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Performance Index for Watershed Development

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ABSTRACT
Watershed is a natural hydrologic dynamic unit with a certain extent of homogeneity and uniformity and is a limited, convenient, clearly defined unit. It can be adopted as a basic erosion landscape unit where land and water resources interact in a perceptible manner. Natural resources are developed by adopting the watershed as the basic developmental planning unit. Action plans are generated for land resources and water resources using RS and GIS techniques. Subsequently, the concerned line departments are implementing these action plans in the field. The Ministry of Rural and Agricultural Departments at Central and state level invest both physical and financial resources in watershed development through the programs like National Watershed Development Project for Rainfed Areas (NWDPRA), Integrated Mission for Sustainable Development (IMSD) and Drought Prone Area Programming (DPAP). Monitoring and impact evaluation should also be a part of program in natural resources management and has the potential to be used for these activities. Case studies are carried out in parts of Madhya Pradesh and Maharashtra, and collected collateral information using questionnaires and field interviews with the farmers and the officers involved in plan preparation and implementation regarding human and financial resources incurred for various developmental activities in a watershed. To evaluate the impact of watershed development activities, there is no common scale to assess the natural resources, socio economic and climatic parameters that influence the end result. An effort has been made to combine all the relevant parameters and develop an index to assess the watershed development.

INTRODUCTION

Watershed is the unit of decentralisation chosen by Mother Nature. It is a natural geographical unit with a certain extent of homogeneity and uniformity. A watershed is a limited, convenient, clearly defined and unambiguous topographic unit, available in a nested hierarchy of sizes on the basis of stream ordering. It can be taken as a basic erosional landscape unit where land and water resources interact in a perceptible manner (Sebastian et al. 1993).

The consideration of watershed as the basic unit in development planning is again necessitated by the fact that down stream is often affected due to developments in the upstream (Seshagiri Rao 2000). Also, a watershed is an open physical system in terms of inputs of precipitation and solar radiation and out puts of discharge, evaporation and re-radiation. For all practical purposes it can be taken as balanced system, whether it is water balance or energy balance (NRSA 1999). Thus, the watershed approach is holistic, linking upstream and down stream areas and the chain of cause and effect relationships is related by hydrologic processes. Watersheds are also convenient units for performing economic analysis and for considering many physical changes that are linked to resource utilization and development. Most facets of resource development, including on-site (project) and off site changes and impacts can be evaluated (Ministry of Water Resources 1997).

The action plans, area specific and locale specific, generated through watershed concept are implemented in the field. Cost benefit analysis is the technique widely used for evaluating the rural development programme, water resources and highway development, other investments etc (Bently & Tiwari 1996). Benefit-Cost analysis is based on economic principles and is analogous to the capital budgeting process for the investor owned firm. However, the govt. considers, in addition to economic benefits, social and environmental consequences of investment proposals (Shanmuganathan 1998). Based on these parameters an approach is developed for evaluating the performance of various watersheds. The approach considers Develop Index between zero and one, weightage considered for each parameter and working out watershed development units before and after the developmental activities.

INTEGRATED APPROACH FOR SUSTAINABLE DEVELOPMENT

When the objective of the watershed management programme is the development of the land and water resources in an optimal and sustainable way, the approach has to be holistic and integrated one(Virmani et al. 1994) . The notion of sustainability is often associated with the management of a resource for maximum continuing production consistent with the maintenance of a constantly renewable resource stock. Such a view of sustainability requires the maintenance of the 'maximum sustainable stock', i.e. the level of the resource stock at which the renewability of the resource attains it's maximum (Rao 1992). This calls for maintaining the fragile balance between productivity functions and conservation practices through the monitoring and identification problem areas and implementation of locale-specific development plans. As the developmental needs are locale-specific, controlled by a number of factors related to state and extent of the resources, socioeconomic profile, aspects of climate and topography, etc., the action plan for resource utilization and management can be arrived at only by the synthesis of various information (Srinivasa Rao et al. 1994). Only such an approach can ensure the optimal level of interaction between three systems namely the biological and resource system, the economic system and the social system through a dynamic and adaptive process of trade off.

Selection of a particular approach depends upon the overall objectives and also the resource available and will vary from place to place according to the administrative setup. The best approach may be the one, which considers the ground reality and available resources and gives equal importance to planning and implementation.

Remote Sensing and Geographic Information Systems (GIS) for Integrated Watershed Management

Remote Sensing is a powerful tool for generating large amounts of data related to nature and it's resources in a relatively short time, and can be prominent source of information for a GIS (Srinivasa Rao et al. 1996). More over, a GIS represents the most effective mechanism for utilising remotely sensed data and also enhances the effectiveness of this data through correlation of Remote Sensing input with data already stored in a GIS (Rao, Chandrasekhar & Jayaraman 1995).

The effective utilization of the large amounts of spatial data produced by Remote Sensing systems is dependent upon the existence of an efficient geographic data handling and processing system that will transform the data into usable information (Navalgund 1991). Through the operationalisation of Remote Sensing technology in watershed management is not yet fully achieved, its capability is emphatically proved. The results are encouraging, but the quest for further refinement as well as extension of this technology has to be continued enthusiastically.

Geographic Information Systems (GIS) have become an effective tool in planning the integrated development of a watershed as Remote Sensing derived information can be matched or integrated with the conventional database (Navalgund & Tamilarasan 1998). The quantity and type of information to be coupled to arrive at a decision may be too large that it may become a Herculean or impossible task in most cases. These diverse data systems can be input into the computer system and may be modified, manipulated or converted into consistent map format. Using suitable software, specific integration and analysis of these data can be performed to derive useful out puts in the form of maps or statistical data.

Approach

A practical approach in planning, directed at preservation, conservation, development, management and exploitation of the natural resources of the watershed for the benefits of the people has to operate with in the frame work of

- Physical and biological attributes
- Socio economic conditions and
- Institutional constraints.

Physical and biological attributes comprise baseline data on geomorphology, geology, soils, hydrogeology, hydrology, climate, demography, plant, animal and other biological resource (Our Common Future 1987). Socio economic conditions relate to information on basic needs of the people (Nayak & Anil Mahajan 1991), input output relationships, marketing and transportation arrangements, developmental incentives and facilities, such as technologies, equipments, labor, material, energy/power, etc. Institutional constraints relate to laws, regulations and ordinances; Governmental policies and priorities; political acceptability; accepted customs, beliefs and attitudes of the people and administrative support (Krishna Murthy , Radhakrishnan & Chandrasekhar 1993).

Planning Goals: Based on the preparatory information, the following broad planning goals are addressed.

- Provide for basic needs of the people - water, fuel, food, and fodder
- Develop and optimize primary production systems and practices - Agriculture, Forests, Grasslands, fruit and other Economic plantations.
- Control of soil erosion /land degradation and reclamation of degraded lands
- Soil conservation, sediment control and run-off moderation
- Optimize production minerals with proper plans for rehabilitation of mined areas
- Restore wastelands to their production potentials consistent with land capability classification
- Development and management of surface and ground water resources
- Optimize irrigation and management of agricultural land
- Promote animal husbandry, dairy development and poultry
- Industrial growth, environmental security and improvement of socio-economic conditions

Resources Data Bases – Primary Spatial Data Generation

Consistent with the watershed level planning requirement, thematic maps are generated using Indian Remote Sensing Satellite (IRS) data. Both the digital and visual techniques are followed interactively. Special technique of stratification, layered approach and composition, aggregation, refinements are adopted wherever necessary to improve the quality of mapping. The primary thematic maps generated are land use / land cover, soil, geology, geomorphology, digital elevation, drainage and watershed boundaries, transport network & village boundaries.

Derived Spatial Data Base : Basic maps are used to produce utilitarian types of maps to serve planning decision. They are derived, in some cases, by direct translation of single thematic map and in others by combination of two or more thematic maps or chosen parameters of the different themes. These are slope, land capability, land irrigability, ground water potential, run-off potential, run-off depth, peak run-off rate, peak run-off volume etc.

Attribute Data Base Compilation: As mention earlier, socio-economic condition and institutional constrains greatly influence the developmental programmes. Voluminous information on these aspects exists at various sources and at different levels are collated and quantified. These are demographic, basic facilities, sociologic, financial, policies and priorities and complementary data such as agronomy, forest, industrial and achievements and on going activities.

Data Integration And Development Alternatives: The integration of the various thematic maps and attribute data and further manipulations/ analysis for identifying alternatives for development is carried out using the state-of-art geographic information system. The digitally classified outputs corresponding to geology, geomorphology, soils, land use and their derivatives is feature-coded and stored in the map information system. These individual maps from corresponding map file is integrated to arrive at "Composite Mapping Units" (CMUs). The socio-economic, institutional and other statistical data is entered into the attribute database. The decision criteria is structured within the framework of resources potential and other determinants to evolve a pragmatic model.

Composite Mapping Units : It is three dimensional landscape unit homogenous in respect of characteristics and qualities of land, water and vegetations and separated from other dissimilar units by distinct boundaries. The CMUs characteristics imply physical parameters of the component resources of a biophysical domain (Indian Space Research Organisation 2001). Whereas qualities are suggestive of their potential for specific user under the defined sets of conditions. Based on the interaction among the basic resources of land, water and vegetation which form the major component of primary production system, useful inferences is drawn about their predicted behavior in meeting the various planning goals (Kakde 1985).

Integration of geological, geomorphological, hydro geological and land use data with geophysical investigations gives ground water potential. On application of land capability classification (LCC) models, optimal broad land use category is derived from composite mapping unit (CMUs). This when matched with present land use (indicated by CMU) helps decision of broad land use revision matching LCC. The need for specific programme of development, conservation and management is accessed by application of run-off potential classification (RPC) model, land irritability classification model (LIC) and productivity index value (PIV).

Transfer of action plans from small scale to large scale: The action plans for land resources and water resources and soil conservation measures are generated at 1:50,000 scale in GIS environment. It becomes difficult to identify the site specific and area specific action plans at the individual farmer or group of farmers. It is a necessity to transfer the action plans from 1:50,000 scale to large scale i.e. 1:12,5000 scale. There are no topographical / base maps available at this scale. The large-scale maps available are on 1:4000 scale depicting individual land holding details. The scale range is too high from 1:50,000 scale to 1:4,000. The satellite data available in different spatial, spectral, radiometric and temporal resolution is possessing the cartographic potential at different scales. The cadastral (village) maps are registered with High Resolution Edge Enhance Color Composite (HREECC), generated using IRS – panchromatic data of 5.8 meter spatial resolution and multi spectral data of 23 meter spatial resolutions. This output makes it possible to transfer the action plans from small scale to large scale (Rao, Navalgund & Krishna Murthy 1996).

Implementation and Monitoring

The actions are implemented in the field from the funds available through various schemes at district level. The Chief Executive Officer will be nodal officer along with two committee's namely Central Coordination Committee and Project Implementation Committee will monitor the utilization of funds and smooth coordination of implementation programme (NRSA 1995).

PERFORMANCE OF THE WATERSHED

The performance of the watershed in terms of increased productivity depends upon the

- Effectiveness of the planning
- Financial Inputs
- Natural Inputs

Pragmatic development planning : The developmental plans are generated using pragmatic approach. Practically feasible, economically viable and technically sound approach is envisaged while generating the action plans (Rao, Chandrasekhar & Jayaraman 1995). The sustainable action plans are generated using

- Watershed as the basic developmental planning
- Use of Remote Sensing & GIS for thematic map generation and integration
- Integrated approach rather than sectarian
- Optimum utilization of land and water resources in a perceptible manner
- Micro level planning

The benefits of Remote Sensing based action plan over an action plan prepared with conventional techniques is on positive side. A discerning observer would realize that RS gives at the end of day is just information – and this could be obtained through conventional techniques as well. Only the information obtained through RS is cost effective, a lot more credible, timely, and accurate and takes a holistic perspective etc (Shanmuganathan 1998). These factors will contribute to a better societal value and could be legitimately attributes to RS.

The performance of Remote Sensing and Conventional against the parameters considered, i.e., holistic approach, timeliness, accuracy, acceptability, spatial information, thematic density, repeatability and cost, were obtained from the experts and coordinators of watershed development activities (Shanmuganathan 1998).

Σ RS * W = 6.35 and Σ Conv * W = 2.87, against a theoretical maximum score of 7. This clearly demonstrates that Remote Sensing is a superior method of Information Generation.

The sustainable development aims at overall improvement in the quality of life of the concerned people centered on preservation, conservation and optimum management of natural resources, through balancing the requirements of present generation and meeting the needs of the future generations (Rao 1996).

The basic needs of present generation can be assessed through drinking water, food and fuel wood and fodder needs of the cattle population (Ministry of Rural Development 2000). The RS derived information and socio economic data can be collectively used for estimating the demand and supply conditions of basic needs and the planning can target on the surplus / deficit conditions (Joshi et al. 1995). This type of assessment is one among the best tools for analyzing the performance of the watershed.

The above activities will ensure that the action plans are sustainable and if implemented according to these suggestions, and the watershed is bound to show positive impact and the overall productivity will increase.

Financial Inputs

The action plans that are implemented are area specific and local specific. The activities that are carried out in the field are loose boulder structures, check dams, nala bunds, percolation tanks, under ground bandharas, farm ponds, minor tanks, paddy bunding, contour trenching, social forestry, dug wells, bore wells, hand pumps, silvi pasture, horticulture, agro-horticulture, agro-forestry etc (Sharma et al. 2001). In National Watershed Development Project for Rainfed Areas (NWDPRA) and in IMSD projects, the amount sanctioned and utilized for implementation is in the tune of Rs. 1,500/- to Rs. 5,000/- per hectare. The implementation period is around 5 years.

Cost benefit analysis is the technique widely used for evaluating the rural development programme, water resources and highway development, other investments etc. Benefit-Cost analysis is based on economic principles and is analogous to the capital budgeting process for the investor owned firm. However, the govt. considers, in addition to economic benefits, social and environmental consequences of investment proposals.

Accurate cost-benefit analysis is especially difficult in the context of government on account of

- the benefits of investments are the sum of the gains to all citizens, not simply revenue to the government; the same is true of costs
- the benefits and costs are not confined to monetary flows, but can include non-monetary or intangible values
- government must ask if the prices are correct estimates or indicators of social benefits and social costs; Adjusting prices to reflect non-market effect raises innumerable analytical and value questions

The costs involved in watershed development can be broadly categorized into two (2) categories.

- Plan Preparation Cost (PPC)
- Plan Implementation Cost (PIC)

The costs involved in generating action plans (PPC) using RS & GIS ca be grouped under the following four heads

- Costs of satellite data
- Costs of ancillary data
- Man Power costs
- Costs of Image interpretation and Analysis
- Field verification Costs
- Depreciation and Maintenance
- Institutional Overheads

There also may be indirect costs associated with the project and are indirectly born by others.

Estimating benefits :

Benefits are also classified as being direct and indirect. Direct benefits are those that will result in an increase in national income. The benefits that are often considered in benefit – cost analysis are

National Economic development benefits: changes in the economic value of the national output of goods and services

Environmental quality benefits: Non-monetary effects on significant natural and cultural resources

Regional development benefits: changes in the distribution of economic activity among regions that may result from each alternative plan

Other social benefits: benefits relevant to the planning process but not reflected in the other three categories

The range of these benefits suggests that we should take a broad approach to the definition of benefits. The following benefits should also be taken into consideration, like the value of additional output of agricultural products – increase in cropping intensity, increase in cash crop acreage, increase in crop yields, increase in ground water storage, decreases in run-off volumes and decrease in soil loss. These benefits indirectly benefit in terms of mitigating the drinking water problem, increase in economic strength of individual farmers, round the year work, strength to face drought and famine and increase in social status of individuals. Based on the above-mentioned procedure, cost benefit analysis can be carried for each watershed and can be evaluated based on the ratio.

Natural inputs

The development of the watershed also depends upon the rainfall- amount, duration and timeliness. If there is any deviation in the rainfall, it will severely effect the natural resources of the watershed and human and cattle population. The deviation of the rainfall from its normal may have positive or negative impact on the watershed. An increase in the rainfall, without causing floods, can improve the development of the watershed. The overall development depends upon the natural inputs like rainfall and energy in addition to the additional developmental activities. The effect of these two parameters have to separately identified and estimated. The absolute increase/decrease in the natural inputs can have varying impact on different watersheds. Hence, it is ideal to model these inputs according to the agro-climatic zones. Hence, development of performance indicators for watershed development at agro-climatic zones will meet the requirements.

Batelle Environmental Evaluation Systems

Environmental Evaluation System (EES), developed by Batelle, is being used to quantify the environmental impacts of water resources development project with respect to ecology, environmental pollution, esthetics and human interest (Srinivasa Rao 1995). Measures of impacts in each of these categories are expressed in Environmental Impact Units (EIU) to allow for explicit trade offs between beneficial and adverse environmental changes. Thee EES also provides an alerting system that identifies particularly environmentally sensitive areas of a proposed project. In addition to providing information on environmental impacts of specific project proposals, the EES can be used in the planning phase to identify project designs that meet most development objectives while minimizing adverse environmental impacts.

The BEES can be adopted for analyzing the watershed performance. The system has envisaged more of environmental quality in terms of water pollution, air pollution, noise pollution, ecology, and human aspects. The cost benefits, the rainfall inputs and the intangible benefits were not considered effectively in BEES, which are critical for watershed performance analysis, in BEES. But the logical framework provided by BEES can be adapted for evaluating the watershed performance.

METHODOLOGY FOR PERFORMANCE INDEX DEVELOPMENT

The above mentioned performance analysis techniques have worked very well using different parameters. The cost benefit analysis considers the parameters which has economic importance only. The target based analysis, like food, fodder and fuel wood considers the changes in demand/supply pattern. The NWDPRA index considers mostly the parameters that can be derived using Remote Sensing data. Each one has its significance based on the approach that can be utilized to determine the performance of the each watershed. An effort is made here to combine the advantages of the different techniques and generate one single performance index that can work effectively. The categories and the parameters considered are

- Derived from Remote Sensing Data (350)
- Food, Fodder and Fuel wood status (300)
- Socio-economic conditions (200)
- Derived indices from spatial data (150)

Derived from Remote Sensing Data (350)

- Cropping intensity (70)
- Wastelands (70)
- Residual fallow land (70)
- Water body (70)
- Forest density (70)

(Open to Dense, Degraded to Open, and Blank to Degraded)

Basic needs status (300)

- Drinking water condition (60)
- Demand / Supply status of pulses (60)
- Demand / Supply status of cereals (60)
- Demand / Supply status of fuel wood (60)
- Demand / Supply status of fodder (60)

Socio-economic conditions (200)

- Social backwardness (50)
- Economical backwardness (50)
- Economic infrastructure and services (50)
- Basic amenities (50)

Derived indicators from spatial data (150)

- Run-off from the watershed (50)
- Soil erosion (50)
- Ground water condition (50)

Quantitative elements of the Watershed Development

Watershed development is expressed in watershed development units. To express the development in the commensurate units, it is necessary to develop for each parameter a Value function and Parameter weights. In the development of these two elements, it is important to include individuals that represent a cross section of society. In this way the value functions and weights will not reflect individual bias. Developing value functions:

Scientific information and professional judgment formed the basis for the development of the value functions. This information would specify the form of the function and the points of inflection or change. The suggested procedure for this estimation divides the watershed development index (DI) range (0 – 1) into an equal number of intervals. For each of these intervals an estimate of the functional relationship between the watershed development and the parameter value is determined.

Developing parameter weights

The relative importance of the parameters in the watershed development analysis was expressed in commensurate units (PIU) by quantifying several individual's subjective value judgments. Delphi procedure is used to produce a technique that, in general, is systematic in nature, minimizes individual bias, produces consistent comparisons and aids in the convergence of judgments.

Relative Parameter Weighting

Parameter importance units are assigned to the parameters by first distributing the 1000 PIU to the 4 categories, then to the 17 quantitative parameters. The parameter weights reflect the relative importance of respective parameter measurements as indicators of overall development of the watershed. Subsequently, the Watershed Development Units (WDU) are arrived in the following way.

$WDU = PIU * DI$,
where

WDU = Watershed Development Units
PIU = Parameter Importance Units
DI = Development Index (0- 1)

The WDU for the watershed can be calculated before and after the particular development programme. The absolute values indicate the overall development of the watershed and the differences in WDU represents the impact of a particular development programme carried out in the watershed. However, the natural inputs and the financial inputs will influence the WDU. The WDU will be normalized to derive the effective watershed development units.

The rainfall normalized Watershed Development Units (WDU) of a particular watershed over a period of time is calculated below

$WDU_{r,2} = WDU_2 * R_1 / R_2,$
where

$WDU_{r,2}$ Effective watershed development units in the post season
WDU_2 Watershed development units in the post season
R_1 Average annual rainfall in the pre season
R_2 Average annual rainfall in the post season

The Performance Index (PI), i.e., the impact of the developmental activities in a watershed is calculated in terms of WDU

Performance Index = $WDU_{r,2} - WDU_1$

The positive performance index indicates the positive impact of the developmental activities in a watershed.

For comparing the PI of various watersheds, the financial inputs also should be taken into consideration. The Normalized Performance Index $(PI)_n$ can be calculated in the following way

$PI_n = PI_1 / C_1 = PI_2 / C_2$,
where in

PI_1 = Performance Index of the watershed 1
PI_2 = Performance Index of the watershed 2
C_1 = Total Cost of Plan Preparation & Implementation of watershed 1
C_2 = Total Cost of Plan Preparation & Implementation of watershed 2

The above methodology for developing performance index of watershed for analyisng the impact of watershed developmental activities using DI, PIU, WDU, WDU_n , PI and PI_n is being applied in many watersheds.

DISCUSSION

Uma_Gani watershed comprising of 17000 ha has been prioritized and selected based on its socio-economic backwardness and resources potentials for detailed analysis and action plan generation.

The satellite data for the years 1995, 1996 and 1997 are evaluated for changes in Land use/Land cover and the impact. Some of the salient statistics are given below. The cropping intensity has increased from 107% to 127%, the horticulture plantation area has increased from 5% to 6%, the average yield of Rice has increased from 1.6 to 2.4, the wheat from 0.65 to 1.1 and the cotton has 1 to 2.1 t/ha. The ground water table level has increased attaining equilibrium condition and the problem of drinking water was solved in the watershed using ground water conservation and recharge measures. Although the rain input in the year 1996 to 1997 is around 60% of the average annual rainfall, the cropping intensity and the yields have increased significantly showing trends of sustainable development. On a sample basis, farmer level information collected to identify the trends in the economic reforms. The farmer has achieved good economic returns to the tune of 10 folds in the marginal lands (100$ to 1,000$), 4 folds in moderately developed lands (300$ to 1,200$) and more than 2 folds in developed lands (600$ to 1,400$).

Using the performance index, IMSD, NWDPRA and DPAP area watersheds are analysed. The Uma-Gani nadi watershed has shown an improvement of 19 % (from 419 to 498), Malthan watershed 14% (from 369 to 420) and Junginala watershed an improvement of 15% (from 384 to 441). In these study due non-availability of information regarding derived indicators, they are not included in the final analysis.

CONCLUSIONS

Using the performance index, the IMSD, DPAP and NWDPRA watersheds are analysed successfully. All or some of the parameters, depending upon the availability, can be used for evaluation of the watershed. Comparison of the performance of the different watershed is possible. The system has the capability for holistic approach of evaluating ecological and economical benefits.

In future, some more parameters and sub-parameters can be included to make it more effective for evaluation of the different watersheds across various terrains.

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