ABSTRACT

In recent years, a pressing agricultural dilemma has been emerging, with a significant shift observed in farming practices due to persistent animal interference. A startling 90% of farmers in area like Dholka, Daskroi and Hansot (Gujarat) have transitioned from cultivating essential food crops to the production of flowers, driven by the relentless impact of animals on their harvests. This alarming trend is not isolated, as regions like Arunachal Pradesh face analogous challenges, where rampant rat infestations result in widespread crop destruction along with areas in Uttarakhand where potato represents 43.6% of total crop yield loss due to wildlife. Monkey and wild boar alone accounted for about 50% to 60% of total crop damage in the study villages. Adding to the complexity of this issue is the exponential growth in the human population, which acts as a catalyst for the escalation of human-animal conflict. As human settlements expand and infringe upon natural habitats, encounters between people and wildlife become more frequent, intensifying the challenges associated with coexistence.

Studying the behavioural patterns of wild boars' aids in monitoring affected areas. By employing epidemiological models, valuable insights are gained, vigilant monitoring of animal numbers, feed capacity, and visit frequencies. enabling significant contributions to the understanding and management of issues related to these animals.

Food security hinges on the interconnected pillars of accessibility, utilization, stability, and availability. This study advocates leveraging Geographic Information Systems (GIS) for monitoring and mitigation strategies. GIS enables precise tracking of agricultural dynamics, aiding in the identification of areas susceptible to animal interference. Additionally, proposal of a mathematical model to gauge the extent of contributing factors and determine necessary technical interventions. By integrating GIS and a robust mathematical framework, this approach aims to fortify food and health security, providing a holistic solution to the challenges posed by animal interference in agriculture.

Keywords: Food security, Human-Animal Conflict, GIS, Health security

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

ABM: Agent Based Model

AMR-CAMP: Antimicrobial-resistant Campylobacter

ASFV: African Swine Fever Virus

BCN: Barcelona

CSF: Classical Swine Fever

GIS: Geographic Information System

HAC: Human Animal Conflict

WB: Wild Boar

CONTENTS

Chapter 1

INTRODUCTION

Outline of chapter

1.1 Motivation
1.2 Scope
1.3 Objectives

1.1 Motivation

Monitoring areas prone to human-animal conflict (HAC) is crucial for both food and health security, and spatial data emerges as the most effective tool for this purpose. Spatial data, which includes geographic information system (GIS) technologies, satellite imagery, and remote sensing, offers a comprehensive and dynamic perspective of the landscape. In the context of HAC, where the interaction between humans and wildlife often leads to agricultural losses, property damage, and even threats to human lives, spatial data allows for a nuanced understanding of the spatial patterns and temporal dynamics of such conflicts.

One key advantage of using spatial data in HAC monitoring is its ability to precisely map the distribution and movement patterns of wildlife populations. By integrating satellite imagery and GIS, it is easier to identify critical habitats, migratory routes, and hotspots of wildlife activity. This information is invaluable for implementing targeted interventions such as the installation of wildlife corridors or the establishment of buffer zones to mitigate conflicts. It enables authorities to design and implement effective land-use planning strategies that balance the needs of both human communities and wildlife, thereby minimizing the potential for conflicts. Furthermore, spatial data aids in assessing the impact of human activities on local ecosystems, contributing to a holistic understanding of the factors that escalate human-animal conflicts. For instance, land-use changes, deforestation, or encroachments into natural habitats can disrupt the ecological balance, forcing wildlife to seek food and shelter in human-populated areas. Through spatial analysis, researchers can identify the root causes of these conflicts and formulate sustainable strategies to address them, thereby promoting the coexistence of humans and wildlife.

In the context of food security, spatial data plays a pivotal role in assessing the extent of agricultural damage caused by wildlife. GIS technologies enable precise mapping of crop fields, and remote sensing allows for the detection of changes in vegetation cover. By overlaying this information with data on wildlife movements, authorities can predict and prevent potential conflicts, safeguarding crops and ensuring food security for local communities. Additionally, understanding the spatial distribution of diseases carried by wildlife is crucial for health security. Spatial data facilitates the identification of areas at higher risk of zoonotic diseases, allowing for targeted public health interventions and surveillance measures.

The utilization of spatial data in monitoring areas susceptible to human-animal conflict is indispensable for fostering sustainable coexistence, ensuring food security, and maintaining health security. The comprehensive insights provided by spatial analysis empower policymakers and conservationists to implement evidence-based strategies that mitigate conflicts, protect agricultural resources, and safeguard the well-being of both human and animal populations in the concerned regions.

1.2 Scope

The scope of employing spatial data in monitoring Human-Animal Conflict (HAC) extends far beyond conventional methods. By integrating geographic information system (GIS) technologies and satellite imagery, researchers can not only track wildlife movements but also predict population density in vulnerable areas. This predictive modelling enables the proactive identification of regions susceptible to heightened conflict, allowing for targeted interventions. Such spatial insights facilitate strategic planning to minimize agricultural losses, ensure food security, and mitigate potential health risks associated with zoonotic diseases. The comprehensive scope of this study lies in its ability to offer a dynamic, data-driven approach, enhancing the effectiveness of measures aimed at fostering coexistence and safeguarding the well-being of both human and animal populations in the monitored areas.

Food insecurity elimination is a major focus of the Sustainable Development Goals and addresses one of the most pressing needs in developing countries. With the increasing incidence of food insecurity, poverty, and inequalities, there is a need for realignment of agriculture that aims to empower especially the rural poor smallholders by increasing productivity to improving food security conditions. Using a set of GIS-based indicators, and a small-area approach, we combine Principal Component Analysis and GIS spatial analysis to construct one composite index and four individual indices based on the four dimensions of food security (access, availability, stability, and utilization) to map the spatial dimension of food insecurity in Vihiga County, Kenya. Data were collected using a geocoded household survey questionnaire [2].

1.3 Objectives

The Research gaps and the Research Objectives of this study are as follows:

Research Gaps:

- Lack of practical models of population prediction for geographically smaller region.
- Study of behavioural pattern of animal but no mitigation technique to reduce the adverse effects caused by HAC (Human Animal Conflict).

Research Objectives:

- To develop a suitable mathematical model for predicting food and health security of a defined geography.
- To identify and analyze wild boar impact zones in Gujarat districts for effective mitigation.

Chapter 2

BASIC TERMINOLOGIES

Outline of Chapter

2.1 Food Security

2.2 Population prediction methods

2.3 HAC (Human Animal Conflict)

2.4 Health Security

2.1 Food Security

Food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO 2008).

For food security objectives to be realized, all four dimensions must be fulfilled simultaneously.

Table 1: Dimensions of Food Security

Physical AVAILABILITY of food	Food availability addresses the “supply side” of food security and is determined by the level of food production, stock levels and net trade.
Economic and physical ACCESS to food	An adequate supply of food at the national or international level does not in itself guarantee household level food security. Concerns about insufficient food access have resulted in a greater policy focus on incomes, expenditure, markets, and prices in achieving food security objectives.
Food UTILIZATION	Utilization is commonly understood as the way the body makes the most of various nutrients in the food. Sufficient energy and nutrient intake by individuals is the result of good care and feeding practices, food preparation, diversity of the diet and intra-household distribution of food. Combined with good biological utilization of food consumed, this determines the nutritional status of individuals.
STABILITY of the other three dimensions over time	Even if your food intake is adequate today, you are still considered to be food insecure if you have inadequate access to food on a periodic basis, risking a deterioration of your nutritional status. Adverse weather conditions, political instability, or economic factors (unemployment, rising food prices) may have an impact on your food security status.

The basic concept of food security globally is to ensure that all people, at all times, should get access to the basic food for their active and healthy life and is characterized by availability, access, utilization and stability of food. Though the Indian Constitution does not have any explicit provision regarding right to food, the fundamental right to life enshrined in Article 21 of the Constitution may be interpreted to include right to live with human dignity, which may include the right to food and other basic necessities (National Food Security Act, (NFSA) 2013).

2.2 Population Prediction Methods

Models allow a better understanding of how complex interactions and processes work. Modelling of dynamic interactions in nature can provide a manageable way of understanding how numbers change over time or in relation to each other. Many patterns can be noticed by using population modelling as a tool. Ecological population modelling is concerned with the changes in parameters such as population size and age distribution within a population. This might be due to interactions with the environment, individuals of their own species, or other species. Population models are used to determine maximum harvest for agriculturists, to understand the dynamics of biological invasions, and for environmental conservation. Population models are also used to understand the spread of parasites, viruses, and disease. Another way populations models are useful are when species become endangered. Population models can track the fragile species and work and curb the decline.

2.2.1) Linear trend model

In this model, the average increase in future population forecasting per decade is calculated from the past census reports. This increase is added to the present population to find out of the population next decade. Thus, it is assumed that the population is increasing at constant rate. Hence

The rate of change of population with respect to time is constant

$$\frac{dP}{dt} = C \tag{1}$$

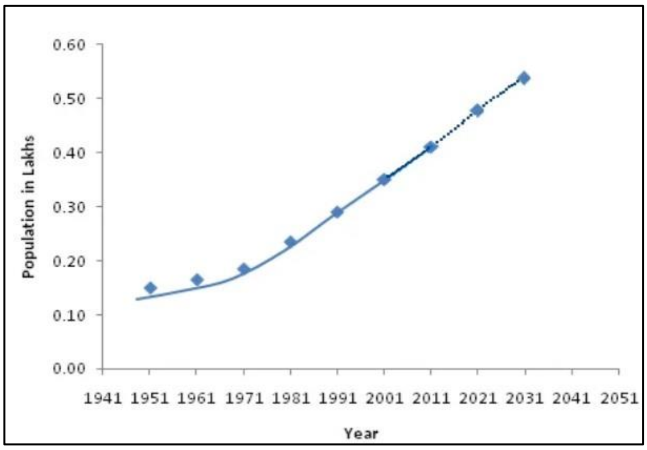
Therefore, Population after nth decade will be

$$Pn = P + nC \tag{2}$$

Where, P n is the population after ‘n’ decades and ‘P’ present population. [15]

Graphical representation of a linear model for population prediction involves plotting a straight line those best fits observed data points. The x-axis typically represents time, while the y-axis denotes the predicted population. It simplifies understanding the model's trend and facilitates insights into population growth or decline over time.

Fig 1: Graphical Representation of Linear Population Model



2.2.2) Geometric Increase model

The percentage increase in population from decade to decade is assumed to remain constant. Geometric mean increase is used to find out the future increment in population. Since this process gives higher values and hence should be applied for a new industrial town at the beginning of development for only few decades [15]. The population at the end of ‘nth’ decade P_n can be estimated as

$$Pn = P(1 + \frac{IG}{100})^n \tag{3}$$

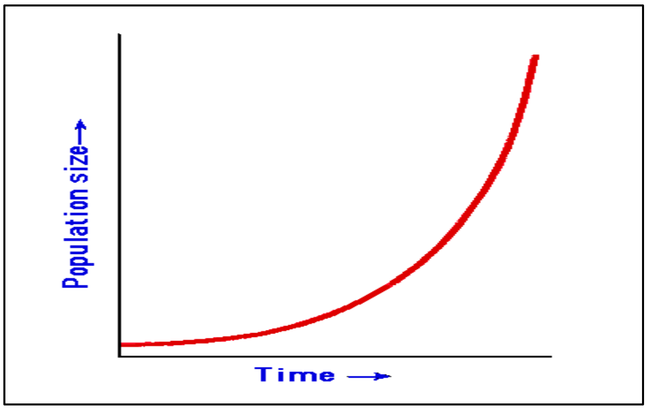
Where, I_G = Geometric mean (%)

P = Present population, and

n = Number of decades.

The graphical representation of a geometric increase model for population prediction displays a distinct exponential growth curve. As time progresses, the population sharply rises, showcasing a compounding effect. It illustrates the model's prediction of accelerating population growth, emphasizing the significant impact of each successive generation on the overall increase.

Fig 2: Graphical Representation of Geometric Increase Model



2.2.3) Logarithmic model

This model is used when the growth rate of population due to births, deaths and migrations takes place under normal situation and it is not subjected to any extraordinary changes like epidemic, war, earth quake or any natural disaster, etc., and the population follows the growth curve characteristics of living things within limited space and economic opportunity.

This is the required equation of the Logistic curve, which will be used for predicting population. If only three pairs of the characteristic values P_0, P_1, P_2, at times t =t_0 = t_1 and t_2 = $2t_1$ extending over the past record are chosen, the saturation population P_s and constant m and n can be estimated by the equation, as follows

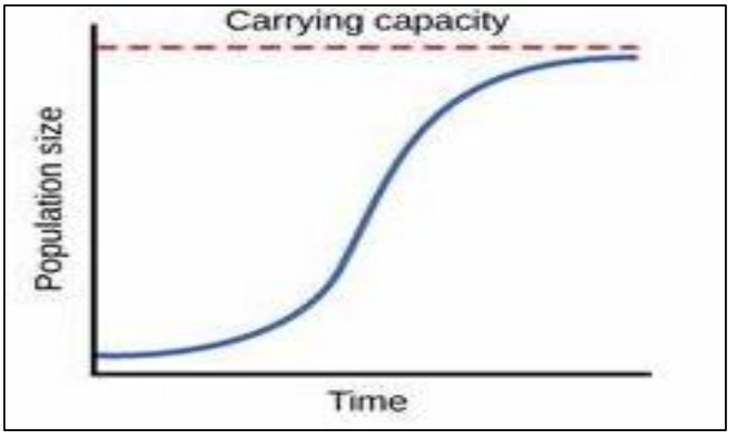
$$Ps = \frac{\{2P0P1P2 - P1^2\,(P0+P2)\}}{P0P2 - P1^2} \tag{4}$$

$$m = \frac{Ps - P0}{P0} \tag{5}$$

$$n = \frac{2.3}{t1} \log \frac{P0(Ps - P1)}{P1(Ps - P0)} \tag{6}$$

Forecasting of population can be accomplished with short term different mathematical models by using present and past population records that can be obtained the future population. Graphical projection of the past population growth curve continuing whatever trends the historical data indicate the future population can be predicted by plotting the population of other methods.

Fig 3: Graphical Representation of Logarithmic Model



If the past observations cover a long period, they may well be indicative of a trend; if they extend over a short period only, such as the most recent decade, they may be considerably influenced by temporary fluctuations; a very long past period, however, is not necessarily indicative of a future trend, because much time has elapsed since the beginning of the past period and relevant conditions may meanwhile have changed significantly [5].

2.3 Human Animal Conflict

The species wild boar (Sus scrofa), once threatened, is one of the latest domesticated species. Wild boar is so successful that currently it causes strong economic and ecological damages all over the world. The interest in Sus scrofa continues to grow rapidly, not only within its native range, but also in all other continents where wild boar and feral pigs have been introduced [6].

Human-animal conflict, exacerbated by the intrusion of wild boars into human habitats, poses a significant threat to agriculture and various spheres of human life. Wild boars, seeking food and habitat, often encroach upon farmlands, causing extensive damage to crops. Their foraging behavior disrupts agricultural ecosystems, leading to economic losses for farmers and threatening food security. Additionally, the increased proximity of wild boars to human settlements raises the risk of diseases transmitted between wildlife and humans. Beyond agriculture, these conflicts extend to safety concerns, as encounters between humans and wild boars can result in injuries or fatalities. The destruction of property, including gardens and landscapes, further intensifies the tensions. Addressing the human-animal conflict involving wild boars requires a comprehensive approach, combining habitat management, agricultural practices, and community awareness.

2.4 Health Security

Zoonotic diseases account for 60.3% of human diseases and 71.8% of emerging infectious diseases originate from wildlife [8]. Eurasian wild boar (WB, Sus scrofa) has a major epidemiological role as host and reservoir for zoonotic and non-zoonotic pathogens shared with livestock, companion animals and humans, participating in the maintenance of multi-host pathogens. The risk of spillover to humans depends on infection prevalence in host population, contact rate between humans and other infected animal hosts, and infection probability upon contact [16]. Accurate health risk assessments allowing effective mitigation strategies rely on better understanding of wildlife-pathogen dynamics at the human-wildlife-livestock interface. Since such understanding cannot be achieved through in vitro and field studies alone, theoretical epidemiology and simulated models allow testing hypotheses concerning environment, social structure, behaviour, and other factors. Spatial models consider adaptive surveillance strategies for disease emergence, including the effects of anthropogenic resources on local dynamics and movement connectivity in order to understand the persistence and spatial spread of pathogens [8].

Chapter 3

Literature Review

Outline of chapter

3.1 Population Models
3.2 Health security (Epidemiological Model)

3.1 Population Models

Governments use population forecasts at all levels (national, regional, city, international) for planning purposes, broadly defined. The basic purpose of government is to provide services for citizens, and this requires knowing how many people there will in the future, often broken down by age, sex and other characteristics, such as race and geography. Population forecasts are also widely used in the private sector for strategic planning, and by academics and other researchers, particularly in the health and social sciences. The forecasts are used as inputs to global modelling, such as for food security and climate change. Many countries also use them for their national planning [9].

The three components of population change are births, deaths, and migration [10]. The main approaches to producing probabilistic population forecasts include ex-post analysis, time series methods and expert-based approaches [11]. Ex-post analysis is based on the errors in past forecasts [12]. The time-series analysis approach uses past time series of forecast inputs, such as fertility and mortality, to estimate a statistical time series model, which is then used to simulate many random possible future trajectories. Simulated trajectories of forecast inputs are combined via the CCMPP to produce predictive distributions of forecast outputs. In the expert-based method, experts are asked to provide distributions for each forecast input. These are then used to construct predictive distributions of forecast outputs using a stochastic method like the time series method [13].

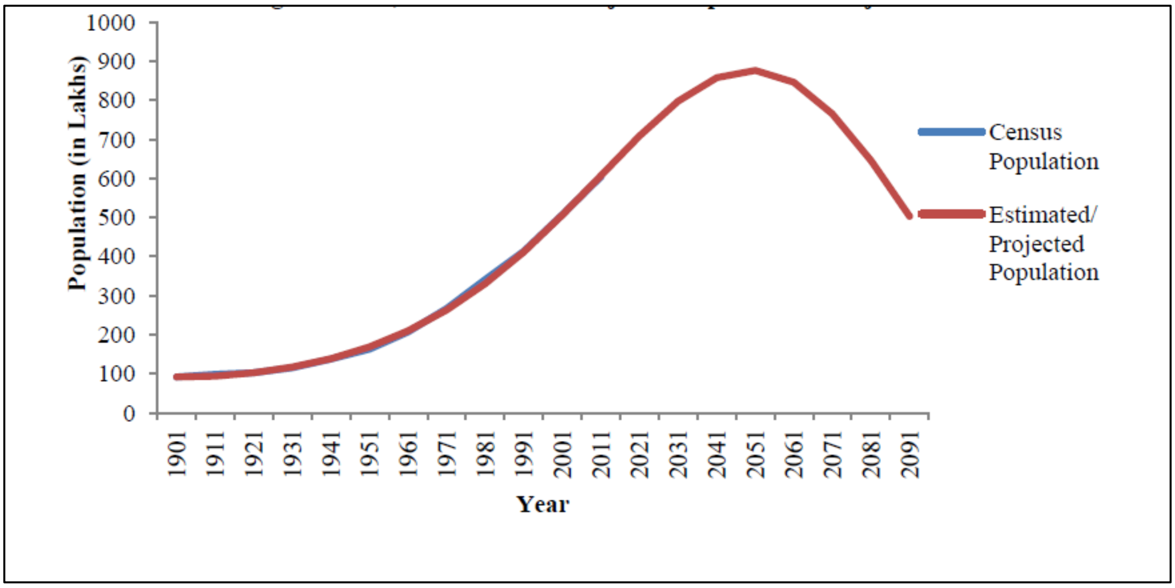
The results show a likely stabilization of the world population in the 22nd century, with a slight decline in the 23rd century [9].

A population growth model is proposed, using this proposed model, fitted curves with striking accuracies in the decadal census populations of India and 15 Indian states have been obtained, and hence populations of the country and the states have been estimated from 1901 to 2011 and projected from 2021 to 2091. [18] assumed that a growth model must contain an increasing population of a geographical region must have an upper ceiling called carrying capacity the carrying capacity is the maximum population that can be sustained by the environmental resources of the region. All these growth models are found to be not doing well in estimating population of developing countries like India since available population data of developing countries like India are scanty, e.g., sparse decadal census data of population is available for India.[17] explain that in such cases of sparse census data the relative growth rate (RGR) behaves differently unlike the common decreasing trend of logistic curves. [14].

Gujarat, Jharkhand, Karnataka, and Madhya Pradesh states are predicted to rise their populations up to 877.17, 494.84, 832.54 and 1210.26 lakhs in the years 2050, 2054, 2051 and 2056 respectively and then decline [14].

The estimates of the population against available census populations are very close which are shown in the data provided in the following graph.

Fig 4: Census, Estimated and Projected Population of Gujarat



3.2 Health Security (Epidemiological Model)

The study of boar behavioural patterns is deemed crucial for addressing prolonged human-animal conflicts and finding effective solutions. By understanding the behavior of boars, conflict resolution strategies can be developed to mitigate the problem.

Behaviour is defined as control and exercise of movements or signals with which an animal interacts with conspecifics or other components of its animate and inanimate environment, as well as activities which serves for the homoeostasis of an individual [19]. There is a lack of recent field studies under natural conditions because wild boar is widely seen as a pest because of their constant conflict terms with humans, such as crop damage, disease transmission [6]. Direct observations (compared to radio telemetry) are required to record the behaviour of animals and consequently also get information on activity and habitat choices. One cost-efficient method for the observation of free roaming wild boar is the use of camera traps. The advantage of camera traps is that they are non-invasive, and consequently, ideal to study nocturnal and crepuscular animals which avoid humans [20].

The high reproductive rate, great adaptiveness to different environments and widespread lack of predators of wild boar have favoured increases in its populations. Encounters between humans and wild boars are rare because of the predominantly nocturnal lifestyle of the latter, and wild boar management by hunting is a challenging task. Animal activity patterns are important for understanding the behaviour of a species. GPS telemetry and acceleration measurements to shed light on this part of wild boar behaviour, observing 34 animals in Central Europe. The wild boars were predominantly nocturnal, with peak activity at approximately midnight. Significant behavioural categories are olfactory (22.02%), vigilance (13.33%) and foraging behaviour (8.81%) [21].

Transmission can occur from animals or animal products to humans, particularly through faeces. The BCNWB-EPI model predicted exposure to HEV of 452 citizen agents (0.79% of the modelled population) in the study area of Barcelona after 365 simulated days, 67 of them considered citizens at risk. The model's predictions matched World Health Organization (WHO)'s estimations of 0.8% of the human population exposed to HEV annually, equivalent to 480 humans in the modelled population. As for AMR-CAMP scenario, the model predicted 461 citizens (0.80% of the modelled population) exposed after 365 days, with 55 of them considered to be at risk. These findings fall within the estimated 0.44% to 0.93% annual human exposure range to AMR-CAMP (i.e., 264 to 558 individuals for the modelled population [8].

The observed behavior of wild boar is found to be a significant contributor to Human Animal Conflict (HAC). They function as vectors for the spread of diseases, either through direct contact or from carcasses. In order to guarantee minimal HAC and mitigate the dissemination of diseases, it is deemed essential to apply epidemiological modelling to wild boar populations. This modelling approach enables a comprehensive understanding of the dynamics involved, aiding in the formulation of effective control measures to curtail the impact of wild boar activities on HAC and disease propagation.

Chapter 4

Methodology

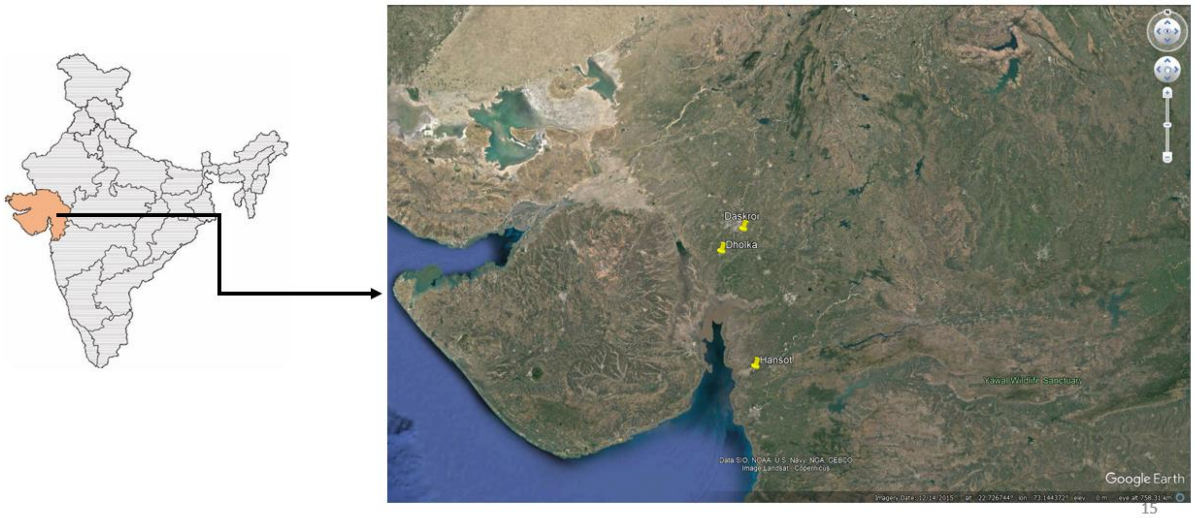
Outline of chapter

4.1 Area of Consideration
4.2 In-Situ Data
4.3 Processed Data

4.1 Area of Consideration

The focal point of this study is the vibrant state of Gujarat, specifically zooming in on two pivotal districts, Ahmedabad and Bharuch. Delving deeper, the research narrows its focus to specific blocks within these districts: Dholka and Daskroi in Ahmedabad, and Hansot in Bharuch.

Fig 5: Area of Consideration

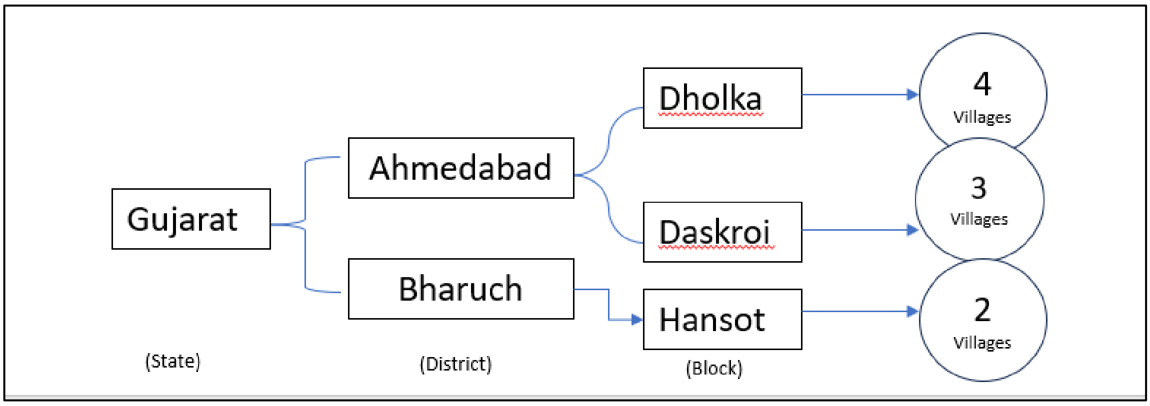


Dholka Taluka of Ahmadabad district has a total population of 249,852 as per the Census 2011. Out of which 130,113 are males while 119,739 are females. In 2011 there were a total 50,721 families residing in Dholka Taluka. The Average Sex Ratio of Dholka Taluka is 920. As per Census 2011 out of total population, 32.4% people live in Urban areas while 67.6% live in the Rural areas. The average literacy rate in urban areas is 82.1% while that in rural areas is 75.5%. The Sex Ratio of Urban areas in Dholka Taluka is 932 while that of Rural areas is 915. The population of Children of age 0-6 years in Dholka Taluka is 32034 which is 13% of the total population. There are 17130 male children and 14904 female children between the age 0-6 years. Thus as per the Census 2011 the Child Sex Ratio of Dholka Taluka is 870 which is less than Average Sex Ratio (920) of Dholka Taluka. The total literacy rate of Dholka Taluka is 77.64%. The male literacy rate is 75.26% and the female literacy rate is 59.45% in Dholka Taluka.

Daskroi Taluka of Ahmadabad district has a total population of 321,817 as per the Census 2011. Out of which 166,727 are males while 155,090 are females. In 2011 there were a total 67,131 families residing in Daskroi Taluka. The Average Sex Ratio of Daskroi Taluka is 930. As per Census 2011 out of total population, 42% people live in Urban areas while 58% live in the Rural areas. The average literacy rate in urban areas is 87% while that in rural areas is 77.8%. The Sex Ratio of Urban areas in Daskroi Taluka is 908 while that of Rural areas is 946. The population of Children of age 0-6 years in Daskroi Taluka is 42904 which is 13% of the total population. There are 23004 male children and 19900 female children between the age 0-6 years. Thus as per the Census 2011 the Child Sex Ratio of Daskroi Taluka is 865 which is less than Average Sex Ratio (930) of Daskroi Taluka. The total literacy rate of Daskroi Taluka is 81.7%. The male literacy rate is 77.28% and the female literacy rate is 63.85% in Daskroi Taluka.

Hansot Taluka of Bharuch district has a total population of 61,268 as per the Census 2011. Out of which 31,713 are males while 29,555 are females. In 2011 there were a total 13,701 families residing in Hansot Taluka. The Average Sex Ratio of Hansot Taluka is 932. As per Census 2011 out of total population, 8.9% people live in Urban areas while 91.1% live in the Rural areas. The average literacy rate in urban areas is 84.8% while that in rural areas is 80%. Also the Sex Ratio of Urban areas in Hansot Taluka is 780 while that of Rural areas is 948. The population of Children of age 0-6 years in Hansot Taluka is 6349 which is 10% of the total population. There are 3332 male children and 3017 female children between the age 0-6 years. Thus as per the Census 2011 the Child Sex Ratio of Hansot Taluka is 905 which is less than Average Sex Ratio (932) of Hansot Taluka. The total literacy rate of Hansot Taluka is 80.45%. The male literacy rate is 77.2% and the female literacy rate is 66.65% in Hansot Taluka.

Fig: 6 Villages under consideration



4.2 In-Situ Data

During the visit to Ankleshwar, a village in Hansot, we engaged in data collection through meetings with the Gram Panchayat and villagers across three distinct locations. The primary agricultural focus in this region centres on sugar cane cultivation. However, a significant challenge faced by the local farmers is the frequent intrusion of wild boars, causing extensive damage to their crops. This destructive interference has resulted in a marked reduction in farming productivity, leading to a substantial decrease in profit margins. The data collected indicates a pressing need for strategies to address the issue of wild boar infestations, such as implementing effective pest control measures or exploring crop diversification to mitigate risks. Such data is crucial for local authorities and organizations to develop targeted interventions and support the livelihoods of the villagers in Ankleshwar.

The primary challenge faced during on-site data collection was the occurrence of waterlogging and the intrusion of wild boars into agricultural fields, leading to significant crop losses for local farmers.

Fig 6: In-Situ Data Collection

4.3 Processed Data

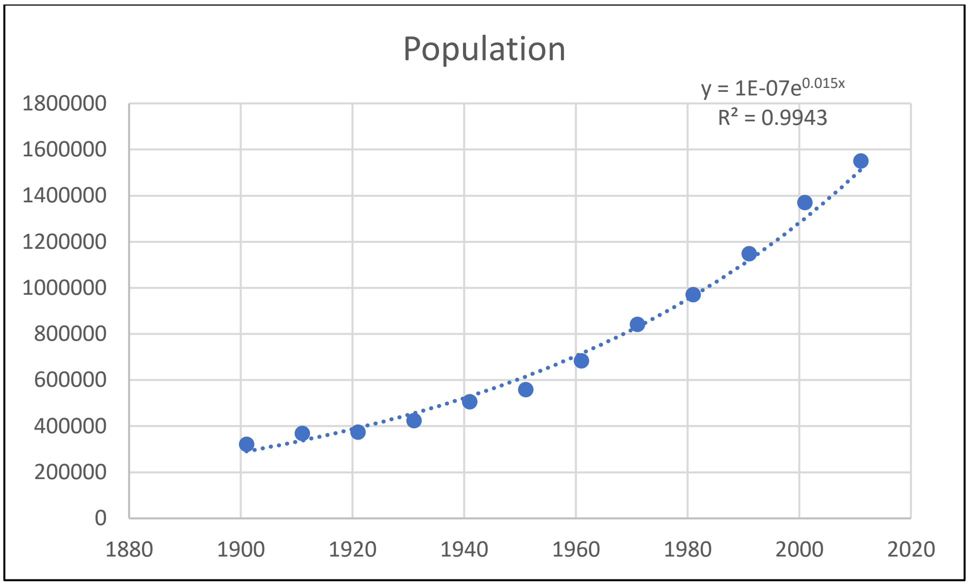
4.3.1 Population Data

The decadal population data collected for Bharuch district, spanning from 1901 to 2011, is encapsulated in the table, providing absolute population values for each decade. In contrast, the accompanying graph visually illustrates the observed trends over the same period, portraying the dynamic plot of population fluctuations. The table serves as a quantitative reference, offering precise numerical insights, while the graph imparts a visual narrative, enabling a more intuitive understanding of the population dynamics in Bharuch district across the decades. Together, these representations provide a comprehensive overview of the demographic changes and trends in the region over the specified time frame.

Table 2: Decadal Population Data of Bharuch

State Code	District Code	State/District	Census Year	Persons	Variation since the preceding census		Males	Females
					Absolute	Percentage		
24	488	Bharuch	1901	321528	-----	-----	164057	157471
			1911	368466	46938	14.59842	189919	178547
			1921	374101	5635	1.529313	192539	181562
			1931	423980	49879	13.33303	220689	203291
			1941	506264	82284	19.40752	262000	244264
			1951	558930	52666	10.40287	287218	271712
			1961	684166	125236	22.40638	351810	332356
			1971	841048	156882	22.9304	432542	408506
			1981	970172	129124	15.35275	500547	469625
			1991	1148252	178080	18.35551	596610	551642
			2001	1370656	222404	19.36892	713676	656980
			2011	1551019	180363	13.15888	805707	745312

Fig 7: Graphical Representation of Decadal Population of Bharuch



4.3.2 Health Security Relation

A generalized mathematical model for biological growth is introduced in which includes the known functions such as Generalized Logistic, Case of Logistic, Richards, Von Bertalanffy, Brody, Logistic, Gompertz, Generalized Weibull, Weibull, Monomolecular, Mitscherlich and many more new models.

The classical model of a predator-prey problem was originally developed in the 1920s by Vito Volterra, and since then many related studies have been conducted. The Lotka-Volterra predator-prey equations are first-order and nonlinear differential equations defined

$$\frac{dV}{dt} = aV - bVP \tag{7}$$

$$\frac{dP}{dt} = -cP + dVP \tag{8}$$

In the classical model, *a, b, c, d* are all positive constants.

The modified predator-prey model is defined as follows:

$$\frac{dx}{dt} = r(t)x \tag{9}$$

$$\frac{dy}{dt} = -vx + sxy \tag{10}$$

where x is population size or density of prey; y is population size or density of predator communities in the system; r to be a relative growth rate function which is positive valued function of time t. The other parameters *s, u, v* is positive constants [22].

A proposed model, with due consideration to factors such as the number of animals, feed capacity, and the frequency of wild boar visits, aims to calculate the consumption of food by animals. This model is intended to be like existing frameworks but adapted to the specific needs of the geographic area under scrutiny. The primary objective is to assess and quantify the potential damage that could be inflicted, considering the ecological balance and agricultural sustainability.

$$C = N^a f^b \gamma^c$$

Where, C is the consumption by wild boars, N is the number of animals, f is feeding capacity of animal, ɣ is frequency of visit and *a, b, c*, are constants.

The proposed model, leveraging animal numbers, feeding capacity, and visit frequency, promises to revolutionize consumption calculations. Its application not only distinguishes human-animal conflict zones but also enhances health security.

Chapter 5

Conclusion

In conclusion, the imperative for an integrated approach in addressing the challenges posed by human population increase and ensuring food security has been highlighted. The necessity of monitoring availability, intricately linked to factors such as growth rate, import rate, consumption, and export rate, has been underscored throughout the report. It is emphasized that a comprehensive strategy, encompassing these key elements, is essential to navigate the complexities of sustaining food resources amidst a growing population. The importance of a nuanced understanding of the interplay between these factors is crucial for effective policy formulation and implementation in fostering long-term food security.

The forthcoming population prediction will be formulated based on the selected blocks, constituting the primary model. The predominant choice leans towards the logarithmic model, aligning with initial studies that recommend its efficacy. As a secondary model, the focus shifts to food security, incorporating elements of availability and stability. This model acknowledges the nuanced factors influencing food supply and stability within the system. Finally, the tertiary model emerges, addressing consumption by animals and potential crop damage. The proposed approach involves leveraging GIS data to comprehensively assess and integrate factors related to Human-Animal Conflict (HAC). By layering these models, a comprehensive understanding of population dynamics, food security challenges, and potential conflicts is anticipated, offering a robust framework for informed decision-making and policy formulation in managing the evolving landscape of population and agriculture.

MTP 1 was more focused on the literature review of the population prediction models, epidemiological models, behavioural pattern of wild boars and hands on practice on the software (QGIS and GEE) which will be used for analysis. MTP 2 will be more focused on the collecting the data and applying the algorithms and models best suited for the area under consideration. The outcome of the MTP 2 will be to monitor the extent of damage in AOC due to different factors involved using:

1) Tertiary Mathematical Model

2) Map Identifying HAC Zones

REFERENCES

1. Rao, Kottapalli & Maikhuri, Rakesh & Nautiyal, Sunil & Saxena, K. (2002). Crop damage and livestock depredation by wildlife: A case study from Nanda Devi Biosphere Reserve, India. Journal of environmental management. 66. 317-27. 10.1006/jema.2002.0587.

2. Mathenge, M., Sonneveld, B.G.J.S. & Broerse, J.E.W. Mapping the spatial dimension of food insecurity using GIS-based indicators: A case of Western Kenya. *Food Sec.* **15**, 243–260 (2023). https://doi.org/10.1007/s12571-022-01308-6

3. FAO 2008 Published by the EC - FAO Food Security Programme

4. National Food Security Act, (NFSA) 2013 (https://nfsa.gov.in/portal/NFSA-Act)

5. (PDF) Chapter III TEMPO OF URBANIZATION AND IJRBAN CONCENTRATION | liberty mandishona - Academia.edu

6. Keuling, Oliver & Náhlik, András & Fonseca, Carlos. (2014). Wild Boar Research – A Never Ending Story?. Wildlife Biology in Practice. 10. i-ii. 10.2461/wbp.2014.un.0.

7. Zhou, Y., Varquez, A.C.G. & Kanda, M. High-resolution global urban growth projection based on multiple applications of the SLEUTH urban growth model. *Sci Data* **6**, 34 (2019). https://doi.org/10.1038/s41597-019-0048-z

8. González-Crespo Carlos, Martínez-López Beatriz (2023) Assessing the epidemiological risk at the human-wild boar interface through a one health approach using an agent-based model in Barcelona, Spain, One Health, Volume 17 https://doi.org/10.1016/j.onehlt.2023.100598.

9. Adrian E. Raftery, Hana Ševčíková, Probabilistic population forecasting: Short to very long-term, International Journal of Forecasting, Volume 39, Issue 1,2023,Pages 73-97,ISSN 0169-2070,https://doi.org/10.1016/j.ijforecast.2021.09.001.

10. Preston, Samuel. "Demography: Measuring and modeling population processes. (2000).

11. Bongaarts, Bulatao, and M. Guillot. "Beyond six billion: Forecasting the world's population." *JAMA-Journal of the American Medical Association-International Edition* 287.6 (2002): 779.

12. Alders, M., Keilman, N. & Cruijsen, H. Assumptions for long-term stochastic population forecasts in 18 European countries. *Eur J Population* **23**, 33–69 (2007). https://doi.org/10.1007/s10680-006-9104-4

13. Lutz, Wolfgang, Warren C. Sanderson, and Sergei Scherbov. "Probabilistic population projections based on expert opinion." (1996).

14. Ahamed, Md & Gupt, Bhuwaneshwar & Kumar, Vikash & Phukon, Manoshi. (2021). A NEW POPULATION GROWTH MODEL: POPULATION PROJECTION OF INDIA AND SOME INDIAN STATES. Journal of Critical Reviews. 8. 631-645.

15. Lal, Shankar. (2023). Mathematical modeling of Population forecasting in India. Journal of Interdisiplinary Cycle Research. Volume XII, Issue I, January/2020. 275-283.

16. James M. Hassell, Michael Begon, Melissa J. Ward, Eric M. Fèvre, Urbanization and Disease Emergence: Dynamics at the Wildlife–Livestock–Human Interface, Trends in Ecology & Evolution, Volume 32, Issue 1,2017, Pages 55-67, ISSN 0169-5347, https://doi.org/10.1016/j.tree.2016.09.012.

17. Arindam Gupta, Sabyasachi Bhattacharya & Asis Kumar Chattyopadhyay (2012) Exploring New Models for Population Prediction in Detecting Demographic Phase Change for Sparse Census Data, Communications in Statistics - Theory and Methods, 41:7, 1171-1193, DOI: 10.1080/03610926.2010.538794

18. Verhulst, P.F. (1838) Notice sur la loi que la population suit dans son accroissement. Correspondence Mathematique et Physique (Ghent), 10, 113-121.

19. Erdtmann D, Keuling O. 2020. Behavioural patterns of free roaming wild boar in a spatiotemporal context. *PeerJ* 8:e10409 https://doi.org/10.7717/peerj.10409

20. Rovero F, Zimmermann F, Berzi D, Meek P. "Which camera trap type and how many do I need?" A review of camera features and study designs for a range of wildlife research applications. Hystrix, the Italian Journal of Mammalogy. 2013;24(2):148-156. doi:10.4404/hystrix-24.2-8789.

21. Johann, F., Handschuh, M., Linderoth, P. *et al.* Adaptation of wild boar (*Sus scrofa*) activity in a human-dominated landscape. *BMC Ecol* **20**, 4 (2020). https://doi.org/10.1186/s12898-019-0271-7

22. Dawed, Mohammed & Purnachandra Rao, Koya & Taye, Ayele. (2014). Mathematical Modelling of Population Growth: The Case of Logistic and Von Bertalanffy Models. Open Journal of Modelling and Simulation. 02. 113-126. 10.4236/ojmsi.2014.24013.