Journal of Tourism Sciences (Toursci)
e-ISSN 3046-7713
p-ISSN 3032-7539

Mathematical Analysis of Overtourism and Carrying Capacity in Bali Tourism Using a Logistics Growth Model

Melia Sukma Asyifa [1] , Hanugerah Kristiono Liestiandre [2] , Muhammad Arfin Muhammad Salim [3]
[1] Bali Tourism Polytechnic. Indonesia. Email: meliasyyfa35@gmail.com
[2] Bali Tourism Polytechnic, Indonesia. Email: hanugrah@ppb.ac.id
[3] Makassar Tourism Polytechnic, Indonesia. Email: arfin70@yahoo.com
Corresponding Author. Email: meliasyyfa35@gmail.com

Abstract
Background. The growth of tourism in Bali has become a complex and multidimensional phenomenon, where the increase in tourist numbers has a significant economic impact but also triggers environmental, social, and cultural pressures. Overtourism occurs when the number of tourists exceeds a destination's carrying capacity, creating an imbalance in the system. Empirical studies show that the post-pandemic surge in tourism has a positive economic impact but also increases pressure on the environment and infrastructure.
Aims. This research develops a dynamic logistics growth-based mathematical model to explain the relationship between the number of tourists and the capacity to accommodate in Bali's tourism system. The model is formulated as a nonlinear differential system in which capacity is treated as a time variable.
Results. The results of the analysis show that carrying capacity is dynamic and degrades as tourist pressure accumulates.
Conclusion. This study introduces the concept of effective capacity and shows that overtourism is an endogenous phenomenon in the tourism system.

Keywords: math, overtourism, carrying capacity, tourism, Bali

INTRODUCTION

Bali tourism is one of the growing economic systems dynamically and complexly, where the interaction between economic, social, and environmental factors forms a non-linear system. The growing number of tourists indicates the expansion of the tourism system, which not only has an impact on increasing income, but also on changes in spatial structure and pressure on the environment

Bali Tourism has seen an significant increase in the Number of tourists in recent years. Based on data from the Central Statistics Agency, the number of foreign tourist visits to Bali has grown rapidly, especially after the post-COVID-19 pandemic recovery. In the pre-pandemic period, the number of tourist visits reached more than 6 million people per year, which then decreased drastically during the pandemic, and increased again significantly after 2022.

This increase in the number of tourists shows that there is increasing pressure on the carrying capacity of destinations, both in terms of the environment, infrastructure, and social. This condition reinforces the assumption that carrying capacity in the tourism system is not static but varies with the intensity of tourism activities.

Suyadnya (2021) shows that tourism development in Bali is driving significant spatial transformation through tourism gentrification, characterized by increased investment, land-use changes, and higher tourist density. This phenomenon shows that tourism growth is not only quantitative, but also has an impact on changes in the social, economic, and environmental structure of the destination. In this context, the phenomenon of overtourism emerged as one of the issues in modern tourism management. Overtourism not only reflects an increase in the number of tourists, but also the condition in which the destination system is no longer able to accommodate tourism activities without a decrease in quality. This shows that there are dynamic limits in the tourism system that cannot be treated as fixed values.

The main problem in tourism studies is the tendency to assume that carrying capacity is constant. In fact, the carrying capacity of a destination is influenced by tourism itself, so it changes over time. Therefore, a mathematical approach is needed that can capture these dynamics systematically.

The logistics growth model provides a basis for limited-growth analysis, but it needs to be developed to represent the interaction between the number of tourists and the carrying capacity in a dynamic system. The development of tourism in Bali has shown a significant transformation in recent decades. Tourism is not only a major economic sector, but also a powerful force. shaping the social and spatial structure of society. In this context, the increasing number of tourists has consequences for the carrying capacity of destinations.

The phenomena shown in this mathematical model are consistent with empirical data on Bali tourism. An increase in the number of tourists in recent years indicates a direct relationship between tourist growth and pressure on destinations' carrying capacity. Data from the Central

Statistics Agency shows that the post-pandemic surge in tourist visits was followed by increased density of tourist areas, congestion, and pressure on the environment and public facilities. In the context of the developed mathematical model, this condition can be interpreted as a variable increase that causes a gradual decrease. Thus, the model's results are not only theoretical, but also have strong empirical relevance to $T(t)K(t)$ real conditions in Bali.

Research on *overtourism* and *carrying capacity* in tourism has evolved from a descriptive approach to a dynamic systems and sustainability approach. The initial concept was developed by Richard W. Butler through the Tourism Area Cycle of Evolution theory, which posits that tourist destinations undergo stages of growth until they reach saturation. Furthermore, research by Stefan Gössling emphasizes that overtourism leads to environmental degradation, pollution, and pressure on the infrastructure of tourist destinations.

Empirical studies in Bali show that the growth of tourists has an impact on spatial change, tourism gentrification, and socio-ecological pressures. Research by I Nyoman Suyadnya highlights the transformation of space due to investment and tourist density, while another study confirms that the post-pandemic increase in tourists accelerates pressure on the environment and public facilities.

On the methodological side, most overtourism research still uses empirical approaches, descriptive statistics, or policy analysis. The mathematical model used generally still adopts the classic logistics growth model assuming that carrying *capacity* is static *(static carrying capacity*). In fact, the real condition of tourist destinations shows that the carrying capacity changes dynamically due to the activities of tourists themselves

This research expands on the state of the art by developing a dynamic logistics growth model based on a non-linear differential system, where *carrying capacity* is treated as a time variable influenced by the number of tourists. This approach allows for a more realistic analysis of the relationship between tourist growth and destination capacity degradation.

METHODS

This study uses a mathematical approach based on a non-linear differential system to analyze the dynamics of overtourism and carrying capacity in Bali tourism. The model was developed from the classical logistics growth equation by modifying the carrying capacity parameter into a time function influenced by tourist activity. This approach allows for the analysis of the reciprocal relationship between the number of tourists and the carrying capacity of the destination.

The analysis methods used include qualitative analysis of differential systems to understand the general behavior of the system, as well as stability analysis using Jacobian matrices to identify the equilibrium characteristics of the system. In addition, conceptual interpretation is carried out by relating the results of the mathematical model to the empirical conditions of Balinese tourism obtained from various literature reviews**.**

Logistic models and mathematical structures

The logistics growth model is a non-linear differential model used to describe population growth with maximum limits. In the context of tourism, the number of tourists can be seen as a growing population in a system with limited capacity.

The logistics model is expressed as:

$$T'(t) = rT\left(1-\frac{T}{K}\right)$$

This equation contains two main components, namely the exponential growth component and the limiting component. When the number of $rT\left(1-\frac{T}{K}\right)$ touristsStill small compared to capacity, the growth is exponential. However, when the number of tourists approaches capacity, growth slows down until it reaches a state of equilibrium.

The explicit solution of this model is:

$$T(t) = \frac{K}{1 + Ae^{-rt}}$$

Which indicates that the number of tourists will be close to the maximum capacity asymptologically. However, the main assumption in this model is that capacity is fixed. In a dynamic tourism system, this assumption is invalid because capacity is affected by tourism activities.K

Development of Mathematical Models

The classical logistics growth model provides a basis for understanding tourist growth as a system with finite limits. However, in the context of Bali tourism, the assumption that carrying capacity is constant cannot be maintained. This is because tourism activities directly affect environmental, social, and infrastructure conditions that determine a destination's carrying capacity.

To overcome these limitations, a logistics model was developed by making carrying capacity a dynamic variable that changes over time. Thus, the model used in this study is formulated as the following system of differential equations:

$$\frac{dT}{dt} = rT\left(1 - \frac{T}{K(t)}\right)$$

$$\frac{dK}{dt} = -\beta T$$

The first equation describes the rate of growth in the number of tourists, which depends on the system's actual capacity at any given time. In contrast to the classic model, in which capacity is considered constant, this model makes capacity time-dependent, providing greater flexibility in describing real conditions.K

The second equation shows that the carrying capacity has decreased as the number of tourists has increased. The parameters in this case represent the level of sensitivity of the capacity to tourist pressure. A high value indicates that the system is highly vulnerable $\beta\beta$ against overtourism, while low values indicate that the system is relatively more resistant to stress.β

This model creates a dynamic system with two interacting variables, resulting in a feedback structure not found in the classic logistics model.

Mathematical Analysis of Systems

The results of the analysis show that the tourism system has the characteristics of nonlinearity and dynamic interaction between the number of tourists and the carrying capacity. In the early stages, the number of tourists increased significantly because capacity was still high. However, this increase puts pressure on the environment and social systems, reducing capacity.

Suyadnya (2021) shows that an increase in tourism activities leads to land use changes, increased density, and pressure on people's living spaces. This is in line with the model's results, which show that capacity will decrease as the number of tourists increases. In the developed model, the system does not achieve static equilibrium as in the classic logistics model. Instead, the system exhibits dynamic behavior in which tourist growth is limited by capacity constraints.

This model results in the phenomenon of self-limiting, in which the growth of excessive ones actually causes a decline in the system. This shows that overtourism is an internal mechanism in the tourism system. In addition, this model introduces the concept of effective capacity, i.e., actual capacity that is lower than theoretical capacity. Effective capacity reflects the actual state of the system after accounting for tourist pressure.

Model Simulation

To understand the behavior of the system quantitatively, numerical simulations were performed using the parameters and initial conditions. The simulation results showed that the number of tourists increased in the early stages, reached a maximum, and then decreased as the carrying capacity decreased. Meanwhile, the value of carrying capacity has decreased continuously due to the accumulation of tourist pressure.$r = 0.3\beta = 0.02T(0) = 10K(0) = 100$

Non-Linear System Structure

The system formed by the two differential equations is a non-linear system because of the product of variables, namely *T* and *K(t)*. This illinearity is a major source of complexity in system behavior. In the classical logistics model, the system dynamics are relatively simple because they involve only one variable. However, in this model, the existence of two interdependent variables leads to much more complex dynamic properties.

Capacity Change Rate Analysis

Equations:

$$\frac{dK}{dt} = -\beta T$$

Indicates that the change in capacity is directly dependent on the number of Tourists. This has an important implication: any increase in the number of tourists will lead to a direct decrease in capacity. If a simple integration of this equation is performed, it obtains:

$$K(t) = K_0 - \beta \int_0^t T(s)\, ds$$

This equation shows that capacity at a given time depends on the total number of tourists accumulated over the period. In other words, the reduction in capacity is cumulative and does not depend solely on momentary conditions.

Variable Interaction Analysis

The interaction between *T(t)* and *K(t)* indicates a strong reciprocal relationship. As the number of tourists increases, capacity decreases, and that decrease in capacity in turn limits tourist growth. This relationship can be understood as a negative feedback system. In dynamic systems theory, negative feedback stabilizes the system, but under certain conditions it can also lead to overall decline.

Long-Term Behavior Analysis

To understand the system's long-term behavior, note that capacity continues to decline as long as the number of travelers remains positive. This means that in the long run, capacity can be close to zero if there is no recovery mechanism in place. When capacity decreases significantly, the rate of tourist growth becomes negative because:

$$1 - \frac{T}{K(t)} < 0$$

which causes:

$$\frac{dT}{dt} < 0$$

This indicates that tourist numbers will start to decline when capacity falls below a certain level.

System Stability Analysis

To understand the stability of the system, the Jacobian matrix approach is used:

$$J = \begin{bmatrix} r\left(1 - \frac{2T}{K}\right) & \frac{rT^2}{K^2} \\ -\beta & 0 \end{bmatrix}$$

The eigenvalue analysis of this matrix shows that the system does not have a simple stable equilibrium point. This is due to ongoing capacity changes. If a local approach is taken around a specific condition, the system can exhibit different behaviors depending on the values of the parameter and. Under certain conditions, the system may exhibit temporary stability, but $r\beta$In the long term, it continues to decline.

Model Simulation

To understand the system's behavior more concretely, numerical simulations were carried out on the developed models. The parameters used in this simulation are r=0.3, β=0.02, with initial conditions T(0)=10 and K(0)=100. The simulation was carried out to observe the dynamics of tourist numbers and changes in carrying capacity over time.

The simulation results show that the number of tourists increases in the early stages, peaks, and then decreases. This decrease was caused by a decrease in carrying capacity due to increasing tourist pressure. Meanwhile, the value of carrying capacity has decreased continuously, indicating a degradation of capacity due to the accumulation of tourism activities.

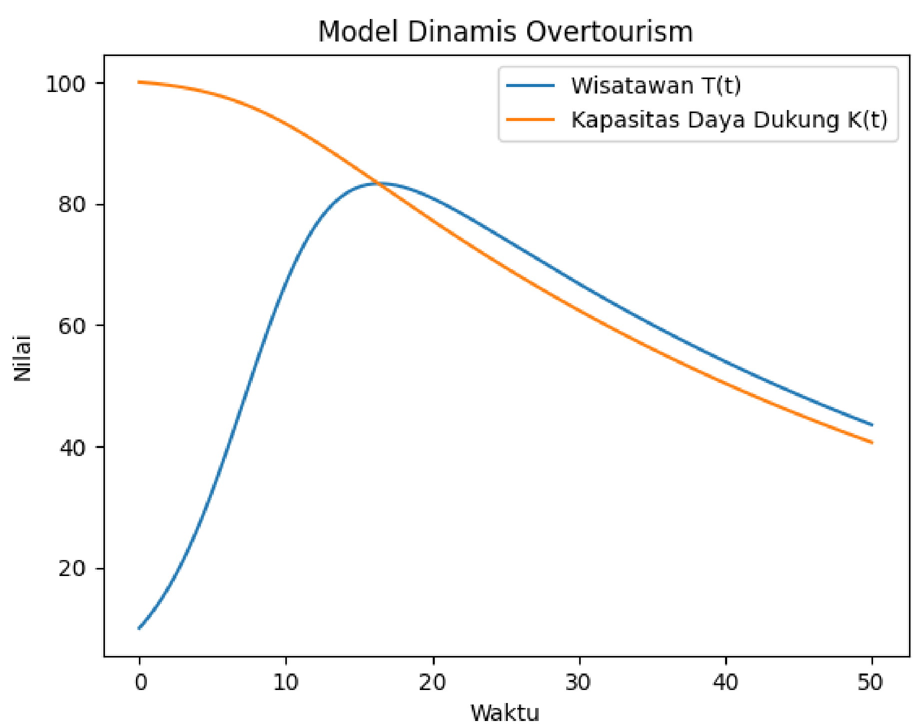

Figure 1. Dynamics of the number of tourists and carrying capacity over time based on a dynamic logistics model

As shown in Figure 1, the number of tourists increased in the early stages, then peaked and decreased, while carrying capacity showed a continuous downward trend due to tourist pressure.

DISCUSSION

The model developed shows that the tourism system cannot be understood as static. Instead, these systems exhibit dynamic characteristics and complex interactions among variables. In understanding the phenomenon of overtourism in Bali, the mathematical approach cannot stand alone without integrating with the empirical reality on the ground. This is because the tourism system is an open system that is influenced by various external and internal factors, including economic, social, environmental, and policy factors. Therefore, the logistics growth model developed in this study not only serves as a mathematical abstraction tool but also as a conceptual representation of the real dynamics of Bali's tourism system.

Mathematically, the classical logistics model used as a basis shows that the growth in the number of tourists follows an exponential pattern in the early stages, before eventually slowing down when it approaches the maximum capacity limit. However, in the Balinese context, the assumption that such capacity is permanent is unacceptable. This is because empirical studies show that the carrying capacity of destinations has changed due to tourism activities. For example, research on the impact of overtourism shows that an increase in the number of tourists leads to the accumulation of waste, air and water pollution, and the degradation of biodiversity, which directly degrades the environmental quality of destinations (Gössling et al., 2018). Furthermore, this phenomenon is also reinforced by research showing that overtourism not only has an impact on the environment, but also on the social and cultural structure of local communities (Milano, 2018). Disruptions such as congestion, social conflicts, and changes in cultural values are indications that the tourism system is under pressure that exceeds its capacity. From a mathematical perspective, this condition can be interpreted as a dynamic decrease in carrying capacity, which then affects the growth rate of tourists.

The model developed in this study explicitly incorporates these dynamics through differential equations:

$$\frac{dT}{dt} = rT\left(1 - \frac{T}{K(t)}\right)$$
$$\frac{dK}{dt} = -\beta T$$

The second equation has a very important conceptual meaning. The parameters represent the intensity of the traveler's pressure on the system's capacity. The greater the number of tourists, the faster the capacity decreases. This is in line with empirical findings showing that the post-pandemic increase in tourist visits puts significant pressure on the infrastructure, environment, and social life of the Balinese people.β

If analyzed further, the integration of the second equation results in the form:

$$K(t) = K_0 - \beta \int_0^t T(s)\, ds$$

This equation shows that carrying capacity is historical, with current conditions influenced by the accumulation of past tourism activity. In an empirical context, this can be seen in how environmental damage does not occur instantly but results from the long-term accumulation of tourism activities. For example, increased tourism infrastructure development, driven by investment and gentrification, has led to significant land-use changes in Bali, which ultimately accelerate the emergence of overtourism.

Furthermore, Bali's tourism system is also affected by external shocks, such as the global economic crisis or a pandemic. Research shows that the shock induces fluctuations in the traveler's demand cycle, thereby affecting the overall dynamics of the system. In mathematical models, this phenomenon can be interpreted as a disruption of variables that then leads to changes. This shows that the tourism system is not only dynamic but also unstable and sensitive to external changes.$T(t)K(t)$

Under certain conditions, when the number of tourists exceeds the effective capacity, that is, the rate of tourist growth becomes negative. This condition reflects the phenomenon of declining destination quality, which ultimately leads to a decrease in the number of tourists. In reality, this can happen when destinations experience overcapacity, prompting tourists to look for more comfortable alternatives. Thus, this model shows the existence of a self-limiting mechanism, in which the system naturally limits its own growth due to internal stress. In addition to environmental and social aspects, the economic dimension also plays an important role in the dynamics of overtourism. Bali, as a global tourist destination, relies heavily on the tourism sector, making it vulnerable to fluctuations in tourist numbers. Research shows that the tourism sector is the main source of regional income, but it is also highly vulnerable to external disturbances (UNWTO, 2019). In mathematical models, this can be interpreted as a system's dependence on variables, where a small change in the number of tourists can have a major impact on the system as a whole.$T(t) > K(t)T(t)$

In an effort to address overtourism, various policy approaches have been proposed, including the implementation of a tourist tax. This policy not only serves as a source of regional revenue but also as a mechanism to control the number of tourists. Research shows that implementing the tourist tax can create a feedback mechanism in the system, where higher visitor costs can reduce pressure on destinations. From a mathematical perspective, this policy can be modeled as a reduction in the growth rate, thereby making the system more stable. However, policy implementation is not always effective. Research shows that overtourism management in Bali still faces various challenges, including inter-agency coordination, lack of oversight, and dominance of short-term economic interests. This shows that the solution to overtourism requires not only a mathematical approach, but also a strong institutional approach.r

Overall, the integration between mathematical models and empirical studies shows that overtourism is a complex phenomenon that cannot be explained through a single approach. The model developed in this study provides a conceptual framework that more realistically explains the system's dynamics by accounting for the interaction between tourist growth and capacity degradation. The concept of effective capacity introduced in this study makes a new contribution to understanding the optimal limits of the tourism system, which is not fixed but changes over time. Thus, the mathematical approach developed not only serves as an analytical tool but also as a basis for formulating more sustainable tourism policies. This model shows that tourism management must consider the system's dynamics as a whole, including the interactions among economic, social, and environmental factors. Without an integrated approach, overtourism will continue to be a major challenge in the development of Bali tourism.

The concept of effective capacity emerged from system dynamics. Effective capacity is the actual capacity available after considering tourist pressure. In this model, effective capacity cannot be defined as a fixed value, but rather as a function of time:

$$K_{efektif}(t) = K(t)$$

Because it continues to decline, the effective capacity is always smaller than $K(t)$ Initial Capacity:

$$K_{efektif}(t) < K_0$$

This shows that the optimal limit on the number of tourists is not constant but varies with the system's conditions.

The main novelty of this research lies in the development of a dynamic mathematical model to explain the phenomenon of overtourism in Bali's tourism system. In contrast to previous studies that treated carrying capacity as a constant, this study modeled it as a dynamic variable that decreased under tourist pressure.

In addition, this study introduces a new concept: effective carrying capacity, namely the actual capacity of destinations after accounting for the accumulated pressure on the environment, society, and infrastructure. This concept shows that the optimal number of tourists is not fixed but varies over time according to the system's conditions.

Another novelty is the use of a non-linear differential system with negative feedback to describe the self-limiting tourism mechanism. In this model, an excessive increase in tourists actually reduces the destination's capacity, which then limits the growth of tourists. This approach provides a new perspective that overtourism is an endogenous phenomenon in the tourism system, not just an external consequence.

State of the Art	Research Gap	Novelty
Overtourism research has developed through the study of sustainability, carrying capacity, and socio-ecological impact of tourism.	Most of the research is still descriptive and does not yet use dynamic mathematical models.	Development of a mathematical model based on a non-linear differential system to explain overtourism dynamically.
The classic logistics growth model is used to	Carrying capacity is still assumed to be	Carrying capacity is modeled as a dynamic

State of the Art	Research Gap	Novelty
explain the growth of tourists with a fixed maximum capacity.	constant and unchanged over time.	variable influenced by tourist activities.
The Bali study shows that there is tourism pressure on the environment, social, and infrastructure.	There has been no integration between Bali's empirical data and the tourism dynamic system model.	Integration of mathematical approaches with the empirical phenomenon of overtourism in Bali.
The literature on overtourism highlights the degradation of destinations due to the accumulation of tourists.	There is no mathematical concept yet regarding the actual capacity of destinations after pressure from tourists.	Introduction of the concept *of effective carrying capacity* as the actual capacity of a system.
Policy studies emphasize more administrative and regulatory solutions.	Predictive models for sustainable tourism policy simulations.	This model can be used as the basis for simulating overtourism control policies.

CONCLUSION

This study shows that a mathematical approach based on classical logistics models is not enough to explain the complex dynamics of Bali tourism. The development of a dynamic logistics model by including carrying capacity as a time variable provides a more realistic understanding of the relationship between the number of tourists and carrying capacity.

Mathematical analysis shows that the system exhibits non-linear characteristics with negative feedback: an increase in the number of tourists reduces capacity, which in turn limits tourist growth. This shows that overtourism is a phenomenon driven by the system's internal dynamics.

In addition, this study introduced the concept of effective capacity, which shows that the optimal limit on the number of tourists is not fixed but depends on the system's condition, which changes over time. This concept provides a new perspective in tourism management, in which policies must consider capacity dynamics, not just the number of tourists.

Thus, this research contributes to the development of a more comprehensive and realistic mathematical model of tourism and opens opportunities for further research into the analysis of dynamic systems in the tourism sector.

BIBLIOGRAPHY

Butler, R. W. (1980). The concept of a tourist area's cycle of evolution: Implications for resource management. *Canadian Geographer*, 24(1), 5–12.

Cole, S. (2012). A political ecology of water equity and tourism: A case study from Bali. *Annals of Tourism Research*, 39(2), 1221–1241.

Dodds, R., & Butler, R. (2019). *Overtourism: Issues, realities and solutions*. Berlin: The Gruyter

Gössling, S., Scott, D., & Hall, C. M. (2018). Overtourism: A growing global problem. *Journal of Sustainable Tourism*, 26(8), 1–18.

Milano, C. (2018). Overtourism, tourismphobia, and global trends. *Tourism Planning & Development*, 15(4), 353–357.

Pratama, R. (2025). The impact of overtourism on the environmental degradation of tourist destinations. *Journal of Sustainable Tourism*, 7(2), 45–58.

Rahmad, M. (2026). Overtourism and its implications for tourism sustainability. *Journal of Tourism Development*, 9(1), 33–47.

Suyadnya, I. (2021). Tourism gentrification in Bali. *Journal of Tourism Studies*.

United Nations World Tourism Organization (UNWTO). (2019). *Overtourism? Understanding and managing urban tourism growth beyond perceptions*. Madrid: UNWTO.

Utama, I. G. B. R. (2024). Analysis of overtourism in Bali tourism. *Indonesian Journal of Tourism Sciences*, 12(1), 10–25.