STATISTICAL DYNAMICS OF SUSTAINABLE DEVELOPMENT

29th Convocation Address

By

Professor U. R. Rao

Member, Space Commission

Bangalore, India.

Delivered on February 1, 1995

at

INDIAN STATISTICAL INSTITUTE

CALCUTTA

STATISTICAL DYNAMICS OF SUSTAINABLE DEVELOPMENT

29th Convocation Address

By

Professor U. R. Rao

Member, Space Commission

Bangalore, India.

Delivered on February 1, 1995

at

INDIAN STATISTICAL INSTITUTE

CALCUTTA

STATISTICAL DYNAMICS OF SUSTAINABLE DEVELOPMENT

Mr President, Mr Chairman, Graduates of the year, Distinguished Guests, Ladies and Gentlemen,

I consider it a great honour and privilege to be your chief guest today and deliver the convocation address of this world renowned institute, founded and nurtured by some of the most distinguished scientists of our nation. I extend my hearty congratulations to the graduates of the year, who will no doubt distinguish themselves in serving our country in the years to come.

The birth of the new paradigm, chaos, combined with the discovery of quantum mechanics and subsequent understanding of the role of chance and probability, practically demolished the earlier deterministic view of Newtonian classical mechanics, which was embodied in Laplace's theological statement that "for an intelligence which, at a given instant, would know all the forces by which nature is animated and the respective situation of the elements of which it is composed, nothing would be uncertain and the future as well as the past would be present to its eyes". The statement that a precise knowledge of the initial condition will lead to equally precise future prediction is untrue for a non-linear system in nature, which characterises practically all the known physical, biological and social phenomena. Indeed the state of even the initial conditions may not be deterministic at a micro level and in fact may have a certain probability distribution. The oft quoted example of the application of deterministic theory to population dynamics, which can lead to absurd conclusion of either eventual infinite population growth or its total extinction depending on the operation of positive or negative growth functions, is a good illustration of the problems of purely deterministic logic. The classical example of the inability of medium range weather prediction, which in spite of using complex numerical integration techniques involving a large number of short and long range physical parameters, to accurately forecast weather status beyond a week, due to the uncertainties in the initial conditions as well as accumulation of errors caused by the dynamic perturbations in the atmosphere, dramatically emphasises the importance of chaos and statistical dynamics in dealing with predominantly non-linear phenomena.

Since the last two decades of my life time has been spent in developing space technology and its extensive applications to solve the grass root problems of our society, I consider it most appropriate for me to highlight the role of statistics in space technology. Realisation that practically all the physical and natural systems in nature are non-deterministic, nonlinear, irreversible and affected by random fluctuations has naturally made statistics and probabilistic computation an integral part of all physical, biological and natural systems. The uncertainties in propulsion characteristics, aerodynamic behaviour of the rocket through the unstable atmosphere, influence of external factors such as gusts, winds and turbulence need to be evaluated using statistical techniques for deriving appropriate control functions to guide the rocket trajectory along the predetermined path. Similar processes, involving both gravitational perturbations and instrumentation characteristics, require to be extensively modelled to compute the precise orbital trajectories of the satellites and rockets in motion. Application of space based or ground observations to complex physical phenomena involving dynamical systems such as climatic perturbations, management of natural resources with their profound implications to the quality of life on earth is yet another area where statistics plays a dominant role. God does seem to play with dice made up of complex nonlinear dynamical systems which exhibit chaos, in total contradiction to the classical belief in "Laplacian Fantasy of Determistic Predictaility". This essentially means that short term fluctuations are often as important as the continuum itself in the complex physical and natural systems, the geometry of nature is built on non-reversible dynamics and the negative as well as positive feedbacks, in essence, separate the future from the past. The main thesis of my talk is going to be on the importance of gaining a clear understanding of the statistical relationships involved in effectively dealing with the dynamics of sustainable integrated development, which alone can ensure a common future to the coming generations.

Challenge of the future :

The most challenging problem which our country has to face in coming decades will be to provide food, health and economic security to the millions of our population, which requires a careful matching of technological vectors with social dynamics. Nowhere the concept of "taming of uncertanity" which as Prof C.R. Rao rightly defined as the central theme of statistical sciences, is so intimately interwoven as in the highly complex and inter linked natural processes involved in improving the carrying capacity of the

country through optimal management of its natural resources. Nowhere the need for a clear understanding of the interdisciplinary character of the problem and a proper appreciation of the cybernetic relationships involved in scientific and social systems is so great as in building up sustainable regenerative capacity of the land and water resources to provide basic food and economic security to the people at large, without compromising on the ecological and environmental integrity.

A critical appraisal of the statistical behavioural pattern of the demographic trends in the last few decades shows even with the most optimistic assumption of reducing the present birth rate of over 26 per thousand to 21 per thousand by 2025, the total population in India will reach a figure of 1.8 billion by 2075. The population increase, as is well established, will continue for at least 40 years beyond the achievement of fertility replacement birth rate, till the newly born infants cross their productivity age and the demographic distribution pattern changes from a typical pyramidical distribution to a more rectangular one, signaling the balance between the birth and death functions. Consequently the available limited land which at present is 0.17 ha per capita will further dwindle to less than 0.1 ha per capita, one fifth of what is available in developed countries, resulting in the inevitable migration of rural population to urban areas. The inability of limited land to sustain large rural population is at the centre of the dynamics of the phenomenal urban expansion, already taking place in practically all the developing nations of the world, virtually pushing the major megacities beyond the threshold of their vulnerability. Since neither philosophical sermons nor blind optimism can wish away the above reality, while we continue to press population control measures, it is absolutely imperative that we appeal to the developments in science and technology for building up the carrying capacity of the country on a sustainable basis.

Over 70% of the total energy consumption of 330 EJ in the world is shared by the developed countries, which account for less than 20% of the global population. In spite of the five fold increase in the energy generated from about 60 million KWh to 300 million KWh during the last twenty five years, the per capita consumption of energy in India is still around 0.3 ton coal equivalent, just one fortieth of that in US. Urgent necessity for adoption of energy intensive agricultural practices and promotion of rapid industrialisation has become the basic economic imperative, demanding substantial capital investments for accelerating the pace of development. The need

for developing efficient methods of energy utilisation and implementation of environment friendly technology to control the environmental pollution caused by waste heat from industrial activities place an additional demand on the poor resource capital base of the country. Even to ensure a minimum of 2.5 KW per capita of energy by 2075, the energy production has to increase substantially by almost a factor of 20 from the present 7 EJ to 140 EJ, which in the context of the fast depleting non-renewable resources, is undoubtedly going to be a Herculean task.

Explosive growth of human population, particularly in the developing countries like India, has led to severe encroachment of over 600 m.ha. of forest and grass lands in the last 70 years alone, resulting in the alarming rate of deforestation of over 17 m.ha. primarily in the tropical belt, blessed with rich bio-diversity. The deforestation of over 10 m.ha. of closed forest in India during 1973-1983 reducing the closed forest cover from 14% to a meager 11% of our geographical area is a clear indication of the neglectful policies followed in the country. Even though awareness of the extent of severe deforestation dramatically brought about by space remote sensing has arrested further depletion, the consequences of the past mismanagement of forest land has already led to intensive soil erosion ranging from 10 t/ha. to 50 t/ha. in the hilly regions of the country. Inevitable consequence of large scale deforestation has been depletion of top soil, severe degradation of land, sedimentation of water bases and increased run-off of rain water resulting in increasing desertification and flooding of rivers. The annual sedimentation load carried by just Ganges and Brahmaputra alone exceeds 2000 mt, almost a quarter of the total sedimentation load transported by all the rivers in the world.

In spite of the green revolution, the agricultural productivitity in India is one of the lowest being about 1.6 t/ha. as against world's average of 2.6 t/ha and world's best of 5 t/ha. The average yield of rice in India is just about 1.7 t/ha as against 5.0 t/ha in California. The average yield of wheat is about 2.2 t/ha as against 3.7 t/ha of world average and 5.4 t/ha in USA. It is important to note that the green revolution and increased productivity realised by most of the developing countries like India has been largely due to intensive irrigation of over 30% of their land area, as against less than 10% in developed countries. However, this very practice of large scale irrigation, extensive use of chemical fertilizers and pesticides, inadequate drainage and bad agricultural practices has led to an alarming increase in soil salinity,

making some of our most fertile land unproductive and severely degraded resulting in the distruption of ecosystem over large areas. Over 25% of the arable land in all the continents has become problem land with another 25% having very low productivity. The practice of shifting cultivation or jhumming adopted in the ancient farming system in which farmers used to keep the agricultural land fallow for periods of about 10 years to restore the replenishment of nutrients in the soil through natural processes, has now become a social menance due to the extreme pressure of population and consequent drastic reduction in the fallow period.

Poor management of water resources in the country has been even more pathetic. Optimal management of water resources is of paramount importance to a tropical country like India where most of the precipitation occurs in less than 100 days unlike in temperate climates where snow and rain precipitation keep the soil moisture healthy for almost 8 months in a year. Over-exploitation of underground water without taking adequate care to recharge, has resulted in dipping into the static water table in most parts of the country. Typical is the example of Ahmedabad where water table has dipped from 100 feet to 300 feet during the last thirty years alone.

Superimposed on these seemingly insurmountable difficulties is the real prospect of the widely accepted global warming scenario due to the unprecedented anthropogenic intervention through indiscriminate industrial activity and deforestation, threatening to upset the delicate greenhouse equilibrium which could lead to irreversible climatic changes. Rapid increase in the greenhouse gases in the atmosphere, large scale affects of acid rain, environmental pollution by oil wells, smoke etc., are changing the ecological balance in a definitive way. Particularly since the beginning of the industrial revolution, CO_2 concentration in the atmosphere has steadily increased from 280 ppm to 350 ppm and at the present rate of increase is expected to reach at least 450 ppm by 2050. Concentration of methane in the atmosphere has also been increasing steadily at the rate of about 0.9% per year and has already reached 1.7 ppm. Rigorous statistical analysis of surface temperature over the last century seems to, on first sight, substantiate the average increase in temperature of about 0.5° K, which is also supported by the Paleo-climatic evidence gathered from deep sea ice cores from Arctic and Antarctic regions. While uncertainties in the past measurements as well as the recent satellite measurements have cast considerable doubt on the reality of global warming scenario, the increasing concentration of green house gases including CFC's in the atmosphere are not in doubt.

Natural disasters, whether meteorological such as cyclones, floods and droughts or geological disasters such as earthquakes and volcanoes, have further contributed to the misery of vulnerable population, particularly in the developing countries. During the last two decades alone, these extreme natural disasters have resulted in the loss of life of over 3 million people and have affected over 800 million people all over the world, causing damage to property to the tune of 50-100 billion dollars. Over 70% of all the major disasters have occurred in the most vulnerable developing countries of which nearly 50% of the annual damage, estimated at 2 billion dollars, is attributable to floods and cyclones alone. Likewise, drought, a creeping disaster resulting from climatic changes, often aggravated by human induced factors such as poor land and water management, has become a regular recuring cause of destablilising food security particularly in Asia, Africa and Latin American regions of the world.

Space Technology for Food Security :

The spectacular achievements in the last three decades have firmly established the capability of space technology for bringing out a socio-economic revolution in the world, because of its immense potential to transform even stagnant societies in a most cost effective and timely manner. The benefits from space today already operationally extend over communication, meteorology, TV broadcasting, education, agriculture, industrial growth, resource management, environmental pollution, disaster mitigation, flood and drought management, health and entertainment virtually touching every facet of human endeavour. Space technology inputs, for the first time, are providing a new capability to treat the global disease of environmental degradation and combined with biotechnological inputs have established their capability to initiate sustainable integrated strategies across the world through implementation of proper land, water and environmental conservation measures.

Detailed rigorous statistical treatment of the problem clearly indicates the need to increase the food grain production in India by at least a factor of 2.5 to meet the basic needs of the projected 1.8 billion population by 2075, if we are to avoid the macabre specter of millions dying of naked starvarion. The ability of remote sensing satellites to delineate wasteland of different categories and classifying them based on their soil, water and geomorphological features has been very effectively exploited in India for identifying 54 m.ha. of wasteland, nearly half of which can be reclaimed for productive

purposes. Similar studies carried out on a global scale have shown that the potential agricultural land in the world can be increased from the present 1500 m. ha. to almost 2,200 m.ha. While these exercises can at best provide an additional twenty percent capacity augmentation, substantial increase in food grain production has to necessarily come from optimal management of our natural resources. The only solution to avoid a global human disaster is adoption of sustainable development strategies, through a better understanding of the statistical linkages between natural phenomena and anthropogenic intervention on global, regional and local scales.

Rapid strides made in the application of space technology have enabled detailed mapping of soil, soil moisture and agro-climatic conditions necessary for optimal land use planning. These in turn have led to the possibility of identifying agro-climatically coherent regions having homogeneous characteristics such as slope, soil depth, texture and water holding capacity, which is vital for developing locale specific cropping practices without impairing the fertility of the land. Repetitive coverage provided by satellites has been widely used for mapping of ground water and surface water bodies in addition to providing a reliable estimate of water storage in the reservoirs thereby facilitating optimal scheduling of irrigation. Detailed surveys through satellite remote sensing have been found to considerably narrow down the areas for ground water exploitation with a success rate of over 92%. Satellite-based glacier inventory has been found very promising to plan and operate mini and micro hydroelectric stations. Appropriate regression models based on temporal changes in the area extent of seasonal snow fall have been developed to predict snow-melt runoff. Identification of waterlogged areas in the command areas of irrigation projects and inventory of crop lands and cropping patterns have facilitated efficient water use, thereby increasing the cropping intensity.

The ability to monitor individual crop growth and forecast acreage as well as yield estimates is now possible though repetitive remote sensing and use of sophisticated statistical sampling techniques. With appropriate straitfication of geographical units based on agroclimatic zoning and vegetation density, into small grids calibrated against actual ground truths on statistically valid sampling basis, even a single date imagery has been able to provide yield estimates of individual crops with an accuracy of better than 95% at 90% confidence level. Space remote sensing imageries together with application of appropriate statistical techniques now enable optimal planning of urban expansion including drainage requirements, alignment of roads and

railways and environmental pullution over the land and seas. Even more important, repetitive coverage from space combined with the powerful analytical tools such as the geographical information system have made it possible to continuously monitor the changes which is crucial to avoid the past mistakes such as the negative repercussion of the green revolution of the 60s, through timely corrective measures.

Management of natural disasters on a long term basis requires careful cultivation of the ecosystem and reconstruction of the environment to reduce their susceptibility to such calamities. Use of remote sensing information to monitor crop pest, flood, drought and cyclone disasters over a period of time have provided sufficient database which has led to the forecasting and identification of high risk areas, which can then be adequately treated to lessen the severity of damage without impairing environmental integrity.

Nowhere the role of statistics is as pronounced as in the case of weather and climatic predictions which require a complete understanding of the nature and fluctuation of the forcing functions, effect of the anthropogenic activities such as deforestation, land degradation and increase in green house gases and the impact of the natural processes such as volcanoes and El Nino on global weather phenomena. The so called Butter-fly effect, which can multiply even tantalisingly small perturbations to cascade into continental turbulent features in the global weather phenomena, has been the bane of meteorologists all over the world. Even though the uncertainties in the measurement of forcing functions combined with our level of ignorance regarding the complex phiysical, chemical as well as biological interactions between the occans, land and the atmosphere, continue to pose a formidable problem, availability of high resolution data from future spacecrafts and improvement in statistical modelling techniques will go a long way in solving the problem of accurate long term weather forecasting.

Achievement of Sustainable Integrated Development :

Sustainable development of natural resources is based on maintaining the fragile balance between productivity functions and conservation practices through monitoring and identification of problem areas which require application of alternate agricultural practices, crop rotation, use of bio-fertilizers, energy efficient farming methods and reclamation of underutilised lands. The model calls for judicious use of natural resources and emphasizes the need for conservation at micro level taking into account the likely impact of

the global changes on the productivity functions. It calls for an understanding of the mutual inter-dependencies of various resources, both renewable and non-renewable, integration of the land and water resources, characterization of coherent zones of agricultural identities and identification of the constraints and ecological problems at the micro level. Experience has shown that effective use of space based remote sensing information along with other collateral socio-economic data can lead to locale specific prescriptions for achieving food security on a sustainable basis.

The key to the achievement of sustainable integrated development is the adoption of environmental friendly, scientific and technological approach for achieving rapid progress without sacrificing "the owl". As beautifully summarised in the historic earth summit at Rio in 1992 "Humanity stands at a defining moment in the history. We are confronted with a perpetuation of disparities between and within nations, a worsening poverty, hunger, ill health and illiteracy and the continuing deterioration of the eco system on which we depend for our well being. However, integration of environment and development concerns and greater attention to them will lead to the fulfillment of the basic needs, improved living standard for all, better protected and managed ecosystem and a safe, more prosperous future". Advances in agricultural sciences and biotechnology, phenomenal progress in space technology and developments of appropriate statistical tools and interpretation techniques have made it possible to improve the global as well as local carrying capacity to meet the present and projected needs of future generations without impairing ecological and environmental integrity. As President Kennedy stated "never before has man had such capacity to control his own environment, to end thrist and hunger, to conquer poverty and disease, to banish illiteracy and massive human misery. We have the power to make the best generation of mankind or to make it the last". I hope we choose the former and replace the old practice of mindless exploitation of the planet earth with a new culture of sustainable integrated development to enable the humankind as a whole to have a common futurs.

Mere acceptance of the fact that "quantitative transformation of our societies as well as their very survival depends on the optimal utilisation of science and technology" is not enough unless we concurrently recognise the importance of building a self-reliant technological base in the country. Science and technology have become the most powerful currency of power for continued exploitation and domination of the developing world. The

vision of future India has to be built around scientific and technological development. I am convinced that if you were to "replace the inferiority complex and defeatist spirit imbibed during the last three hundred years, with a spirit of confidence and victory, of determination and commitment, you will have your rendezvous with destiny". I once again congratulate all the graduates of the year and pray that you become the torch bearers for ushering a non turbulent and smooth future for our society.