Agent based simulation modelling for evacuation during floods

Integrated Post Graduate (IPG) Master of Technology

in
Information Technology
BTech Project - Evaluation Report

by

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GWALIOR-474 015

2022

CANDIDATE DECLARATION

I hereby certify that the work, which is being presented in the report, entitled **Agent based simulation modelling for evacuation during floods**, in partial fulfillment of the requirement for the award of the Degree of **Bachelors of Technology** and submitted to the institution is an authentic record of our work carried out during the period *May 2022* to *September 2022* under the supervision of **Dr. W Wilfred Godfrey**. I have also cited the reference to the text(s)/figure(s)/table(s) from where they have been taken.

Date:21/09/2022 Signature of the Candidate

This is to confirm that the candidate's above statement is true to the best of my knowledge.

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ABSTRACT

Throughout history, humans have commonly begun to escape before it's too late during floods and in a disorderly manner, resulting in a large number of deaths. Flooding has an impact on the entire population of the globe. It is critical to understand how flood evacuation on shorelines can appear in order to prevent floods from taking a toll on human lives. Agent based modelling technique has been used in this project. When looking into the inner workings of large adaptive systems, agent-based models are an invaluable resource. In a nutshell, complex adaptive systems are groups of independently acting entities whose interactions yield aggregate results that cannot be reliably predicted from studying the entities alone. In society flood risk management, having a clear awareness of the flood hazard will guarantee that suitable and effective actions will be taken to decrease and mitigate the risk. NetLogo an integrated development environment and multi-agent programmable language has been used for modelling this simulation. The different agents used in this model are flood parameters, terrain creation parameters and human parameters that behave independently in a complex environment. Several experiments have been performed for different values of these parameters and the flood evacuation process is monitored.

Keywords: Agent based modelling, NetLogo, simulation, flood model.

Acknowledgement

I am highly indebted to **Dr. W Wilfred Godfrey** for giving me the autonomy of functioning and experimenting with ideas. I would like to take this opportunity to express my profound gratitude to them not only for their academic guidance but also for their interest in my project and constant support coupled with confidence boosting and motivating sessions, which proved very fruitful and were instrumental in infusing self-assurance and trust within me. The nurturing and blossoming of the present work is mainly due to their valuable guidance, suggestions, astute judgment,constructive criticism, and an eye for perfection. My mentor always answered a myriad of my doubts with smiling graciousness and prodigious patience, never letting me feel that I am a novice by always lending an ear to my views, appreciating and improving them, and by giving me a free hand in my project. It's only because of their overwhelming interest and helpful attitude, the present work has attained the stage it has.

Finally, I am grateful to my Institution and colleagues whose constant encouragement served to renew my spirit, refocus my attention and energy and helped me in carrying out this work.

{Shashwat Gupta}

TABLE OF CONTENTS

ABSTRACT **ii**

ACKNOWLEDGEMENT **iii**

LIST OF FIGURES **v**

ABBREVIATION **vii**

1 INTRODUCTION **1**

1.1 Background information and motivation . . . 1

1.2 Literature Survey and current state-of-the art models . . . 3

1.3 Project Objectives . . . 4

1.4 Report Layout . . . 4

2 LITERATURE REVIEW **5**

2.1 Findings from the key related research . . . 7

3 SYSTEM ARCHITECTURE AND METHODOLOGY **9**

3.1 System Architecture of the agent based model used . . . 9

3.2 Proposed Methodology and Implementation Details . . . 11

3.2.1 Modules that make up the environment . . . 11

4 Experiments and Results **17**

4.1 Experiment design . . . 17

4.1.1 Experiment 1 . . . 17

4.1.1.1 Parameter settings . . . 17

4.1.1.2 Experiment description . . . 17

4.1.1.3 Results and discussion . . . 18

4.1.2 Experiment 2 . . . 19

4.1.2.1 Parameter settings . . . 19

4.1.2.2 Experiment description . . . 19

4.1.2.3 Results and discussion . . . 19

4.1.3 Experiment 3 20
4.1.3.1 Parameter settings 20
4.1.3.2 Experiment description 20
4.1.3.3 Results and discussion 21
4.1.4 Results Table 22

5 CONCLUSION **24**
5.1 Advantages 24
5.2 Limitations 24
5.3 Future Scope For Improvements 24

REFERENCES **24**

LIST OF FIGURES

1.1 Every year large part of mumbai east ward gets flooded [16] 2

3.1 Flowchart overview of evacuation during a flood 10
3.2 Graph of percent dead people formed during a simulation 16

4.1 Initial setup for experiment 1 18
4.2 Final result for experiment 1 18
4.3 Initial setup for experiment 2 19
4.4 Final result for experiment 2 20
4.5 Initial setup for experiment 3 21
4.6 Final result for experiment 3 21
4.7 Five input values of the attributes used in the 10 experiments 22
4.8 Two input values of the attributes and output values of the 10 experiments 23

ABBREVIATIONS

ABM	Agent Based Modelling
FIM	Flood induntation mapping
GIS	Geographic Information Systems
HEC-HMS	Hydrologic Engineering Center's Hydraulic Modeling System
SWMM	Storm water management model

CHAPTER 1

INTRODUCTION

One of the worst natural catastrophes in terms of casualties and property damage is flooding. The losses can be minimised and the pace of recovery can be made quiker by properly preparing for and implementing disaster management. People in high-risk flood zones are moved to safer places/shelters as part of an evacuation plan, which is one of the most important preemptive actions taken to reduce fatalities. Preventing unnecessary human and material losses is the primary goal of any evacuation strategy. Preparing an evacuation plan ahead of time is crucial to easing the process and making the evacuee familiar with following the instructions as well as preventing last-minute turmoil that may arise when numerous decision-makers are involved. A flood is defined as overflow of water covering land not usually covered by water. Floods are of two types:

1. Slow floods.

2. Flash floods develop without any signals of rainfall.

Thunderstorm activities at sea can flood coastal communities, causing waves to overtop fortifications or, in severe circumstances, by tsunamis or tropical cyclones. Preparation and mitigation actions, such as relocating away from watersheds and elevating properties, may lessen the severity of flash flood damage and the likelihood of death.

1.1 Background information and motivation

Human-caused climate change has long been known to wreak havoc on the water cycle and increase the likelihood of flooding throughout the world. As a result of climate change, floods have become more common and difficult to anticipate, resulting in many deaths and extensive property damage. Few examples of flood catastrophes along with their evacuation statistics are the floods in New Orleans in 2005, even though 80–90%

of the population had evacuated. More than 1,100 persons lost their lives throughout the state of Louisiana [1]. Flooding and obstruction of transit routes between the defence storage depot and the deployment location prevented the deployment of temporary protection during the summer floods that struck the United Kingdom in 2007 [1]. On the other hand, when the floods that occurred in Hull in June 2007, FIM was not greatly impacted by issues like as the inability to start up computer systems and the loss of rainfall radar information, a severe flood warning wasn't provided in a timely manner during the same incident [1].

There has been a history of flooding in Mumbai. In a 24-hour period beginning on July 26, 2005, a cloudburst dumped 944 millimetres of rain on the city of Mumbai. On August 29, 2017, the area was hit by catastrophic floods again when 330 millimetres of rain fell in only 12 hours, claiming the lives of over 20 people [16].

Figure 1.1: Every year large part of mumbai east ward gets flooded [16]

It is abundantly evident that new strategies are necessary to help flood risk managers in their efforts to limit the number of lives lost and the amount of property damage, as well as to investigate the extensive variety of occurrences that might take place during a flood catastrophe. There are cases in which the lives of the people were saved for example in the devastating floods include the 2002 flooding in the Czech Republic in which there were deaths of 17 and evacuation of 225,000 people [17]. But in other cases there are huge number of deaths example the death of 230 000 people in 2004 flooding in Indonesia [18].

This is why it's crucial to establish a plan for how to evacuate people from coastal regions in the event of a flood, so that as many people as possible may be saved.

Economic, environmental, and political aspects are also difficult to mathematically calculate and measure, yet they have an impact on the spread of floods. To include the various aspects of the actual world into its simulation model and to conduct the required experiments, an agent based modelling technique is a viable alternative. Nonlinear and emergent properties of systems may be investigated through agent-based modelling, which involves mimicking the behaviour of autonomous agents inside a system. Systems like the financial markets or city traffic are examples of this, where the actions of a single player may have a domino impact on the choices of many others, at least until the system as a whole alters its behaviour. The occurrence of flooding is due to the complex interplay of several natural system components, including but not limited to rainfalls, agricultural use, sediment, terrain, and features of channels. The process of evacuation during floods focuses primarily on modelling the flooding event as a consequence of the interplay between those components.

1.2 Literature Survey and current state-of-the art models

This section depicts the reason behind this project and the main objectives of model proposed.

Suria Darma Tarigan, "Modeling effectiveness of management practices for flood mitigation using GIS spatial analysis functions in Upper Cilliwung watershed" The most recent and cutting-edge versions of hydrological models, such as SWAT and HEC-HMS, have been dissected and analysed here. The aggregated nature of these models makes it difficult for them to account for discrete management techniques in their analyses. Some examples of discrete management methods are infiltration springs, and silt dumps. My finding is that currently there are no functionalities for multi agent systems in such models [2].

Another state of the art model to create flood inundation and, ultimately, hazard maps for different inland hydraulic situations, a three-way connected flood model is the MIKE FLOOD platform, taking into account river, stormwater, overland flow, and tidal effects [3].

Another study by Jingxuan Zhu, Qiang Dai, Yinghui Deng, Aorui Zhang, Yingzhe Zhang and Shuliang Zhang "Indirect Damage of Urban Flooding: Investigation of Flood-Induced Traffic Congestion Using Dynamic Modeling ," The state of the art model used was Storm Water Management Model (SWMM) and TELAMAC-2D, a flood simulation was carried out in order to make a prediction about the geographical spread of flooding. The conventional approaches and conclusions, which are derived from an integrated study of hydrology and transportation, have the potential to contribute to the reduction of traffic jams during flood weathers, the facilitation of risk management of urban flooding and early warning, and the assistance of users in making them aware regarding travel [4].

1.3 Project Objectives

There exists many toolkits to perform agent based simulation including swarm, repast, mason, ascape, netlogo. Our objectives are:

1. To simulate the process of evacuation of humans residing on the shoreline area and in the nearest locations during the approaching flood.
2. To provide the flexibility to feed the actual parameters of land and population.
3. To calculate the current height of the flood in real time.
4. To calculate the number of alive and safe people and plot the graph of percentage dead people in real time.

1.4 Report Layout

Chapter 2 Literature Review describes all the previous works done in this field and that helped us in the development of this project.
Chapter 3 System Architecture and Methodology describes the architecture of the project, it's working, and the tools that are being used to build this project.
Chapter 4 Experiments and Results provides the result of this project for the better understanding.
Chapter 5 Conclusion specifies the advantages, limitations and future scope of this project.

CHAPTER 2

LITERATURE REVIEW

This section is about the research papers and articles referred for any information and knowledge regarding the projects.

Title	**Source/ Journal**	**Author**	**Year**
Urban Water-log Simulation and Prediction based on Multi-Agent Systems [1].	Geo computation conference	Shitai Bao and Changjoo Kim and Wenping Ai and Zehui Lai and Jian-fang Wang,	2015 .
Modeling effective-ness of management practices for flood mitigation using GIS spatial analysis functions in Upper Cilliwung watershed [2].	IOP Conference Series: Earth and Environmental Science	Suria Darma Tarigan	2016
Using Agent-Based Modeling for Wa-ter Resources Plan-ning and Manage-ment [5].	Journal of Water Resources Plan-ning and Man-agement	Berglund, Emily	2015

Testing the impact of direct and indirect flood warnings on population behaviour using an agent-based model [4].	Natual hazards and earth system sciences	Thomas O'Shea, Paul Bates, and Jeffrey Neal	2020
A systematic review of agent-based model for flood risk management and assessment using the ODD protocol [6].	Springer Journal of Natural Hazards.	Anshuka, A., van Ogtrop, F.F., Sanderson, D.	2022
An agent-based model for risk-based flood incident management [1].	Springer Journal of Natural Hazards.	Dawson, R.J., Peppe, R. and Wang, M.	2011
An agent based model for land use policies in coastal areas [7].	Coastal Engineering Proceedings	Shima Nabinejad and Holger Schüttrumpf	2017
Performance evaluation of potential inland flood management options through a three-way linked hydrodynamic modelling framework for a coastal urban watershed [3].	Inter -national water association publication hydrology research	Mousumi Ghosh, Mohit Prakash Mohanty, Pushpendra Kishore, Subhankar Karmakar	2020
A data-driven agent-based simulation to predict crime patterns in an urban environment [8].	Computer environment and urban system journal	Raquel Rosés and Cristina Kadar and Nick Malleson	2021

2.1 Findings from the key related research

In the paper by Shitai Bao et al. [9] the study's primary contribution was the introduction of a multi-agent-based technique to modelling urban water-logging. Since urban surfaces are often fragmented and spatially complex, simulating urban water-logging using traditional quantitative runoff computations is impractical. Instead, a multi-agent model is employed to achieve this goal. It is hypothesised that the drainage system is one of the inducers in this study, with the flood flow and water-log agents standing in for the active features present during a storm.

The gaps in the ability of current hydrological models like HEC-HMS and SWAT and to account for multi-agent systems and discrete management techniques like infiltration wells are presented by Suria Daria Tarigan [2].

To account for the influence of human decision making, behaviour, and adaptation in water resource management, agent-based modelling has been used to analyse, simulate, and predict the outcomes of infrastructure design and policy decisions. The goals of the work by Berglund Emily [5] are to (1) expose academics, students, and practitioners in the area of water resources to agent-based modelling and (2) investigate water resources systems as complex adaptive systems that may be studied using this technique.

2005 flood in Carlisle, United kingdonm is used as an example in the model by Thomas O'Shea et al. [10], which is built with the help of the LISFLOOD-FP hydrodynamic model and the NetLogo agent-based framework. This article indicates that possible human reactions to floods may be included in such measurement.

Decision making in humans has received a lot of attention from researchers, and solid arguments have been made in favour of human decision making. Anushka A. et al. [4] gave various examples of ABMs in various different subject areas illustrate the effectiveness of flood warnings, evacuation, and other policies within the context of a particular system. Because of the breadth of ABM's study, specialists in the hydrological field and social scientists may be able to interact more successfully. Hydrological details are mostly addressed by the sub-model approach.

While the flood itself is the primary subject of this study, the advantages of specific actions made in advance of a flood occurrence are also considered in terms of reduction of flood losses. Conventional wisdom is that flood risk equals the sum of two factors: the frequency with which flooding occurs and the severity of any resulting damage is out by Dawson R.J. et al. [6]. Large uncertainties may exist with regards to flood disasters, but by investigating various events and estimation techniques, the choices that are as resilient as feasible to uncertainties can be found. In order to evaluate a wider variety of actions for managing flood events, future development will concentrate on integrating additional agents like technicians and emergency workers.

Human-flood interactions may be modelled with the help of an Agent Based Model, which incorporates judgement, scientific, and cultural aspects. In the framework put forward by Shima Nabinejad et al. [1], landowners are seen as autonomous persons whose choices are influenced by a variety of factors, including weather, crop production, pricing, the severity of floods, the farmers' own sense of risk and vulnerability, and their connections with others. To do this, the Agent Based Model has three core modules: hydrology, flood analysis, and a strategic planning module. In every iteration of the hydrological module, agriculture yeilds are calculated using the most up-to-date available data as inputs.

Mousumi Ghosh et al. [7] created a model including multiple coastal hydraulic possibilities taking into account a wide range of bridge and padding fabric alternatives, this research presents a unique, complete hydrodynamic flood simulation methodology to lessen the impact of flooding. Mithi river basin in Mumbai, the financial hub of India, is the study's focal point. This paradigm might be useful in other thickly urbanized metropolitan catchments where the adaption of design approaches for flood control is challenging due to a lack of land.

Raquel Roses et al. [3] used agent-based models (ABMs) in criminality for theoretical research. In addition, numerical methods (like machine learning) used in crime prediction models heavily depend on data collected from the actual world. The software is tested by comparing its output to actual crime data at the block level to ensure it generates credible crime statistics.

CHAPTER 3

SYSTEM ARCHITECTURE AND METHODOLOGY

There are lots of agents that behave differently in a complex adaptive environment. NetLogo is a multi-agent programmable modelling environment used for agent-based modelling has been used in this project. Because it is suitable for research as well as educational purposes. Each of the agents has some attributes and behaviour. Combining all the agents leads to a complex behavioural simulation model. It allows us to modify the agent parameter values easily and also provide enough data in the form of graphs. Whole is more than sum of its part is the logic behind using agent based modelling. A similar mechanism underlies the operation of agent-based models, which consist of the ability to programme rules for agents that specify the behaviours and responses that an agent could exhibit while interacting with other agents. These relationships, in turn, generate intriguing patterns of simulated collective behaviour. These patterns have the potential to reveal insights into social, economic, or ecological phenomena that are seen in the actual world. ABMs are often used to the investigation of difficult problems that can't be handled by conventional mathematical models. They assist us in forecasting or examining what-if possibilities given the many factors in the system have the ability to toggle and fine tune the parametric values.

3.1 System Architecture of the agent based model used

Figure 3.1 shows the flow chart of the steps involved in the simulation of the agent based model. It starts by setting up the various values of the parameters and stabilises when the number of dead humans become constant.

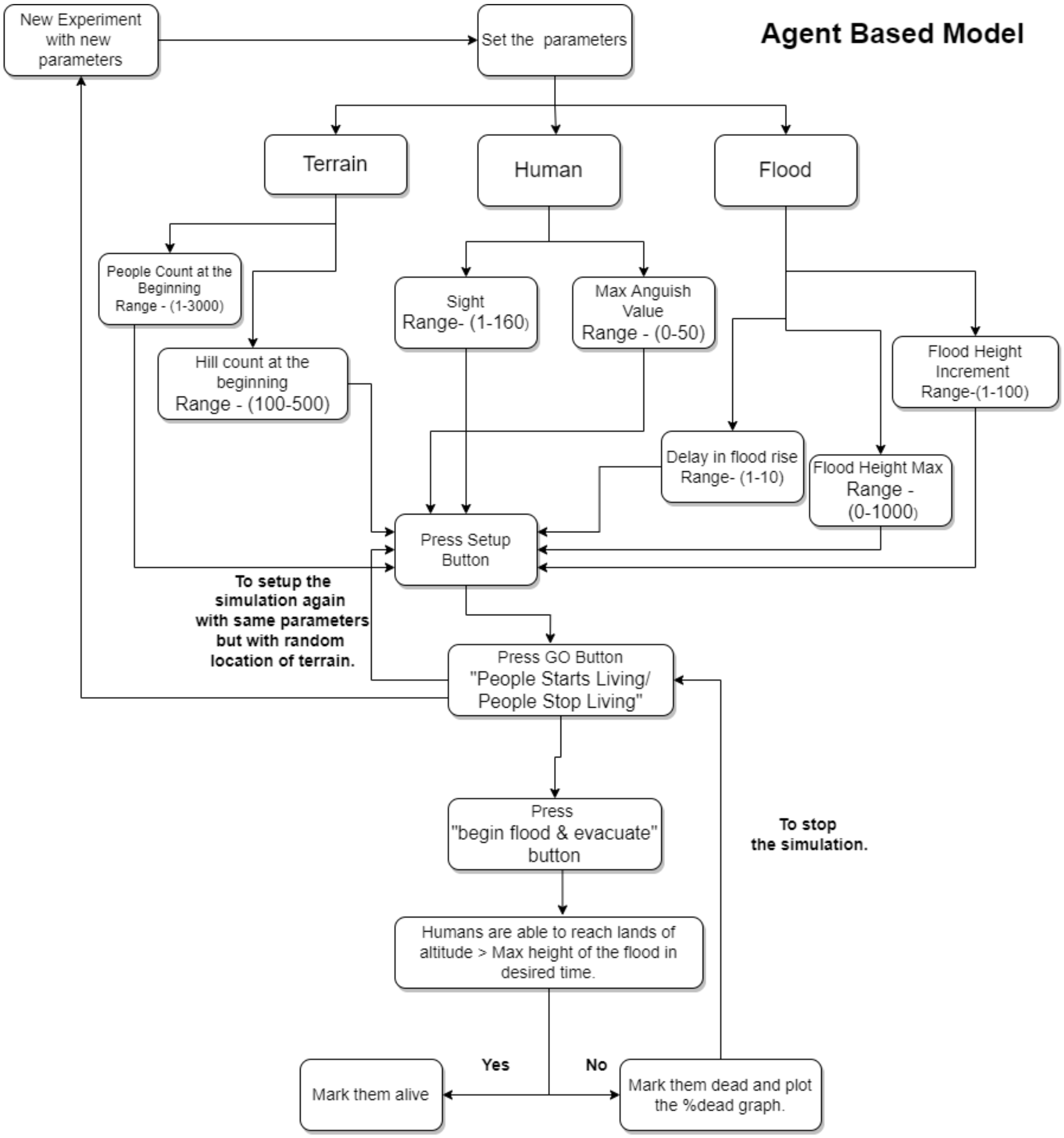

Figure 3.1: Flowchart overview of evacuation during a flood

3.2 Proposed Methodology and Implementation Details

Methodology is a relevant structure for research. The simulation in NetLogo is built on interactions between agents and between agents and their environment at each tick in the simulation's time-step. The turtles are agents, and the patches are locations in the NetLogo environment (simulation space). Multiple user-defined characteristics are possible for both turtles and patches. In the simulation, patches represent the environment as land and water. Patches in green represent land and brown with shades of brown represents lands of higher altitudes. The blue represent the water flow.

When the setup button is pressed it clears all past data and generates a new random data and sets up the seashore, water, color of the water, range of the color of land. In order to create seashore, the patches are chosen randomly and set their height as 1. The height is re-scaled between 0 to 1000 by diffusing the height gradually. The areas which will be later covered with water, their height will be made zero. In order to create the humans, use the sprout inbuilt method and set their color as orange and their anguish value as 0. Different elevation patches are shown by different colours on the map. For example if the altitude is between 0 to 50 then pcolor of 51 is assigned. Before the start of the flood, it is required to ensure the people are living their life randomly turning left and right, until they are pointing the boundary or water. When the begin food and evacuate button is pressed the flood method and evacuate method are launched.

The water will rise in a condition that the patch is lower height than the flood-height-max value and is surrounded by flood. If the anguish value obtains its maximum permissible value then the max number of unsuccessful attempts by an individual is achieved hence, the turtle will become static and stop looking for further higher grounds. A turtle chooses a target which is closer and higher than others. If the movement by turtle towards the target gets exhausted it will randomly select a surrounding patch and shift there.

3.2.1 Modules that make up the environment

1. *setup* : It is one of the most crucial buttons. It sets up the environment of all the agents. This setup method can either be called by pressing the setup button or calling "setup" in the observer window. Loads the data with the current parameters randomly. If setup button is pressed again and again, the configuration of turtles get changed everytime randomly because a random function is used for allocation.

Logic implemented: As the setup button is pressed it deletes all the past values of the interface. Then the default design of the turtles is set to humans. At the beginnning all the patches are set to be land. Then procedures to formulate the shoreline and water are called. Appropriate color is assigned to them by calling the color procedure. The humans are spawned depending on the user input. By default the increment count is set to 1. At the end call the timer of ticks is reset.

2. *go*: It is a button. The environment starts living. The turtles start moving randomly. The button's actions are executed repeatedly rather than just once when the "Forever" option is checked. To begin the new simulation first press the Go button then hit the setup button.

   Logic implemented: If the begin-flood and begin evacuate methods are true then the height of the flood is incremented gradually. And the timer in the form of ticks is increased.

3. *begin-flood-and-evacuate* : It is a button. The water level starts rising, causing a flood. The humans will start evacuation by moving towards patches of higher altitudes.

   Logic implemented: Firstly the location of a human is checked if it is covered by water then he is drowning and will be marked as dead. Now on checking for the current number of unsuccessfull attempts that is the anguish value, if it has surpassed the max set anguish value then the human will not look further for higher altitudes and will stay at that location only.
   Now if the human or turtle is at the goal location, it is marked with color red. If the human has yet not reached its goal location and that goal lies in the scope of sight then that goal is picked which has highest peak. This highest peak will be the new current goal for this particular human. It may also happen that a human is already standing on a goal, but a better goal may be in the sight of that human, it will look for a goal whose distance is less than 20 and higher its current location. This new goal is now the another goal to be achieved.

   If the human is not on the goal and the distance between human and the goal is less than 1 then the human is near the goal. On a particular patch location only one human can be accomodated. If the count of humans on that goal is zero, then this new human can be accomodated there and the human is moved there. Next step is to mark the count of humans on that goal as one.

   Choosing the orientation direction of the human is also crucial. It should be facing towards the goal. A human can move to the forward patch if the path is clear. Path is checked if the patch next to this location in the direction of the goal has another human or not. Along with that the patch next to this location must also be land. If these two conditions are met then the human moves forward to the next patch.

If the human find that the next patch in the direction of the goal is not feasible to move then it randomly chooses a surrounding and changes its new location to be this location.

At the last part of this module, when the human was not able to reach its goal, the number of unsuccessful attempts is incremented by one. Now from this location the turtle searches in the direction of goal, if in the next location the number of human in its next move is zero. Then finally it moves forward towards the new goal.

4. *people-count-at-beginning*: First terrain creation attribute. It is a slider and a global variable. It determines at the beginning of the simulation environment how many humans will be generated at random locations. Range of the count of people can be between 1 and 3000. The default value is set to 500.

   Logic implemented: First step is to check whether a particular patch is a land or water. It is a land then a new human is created using the sprout inbuilt method to create the turtles.
   There are some inherit parameters that are needed to be set for the humans. The color of the humans are set to be orange. The number of unsuccessful attempts ie the anguish value is set to be zero.

5. *hill-count-at-beginning*: Second terrain creation attribute. It is a slider and a global variable. It determines in the beginning of the simulation how many hills will be created. Hill represents lands of higher altitudes. Range of the hills can be between 100 and 500. The default value is set to 200.

   Logic implemented: It is done inside the method of shoreline formation. From the parts where there is no water, the height of the remaining patches whose x coordinate of the patch is greater than 30 are set to be 1. Now, depending on the input number of peaks set by the user the heights of the surrounding patches are set accordingly by diffusing the heights by a factor of 0.2. This process is repeated 400 times. Doing this creates a genuine terrain with progressive heights. For implementing this diffuse inbuilt method is used, hence the height range ie 1 to 1000 is adjusted between 0 and 1. If the x coordinate of a patch is less than 15 then its altitude is made zero.

6. *flood-height-max*: First flood creation attribute. It is a global variable. It defines the max height to which water can rise. The value can range between 0 and 1000. The default value is set to be 350.

7. *flood-height-increment*: Second flood creation attribute. It is a slider and a global variable. It defines the increase in the height of the flood in any duration of time and denotes the systematic increase in flood level. The value can range between 1 and 100. The default value is set to be 40.

   Logic implemented: This is a module to increase the height of the flood gradually. There are some conditions to be checked that the current patch should be water, and the current height of the patch must less than the height of the surrounding patches, then only it will get flooded first.

   Using an inbuilt function patch-at-heading-and-distance which returns the coordinates of the single patch that is the specified absolute heading away from this turtle or patch. If the y coordinate of a patch is less than 150 then that patch heads towards the coordinate (0, 1). If at the altitude of this location is less than the sum of the current flood height and increment in flood height, then this part of land gets submerged in water.

   If the x coordinate of a patch is less than 150 then that patch heads towards the coordinate (90, 1). If at the altitude of this location is less than the sum of the current flood height and increment in flood height, then this part of land gets submerged in water.

   If the y coordinate of a patch is greater than 0 then that patch heads towards the coordinate (180, 1). If at the altitude of this location is less than the sum of the current flood height and increment in flood height, then this part of land gets submerged in water.

   If the x coordinate of a patch is greater than 0 then that patch heads towards the coordinate (270, 1). If at the altitude of this location is less than the sum of the current flood height and increment in flood height, then this part of land gets submerged in water.

Delay of flood is calculated by the ratio of current value of ticks and water surge speed. Delay is a time period in which the next increment in the height of the flood will occur.

If the sum of current height of the flood and flood height increment value is less than the max peak of the flood, then the current height of the flood is updated by sum of current height of the flood and flood height increment value set by the user. And the value of surge counter is incremented by 1. Else if it greater then the current height of the flood is set to be the max peak of the flood. Again in this case as well the surge counter is incremented by 1. This new patch is finally colored with water.

8. *delay-in-flood-rise*: Third flood creation attribute. It is a slider and a global variable. It is the delay that you want your flood to have in between two successive values of flood heights. If the delay is = 8, then 8 ticks mean 1 level of increase in the current height of flood by flood-height-increment value.

9. *scale shoreline*: In orde to rescale the value of altitudes between 0 and 1 this method is called. Implemented logic: Take a variable lowest which denotes the minimum altitude in the patch which is land. Take another variable highest which denotes the maximum altitude of the patch which is land. Range of heights is the difference between lowest and the highest value. Then a new altitude will be scaled by subtracting lowest from it and then multiplying it by 1000 and dividing by the range.

10. *sight*: It is a slider. It is a global variable. It helps the humans to look for the highest altitude place. It will also take longer duration to reach that place. Range from 1 to 150 with a default value of 50.

11. *max-anguish-value*: It is a slider and a global variable. It tells about the number of unsuccessful attempts taken in search of higher altitude places. Range from 0 to 50 with a default value of 20.

12. *anguish-value*: It is a local variable. It is the number of unsuccessful attempts taken by the human.

13. *current-flood-height*: It is a monitor. It shows the height of the flood currently. Its value rises from 0 to upto flood-height-max.

14. *alive and safe people*: It is a monitor. Denotes number of alive humans at a particular instant of time. Real time data is shown here. In steady state this value becomes constant.

15. *number of dead people*: It is a monitor. Denotes number of deaths at a particular instant of time. Real time data is shown here. In steady state this value becomes constant.

16. *% dead people*: It is a monitor. It is a graph diagram that rises as the number of deaths increases. The % dead-people, is defined by the expression:

$$\%dead\_people = \frac{number\_Of\_deaths * 100}{Number\_of\_humans\_at\_the\_start}$$

. In steady state the graph becomes parallel to x-axis.

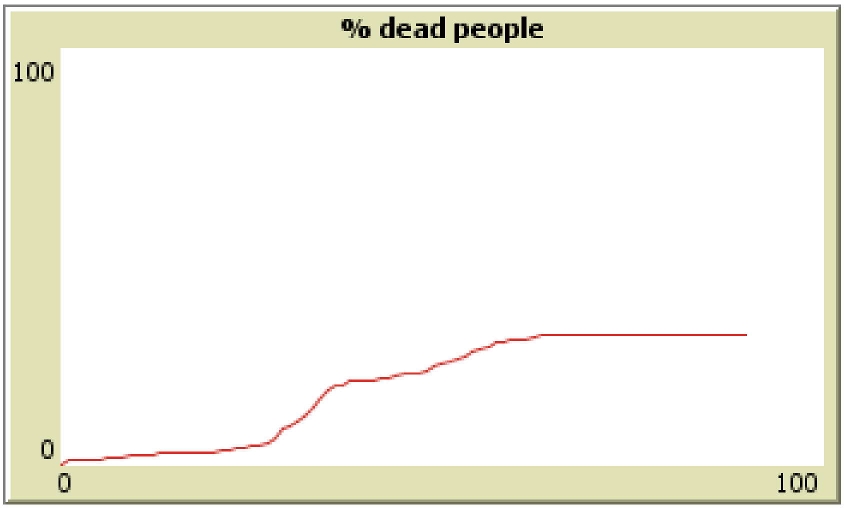

Figure 3.2: Graph of percent dead people formed during a simulation

17. *aim-patch*: It is a local variable. It is the highest point in the line of sight.

18. *Altitude* : Represents the height of the patch.

19. *Water* : Returns true if a particular patch is water or not.

20. *is-on-aim*: It is a local boolean variable. It returns true whether humans will reach their goal point.

21. *next-aim*: It is a local variable. It is a patch location if the person fails to reach the previous goal, it will start moving towards the next goal.

These all modules are written in the codetab inside the NetLogo toolkit and executed. The results are shown in the interface tab. The GitHub link to the repository can be found here: `https://github.com/shashwat0105/Agent-based-simulation-modelling-for-`

CHAPTER 4

Experiments and Results

In this section multiple experiments have been performed by tuning the values of various attributes. Three experiments are demonstrated in detail. A table of total 10 experiments performed is shown in the results section.

4.1 Experiment design

4.1.1 Experiment 1

4.1.1.1 Parameter settings

The flood formation parameters namely *flood-height-max* is set to 350, *flood-height-increment* is set to 65, *delay-in-flood-rise* is given minimum delay of 1.
The terrain formation parameters namely *people-count-at the beginning* is set to 700 and *hill-count-at-the-beginning* is set to 350.
The human parameters namely *sight* is set to 50 and *max-anguish-value* is set to 20.

4.1.1.2 Experiment description

Using the sliders, parameters with desired values are set. Then the setup button is pressed. A random patch with desired attributes is generated. When the GO button is pressed the environment starts living, the humans move randomly. Now, on pressing the begin flood and evacuate button, to initiate the flood flow. The water level rises and start covering the land areas of altitudes lower than flood height.

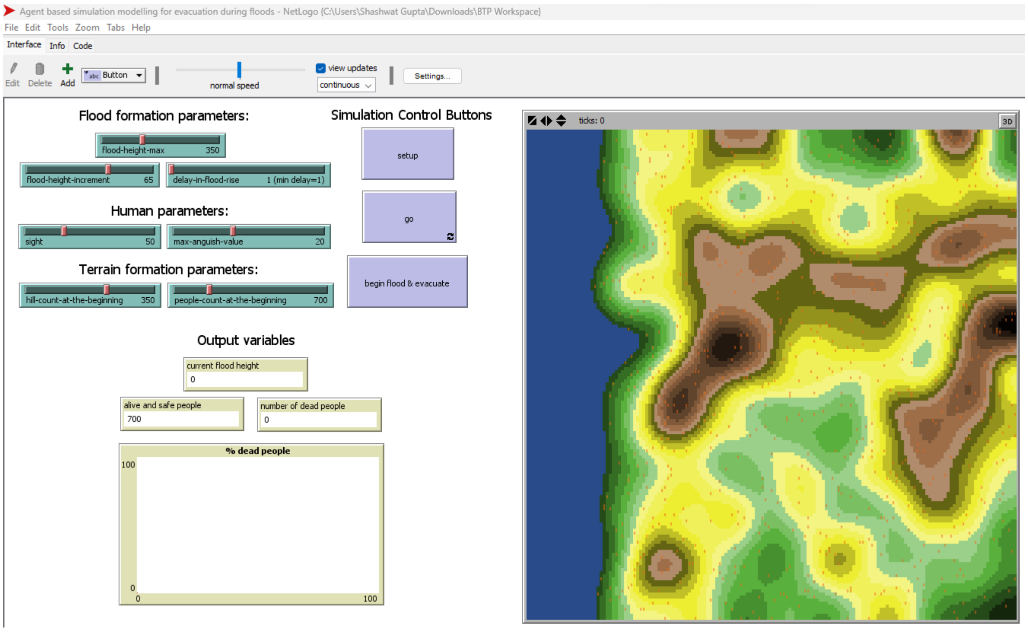

Figure 4.1: Initial setup for experiment 1

4.1.1.3 Results and discussion

The number of dead people was 53 out of 700. As can see that since the flood height was low hence the mortality rate was 7.5%. The water was unable to cover large area of land, hence large number of people were able to survive.

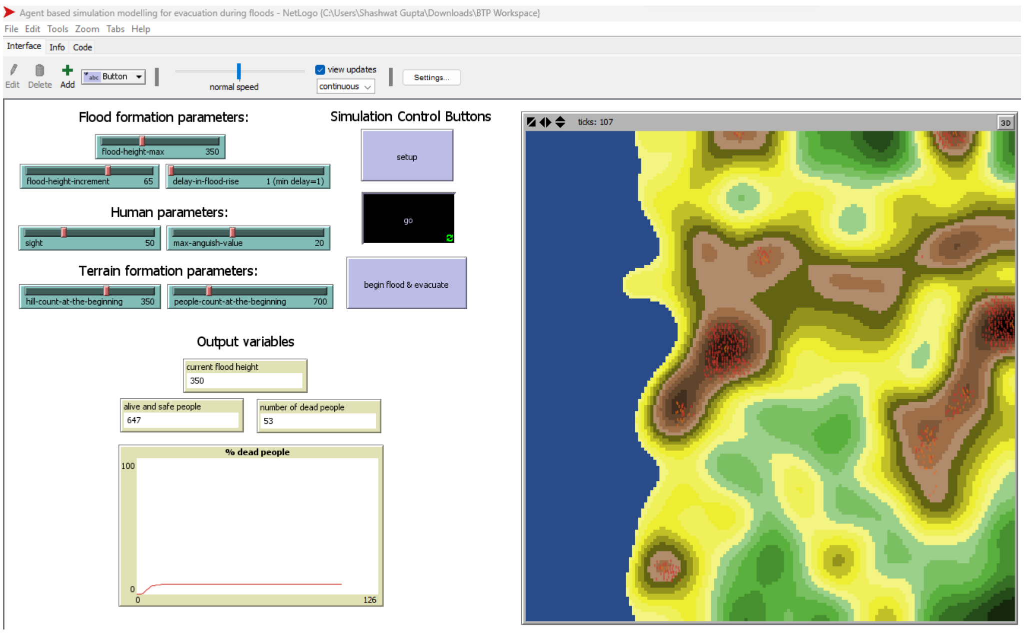

Figure 4.2: Final result for experiment 1

4.1.2 Experiment 2

4.1.2.1 Parameter settings

The flood formation parameters namely *flood-height-max* is set to 475, *flood-height-increment* is set to 25, *delay-in-flood-rise* is given minimum delay of 1.
The terrain formation parameters namely *people-count-at the beginning* is set to 1400 and *hill-count-at-the-beginning* is set to 400.
The human parameters namely *sight* is set to 80 and *max-anguish-value* is set to 25.

4.1.2.2 Experiment description

Apart from the steps involved in experiment 1. Now the flood height is increased as well as people ability to search for higher grounds i.e. their sight. Hence, there will be a tradeoff between the results.

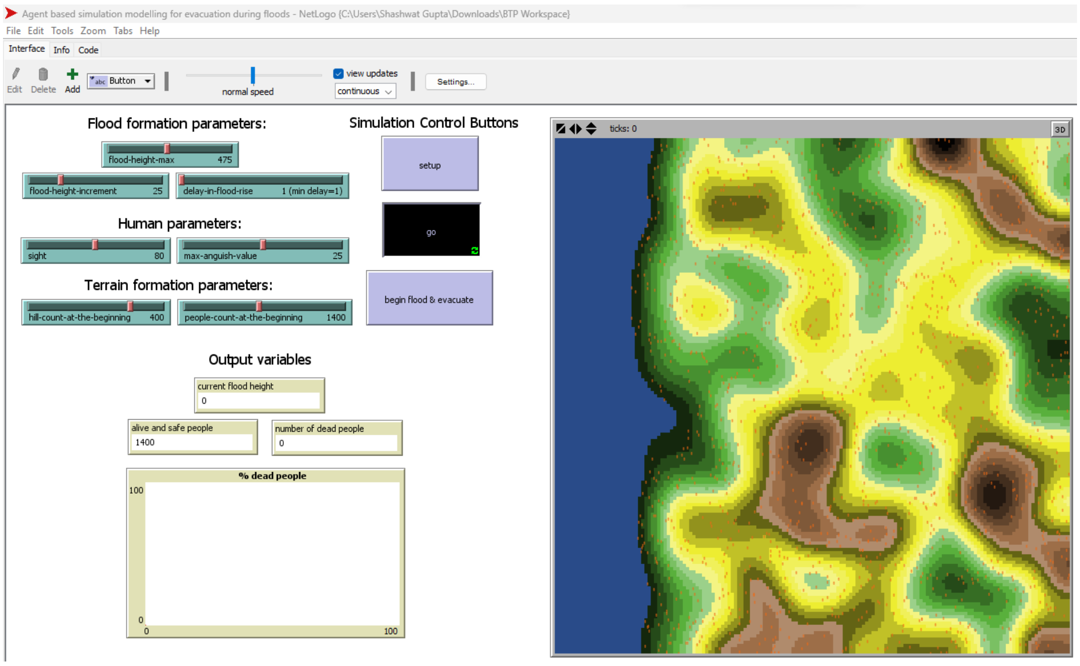

Figure 4.3: Initial setup for experiment 2

4.1.2.3 Results and discussion

The first image show simulation of the setup and the second image shows the simulation view after the flood. It is found that 446 people died out of 1400 people. The death rate is 31.8%. The flood was higher than experiment 1. If the sight of people weren't increased the mortality rate would have been even severe.

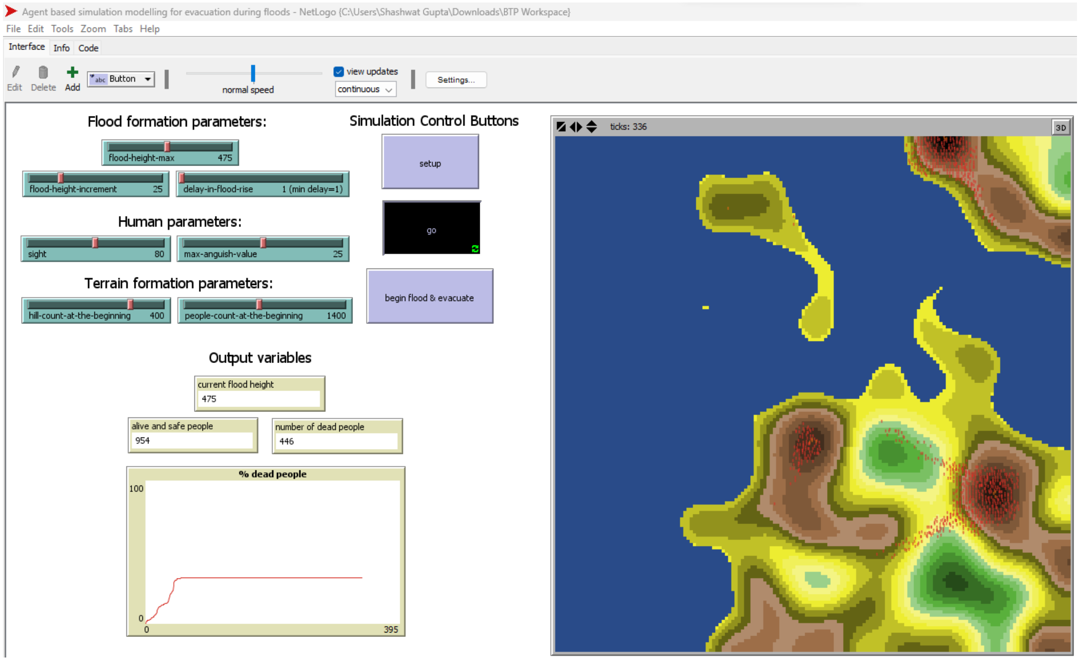

Figure 4.4: Final result for experiment 2

4.1.3 Experiment 3

4.1.3.1 Parameter settings

The flood formation parameters namely *flood-height-max* is set to 625, *flood-height-increment* is set to 25, *delay-in-flood-rise* is given minimum delay of 1.
The terrain formation parameters namely *people-count-at the beginning* is set to 2000 and *hill-count-at-the-beginning* is set to 400.
The human parameters namely *sight* is set to 75 and *max-anguish-value* is set to 25.

4.1.3.2 Experiment description

Apart from experiment 1, increasing the flood height drastically along with lower ability to find higher grounds is also performed, ie sight value is reduced. The people count is increased along with that the hill count and anguish value is kept the same.

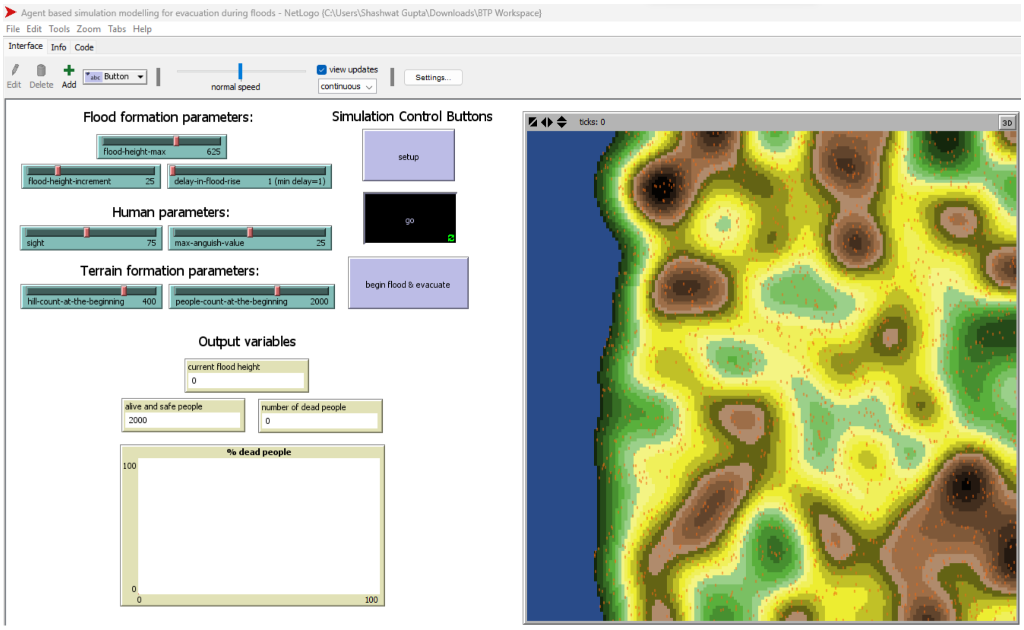

Figure 4.5: Initial setup for experiment 3

4.1.3.3 Results and discussion

The number of deaths recorded were 1193 out of 2000 humans giving a death rate of 59.65%. It can also be seen that most of the land got submerged in the water.

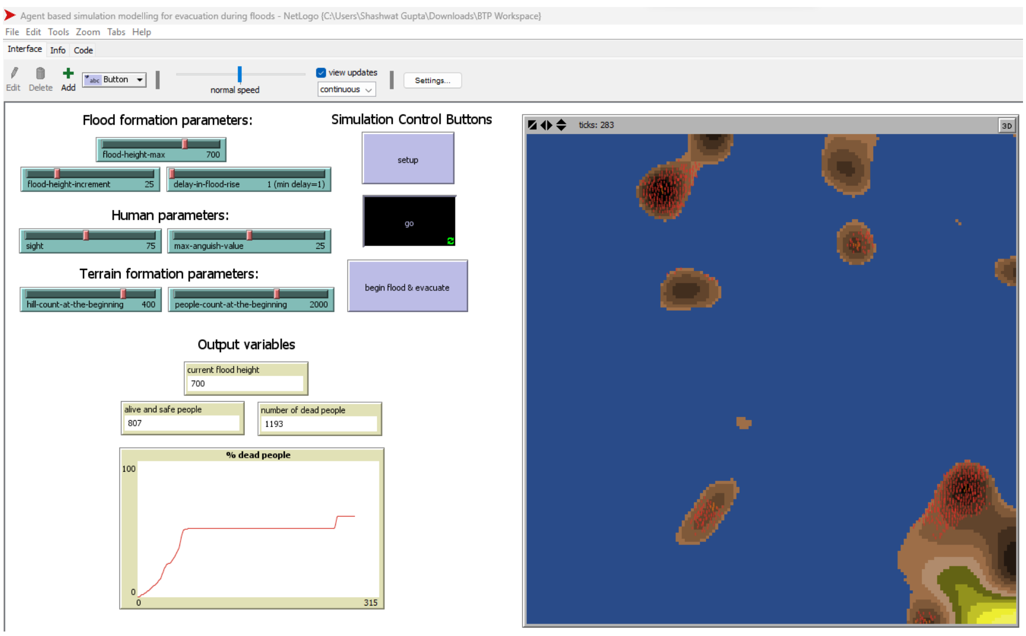

Figure 4.6: Final result for experiment 3

4.1.4 Results Table

Experim-ent Number	Flood Height Max	Flood Height Increment	Delay in flood rise	Sight	Max Anguish Value
Exp. 1	350	65	1	50	20
Exp. 2	475	25	1	80	25
Exp. 3	625	25	1	75	25
Exp. 4	400	28	2	65	15
Exp. 5	440	30	2	70	13
Exp. 6	480	27	2	70	32
Exp. 7	430	40	3	30	32
Exp. 8	550	50	3	45	15
Exp. 9	650	50	4	100	45
Exp. 10	680	55	4	120	40

Figure 4.7: Five input values of the attributes used in the 10 experiments

Inference and Significance: The five input independent parameters are fine tuned in these experiments. The value of flood height max is modified between 350 to 680. The value of flood height increment is modified between 25 and 65. The value of delay in flood rise is fine tuned by increasing delay from 1 to 4. The sight of the humans is modified from 30 to 120. The number of unsuccessful attempts given to a human ranges from 13 to 45.

Experim-ent Number	Hill count at the beginning	People count at the beginning	Number of Deaths	% Dead People
Exp. 1	350	700	53	7.5
Exp. 2	400	1400	446	31.8
Exp. 3	400	2000	1193	59.65
Exp. 4	430	850	5	1.25
Exp. 5	370	1100	287	26.09
Exp. 6	375	1150	375	32.6
Exp. 7	200	1300	24	1.84
Exp. 8	150	1350	1097	81.2
Exp. 9	500	2500	2316	92.72
Exp. 10	480	2800	2339	83.53

Figure 4.8: Two input values of the attributes and output values of the 10 experiments

Inference and Significance: The remaining two input independent parameters are fine tuned in these experiments to produce output on the dependent variable number of deaths. The value of hill count at the beinning is modified between 150 to 500. The value of people count at the beginning ranges from 700 and 2800. The output variable ie the number of deaths ranges from 5 to 2339. The average number of deaths in the 10 experiments are 814.

CHAPTER 5

CONCLUSION

The quantity of individuals created in each simulation is crucial, and that the location of hills and the extent to which they are distributed in the generated landscape are also crucial factors in predicting the output of our simulation. Those who are at the seashore at the moment of the storm and do not get to higher ground quickly enough will likely perish. Hence, this model can predict and simulate the flow of the flood and calculate the number of deaths that may happen beforehand so that this data can tell about the severity of the flood and extent of the necessary actions required.

5.1 Advantages

The landscape in this virtual simulation exercise is created at random. But the model may be used on any real terrain by simply adding genuine data, such as a topography with elevations and, the actual population of the region.

5.2 Limitations

Since, the patches are generated randomly in every setup the output also depends on the location of higher altitudes whether they are generated at the borders or at the center or near the coaster region.

5.3 Future Scope For Improvements

1. Machine learning models can be used together with agent based modelling, the former will predict the quantity while the later will predict and simulate the effect.

2. Geographical Information Science (GIS) and Agent-Based Modeling (ABM) can be used together for spacial modelling for a particular map area.

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