Agent-based model Mexico City

ODD Protocol

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# Introduction

This document describes the details of the Agent based model of the MEGADAPT project. The model simulates the coupling between biophysical processes and the decisions of residents and the water authority of Mexico City. The aim of the model is to investigate the consequences of this coupling on the spatial distribution of socio-hydrological vulnerability in Mexico City. The model simulates decisions on investments in infrastructure by the water authority agents, which is done by evaluating the condition of the landscape across the neighborhoods. These investments in turn trigger actions in selected neighborhoods. These actions then influence the condition of the socio-political and physical attributes in the landscape that in turn modify the biophysical condition that influence the production of risk to infrastructure hazards.

The decision making process of the water authorities involve the identification and selection of neighborhoods that need investments. This prioritization of neighborhood for investments is rooted in computing a multi-criteria metric in which the actor evaluate the landscape based on a set of criteria that are weight differently in the decision, based on the priorities of the actors. To compute the multi-criteria metric the model relay heavily on empirical data derived from mental models and translated into a multi-criteria decision framework, which are inputs to the model. The decision-making process of the residents is also done via a multi-criteria decision metric, but in this case the evaluation is only in their neighborhood and the action taken modifies only those local attributes. Figure 1 shows an overview of the basic processes included in the model.

The current version incorporates stochastic simulations of weekly water supply and annual production of floods in the city based on empirical observation of the events.

With the model we aim to investigate the dilemmas and spatial patterns of vulnerability to infrastructure hazards that emerge due to the actions and decision-making process of the agents.

The advantage of Netlogo is its versatility to develop agents as objects, which allow to define actors their actions and the infrastructure systems as separate computational entities. This provide flexibility for creating association between agents. This allow the developer the flexibility to consider new interaction between actors, or incorporate new agents follow simple protocols.

Version: The current version of the model is constructed in Netlogo V 6.2.1.

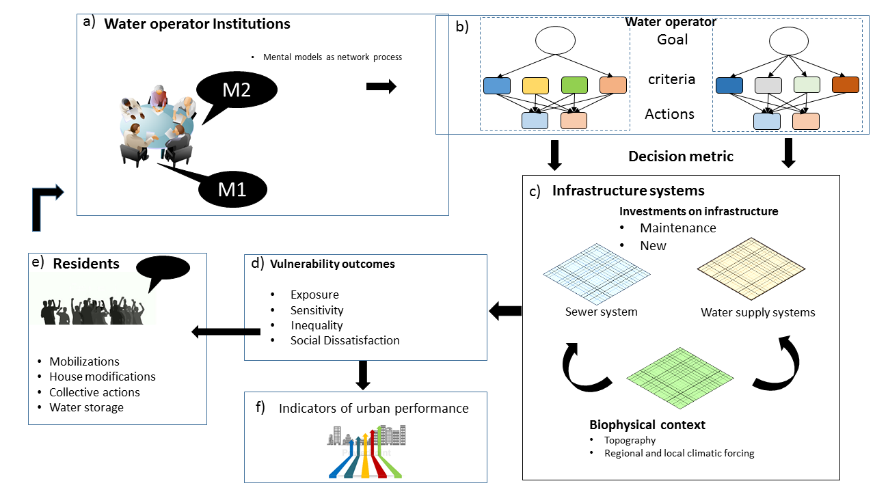


Figure 1: Overview of the Agent-based model

# Agents, actions and scale

Three types of agents are incorporated in the model: Water operators, residents and infrastructure systems. Resident are located in neighborhoods. Each neighborhood is indexed using symbol and the total number of neighborhoods by symbol . Infrastructure systems are also consider as agents when they are defined as object, with properties and methods similar to those of other agents.

Water operators make investments on different infrastructure systems, in selected neighborhoods. These investments are related to the actions of: 1) repairs and maintenance,, 2) construction of new-infrastructure , 3) distribution of water , extraction of water, . Residents, can take different actions as well. These actions are: 1) house modification , 2) collective actions, , and 3) protesting, .

The decisions to invest by the water operators and to modify the local environment by residents, are evaluated based on a multi-criteria metric, that its calculation requires a set of criteria, criteria weight, alternative weights each specifically related to the actor and the actions they take. This information and the actual actions of the agents is obtained from empirical data from the actor’s mental models, and obtained from focus groups, interviews and workshops with the managers and operators of the water system, and residents. This information was pre-processed and transformed into an analytical network process (ANP).

Infrastructure systems are labeled with the symbol . The current version of the model includes as infrastructure systems the wells for water extraction, , the system of pipes for potable water distribution, , the system of mobile water distribution (trucks) , the sewer system . In the corrent version the system of pipes and sewer are represented as a set of atributes in each neighborhood, such as average, condition, and capasity. In the other hands wells are define as agents in the model with atributes specific for them. However neighborhoods also storage as a tributes the set of wells that bellow to each neighborhood.

The model also contains procedures to represent the stochastic production of hazard events related to the risk of flooding, scarcity and gastro intestinal disease incidence. These models are defined based on the empirical information about pass events in Mexico City. In the model the frequency of these hazards are assumed to be related to failures in the provision of services by a particular infrastructure system. These failures are in turn associated to the local conditions of the system, and local biophysical conditions in the neighborhoods.

The actions the agents take modify the attributes of the neighborhoods that in turn will influence the stochastic production of hazards. These changes in events in turn inform subsequent decisions by the actors. Therefore the model simulates the feedback loop between actor’s decisions and biophysical changes in a dynamics and spatial explicit platform.

The spatial resolution of the model is the neighborhood, represented in the model by census blocks of Mexico City and the state of Mexico. The spatial scale of the model engulfs all the neighborhoods in these two states. Each neighborhood is also identify by the municipality to which bellow to. The temporal resolution of the model is 1 week.

# Process Overview and scheduling

The model currently is composed of three files. A setup file (“setup.nls”), a value-function file (“value-functions.nls”) and the code file (“ABM-Empirical-MexicoCity\_6.nlgo”). The setup file defines and set values for global variables, and the agents and their attributes. It also contain procedures to read the information that will define the decision making process of the agents. Namely, their actions, the criteria set, criteria weights and action weights. Finally, in setup, the GIS layers are loaded from which the value neighborhood attributes are defined.

The file value-function contains the procedures to update the information needed for the actors to calculate the multi-criteria decision metric. Specifically, these procedures update the standardize values of the attributes of neighborhoods that are criteria for decision, and calculate the distance metric.

The code file contains the procedure call “GO”. Procedure “GO” involves the suitability assessment and site selection procedures, which define the neighborhoods that will be selected for investments by the water authorities. Once the neighborhoods have been selected, the model invokes the actions of the different agents, which will in turn modify the attributes of the landscape.

Inside the code file, there are also procedures to calculate indicators of performance at the scale of the neighborhood, municipality and city.

To run the dynamic part of a single simulation, the observer needs to invoke the procedure “GO”, which will trigger a set of processes related to the stochastic simulation of water allocation, flood and health models, the decision-making process of actors, the action of the actors, and the changes that those actions caused to the attributes of the neighborhoods. The decision making process of the water authorities includes procedures to a site selection process and suitability of neighborhoods In the case of the residents this involve a selection of actions. Within in each cycle of decision, the actions will modify the attributes of the landscape associated to each action in each neighborhood. Details about these processes are provided in the section “sub-models”.

# Design concepts

## Basic principles

The model aims to represent the decisions of important actors in Mexico City water management system in a geo-spatial and dynamical platform. The decision making process of the actors involves a multi-criteria decision procedure in which the actors evaluate a set of criteria they consider as important for decision (criteria), and they consider them with different importance (criteria weights). In the model each criterion is associated to an attribute of the landscape. Therefore the agents evaluate the attributes in the landscape to make decisions related to investments in the case of the water authority and adaptation in the case of residents. The attributes in the landscape change over time according to the stochastic variability generated by the statistical processes of hazard production, and, most important, due to the changes in the attributes made by the actors’ action.

Emergence

From the interaction between agent’s actions and the modification to the attributes of the neighborhoods, we expect the emergence of spatial patterns of investments that in turn should influence the spatial pattern of vulnerability of neighborhoods to infrastructure related hazards.

### Observation

The agents observe the attributes of the landscape that are considered as criteria in the decision-making process. The observer can evaluate the vulnerability of the city using different indicators of performance and a metric of vulnerability. We compute the average age of the infrastructure, the numbers of day in a year without water, and the number of actions made by the water operators. These observations are computed by each neighborhood and aggregated by each municipality.

Adaptation

Neighborhood can modify their local environment to reduce their sensitivity to the exposure to flood and scarcity hazards. Thus the action “modification of house” reduces the sensitivity of the neighborhood to flooding, whereas the action water storage reduces the sensitivity of a neighborhood to suffer exposure to water scarcity. These processes over time can be consider as adaptation to their local environment.

Interactions

The water operators and resident agents interact with the neighborhoods and the infrastructure systems by modifying their attributes. The attributes of the neighborhoods in turn influence the risk of infrastructure failures which will influence subsequence decisions of the water operator and the residents. There also interaction between actors that influence their decisions. Specifically, the action of the residents to protest generate social pressure which is one of the criterion that is used in the decision-making process of the water authorities.

Stochasticity

The model has procedures that generate stochastic events of hazards related to flooding, scarcity and health. Currently, the model incorporate two different methods to generate flooding events: A linear regression model that generate expected number of events per year using a set of infrastructure-related and biophysical independent predictors from each neighborhood. The second method is based on contingency table using Bayes rules, where flood outcomes of certain magnitude are cross classified according to a finite number of states that are related to the condition of the infrastructure.

Water distribution by pipes is simulated using a Poisson process which generates number of days that neighborhoods received water by the system of pipes, P. The model assumes that the mean of the Poisson process is driven by the condition of the infrastructure and its propensity to fail in the delivery of water by the pipe system.

## Details

Initialization

The model is initiated by invoking the procedure “SETUP”, which triggers the procedures inside the setup.nls file. These procedures are: 1) “define-global-variables” 2) “define-type-of-agents” 3) “define-agents-attributes” 4) “load-GIS-data” 5) “define-neighborhoods” and 6) “define-ActionsCriteria”, 7) “define-infrastructure-systems”, 8) read”-statistical-data”, 9) “set-initial-values-globals”, 10) “set\_maximum” and 11) “set-matrix-contj”.

Procedure 1) defines the global variables needed (table #) in 2) the model sets the type of agents or “breeds” in netlogo terminology, and in 3) their attributes. Procedure 4 contains methods to read layers of geo-spatial information using the GIS-Netlogo extension. In procedure 5) this gis layers are used to fill-up the initial condition of the attributes of the neighborhoods, including location. Procedure 6) contains methods to read data to define the actions and the information to define the multi-criteria decision mechanism involve in the decisions of the actors. In 7) are the algorithms to define the infrastructure systems, . In 8) are methods to read data needed to simulate stochastic realizations of flooding and water supply. Procedure 9) defines the initial values for the global variables, and 10) sets the maximum values of the attributes of the neighborhoods. This is needed to define the range of variability in the attributes, which in turn will inform the computation of the decisions. Finally, procedure 11) defines the neighborhoods that are associated with each other based on the contiguity matrix. This defines the local network of interaction between neighborhoods that influenced each other. Which is needed to simulate the health model.

Input data

The setup procedure invoke a procedure that loads layers of geographic information to fill the attributes of each neighborhood that will define the criteria for decisions. Table 1 shows the attributes of each neighborhood. The model also need to data to define the actions, the criteria, criteria weights and action weights. This information is read by the procedure setup using csv. Files from software *super decision* (ref). Another type of input data is the average number of days without water by municipality, which is needed to simulate the days with water by the system of pipes, , using a Poisson process. Finally, the model contain procedures to read data to represent the probabilities of flood using Bayesian contingency matrix analysis () and regression analysis of health.

# Sub-models and components

## Water authority decision procedure

### Suitability assessment

Suitability for investment of each neighborhood is obtained through multicriteria evaluation to take into consideration the relevance of the decision criteria:

(1)

where is the distance to the ideal point of neighborhood j with respect to decision and system ; is the criterion weight of criterion related to system ; is the standardized score in a neighborhood of the attribute corresponding to criterion of infrastructure system and decision ; is the departure of an alternative from the ideal point for a criterion; , , , and are indices for criteria, neighborhoods, action, time and infrastructure system, respectively. In Equation 1, the standardized score, , represents a judgment about the importance of an observable value of a certain criterion for the water authority’s decision.

Given that the variables representing the criteria are continuous and interval- and ratio-scaled, these scores are obtained by means of value functions (Beinat 1997), which transform the natural scale of a criterion to a [0, 1] value scale (1 represents the most undesirable state and 0 the most desirable state).

### Site selection

Every year site selection is invoked by the water authorities for choosing a single investment on on system v,, in a specific number of neighborhoods that is established by budgetary constraints, . Formally, this involves using 0-1 (or binary) programming model (Dykstra 1984) in which the objective function maximizes . In this way, the model simulates a preference for investing in the neighborhoods where investment on infrastructure of system is most needed; formally:

Subject to

where is the number of neighborhoods where investment related to action can take place; is the 0-1 decision variable for action for system in neighborhood at time (, if neighborhood is selected for investment, or 0 otherwise);

### Update-criteria-and-valueFunctions

##### This procedure updates the information needed to evaluate distance to the ideal point of each neighborhood related to each action , and system . This procedure is called every cycle of decision. The information will define the vectors of criteria and will update their representation in a standardize scale using the procedure report “value function”.  This steps is critical to quantify relationships between condition of the attributes in the landscape (e.g., age, capacity, etc) and the perceived response by agents. Formally this procedure takes the following formulation:

Where is the perceived magnitude of stimulus defined by the state of attribute in neighborhood at time , . Parameter is refers to the constant fraction. Function is often represented by a logarithmic function:

In the current version of the model, the function is implemented using a set of cutoff , such that

Where follow the Weber-Fechner progression {0.5,0.25 0.125,0.0625}

In the current version of the model, this procedure is called in the context of actions, which are called in the context of the neighborhood. Table # and # summarize the criteria and its representation using the attributes of the landscape.

## State of infrastructure

It is an index that tracks the condition of infrastructure system, , as they decline over time in the a neighborhood, , from a municipality, *d*; therefore the age of the infrastructure in a neighborhood . changes weekly accordingly to:

where is a single weekly time-step.

## Infrastructure coverage

Each neighborhoods can have access to the sewer or potable water system by investments. We define this layer using data on track the percentage of houses without connection to infrastructure system ,. Thus, when all the houses in neighborhood are connected to system , and if none.

## Exposure

Exposure of neighborhoods to infrastructure hazards is assumed to be related to the average risk of water supply disruption and flooding. Floods also influence the exposure of the population to waterborne pathogens.

In addition to the landscape (that is, exposure to water scarcity increases), the risk associated with these hazards depends on the condition of clean water and sewer systems, *c*; formally (ten Veldhuis, Clemens, and van Gelder 2011):

where is the rate of decline of the infrastructure , is the infrastructure´s age, is time in weeks. The function assumed a exponential decay in the condition related to the aging process of the infrastructure system, . refers to the effect of subsidence on the condition of the infrastructure associate to the rate of subsidence in neighborhood , with:

,

Where is the subsidence rate [mm/year] in each neighborhood, and is the effect of subsidence to system . It is a conversion parameter that must be parametrize to ensure that .

### Exposure to water supply disruption

A neighborhood can have weekly disruptions in water supply. These disruptions are assumed to be caused by failures of the infrastructure system . We also assumed that water supply can only be delivered within each municipality by either the pipe system network , or by distribution by mobile sources, , such as trucks. Formally, we define the weekly supply of water to neighborhood using system as,

Accordantly, the risk of exposure to water supply disruption from the network of pipes *P*, is assumed to be associated to the condition of the system. Formally we assumed that the average number of days in a week that a neighborhood is without clean water service from pipes is represented by:

Where is the mean number of days in a week without piped water, is the estimated average number of days without piped water in a municipality ( A parameter estimated using available survey data). Parameter is the additional number of days without piped water due to disruptions associated with the condition of the pipes and the local correction factor for altitude difference of neighborhood from the mean altitude of the municipality, such that:

Where, is the altitude in neighborhood, and is the mean altitude of municipality.

We simulate stochastic realization of days with water per week per neighborhood using a Poisson process, truncated between 0 and 7 using

Thus the amount of water delivered by the pipe system to neighborhood is

Where is the volume of water supplied by the pipe system to neighborhood . is the number of people in neighborhood ,and is the proportion of population connected to the system of pipes . Parameter is the requirement of water per person, in units of volume. Therefore it is assumed that water is delivered proportionally to the population requirement and the provision of infrastructure.

### Exposure to flooding

Another assumption is that the risk of flooding associated with malfunctions of sewer systems in a neighborhood depends on the condition of the sewer infrastructure system, which is influenced by age and capacity, and the effect of subsidence. Yearly number of flooding events were simulated using contingency matrix and Bayes rules, to calculate posterior marginal probabilities of the number of events, conditional to the condition of the sewer system. The first then was to separate the city between old and new. Thus we define the set of old neighborhoods as

The probability of having more than f event of flooding is calculated using

The predicted posterior distribution of the number of events of magnitude m, given the observation of *F* events in a year, given the condition C and the observations, that is the likelihood, and is the prior information of the capacity, given the observations. Whenever the value of the risk associated with age and capacity is higher than a random number generated from a uniform distribution, :

The model also includes other procedures to simulate flooding events based on a linear regression model:

Where is the expected number of flood events in neighborhood in year . ,, are the regressor parameters associated to the independent variables age , capasity , and hydraulic cost, of the sewer system , respectively.

### Exposure to gastro intestinal diseases

A regression model of the form

……………………………(A‑5)

was used to incorporate the full set of predictors and the spatial dependency observed in the data. is an vector of observations of the dependent variable, with one observation for every neighborhood, is the number of flooding in neighborhood , is a parameter that relates the number of flooding to the risk of grastrointestinal diseases. is a vector of disturbance terms, where is assume to be independently and identically distributed for all , with zero mean and variance . In order to capture the spatial dependency observed in the incidence data, the model incorporates an additional regressor in the form of a spatially lagged variable,(Anselin, 2001). This variable captures cross-section dependencies, in which exist a covariance structure in different locations derives from the geographic space (Anselin 1998, Anselin, 2001). The term is the unknown spatial lag coefficient, and *W* is the contiguity matrix. This equation was estimated empirically in (*Baeza et al. In review*).

## Water authority actions and changes on neighborhoods’ attributes

` Once the model computes the distance metric for each neighborhood and the selection procedure is activated, a set of actions are invoked. These actions change specific attributes of the landscape. Here we explain the actions and its consequences on the neighborhood attributes. Table 2 summarize these actions and the original explanation contained in the matrix input files.

### Maintenance

Maintenance reduces the age of infrastructure system, , proportionally to its effectiveness, formally:

where is the effectiveness of maintenance.

### New Infrastructure

New infrastructure provision influence the coverage of neighborhood with infrastructure system , such that:

where is the effectiveness of the action “new-infrastructure” in providing system to the proportion of houses that lack of coverage, .

In addition, we assumed that when the action new-infrastructure is invoked, the wells in neighborhood , , with , are replaced by new ones such that

The new well is located in the same place and inherits the same extraction rate as the old one.

### Water distribution

The action water distribution, is the action of supplying water to areas that had a disruption in the supply of water by the system pipes, . When the water distribution procedure is invoked, a set of neighborhoods, defined by the site selection procedure and the budget , are scheduled to receive water by system of “trucks”, , such that the days with water delivered by trucks,, is formally defined as

Thus, when the action water distribution,, is taken in a neighborhood, that is , the number of days water was delivered by trucks is set to the difference between the days with water by pipes and the max number of days in a week (7).

### Water extraction

The action water extraction, , represents the yearly increment in the system of wells, . We assume that in each year neighborhoods can receive a new well. Thus when the procedure water extraction in invoked, the number of wells per neighborhood, , increases according to:

Subsequently, the subsidence rate, , is influenced by water extraction pressure. This is implemented by assuming that the rate of subsidence, , changes over time with:

where and are the total number of wells inside aquifer , at time , and time 1 respectively, and are formally calculated using:

Where , is the number of wells in neighborhood at time , and identifies the aquifer in which the neighborhood belongs to.

## Resident actions

Residents invoke actions that influence the local infrastructure of the neighborhood or change the socio-political landscape by protesting.

### House modification

House modifications influence the sensitivity of the house to suffer hazard events. We define the sensitivity of the house as the modulation of the perception of the magnitude of hazards. We assumed also that modifications are cumulative, but it saturates, meaning that there is a limit to adaptation and a rate at which these changes influence the sensitivity. Formally we assume that sensitivity is defined by

Where

Is the accumulated times that the action house modification was invoke by the residents of neighborhood

### Protests

When the procedure protests in a neighborhood, , are triggered when the valuation of the action protest exposure to infrastructure hazards, the response of the water authority, and the tolerance of local inhabitants to those hazards; accordingly:

where is the distance to the ideal point related to action protest, .

## Social pressure

Social pressure, , is a measure that results from the accumulation of protests in a neighborhood in a period of time , formally:

## Policy scenarios

We define a policy scenarios as the set of parameters and variables associated to each actor’s action. These include the criteria name, the biophysical variables associated to each criteria, the set of criteria weights, the set of alternative weights, and the cutoffs of each value function. Currently the model includes the policy scenarios from the two water operators. Table # summarize the information.

## Indicators

At the end of the period of simulation, the following indicators were obtained:

### City-average age of infrastructure system

this indicator corresponds to the average age of the infrastructure in the city over the last years of the simulation, formally,

where is the average age of infrastructure system , and the total number of neighborhoods in the urban landscape.

### The city-average exposure to flooding and scarcity .

This indicators is calculated using

Where is either the exposure to events of flooding or scarcity in neighborhood in year T. is the final time-step of the simulation and the number of neighborhoods in the urban landscape.

### City-average level of socio-political pressure

This index is calculated using the accumulated protests over the last time-steps of the simulation and then divided by the total number of neighborhoods :

### Vulnerability index

The vulnerability of a neighborhood is calculated using the definition of “surface of vulnerability” by (Luers 2005). In this framework, the vulnerability index is summarized as the ration between the product of exposure E and sensitivity S, and the adaptive capacity of the neighborhood. Formally

Where is the vulnerability in neighborhood at time . is the exposure, defined as the level of flooding or scarcity of water. represents the sensitivity of neighborhood j to hazard events . We measure this by keeping track of the number of decisions that involve house modifications and water storage. More of these actions will generate less sensitive area to the risk. Parameter represents the adaptive capacity of the neighborhood. We assume that

Where is the income-index of neighborhood . Thus, we explicitly assumed that neighborhoods with more resources have higher adaptive capacity than poor neighborhoods. that wealthy areas are less vulnerable because they can have more access to resources to take actions. We use the purchase power as indicator of adaptive capacity.

### Inequality in exposure

This index is obtained by calculating the Gini coefficient. The gini coefficient is a measure of dispersion, often used to measure dispersion in income and wealth in a population. We use it here to evaluate the dispersion in combined exposure to flooding and scarcity. The Gini coefficient is an index between 0, complete equal, to 1 completely unequal. Thus the larger the value of the index the higher the inequality in exposure we day. The Gini is effectively calculating by

Where N is the population of neighborhoods.

is the sum of exposure to flood and scarcity at time t, where , are the values of exposure of the neighborhoods indexed in increasing order (). The inequality index is then the average of the gini coefficient over the last 10 cycles of decision:

### Sensitivity to policy changes

To evaluate the sensitivity of each neighborhood to changes in the policy scenarios, we calculate the coefficient of variation in exposure. The coefficient of variation is measure of the variance in a sample relative to its mean as is calculated.

Where is the mean in exposure in neighborhood at the end of a set of simulations, and its standard deviation. Thus, if neighborhood a) has higher coefficient of variation than neighborhood b, we say that neighborhood a) is more sensible to changes in policy.

# Appendix

## Extensions

The extensions needed to run a run of decisions are the gis extension, which allow to load the geo-information. Also, the \*.csv extension is needed to allow the read of text files into Netlogo. Matrix extension is used to update the priorities (weights) of neighborhoods when ANP are used.

## Generating classes of neighborhoods using a k-mean clustering classification

## GIS pre-processing information

## Instructions to create new type of agents and actions

## Create actions as agents

### Set value variables new agents

A list of criteria

A list of criteria weights associated to the criteria

A list of action-weight

Tables

Table #: Attributes of the neighborhoods of Mexico City.

|  |  |  |  |
| --- | --- | --- | --- |
| Variable | description | Symbol | name variable in netlogo |
| Neighborhood ID | Numerical key to identify each neighborhood |  | ID |
| CVEGEO | Unique National identifier | - | CVEGEO |
| Estate | Administrative units |  | CV\_estado |
| municipality | units |  | CV\_mu |
| aquifer | The aquifer that is below the neighborhood |  | Aquifer |
| Aquifer Zone | The zone of the aquifer below the neighborhood |  | zona\_aquifera |
| Altitude | Meters above see level |  | altitude |
| group cluster ID | A classification of the neighborhoods of MC based on socio-economic and environmental similarities (appendix) |  | group\_kmean |
| Scarcity | Days with no water |  | scarcity |
| Flooding | Number of flood events by year |  | flooding |
| Protests | Social manifestations per week (0-1) |  | protests |
| Health | Annual incidences of gastrointestinal diseases |  | salud |
| Social pressure | Number of protests per year |  | Presion\_social |
| Media pressure |  |  |  |
| Wells | Set of wells within a neighborhood |  | Pozos\_neighborhood |
| Infrastructure coverage | % houses connected to infrastructure system |  | Houses\_with\_*v* |
| Age Infrastructure | Age infrastructure system |  | Antiguedad-infra\_v |
| Condition | An index of the state of the infrastructure system in neighborhood |  | condicion |
| Hydraulic cost | Average volume of water per unit of time received by the sewer system in a year |  | Gastro-hydraulico |
| Capacity | Index of the capacity of the pipes of system |  | capasidad |
| Rainfall | A total annual rainfall in neighborhood municipality |  | precipitation |
| Subsidence | Rate of subsidence per year |  | hundimientos |
| Income-Index | The purchase power by neighborhood |  | Income-index |
| Garbage | Garbage produced in each neighborhood |  | garbage |
| Water quality | Index of the quality of potable water |  | water\_quality |
| Urban growth | Percentage of neighborhood considered as urbanized |  | urban\_growth |

Table 2

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Actions | symbol | Definition | Attribute changed | Decision cycle | Action weight |
| Water Authority | Distribution |  | Refer to the water distributed by government trucks to areas without connection to the supply network |  | Weekly |  |
| Extraction |  | Increase extraction by increasing number of wells |  | Annual |  |
| Maintenance |  | Repairing infrastructure system *v* |  | Monthly |  |
| New infrastructure |  | Refer to the action of providing new infrastructure in neighborhoods that lack of coverage |  | Monthly |  |
| Residents | Collective action |  | Refer to the action of organizing to demand changes from the authority or to internally generate change locally | TBD | TBD |  |
| Rain-water capture | TBD | refer to the capture of water from rainfall | TBD | TBD |  |
| Purchase of water | TBD | refer to the action of buying water from private sources | TBD | TBD |  |
| House modification |  | Action to modify local condition of dwelling to reduce damage from flooding |  | Annual |  |
| Mobilizations/protests |  | To express dissatisfaction with the public services of water delivery and sewage |  | Monthly |  |
| Water Re-uso |  | the action of recycling and re-using water | TDB | TDB |  |

|  |  |  |
| --- | --- | --- |
| Criteria for calculating decision Metric of Residents | |  |
| Criteria | Description | Attribute associated |
| Urbanization | Percentage of area urbanized  (driver of change from simulations of urban growth model) |  |
| Waste of water |  |  |
| Water deviación | The idea that water is being distributed to other areas |  |
| Service efficiency | related to efficiency of infrastructure system |  |
| insuficient infrastructure | Represented by the percentage of population in each neighborhood connected to the drainage network |  |
| Contaminación de agua/water quality |  |  |
| drainage system clooged | accumulation of garbage connected to the failure of the drainage system |  |
| water scarcity | Number of days without water supply |  |
| Flooding | Number of flooding events per year |  |
| Health risk | Number of incidences per pear |  |

|  |  |  |  |
| --- | --- | --- | --- |
| Criteria for calculating decision Metric water supply operator | | | |
|  |  | definition gis-layer | unit |
| Infraestructura | Age of infrastructure | Average age of infrastructure per neighborhood | years |
| Capacity | Capacity [in length of pipes] of the infra to supply water or to discharge | Mts/area |
| Failures | An index of the number of infrastructure related hazards per year (e.g. pipes break) | [events/year] |
| Lack of infrastructure | The lack of supply and discharge connections | 1 - % houses connected to the drainage or water supply system |
| Hydraulic pressure | pressure in pipes | ? |
| Budged | amount | The importance of the budget received from central authority? | ? |
| Risks to the population | Water quality | TBD | ? |
| Water scarcity | Index of scarcity that is a function of days a week with water, | ? |
| Flooding | number of flood events per year | [events/year] |
|  | Health | Number of incidences per year | [events/year] |
| Socio-institucional  Socio-institucional | Water Supply | population requirements | [pop \* need/pop.] |
| Petitions from Neighborhoods | Demand of population funneled by politician at the level of the municipality. It epresents the collective level of response from each municipality |  |
| Social pressure | Accumulation of protests per year | [pop \* need/person] |