# Assessing collective action using spatial household data

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## 1. **Introduction**

The micro-economic theory of agrarian development focuses largely on the effects of economic institutions on the efficiency of resource use, investment, agricultural production and exchange. Four types of agrarian institutions are noted as having fundamental effects on these economic outcomes: property rights, organizations for collective action, factor and output markets, and credit and insurance contracts. The System-Wide Programme for Property Rights and Collective Action is concerned with the effects of property rights and collective action institutions.

All of these institutions define economic activity over time and across physical space. Economic models and analytical techniques have developed quite rapidly during the last 20 years to incorporate the temporal dimensions of economic activity. Differential calculus, dynamic programming and time-series econometric analysis have facilitated the development of the theory and methods; national and international statistical services have provided the bulk of the time-series data. However, economic theory and quantitative analysis have not developed so quickly to incorporate the spatial dimensions of economic activity or economic institutions (Bockstael, 1996). I propose that three inter-related factors help to explain this slow development: (1) space is not important per se; (2) spatial units are not well suited to economic analysis; and (3) spatial data bases present data in inappropriate ways for economic analysis. The next section of this paper discusses these propositions in more detail.

This paper seeks to demonstrate that new advances in the collection and processing of spatial data provide good opportunities for economists and other social scientists to investigate the spatial dimensions of economic institutions and economic activity. There are special opportunities for empirical applications of spatial analysis in developing countries where space is highly correlated with the costs of transportation and transaction and where it is cost-effective to collect large sets of geo-referenced household data. The particular problem that is explored is an example of collective action for the provision of a mixed local public-private good. The case study is in Ethiopia, a country renowned for the poverty of its people and the poor state-of its transportation and communication infrastructure. Geographically-referenced household data are used to test several hypotheses about the effects of local group characteristics on the effectiveness of collective action. The tools of Geographic Information Systems (GIS) and econometrics are used in the analysis.

## 2. The spatial dimensions of economic institutions and outcomes

This section considers the three possible deterrents to the development of economic theory and quantitative analysis of spatial phenomena: (1) space is not important per se; (2)

spatial units are not well suited to economic analysis; and (3) spatial data bases present data in inappropriate ways for economic analysis. Three propositions are presented and discussed.

*Proposition 1: Space is not important per se, but in countries with poor transportation and communication infrastructure, it often is an excellent indicator of important economic factors.*

An obvious economic impact of space is on transportation costs: the greater the distance to an input or output market, the greater the purchasing or marketing costs. This relationship is particularly strong in rural Africa where walking, bicycles and donkeys are important forms of transportation. Jayne (1994) and Omamo (1995) have shown that differences in transportation costs explain spatial patterns of land allocation in Zimbabwe and Kenya. Transportation costs drive a wedge between the incentives to grow crops for which the household is a net supplier (e.g. cotton) and crops for which the household is a net demander (e.g. maize). The further farmers are from market centres, the less likely they are to grow cotton and the more likely they are to grow maize. Spencer and Badiane (1995) argue that high transportation costs and poor transportation infrastructure are a major deterrent to the widespread adoption of the green revolution technologies in Sub-Saharan Africa. For locally-supplied inputs such as labour or oxen, the density of households in the area around a household may be more important than the distance from the household to commercial market centres. Bromley and Chavas (1989) argue that the density of transaction possibilities ~ a product of transpiration costs and human population density - is an important determinant of economic growth. Besides deterring exchange, high transportation costs may also limit opportunities for collective action.

The three types of transaction costs ~ information, contracting and enforcement — are also influenced by space. In the absence of telecommunications infrastructure and mass media, information is primarily disseminated through personal communication networks. Farmers who live in close proximity to their neighbours and market centres are likely to obtain information cheaper, faster and more efficiently than farmers who live further from their neighbours and the formal information outlets. Space also defines opportunities for entering into formal or informal contracts and for enforcing those contracts. A farmer's personal observations of their neighbours will help him or her to identify possible gains from trade and to detect compliance or deviation from contracts.

*Proposition 2: Spatial units are not generally well suited to economic analysis. A better match between spatial units and the behaviour of individual economic agents or groups is possible if more attention is paid to the social, economic and cultural definition of spatial units.*

The foundations of micro-economic theory are the assumptions of utility maximization by individual consumers and profit maximization by individual firms. Game theory and institutional economics build upon that foundation to understand the outcome of interactions among groups of consumers or firms. Lacking is an economic theory of the behaviour of spatial units; such theory is the domain of ecologists. Economists have at least two options -for achieving a better match between economic theory and spatial analysis: (1) they can define spatial units that correspond to individual economic agents; and (2) they can define spatial units that correspond to well-defined communities or groups of agents that act together to determine a outcome that is defined in terms of space. Both of these options are illustrated in the case study described below.

*Proposition 3: Spatial data bases often present data in ways that are inappropriate for economic analysis. Economists need to contribute to the design of new data layers that are better suited to spatial analysis.*

Recent advances in remote sensing provides opportunities for the collection of data for spatial units that are under the control of particular households. Indeed in some places it has become necessary to obscure remotely-sensed data to protect the privacy of individual farmers (Michael Young, personal communication, 1995). At the same time, advances in the use of Global Positioning Systems allows researchers to attach geographical references to market-level, household-level and even plot-level data. The tools of geographical information systems are also developing for processing new data layers and creating spatial variables for use in statistical analysis (ref).

3. Tsetse control by the use of pourons

African animal trypanosomosis is an animal disease that constrains livestock productivity and agricultural development across much of sub-Saharan Africa. Trypanosomosis is caused by parasitic protozoa and transmitted by several specie of tsetse fly *(Glossina* spp.). Trypanosomosis is particularly important in Ethiopia where 7-10 million cattle are at risk of contracting the disease and cattle are the main source of traction for crop cultivation. Since January 1991, ILCA and ILRAD (now ILRI) have been conducting a tsetse control program using a cypermethrin high-cw pour-on (ECTOPOR ®, Ciba-Geigy, Switzerland) in the Ghibe Valley (Gullele area) of Southwest Ethiopia (Leak *et al*, 1995 and Swallow *et al.*, 1995). A solution of insecticide is applied directly to cattle as a pour-on. Tsetse flies and other external parasites that attempt to feed on the treated animals contact the insecticide and die. The pour-ons treatments were cost free until December 1992 when a cost recovery scheme was introduced. Thereafter individual cattle owners have been charged 3 Ethiopian Birr (about US$ 0.50) for each animal treated (Swallow *et al*, 1995). Any farmer who wishes to have animals treated can present their animals at one of the nine treatment centres where ILRI makes the pourons available one day each month. Figure 1 is a map of the study site.

«Figure 1»

Over the period 1991-92, free pour-ons were given to 2000 cattle each month. Since December 1992 period there have been high seasonal fluctuations in the number of cattle treated. Data on overall use of the pour-on, density of tsetse flies, and prevalence of trypanosomosis in farmers' cattle are being monitored each month. Demand for the pour-on has increased-from year to year but is always highest during the wet season (June to September) and lowest during the dry season (November to February) (Leak et al, 1995 and Swallow et al., 1995).

3.1 *The local public and private benefits of pouron use*

Previous studies in the Ghibe Valley show that farmers perceive three main benefits from use of the pour-on: (i) less trypanosomosis in cattle; (ii) fewer problems with biting flies; and (iii) fewer problems with ticks (Swallow *et al.,* 1995). Leak *et al.* (1995) have confirmed these perceptions: use of the pour-on was associated with large reductions in trypanosomosis prevalence in cattle and in the relative densities of 3 tsetse species and 2 species of biting flies. Farmers who treat their cattle with pour-ons produce private benefits - tick control for animals treated - and local public benefits - control of tsetse and other biting and nuisance flies (Swallow *et al.,* 1995). Pour-ons are thus described in economic terms as mixed public-private goods. Farmers who use pour-ons also incur 2 types of costs: (i) cash cost of the treatment (3 Ethiopian Birr per animal treated) and (ii) transaction costs related to the distance from farmers homesteads to the supply points.

3.2 *Collective action for tsetse control*

The ILRI team in the Ghibe Valley delivers the pourons to the nine supply points and applies the treatments to animals that are presented by farmers. ILRI team members periodically engage local cattle owners in formal and informal discussions about the effectiveness of the pourons and the need for a minimum level of pouron application to maintain low levels of tsetse density and trypanosomosis prevalence in cattle. Local cattle owners are responsible for building and maintaining the treatment centres in their localities. ILRI has not attempted to organize local farmers into formal organizations and does not systematically work with local administrative officials. Tsetse and trypanosomosis control has been effective for over 5 years without such interventions.

It is possible, however, that existing farmer groups are supporting the public good component of pouron use in the area. The most formal farmer group in the area is the Kabele (peasant association), the lowest level of government administration in rural Ethiopia. Farmers from 23 Kabeles obtain pouron treatments at the nine treatment centres (see Figure 1). Kabeles in this area contain an average of 200-250 households. Less formal and smaller farmer groups are cooperative herding groups (involving 2-10 households), cooperative work groups (involving 2-15 households), funeral societies and rotating credit societies. It is also possible that informal farmer groups have arisen to support the maintenance and management of the treatment centres. Farmers living at some distance from any treatment centre have told us, for example, that they are not welcome at certain treatment centres. Farmers in tsetse control areas of Western Zambia prohibit non-residents from bringing animals into the grazing areas of their cattle (Dietvorst, 1994).

The theories of collective action and group cooperation suggest that farmers may support the public good component through their strategic interactions. Strategic interactions may be supported by the deliberate actions of the agents or by credible threats of future retaliation against deviant behaviour (such as the trigger strategies described by Friedman (1986), the tit-for-tat strategies described by Alexrod (1984) or the stick-and-carrot strategies described by Abreau (1986)). Strategic interactions are more likely to support cooperation outcomes when: (1) the group is small and well-defined; (2) the members of the group interact repeatedly over time; (3) the members of the group share a common culture and common objectives; (4) the members of the-group have relatively equal wealth levels; (5) the costs of monitoring of others' behaviour are low; and (6) the members share a high level of technical knowledge of the problem (from reviews by Swallow and Bromley (1995) and McCarthy (1996)).

## 4. A **model of household demand for pourons**

This section develops a model of household demand for pour-ons that considers the nature of the mixed public-private nature of the benefits of their use. Equation (1) defines the profits from cattle keeping for individual i as the difference between revenues and costs. A profit-maximizing livestock producer will choose the level of pouron use (Poi) that maximizes that difference. Revenues are defined as the product of an aggregate product price (P) and the productive capacity of the individual's cattle herd (Hci). That productive capacity is determined by the number of cattle (Qi), the proportion of the herd that are oxen (Poxen), the proportion of the herd that are cows (Pcows), the level of pouron use of the individual Poi, and the level of pouron use by other individuals who raise livestock in the area (Sn Poj\i). Herd size (Qi) and herd composition (Pcows, Poxen) are assumed to be quasi-fixed assets that are unaffected by pouron use in the short term. Thus the only the costs associated with the pouron use are the costs of the pourons themselves (c) and the transportation and transaction costs associated with the pouron treatments (ti). Here it is assumed that the costs of the pourons are constant for all individuals, while transaction and transportation costs vary across individuals. The main determinant of transaction and transportation costs is distance to the treatment centre.

The input demand function resulting from solution of the maximization problem presented in equation (1) is given in equation (2).

$$\underset{Poi}{\text{Max}}\ \pi i = Ri\ (P * Hci\ (Qi, Poxen, Pcows, Poi, \Sigma n\ Poj\backslash i) - (c+ti(di))\ Poi \qquad (1)$$

$$D\ Poi = f\ [P, c, di, Poxen, Pcows, (\delta\ Hci\ /\ \delta\ Poi), \qquad (2)$$
$$(\delta\ Hci\ /\ \delta\ Poj\backslash i * \delta\ \Sigma n\ Poj\backslash i\ /\ \delta\ Poi), (Hci\ /\ \Sigma n\ Hcj)]$$

The model thus supports the hypotheses that pouron use by individual i will be:

(H1) A positive function of livestock output price (P) and a negative function of the cost of the pouron (c). Since P and c vary over time but not across space at a particular time, it is not possible to test these hypotheses using cross-sectional data.

(H2) A negative function of distance to the treatment centre (di).

(H3) A positive function of herd size and the proportions of oxen and cows in the individual's herd. This hypothesis was supported by the earlier analysis of Swallow et al. (1995).

(H4) A positive function of the magnitude of the marginal productivity increase that results from a marginal increase in pouron use by the individual.

(H5) A positive function of the magnitude of the marginal productivity increase that results from a marginal increase in pouron use by other members of the group, multiplied by the marginal strategic response of others to a change in the individual's behaviour.

(H6) A positive function of the proportion of total herd productive capacity that is owned by individual i.

## 5. **Data collection, generation and analysis**

### 5.1. *Geo-referenced household census*

A geo-referenced census of all households in the 'market shed' of the 9 supply points for the pour-on in the Ghibe Valley was undertaken between March and July 1996. Administration of the census questionnaire began with the villages immediately adjacent to the pour-on supply points and moved from village to village away from the distribution points in all directions to the boundaries of the market shed. A village was judged to be within the market shed if more than 2 households in the village reported having cattle treated with pour-ons during the previous dry-season or wet-season, while a village was judged to be outside of the market shed if less than 2 households reported having cattle treated during those time periods.

The census questionnaire was prepared in English, translated into Amharic, pre-tested with 20 households, modified, and administered by enumerators during personal interviews with household heads. The census questionnaire was brief and took an average of 10 minutes to administer to each household. Data were collected on livestock ownership, use of pour-on treatments, crop production and migration. Almost all of the questions were pre-coded closed-ended questions. Enumerators carried portable global positioning system (GPS) units and recorded the longitude and latitude co-ordinates for each household. The geographical referencing facilitated the creation of several spatial variables for each household including distance to the crush and relationship with neighbours.

5.2 *Generation of neighbour and neighbourhood variables using GIS*

After translation into English, all data were entered using *Visual Dbase* (Borland, 1995) and verified in *SPSS* 6.1 (Norusis, 1994). Data were then moved into *PCARC/INFO* (ESRI, 1996) a GIS software, for creation of the spatial variables. The *PCARC/INFO* POINTDIST command was used to create a Point Attribute Table (PAT) file on neighbours in the 1-km radius neighbourhood. Microsoft FoxPro Version 3.0b (Kennamer, 1995) was used to sort the PAT datarfile created by the POINTDIST command and to generate attribute data on neighbours within a radius of 1 kilometre of each household. The NEAR command was used to calculate the nearest treatment centre for each household.~*ArcView* (ESRI, 1995) was used to map the locations of households and treatment centres. The augmented data set was then brought into *SPSS* for econometric analysis.

In this analysis we relate the behaviour of households to the behaviour of their neighbours within a 1 kilometre radius. Two assumptions support the choice of lkm: (1) The effective suppression of tsetse in any particular pocket of 3-4 km2 will produce noticeable tsetse control benefits to the local cattle owners (Steve Leak, pers. Comm.); and (2) people will not be able-to monitor the tsetse control actions of households located more than 1 km away from their homesteads.

Figure 2 illustrates how the neighbour variables were created. Eleven households are depicted by the capital letters and subscripts and located in the two-dimensional space according to their longitude and latitude coordinates. Circles, or buffers, of radius 1 kilometre are drawn around 4 of the households - Al, Bl, Cl and Dl. A1 has 4 neighbours, Bl has 3 neighbours, Cl has 6 neighbours and Dl has no neighbours. Obviously the neighbourhoods overlap, households that are close together are likely to have most of the same neighbours.

«Figure 2»

5.3 *A logit model of pour on demand*

*A* logistical regression model was estimated to test hypotheses about factors affecting the probability that a household treated any cattle with pourons during the previous wet season. The regression model follows from the conceptual model presented above:

Probi = f (household attributes - age and sex of household head,

— herd attributes — herd size, proportion of oxen, proportion of cows, —

distance to the treatment centre - including the square to allow for a quadratic,

proportion of benefits appropriated ~ herd size relative to total cattle herd in the area,

treatment centre — a possible unit of collective action,

Kabele — a possible unit of collective action,

inequality in herd size in 1 kilometre radius — coefficient of variation of herd size,

group size — number of cattle-owning households in 1 kilometre radius,

- number of cattle owned by all households in 1 kilometre radius,

strategic response — number of cattle treated by others in 1 kilometre radius)

Five versions of the model were estimated. The first version considered only characteristics of the household and the herd that can be easily obtained from respondent recall: age of household head, sex of household head, total number of cattle held, proportion of cattle that are oxen, and proportion of cattle that are cows. The second version considered household and herd characteristics, as well as distance from the household to the nearest treatment centre. The square of distance was also included. The third version considered household, herd and distance characteristics, as well as the characteristics of the neighbours and the ratio between the size of the individual herd relative to the total number of cattle in the lkm radius of the household. The fourth version was the same as the third, but added eight binary variables to account for the effects of the nine treatment centres (as a possible unit of collective action). The fifth version was the same as the fourth, but also included 22 binary variables to account for the 23 Kabeles in which people in the area live (as another possible unit of collective action).

## 6. Results

About 5,000 households were enumerated during the census, two-thirds of which owned cattle. The average cattle-owning household held 4.7 cattle at the time of the survey, 51% of which were oxen and 17% of which were cows. Ten percent of cattle-owning households were headed by females. Among the cattle owners, 70% treated some cattle during the previous wet season (June-August 1995), 46% treated some cattle during the dry season, 44% treated some cattle during both the dry and wet season, and only 1.6% only treated cattle during the dry season.

The average cattle-owning household in the area was located 2.5 km from the nearest crush (or the crush to which they normally went) and within a 1 km radius had 53 cattle-owning neighbours who treated 59 cattle during the previous dry season and 102 cattle during the previous wet season. The average household owned 3.8% of all cattle within the 1km radius of their household. However, there was large variation in these spatial variables between households. Some households had as many as 143 cattle-owning households within a 1km radius, others had no cattle-owning neighbours within a 1 km radius. Some households resided in places where within a 1km radius, 301 cattle were treated during the previous wet season and 240 cattle were treated during the previous dry season. Other households resided in places where no cattle were treated within a 1 km radius in the previous dry season or wet season (Table 1).

Households in the market-shed of the 9 treatment centres resided in 23 Kabeles (local administrative units). The average Kabele had 142 cattle-owning households and 216 total households. Kabeles ranged in size from 27 to 317 households. The average treatment centre served about 363 cattle-owning households, with one recently-constructed treatment centre serving only 13 cattle-owning households and another serving 1,208 households. Figure 3 shows the geographical locations of the 5000 households.

«Table 1»

«Figure3»

Several findings stand-out from the results of the logit model of wet-season demand presented in Tables 2 and 3. First, the age and sex of the household head (age and sex) had no effect on pouron demand. This is consistent with the earlier finding of Swallow et al. (1995). Second, the coefficients on the herd size and structure variables were significant in all -versions of the model. Oxen are more likely to be given treatments than cows, and cows are more likely to be given treatments than other cattle (bulls, heifers). Third, the number of cattle in the lkm radius of the household had a negative effect on the probability of wet-season treatment, while the number of cattle treated in the lkm radius had a positive effect. These results are consistent with the hypotheses about the negative effect of group size and the effects of strategic interaction between households.

The different versions of the model produced inconsistent results with respect to the effects of distance to the treatment centre, the treatment centre as a focus of collective action, and the Kabele as a focus of collective action. The estimated coefficients on distance and distance squared were significant in versions 2, 3 and 4 of the model: version 3 of the model indicates that the probability of wet-season treatment increases with distance for households located less than 6.25 kilometres from the crush, then declines. In version 5 of the model, neither of the distance variables are significant. Version 4 of the model indicates that, everything else equal, households within the market sheds of 3 of the treatment centres were less likely to treat their animals than households within the market sheds of the other centres. In version 5 of the model, none of the binary variables for treatment centre were significant.

Version 5 of the model, with the Kabele binary variables included, indicates that the Kabele within which the household resides has important effects on the probability that it treated animals during the previous wet season. The results suggest that 23 Kabeles can be roughly divided into 5 classes of treatment likelihood. Figure 4 depicts the 5 classes and illustrates that all of the areas of highest intensity use, ceteris paribus, are contiguous and located near to treatment centres. Areas of lowest intensity use, ceteris paribus again, are located further from the treatment centres. The fact that the variables measuring distance to crush and treatment centre became insignificant when the Kabele variables were included indicates that the Kabele effects are more relevant than the treatment centre or distance effects, but correlated with distance and treatment centre.

«Tables 2 and 3»

«Figure 4»

## 7. Discussion and Conclusions

The econometric results presented above support the hypotheses that there is an informal type of collective action supporting the collective use of the pourons in the study site. Within local neighbourhoods, there appears to be strategic interactions between households that supports, or does not support, collective action. In this analysis we considered neighbourhoods of lkm radius around each household (3.14 km2); the effects of smaller or larger neighbourhoods could also be investigated since there is little theoretical support for particular sizes (either social or ecological).

The results also support the hypothesis that there is some more formal collective action at the level of the Kabele. This needs to be explored further. One possibility is that the Kabele structures support the dissemination of information about the availability of pourons. A second possibility is that the populations of each Kabele, or sub-populations within the Kabele, actually agree upon common approaches to pourorruse. The results do not indicate any form of collective action at the level of the treatment centre.

Several things about this study distinguish it from other studies of input demand and technology adoption in developing countries. First, the large number of observations allowed the estimation of parameters with greater accuracy than is usual. Second, the large number of observations allowed the accurate estimation of more parameters and thus more complete testing of hypotheses. Third, the geo-referenced census yielded information about all of the neighbours of every household. Manipulation of the census data with the GIS tools allowed the creation of the neighbour and neighbourhood variables and the novel tests of hypotheses from collective action theory. Fourth, the geo-referencing of the census data allowed us to create several new spatial data layers that can be used for other purposes. Fifth, the particular type of spatial analysis conducted herein was possible because of a close collaboration between economists and geographers and the availability of computer software and hardware for GIS and econometric analysis.

Table 1: Descriptive statistics on household population included in household census
(Data for 3,267 cattle-owning households)

| Variable name | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|
| Use of pourons | | | | |
| ~ propn hhs in dry season | 0.46 | | | |
| ~ propn hhs in wet season | 0.70 | | | |
| — cattle treated in dry season | 1.38 | 1.95 | 0 | 25 |
| ~ cattle treated in wet season | 2.16 | 2.36 | 0 | 30 |
| Household hh characteristics | | | | |
| —Age (years) | 41.50 | 14.60 | 16 | 111 |
| -Sex (l=m, 2=f) | 1.10 | 0.30 | 1 | 2 |
| Herd traits | | | | |
| — number cattle | 4.70 | 4.60 | 1 | 56 |
| — proportion oxen | 0.51 | 0.36 | 0 | 1 |
| — proportion cows | 0.17 | 0.20 | 0 | 1 |
| Distance | | | | |
| — Kilometres | 2.50 | 3.10 | 0 | 19.8 |
| Neighbour traits | | | | |
| — no. cattle owners in 1 km | 52.67 | 33.23 | 0 | 143 |
| - no. cattle in 1 km | 247.66 | 164.59 | 0 | 755 |
| — cv in herd size | 0.03 | 0.03 | 0 | 0.58 |
| ~ % cattle owned by hh | 3.82 | 12.88 | 0.14 | 100 |
| — no. treated in lkm, dry season | 59.13 | 45.73 | 0 | 240 |
| — no. treated in lkm, wet season | 102.39 | 66.69 | 0 | 301 |
| — no. cattle-owning hhs in Kabele | 142.04 | N.A. | 27 | 317 |
| — no. cattle-owning hhs using crush | 363.00 | | 13 | 1208 |

Table 2: Results for versions 1, 2 and 3 of the model of pouron demand, estimated for 3,221 cattle-owning households in the Ghibe Valley of Ethiopia

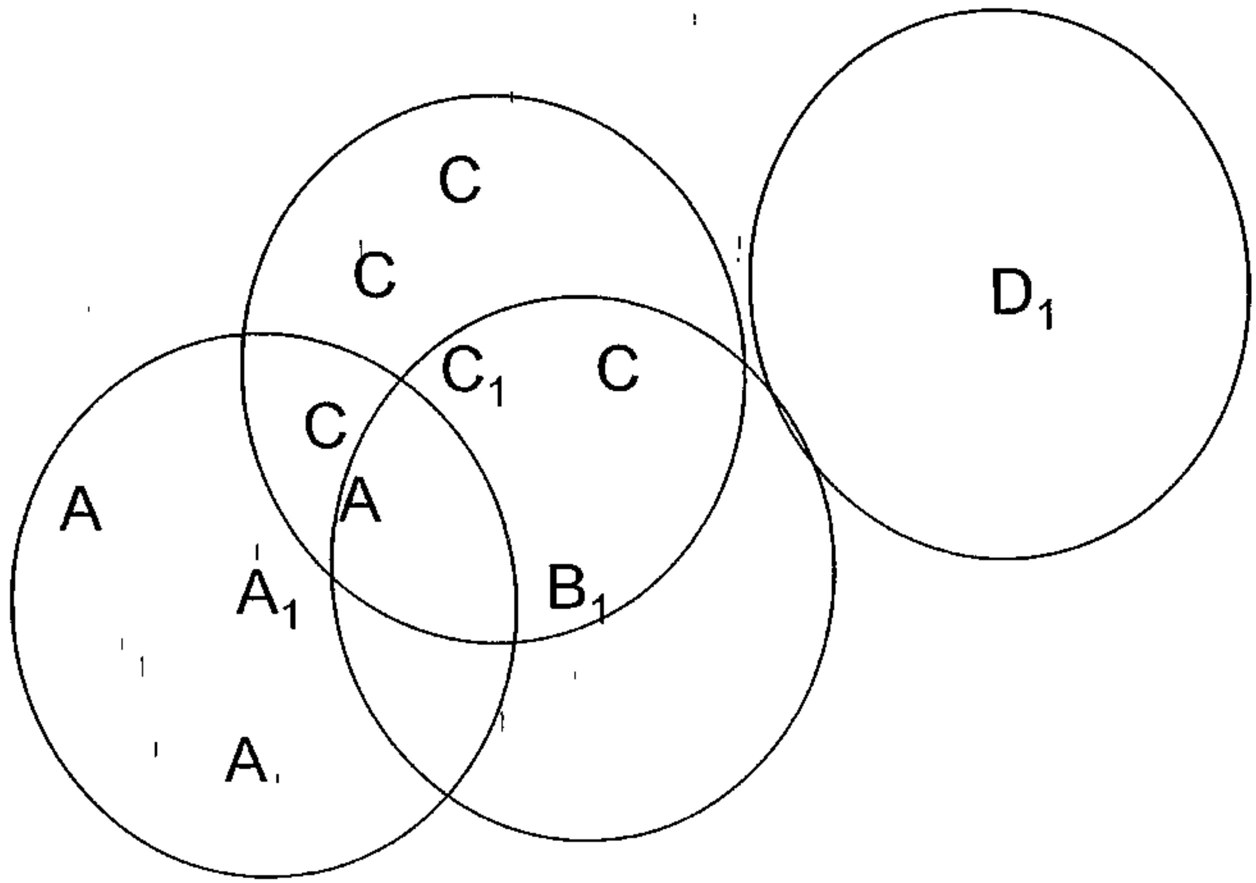
| Variable | Model 1 | | Model 2 | | Model 3 | |
|---|---|---|---|---|---|---|
| | Coef. | P-value | Coef. | P-value | Coef. | P-value |
| Constant | -.8919 | .0000 | -1.2936 | .0000 | -1.3841 | .0000 |
| Household traits | | | | | | |
| -- age of hh head | .0006 | .8336 | .0013 | .6520 | .0028 | .3478 |
| -- sex of hh head | -.1135 | .3881 | .0247 | .8538 | .0472 | .7353 |
| Herd traits | | | | | | |
| -- number cattle | .1889 | .0000 | .1820 | .0000 | .1802 | .0000 |
| -- proportion oxen | 1.8617 | .0000 | 1.7873 | .0000 | 1.692 | .0000 |
| -- proportion cows | .7935 | .0006 | .8185 | .0004 | .8406 | .0006 |
| Distance | | | | | | |
| -- metres | | | .0003 | .0000 | .0002 | .0000 |
| -- metres squared | | | -2.2E-8 | .0000 | -1.4E-8 | .0002 |
| Neighbour traits | | | | | | |
| -- no. cattle owners in 1 km | | | | | -.0006 | .4586 |
| -- no. cattle in 1 km | | | | | -.0123 | .0004 |
| -- coef. variation in herd size | | | | | -.6056 | .7465 |
| -- proportion cattle owned by hh | | | | | -.0043 | .3303 |
| -- no. cattle treated in 1km | | | | | .0173 | .0000 |
| Chi-square | 367.8 | | 410.6 | | 583.5 | |
| % correct predictions | 75.8 | | 75.4 | | 76.1 | |

Table 3: Results for models 4 and 5 of pouron demand, n = 3,221 cattle-owning households in the Ghibe Valley of Ethiopia

| Variable | Model 4 | | Model 5 | |
|---|---|---|---|---|
| | Coef. | P-value | Coef. | P-value |
| Constant | -1.3303 | .0000 | -.0859 | .0589 |
| Household traits | | | | |
| -- age of hh head | .0023 | .4434 | .0020 | .5336 |
| -- sex of hh head | .0353 | .8021 | -.0823 | .5783 |
| Herd traits | | | | |
| -- number cattle | .1808 | .0000 | .1910 | .0000 |
| -- proportion oxen | 1.6968 | .0000 | 1.8377 | .0000 |
| -- proportion cows | .8540 | .0005 | 1.1102 | .0000 |
| Distance | | | | |
| -- metres | .0002 | .0000 | 2.49E-6 | .9671 |
| -- metres squared | -1.6E-8 | .0001 | 3.30E-9 | .5413 |
| Neighbour traits | | | | |
| -- no. cattle owners in 1 km | -.0120 | .0009 | .0055 | .2883 |
| -- no. cattle in 1 km | -.0009 | .2538 | -.0023 | .0463 |
| -- coef. variation in herd size | -.8371 | .6606 | 2.1553 | .3345 |
| -- propn cattle owned by hh | -.0035 | .4333 | -.0054 | .2809 |
| -- no. cattle treated in 1km | .0184 | .0000 | .0055 | .0079 |
| Treatment Centre -- Gullele | .3074 | .1795 | -.0838 | .7583 |
| -- Bilo Wayu | -.3453 | .0339 | .1183 | .5841 |
| -- Bosso | .3550 | .1153 | -.1040 | .7253 |
| -- Legaboter | -.3584 | .0432 | .0712 | .7849 |
| -- Wayu | -.6906 | .0000 | -.0386 | .9529 |
| -- Yatu | -.1339 | .0000 | -.2892 | .4372 |
| -- Silk Amba | -.0111 | .0000 | .6719 | .2704 |
| -- Kondala | -.6040 | .0093 | -.5325 | .1472 |
| Kabele -- 2 | | | -1.3192 | .0000 |
| --3 | | | -.6777 | .0338 |
| --4 | | | -.3582 | .2250 |
| --5 | | | -5.2243 | .0000 |
| --6 | | | -1.4439 | .0000 |
| --7 | | | -1.0154 | .0000 |
| --8 | | | -2.7807 | .0000 |
| --9 | | | -.6832 | .0500 |
| --10 | | | -2.3386 | .0000 |
| --11 | | | -1.5105 | .0000 |
| --12 | | | -.6367 | .0507 |
| --13 | | | -1.6926 | .0000 |
| --14 | | | -1.9867 | .0000 |
| --15 | | | -1.7014 | .0000 |
| --16 | | | -.3853 | .2936 |
| --17 | | | .0777 | .8525 |
| --18 | | | .1656 | .6936 |
| --19 | | | 1.0426 | .0292 |
| --20 | | | -.9411 | .0064 |
| --21 | | | -.5585 | .2023 |
| --22 | | | -2.0462 | .0000 |
| --23 | | | -2.3901 | .0000 |
| Chi-square | 606.7 | | 892.3 | |
| % correct predictions | 76.3 | | 78.4 | |

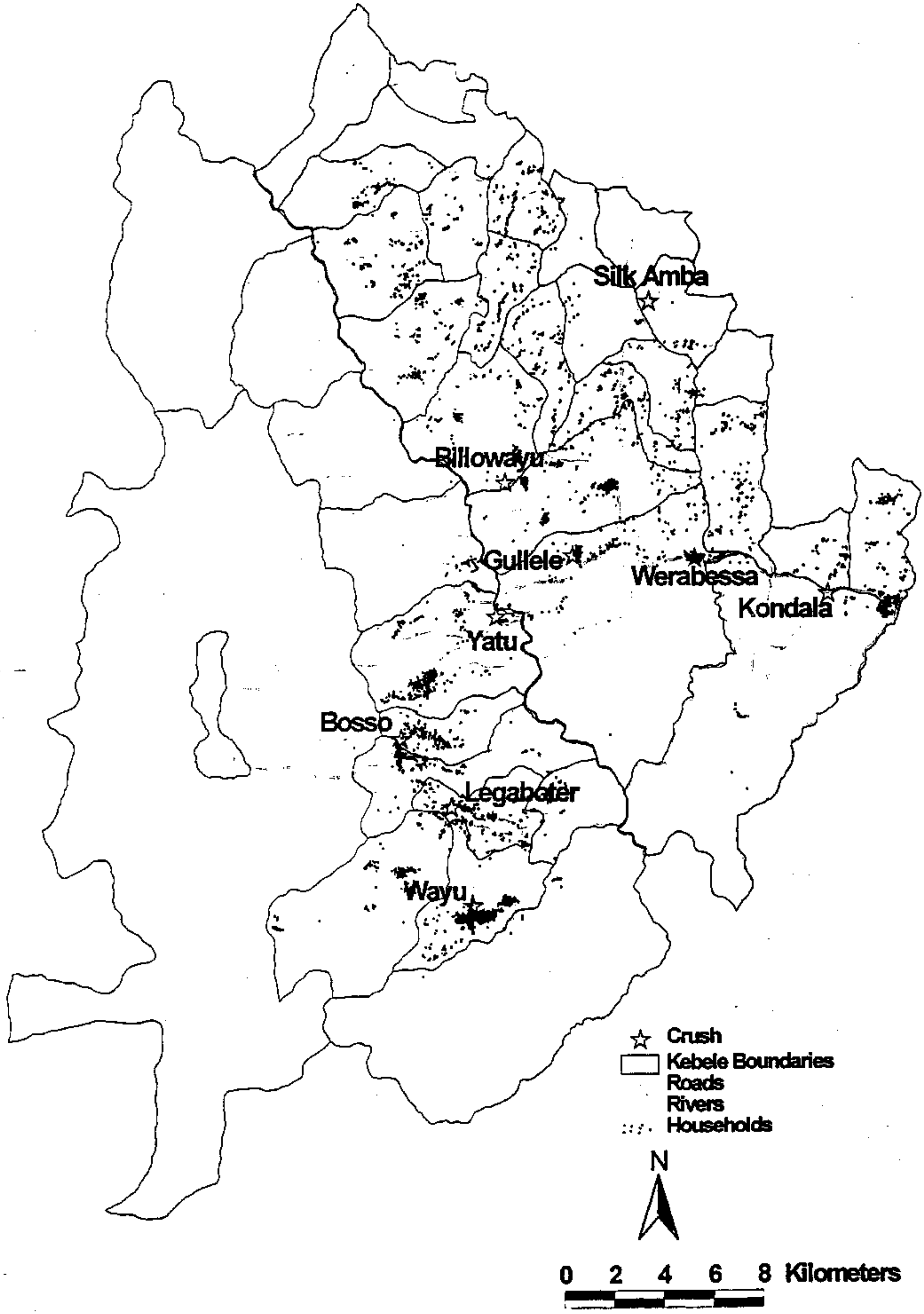
Figure 2

# Neighbours and neighbourhoods in perspective

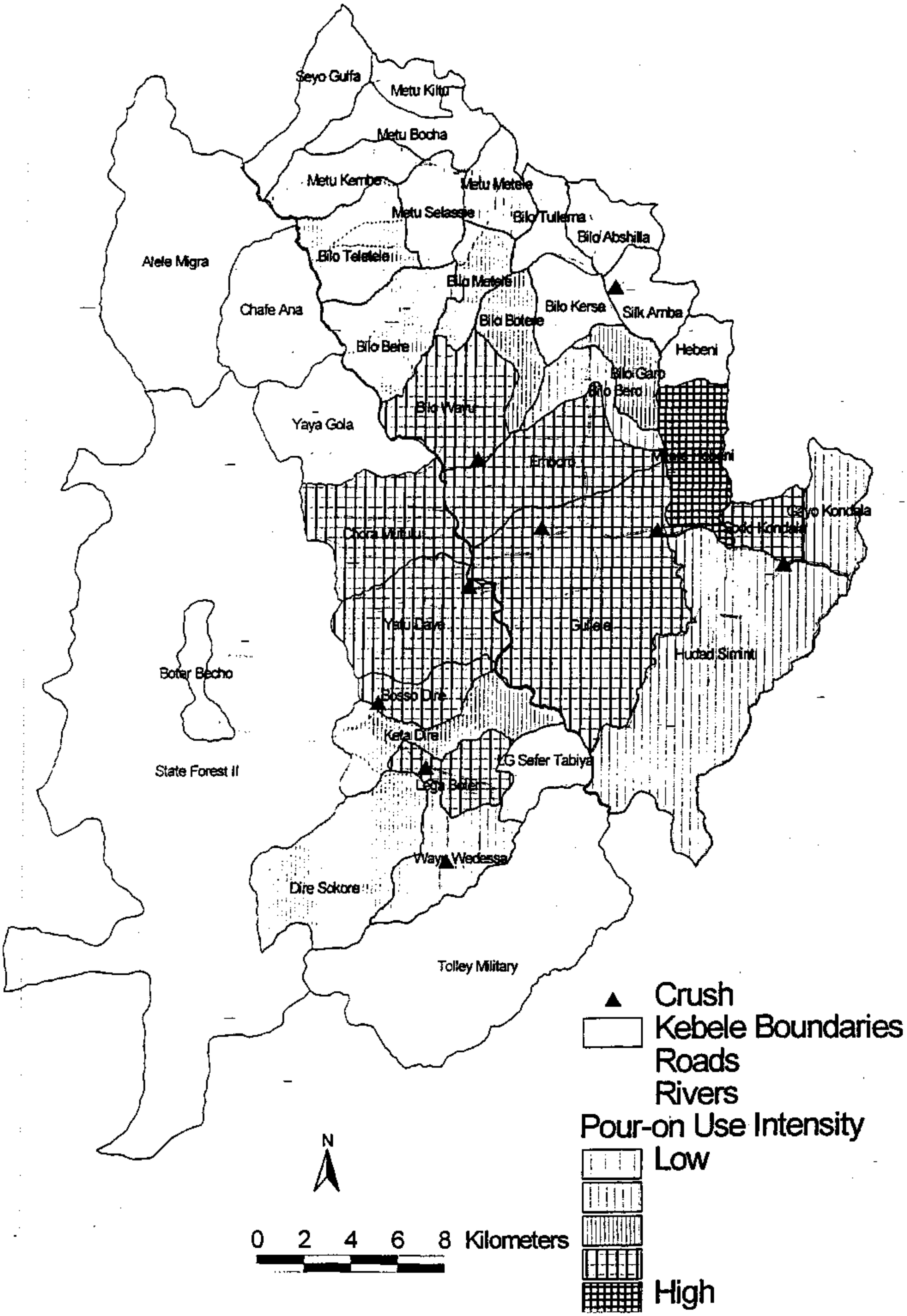



- $A_1$ has 4 neighbours
- $B_1$ has 3 neighbours
- $C_1$ has 6 neighbours
- $D_1$ has 0 neighbours

# Locations of households in the Ectopor study area



# Intensity of pour-on use, controlling for other effects



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