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Geoinformatics for ecological-economic zoning towards land use planning in Yerrakalava Catchment, Andhra Pradesh

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Abstract

Ecological and economic zoning (EEZ) is an alternative approach to Agro-Ecological Zoning (AEZ). In this alternative approach socio-economic factors are also included. The Errakalava catchment is selected for its variability in resources and social aspects. The information system is developed for resource inventory of primary and secondary data in a GIS environment. Relationships established among all the parameters, find limited significant parameters for zoning. By overlaying the physiography, irrigation, slope, soil depth, surface texture, ground water potential, production systems, population density, literacy per cent and infrastructure, 42 zones are mapped under the EEZ approach. The delta is characterised with better physical resources, canal irrigation, high literacy per cent and limited social conflicts. It needs a policy on long term education and employment with short term land rights.

Additional keywords : GIS environment, sustainability, policy.

Introduction

Ecological and economic zoning (EEZ) is an alternative approach to Agro-ecological Zoning which is based on physical factors and crop production only. It includes socio-economic factors and a wider range of land uses (FAO 1996). The increasing pressure for food security and desire for improved economic returns from land resources have become the major concern for the policy makers and conservationists. There is a need to establish a balanced approach to maintain sustainability. To achieve any goal, all the variables and their contributions must be analyzed critically for improving the possible and economically feasible condition. In princi-

ple, EEZ deals with people and their social organization. People comprise the actual or potential land users, including individuals, communities or governments holding traditional, current or future land rights.

The principle aims of EEZ (Sombroek 1994) are (i) to identify areas where particular uses may be encouraged through development programmes, services, financial incentives etc., (ii) to identify areas with special needs and problems, as well as areas which require protection or conservation, and (iii) to provide a basis for infrastructural development.

EEZ has no priori bias towards high-input and high-producing agricultural land use. It considers a wide range of uses which may satisfy the needs of the stakeholders. These needs may be incompatible to a greater or lesser extent and they may change over time. The use of "multiple goal analysis" and subsequent optimization enable the ranking and periodic reassessment of objectives to select the optimum use (or non-use) of the defined area.

EEZ is applicable to all geographic scales and for lands of any intensity of use. In practice, it is mostly used in large tracts of land such as major river catchments and physiographic regions that have as yet a sparse human population. An essential element of EEZ is its dynamic character due to changing economic scenario both inside and outside the system.

The ability of the world's natural resources to satisfy the needs of its growing population is a fundamental issue, where the basic problem is mounting pressure on natural resources. Limits to the productive capacity of land resources are set by climate, soil and landform conditions, and by the use and management practices. The purpose of zoning, as carried out for rural land use planning, is to separate areas with similar sets of potentials and constraints for development. The AEZ, envisaged in FAO studies, defines zones on the basis of combinations of bio-physical patterns (soil, landform, climate, etc.). AEZ can be regarded as a set of core applications, leading to an assessment of land suitability and potential productivity. Several studies were carried out using AEZ approach world over (FAO 1978; Higgins and Kassam 1981; Krishnan 1988; Sehgal *et al.* 1990; FAO 1994).

The Socio-Economic Zoning (SEZ) can be regarded as a set of core applications leading to an assessment of population support capacity, infrastructure require-

ments, acceptability of proposals, social conflicts, etc. The SEZ defines the zones based on the combinations of social and economic patterns (population density, population growth rate, literacy per cent, tribes density, infrastructure, farm size, etc.). Each zone has a similar combination of constraints and potentials for land use, and serves as focus for targetting the recommendations designed to improve the existing land use situation.

The term 'geoinformatics' is regarded as follows:

- 'Geo' stands a short form for geographical which represents spatial data. This data must be referenced with space, i.e. georeferenced and displayed in the form of a 'map' (Meijrink *et al.* 1994).
- 'Infor' is a short form of information, which may be viewed as data with added knowledge. This excludes the input-output system for storage, retrieval and display of data.
- 'matics' may be referred as system, which is for structured communication between user and computer to provide information for support operations, management, analysis and decision making.

Study area

The study covers the catchment area of Errakalava and its continuation as Yenamadurru drain in irrigated deltaic region. It lies between 81° to 81°30' East longitudes and 16°30' and 17°30' North latitudes covering an area of about 2450 sq. kms. The area is broadly divided into three natural regions viz. Delta, Upland and Agency areas. The mandals (administrative regions) covering this area are Chintalapudi, T. Narasapuram, Jeelugumilli, Buttayagudem, Jangareddygudem, Koyyalagudem, Kamavarapukota, Dwaraka Tirumala, Nallajherla, Devarapalli, Tadepalligudem, Niddadavolu, Undrajavaram, Tanuku, Pentapadu, Attili, Ganapavaram, Pemumantra and Palakoderu.

Methodology

The FAO's AEZ concept is essentially a simple one and widely applied in many studies. The combination of the AEZ and SEZ would result in EEZ for the land use planning as the methodology shown in the figure 1. The nature of analysis, which involves the combination of layers of spatial information to different zones, lends itself to the applications of a geographical information system. A series of

databases are linked to the GIS and dedicated computer models, which have multiple potential applications in natural resource management and land use planning.

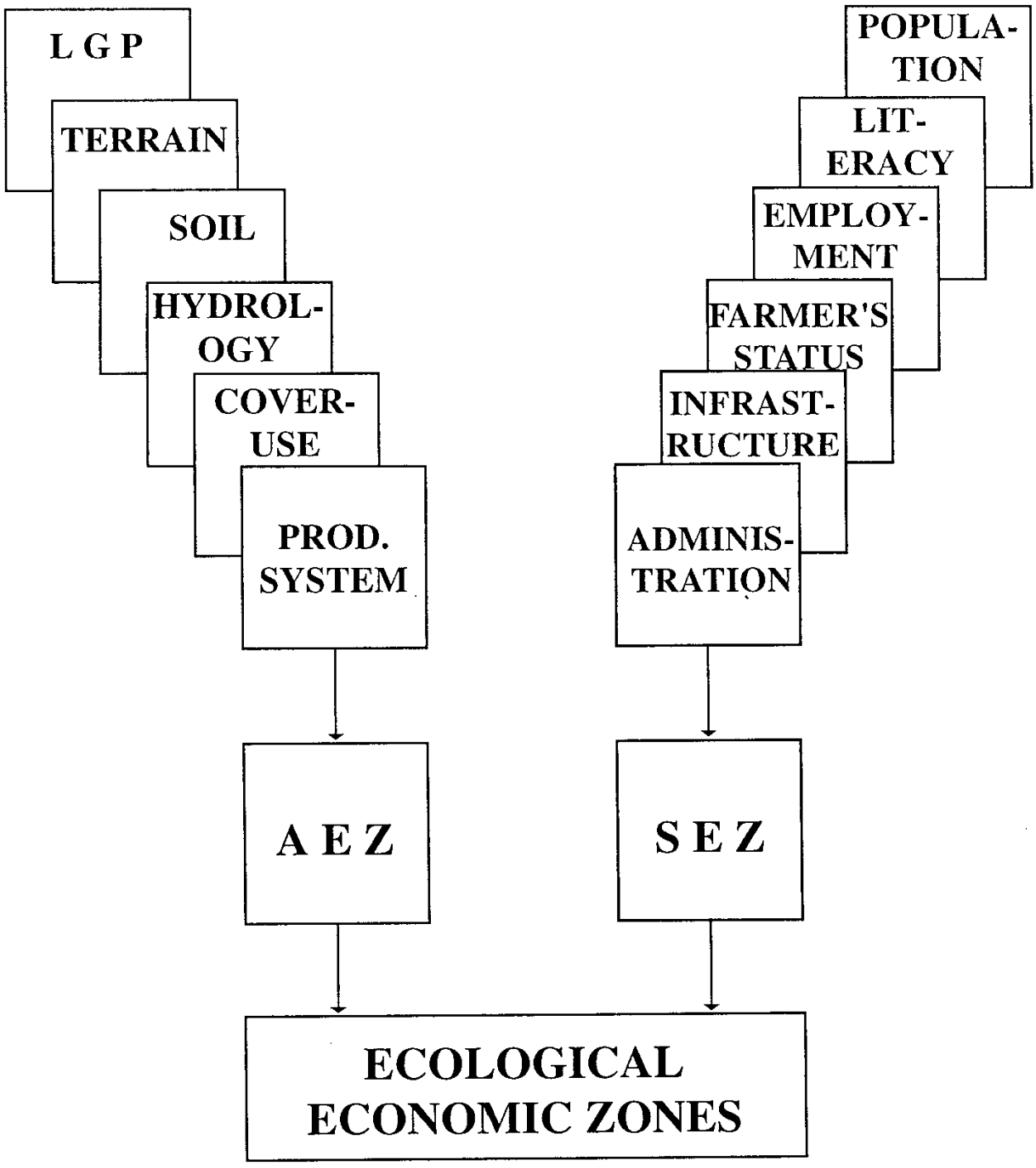

Fig. 1. Flow chart for ecological - economic zoning algorithms.

The biophysical factors considered for this study are length of growing period (LGP), terrain, slope, hydrogeomorphology, ground water potential, soil depth, surface texture and soil reaction (pH). The hydrogeomorphological map of West Godavari district (1:250,000) prepared by state ground water board and NRSA in 1990 is referred to for the mapping in the study area. The map is modified with the ground truth, toposheets of 1:50,000 and digital images of LISS III data. The soil resource map of Andhra Pradesh (Reddy *et al.* 1996) is referred and modified with ground truth for soil related parameters. The contour lines of 20 metres interval and some benchmarks in the delta are digitized and DEM is generated. Slope map is derived from the DEM and reclassified as per the classes given by Sehgal et al. (1987). The concept of integrating remote sensing and GIS is comparatively new and has proved to be an efficient tool in ground water studies (Tustafsson 1993; Saraf and Jain 1994; Saraf et al. 1994; Krishna Murthy and Srinivas 1995; Krishnamurthy et al. 1996). The characterization of geomorphology of the area and its relationship with geology and ground water potential was established. The land use/cover map is prepared using digital image processing IRS LISS-III data and ground truth. A relationship among biophysical factors has been established and area analysis is carried out in GIS.

The socio-economic data of 1991 has been taken from the district hand book of statistics published by the Chief Planning Officer. The mandal boundaries are digitized over the same base, and socio-economic data is generalised and linked with the mandal maps.

A relation is established among the social parameters and also social factors with production factors. The social factors considered for analysis are population density, population growth rate, literacy per centage, scheduled tribes and caste density, employment and status of farmers. The production systems considered to find the relationship are food crops, non-food crops, cattle, buffaloes, poultry, etc.

EEZ is in fact a form of land use planning that needs many bio-physical and socio-economic factors to be considered, correlated to the social aspects and also with production systems. To reduce the ambiguity in mapping 10 significant parameters are considered viz. LGP, physiography, groundwater potential, slope, soil depth, surface texture, production systems, population density, literacy and infrastructure. The selected parameters varied based on the ecological and economic scenarios of the area.

To establish the relation between the bio-physical factors and social aspects, overlay techniques of GIS have been used. The population density, literacy per cent, farmer's status, tribal population density, are generalized and overlaid with the bio-physical maps. The spatial distribution of different categories are analyzed using GIS and tabulated.

Results and discussion

Length of growing period/irrigation : The concept of growing period is essential in providing seasonality in land resource appraisal. The LGP is ranging from 190 days to 230 days, but there is assured canal irrigation for 11 months in the delta, so the area is considered in 2 distinguished classes viz. canal irrigated (I) and rainfed (R) where the LGP is 190-210 days.

Drainage and watershed : The study area is a catchment of river Errakalava, fed by several small rivers like Jalleru Vagu, Baineru Vagu and Gostanadi draining the watershed. The Errakalava drain is of the 6th order, which fans out before entering the delta showing yazzo pattern. It may be due to the sediment deposition in the depressions over a period or due to some tectonic activity. The river again recollects to form a single channel after entering the delta. The drainage pattern has been converted into canals and drains in the intensively cultivated area.

Hydrogeomorphology : On the basis of weathering, buried pediplain can be further sub-divided into deeply and moderately weathered pediments of various rocks. The pediplain and pediment with inselbergs are also mapped based on geology. The hills and ridges comprise Khondalites and Charnockites. The delta and transitional plains comprise alluvium. The geomorphological map is digitized, polygonized and attributed using ILWIS ver. 2.1 (1997). The relationship for hydrogeomorphology, soil and ground water prospects is established and listed in table 1.

Slope : The per cent slope map generated from DEM has been applied a 3X3 majority filter to smoothen its boundaries. The slope classes have been defined. The deltaic plain and transitional plain and some parts of the flood plains are under slope class level (0-1%) covering an area of 128517 ha. The area under 'very gently sloping' class is 72336 ha. and 15368 ha in 'gently sloping' class covers uplands. Whereas, moderately steeply sloping, steeply sloping and very steeply sloping lands cover the hill and ridges of Eastern Ghats and Chintalapudi Sandstone areas.

Table 1. Hydrogeomorphological relationships of the study area.

Geomorphology	Lithology	Area (ha)
Delta Plain	Alluvium	44675
Transitional Flood Plain	Alluvium	10533
Transitional Plain	Alluvium	4125
Transitional Pediplain	Alluvium	5799
Uplands Filled Valley	Colluvium	14121
Uplands Pediplain	Deccan Traps	2864
Uplands Pediplain	Tirupati Sandstone	13598
Uplands Pediplain	Gollapalli Sandstone	8013
Uplands Pediplain	Chintalapudi Sandstone	76727
Uplands Pediplain	Khondalites	6985
Bazada	Detrital Material	22694
Uplands Pediment	Raghavapuram Shales	2288
Uplands Pediment	Gollapalli Sandstone	1421
Uplands Pediment	Chintalapudi Sandstone	8986
Eastern Ghats Pediment	Khondalites	4460
Eastern Ghats Hills & Ridges	Khondalites	17794

Ground water prospects : Ground water occurrence is influenced by the climate, physiography, drainage and geology of the area. The ground water potential zones are deduced after integration of hydrogeomorphological and lineament maps. Various hydromorphic units are grouped into very good, good, moderate, poor and non-potential zones.

The depth to ground water table varies in the delta from 7 to 35 m. The water table has risen significantly near Jangareddygudem after construction of Vengalaraya Sagar. The prospects of water and rise of water table is noticed after construction of several dams and water harvesting check dams. Near the flood plain, the water table has risen to 30 m depth from the ground. The depth to water table in the uplands ranges from 60 to 100 m in the pediplains and bajada. The delta plain, transitional

plain and flood plain have very good ground water potential. The pediplains of both stages of weathering have moderate potential. Bajada and pediments have slight potential. The hills and inselbergs have no prospects of ground water.

Delta plain is having very good potential, covering an area of 78705 ha. (32%), followed by the area of good potential in the uplands near the Yerrakalava plain over sandstone covering an area of 98833 ha. (40%), bazda and pediments have slight potential and cover 35952 ha. (15 %). There is no scope of ground water potential under hills and pediments of Khondalites, but limited scope may exist along the lineaments like faults and joints in this area.

The depth to ground water in the delta is mostly shallow (<20 meters) covering an area of 44693 ha. (18%), moderate depth (20 to 40 m) in the transitional plains and along filled valley covering an area of 36014 ha. (15 %). The area under deep (40 to 80 m) class is in sandstone area of pediplains covering 102041 ha. (42 %). The area under very deep (> 80 meters) class is in bazada and pediments covering an area of 39997 ha. (16 %). The area under hills and inselbergs is devoid of ground water. The water quality is saline in some pockets of delta, otherwise the ground water is good for irrigation.

Soil Depth : Depth of soil determines the effective rooting depth for plants, the texture, mineralogy and gravel content, determine the capacity of the soil to hold water and supply plant nutrients.

The seven depth classes as given in Field Manual (Sehgal *et al.* 1987) were used to classify the soil mapping units. The soil depth classes are extremely shallow (<15 cm), very shallow (15–25 cm), shallow (25–50 cm), moderately shallow (50–75 cm), moderately deep (75–100 cm), deep (100–150 cm) and very deep (>150 cm). The area of very deep soils occurs in delta and transitional zone.

Surface texture : The surface layer of soil to a depth of about 25 cm is the layer that is most used by crops and plants. The soil texture provides a guide to understanding soil-water retention and availability, workability, nutrient holding capacity, infiltration, drainage, physical and chemical behavior, microbial activity and crop suitability (Biswas and Mukherjee, 1994). The surface textural classes observed are sandy clay loam, sandy clay, clay loam, loamy sand, clay loam and clay in the area of which sandy clay loam is covering about 50% in uplands, clay in delta and clay loam in hills and transitional zone.

Population : The population density is as high as 1000 per square kilometer in Tanuku (an urban township). It is as low as 162 per sq. km in uplands of T.Narasapuram and Jeelugumilli area and very high in the delta plains.

The population growth rate is the lowest in Attili mandal, which is about 1.1 per cent in delta and very high in Jangareddygudem mandal, which is about 3.6 per cent in uplands. The general tendency of higher population growth is in uplands than in the delta area. The spatial variability of population growth rate is generalised into various classes viz; low (<1%), medium (1-2%), high (2-3%) and very high (>3%).

There are some weaker sections in the society, protected by the Indian constitution due to the past discriminations under the section of 'Right to Equality' and covered by various schemes for upliftment of such sections. The scheduled caste distribution ranges from 7 to 31 per cent but does not follow any trend of bio-physical resources. But scheduled tribes follow a pattern with 61 per cent population in Buttayagudem and above 25 per cent in rest of the uplands. The delta is having below 1 per cent tribal population. The spatial distribution of tribal population density is generalised into various classes viz; low (<1), medium (1–10), high (10–25) and very high (>25).

Literacy per cent : The literacy per cent is the lowest in the T.Naraspuram mandal, about 27 per cent and the highest in Tanuku mandal with 56 per cent. In general, the literacy per cent is more in the delta than the uplands. The male literacy per cent is more than the female literacy all over the area, the difference being about 10 per cent.

Operational holdings : The economic status of the farmer can be represented by the size of the operational farm holdings. The farmers were grouped under various categories like marginal (<1 ha.), small (1–2 ha.), semi-medium (2–4 ha.), medium (2–4 ha.) and large (>4 ha.) farm holdings. Majority of the farmers are under the category of marginal land holdings and very few are under the large farm holdings. The number of large land holding farmers is below 10 in each mandal in the delta, whereas it is more in uplands compared to delta

Employment : The employment in the area is from 35 to 56 per cent of the population. Most of the employment is agriculture based and non-agriculture employment is in the urban fringes.

Production systems : In general, land use refers to management activities, conducted by man, related to a tract of land or an ecosystem (de Bie, *et al.* 1996). Actual land use must be described as a part of the production system.

To describe a production system and analyze its performance, individual system elements and their relationships must be identified. The dominant production systems in the area are food crops, non-food crops, plantations (mango, cashew, coconut, cocoa, oil palm, lemon), poultry and fishery, urban and industries and forest.

Relationship of social aspects : The social aspects are inter-related in their distribution in the area. The relationship among the social factors are listed in table 2. The positive significant correlation of marginal farmers and literacy per cent with population density indicates the small farm size in the densely populated area had more literate people. The significant negative correlation of population density with agriculture workers indicates higher non-agriculture employment. The significant negative population growth with literacy indicates this as major factor for contributing more population growth. The negative correlation of literacy per centage with agriculture workers indicates the illiteracy in agriculture labourers.

Relationship of social aspects with production systems : The social aspects have the influence on production systems and vice versa. The correlation of social aspects with production systems are listed in table 3. The cattle has the positive correlation with the agricultural workers which indicates that the agriculture workers use animal power. The buffalows, which are mainly milching are positively and significantly related with marginal and small farmers. The poultry has a positive correlation with population density and literacy per cent. The food crops (cereals and pulses) are positively and significantly correlated with literacy and marginal farmers. The food crops are mostly labour intensive, so the marginal and small farmers, who work in their farms, prefer to grow food crops, whereas large farmers prefer non-food crops like orchards, cash crops which have less labour requirements.

Relationship of social aspects with biophysical parameters : The social aspects are overlaid with hydrogeomorphology using GIS. The morphological units were also related with biophysical parameters. The present study indicates that there is a significant relation in distribution of population density, literacy per cent, infrastructure and production systems have the relation with all biophysical parameters.

Table 2. Correlation matrix of social factors

Factors	Population Density per sq. km	Population Growth per Year	Scheduled Tribes (%)	Scheduled Castes (%)	Literacy (%)	Agri. Workers (%)
Population Density	1					
Population Growth	–0.5942	1				
ST%	–0.3902	0.1697	1			
SC%	–0.5075	0.5423	–0.2981	1		
Literacy %	0.9387	–0.6354	–0.4685	–0.4976	1	
Agri. Workers	–0.8157	0.3964	0.5167	0.4222	–0.8256	1
Marginal Farmers	0.8151	–0.5128	–0.6027	–0.3907	0.8204	–0.79807
Small Farmers	–0.0302	0.339	–0.6886	0.378	0.0423	–0.2168
Semi-medium	–0.4872	0.691	–0.3729	0.6466	–0.4198	0.1538
Medium	–0.6852	0.7958	–0.1527	0.7962	–0.6608	0.4421
Large	–0.7809	0.8232	0.022	0.7532	–0.7723	0.5912

Table 3. Correlation between the social factors and production system factors

Factors	Cattle	Buffalo	Poultry	Food Crops %	Non Food Crops %	Paddy %
Population Density	–0.823	0.2163	0.5355	0.6619	–0.182	0.7736
Population Growth	0.7783	0.1684	–0.2165	–0.6876	0.3341	–0.8123
ST%	0.5274	–0.4883	–0.1744	–0.4614	0.1423	–0.3549
SC%	0.3693	–0.0574	–0.1402	–0.4372	0.382	–0.6358
Literacy (%)	–0.857	0.2713	0.3967	0.726	–0.2526	0.8323
Agri. Workers	0.6092	–0.5066	–0.2993	–0.5954	0.3442	–0.5947
Marginal Farmers	–0.6889	0.5979	0.4251	0.8177	–0.072	0.7948
Small Farmers	0.0035	0.7333	–0.0578	0.3228	0.1345	0.0518
Semi-medium	0.4522	0.4393	–0.3223	–0.1586	0.1933	–0.4487
Medium	0.6473	0.1416	–0.3613	–0.4653	0.2916	–0.7125
Large	0.7469	0.0194	–0.3722	–0.6081	0.2368	–0.7999

Ecological and economic zones : The layers considered for the EEZ mapping, the key and the code book for the map are depicted in the figure 2.

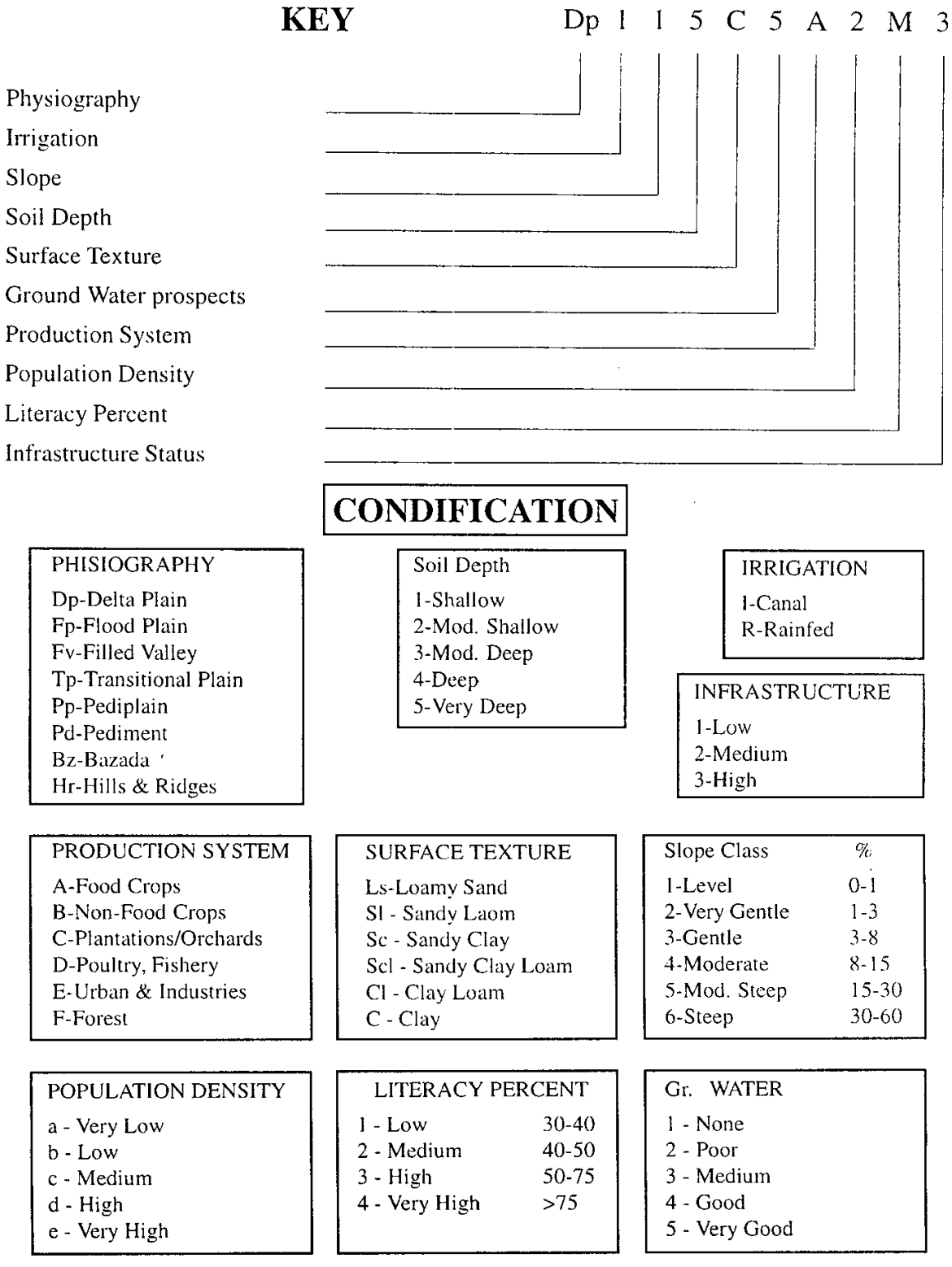

Fig. 2. The key and codification of the EEZ mapping units.

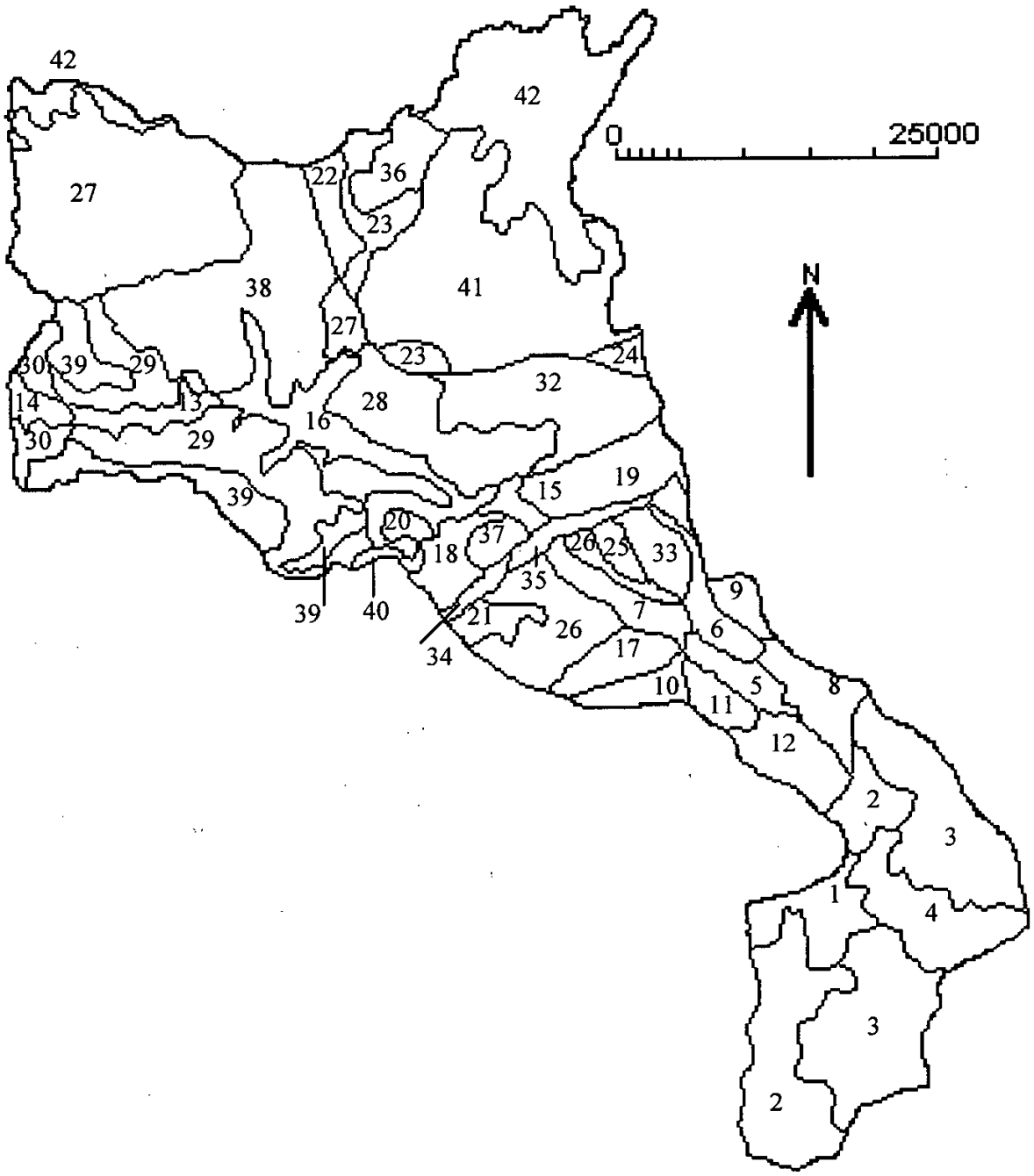

Fig. 3. Ecological-economical zone maps of the study area.

The EEZ map is generalised and the mapping units less than 500 hectares are merged with the adjacent units. The ecological and economic zones are illustrated in figure 3. The area under delta is canal irrigated and the cropping pattern is rice-rice-pulses along with poultry and farming. It is also having high population density, high literacy and good infrastructure facilities. The uplands have good ground water prospects, mixed rainfed cropping pattern along with sugarcane and orchards as main production systems. Generally the population density, literacy per cent and infrastructure are medium. The bazada landform with poor ground water potential, has production system of tobacco as a major crop, low literacy and low infrastructure facilities and low irrigation facilities. The spatial distribution of the various zones is shown in the table 4.

Table 4. Area analysis of ecological - economic zones of the study area

Unit No.	Code	Area (ha.)	Area (%)	Unit No.	Code	Area (ha.)	Area (%)
1	DpI15C5A2M3	4138	1.69	22	PpR21Scl1B1L2	2151	0.88
2	DpI15C5A3M3	13150	5.37	23	PpR21Scl1F2L1	4240	1.73
3	DpI15C5A4M3	20874	8.52	24	PpR21Scl1F2L2	891	0.36
4	DpI15C5A5M3	6433	2.63	25	PpR23Scl5A2L2	1086	0.44
5	FpI15Sc5A3M3	2108	0.86	26	PpR23Scl5B2L3	7497	3.06
6	FpR15Sc5A2L2	2454	1.00	27	PpR23Sl4B1L1	23290	9.51
7	FpR15Sc5A2L3	2869	1.17	28	PpR23Sl4B2L2	8859	3.62
8	FpR15Sc5A4M3	3694	1.51	29	PpR24Scl4B1L2	13026	5.32
9	TpI15Cl5A2L2	1424	0.58	30	PpR24Scl4B1L3	2493	1.02
10	TpI15Cl5A2L3	1969	0.80	31	PpR24Scl4B2L3	2194	0.90
11	TpI15Cl5A3M3	1818	0.74	32	PpR24Sl4B2L2	9592	3.92
12	TpI15Sc5A4M3	4054	1.65	33	PpR25Scl5A2L2	3084	1.26
13	FvR15Ls4A1L2	3086	1.26	34	PdR12Cl2B1L3	816	0.33
14	FvR15Ls4A1L3	1237	0.50	35	PdR12Cl2B2L2	1585	0.65
15	FvR15Ls4A2L2	1030	0.42	36	PdR31Cl1F1L1	3213	1.31
16	FvR15Ls4A2L3	8123	3.32	37	PdR31Cl3F2L2	1226	0.50
17	PpR12Cl3A2L3	2861	1.17	38	PdR31Sl3B1L2	18243	7.45
18	PpR13Scl4B1L3	2612	1.07	39	PdR31Sl3F1L2	7522	3.07
19	PpR13Scl4B2L2	5336	2.18	40	PdR31Sl3F1L3	553	0.23
20	PpR13Scl4B2L3	769	0.31	41	BzR22Scl3B2L1	22524	9.19
21	PpR13Sl5B2L3	1643	0.67	42	HrR53Cl1F1L1	19233	7.85

Conclusions

The geoinformatics used for the EEZ provides a view of resource limitations and social constraints for the land use planning after consideration of physical, social and economic aspects. The 42 zones considering physiography, irrigation, slope, soil depth, surface texture, ground water potential, production systems, pop-density, literacy per cent and infrastructure show the variability for problem analysis and planning. The delta is having better physical resources, canal irrigation, high literacy per cent and good infrastructure indicating high carrying capacity of population density. The uplands with moderate resources, good ground water prospects with single rainfed crops, sugarcane and orchards have potential provided the irrigation infrastructure is created. The low literacy per cent and limited resources along with non-food cropping pattern in bazada has the problems of high population growth and social conflicts, and hence needs a policy of long term education and employment with short term land right.

References

FAO (1978). 'Report on the Agro-Ecological Zones project'. Vol. 1. Methodology and results of Africa, Rome, FAO.

FAO (1994). AEZ in Asia. Proceedings of regional workshop on Agro-Ecological Zones Methodology and Applications. Bangkok, Thailand, 17-23 November 1991, World Soil Resources Report 75, Rome, FAO.

FAO (1996) 'Agro-ecological Zone Guidelines', FAO Soils Bulletin 73, Rome, Italy.

Gustafsson, P. (1993) High resolution satellite data and GIS as a tool for assessment of groundwater potential of semi-arid area. IX th Thematic Mapping Conference on Geologic Remote Sensing, Pasadena, California, USA. 8-11 February 1993.

Hand Book of Statistics (1991). West Godavari District, Chief Planning Officer, Eluru, Andhra Pradesh.

Higgins, G.H., and Kassam, A.H. (1981). Relating potential productivity to soil base (FAO) Land and Water Development Division, Technical new letter, 9 (July 1981).

ILWIS ver 2.1 (1997). 'ILWIS Applications Guide', (ITC : The Netherlands.).

Krishna Murthy, J., and Srinivas, G. (1995). Role of geological and geomorphological factors in ground water exploration : A study using IRS-LISS II data, *International Journal of Remote Sensing* **16,** 2595-2618.

Krishnamurthy, J., Venkatasesa Kumar, N., Jayaraman, V., and Manivel, M. (1996). An approach to demarcate groundwater potential zones through remote sensing and a geographical information system. *International Journal of Remote Sensing* **7,** 1867-1884.

Krishnan, A. (1988). Delineation of soil climatic zones of India and its practical application in agriculture. *Fertilizer News* **33,** 11-19.

Meijerink, A.M.J., Hans A.M. de Brouwer, Chris M. Mannaerts, and Carlos R. Valenzuela. (1994). Introduction to the use of geographical information systems for practical hydrology. ITC publication 23.

Reddy, R.S., Shiva Prasad, C.R., and Harindranath, C.S. (1996). Soils of Andhra Pradesh for optimising land use, NBSS Publ. 69 (Soils of India Series 8), NBSS&LUP, Nagpur.

Saraf, A.K., and Jain, S.K (1994). Integrated use of remote sensing and GIS methods for groundwater exploration in parts of Lalitpur district, UP. International Conference on Hydrology and Water Resources, NewDelhi, 20-22 December 1993.

Saraf, A.K., Gupta, R.P., Jain, S.K., and Srivastava, N.K. (1994). GIS based processing and interpretation of ground water quality data. In proceedings of the regional Workshop and Environmental Aspects of Ground water Development, 17-19 October 1994, Kurukshetra, India.

Sehgal, J.L., Mandal, D.K., Mandal, C., and Vadivelu, S. (1990). 'Agro-Ecological Regions of India', NBSS Publ. 24, (NBSS&LUP : Nagpur.).

Sehgal, J.L., Saxena, R.K., and Vadivelu, S. (1987). 'Field Manual - Soil Resource Mapping different States of India'. NBSS Publ. Technical Bulletin 13., (NBSS&LUP : Nagpur.).

Sombroek, W.G. (1994). Introduction to the philosophy, concepts and methods of ecological-economical zoning. Manaus workshop on EEZ in the Amazoan region 25-29 April 1994, Rome, FAO.

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