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A DISCRETE MATHEMATICAL MODELLING OF CARRYING CAPACITY OF ECOTOURISM-A STUDY ON BACKWATER TOURISM OF KERALA

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Abstract: *The tourism carrying capacity can be defined as the maximum number of tourists that can be contained in a certain destination area. The capacity is dictated by how many tourists are wanted rather than how many tourists can be attracted. As the system being complex without proper statistical data, we have studied the system by developing a digraph model. In fact, the digraph model has identified the variables determining the stability of the system. The different determinants have been used to formulate a relationship that explain the system. The model so developed has been simulated by observing the variations in the system by the pulse process; in fact, simulation exercise has helped the policy formulation.*

1. Introduction

It is difficult to quantify the carrying capacity. Characteristics of an ecosystem cannot be predicted from the knowledge of the elements of the system. Similarly the extent of the ecotourism capacity of the ecosphere could not be predicted on the basis of knowledge of its component ecosystem[1]. Carrying capacity is depend on the goals that are specified for the development.

In the tourism context the carrying capacity is dependent on the location and the factors affecting the carrying capacity varies various places. The factors that influence the carrying capacity varies from Thiruvananthapuram to Housdurg along the backwaters. So the quantification of the carrying capacity is difficult and considerable expenditure might be required to determine even one or two carrying capacity limits for individual aspects of the natural environment. The principle “up to a point, the bigger the better, beyond that point, the bigger the worse” can be applied to the case of carrying capacity determination[2].

In the case of backwater tourism, the general factors which influence the environmental carrying capacity are 1) The population of the area , 2) The social and economic status of the area, 3) Demand on drinking water supply, 4) Land availability, 5) Water quality, 6) Resilience of flora and fauna to tourist disturbance, 7) Transportation and communication facilities, 8) Other infrastructure facilities such as shelters, restaurants, etc. 9) Characteristics of tourists, 10) Nature of tourism development and 11) Political organisations.

The interrelationships between all these factors need to be taken into account to ensure appropriate tourism development. The major factor we should kept in mind while defining carrying capacity of backwater tourism is the character of the place. We should have regard to conserve the natural beauty and amenity of the villages. These places are a set of ecosystems and settlements and units of agricultural production. Its diversity, culture and history are essential elements of its value[3].

2. Modelling Methodology

Most of the extremely complex environmental systems can be modelled by using discrete mathematics. In this present study the n\modelling is based on Graph Theory, which was first applied by famous Konigsberg Bridge Problem[4] and has been used in number of problems in ecology, transportation, communication, energy, and son on. In an adaptive out look, if we analyse the system we can apprehend the dynamic variables. This model is used to ferret out the associated variables, its gravity and vulnerability with the iner-linked change propagation[5]. The absence of statistical data and presence of number of complex variables interacting in complex ways and the rate of change is almost transient in nature; the digraph modelling is selected for the study of the behaviour of the system. The variables like ecological sensitivity have no precise measure. The digraph model can be used in such situation to make a precise definition of the problem and choose possible strategy alternatives for meeting environment constraints. Following are the fundamental Graph theoretical terminologies[6].

Digraph: A digraph G is pair (V, E) where V is non-empty set whose elements are called vertices of G and E is a sub set of VxV whose elements are called edges of G[7].

Adjacency Matrix of Signed Digraph: in a graph G=(V,E) if u_1, u_2, u_3,……u_n is the lists of its vertices, the adjacency matrix associated with the graph G is the matrix a_{ij} defined by

$$a_{ij} = \begin{cases} +1 (if\ (u_i, u_j) \in E \text{ and its sign is + ve}) \\ \text{-}1\,(if\ (u_i, u_j) \in E \text{ and its sign is - ve}) \\ \qquad\qquad 0 \text{ otherwise} \end{cases}$$

Pulse Process: The effect of change in value of a vertex on other vertices can be analysed by using pulse process. We assume that each vertex u_i attains a value $v_i(t)$ at discrete times t= 1, 2, 3,….and the value $v_i(t+1)$ is determined from $v_i(t)$ and the change of other vertices u_j adjacent to u_i. If (u_j, u_i) is +ve and $p_j(t)$ is a number representing a change in u_j at time t, then the effect on u_i at time t+1 of the change in u_j is an increase in u_j of $p_j(t)$ and vice versa. The change $p_j(t)=v_j(t)-v_j(t-1)$ if t>0 is called a pulse, and it can be defined as follows:

$$sign(u_i, u_j) = \begin{cases} +1 (if\ (u_j, u_i) \text{ is + ve}) \\ \text{-}1\,(if\ (u_j, u_i) \text{ is - ve}) \\ 0 \text{ (if there is no arc } (\mathrm{u}_j, u_i)) \end{cases}$$

Then for t≥0, $v_i(t+1) = v_i(t) + \sum_{j=1}^{n} sign(u_j, u_i) p_j(t)$

In the autonomous pulse process on the digraph we use initial vector values v(start)=v_1(start), v_2(start), v_3(start),…….,(v_n(start). Initially we assume v(start) = (0,0,0,…0), i.e., v(0)= ($v_1(0)$, $v_2(0)$,…..,$v_n(0)$) and by a vector P(0)=($p_1(0)$, $p_2(0)$,….,$p_n(0)$).

Stability in Pulse Processes: Here we take two definitions of stability, the value stability and pulse stability, i.e., the value $v_j(t)$ of a vertex u_j and the pulse $p_j(t)$ respectively does not get too large in magnitude. A vertex u_j is pulse stable under a pulse process if $\{|p_j(t)|:t = 0,1,2,\ldots\}$ is bonded. Under any pulse process, value stability implies pulse stability since for t>0,

$$|p_j(t)| = |v_j(t)-v_j(t-1)| \leq |v_j(t) + v_j(t-1)|$$

Antithetically, pulse stability does not imply value stability. The stability can be tested by fining the eigenvalues of the digraph D.

2.1 Model Building

Seven important variables that determine the carrying capacity have been identified from available literature on carrying capacity[8,9,10]. They are 1. Infrastructure Facility 2. Land Availability 3. Pollution 4. (Fresh) Water Availability 5. Ecological Sensitivity 6. Population and 7. Socio-economic Status of the Region.

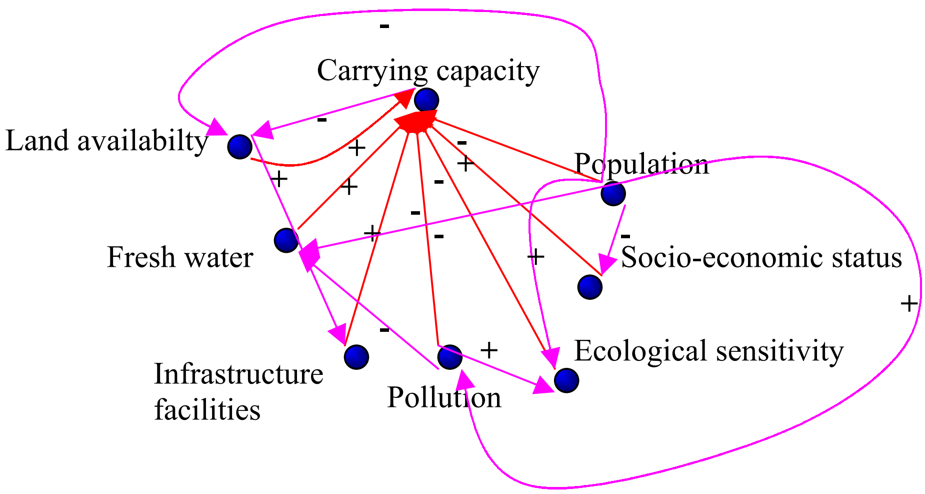

Fig 1. Digraph of Carrying Capacity.

The population of the region is an important factor that determines the carrying capacity. Carrying capacity is usually described for the present population will inhibit the carrying capacity because it affects the land use, economy, etc. of the region. The availability of fresh water is one of the important and vital factors determining the carrying capacity. Since fresh water being distinguished as primary commodity, the promptness in providing clean water is a significant factor. There should be open land spaces for the development of tourism; hence the land availability influences the carrying capacity. The most important factor is the ecological and archaeological sensitivity of the region. Since backwaters have a fragile ecological system, carrying capacity is very much dependent on this. This is closely linked with the pollution of the waters. Backwaters are subjected to a high degree of pollution through effluent discharges from various sources. Tourists visiting the area and other tourism activities can add to pollution of the backwaters. Another important variable is the infrastructure provided. It is apparent that more infrastructure facilities will attract more tourists. The socio-economic status of the region also affects the carrying capacity. Tourists are most cherished in a society where the socio-economic status is better. The inter-relationships of the different variables are shown in the digraph above.

3. Results and Discussion

3.1 Pulse process and analysis of stability

The adjacency matrix for the original digraph (carrying capacity also as a state variable) is an 8x8 matrix as follows:

$$A = \begin{bmatrix} 0 & 0 & 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & -1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & -1 & 1 & -1 & 1 & 0 & -1 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

The eigan values of A are

0, 0, 0, -0.5961, 0.2980+1.8073i, 0.2980-1.8073i, 0, 0

The stability of the system is ascertained by using simple pulse process and the theorems stated above. The eigan values of the digraph is determined and found that magnitude of two eigan values exceeds unity. Hence we can hypothesize that the existing system is no way pulse or value stable under simple pulse process. Therefore our attempt is to make the system stable. For that we use best stabilizing strategies to make the system stable. Deletion of arc strategy is performed as a stabilising strategy. The arcs (*carrying capacity*+⇒ *pollution*) and (*carrying capacity* -⇒ *land availability*) are deleted as the best of possible change. The adjacency matrix of the modified digraph is as follows:

$$A = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & -1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & -1 & 1 & -1 & 1 & 0 & -1 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

The eigan values of the modified digraph are:
0, 0, 0 , 0, 0, 0, 0+1.0000i, 0-1.0000i

Now the system turns pulse stable under simple pulse process. This will correspond to establishing policies that carrying capacity should be increased up to a limit that will not pollute the backwaters and shoul use only the available land. It is also seen that the addition of the arcs (*infrastructure*+⇒ *socio-economic status), (infrastructure*+⇒ *ecological sensitivity), (land availability* +⇒ *population), (socio-economic status*-⇒*population)* does not affect the pulse stability. It is also observed that the digraph is *unilaterally connected* (i.e., for every pair of vertices at least one is reachable from the other). The results should be regarded as tentative and should be checked by other means.

4. Conclusion

Based on simulations of the digraph model using Simulink®, it is found that up to the 10th pulse the carrying capacity has not shown any significant change. After 13th pulse it can be seen that the carrying capacity dropped drastically. In the long run increase in population will lean the carrying capacity (referring figure 2).

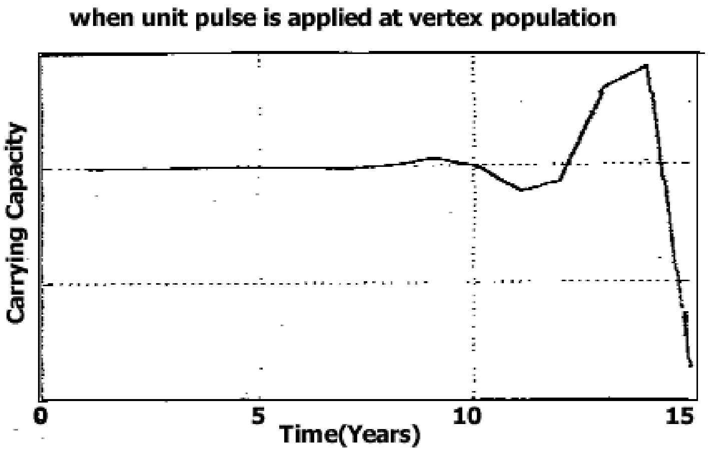

Figure 2

The tourists visiting the region can affect the ecological sensitivity of the region. In the long run if the number of tourists are increased beyond the limits the carrying capacity can be affected negatively, i.e., the carrying capacity will be lowered. So we should develop tourism only upto a limit that will not degrade the ecosystem of the backwaters.

Carrying capacity is found to show a decreasing trend in the long run due to increased pollution load. Hence we can deduce that we should enforce strict pollution control laws to prevent the polluting of the back waters and there by destroying the ecology and scenic beauty of the backwaters (referring fig.3).

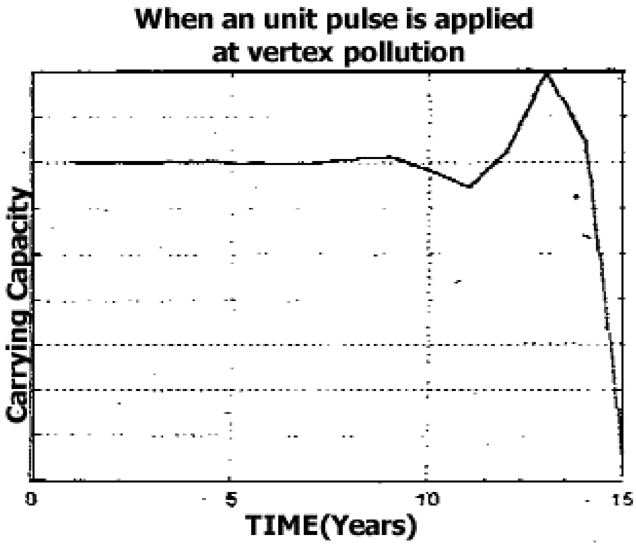

Figure 3

Infrastructural facilities are the most important factors that influence the tourism development. It can be presumed that more infrastructure facilities will increase the tourism potential. Only ecofriendly facilities should be provided in order to avoid the degradation of the ecosystem and the scenic beauty of the backwaters (referring fig.4). The different simulation exercise have been conducted using the MATLAB® 4.2C software.

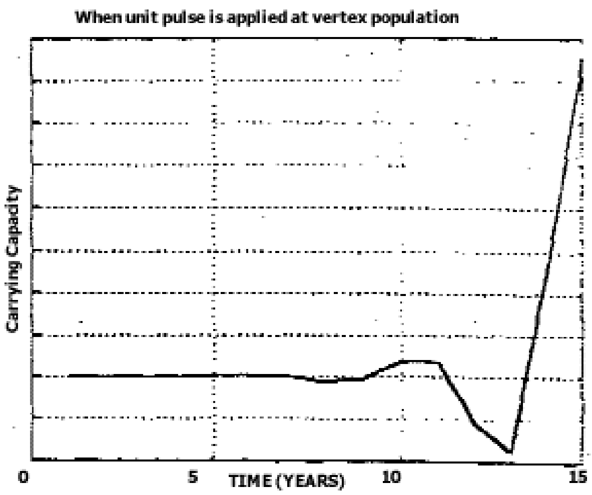

Figure 4

Limitations of a signed digraph model are that it assumes different relations as similar and fails to explain the degree of amplifications and counteractions. In fact, a detailed cross-impact assessment could incorporate more variables and their inter-relationships.

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