sobre población e indicadores socio-económicos en San Pedro Sula (EPIS'95). Dirección de Investigación y Estadística Municipal (DIEM). Honduras.

DIEM (1999). Recuento censal de poblacion, vivienda, y establecimientos comerciales, 1999. Dirección de Investigación y Estadística Municipal (DIEM). Honduras.

Instituto Geográfico Nacional (1983). Mapa topográfica de San Pedro Sula-La Lima. Ministerio de comunicaciones, obras publicas, y transporte. Tegucigalpa, Honduras.

Larrea, S., Levy, R., Montgomery, R., and Brito, E. (2002). Proyecto de agues y saneamiento de San Pedro Sula (HO-0211): Informe de impactos ambiental y social. Interamerican Development Bank.

Región Sanitaria (2003). Informe preliminary del problema de diarrea y enfermedades de la piel en la comunidad de Cofradía. Región Sanitaria No. 3, Municipio de San Pedro Sula, Departamento de Cortes.