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The politics of poison

Elite capture of clean water in Bangladesh

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The Politics of Poison: Elite Capture of Clean Water in Bangladesh

Abstract: Fifty seven million Bangladeshis consume well water with arsenic concentrations exceeding WHO safety standards. NGOs and the Bangladeshi government's Department of Public Health Engineering (DPHE) have installed over 200,000 low-arsenic deep wells to alleviate this problem. However, the spatial distribution of these deep wells does not maximize their accessibility to populations currently drinking contaminated water. We investigate the extent to which elite capture can explain the existing inefficiency in deep well placement. We first show that local politicians are more likely to have a deep well built near them during periods when their political party is in power. We then incorporate our estimates of the extent of political preference into a model of deep well placements using a maximal cover algorithm. In total, we estimate that elite capture accounts for about a fifth (18%) of current inefficiency in deep well placement.

1 Introduction

The World Health Organization has referred to Arsenic contamination of well water in Bangladesh as “the largest poisoning of a population in history” (Loewenberg, 2017). Arsenic is naturally released by sediments into groundwater, contaminating well water consumed by villagers. As a result, an estimated 57 million Bangladeshis chronically consume drinking water with arsenic concentration exceeding the WHO safety limit for arsenic (Kinniburgh and Smedley 2001). Arsenic contamination is not unique to Bangladesh. In West Bengal, an additional 9.5 million people drink well water with Arsenic concentrations exceeding WHO guidelines (Dey et al. 2014).

The effects of chronic exposure to arsenic on human health and economic productivity are severe. Arsenic has been linked to skin lesions, internal cancers, all-cause death, cardiovascular disease, infant mortality, and impaired intellectual and motor functioning in children (Van Geen et al. 2014). In terms of economic welfare, Arsenic exposure negatively effects productivity. Pitt Et. Al Estimates that reducing Bangladeshi Arsenic retention to US levels would, on average, increase household income by 9% per male worker. At the national level, arsenic related mortalities are expected to cost Bangladesh US $12.5 billion over the course of 20 years (Flanagan, Johnston, and Zheng 2012).

Proposed solutions to Arsenic contamination mostly rely on changing how rural households access water. Currently 95% of rural households drink water from privately owned shallow wells (Pitt, Rosenzweig, and Hassan 2012). Despite a large portion of these wells being unsafe for drinking, an estimated 90% of households live within walking distance of an uncontaminated shallow well. Thus, one solution to the arsenic crisis is to inform residents which wells are safe. In this way, residents who own unsafe wells can make arrangements with their neighbor to access a different well. However, low-income households may be less able to barter for access to a neighbor’s uncontaminated shallow well than households which are better off (Madajewicz et al. 2007).

Another solution is to install deep tube wells. Deep tube wells are defined as wells deeper than 150 meters by the government’s Department of Public Health Engineering (DPHE) (Van Geen et al. 2005). Almost all (99.95%) deep tube wells are low in arsenic (Van Geen et al. 2005). However, deep wells are too expensive for single households to install on their own (Van Geen et al. 2005). Thus, a large share of government and donor funds has been dedicated to installing deep wells. As of 2007, 200,000 deep wells have been installed across Bangladesh (Van Geen et al. 2005). Public deep wells may be an especially promising solution for low-income households that are unable to bargain for access to their neighbors’ shallow wells.

Unfortunately, existing deep wells are not spatially distributed to maximize coverage of at risk populations. Most individuals are willing to walk a maximum of 100 meters past their current well to draw water from a less contaminated well. Furthermore, their willingness to use a different well drops sharply for wells located more than 100 meters away from a current well (Chen et al. 2007). Thus, it is generally inefficient to install two deep wells located within 200 meters of each other because some households will be located within 100 meters of both wells at the cost of others having access to neither. Nevertheless, prior research shows that in Araihazar, a province of Bangladesh, deep wells were placed in highly clustered patterns such that many deep wells were within 200 meters of another deep well (Van Geen et al. 2015). Additionally, while only 29% of contaminated wells in Araihazar were within 100 meters of a deep well, at least 74% of contaminated wells could have been within 100 meters of a deep well had Araihazar's deep wells been better placed (Van Geen et al. 2015).

We investigate the extent to which elite capture by political elites is responsible for the current inefficient distribution of deep wells. Elite capture occurs when social, economic, or political elite are able to usurp resources intended for the general population. Our study is motivated by existing literature suggesting that deep wells in Bangladesh are subject to elite capture. For example, one third of deep wells were placed in locations such as private households that are inaccessible to the public (Van Geen et al. 2015). A possible explanation for this finding is that these wells are being placed on the property of local elites. In accordance with this explanation, a previous field experiment showed that villagers reported greater access to clean water when well locations were decided under guidelines intended to prevent appropriation by local elites (Madajewicz, Tompsett, and Habib 2015). Finally, anecdotal evidence from local villagers suggests that local politicians are able to influence the placement of deep wells (Loewenberg 2017).

In order to determine whether wells were preferentially placed near elites, we conducted a survey in which we interviewed knowledgeable villagers about the locations of elite households. We then cross-referenced the elite locations with existing well data to determine whether deep wells tended to be placed closer to elites. Our results suggest that after Awami League's 2009 takeover of the national government, deep wells were more likely to be placed near Awami League politicians. We show that Awami League politicians received more wells in the years when their political party controlled the national government. We then estimate the social cost of elite capture using a model of the government's well placement decisions. We demonstrate that while 90% of contaminated wells could have been within 100 meters of a deep well, only 29% of contaminated wells actually were. Additionally, our model suggests that elite capture reduced access to public wells by 11%, explaining about a fifth (18%) of the 61% loss in coverage.

Our study makes several contributions to the literature on the Arsenic crisis in Bangladesh. First, we improve on existing estimates of optimal deep well placements. A prior study estimated that 74% of contaminated wells could have been within 100 meters of a deep well had deep wells been better placed (Van Geen et al. 2015). However, using a more advanced facility location algorithm we demonstrate that 90% of contaminated wells in Araihazar could have been within range of deep wells had those deep wells been optimally placed. This improved algorithm can be useful for determining ideal future deep well placements. Second, using our well placement model, we present the first estimate of social cost as a result of elite capture of deep wells.

Our study also makes important contributions to the literature on elite capture. Prior studies have investigated how institutional changes in village level meeting rules reduce elite capture. In a randomized field experiment, villages were found to report greater benefits from public works projects when those projects were chosen through election based plebiscites instead of by representatives (Olken 2010). In the same vein, meeting rules designed to limit appropriation of deep wells by elites were to increase access to safe drinking water by 25% (Madajewicz, Tompsett, and Habib 2015). Our study complements the existing literature by offering evidence that national politicians are active players in enabling local elite capture by village elites. Another important contribution to the elite capture literature is our social cost model. Our model provides a robust template for estimating the effect of elite capture in other cases concerning the spatial distribution of public works projects.

This paper proceeds as follows. Section 2 describes the datasets used in our analysis. Section 3 presents our analysis demonstrating that elite capture affects the placement and accessibility of deep wells. Section 4 presents the model with which we estimate the social cost of elite capture. Section 5 summarizes the policy implications of our study and concludes.

2 Datasets

2.1 Study Location

We collected all our data in Araihazar, a 183 Km^2 province of Bangladesh. Our primary reason for researching deep well placements in Araihazar was that the most recent blanket survey of wells in the country was conducted in 2012-13 in Araihazar. Additionally, Araihzar has an abundance of underground aquifers, allowing deep wells to be easily installed throughout the region (Choudhury et al. 2016). Therefore, we were able to cross-reference deep well and elite locations without needing to correct for the presence of underground aquifers.

2.2 Wells Data

We used data collected in a 2012-2013 blanket survey of all wells in Araihzar (a total of 48,799 wells). These data included the geo-coordinates, depth, arsenic concentration, and age in years of every well.

Additionally, the data describes whether or not a given well was used for drinking or cooking. Finally, prior interventions had labelled most wells either red or green to indicate whether the wells were safe or unsafe for consumption. The wells data records whether a given well is labelled either red (unsafe), green (safe), or is unlabeled. The wells dataset is described in greater detail in Van Geen et. al 2014.

In order to facilitate analysis, we classified wells of depth greater than 300ft (91 m) as deep. Additionally, we classified wells with Arsenic concentrations above the Government of Bangladesh's safety standard (50 micro gram/liter) as contaminated. We chose to use the government's safety standard because we aim to model the government of Bangladesh's well placement decisions.

A summary of our well dataset is presented in Table 1**.** Almost half of all shallow wells are contaminated (46%), while all but 10 deep wells are low in arsenic (99%). Our data shows a large increase in the number of deep wells built from 2009-2012 (Figure 1). All four years with the largest construction of deep wells occurred in this time period, during which 61% of all deep wells were built in Araihazar. While our data suggests that well construction slowed in 2012, this apparent trend may be a result of incomplete well data. Data collection began in March 2012 and ended in September 2013. Therefore, it is possible that for any given location visited by surveyors in 2012, additional wells were built after surveyors had already completed their visit. Our data also suggests that no deep wells were built in 2013. However, this observation is likely due to the fact that surveyors listed well age, not well construction year. Furthermore, surveyors only listed well ages in whole number of years and did not list any ages less than one year. Thus, all wells built in 2013 would have been listed as 1 year old and grouped under wells built in 2012. Thus, the data reveals that the rate of deep well construction increased around 2009 and may have remained high beyond the end of our study data. We hypothesize that this trend is a result of an intentional effort by the national government to construct deep wells and end the arsenic crisis. We further assume that the governments' Department of Public Health Engineering (DPHE) was responsible for overseeing most of this well construction.

2.3 Accessibility Survey

We obtain a survey from a prior study investigating whether wells were being constructed in accessible locations. Surveyors in this study randomly selected a group of 30 deep wells constructed by DPHE and ranked their accessibility as either low, medium, or high. Wells constructed in "isolated area[s] inaccessible to nonhousehold members" were encoded as having low accessibility. Wells that allowed for "limited access provided to neighboring households" were encoded as having medium accessibility. Finally, wells in "public locations accessible to any villager" were encoded as having high accessibility. The survey from the prior study also recorded a unique ID for each of the 30 wells. In total, there were 12 low accessibility wells, 10 medium accessibility wells, and 8 high accessibility wells. The unique ID chosen was consistent with the ID naming convention of our larger blanket survey which allowed us to match the 30 wells in the accessibility survey with the data in the blanket survey.

2.4 Village and Union Data

According to Bangladesh's 2011 Population and Housing Census, Araihazar is divided into 322 villages. Villages consist of clusters of several hundred households and buildings, with individual villages often separated by large tracts of farmland. In practice, boundaries between villages are often informal. Thus, we used these tracts of farmland as well as local knowledge to demarcate informal village borders in arcGIS (Figure 2). Ultimately, we demarcated 294 informal villages. The villages of Araihazar are grouped into 12 different unions each containing between 15 and 40 villages. We had access to union boundaries and were able to record to which union each of the 294 villages belonged.

2.5 Elites Data

We surveyed one respondent from each census village who was knowledgeable about political elites living in their village. Political elites consisted of candidates for union level offices. Every union elects a single union chair and several union ward members. We asked respondents to name people who were living in their villages who had run for both these offices in the 2003 and 2011 elections. It was possible for respondents to indicate that any number of political elites were living in their village (including none).

For every elite named, we asked respondents to locate that elite's household. The surveying team then walked to the elite's house and recorded its location with a GPS device and recorded its geocoordinates. We also collected additional information about elites such as political affiliation, term in office (for political elites who won elections), age, gender, and whether the elite's parents or children lived in the same village as the elite. Overall, we identified 1552 political elites.

2.6 Landmarks

A good strategy for deep well placement might be to place deep wells next to important community centers, such as markets, in an attempt to maximize public access. A decision to place wells near community centers could explain the close proximity of deep wells to village elites, who may disproportionately choose to live near village centers. Thus, in our regression analysis, we controlled landmark locations as a proxy for village centers. In particular, we used data published by the Local Government Engineering Department (LGED) that was collected between 1992 and 1994. The LGED data records the locations of mosques, schools, and markets, among other important landmarks[1]. One concern with the data was that certain

[1] In particular, LGED recorded the locations of the following landmarks: colleges (n=4), cottage industries (42), family welfare centres (21), Ferry Ghat (2), Food Godown (3), Graveyard (3), Growth Centre (5), Helipad (1), High Schools

categories of landmarks were clearly not properly surveyed. For example, only one post office was reported across the 297 villages. Other landmarks were unlikely to be located in town centers (eg: helipads or mobile towers). To alleviate these concerns, we counted only bazars, primary schools, high schools, madrasas, places of worship, cottage industries, and family welfare centres in our analysis.

3 Analysis

3.1 Well Placement and Clustering of Deep Wells

A total of 915 deep wells were installed in Araihazar as of 2013. We aim to determine whether these deep wells were installed in locations that serve the public good. Accordingly, we develop a simple way to measure how effective a spatial distribution of deep wells is at providing clean water to Araihazar's population. We say that a shallow well *s* is *covered* by a deep well *d* whenever *s* is within 100 meters of *d*. Further, we assume that residents who would normally drink from *s* can choose to drink from *d* so long as *s* is covered by *d*. Our assumption is based on the fact that most individuals are willing to walk at most an additional 100 meters past the well they currently use to a less contaminated well, and that an individual's willingness to use a different well rapidly declines for wells located more than 100 meters away from their current well (Chen et al. 2007). Accordingly, the number of contaminated wells covered by at least one deep well is a good measure for how much a group of deep wells benefits the public.

Returning to our data, we found that 29% of shallow wells in Araihazar were covered by a deep well. Further, using a facility location algorithm (described in section 4), we were able to determine that an ideal placement of deep wells would cover 90% of Araihazar's contaminated wells. Thus, inefficient deep well placement is responsible for a 61% loss in coverage.

The inefficiency in the observed deep well placement is partially due to deep wells being installed within 200 meters of each other, such that their 100 meter radii of coverage overlap. We find the average distance between a deep well and the nearest other deep well is smaller in the actual placement of deep wells than in the optimal placement (104 meters vs 191 meters, $p < 1e\text{-}10$). Additionally, in the actual placement, 68% of the households within 100 meters of a deep well are within in walking distance of a second deep well, while in the optimal placement, only 25% of households in range of a deep well are also in range of a second deep well.

Similar to deep wells, we find that elites are also clustered. Elites are on average twice as close to the nearest elite as a regular household is to its nearest elite neighbor (57 m vs 114 m, $p < 1e\text{-}10$). Additionally, the

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(20), Low Lift Pump (7), Madrasa (20), Mills/Factories/Industries (7), Mobile Tower (11), Mosques/Eidgah/Church (55), Post Office (1), Primary Schools (1), Small Hat/Bazar (43), Telegraph Office (1) probability that an elite is located within 200 meters of the nearest elite is higher than the probability that a regular household is located within 200 meters of the nearest elite (Pr = .96 vs Pr = .85, p < 1e-10). Importantly, elite clustering could explain the observed deep well clustering under conditions of elite capture. Two elites living in close proximity to each other may each demand that a deep well be installed in the immediate vicinity of their households. If these elites are within 200 meters of each other and both their demands are met, two deep welals would be installed with overlapping circles of coverage. Alternatively, an elite may demand one deep well for himself and one for close friends or family members living nearby – again resulting in two deep wells with overlapping coverage. Finally, elites may request that a deep well be installed in a location such as a fenced in yard that is only accessible to themselves. In such cases, a public deep well may be constructed in addition to the private deep well, again resulting in the observed clustering. Consistent with this final explanation, a survey in a prior study found that 40% of deep wells are built on private property in places inaccessible to the general public (Van Geen et al. 2015).

3.2 Determinants of Deep Well Placement

We wish to determine which structures (households, elite households, landmarks, etc.) are spatially correlated with deep wells. To this end, we placed a hexagonal grid over Araihazar (Figure 6). We excluded hexagons whose centroids did not fall in our pre-defined village boundaries in order to exclude large tracts of farmland and wilderness where no deep wells were built. For every hexagonal grid cell i we then computed Y_i, the total number of deep wells in that cell. To find the determinants of deep wells we estimated the following spatial regression model:

$$Y_i = \beta_0 + \beta_1 N_i + \beta_2 C_i + \sum_j \beta_j E_{i,j} + \beta_3 L_i + \varepsilon \qquad \text{Eq. 1}$$

Where for grid zone i: N_i is the number of non-contaminated shallow wells; C_i is the number of contaminated shallow wells; $E_{i,j}$ is the number of political elites of party j where j represents the political party the elite belongs to; and, finally, L_i is the number of landmarks of the types listed in section 2.6.

In our regression model, we use contaminated and uncontaminated wells as a proxy for regular households because small groups of one or two households will often build their own shallow well. In particular, every shallow wells serves an average of 7.7 people or 1.92 households[2]. We control for landmarks in order to correct for the fact that elites and landmarks may be spatially correlated: elites may prefer to live near landmarks, and well-meaning officials may install deep wells near public landmarks to maximize public access.

[2]We found a Median household size of 4 based on an analysis of rural households in the 2010 Household Income and Expenditure Survey.

We estimate equation 1 separately for two different time periods to investigate whether deep wells built in a given period were preferentially placed near politicians belonging to the party controlling the national government during that period. We collected complete data on both local politicians and well placements from 2003 to 2011[3] .We split these years into 3 time periods, each corresponding to a different national government. During these years, Bangladesh politics essentially operated according to a two party system, with the Bangladesh National Party (BNP) and the Awami League (AL) dominating national politics. BNP controlled the national parliament and prime minister's office from 2003 through most of October 2006 (time period 1). Starting in late October 2006, a military backed caretaker-government took power (time period 2). This government yielded to a democratically elected government in January 2009, at which time the Awami League won a majority of parliamentary seats as well as control of the prime minister's office. The Awami League has controlled the national government ever since (time period 3).

We then define the dependent variable to be either wells built during the AL government or wells built under the BNP government, and estimate two separate regressions - one for each dependent variable. We find that under the AL government, wells were significantly more likely to be built near local AL politicians. In the preferred 75 meter grid zone specification, the average AL politician's household was equivalent to 12.14 shallow wells, or approximately 24 regular households (Table 2) Furthermore, BNP politicians did not fare as well during AL's control of the national government – the coefficient on BNP politicians was much smaller than for AL politicians and insignificant.

Importantly, our dependent variable does not differentiate between deep wells built by politicians and deep wells built by NGOs. Presumably, wells built by NGOs are less subject to preferences expressed by politicians who wield influence primarily through their connection to government. Therefore, our regression model is likely to be underestimates the level of influence politicians have over wells built by the government. Likewise, the model may over-estimate the relative weight of contaminated shallow wells have on the construction of deep wells. Therefore, our estimate that a politician is equivalent to about 7 households in need of clean water is a lower bound on politicians influence.

3.3 Effects of Political Party

DPHE is a department of Bangladesh's national government. Thus,.

To account for party affiliation, we modify regression equation (1). Instead of controlling for the presence of any politician, we now control separately for AL and BNP politicians. Additionally, we change the

[3] Specifically, we define a politician as a candidate in the 2003 or 2011 elections. Thus, our oldest politicians are those who ran in 2003. Furthermore, because data on wells was collected started in 2012, our deep well data is only complete for deep wells built no later than 2011.

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Turning our attention to deep wells built during the BNP's control of the national government, we find that neither AL nor BNP politicians were able to influence well placements. Although the coefficient on AL politicians and the ratio of AL politicians to regular households drinking contaminated water was significant in our preferred 75 meter grid cell, the relative influence of AL politicians was much smaller than during AL's control of the national government. During AL's control AL politicians were equivalent to about 24 regular households while during BNP's control of the nation government, the same politicians were equivalent to only 9 regular households. Turning our attention to BNP politicians, we found that they too did not wield significant influence during their party's control of the national government. A major question of interest is why AL politicians appear more able to take advantage of a friendly national government than their BNP counterparts. A likely explanation is that the large number of deep wells built in 2010 and 2011 were part of a concerted effort to resolve the arsenic crisis orchestrated by the national government. It may have been easier for AL politicians to systematically take advantage of this concerted well building effort than it was for BNP politicians to take advantage of the sporadic well construction that occurred between 2003 and 2005.

3.4 Inefficiency of Deep Wells Near AL Politicians

DPHE's preferential treatment of AL politicians is inefficient for three reasons. First, deep wells may be placed in less populous regions only because politicians live there. Second, as a result of politicians being spatially clustered, deep wells may be built in close proximity to one another, thereby resulting in deep wells with overlapping coverage areas. Third, politicians may prevent the public from accessing deep wells placed on their land. We now investigate the loss in clean water access as a result of the latter two reasons: clustering and restriction of public access. In every grid cell *i*, we compute the share of shallow wells marked as contaminated that are being used for human consumption:

$$S_i = \frac{(Total\ Wells\ Marked\ as\ Contaminated\ Used\ For\ Consumption\ in\ Grid\ i)}{(Total\ Wells\ Marked\ as\ Contaminated\ in\ Grid\ i)}$$

We then estimate the following regression model:

$$S_i = \beta_0 + \beta_1 D_i + \beta_2 F_i + \beta_3 E_i + \varepsilon \qquad \text{Eq. 3}$$

Where for every grid zone i: D_i represents the number of deep wells not within 100 meters of an AL politician; F_i represents the deep wells within 100 meters of an AL politician; and E_i represents the number of AL politicians. Consistent with the expectation that deep wells reduce consumption of contaminated water, β_1 and β_2 are negative across all grid sizes (Table 3). We also find that the effect of either kind of deep well is greater in smaller grid zones than in larger ones. For example, in 50m grid zones every additional deep well near an elite reduces the share of contaminated wells being used for consumption by 12% and every additional deep well not-near an elites reduces share of consumption by 19%. In the 150 m grid zone, however, these respective figures are only 3% and 5%. This is because in a small grid zone a greater proportion of that cell's shallow wells will be in range of deep well placed in that grid cell. Thus, the presence of a deep well in a small grid cell has a greater impact on the share of households consuming contaminated water than in a large grid cell.

Importantly, we also find that across grid sizes $\frac{\beta_2}{\beta_1} < 1$, i.e. wells placed near AL politicians are less effective at reducing consumption of contaminated water than wells otherwise placed (Table 3, final row). Depending on grid size, our estimate for $\frac{\beta_2}{\beta_1}$, the ratio of effectiveness of a deep well near an elite to the effectiveness of a deep well not near an AL politician ranges from 51% to 65% (Table 3, final row). In our preferred 75 meter specification, deep wells placed near elites are only 60% as effective as other deep wells at reducing consumption of contaminated water.

Note that because we control for the total number of elites in a grid zone, the reduced efficiency of deep wells near AL Politicians is due to the presence of an AL politician, not other properties of the surrounding land that happen to be spatially correlated with elites. Furthermore, because our dependent variable is S_i, the share of all wells marked as unsafe being used for consumption, and not the total number being used for consumption, our present regression model does *not* measure loss of efficiency as a result of deep wells being moved away from populated areas. Rather, as we stated earlier, the estimated loss in efficiency is the net effect of i) deep wells near elites having overlapping coverage areas and ii) deep wells near elites being restricted to the public. This distinction will prove important in the construction of our social cost model.

The accessibility survey provides evidence that the loss in efficiency in wells near politicians is in part due to influential politicians requesting that wells be constructed in inaccessible areas such as private yards. Of the 30 wells randomly chosen for the survey, 9 were within 100 meters of an AL politician and 21 were not. We found that 46% of wells within 100 meters of an AL politician have low accessibility, while only 37% of other deep wells had low accessibility. Although a chi-square test comparing the accessibility rankings of wells near AL politicians and other deep wells did not report a significant result (p=.72), this is likely because only a relatively number of wells were surveyed for accessibility.

We also find descriptive evidence that wells near AL politicians are more clustered. The mean distance from a deep well not near an AL politician to another deep well is 114 meters, while the mean distance from a deep well near an AL politician to another deep well is only 81 meters (p=.003). Accordingly, deep wells near AL politicians are six percentage points more likely to be within 200 meters of another deep well than deep wells not near a politician (p=.019).

4 Social Cost Model

4.1 Outline

We now model the decision making process that determines well placements. We first present a general outline of our model structure. Next, we vary the assumptions in our model to represent well placement under different conditions of elite capture. The primary output of our model is the total coverage of contaminated shallow wells, i.e the percent of contaminated wells within 100 meters of a deep well. We will estimate the social cost of elite capture by observing how the coverage contaminated shallow wells varies between conditions that reflect elite capture to the and conditions in which wells were placed fairly.

We frame our model as a maximal cover problem. In an unweighted maximal cover problem, N facilities are placed so as to maximize the number of demand points p_k that are within some distance r of at least one facility. In a weighted maximal cover problem, each demand point is assigned a weight w_k so that some points are more influential in the placement of facilities than others. More formally, let $D = \{d_n \mid n = 1, 2, \ldots N\}$ be the location of the N facilities. Further, let $s_k = 1$ if there exists at least one d_n such that $\| p_k - d_n \| \leq r$ and let $s_k = 0$ otherwise. Then a weighted maximal cover algorithm seeks to choose D so as to maximize:

$$\sum_k w_k s_k \tag{3}$$

In our model, the N facilities to be placed are deep wells. The demand points p_k consist of shallow wells (representing regular households) and elite households. Finally, we make the choice of $r = 100$ meters, to reflect the fact that deep wells should be placed in walking distance of households.

At first glance, it may appear that we must choose deep well locations from an infinite number of possible installation points. However, an optimal solution can always be chosen from a finite set of deep well locations: Construct a circle of radius r around every point p_k. Let I be the (finite) set of intersection points between these circles. Then so long as every circle intersects with at least one other circle there exists a choice of facility locations D such that $d_n \in I \forall d_n \in D$ and equation 4 is maximized (Gelman et al. 2004). However, it is computationally impractical in a large dataset to check every possible combination of deep well locations from this finite set of possible facility locations. We therefore use a greedy algorithm as an approximation: we choose the first well so as to maximize the weighted sum in equation 4, then, having placed the first well, we choose the second well, and so on. Although the greedy algorithm is not guaranteed to find an optimal solution, it is guaranteed to solve the problem with a worst case approximation ratio of $1-\frac{1}{e} \approx .63$ (Hochbaum 1996). Furthermore, in practice, we found that the greedy algorithm significantly outperformed this approximation ratio[4].

Having described the structure of our model, we now vary the assumptions of our model to reflect well placement under different conditions of elite capture (Table 4, Panel A). In condition 1, we assume that all deep wells were placed so as to maximize coverage of contaminated shallow wells. Specifically, we let $w_k = 1$ for contaminated shallow wells, and $w_k = 0$ for all other points. The result is that only contaminated shallow wells are considered when placing deep wells. Additionally, we let $N = 915$ so that all deep wells are placed using the greedy algorithm. Condition 1 thus represents an optimal placement of all 915 deep wells.

Recall our hypothesis that a coordinated deep well construction program started around 2009. Condition 2 assumes that deep wells built prior to 2009 are fixed in their actual locations, and seeks to estimate what coverage would have been like had the large number of wells built starting in 2009 been installed in optimal locations. To reflect this condition in the model, we let $N = 503$ so that the greedy algorithm only places the deep wells built after 2009. Further we let $w_k = 1$ for contaminated shallow wells *not* within 100 meters of a deep well built before 2009, and $w_k = 0$ for all other points.

Condition 3 begins to look at potential failings of the hypothesized 2009 deep well construction program. An optimal strategy in placing post-2009 wells would have been to build deep wells far away from areas

[4] In all 3 modeling conditions, we can cover at most 100% of all wells. Thus, the worst case scenario is bounded below by 63%. However, condition 3, which had the smallest coverage (72\%) still significantly outperformed the highest possible worst case scenario.

already covered by a well built prior to 2009 as in condition 2. One possible shortcoming of the program, however, is that deep wells were not constructed taken to consideration pre-existing facilities. To observe the effect of such a decision of our model, we let, $w_k = 1$ for contaminated shallow wells *regardless* of whether they are already within 100 meters of a pre-2009 deep well, and $w_k = 0$ for all other points.

Condition 4 models the loss in coverage as a result of post-2009 deep wells being built near politicians instead of near populations drinking contaminated water. Recall the interpretation of our grid based regressions: the presence of one AL politician's household in a grid cell is equivalent to about 11 contaminated shallow wells. Thus, to reflect the additional influence of AL elites, we let $w_k = 11$ for elite households, $w_k = 1$ for contaminated shallow wells, and $w_k = 0$ otherwise. As in the regression model, 11 co-located shallow wells in our social-cost model would have the same effect on predicted deep well placement as one elite household.

Note that condition 4 does not account for any loss in coverage due to clustering of wells. When two elites are located within 200 meters of one another, the greedy algorithm will generally choosing a single location that covers both elites over a location that covers just one. Accordingly, we find that the deep wells under condition 4 are not significantly more clustered than in the actual distribution of deep wells. In both conditions, deep wells are on average 156 meters from the nearest neighboring deep well. Additionally, note that condition 2 does not model any loss in coverage due to elites making certain wells inaccessible to the public. Thus, condition 4, only models loss of coverage due to deep wells being moved away from areas with large populations of contaminated wells towards elites.

Condition 5 builds on condition 4 by addressing the problems of clustering and privatization of deep wells. Recall that using regression equation 4 we estimated that deep wells become 40% less efficient when placed within 100 meters of an elite. We claimed further that this loss in efficiency was only due to clustering or privatization, not relocation of deep wells to less populous areas. Therefore, by accounting for this inefficiency in condition 5 on top of the weights used in condition 4, we may estimate the net loss in coverage as a result of i) movement of wells to less populated areas, ii) clustering, *and* iii) private-access wells. Let M be the number of deep wells built within 100 meters of an AL politician in the actual distribution of deep wells. Since a deep well placed near an elite is on average only 60% as effective as a deep well not near an elite, we estimate that in the actual distribution of deep wells the public effectively loses access to .4M deep wells. In order to model this loss, we simply use the greedy algorithm to place $\lfloor N - .4M \rfloor$ wells instead of N wells. We keep the weighting scheme from condition 2 that prefers elites, because we would like to reflect the fact that less efficient clusters of wells are still being placed near elites, not in more populous areas. In actuality, $M = 273$ wells so that condition 5 removes .4M = 109 wells and applies the greedy algorithm with $N = 440$ deep wells.

4.2 Measuring "Actual" Coverage

Recall that we wish to compare our optimal coverage to coverage under an actual placement of wells in order to estimate the total loss in coverage due to placement of deep wells. We can, however, use two separate definitions of coverage under actual placement. First, we might consider any contaminated well within 100 meters of an actual deep to be covered. Under this definition of coverage, 28.9% of all wells are covered. However, this definition does not account for actual deep wells that may were built to be inaccessible to the public despite being near contaminated wells. To address this problem we compute a second estimate of actual coverage in which a certain subset of deep wells are assumed to be inaccessible to the public. Since we do not know which wells are inaccessible, we will randomly select a subset of deep wells which we then deem ase inaccessible. Furthermore, recall that we estimated in condition 5 that private-access wells and well clustering result in an effective loss of about 109 deep wells and that we were unable to disentangle the effects of private-access and clustering. For our metric of actual coverage, we will assume conservatively that the loss in efficiency was due entirely to private-access wells such that we select 109 random wells which we assume are private-access wells. In computing total coverage, we count any contaminated well as covered if and only if it is within 100 meter of a deep well that is not one of these 109 randomly selected wells. Because the selection of private-access wells is random, we recomputed this metric coverage ten times to compute a mean and standard deviation for total coverage. In total, we found that an average coverage of 27.18% +/- 0.34%. Because this metric of coverage overestimates the loss in coverage due to private-access wells while our first metric of coverage assumed no private-access wells, we can conclude that the true measure of coverage is somewhere between 27.18% (coverage overestimating private-access wells) and 28.9% (coverage assuming no private-access wells). A likely explanation for why these metrics of coverage are quite close is that wells are so clustered that designating some wells as private-access does not greatly change which populations have access to clean wells. In other words, private-access wells are not primarly harmful because they prevent nearby populations from having access to the only source of clean water nearby. Rather, their primary harm is that they cause resources to be diverted from building wells in locations that have no other deep wells to locations that have too many.

4.3 Discussion of Model Results

We highlight several salient points from our model results (Table 4, Panel B). First, perfect deep well placement would have resulted in 90% of contaminated shallow wells being within 100 meters, an increase of 61-63% percentage points, or 26,875 households, over the 29-27% of contaminated wells covered in the actual distribution. Furthermore, we find that wells were installed sub-optimally even before elite capture during the post 2009 well building push. If we place post-2009 deep wells optimally but fix pre-2009 wells in their actual location our model reveals a drop in coverage of ten percentage points (4,535 households) from 90% to 80%. Additionally, coverage drops another four percentage points (2,036 hosuehold) from 80% to 76% if we assume that the government did not account for wells built before 2009 when deciding where to build new wells during the post-2009 well building push.

Turning to elite capture, we find that as a result of wells being moved towards AL politicians and away from populations in need of clean water, coverage drops another 3 percentage points (1,188 households) from 76% to 73%. Coverage drops further from 73% to 65% (3,455 households) once we account for the loss in effectiveness of deep wells near politicians due to clustering and politicians installing wells in locations inaccessible to the public. In total then, elite capture politicians is responsible for a drop in coverage of 11 percentage points (4,643 households). Elite capture thus explains one fifth (17-18%) of the 61-63% loss in coverage due to inefficient placement of deep wells.

4.4 Effects of Suboptimal Well Placement on Consumption

Building off prior research, we provide an estimate of the effects of elite capture on total household consumption. Pitt et al. estimates that every 1% reduction in an adult male worker's arsenic retention raises household consumption by approximately .094%. Furthermore, switching from a contaminated well to a deep well reduces arsenic retention by an average of 65% (Chen et al. 2007). Using these figures, we estimate that switching from a shallow well to a deep well would result in a 10% increase in household consumption for every male worker in the household. Furthermore, using Bangladesh's 2010 Household Income and Expenditure Survey, we found that rural households in Bangladesh have a median of 1 adult male worker and 2 adult female workers. As in Pitt et. al, we assume conservatively that female workers are half as productive as male workers. Accordingly, we estimate that a household switching from a contaminated well to a deep would see an average increase in household consumption of 21%.

We now estimate the effects of elite capture on Araihazar's population-level expenditures (Table 4, Panel B). We reporrt all percent changes in consumption relative to consumption under an actual distribution of deep wells. Furthermore, we compute two separate estimates, each under a different assumption. First, we assume perfect deep well usage – namely, we assume that 100% of households using a contaminated shallow well switch to a deep well when that deep well is within 100 meters of their shallow well. Second we assume partial deep well usage, i.e. only 20% of households within 100 meters of a deep well switch to using that deep well. The latter assumption is consistent with our estimate that the presence of a deep well reduces consumption from nearby contaminated shallow wells by 20% (Table 3). Assuming perfect deep well usage, an optimal placement of wells could have resulted in a 7% increase in Araihazar's total consumption. This figure is reduced to 1.4% under assumptions of partial deep well usage. Turning to elite capture, we find that eliminating elite capture would result in a total consumption increase of either 1.2% (full usage) or 0.2% (partial usage).

5 Conclusion and Policy Implications

Our research has three main policy implications. First, better coordinated deep well construction programs are crucial to resolving the arsenic crisis. In the case of Araihazar, constructing wells in optimal locations would have increased the percentage of Araihazar's population drinking arsenic-contaminated water with access to clean water by over 60%. Second, better placed deep wells will not completely resolve the arsenic crisis since those deep wells are not necessarily used by nearby villagers. In particular, deep wells are correlated with only a 20% reduction in consumption from nearby contaminated shallow wells. Thus, in order to fully benefit from a deep well program, NGOs and the government of Bangladesh should continue to support programs that promote deep well usage. Finally, our analysis suggests that national politicians contribute to the elite capture problem. In particular, our results suggest that national politicians grant favors to local political allies, even when those allies do not hold office. Thus, future programs should make sure to protect against corrupt practices that involve cooperation between national and local politicians. If all these policy goals had been implanted in Araihazar when the deep wells were originally built, we estimate that Araihazar's total household expenditures would be 7% higher than current levels. Furthermore, an additional 24,000 households would have seen the health benefits of consuming water uncontaminated by arsenic.

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7 Tables

Table 1: Descriptive Statistics by Type of Well

Well Type	Shallow, Uncontaminated	Shallow, Contaminated	Deep Uncontaminated	Deep Contaminated
N	25600	22264	905	10
Proportion of Wells of Same Depth	54%	46%	99%	1%
Proportion used for drinking or cooking	97%	85%	97%	78%
Mean Depth (ft)	95	63	688	565
Mean As Concentration (ug/L)	9	217	3	170
Median Construction Year	2007	2007	2010	2007
% Covered by deep well (actual)	18%	28%	NA	NA
% Covered by deep well (optimal)	35%	89%	NA	NA
% Covered by > 1 deep well (actual)	29%	46%	NA	NA
% Covered by > 1 deep well (optimal)	6%	10%	NA	NA
Distance to nearest neighboring deep well (actual)	330	280	104	
Distance to nearest neighboring deep well (optimal)	445	83	191	

Notes: I) A shallow well "covered" by a deep well is defined as a shallow well within 100 meters of a deep well. II) In addition to reporting actual coverage rates and distances to nearest deep well, we also report coverage rates and distances that would be observed had deep wells been installed in optimal locations. Our algorithm for determining the optimal distribution of deep wells is described further in section 4.

Table 2: Effect of Political Elites on Well Placement by Party Membership and National Government Control

	1	2	3	4	5	6
VARIABLES	Deep Wells Added During AL Government			Deep Wells Added During BNP Government		
No. of Uncontaminated Shallow Wells	-0.004***	-0.003***	-0.002***	-0.001	-0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
No. of Contaminated Shallow Wells	0.017***	0.018***	0.014***	0.004***	0.004***	0.004***
	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
AL Politician Count	0.249***	0.191***	0.170***	0.016	0.019	0.024***
	(0.049)	(0.035)	(0.019)	(0.017)	(0.013)	(0.008)
BNP Politician Count	0.089	0.026	0.005	0.005	0.047**	0.013
	(0.080)	(0.054)	(0.029)	(0.028)	(0.021)	(0.012)
No. of Landmarks	0.091	0.050	0.052**	0.075***	0.045***	0.005
	(0.060)	(0.041)	(0.023)	(0.021)	(0.016)	(0.010)
Constant	0.070*	0.042**	0.031***	0.016	0.008	0.007***
	(0.037)	(0.018)	(0.006)	(0.013)	(0.007)	(0.003)
Observations	1,727	2,969	6,753	1,727	2,969	6,753
R-squared	0.099	0.084	0.050	0.047	0.033	0.018
Side Length	175m	125m	75m	175m	125m	75m
AL Politician To Household Influence	28.36	20.56	23.62	7.71	9.12	11.82
AL Politician To Household Influence (P-value)	0	0	0	.418	.221	.01
BNP Politician To Household Influence	10.17	2.76	.75	2.33	22.36	6.29
BNP Politician To Household Influence (P-value)	.32	.763	0.952	.919	.04	.383

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 3. Efficiency of Deep Wells by Presence of AL Politician

	(1)	(2)	(3)	(4)	(5)
Dependent Variable: Fraction of Unsafe Wells Used for Drinking					
Deep Well Not Within 100 meter of AL Politician	-0.0548***	-0.0709***	-0.0979***	-0.125***	-0.191***
	(0)	(0)	(0)	(0)	(0)
Deep Wells Within 100 meter of AL Politician	-0.0280***	-0.0348***	-0.0484***	-0.0749***	-0.124***
	(0.00267)	(0.000268)	(1.29e-05)	(3.23e-08)	(0)
AL Politician in Grid Cell	-0.00819	-0.00553	0.0229	-0.0441	0.0123
	(0.758)	(0.836)	(0.439)	(0.149)	(0.721)
Constant	0.781***	0.775***	0.763***	0.765***	0.750***
	(0)	(0)	(0)	(0)	(0)
Observations	995	1,206	1,580	1,874	2,628
R-squared	0.083	0.079	0.073	0.073	0.071
Grid Side Length	150m	125m	100m	75m	50m
Efficiency Ratio	.51	.49	.49	.6	.65
Efficiency Ratio (P-Value)	.013	.001	0	.002	.001

pval in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Note: The efficiency ratio is computed as the coefficient on deep wells within 100 meters of an AL politician to the coefficient on deep wells within 100 meters of an AL politician

Table 4: Model Results Using Maximum Cover Algorithm

Panel A

Condition	Causes of Inefficiency (Cumulative Across Conditions)	Deep Wells Being Placed	Weights on Contaminated Shallow Wells	Weights on AL Politicians	N
1.Optimal	Optimal	All deep wells placed by algorithm	1	0	915
2.Wells During 2009 Building Push Optimized	Pre-2009 Wells Fixed In actual locations (Not optimized by algorithm)	Pre-2009 wells fixed in actual locations,building push wells placed by algorithm	1 if not within 100 meters of a Pre-AL Deep Well. 0 otherwise	0	549
3.Wells During 2009 Well Building Push Optimized, Ignoring Pre-2009 Wells	Building push wells optimized, but ignoring existing pre-2009 wells	Pre-2009 wells fixed in actual locations, building push wells placed by algorithm	1	0	549
4.Politicians Weighted More Heavily than Regular Households	Pre-2009 Politicians Draw Deep Wells away from Contaminated Populations	Pre-2009 wells fixed in actual locations, building push Wells placed by algorithm	1	11	549
5.Politicians Weighted More Heavily,Politicians cause Deep Well Overlap and Made Inaccessible	AL Politicians cause Clustering and Privatization	Pre-2009 wells fixed in actual locations, building push Wells placed by algo-rithm	1	11	440
6. Actual	Actual well placement, assuming no private-access wells	All deep wells fixed in actual location	NA	NA	549
7. Actual, assuming some private access wells	Actual well placement, with some wells assumed to be inaccessible to public	All deep wells fixed in actual location, 109 wells randomly removed to reflect private-access wells	NA	NA	440

Note: The 2009 building push includes deep wells built in 2009 or later, consistent with our hypothesis that the government began a large deep well construction program in 2009.

Panel B

	Households Owning Contaminated Well Within 100 meters of a Deep well		**% Gain in Total Expenditures (Relative to Actual Well Distribution)**	
Condition	Number Within 100 meters	Percent of Total	Assuming 100% switch to deep well	Assuming 20% switch to deep well
Total	43637	100.00%	7.00%	1.40%
1.Optimal	39521	90.60%	6.00%	1.20%
2.Wells During Well Building Push Optimized	34986	80.20%	5.00%	1.00%
3.Wells During Well Building Push Optimized, Ignoring Pre-Push Wells	32950	75.50%	4.50%	0.90%
4.Politicians Weighted More Heavily than Regular Households	31762	72.80%	4.20%	0.80%
5.Politicians Weighted More Heavily,Politicians cause Deep Well Overlap and Made Inaccessible	28306	64.90%	3.40%	0.70%
6. Actual	12646	28.90%	0.00%	0.00%
7. Actual, assuming some private-access wells	11860 +/- 150	27.2% +/- .3%	-0.18%	0.03%

Note: In Condition 7, a random set of 109 deep wells are seleced as private-access wells. We calculated condition 7 ten different times using ten different randomly selected sets. We report the mean +/- 1

8 Figures

8.1 Figure 1 – Deep Wells Built Per Year

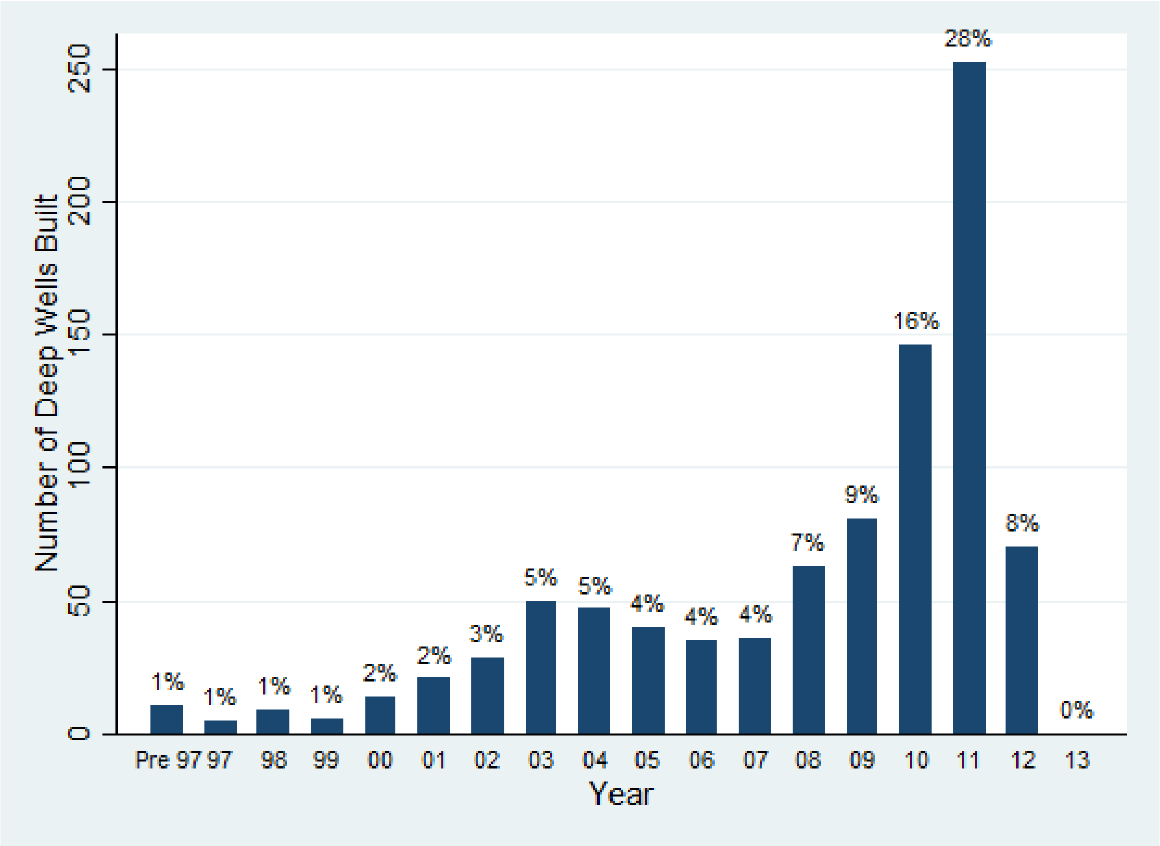

Figure 1: Deep wells built per year. The data for 2012 and 2013 is incomplete. Thus, the data imply that deep wells began were produced at a faster rate starting around 2009, with the increase in deep well construction possibly continuing until past the end of the study period.

8.2 Figure 2 – Example Villages

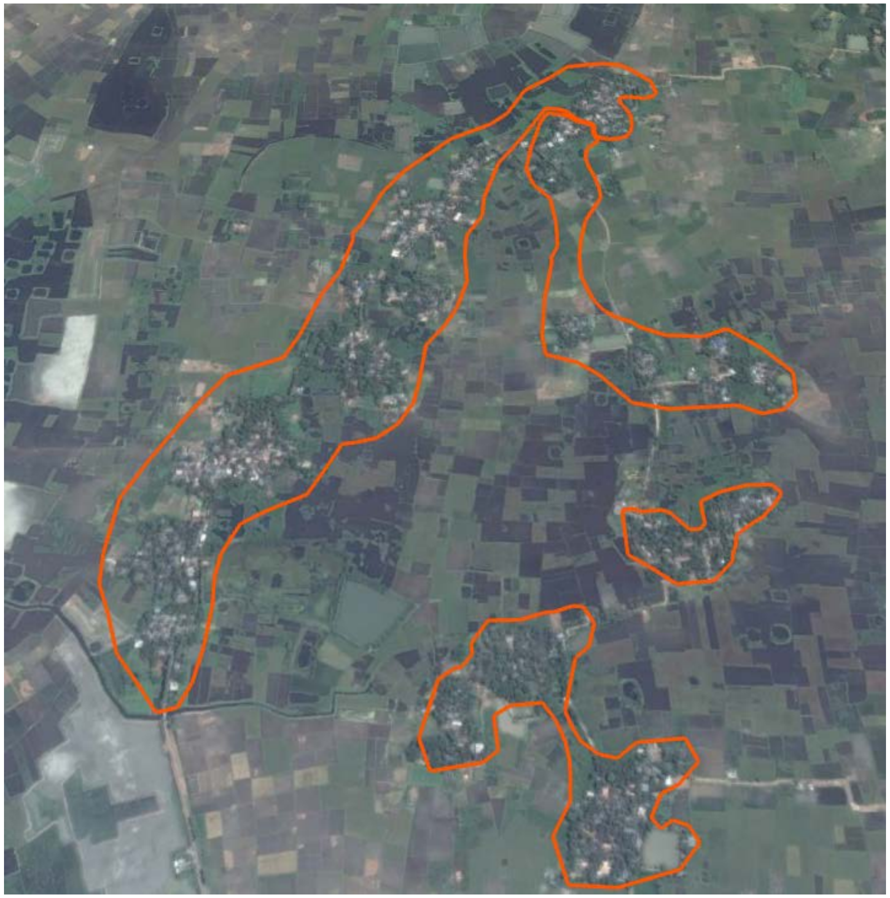

Figure 2: A few example villages, their boundaries (orange) usually demarcated by tracts of farmland.

8.3 Figure 3 – Deep Well Locations

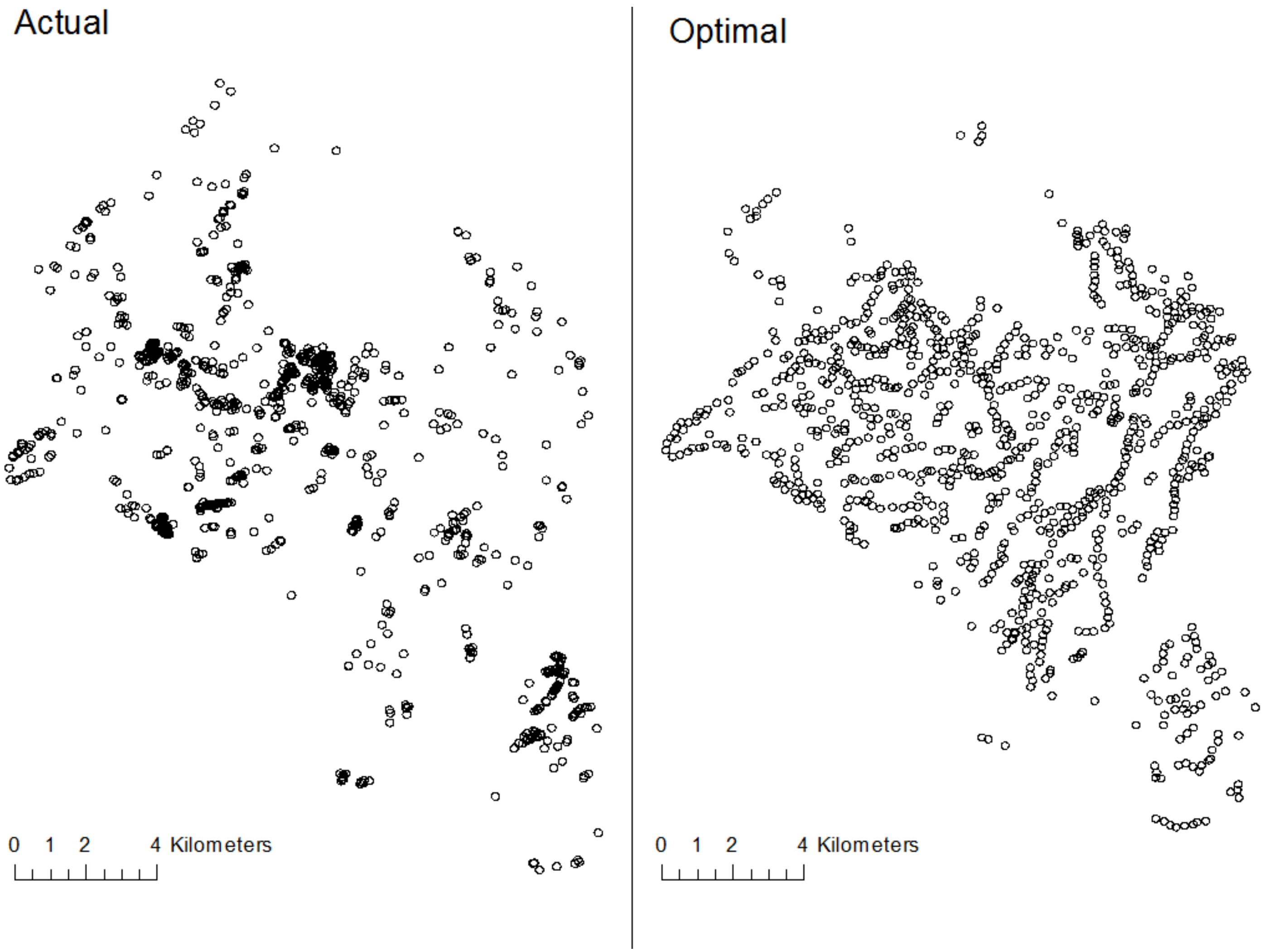

Figure 5: Actual (left) vs optimal (right) placement of deep wells. Note the high clustering of deep wells in the actual placement of deep wells.

8.4 Figure 4 – Hexagonal Grids

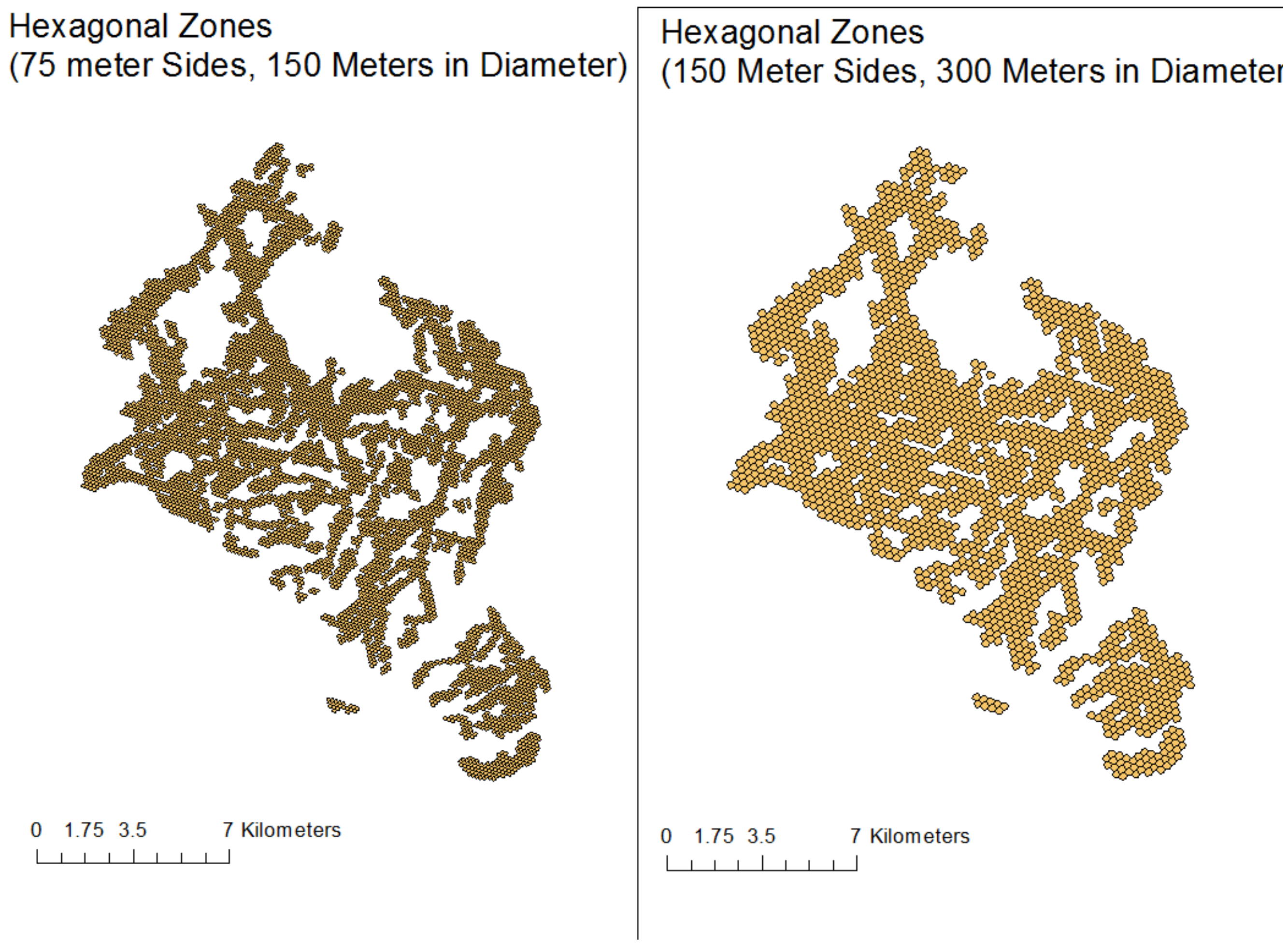

Figure 6: Hexagonal grid zones used in spatial regressions. Two sizes are shown: 75 meter (left) and 150 meter (right).

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