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REMODELLING OF GENERAL STATE VECTOR LINEAR MODEL FOR SUSTAINABLE ECODEVELOPMENT APPLICABLE TO A SAMPLE VALLEY VILLAGE OF HIMALAYAN REGION *

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ABSTRACT

The present work is the consequence of within entity relationship among state effecting variables of energy-flow, which have made us to remodel the previously obtained general state vector linear model for sustainable eco-development.

1. INTRODUCTION

Efforts to understand and subsequently to develop acquaintance with nature and environment have been the subject of concern for the human being since the primitive age. The branch of science, which studies the distribution and abundance of living organisms, and the interactions between organisms and their environment is known as ecology. It is also known as scientific study of the processes influencing the distribution and abundance of organisms, the interactions among organisms, and the interactions between organisms and the transformation and flux of energy and matter.The environment of an organism includes both its physical habitat, which can be described as the sum of local nonliving (abiotic) factors like climate and geology, as well as the other organisms which share its habitat. Modern ecology, however, is now focussed on the concept of the ecosystem, a functional unit consisting of interacting organisms and all aspects of the environment in any specific area. It contains both the abiotic and living (biotic) components through which nutrients are cycled and energy flows. Ecosystems are the basic units of study in ecology just as numbers are the basic units of study in mathematics. Just like numbers, an ecosystem can be big or small. It can have many living and non-living things in it, or just a few. For example, a village may be an ecosystem. The living things in this environment are people, animals like goats and buffaloes, and plants like rice and vegetables. The non-living things in this environment are the houses, the land, or soil, and rainwater that come during rainy season. An ecosystem is a complex set of relationships among living resources, habitats and residents of a region. Ecosystems function by maintaining a flow of

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energy and a cycling of materials through a series of steps of eating and being eaten,of utilization and conversion, called the food chain. Interactions of people and natural resources are of fundamental importance to the maintenance of both rural and urban livelihoods and the integrity of various ecosystems that provide a stream of generally undervalued benefits locally and globally. In order to address sustainability of livelihoods and ecosystems as pressure on soil, freshwater and reserves of biodiversity intensifies, new hybrid models that combine social, economic and ecological feedbacks are required. An account of the works which could suit our theme of this present study can be seen in the works of Allen (1992), Altieri (1995), Edwards !995), Ehleringer (1993), Gliessman (1998), Holling et al (1995), Redman et al (2000) and Vitousek (1997) etc to mention only a few.

Our environment with its dynamic and spatial processes is recognized as complex, highly interacting and spatially distributed. These properties make analyzing, describing, modeling and even simulating our environment a challenging task. A framework that enables us to study, for example, the consequences of human influences on ecological systems without even disturbing these is a valuable and important tool for environmental management is of models, which represent observed or hypothesized relationships of structure and function in simplified or abstract form. They transform a reference situation, usually a complex system or process, in order to make it more accessible or tractable. They are identified as important and necessary tools for studying and understanding ecological processes, testing hypotheses of the functioning of ecosystems in a systematic manner and for investigating environmental response to human impact. Modelling may be defined as iterative, non-unique mapping from some physical domain to some logical domain, with reference to objectives, and usually requiring reduction in size or complexity. "Real world" processes operate at different scales (Allen and Hoekstra 1992, Ehleringer and Field 1993). When we discuss the temporal scale of models, we usually talk in terms of "time step" and "duration." Time step is the smallest unit of analysis for change to occur for a specific process in a model. Duration refers to the length of time that the model is applied. In case if we discuss the spatial scale of models, we talk in terms of "resolution" and "extent." Resolution refers to the smallest geographic unit of analysis for the model such as the size of a cell in a raster system. Models can be categorized in several ways. We could focus on the subject matter of models, on modelling technique or methods (from simple regression to advanced dynamic programming) or model use. The beginnings of widespread use of explicit, quantitative models in ecology can be dated to the last 50 years. This short time span leaves us with a history that is largely biographical and informal. Excellent inside sources are Fretwell (1975), Golley (1993), and Schoener (1987), Agarwal et al (2000), Fitz (1996),Giampietro et al (1996), Lischke (2001), Porte et al (2002), Starfield (1986) etc. Because models are pervasive in science, a history of their use is potentially as complex as the intellectual and social histories of disciplines themselves. A large number of dichotomies are used to characterize specific modeling techniques. For instance, models can be static, without an inherent temporal component or dynamic and thus time-dependent. They can be deterministic**,** using fixed or average expected values for parameters and input variables, or stochastic. Solutions to a model may be mathematical (also called analytical**),** either in the form of equations or graphs; or they may be achieved indirectly through simulation, in which the model takes the form of computational rules executed with software.

The process of applying mathematics to a real life situation is often referred to as mathematical modelling. A model in this sense is a simplified, mathematical concept that represents a real life situation. Mathematical models are developed to help in the understanding of physical phenomena. Formulating a model usually involves making observations, collecting data or carrying out an experiment. The observations made, or the results of our experiment, are then put in a mathematical form, together with some assumptions. Often this means representing our observations or experimental results by an equation or set of equations involving some derivatives of one or more unknown functions. Mathematical modelling is widely used in industry, commerce and government. Perhaps what most people might relate to, and what comes readily to mind when we speak of mathematical modelling, is the process of predicting the weather in meteorology. Some areas in which mathematical modelling has been successfully used are: population dynamics (this includes predictions of population growths and the spread of epidemics, such as the AIDS virus), financial mathematics (for example, trading in stocks and derivatives), modelling traffic flow, modelling conflicts (such as political unrests and wars), etc

Mathematical models of ecosystems incorporate important known and/or hypothesized mechanisms (for example, seasonality, site-specific competition, harvesting) into a mathematical framework, for the purposes of tracking the spatial or temporal evolution of variables of interest, such as species abundance, forest cover, etc. Different model assumptions often give rise to distinct behaviours, so model predictions can be compared to data to determine which mechanisms are active in real-world ecological systems. The strength of mathematical modelling lies in the freedom to 'tinker' with the system, i.e., to incorporate alternative mechanisms into the model and to investigate different scenarios. This flexibility allows the modeller to test and develop hypotheses regarding the governing ecological mechanisms, forecast the time evolution of the system and ascertain the impact of alternative management strategies. By casting the assumptions being made about the system into a quantitative form, the implications of those assumptions can be known precisely and measured. This allows for a better understanding of the relation between assumptions, hypotheses, and observations. Models furthermore provide a unifying framework for thinking about the interplay between the various factors that govern a system. This is an especially important advantage for studying complex ecological relations that may have unintuitive behaviour, and means that mathematical models can aid the decision making process.

Recent ecosystem modelling exhibit the use of high standard mathematical methods, such as the use of numerical solutions of partial differential equations for modelling water and matter transport, as well as population dynamics and migration in real landscapes. These high standard mathematical models are used to develop concepts of solving optimization and optimum control problems for environmental management.

We, (2004) in our earlier study have defined the ecosystem with the help of distinct subsystems comprising spatial variables- human resource, household items, land inventory, farm machinery & implements, energy consumption, settlement and livestock. These subsystems have been further subdivided into distinct subsystems in order to define the state of the system in terms of theoretical general state vector linear model based on the collected data for a sample valley village of Almora district. Error values generated by the comparison of empirically observed values with the theoretical values have in turn suggested the selection of polynomial function as modelling parametric function. With an aim to simulate behaviour of the real system at the highest level of accuracy under the employed modeling strategy, an attempt was made by us (2004), in the direction of developing aggregation model for examining errors and their analysis.

Here an attempt is being made to remodel the general state vector linear model in the light of within entity relationship among certain parameters governing the energy flow relationship.

2. GEOGRAPHY

We had collected information regarding different subsystems and distinct subsystems for a valley village of Almora district. In order to test the suitability of the modelling parameter function for other valley villages of the state, we are processing the data collected for a valley village of Pithoragarh district in conformity with the suggestions of the expert. The process of data collection was performed on the basis of past year experience and following facts-

1. The physical environment, both natural and built, affects human lives profoundly.
2. Vegetation in environmental systems; vegetation dynamics in natural and human-altered environments; impacts of human activities upon vegetation
3. Emphasis on natural and human processes that control the morphology of the land and its waterways
4. Geographic approaches to culture-nature relationships, including human perception of, use of, and adaptation to the physical environment, with emphasis on traditional subsistence systems
5. Analysis of people-nature links, including environmental issues, natural resources, and attitudes toward nature

Our study village (Dwalisera, Patwari region- Pipali) is a valley village of Pithoragarh district situated in the confluence of Kali Nadi (Sharda river) separating India and Nepal and charma river. The land is divided into territories owned by houses. Villages consist of groups of houses, with a duality principle defining village structure. Timber used in the construction of houses has been procured from nearby forests. Physical and human distributions and inter-relationships, with emphasis on the spatial processes and patterns of modernization was collected. Some of them are being reproduced here.

The village has 40 families of 221 members comprising of Hindu Rajputs and schedule castes. Most of the houses are of permanent type. The males are 119 in number and the rest 102 are female. Distribution of the population as per age group is as given in the following table-

Below Five years		6-10		11-15		16-20		21-25		26-30		31-35		36-40		41-45		46-50		51-55		56-60		60^{+}	
M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
12	10	21	10	12	12	11	8	11	12	12	10	8	10	10	7	4	3	2	6	5	5	2	1	9	8

Occupation wise distribution of males and females is as under-

Cultivators		Agricultural labourers		Trade and commerce		Transport, Storage and Communication		Other services		Non-workers	
M	F	M	F	M	F	M	F	M	F	M	F
34	61	02	00	08	00	04	00	14	00	57	41

while the table of villagers prepared according to the education parameter is being reproduced as under-

Primary		Junior		High-School		Intermediate		Under graduate		Post graduate		Technical education		Illiterate	
M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
29	27	29	23	30	15	13	06	03	02	03	00	-	-	13	29

There are 50 married males, o4 widowers in the village and 50 married females and 42 widows in the village. The data of marital stats exhibit the ratios of male to female under sub categories of married, unmarried and widowers as 1, 65/42 and 04/10 respectively.

The compiled data for land inventory has following form-

Cultivated land	= 810 nalis
Uncultivated land	= 154 nalis
Irrigated land	= 810 nalis
Pasture land for grazing	= 60 nalis
Barren land	= 502 nalis
Civil land	= 60 nalis
Forrest land	=100 nalis
Common land open for grazing	= 60 nalis
Common land closed for grazing	= 100 nalis

and the compiled form of the data for livestock is as under-

Milking Cow and Buffaloes	= 51
Non-milking Cow and Buffaloes	= 24
Goats	= 133
Layers	= 30
Oxen	= 40
Horses	= 04
Initial investment	= 50,000 Rs.
Source of Finance	= Self
Fodder requirement per month	= 710 Kg.(Milking)
Fodder requirement per month	= 228 Kg.(Non-Milking)
Total dung product per day	= 334 Kg. (Milking)
Total dung product per day	=134 Kg. (Non-Milking)

The gathering, manipulation, and cartographic representation of geographical data with emphasis on relations between the parameters has yielded following results-

a. Foodgrain production is estimated to be 37,475 kg. or 380 qt.
b. All buffaloes (and buffalo calves) are fed chaffed fodder in manger, so there is no wastage.
   Estimates of fodder production can be made as follows:

$$\text{Fodder production from cultivation land} = \frac{37{,}447 \times 3}{25}$$

$$= 4493.64 \text{ headloads per year}$$

(The ratio between grain and fodder yields has been assumed to be the 3 fodder, which includes straw, chaff, and weeds. One headload of fodder is assumed to weight 25 kg, on an average.)

c, fodder production from supports areas

Individual land (closed to grazing).

502 nalis x 3 headloads / nails / year = 1506 headloads / years

Common land (closed to grazing).

100 nalis x 2 headloads / nail /year = 200 headloads / years

common lands (open to grazing).

502 nalis x 1 headloads / nails / year = 502 headloads / years

Total = 2202 headloads / years.

From the total, 100 loads of Maize and Lahi stalks are deducted. They are to be the used as fuel and its value amounts to be 100 headload/year.

Actual fodder production = 2208 –100 = 2108 of this 130 loads were sold = 2108-130 =1978.

Actual fodder consumed = 1978 headloads / year.

(The fodder consumption per animals unit becomes 1978 / 282 = 7.015)

d. Milk Production

20 cows x 300 kg / cows / year		= 6000 kg / year
31 buffaloes x 500 kg / buffaloes / year		= 15500 kg / year
	Total	= 21,500 kg / year

e. Wood consumption is estimated to be the 22 headloads persons / year. Total village consumption is thus 221 x 22 = 4862 loads / year.

Production is estimated as :

From terrace risers : 60 x 3 = 180 loads / year

From support area (individual):

502 x (1/5) x 6	= 602 headloads / year
From Homesteads	= 100 headloads /year
Crop residues	= 100 headloads /year
From reserve forest	= 200 headloads /year
Total	= 11,82 headloads /year

Since production is much less than consumption, overcutting is obviousely occurring.

f . Spring number 1 had a measured outflow in October of 40 Litres / min. This is estimated to fall to 20 litre / min. in May. Assuming a linear declines, outflow in March would be about 27 litre / min. and the average outflow for the period October- March would be about 27 litre / min.

Total water production for 6 Month would be 27 litres / min. x 60 x 24 x (182 / 1000) =7076m^3 .

Spring number 2 had a measured outflow in October of 35 Litre /min, and an estimated outflow of 6.75Liters / min. May. Outflow in March was taken to be 7 Litre / min, and average outflow for the periods October to March 22 Litre / min.

Total waters production was 22 x 60 x 24 x (182 /1000) = 5765 m^3

Water for domestic consumption (50 Litres / persons / day) and for animals watering (20 Litres / AU / day),Amounting to[(221 x 150 x 182)] /1000 = 3037 m^3 .

Comes from Spring number 2. Surplus water for these 6 months amounts to
7076 + (5765 - 3037) = 9804 m^3.

Evaluation

A. Adequacy of Subsistence materials

Water availability is adequate for present levels of consumption even in the month of May. Increased consumption, probably desired by everyone for increased health and comfort and vegetable cultivation on the homestead , is probably limited by the line and effort needed to carry the water. An estimated 9804m3 of Surplus water is available between October and March for Irrigation.

Milk Sale from the village is estimated to be 21,500 kg / year, equivalent to the amount produced from purchased oilcakes. Milk consumption therefore is the amount daily consumption per persons is

$$\frac{21{,}500 \times 1000}{221 \times 365} = 266ml.$$

We assume that a minimum level of milk consumption should be 250 ml / person /day, or 91 kg / person / year.

Concerning wood consumption we assume that for good health and comfort, 26 headloads / person / year are needed. The present consumption of 22 loads is considered inadequate, and is due to a scarcity of trees in the support areas.

B. Current Carrying Capacity

Carrying capacity of the village ecosystem in terms of milk is

carrying capacity (milk) = $\frac{21{,}500}{91} = 36\,people$

In terms of wood, it is :

Carrying Capacity (wood) $= \frac{1182}{26} = 45\,people$

Taking the smaller of these two figures, we will say that the carrying capacity of the village ecosystem is 36.

C. Current index of Sustainability

Since these are at present 221 residents in the village, sustainability index =

$$\frac{36}{221} = .16$$

This low value confirms our general conclusion, based upon our observation of the denuded support area, that the village ecosystem is being used very unsustainably.

We may recall at this stage that unsustainable use means over-harvesting of trees for wood and fodder. Over-harvesting is inevitable when people's minimum needs cannot be met by sustainable harvesting. The very low index of sustainability (0.16) indicates that productivity is currently declining at a very rapid rate.

3. GENERAL FORMULATION

We have observed that activities like land preparation, weeding, irrigation, harvesting and threshing require involvement of human beings as well as of animals. It suggests the within-entity relationship between elements of these subsystems, which has been demonstrated with the help of M:1 (Many to one), 1:1 and M:M relations. We shall require transfer functions, that describe the calories for food items and work performed by human beings and animals in their day to day activities. They shall be expressed as - $(F_i), i = 1,2,....5$ and shall be dealing with energy aspects of all system variables.

Caloric values on fresh-weight basis for certain agricultural materials (based on Mitchell,1979) as given in the paper of Pandey & Singh (1984) are being utilized here so as to generate the following table for energy input and output for our village of study for Rabi and Kharif crops (The values are in x 10^5 KJ per nail per year)

	Rabi Crops				Kharif Crops		
Parameters	Wheat + Barley	Pulses	Oil seeds	Vegetables	Paddy +	Fallow pulses	vegetables
INPUT							
Labour (Human)	103.15	79.31	158.96	1095.91	112.60	76.003	2344.52
Labour (Bullock)	3317.70	3209.84	2152.90	4225.82	3611.38	3042.66	2852.43
Seed (Kg.)	53.29	38.51	14.62	39.23	45.44	38.26	0.814
Manure (Kg.)	61.97	66.07	52.50	36.88	67.55	45.24	24.89
Fertilizer (Kg.)	13.17	11.94	8.09	27.97	14.25	11.54	18.88
OUTPUT							
Production	28.84	9.24	11.06	2.90	37.13	12.84	0/72
By-products	45.84	0.84				54.14	3.36

Data array containing the elements of the different values was taken as matrix M, for which a locating function was defined under the condition that elements must match

$$c(x) : x > 7.$$

Taking L = Locate (M, c), a matrix L of following form was obtained for input values of Rabi crops, whose columns contain the location (row and column) of each element of the array M that matches the above mentioned condition

$$L_1 = \begin{bmatrix} & 0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 2 & 2 & 2 & 2 \\ 1 & 0 & 1 & 2 & 3 & 0 & 1 & 2 & 3 & 0 & 1 & 2 & 3 \end{bmatrix}$$

while the matrix corresponding to output values of Rabi crop had following form

$$L_2 = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 0 & 1 & 2 & 0 \end{bmatrix}$$

Proceeding in the same manner, matrices corresponding to Input and output values of Kharif crops had following forms

$$L_3 = \begin{bmatrix} & 0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 2 & 2 & 3 & 3 & 3 & 4 \\ 1 & 0 & 1 & 2 & 0 & 1 & 2 & 0 & 1 & 0 & 1 & 2 & 0 \end{bmatrix}$$

and

$$L_4 = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

4. MODELLING FOR STATE OF SYSTEM

The state of system for different values of $i = 1,2,........p$ is defined as

$$x(t) = \sum_{i=1}^{p} x_i(t) \text{ ....(4.1),}$$

where $x_1(t), x_2(t),.......x_p(t)$ (p=10 for our present study), describe the state of system at a given time and are known as system variables.

The value of $x_i(t)$, as described in the book of Efraim Halfon (1979) has been given as

$$x_i(t) = \frac{u_i}{l_i} + \left(x_i(0) - \frac{u_i}{l_i} \right) e^{-l_i t} \qquad \text{...............(4.2)}$$

$$for \quad i = 1,2,.......p$$

The inferences derived on the basis of our earlier study (2004) , had suggested that the modelling parametric exponential function in (4.2) should be replaced by a polynomial function, which has been justified by us by adopting simulation technique. Summation of a finite number of terms is always preferable as it is most likely that summation of infinite number of terms of the exponential function may lead to wrong results. We thus had the state of system as

$$x(t)=\sum_{i=1}^{p}\left\{x_i(\infty)+\left(x_i(0)-x_i(\infty)\right)\left(a_1+\frac{b_1}{l_i+2t}+c_1 l_i\right)\right\} \quad \ldots\ldots\ldots\ldots\ldots(4.3),$$

where a_1, b_1 *and* c_1 are constants.

Discussions under the sub-title 'Mathematical formulation' of the observed data on the energy aspects connote that effect of energy of input values be subtracted from acquired energy of output values. The matrix L_1 of input values when plotted by least square curve fitting generated curves of different shapes. Selecting a curve which could match the significant elements of matrix L_2, the equation of the desired curve for input values vis-à-vis output values was obtained in the form of following polynomial

$$y=a+b(x+5)+cx^5 \quad \ldots\ldots\ldots\ldots\ldots(4.4)$$

The same form of equation was obtained in case of energy differences corresponding to input and output values of Kharif crops. This discussion leads us to derive following expression for state of system

$$x(t)=\sum_{i=1}^{p}\left\{x_i(\infty)+\left(x_i(0)-x_i(\infty)\right)\left(a_1+\frac{b_1}{l_i+2t}+c_1 l_i\right)\right\}-\sum_{i=1}^{p}\left\{a_2+\left(x_i+5t\right)b_2+c_2 x_i^{5t}\right\}\ldots..(4.5),$$

where a_2, b_2 *and* c_2 assume the values in the range 0 to 4.226 x 10^3 for Rabi crops , which are minimum and maximum values of the following two matrices

$$M_1=\begin{bmatrix} 1013.15 & 79.31 & 158.96 & 1.096\times10^3 \\ 3.318\times10^3 & 3.21\times10^3 & 2.153\times10^3 & 4.226\times10^3 \\ 53.29 & 38.51 & 14.62 & 39.23 \\ 61.97 & 66.07 & 52.501 & 36.88 \\ 13.17 & 11.94 & 8.09 & 27.97 \end{bmatrix}$$

and $$M_2=\begin{bmatrix} 28.841 & 9.243 & 11.06 & 2.9 \\ 45.84 & 0.84 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Similarly the values of a_2, b_2 *and* c_2 for Kharif crop shall lie in the range 0 – 54.14 , as is evident from following two matrices

$$M_3 = \begin{bmatrix} 37.13 & 12.84 & 0.72 & 0 \\ 54.14 & 3.36 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

and $$M_4 = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 0 & 1 & 2 & 0 \end{bmatrix}$$

Thus we may say that the range of these constants a_2, b_2 *and* c_2 in present case shall lie in the range 0 – 4.226 x 10^3.

The changes of system variables as function of time shall be described by the differential equation

$$\frac{dv_i}{dt} = f(v_1, v_2, ..., v_n; F_1, F_2, ..., F_n) \quad ....(4.6),$$

where $v_1, v_2, ..., v_n$ are connected with each other in terms of sustainable productivity with the help of relation (4.3) and second part of (4.5) exhibit the relationship among transfer functions $F_1, F_2, ..., F_n$.

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