# **ODD (Overview, Design concepts, and Details):** A Stochastic emulation experiment - effects of population densities in urban India *on the ground water levels and drinking water consumption patterns* during the peak summer season

## Preface

Summer seasons in the Indian Subcontinent are stressful times, especially in large Urban cities with ***higher than average population densities***. Demand for essential resources such as electric power and water consumption (*both for drinking and other purposes)* rise manifold during this period. Shortages and rationing follow leading to severe crises. Drinking water is **a *non-negotiable natural resource*** and its paucity is further accentuated with the depletion of ground water levels due to *indiscriminate housing, loss of green cover and water bodies*. *Poor rainfall* adds to these woes. Cities in India bear the brunt of such problems as they are commercial hubs, attracting huge migrant populations. Such population surges usually lead to *poor urban planning and unprecedented pressure* on the limited drinking water resources. Water shortages are also demographic; higher income areas manage to circumvent the problem by purchase of water supply from external sources while lower income areas suffer the entirety of the problem.

***Agent based modeling*** provides a great platform to model the problem scenario based on certain stochastic parameters and known variables which can be controlled and measured within a specified timeline.

*"Uncontrolled population densities have long been held as the single biggest contributing factor to scarcity of essential resources in the Indian Subcontinent"*

# Contents

# 1. Purpose

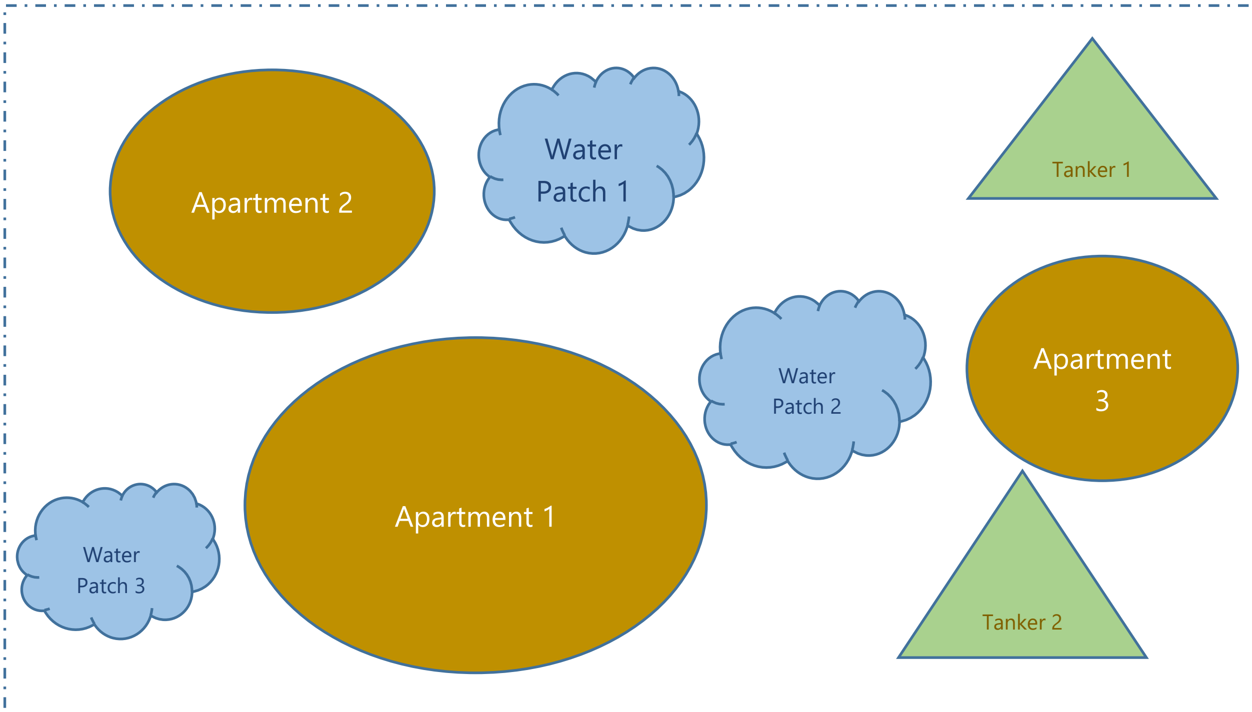
The primary objective for this modelling exercise is to find a critical population mass/density which can be sustained ***without*** the infusion of massive amounts of external drinking water supply, i.e. the ***population mass which is self-sufficient*** to provide for its drinking water needs after a certain period. We are also interested to find which initial conditions, such as the starting ground water ratio with respect to population units, rate of growth of population and number of summer months which lead to the sustaining critical mass. The results of such an experiment will help in *planning of smart urban cities* which can foretell the critical thresholds of population levels which can be sustained with a given configuration of initial conditions.

If such thresholds are predicted to be exceeded, town planning authorities or government agencies can take *corrective actions* to either limit construction of domestic dwellings (apartments or buildings etc.) or can explore the possibility of expanding to areas of lower population densities which have appropriate/abundant quantities of natural drinking water.

**Why is this such an Important social issue worth modelling? Read here**

# 2. Entities, state variables, and scales

This is a social problem and hence the modelled abstraction of all real-world Objects are based on the ***simplification of the actual problem***. An overview of the modelled set up is shown below for clarity and to help corelate with the actual model elements:




In the above diagram, we can visualize the main elements of the model ***without their properties or interaction.*** The outer rectangle ***represents a city***. As such, it doesn't have any specific properties but is an *agglomeration of its constituent entities*. The ***Oval, Cloud and Triangle*** shaped elements are described as follows:

**Oval Shapes:** These represent apartment buildings. For the sake of simplicity, we assume that these are the *only types* of dwellings for humans. Each apartment has an initial population size and grows to a maximum size over several ticks/time-cycles, with a *random rate* of increase. Once maximum size is reached, a new apartment is spawned, and the older apartment size value stops increasing. Apartment population consumes water at a fixed rate. *Water consumption rate of an apartment is proportional to its current population*. Water is initially sourced from the *patches* of water represented by the ***blue shapes***. If an apartment cannot serve *at least 75%* of its water needs it is considered for a tanker service. *A tanker service is selected on first come first serve basis from among the available tankers.*

**Cloud Shapes:** These represent the water bodies and they would be ***fixed over time***. Each of these bodies would have a fixed capacity. They are to be consumed by the apartments based on their population size. Apartment entities have a *fixed field of vision, consisting of units of space on the model surface* and they consume the water from their nearest water bodies based on a fixed unit required per time-cycle/tick. They can change color based on amount of water left in them. Once water bodies run dry, they *change color to brown and are unusable.*

**Triangle Shapes:** These are an abstraction of privately maintained water tankers with *variable capacities and rates per unit of water*. Once an apartment runs out of water bodies (*blue shapes*) in its field of vision, it is provided its required capacity of water from the tankers based on availability. *Tankers also have a total fixed quantity of water and once all the tankers are emptied, the emulation should halt as that would signal the exhaustion of all water sources*.

***Types of entities required:***

**Agents/individuals**: apartment units, population units (within each apartment), tankers

**Spatial units:** water bodies

**Environment**: market price and demand of tanker-based water delivery units

**Collectives:** city, apartment

**Scale:** The ***time scale*** used here is days, i.e. one single unit of time advancement is a day. Hence, we are concerned with *daily water usage, daily population growth and daily rate of unit quantity of water from tankers*. Also, exhaustion of water from water bodies is also calculated per day. The ***area scale*** is per 100 square meters. So, a water body or apartment can span 100 square meters if it takes up a single unit of space on the model surface.

## 3. Process overview and scheduling

At its heart, the complete process is a race against the depleting quantities of available water units. A *typical model execution time* should be about **2-3 months in the real world**, representing the peak summer period in India. The *final quantities to be evaluated* would be the *number of apartments and their average population, number of water bodies and remaining capacity and total tankers used and final average price per tanker unit etc.*

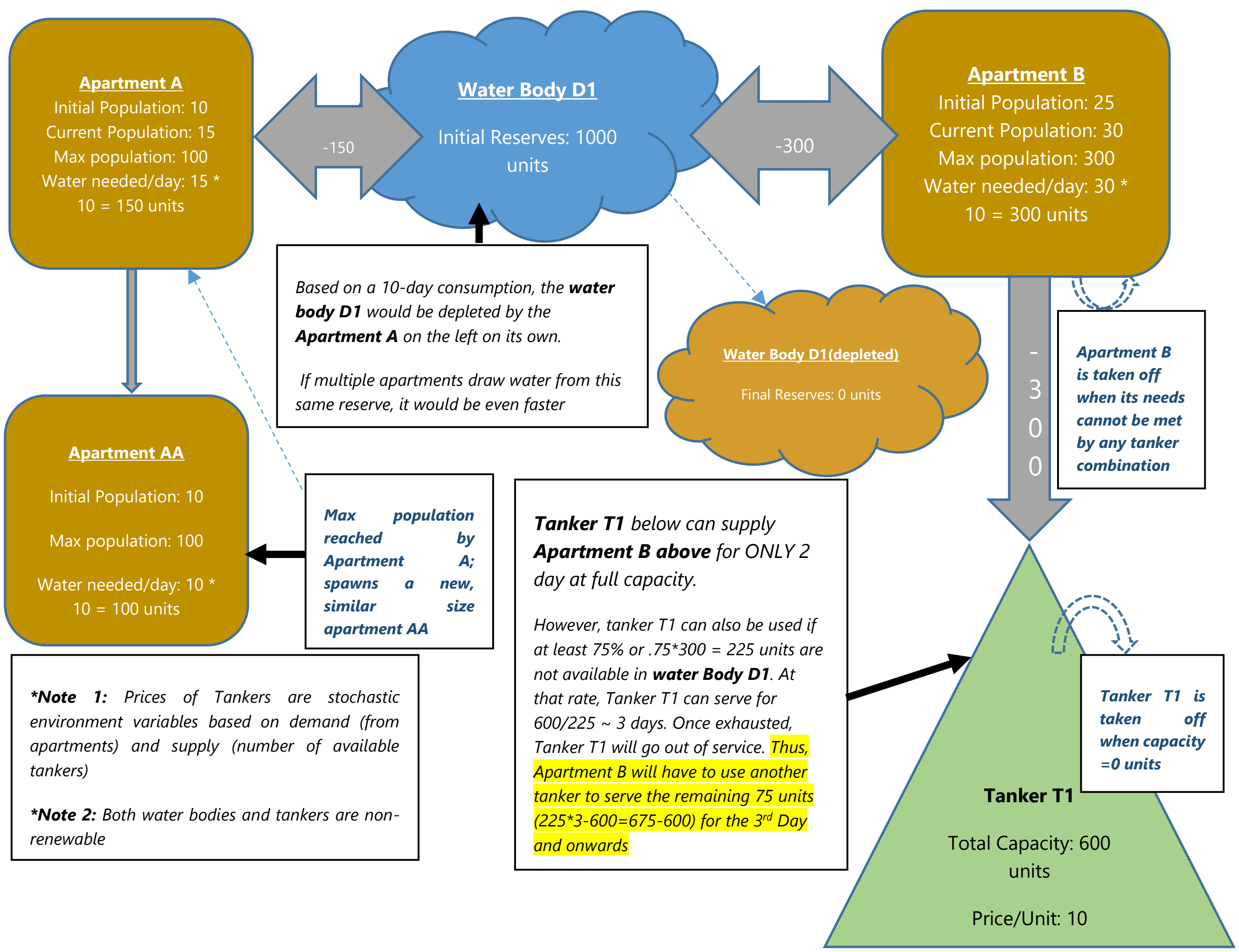
***Success/Failure*** conditions of the experiment is determined by -

a) *if all the water resources are exhausted (complete failure)*
b) at least 75% of the apartments survived by using tanker units (*partial failure*)
c) *no apartment needed to use a tanker service ever (complete success)*

## Some analytical questions posed at the end of the experiment

1. What was the initial ratio of the number of apartments and water bodies? **i.e.** *# of dwelling units(apartments)/ # of water bodies*
2. What was the average population at the end of the experiment per apartment? *i.e. total population / # of dwelling units(apartments)*
3. How many tanker units were used throughout the entire experiment? What was the final price of a tanker unit?
4. How many apartment units required to use tanker units?
5. How quickly were all water bodies depleted (*in days*)?
6. If and how did the population adjust to the shortages? What was the most successful method of *'water conservation'*?

## Simplified Process diagrams with *transitions and interactions* among the various entities



## Pre-set versus random variables

| *Adjustable variables/Can be set manually* | *Random/Stochastically determined variables* |
|---|---|
| *Initial # of Apartments* | Rate of spawning of new apartments |
| *Number of ticks/days to completion* | Growth rate of population per apartment |
| *Unit of water consumed by a population unit/day* | Initial Population size per apartment |
| *Initial price/unit of tanker delivery* | Field vision unit for each apartment |
| | Total # of water bodies |
| | Total # of water tankers |
| | Price increase of tanker delivery (*based on demand/supply*) |
| | Time taken to deliver tanker water to apartment |

## *End-to-End Process Algorithm/Pseudo Code*

**START**

*Initialization Step*: Set # of apartments, water bodies, tankers, price rates, growth rates etc.

*Process Step 1A*: For each apartment;

check population size and calculate daily water requirement;

use field vision to locate nearest water body;

if {water body has enough water (*at least 75% of water requirement*)} use water, decrement water body capacity;

else if {tanker is available} use water, decrement tanker capacity; *## tanker price is an environment variable set dynamically by the system*

else [set apartment state as inactive] *## dwellers cannot survive without a source of water*

*Process Step 1B*: For each apartment;

Check population growth rate, max population size;

[ set new population = old population (1 + growth rate/100)]

if {population size > max population size} [ create ***new*** apartment as copy of initial apartment configuration, set apartment growth rate =0(for the existing apartment)]

*Process Step 2*: For each water body;

Check reserve units of water;

if {reserve unit ==0} [set water body color to brown, state to inactive]

*Process Step 3*: For each tanker;

Check capacity, current market rate/unit;

if {capacity ==0} [set state to inactive]

else [set current market rate/unit]

*Process Step 4A*: For each water body, tanker;

Check current state;

if {state == inactive} [ set *inactive_counter* = *inactive_counter* +1]

if {*inactive_counter* == *total # of water bodies* + *tankers}*

[ end execution and display all values, states] *## Failure state, all water consumed*

*Process Step 4B*: Check max # of days/ticks;

if {max # of days == current days} [ end execution and display all values, states]

*## End state, experiment time over but not all water consumed*

else [ current days = current days +1]

**END**

- **Note 1:** ***All entities***; apartments, tankers and water bodies are *static* and ***don't move on the model map***
- **Each apartment** can draw water combined from a water body and tanker(s) on a given day and ***it is assumed that if at-least 75% of its water need is fulfilled it can survive***
- Newly spawned apartments add to the total water demand. Thus, apartments are the ***ONLY*** entities which can have a growth rate
- Delivery time of tanker is set to immediate for simplicity
- Unlike water bodies, apartments and tankers don't change color on becoming inactive, they are just taken off the map area
- **Note 2:** A detailed analysis of the final states and values is essential to determine the success/failure of the experiment as discussed earlier

# 7. Design concepts

## 1. Basic principles

This model is based on a primary *'demand and supply'* principle. The added dimension is that of a combined internal (*natural water bodies*) and external (*tankers*) supply mechanism which can change the dynamics of survival of an apartment's in-house population.

## 2. Emergence

A ***key point*** that emerges from the exercise is that [ a critical factor to survival is *access to nearby natural water bodies* and evaluating their water content with respect to the ambient population in the apartments/dwellings]. In mathematical terms, "*limited natural supply will lead to increased demand for a stressed resource thus increasing the price and further reducing its availability*".

The advent of water tankers is just a continuation of this market driven theory. Tankers source water from other protected natural resources thus amplifying the problem. However, they provide limited, time-bound recess from complete breakdown of water supply. As the problem surfaces mainly during summer months, *we assume* that natural water supply is replenished post summer. Few details of this multi-facetted problem are available in a Wikipedia article here

## 3. Adaptation

The basic model is simplistic to the extent of being ***naïve to water conservation methods***. Most modern apartments in urban India have several means to conserve and reduce water consumption using:

- Rain water harvesting
- Using water flow limiters in showers, taps, faucets etc.
- In-house water filtration & purification of waste water leading to recycling
- Using metered water supply to promote regulated use among residents

Many other innovative water conservation methods exist but in the Indian context, *political and socio-demographic factors* continue to mar these efforts:

- Rampant filling up of natural water bodies for commercial construction
- Undocumented dwellings which harness the same water supply

- Use of drinking water for industrial and small businesses
- Deforestation leading to reduced rainfall
- *Lack of awareness of the problem leading to negative sentiments related to water conservation*

Given the above factors, we could ***enhance the model to build some intelligence*** into the agents/entities to take advantage of the water conservation methods:

A. Every apartment unit starts with a *randomly assigned private water reserve* (*previously harvested rain-water*)
B. Based on the apartment size, a *random limiter value is set*. This value reduces water requirement by the set % age- an abstraction of limiting water flow from taps etc.
C. If a *filtration unit flag is set (random again),* the apartment can re-use water. This means that on every alternate day, a certain %age of water unit is subtracted from daily requirement
D. Just like with tankers, we can *set a price/unit of water from water bodies* as well. This will emulate regulated water supply

## 4. Objectives

**Primary Objective Question:** ***Can crowded Indian city apartments survive the summer months using ONLY natural water supply without resorting to external sources?***

**Secondary Objective Question:** ***If answer to above question is Yes, what are those conditions and how do we ensure that the situation never goes out of hand?***

Detailed description of process objectives has already been discussed Section 3: *Process Overview section*

## 5. Learning

In the current context, this may be thought of as *the adoption of the **adaptive traits** by apartment dwellers* as explained above in the section on *Adaptation* The table below summarizes some scenarios which elaborate the various aspects of the model discussed above:

| ***Scenario*** | **Emergence** | **Possible *Adaptation*** | **Implied *Learning*** |
|---|---|---|---|
| *All apartments have adequate water bodies in field vision radius* | Most apartments will manage water needs on their own. New apartments will survive if they are near *sparsely populated* areas | New apartments should be created/spawned near water bodies serving less crowded areas with enough reserve capacity | Apartments need to be created based on pre-calculation of present and future water needs. Areas with water bodies having enough reserves should be chosen for the new apartments |
| *Few apartments have nearby water bodies. Most are in far away spots with limited/no water bodies* | Tankers are called into action very early. A lot of apartments in crowded areas will not survive the summer. Tanker delivery unit prices will *rise* to unsustainable values | Use early triggers using sensing to predict high tanker prices; consequently, either *relocate* people from crowded areas or *accelerate* water saving/recycling measures | In the real-world, apartments which depend heavily on tanker services can become unsustainable. Additional measures to 'save water' or link such areas to water bodies should be taken up by the authorities |
| *Apartments start out with adequate, nearby water bodies but growth rate of population is very high* | This is the classic ***'overpopulation'*** syndrome which will result in too many apartments in the current model. Tanker prices will rise and eventually lead to complete dependence on external water supply if unchecked | A healthy ratio of water bodies versus apartments should be maintained. If the optimal ratio value is almost within reach, efforts to reduce the population growth rate or the apartment creation rate should be made immediately | An estimate of the ratio of resources to demand is essential to planning. City planners need such information to ensure that they act proactively rather than wait for a calamity. Uncontrolled growth in areas with limited resources will cause hardships |

## 6. Prediction

Unlike adaptation, which is based on *readily available factors*, *prediction is based on proactively calculated parameters*. For example, in the current context, we could infuse the following **predictive capability** which might lead to a successful result (*self-sustaining water supply for all*):

> Based on the consumption rate, set a higher recycling rate to equalize the two rates,
> *i.e. average daily consumption rate = average daily water recycling rate*
> *This should happen ONLY if {avg daily water recycling rate ~ 90% of avg daily consumption rate}*
> *"The motivation here is that if average daily consumption (calculated monthly) is **quite close to the average recycling rate**, we can strive to increase it and not depend on any external water supply, either natural or external."* **Note** that we might augment the recycling capacity by adding rain-water harvesting etc. as well if required

## 7. Sensing

Sensing is the current context is being able to determine *breach(s) of certain thresholds/limits*. We take the side of the human dwellers in apartments define limits which help save water or reduce water consumption in advance. In the current context, we could set sensors to determine:

- *If the average daily consumption ~ average capacity of water bodies in field vision* [ This could mean that nearby water bodies are almost depleted and this maybe an indication to switch to "*save water*" mode]
- *If current tanker unit price ~ 1.5 * old tanker unit price* [ Tanker water may be required to augment supply but if it exceeds 1.5 times the original price, it might not be *feasible to buy*. Take immediate action to 'reduce water consumption']

## 8. Interaction

*Apartments* interact with *water bodies* and *tankers*. *Tankers* interact with the overall environment to retrieve the market price of a water delivery unit. *Market prices* are set by the system based on demand from apartments and supply of tankers. There is no direct interaction between the in-house *population* and any other entity. *All entities* have their own life cycles which are handled automatically by the system, based on the values of their state variables.

Interaction among entities is discussed in Section 3: *Process Overview section*

## 9. Stochasticity

Quite a few parameters in the model are random. The table shown in *Section 3: Variables* lists them along with the *adjustable/user-determined* parameters. **Note** here that adjustable parameters apply to all instances of an entity (*global scope*).

## 10. Collectives

There are *three major entities in this model*, namely a population unit, apartment unit and a Tanker unit. As seen in the section on entities, Water Bodies are patches which do not act on their own. Thus, in the current model, we have *two collectives*,

a) City: which consists of all the entities and

b) Apartment: consists of population units within it.

### 11. Observation

The model is *observed at the end of the time* set as the peak summer season in India, typically 2-3 months. Though it may make sense to see *how the model is adapting* to the environment during the emulation, only a final success/failure will produce helpful statistics. Some questions posed can be seen in the Section on Analytical Questions

## 8. Initialization

Initialization of the model sets the initial parameter values of the allowed variables.

Please refer to *Section 3: Variables* to see which variables can be set at start. Also, check the sequence of steps in Process Flow Pseudocode above.

## 9. Input data

Though random data has been suggested for the current model emulation, external real-world data can be used. However, the current model state doesn't explicitly mention the details in the sections above. The following table summarizes the impact of using the *model on real-world data instead of random/stochastic model used currently*:

| ***Proposition*** | **Advantage** | **Challenge** |
|---|---|---|
| *Use a real city map as Input. Use latest population census results and water table information.* | More realistic results may be derived and might compare with actual values on ground | Results might vary between cities of different sizes, ecologies and thus might not generalize to all cases |
| | Dynamic updating might be possible to emulate over multiple years for comparison/predictions | Entities tend to become more complex when they have memory of previous states. Could make the model difficult to interpret |

## 10. Submodels

The model in its current form *does not propose a sub-model* structure. The main model is enough to describe the scenario and the experiment.

# Conclusion, further thoughts

The ODD Model presented above is a theoretical exercise meant to provide a base for an actual NetLogo (*or similar*) implementation. The current model is highly simplified to present the basic issues and states that might result from a random emulation of the perceived facts. The results are interpretable by checking the model parameters at the end of the experiment as mentioned and we could assume them to be near-real but never *perfect*.

As the model is primarily stochastic, results will have to be aggregated and visualized on graphs to check trends and patterns emerging out of *repetitively starting with the same initial conditions*. There is room for further enrichment by use of machine learning to predict parameters offline and then compare the results of the model execution to see if the learned parameters fit the model state(s).

*"A primary take-away of the model is that the visual nature of the emulation might help explain the imminent crisis to the unsuspecting masses. Most believe water conservation is an extreme measure to ration water supply"*

*"Adding live data feeds to make the emulations more pertinent might finally convince the population to take concrete steps in the positive direction. This could lead to a more sustainable co-existence of nature & humans"*