F-91-'96/NIES

Towards solving the global desertification problem (4)

—Research on the evaluation of interaction between desertification and human activities—

砂漠化問題の解決に向けて（4）

ー砂漠化と人間活動の相互影響評価に関する研究ー

Edited by Tadakuni Miyazaki and Atsushi Tsunekawa

宮崎忠国・恒川篤史　編

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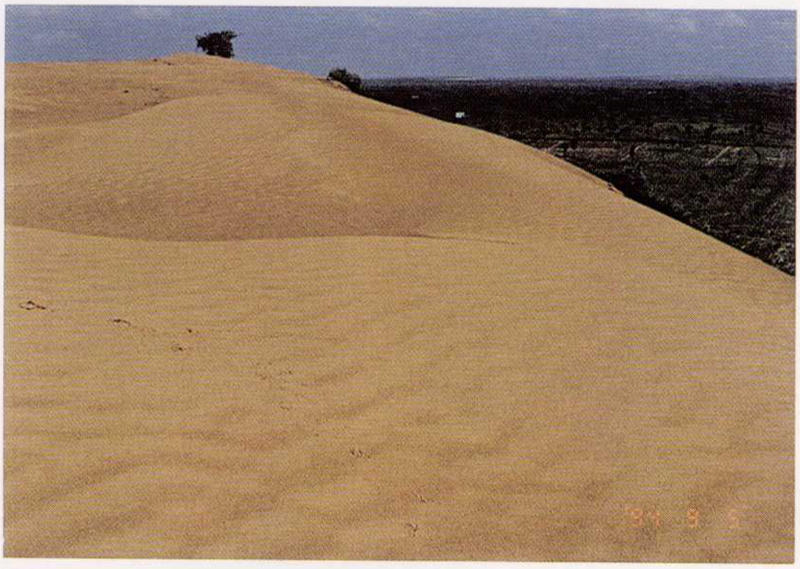

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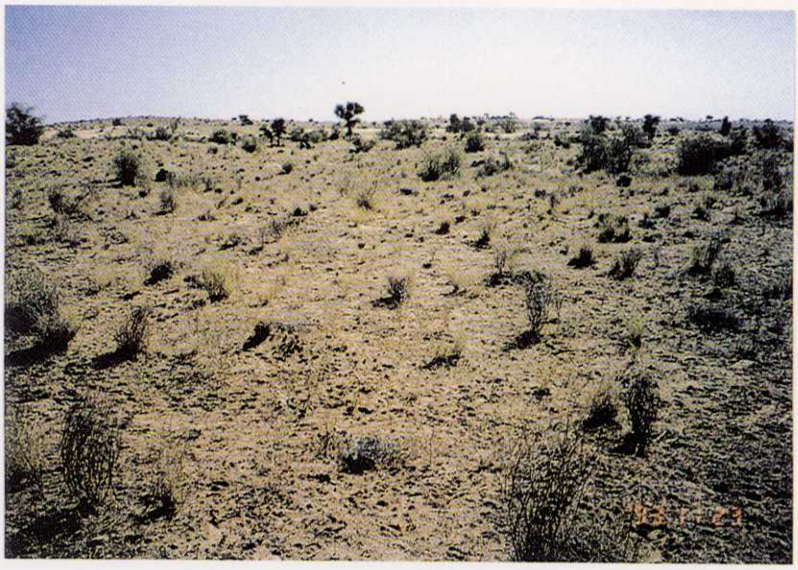

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The Thar Desert in Western India.
(a) Sand dune, (b) and (c) Open pasture land.

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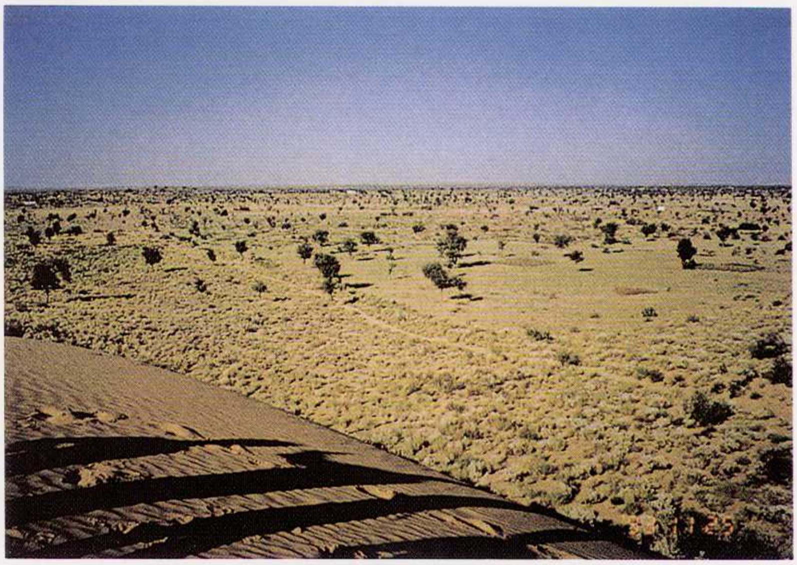

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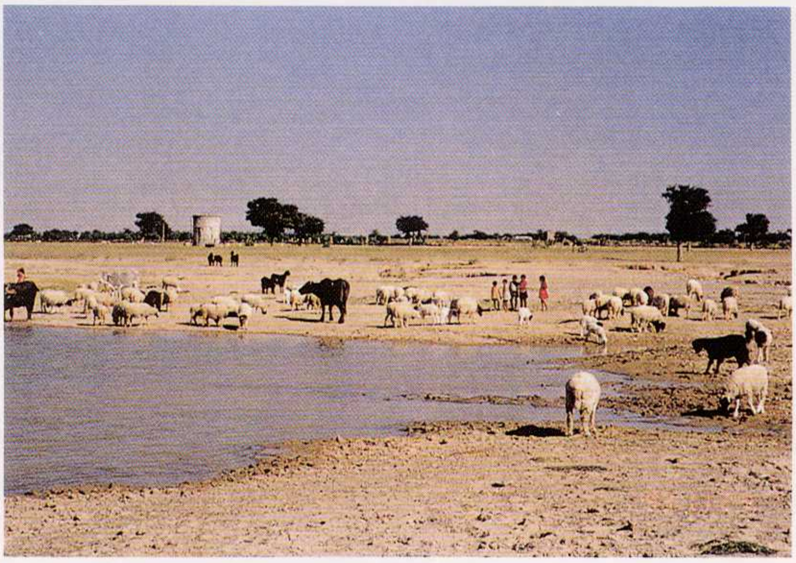

The Thar Desert in Western India.
(d) Rain fed agricultural land, (e) Irrigated agricultural land,
(f) Nadi (Water tank) - A traditional rainwater harvesting system.

Preface

According to a report by the United Nations Environmental Programme (UNEP), a sixth of the entire population, or one fourth of the entire land surface of the earth, has been affected by the desertification or land degradation. Food production has stagnated in these desertified regions, and the affected residents are exposed to famine and malnutrition, which are now big social problems.

Because of this situation, eighty-seven countries including Japan signed the "United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa" on October 14-15, 1994. Under the Convention, the developing countries and regions affected by desertification should prepare and implement action programmes, whereas developed countries including Japan should promote the scientific and technical cooperation relevant to the combat of desertification and the effects of drought.

The Japan Environment Agency established the Global Environment Research Fund in 1990 to enhance research activities to cope with growing global environmental problems. Under the research fund, the Desertification Research Project was started in 1990 as a "Feasibility study on the environmental assessment of desertification in arid and semi-arid areas", for which the National Institute for Environmental Studies played the role of a leading organization. The feasibility study continued for two years until March 1992.

Following the feasibility study, "Research on the evaluation of interaction between desertification and human activities" has been carried out as a three-year program from 1992 up to March 1995. It consists of the following three sub-themes;

(1) "Evaluation of human activities on desertification in arid and semi-arid areas", being conducted by NIES, in collaboration with the Indian Council of Agricultural Research (ICAR) and the Central Arid Zone Research Institute (CAZRI), taking the Thar Desert in India as its subject field.

(2) "Evaluation of human activities on desertification in semi-arid and sub-humid areas", being carried out by the National Institute of Agro-Environmental Sciences and the National Research Institute of Agricultural Economics, in cooperation with the Institute of Geography, Chinese Academy of Science, in eastern China.

(3) "Comparative study of human activities on desertification in arid and semi-arid areas of different countries", being coordinated by NIES.

During the period of the research activities, we have been publishing a series of desertification research reports, which were based on the International Symposium on Desertification held at NIES, Tsukuba. The first report of this series was entitled "Towards solving the global desertification problem (1) - Feasibility study on the environmental assessment of desertification in arid and semi-arid areas" and was issued in March, 1992. It contained chiefly the reports presented at the First Desertification Symposium held at NIES, in February, 1991.

The second of the series entitled "Towards solving the global desertification problem (2) - Research on the evaluation of interaction between desertification and human activities - ", was issued in December, 1994. This report summarized mainly the Indian study and contained a summary of the present status of desertification, reviews of the vegetation studies and methodologies for desertification monitoring using remote sensing techniques, edited in English.

The third report of the series was entitled "Towards solving the global desertification problem (3) - Desertification Bibliography Database -", issued in February 1995. In this "Desertification Bibliography Database", 2805 English and 193 Japanese scientific papers and documents are collected and the users can efficiently retrieve the requested documents by using author name, key words, and journal name.

This volume, the fourth research report of the series, consists of six parts. The part I, II and III are based on the second International Symposium on Desertification held in 22 March 1994 at NIES, Tsukuba and the part IV, V and VI are based on the third International Symposium held in 28 February 1995. The part I summarized the current trend of desertification and soil degradation research as well as the International Convention to Combat Desertification. The part II and IV are the research results from the collaborative research with CAZRI in the Thar desert, India, and the part III and V are the results from the desertification research in Chinese desert. The part VI is the research report of the comparative study of soil degradation in Northeast Thailand, East Africa and Kazakhstan.

As my editorial duties come to a close, I would like to extend my thanks to all of those who made the writing of this report possible, and I would like to thank Ms. Hiroko Okawa for the editorial support. I sincerely hope that this desertification research report would be useful for understanding the desertification phenomena and also helpful when a similar International Program is to be established.

May 1996

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Part I Current Trend in Desertification

Current Trends in Desertification Studies: Major Scientific Issues in Assessing and Combating Desertification

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1. Introduction

This paper reviews some of the current major scientific issues related to an International Convention to Combat Desertification (INCD, 1994 a), based mainly on the author's own experiences from the research in the Sub-Saharan Africa (e.g., Kadomura, 1993) and the discussions at the meetings of the International Panel of Experts on Desertification (IPED), a scientific and technical assisting body of the Intergovernmental Negotiating Committee for the Elaboration of an International Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa (INCD).

The Convention is the realization of the action plans stated in the Chapter 12 of the Agenda 21 (UN, 1992), which was adopted at the United Nations Conference on Environment and Development (UNCED) held in 1992 at Rio de Janeiro, and has been expected to be elaborated in June 1994, together with the regional Annex for Africa (INCD, 1994 b). The objectives of this Convention are, through effective actions at all levels, supported by international cooperation and partnership arrangement, in the framework of an integrated approach which is consistent with Agenda 21 with a view to contributing to the achievement of sustainable development in affected areas, to combat desertification and mitigate the effects of drought, with the priority for Africa (INCD, 1994 a).

Mention is also made of research priorities in the light of the implementation of the Convention.

2. Issues related to the definition

The "desertification" has been variously defined since Aubréville (1949) first used this word to explain the process of environmental degradation in subhumid tropical Africa due mainly to adverse human impact. The United Nations Conference on Desertification (UNCOD) held Nairobi in 1977 (UN, 1978), defined the desertification as follows:

"The diminution or destruction of biological potential of the land, that can lead ultimately to desert-like conditions."

This ambiguous notion in its definition has caused such a mythical image as the progressive, overall desert march to the productive land (Fig. 1), and invited an endless debate not only among the scientists but also in the international community (Odingo, 1991).

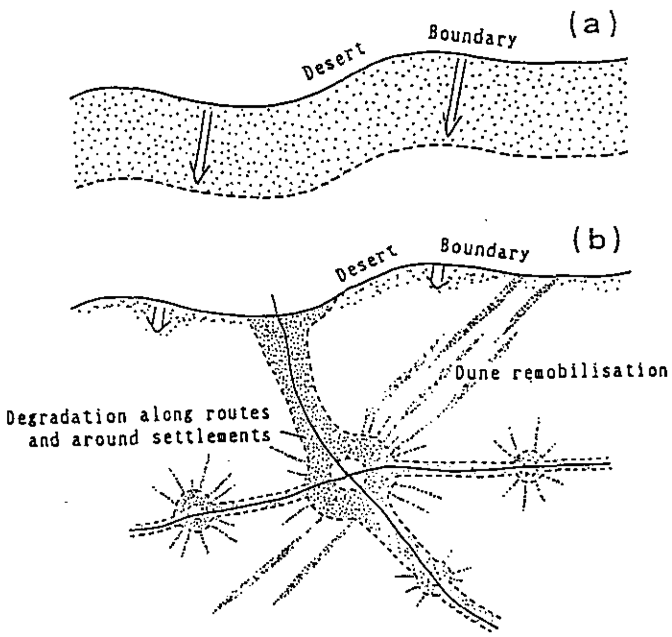

Fig. 1 A schema showing local-scale land degradation/ desertification pattern in the Sahelian "fossil sand dune zone". (a) a myth of overall desert spreading; (b) actual pattern of land degradation (dotted area).

The most recent, internationally accepted definition is that stated in the Chapter 12 (Managing Fragile Ecosystems: Combating Desertification and Drought) of the Agenda 21 (UN, 1992, p. 46).

"Desertification is land degradation in arid, semi-arid and dry subhumid areas resulting from various factors, including climatic variations and human activities."

At the present moment (21, March 1994), this definition is also used in the Negotiating Text of the Convention on Desertification (INCD, 1994 a).

"Land degradation" is much more preferable than

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"desertification" in meaning the processes and results of damage to the sustainability of the land. However, for the purpose of the Convention, clear-cut, scientific but internationally acceptable definitions for all the words baldest in the above sentence are prerequisite, together with definition for "drought", the most important natural causative factor of the land degradation in drylands. Proposed definitions of some of the important words needing continued negotiation (INCD, 1994 a; pp. 4-5) are:

"Drought" means "[sustained, regionally extensive deficiency in precipitation resulting in a period of abnormally dry weather sufficiently prolonged for the lack of water to cause a serious hydrological imbalance;] or [the naturally occurring phenomenon that exists after one or more years during which rainfall has been significantly below average recorded levels.]"

"Land degradation" means "[reduction or loss of biological productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture and forest lands by one or a combination of processes, including, among others:
(1) displacement of soil materials by wind and water erosion,
(2) internal soil deterioration through physical and chemical processes such as salinisation, acidification, crusting, water logging and subsidence;] or [reduction or loss of biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, forest and wood lands by one or a combination of processes and land use systems, including those arising from human activities and habitation pattern, in arid, semi-arid and subhumid areas, such as:
(1) wind, water and soil erosion,
(2) deterioration of soil physical, chemical and biological properties, and
(3) long-term loss of natural vegetation.]"

"Arid, semi-arid and dry sub-humid areas" mean "[areas where the ratio of average annual precipitation to potential evapotransipilation is greater than or equal to 0.05 and less than or equal to 0.65 and where the average annual temperature is greater than 0 degrees Celsius;] or [areas where aridity index (ratio of annual precipitation to potential evapotransipilation) ranges from 0.05 to 0.65 excluding arctic and sub-arctic regions;] "

More difficult question is how and who define or designate "affected areas", "countries experiencing serious drought and/or desertification", affected countries", "affected countries needing assistance", "affected countries needing financial and/or technical assistance", and "affected developing countries", which may be listed in the Annex of the Convention. Although the scientific notions to those words should provide the baseline, listing of areas and/or countries is politically sensitive matter.

It should be emphasized that, contrary to our expectation, no concrete global data sets and maps indicating even the countries falling within arid, semi-arid and sub-humid areas have hitherto been available.

3. Issues related to global assessment

Various attempts have been made to assess the status of desertification/land (soil) degradation at global, regional, national and local levels. Among others, most popular assessments are those with global maps such as those prepared for the UNCOD (FAO/UNESCO/WHO, 1977), UNEP's 1984 general assessment (UNEP, 1984), GLASOD (UNEP, 1990), and World Atlas of Desertification (UNEP, 1992). However, all the pictures presented in these assessments do not show actual status but are the speculation of potential risks based on the combination of supposed vulnerability of physical conditions and human impacts. For this reason, none of these global data sets and maps are too rough to be used for designating "affected areas" or "affected countries" for the purpose of the Convention.

In spite of the past efforts, such as the IN-France in the Sahel Transects (IN-FI, 1993), no existing systems using remote sensing can yield global quantitative assessments of the extent and intensities of desertification/land degradation (UNEP/DC-PAC., 1993). This urgently requires the establishment of an operational system for monitoring and assessing the current status of desertification/land degradation at more detailed scale, i.e., at national, district, and local levels, which should be linked with early warning and long-term monitoring systems.

4. Monitoring and assessment at local level: contribution to bottom-up approach

The Convention (INCD, 1994 a) stresses everywhere the importance of bottom-up approach at local community level to the efforts for combating desertification and mitigating the effects of droughts, which should be incorporated into integrated local development programmes for affected areas, based on participatory mechanism.

For realizing this, in parallel with such socioeconomic restructuring as decentralization of decision making, reformation of land tenure regimes and population policies as well as appropriate sectoral actions for arable, pasture and range, and forest lands, water resources and energy, the establishment of following observation/information system should play a vital role in strengthening drought mitigation strategies and preventive an/or rehabilitation measures. Research priorities regarding this are:

Development and implementation of early warning system linked with local-level monitoring and assessment programmes, including,

(1) Multilevel tempo-spatial monitoring system combined with ground-aerial-satellite observations, on the basis of site- and local-level ground truth observations and linked with regional weather forecasting,

(2) Methodologies and techniques for monitoring, mapping and assessing detailed pattern and processes of land degradation at site level (1:1,000-10,000) (e.g.,UNEP/UNESCO, 1992) and local level (1:50,000-100,000) (DLR, 1993), taking into account of dynamic nature of relations between land use/human activities, morpho-pedological conditions (Fig. 2), and rainfall variations,

(3) Guidelines and handbooks (e.g., Casenave et Valentin, 1989; Herlocker, 1991) for the above used by local extension workers and trained populations for planning and implementing local action plans to combat and reverse land degradation and to assure sustainable use of natural resources, and

(4) Training programmes for capacity building, particularly of leaders of multi-disciplinary working teams, and education and public awareness.

Discussions on these topics should be centered on scale problems (e.g., Kadomura, 1993) and desertification/land degradation indicators. (Table 1).

Table 1 Basic physical indicators for local-level monitoring of desertification/land degradation and/or drought impacts in the Sudano-Sahelian Region

1. Climatic

a. Shift of 150 mm/yr or 200 mm/yr isohyet
b. Shortening of growing period
c. Lowering of Dryness Index : P/ETP (<0.05 = hyperarid, 0.05-0.2 = arid)
* Problems regarding different responses inherent in local/regional edaphic conditions and delayed response in morphological and ecological processes

2. Hydrological

a. Shrinkage and drying-up of streams and lakes
b. Lowering of groundwater level
c. Decrease in soil moisture

3. Morpho-Pedological

a. Sand creeping/shifting
b. Dune mobilisation/remobilization
c. Deflation/blow-outing
d. Rainsplash, rilling, gullying, sand fan formation
e. Spreading of rocky/stony surface (reg-, hamada-like landscape)
f. Spreading of lateritic cuirass outcropping (Bovarisation)
g. Increased frequency of large-scale dust storms
h. Encrusting and other physical deterioration
i. Salinisation and other chemical deterioration
* Problems regarding different responses in relation to local/regional landforms, edaphic conditions, and human activities.

4. Vegetation

a. Decline or disappearance of tree species: e.g. *Acacia albida, A senegal, A. tortilis, Commiphora africana.*
b. Predominance of tree species by more resistant to dryness: e.g., *Caltropis procera, Boscia senegalensis, Balanites eagyptiaca.*
c. Replacement of grass species by more registant to dryness: e.g, from *Andropogon gayanus* to *Cencrus bifrolus, Aristida* spp.
d. Increase /predominance of unpliable, useless species like *Cartropis procera*
e. Decrease in diversity, community density and height
* Problems of irresistibility/resilience in relation to local/regional landforms, edaphic conditions, and human activities.

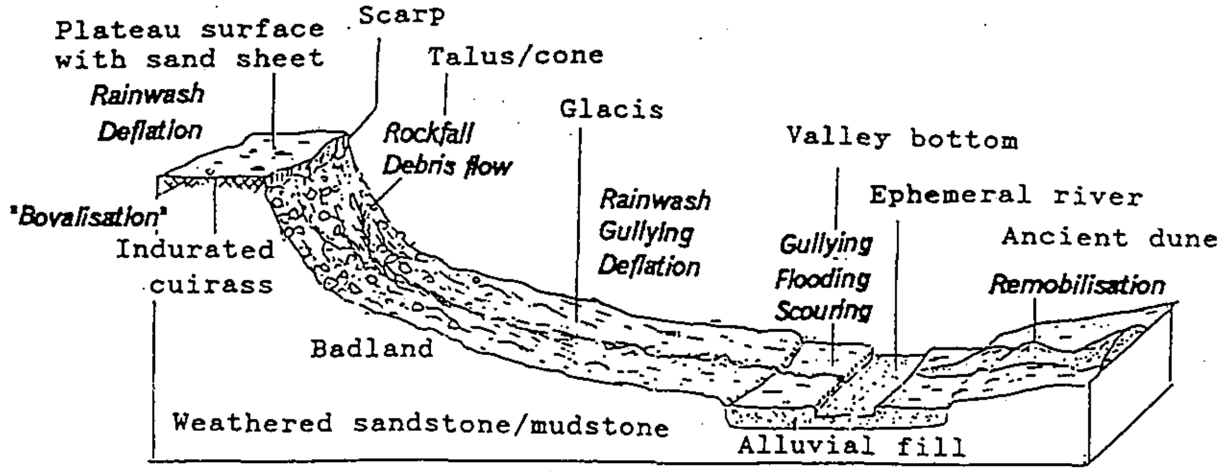

Fig. 2 A schematic representation of local-scale land degradation patterns and processes in cuirass-capped, dissected plateaux in the Sudan-Sahelian Region. Note the spatial differentiation in geomorphic degradational processes by landform types and superficial materials.

5. Long-term monitoring

Since processes of both degradation and recovery in land and vegetation dynamics and in land use systems, as well as human response to environmental change, are generally slow but long-lasting phenomena, long-term, integrated ecological monitoring must play a crucial role in the implementation of medium to long-term anti-desertification programmes. For this purpose the proposal of the ROSET (Reseau d'Observatoire de Surveillance Ecologique à Long Term = Network of long Term Ecological Monitoring) Programme linked with global climate change (SSO/IARE, 1993) by the International Association, OSS (Observatoire du Sahara et du Sahel = SSO: Sahara and Sahel Observatory) (SSO, 1994) may deserve special attention. The ROSET is expected to play an active role in the future implementation of the Convention, because of the following aspects:

It adopts an integrated observation acting systems, for collecting, organizing and processing data on environment in order to put together data which will be compatible with local development problems and regional targets for harmonizing the network. The observation will have the following objectives:

(1) Monitoring natural resources and forecasting their long-term development,

(2) Monitoring the human activities in the area concerned,

(3) Restoring the biological resources,

(4) Establishing a trade-off between resources and land users in order to define optimal land use rate for different types of ecosystems, and

(5) Development of forecast models for long-term ecological successions.

The observation lay-out is designed to allow the integration of ecological, agricultural, and socio-economic data from different regions and environments, both spatially and over time. For the data collecting units, following three levels are considered:

1) ecological site, 2) landscape, and 3) region.

6. Other important issues

Other items needing accelerated research in relation to the Convention are:

(1) Interactions of Desertification and Climate Change;

Despite the efforts made by a joint WMO/UNEP study (Williams and Balling, 1993) and related IPCC works, there are still full of uncertainties as to the effects of land degradation on local and regional climate, and the linkage between anticipated global warming and dryland degradation,

(2) Desertification and Biodiversity;

In spite of their harsh and fragile environments, drylands are the habitat of a variety of flora and fauna, and are the cradle of many of our food crops (e.g., Imevbore, 1993). In view of this the IPED Subgroup on Biodiversity launched a project to compile an inventory of biodiversity and endangered spices in the world drylands, and

(3) Socio-economic Dimensions;

Participatory mechanism, land tenure, decentralization, and alternative livelihoods are the central issues at local-level studies (Toumlin, 1993). Environmental impacts of drought- and desertification-triggered migration, both domestic and transnational, have received increased attention (Anon., 1994).

References

Anon. 1994. The Almeria Statement on Desertification and Migration. *International Symposium on Desertification and Migration*, Almeria, Spain, 9-11 February 1994, 4 p.

Aubréville, A. 1949. Climates, forêts et désertification de l'Afrique tropical. *Société Editions Géographiques*, Maritimes et Coloniales, Paris, 351 p.

Casenave, A. et Valentin, C. 1989. Les etats de surface de la zone saheliennne. *Influence sur l'infiltration. Edition de l'ORSTOM*, Paris, 229 p.

DLR (Department of Land Reclamation, Ministry of Land Reclamation, Regional and Water Development, Government of Kenya) 1993. *Environmental Action Plan for Tharaka-Nithi District.* 26 p.

FAO/UNESCO/WHO 1977. *World Map of Desertification at a Scale of 1: 25, 000, 000, with Explanatory Note*. 13 p.

Herlocker, D. 1991. A Survey Method for Classification on Range Conditions. Range Monitoring Series 1. Range Management Handbook of Kenya. *Volume III. Range Management Division, Ministry of Livestock Development, Nairobi, Ministry of Livestock Development, Range Management of Division/ GTZ*, 31 p.

Imevbore, A. M. A. 1993. Desertification and Desiccation as a Threat to the Conservation and Utilization of Biodiversity. Paper presented at Information Sharing Segment, *1st Substantial Session of the Intergovernmental Negotiating Committee for a Convention to Combat Desertification*, Nairobi, 24-28 May 1993, 29 p.

INCD 1994 a. Revised Negotiation Text of the Convention. *Elaboration of an International Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa.* A/AC.241/15/Rev.1, 28 January 1994, 36 p.

INCD 1994 b. Negotiating Text of a Regional Implementation Annex for Africa (Advanced Text). *Elaboration of an International Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa.* A/AC.241/19, 4 March 1994, 10 p.

IN-FI 1993. Development d'une nouvelle méthode d'evaluation de la desertification de régions saheliennes 1950-1990. *Rapport Final de Phase 1: Etude de 4 Transects*, IN-France, Paris, 51 p.

Kadomura, H. 1993. Environmental Changes, Droughts, Desertification and Land Degradation in the Sudano-Sahelian Region - A Historico-Geographical Perspective. Paper presented at *the 4th Meeting of the International Panel of Experts on Desertification*, 29 November-1 December 1993, Geneva, 25 p.

Odingo, R. S. 1991. The definition of desertification and its programmatic consequences of UNEP and the international community. *Desertification Control Bull.*, No. 18, 31-50.

SSO 1994. Activities Programmes for the Sahara and Sahel Observatory -1994-. *SSO* No. 372, 60 p.

SSO/IARE 1993. Project for the Constitution of a Network on Long Term Ecological Monitoring Observatories (ROSET), Working Document Summary. *SSO* no.329A/JML/CF, October 1993, 8 p.

Toumlin, C. 1993. Combating Desertification: Setting the Agenda for a Global Convention. *IIED Dryland Networks Programme Issue Paper*, No. 42, 36 p.

UN 1978. Round-Up, Plan of Action and Resolution. *United Nations Conference on Desertification.* 29 August-9 September 1977, Nairobi, United Nations, New York, 43 p.

UN 1992. Managing Fragile Ecosystem: Combating Desertification and Drought. *Chapter 12 of Agenda 21*. A/CONF.151/4 (Part II), 46-66.

UNEP/UNESCO 1992. Kenya: Monitoring, Assessment and Desertification Control. UNSO/KEN/89/ X01. *Report of Evaluation Mission*, October

1992. 38 p.

UNEP 1984. General Assessment of Progress in the Implementation of the Plan of Action to Combat Desertification 1977-1984. *UNEP/G.12/9*, 16 February, 1984, 23 p.

UNEP 1990. Global Assessment of Desertification: World Atlas of Thematic Indicators of Desertification. *Proposal Document*, 11 February, 1990, DC-PAC/UNEP, 47 p.

UNEP 1992. World Atlas of Desertification. *Arnold*, London, 63 p.

UNEP/DC-PAC 1993. *Report of the International Expert Panel to Assess Procedures for Measuring and Monitoring Desertification Processes on a World Wide Basis*. Nairobi, 6-9 December 1993, 5 p.

Williams, M. A. J. and Balling, R. C. 1993. Interaction of Desertification and Climate. Executive Summary prepared for WHO and UNEP. Paper presented at *the 4th Meeting of the International Panel of Experts on Desertification (INCD)*, 29 November-1 December 1993, 9 p..

Acronyms

GLASOD: Global Assessment of Desertification

IARE: Institute des Aménagements Régionaux et de l'Environnement (Montpellier)

IN-FI: Institute Géographique National-France International

IIED: International Institute for Environment and Development

INCD: Intergovernmental Negotiating Committee for the Elaboration of an International Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa.

IPED: International Panel Experts on Desertification

SSO: International Association, Sahara and Sahel Observatory = **OSS**: Observatoire du Sahara et du Sahel

UNCED: United Nations Conference on Environment and Development

UNCOD: United Nations Conference on Desertification

UNDP: United Nations Development Programme

UNEP: United Nations Environment Programme

UNEP/DC-PAC: UNEP/Desertification Control Programme Activity Center

UNSO: United Nations Sudano-Sahelian Office

Desertification (Soil Degradation) Due to Soil Salinization under Large-scale Irrigation Agriculture in Kazakhstan, Central Asia.

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1. Introduction

Salt-affected soils in North and Central Asia occupy more than 200 million ha, which corresponds to about 20 % of the total area of such soils in the world (Szabolcs, 1986). The Soviet Union started many large-scale irrigation projects for the establishment of rice-and/or cotton-based agriculture in arid regions in Central Asia in the 1960s. It has recently been reported that the introduction of irrigation water into a farm from major rivers drained off to the Aral Sea and Lake Balkhash, causing a decrease in the surface area and depth of these water bodies (Williams and Aladin, 1991), resulting in soil salinization and adverse effects on human health (Mainguet, 1991). Rozanov (1984) showed 1 million ha of land was lost in Central Asia because of erroneous irrigation practices. According to Khakimov (1981), the percentage of moderate to severe salinized soils in irrigated areas reached 60 to 70 % and crop yields decreased by 30 to 33 % in Kazakhstan.

This study aims to investigate the distribution pattern of saline soils in a farm and its surroundings in order to understand the mechanism of salinization due to irrigation practices, and to establish an appropriate technology for sustainable agricultural production in arid climates. Kazakhstan can be considered one of the representative places for conducting such a case study, and the outcome may be transferred to other areas having similar constraints in a temperate zone.

2. Study site and soil sampling

We set up a study site near Bereke, 250 km north of Alma Ata in Kazakhstan (Fig. 1). Bereke is at an elevation of 375 m above sea level and located in the flood plain of River Ili, originating in the Tien-Shan Mountains. Bereke has a precipitation of about 150 mm per annum, total evapotranspiration of about 1000 mm, and an average air temperature of 9 °C, ranging from -11 °C in January to 27 °C in July.

The study site belongs to a former state farm established in 1979. Farms are mainly planted with rice, alfalfa and barley, besides being utilized for the grazing of sheep and beef cattle. Rice is irrigated and water-logged for four months of the growing season, while alfalfa and barley are not, although irrigation water does

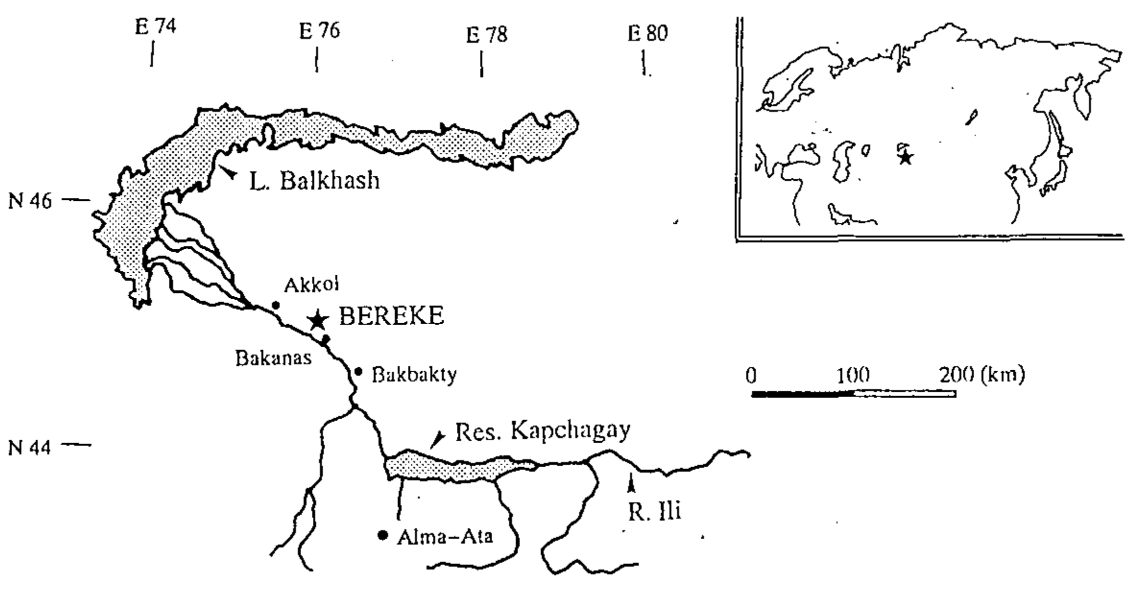

Fig. 1 Location of the study area.

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run in canals during the growing season for early May to early September every year. The yield of rice is reported to be about 4 t/ha. Individual farms are planted with a 4 year rotation, i.e. barley and alfalfa for the first year, alfalfa for the second and rice for the third and forth. Soils encountered in the farms are Sierozems in the Russian Classification System, correlated with Gypsiorthids and/or Calciorthids in Soil Taxonomy and Gypsisols and/or Calcisols in the FAO/UNESCO systems.

The study site included about 2 ha of virgin land, 2 ha of farm planted with barley and alfalfa at the time of sampling, and irrigation canals between them (Fig. 2). While the farm was leveled, such virgin lands have an undulating topography with a difference of 250 cm in elevation from the level of a valley bottom to the top of a sand dune. Zero point of the relative elevation was set on the level of a bridge across the irrigation canal in the study site. The crest parts of dunes are dominated by shrubs of sakusaul (*Haloxylon aphyllum*), the valley bottom by reed (*Polygonum orientale*) and hill slopes of sand dunes by holophytic weeds such as *Karelinea caspia* and *Atriplex tatarzca*.

The surface soils were sampled at an average interval of 25 m along four transects, being 50 m apart from each other, both in the virgin land and the farm (Fig. 2). Seven soil profiles were prepared from representative sites with respect to the topography of the study site, and soil samples were collected from soil horizons designated in these profiles. Irrigation water was running in the canals in the study site at the time of soil sampling in late June. Additionally, we investigated some soil profiles and collected samples under natural sakusaul forest some distance from the study site, from which we observed no effect of irrigation on the morphology of soils but similar environmental conditions in terms of parent material, climate, topography etc.

The collected soils were air-dried, sieved and analyzed for selected physicochemical properties such as pH (1:2.5 in water), electrical conductivity (1:5 in water), water soluble cations and anions (1:5 water extraction), CEC (pH 7.0 in ammonium acetate), organic carbon (Tyurin method) and soil texture.

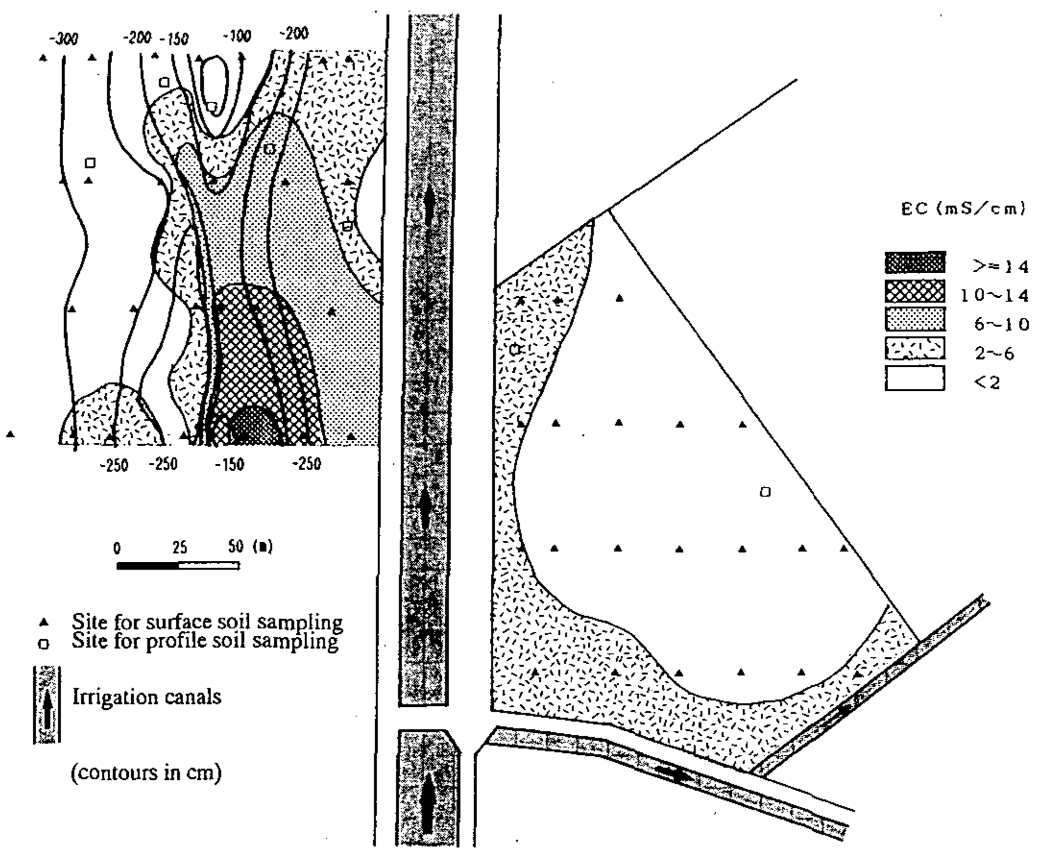

Fig. 2 Soil sampling and salinzation in the study site.

3. Results and discussion

The distribution pattern of electrical conductivity (EC) of surface soils is shown in Fig. 2. The soils near irrigation canals in the farm showed high salinity. The relative elevations of the farm and the surface of irrigation water was -330 cm and -230 cm, respectively. Irrigation water at a higher level than the farm suggests that the high salinity was induced by seepage water from irrigation canals. Although the surface soils of virgin land generally showed a similar pattern, their salt contents were also affected by topography. The highest salinity was observed in the mid-slope of high sand dunes as well as in the crest and mid-slope of low to medium sand dunes, which correspond to areas at a relative elevation between -250 cm and -150 cm. The virgin land generally showed a higher salinity than that of the farm.

Fig. 3 shows the distribution pattern of water-soluble salts in the soil profiles investigated in the study site. The profiles located in the areas showing high salinity in Fig. 2, i.e. P103 and P104, accumulated high amounts of salts in the surface layers. In contrast, salt accumulated layers were observed in the subsoils of profiles P108 and P105, which were located in the crest part of the high sand dunes and in the area distant from the irrigation scheme and, therefore not affected by irrigation practices.

The distribution pattern of water soluble salts in soil profiles suggests that salts originally accumulated in the subsoils in natural conditions were dissolved with irrigation water, then moved upward with evapotranspiration of soil moisture through capillaries, and finally precipitated on soil surface. This upward movement and precipitation in the soil surface of water soluble salts must continue as far as capillary water is held between the water table and soil surface. Profiles P103 and P104 showed water tables shallow enough to keep the capillaries.

In contrast, no water table was observed within 120 cm in profiles P108 and P105, where capillary fringe never reached the soil surface. Profile P109 showed some salt accumulation in a subsurface horizon, i.e. 20 to 60 cm depth, in spite of the fact that no water table was observed at the time of sampling. This suggests fluctuation of the water table, which may come up to within a 100 cm depth to carry salts upward during some period in a year. Even so, it should be noted there is a clear difference in EC between the surface layer and

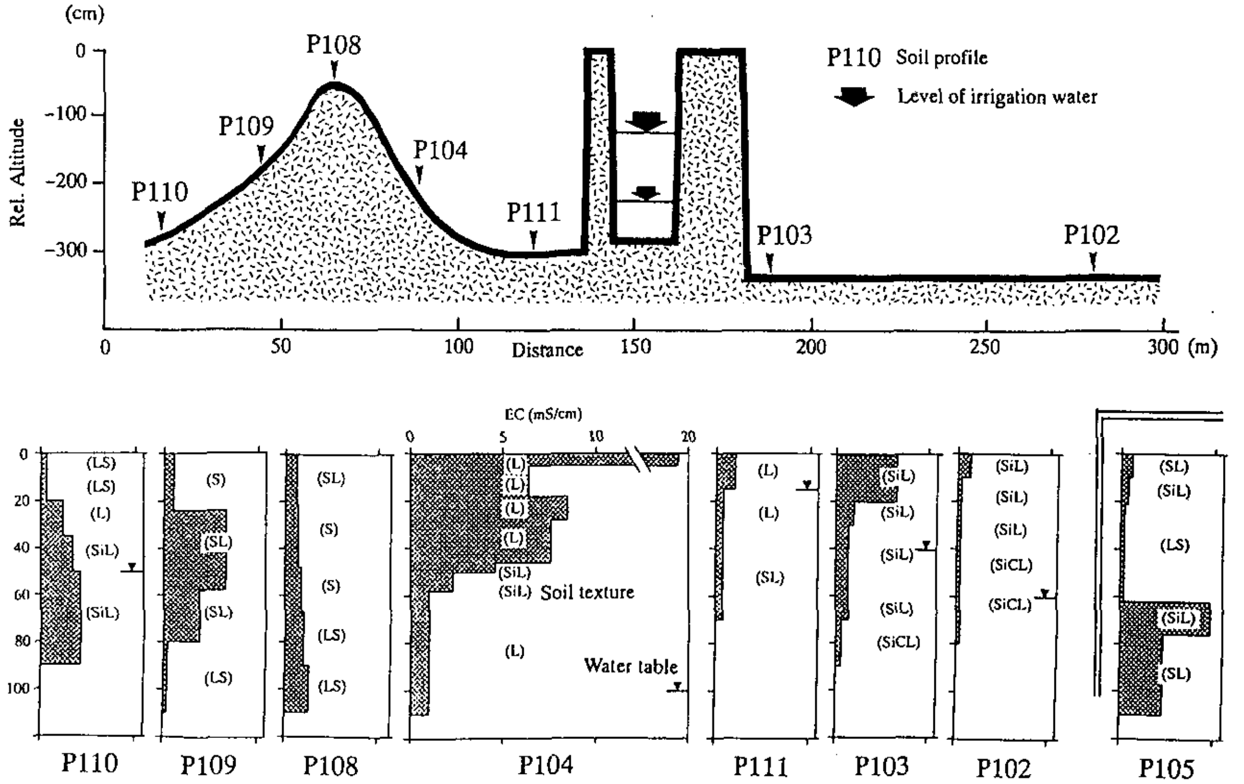

Fig. 3 Distribution of water-soluble salts in soil profiles.

subsurface layer. Textural changes may affect the movement of salts. The surface layer of P109 has a coarser texture than the subsurface layer, thus, capillaries may be cut off to avoid salt accumulation on the soil surface. This mechanism possibly works in Profile P110 as well.

The low EC of profile P111 may be due to seasonal leaching, laterally as well as vertically, produced by too high a water table. A similar mechanism seems to take place in the farm. Water-logging for rice cultivation for 2 cropping seasons out of 4 promotes the leaching of salts, resulting in a lower EC in the farm than in the virgin land in the study site. This effect was also reported as the decrease in alkalinity due to mono-cultivation of rice (Titkov and Gusev, 1989).

Table 1 Electrical conductivity and cationic composition of surface water in selected sites near the study site

Sampling site	EC (mS/cm)	K	Na (ppm)	Ca	Mg
(Non-irrigated area)					
Kapuchagai reservoir	0.47	0.5	21.4	23.0	8.1
(Irrigated area)					
Irrigation canals	0.48	1.4	26.5	23.7	8.3
Seepage	0.74	0.9	43.8	33.9	12.8
Drainage canals	0.97	3.5	48.8	39.4	17.5

The quality of surface water standing or running around the study site was summarized in Table 1. All cation concentrations were the lowest in the Kapuchagai reservoir and the highest in the drainage canals of the study area. This means irrigation water dissolved naturally accumulated salts in the subsoils of the farm and transported some of them to drainage canals and the rest to the soil surface as precipitates. In other words, precipitated salts on the surface originated from subsoils but not irrigation water. An analysis of water soluble salts of salt accumulated layers of selected soil profiles (Table 2) in the study site and its surroundings indicated that sodium sulfates dominated in irrigated areas, both in the farm and virgin land, and gypsum dominated in non-irrigated areas. These results agree with the fact that sodium ions are more mobile than calcium ions.

4. Conclusions

1. Irrigation water has caused and is advancing soil salinization in the farm and its surroundings in the study site. The extent of salinization depends on topography, the level of water table, soil texture and land use.

2. Salinization resulted from the dissolution of water-soluble salts from subsoils into soil solutions supplied with irrigation water, followed by the transportation of salt containing soil solutions through capillaries and the precipitation of free salts when soil water is evapotranspired.

3. When compared to the virgin land, regular water-logging for rice cultivation washed out accumulated salts and reduced salinization. Salinization may be enhanced by changes in the method of land preparation, the type and sequence of crop rotations, and the amount, quality and the method of application of irrigation water.

Table 2 Composition of water-soluble salts in salts accumulation horizons in selected soil profiles (me/100g soil)

Site/	Cations				Anions					
Horizon	Ca	Mg	K	Na	CO_3	HCO_3	Cl	SO_4	NO_2	NO_3
(Non-irrigated area)										
Virgin land/B	24.8	5.5	0.3	4.6	0.0	0.2	9.4	24.8	0.0	0.0
(Irrigated area)										
Farm/A	4.9	4.1	0.8	6.3	0.0	0.6	2.1	14.5	0.0	0.2
Virgin land/A	16.8	13.7	3.0	92.4	0.0	1.0	10.2	114.1	0.0	0.5

References

Khakimov, F.I. 1989. Soil melioration conditions of desertification of deltas. *Puschino Moscow*. p.218

Mainguet, M. 1991. Desertification. *Springer-Verlag*. *Berlin*. p.306

Rozanov, B.G. 1984. Principles of the doctrine on the environment. *IGU*. Moscow. p.273

Szabolcs, I. 1986. Agronomic and ecological impact of irrigation on soil and water salinity. *Advances in Soil Sci*. 4:189-218.

Titkov, A.A. and Gusev, P.G. 1989. Composition and properties of soils of rice rota tions in the Sivash Region of Crimea. *Soviet Soil Sci*. 21(4):110-116.

Williams, W.D. and Aladin, N.V. 1991. The Aral Sea: recent limnological changes and their conservation significance. *Aquatic conservation: Marine and freshwater ecosystems*. vol. 1:3-23

International Convention to Combat Desertification : Its Brief History and Japan's Role

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It is said that at present desertification threatens about 3.6 billion hectares - 70 per cent of potentially productive drylands, or nearly one-quarter of the total land area of the world. It is also said that about one-sixth of the world's population is affected.

In response to these threats, the International Convention to Combat Desertification was adopted last June in Paris, which is the first post-Rio legally binding instrument for sustainable development. And the UN General Assembly adopted, at its 49th session in 1994, the Resolution proclaiming June 17 as World Day to Combat Desertification and Drought.

1. Before Rio

Combating desertification has a long history. In the wake of several years of harsh drought and famine in Africa, particularly in the Sahel region, UN General Assembly decided to convene a conference. The UN Conference on Desertification (UNCOD), convened in 1977 in Nairobi, adopted the UN Plan of Action to Combat Desertification (UN/PACD). UNEP reviewed the status of desertification and implementation of the PACD in 1984 and 1991. The assessments revealed that efforts undertaken until then had not been adequate to cope with the magnitude of the problem and process of desertification remained the same as before.

2. Agenda 21 and convention negotiations

During the UNCED preparatory process, the idea of a convention to combat desertification was discussed. It was only in Rio, however, where language was adopted as the part of Agenda 21 requesting the General Assembly to establish an intergovernmental negotiating committee for the purpose of negotiating a convention. The UN/GA, during its 47th session in 1992, adopted the resolution calling for the establishment of the INCD with the aim of finalizing the Convention by June 1994.

After its organizational session in January 1993, the INCD chaired by Ambassador Bo Kjellen (Sweden) were held in Nairobi, Geneva, New York and Paris. In the course of the negotiations, financial provisions of the Convention had been naturally the biggest issues. There were times during the final session in Paris that delegates thought they would never reach agreement on the provisions. After three all-night sessions, the Convention was finally adopted. Resolutions on Urgent Actions for Africa and Interim Arrangements were also adopted in Paris.

3. Convention to combat desertification

The Convention is the first post-Rio sustainable development convention. Reflecting past failures, the Convention is notable for its innovative approach in recognizing: the physical, biological and socio-economic aspects of desertification; the importance of redirecting technology transfer so that it is demand driven; and the involvement of local populations in the development of national action programes.

The core of the Convention is the development of national and sub-regional/regional action programs to combat desertification. These action programes are to be developed by national governments in close cooperation with donors, local populations and NGOs. An establishment of a series of instruments for science and technology is another essential element of the Convention.

The Convention will enter into force 90 days after it has been ratified by legislatures in 50 countries. It has already been signed by nearly 100 countries (See Table 1). However, ratifications by the countries are still in the process. A process is expected to take about two years.

4. Japan's activities and role

Japan has been actively participated in the negotiating process, who was the coordinator for the Resolution on Urgent Actions for Africa. The negotiations of the Convention have been concluded. The adoption of the Convention, however, is not a goal of combating desertification. Rather, it is a starting point of further efforts. Now, time has come to implement the Convention: translation of the provisions into

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actions.

First task is to ratify the Convention as soon as possible. Without ratification by major donors including Japan, the Convention can not be a effective instrument for curbing desertification.

Also very important are active contributions for on-going activities by INCD for the preparation of the first Conference of the Parties. Not financial supports but intellectual inputs are indispensable. In particular, Japan was recently elected as the Chairman of the Working Group II of INCD whose responsibilities include science and technology issues, and is expected to make positive contributions in this field.

Table 1 States Signing the Convention on Desertification (as of 9 January 1995)

Algeria	Denmark	Ivory Coast	Philippines
Angola	Djibouti	Japan	Portugal
Argentina	Egypt	Kazakhstan	Republic of Korea
Armenia	Equatorial Guinea	Kenya	Saint Vincent and Grenadines
Australia	Eritrea	Lesotho	Senegal
Bangladesh	Ethiopia	Lebanon	Seychelles
Benin	European Union	Libya	Sierra Leone
Bolivia	Federated States of Micronesia	Luxembourg	Spain
Brazil	Finland	Madagascar	Sudan
Burkina Faso	France	Mali	Sweden
Burundi	Gambia	Malta	Switzerland
Cambodia	Georgia	Mauritania	Syria
Cameroon	Germany	Mexico	Tanzania
Canada	Ghana	Mongolia	Togo
Cape Verdi	Greece	Morocco	Tunisia
Central African Republic	Guinea	Namibia	Turkey
Chad	Guinea-Bissau	Netherlands	Uganda
China	Haiti	Nicaragua	United Kingdom
Colombia	India	Niger	United States
Comoros	Indonesia	Nigeria	Uzbekistan
Congo	Iran	Norway	Zaire
Costa Rica	Ireland	Pakistan	Zambia
Croatia	Israel	Paraguay	Zimbabwe
Cuba	Italy	Peru	

Part II Desertification and Human Activities in India

Remote Sensing and Social Investigation for Desertification in Western India

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National Institute for Environmental Studies, Japan

1. Introduction

Land degradation, deforestation and desertification in the arid and semi-arid areas became the very critical environmental problems during the past decades. Solutions to these problems must come from improved management of the land. The problems of improving the management system of these areas are essentially socio-economic, but effective inventory and monitoring of the land are fundamental to any effective management system. The assessment of the current global status of desertification has shown that accurate data to demonstrate with greater precision the degree and rate of desertification in various parts of the world are still lacking. This shortcoming calls for further research and studies to define the magnitude of the problem in all regions and localities, as well as the extent to which the human being is responsible for the process.

National Institute for Environmental Studies, Japan Environment Agency, has undertaken a joint research program with the Central Arid Zone Research Institute at Jodhpur, India, to understand the various facets of desertification problems for effective control measures. The principal objectives of the research are to find the interactions between human activities and processes of desertification in the arid and semi-arid areas of Rajasthan State in India.

Here, the research activities of the collaborative research about land cover monitoring and socio-economic investigation for desertification of the arid and semi-arid lands in Rajasthan are introduced.

2. Location

Rajasthan state is the westernmost state of India and has arid to semi-arid climate. The western part of the state is arid. It forms a part of the Thar desert, or the Great Indian Desert, that extends into Pakistan in the west. In the east its boundary is roughly along the 500 mm average annual rainfall contour. Fig. 1 shows the annual rainfall contour of the Thar desert.

The test sites for detailed investigations were selected in the administrative sub-unit (tehsil) of Osian which is located in Jodhpur district of arid western Rajasthan. Osian tehsil has an average annual rainfall of 300 to 350 mm. Much of it comes in the summer months of July to September, but is erratic in nature. While the southern and south-eastern parts of the tehsil have a dominantly flat sandy or rocky/gravelly terrain with hills, plateaus and shallow plains, the rest of it has sand dunes of 10 to 30 m average height, interspersed with shallow to moderately thick sandy flat or undulating plains. Agriculture largely depends on the rains, and consists of mono-cropping of pearl millet. Irrigation with ground water is restricted mostly to the southern and eastern parts where cultivation is practised in winter as well.

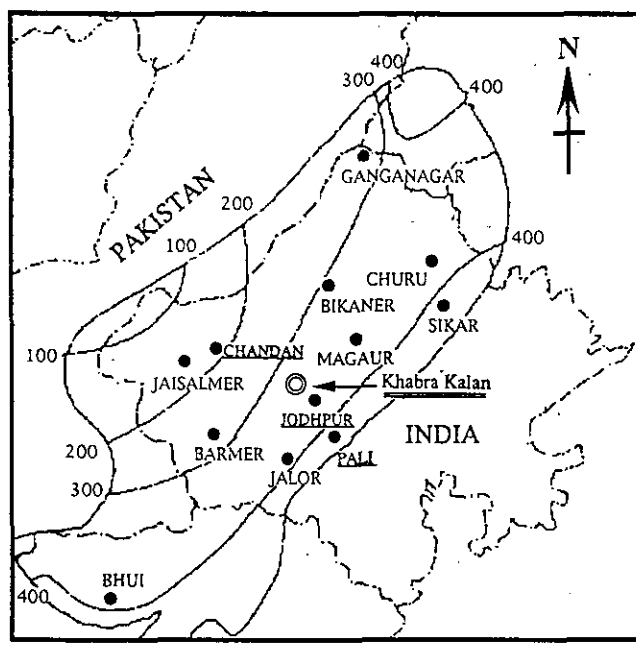

Fig. 1 Experimental site (◎) and annual rainfall contour (-) of the Thar desert.

After a reconnaissance of the area a few sites were selected for joint collaborative research with the Indian scientists. The following themes were decided for field investigations: (a) measuring the spectral response characteristics of different surfaces, (b) to find out the nature of soils, the surface sediments and vegetation, and (c) the socio-economic pattern and its effects on

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desertification. Measurements of spectral characteristics and sampling for soil and vegetation status were carried out on different types of land surfaces and land covers in the southern and western parts of the tehsil, such as flat rocky surfaces, flat sandy plains, sand dunes with and without vegetation, areas with and without crops and natural vegetation, etc. The socio-economic studies were carried out at a small village called Khabra Kalan, about 12 kms to the west of Osian town.

3. Remote sensing study

3.1. Spectral measurement of the ground objects

In various scientific disciplines, techniques for collection of remotely sensed data have progressed very rapidly, but many problems remain in the utilization of these data. One main problem is the lack of good techniques to obtain satisfactory samples of ground data. Since remote sensors operate by detecting or sensing energy levels of emitted and/or reflected radiation over various ranges of the electromagnetic spectrum, it is necessary to make ground measurements of the spectral reflectance from natural surfaces to understand the relationships between spectral reflectance and other surface parameters.

In this experiment, a portable spectro-photometer was used to obtain the spectral characteristics of the different ground objects in the experimental field. The portable spectro-photometer consists of a sensor head and a recorder unit. The sensor head has 17 interference filters and a photo cell and detects the reflected light from a target with the spectral range from 400 nm to 1050 nm within 1 min. The collected data are saved automatically on to the RAM built in the control unit up to 99 measurements. The instrument is calibrated regularly by the standard light source to obtain absolute spectral radiance of the targets. The weight of the sensor head is about 1.8 Kg. Fig. 2 shows the portable spectro-photometer and Table 1 gives the list of typical targets in the test sites.

The spectrum of incident light from the sun and the sky was measured at the target point immediately before or after measurements by recording the light reflected from a horizontally placed white board. Fig. 3 shows the spectral signatures of the ground objects of the test sites. Fig. 3 (a) shows soils and rocks, while (b) is the spectral signatures of different vegetation and water surfaces. All data collected at the field are saved in the Desertification Data Base System with the information of the characteristics of vegetation and soils.

Table 1 Outline of the test sites

Date	Place	Measurement	Target
20 Nov., 1993	Tewri	55	Grazing land, Irrigated land
23 Nov., 1993	West of Osian	28	Grazing land, Irrigated land, Sand dune
24 Nov., 1993	Suburb of Khabra Kalan	35	Grazing land, Pond, River sand
25 Nov., 1993	Bana Ka Ba	12	Grazing land, Irrigated land, Sand dune
26 Nov., 1993	Khabra Kalan	25	Irrigated land, Fallow land

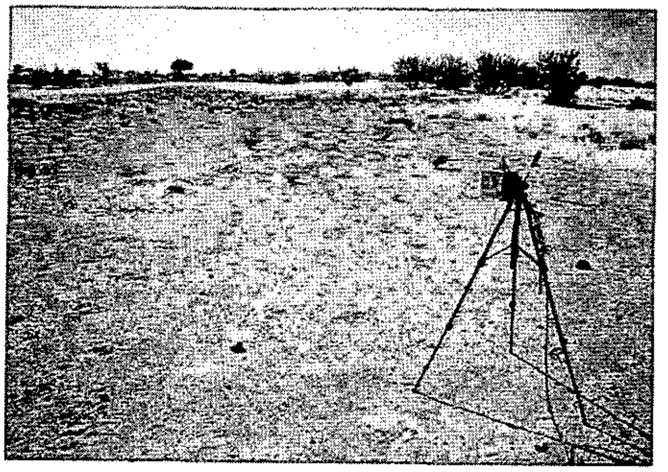

Fig. 2 Measurement of spectral signatures of ground target by a portable spectro-photometer.

3.2. Soil and vegetation analysis

Vegetation at the test site was investigated using some quadrate, in which coverage (%) and height (cm) of each species were measured. Fig. 4 shows the vegetation investigation at a test site.

Soil was investigated by soil sampling and measurement of soil color and soil hardness at the site. The EC, pH and concentration of Na^{+}, K^{+} and NO^{3-} of the collected soil samples were measured in the laboratory. Fig. 5 shows the sampling of soils at a test site.

Furthermore, landuse, grazing pressure, human impact, vegetation type, landform, integrated land type, soil type, soil texture and soil depth were described for each site.

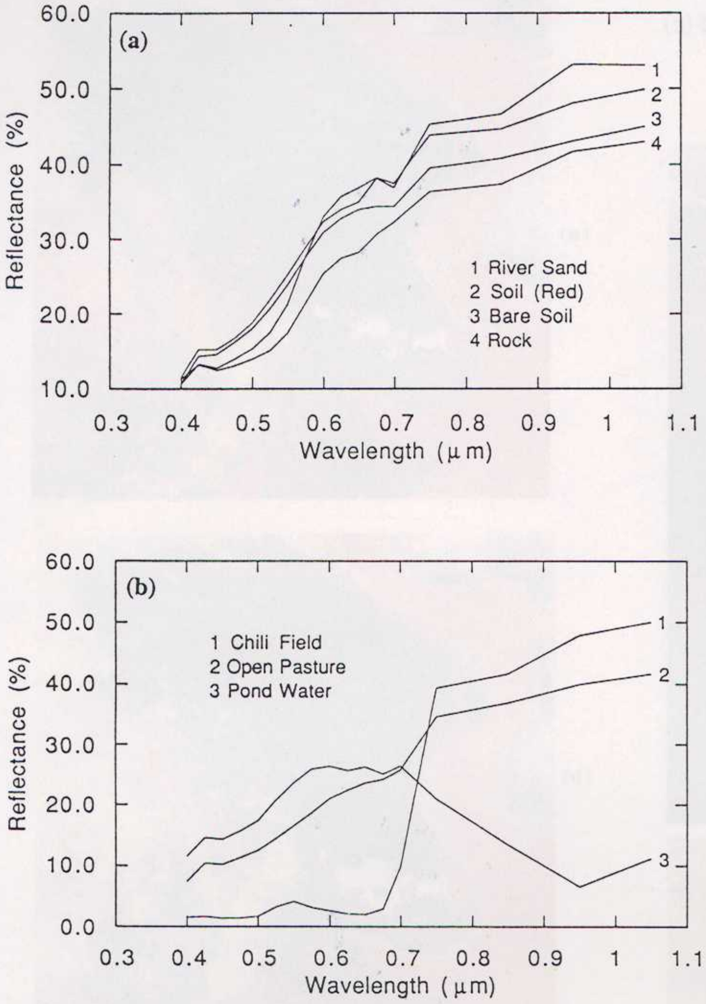

Fig. 3 Spectral signatures of ground objects, (a) soils and rocks, (b) vegetation and water body.

Fig. 4 Vegetation investigation at a test site.

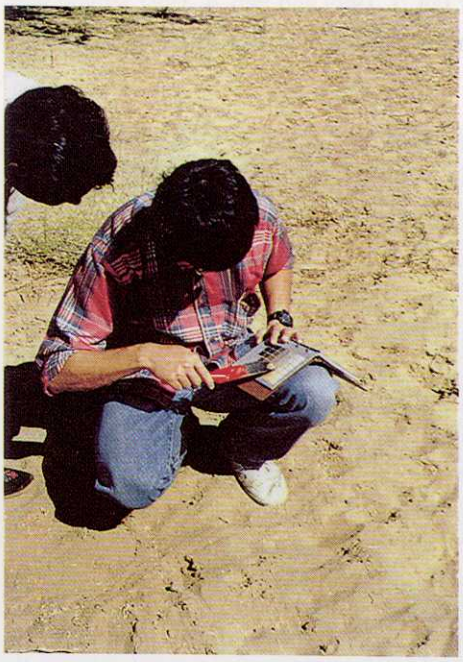

Fig. 5 Soil sampling at a test site.

3.3. Satellite data analysis

Monitoring the surface conditions and their change in the arid area is essential to the management of the environmental problems in both regional and global scales. An outline of the vegetation mapping of whole India and land-cover change detection around west India from NOAA AVHRR data are introduced here.

NOAA AVHRR LAC imageries with low cloud-cover were selected for Indian region from December 1989 to March 1990. A cloud free mosaic map was produced by compositing the images after path radiance and geometric correction of the individual images. The vegetation index was calculated using band 1 and band 2 of the mosaicked images. The Calibrated Vegetation Index, $CVI = 260 \times (A2-A1)/(A2+A1) + 15$, where A1 and A2 denote the albedo in band 1 and band 2, was adopted as the Normalized Difference Vegetation Index. The produced mosaic map and NDVI map are shown in Fig. 6 (a) and (b).

Land-cover change detection with multi-temporal AVHRR images was examined. The method of the spectral signature similarity was applied to the AVHRR LAC images from two different years to enhance the difference in the spectral signatures and to detect the land-cover changes (Yasuoka *et al.*, 1990). An example of the land-cover change detection is presented in Fig. 7. Figure 7 (a) and (b) show the AVHRR images of Jan. 7, 1989 and Feb. 4, 1992 around west India and (c) shows the detected area as changed (white pixels).

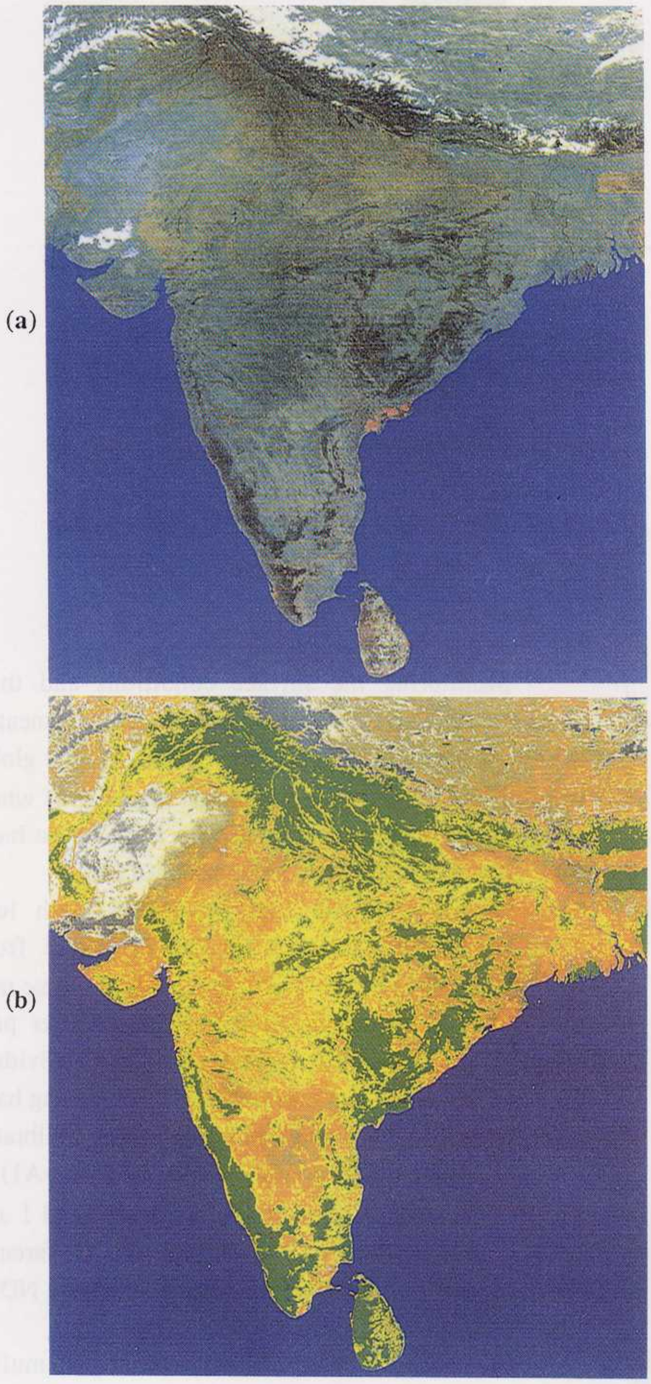

Fig. 6 NOAA AVHRR LAC image mosaic map (a) and NDVI map (b) of India.

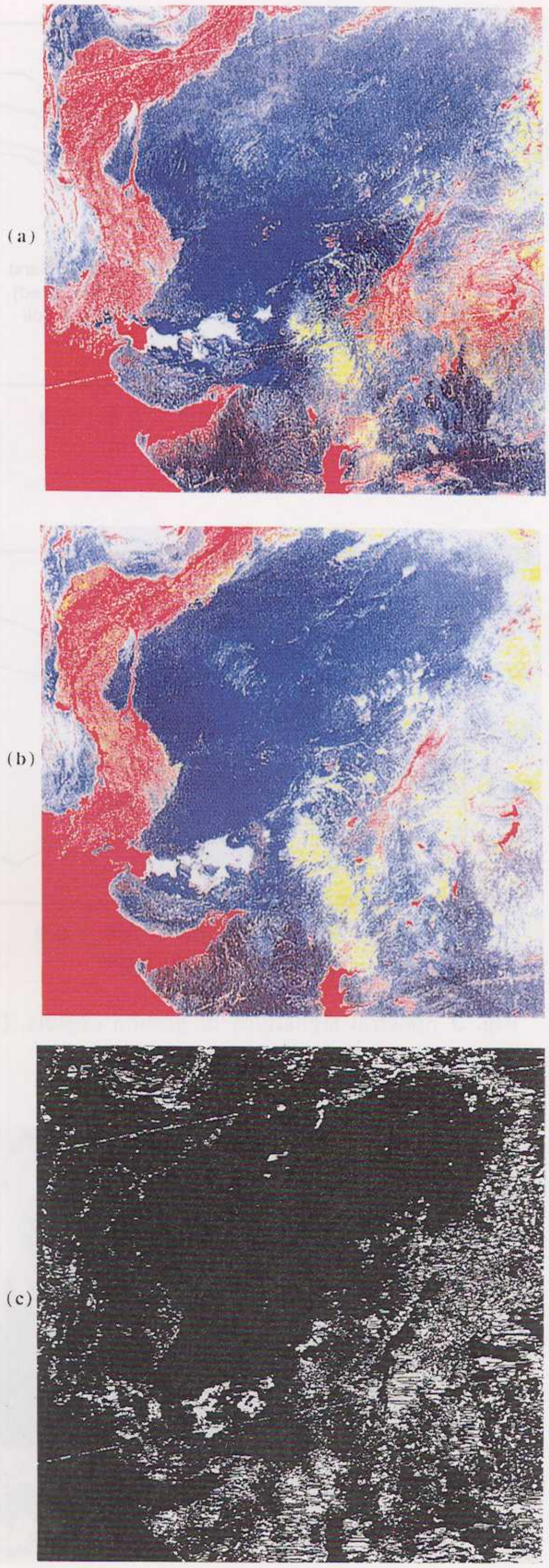

Fig. 7 Land-cover change detection from NOAA AVHRR images around western India. (a) and (b) are original images of Jan. 7, 1986 and Feb. 4, 1992. (c) is detected area as changed (white pixels).

3.4. Discussions

The experiment was carried out in November 1993 in Jodhpur district of western Rajasthan. The spectral signatures of different targets of the arid and semi-arid areas were collected at several test sites with the characteristics of the targets of soils and vegetation. The spectral signatures showed significant difference of different targets. However, spectral signatures of those targets in different seasons would be required to classify the land cover more accurately. The mapping of vegetation distribution and its change in appropriate spatial resolution and temporal interval provides the basis for the effective management in desertification. This preliminary study indicated the usefulness of the NOAA AVHRR LAC data for the large scale vegetation monitoring. However, it was also shown that the combination of the high spectral resolution data such as Landsat TM, SPOT, and IRS with AVHRR data would be required for more practical monitoring of the arid and semi-arid areas.

4. Socio-economic study

4.1. Subject

Village and method of social survey

A case study was undertaken to investigate the perception of desertification in village Khabra Kalan. Data were collected by personal interviews (Fig. 8) through specially designed schedules. The interviews were taken by Indian researchers. Altogether 64 sample farm families representing various castes were interviewed.

Fig. 8 Social interviews by Indian researchers of Central Arid Zone Research Institute.

The area was selected because it is severely affected by wind erosion during the very strong wind in the monsoon season. The village Khabra Kalan is spread over an area of 1,638 ha and had a population of 922. Rainfed agriculture and traditional farming are largely practiced by the farmers. Besides agriculture, animal husbandry is also practiced.

The population of the village Khabra Kalan mainly belonged to Hindu religion. There were nine different castes like Rajput, Jat, Meghwal, etc., and was dominated by Rajputs.

4.2. Results of the survey

1) Fact sheet

Family structure

Average family size was 6.2 persons. The number of male was 297, that of female was 276, and total was 573. Age group of 0-9 was 185 persons (32%), 10-19: 136 (24%), 20-29: 64 (11%), 30-39: 76 (13%), 40-49: 49 (9%), 50-59: 36 (6%), and over 60: 27 (5%).

Education

The people who took education for more than one year was 231 persons (41%).

2) Mechanism and factors of desertification

Human factor of desertification

Villagers perceived important factors of desertification: (1) over-cultivation of land (148 points), (2) plowing by tractor (80 points), and (3) indiscriminate cutting of trees, bushes/shrubs (69 points).

Human population

The average number of total births during the last ten years was male: 1.63 and female: 1.53. The average number of total death was male: 0.37 and female: 0.53. The preferable number of children were male: 2.19 and female: 1.39.

Family planning measures

The number of households adopting family planning measures were 17 (27%). Among them, 5 were males and 12 were females. Most of the respondents adopted family planning measures after 4 children.

Livestock population

The average size of herd was 15.8. The average number of draught animals used for transportation was 0.3, milch animals 2.3, young 2.1, others 11.1. Of the total livestock population goat constituted 6.2, followed by sheep 4.8 and cows 1.8.

Energy use

Annual requirement of wood was 43 kg/year for agricultural implements and 143 kg/year for housing. Energy requirement was 9.8 kg/day of fuelwood, 2.0 kg/day of fodder, 3.9 kg/day of cow-dung, 8.6 liters/day of Kerosene and 4.4 kW/month of electricity.

Water use

The main source of drinking water was well, tubewell and tanks. The average distance from house to the water point is 1.8 km. The average consumption of water in a day was 126.6 liters including the water for animals.

Land area

Land owned by grandfather was 44.0 ha, followed by father 17.8 ha, and the present generation 10.1 ha.

Agricultural style

Mixed cropping is practiced by 52 households (84%). Crop rotation is practiced by 54 households (84%). Average years of keeping land fallow is 1.8 years. 47 households (77%) leave the stubble in the field. For plowing, tractor is used by 64 households (100%), wooden plow: 5 households (8%) and iron plow: 1 (2%).

3) The state of desertification

As far as changes in land use pattern is concerned, during the last 20 years, grazing land and fallow land decreased and land under various crops and sandy land increased. There was an increase in trees, but grasses decreased.

4) The effects of desertification on the human activities

All crop yield including Bajra which is the staple food in the region had decreased. However, the area under crops increased. The effect of declining land productivity is (1) occurrence of famine and malnutrition (155 points), (2) deterioration in living condition (79 points) and (3) shortage of fodder for livestock (67 points). 49 persons (79%) answered that they had experienced the deficit of animal fodder. 2 persons (3.1%) answered that they had moved with livestock during last drought year.

5) Countermeasures for desertification

People put the highest points to (1) soil improvement through conservation (108 points), (2) control of human population by family planning measures (99 points) and (3) long term following system of land (67 points). Each household has spent Rupees 7,610 for soil conservation during the past five years. Trees were planted by 36 households (56%) during the last three years.

4.3. Discussions

Human factor affecting desertification can be considered from two aspects.

The first aspect is a factor affecting land directly. Villagers perceived the following factors of desertification: (1) over-cultivation, (2) tractor, and (3) indiscriminate cutting of trees. The traditional rainfed agriculture of this region has features of (1) plowing by livestock, especially camels, (2) long term following (one year for cultivation and three years for fallow), (3) mixed cropping, (4) leaving the stubble in the field and through such careful land use they made sustainable land use possible.

However, from the result of the survey, mixed cropping and leaving the stubble in the field are still being practiced, but tractors are used instead of camels by all households and following period has decreased from 3 years to 1.8 years.

Judging from the result of people's perception, the soil conservation as the first item and long term following system as the third for measures of desertification, it is estimated that the importance of soil conservation is fully understood by villagers. Actually villagers have spent Rupees 7,610 for soil conservation during the last five years. If the income level of the villagers was taken into account, villagers have spent rather a large sum on it.

The second important factor is the increasing population. Recently the death ratio, especially that of infant and old ages, have drastically decreased through improvement in health care and food condition.

Moreover, the preference for fertility and early marriage lead to population increase. Furthermore, the inheritance system which divides the land evenly among the male successor is a key factor of decreasing land area per household.

Indian government has been promoting family planning measures. It is also recognized as an anti-desertification measure by the villagers. However, only 27 % households are practicing it, and most of the family planning measures are adopted by females only.

Due to the increase in population and the inheritance system, the land holding size has decreased from 44.0 ha to 10.1 ha over the last 40 to 50 years.

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References

Yasuoka, Y., T. Yokota, T. Miyazaki, Y. Iikura. 1990. Detection of vegetation change from remotely sensed images using spectral signature similarity - Discrimination of long term change from seasonal changes -. *Proc. of IGARSS'90.*

Desertification Processes in Arid Western India

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1. Introduction

Desertification has been defined in the Agenda 21, Article 12.2, as land degradation in the arid, semi-arid and dry sub-humid areas, resulting from various factors, including climatic variations and human activities (Cardy, 1994). Although a consensus on the precise understanding of the true causes of desertification has not yet been arrived at, many former views on standardization of its visible symptoms, the physical and socio-economic causes responsible for it and the assessment methods are being increasingly questioned (Hellden, 1991, 1994; Warren and Khogali, 1992; Olsson, 1993; Thomas, 1993; Hentati, 1994). There is also a growing belief now that many earlier conclusions on desertification, based on the analysis of changes in vegetation cover, especially in the African continent, are misleading and these might have succeeded only to confuse the natural spatio-temporal changes in vegetation, that are related to short-term climatic variability, with the long term land degradation (Ahlcrona, 1988; Hellden and Eklundh, 1988; Warren and Khogali, 1992; Thomas, 1993).

It has been estimated that about 40 per cent of the world's total land surface is under the arid, semi-arid and dry sub-humid areas, and hence, is potentially vulnerable to desertification (Thomas, 1993). This excludes about 8 per cent area of the hyper-arid lands, which are usually thought of as non-recoverable. Considering the hyper-arid area as a part of the world's drylands, Dregne *et al.* (1991) estimated that 69.5 per cent area of world's drylands are affected by land degradation. According to a recent estimate by Government of India, 32.7 per cent of the country's land area is now affected by different land degradation processes (unpublished report, Ministry of Agriculture, Govt. of India, 1994). As we have noted earlier, however, many of the estimates may not be able to stand the rigorous tests of scrutiny. Individual perceptions, methods of assessment and attempts to exaggerate the effects of local droughts have often played their parts in the estimation process. Yet, inspite of these cautions, the need for sincere attempts to understand the various facets of desertification can not be understated. Some studies have been carried out by the Central Arid Zone Research Institute (CAZRI), Jodhpur, to understand and map the phenomena of desertification. We shall describe here only the physical parameters of desertification, especially the land surface processes and their manifestations in terms of land degradation, as is being analysed for the arid western part of India.

2. Land surface processes

Physically speaking, and given the latest definition, desertification should usually occur when the natural geomorphic processes are accelerated due to changes in the atmospheric and lithospheric conditions, or due to the human-induced changes, and to such an extent that the erosion or other forms of degradation of soil is at a much faster rate than is being replenished/ restored through new formations. Salinity-alkalinity build up and soil compaction are the other major physical manifestations of desertification. Correct identification and assessment of the problem may be possible through an understanding of the current geomorphic processes and their behaviour under natural and induced conditions.

In the arid western part of India, seven major geomorphic provinces, having their distinctive land-forming processes, could be recognised (Kar, 1995; Fig. 1). The dominant land forming processes over the major parts are the exogenic fluvial and aeolian processes, although there are other processes also which have played significant roles in the evolution of the landforms (Kar, 1992). These processes are operating throughout the Quaternary period. Each of these consists of a nested pattern of processes which operate for both short and long durations. Consequently, a number of landforms with hierarchical arrangement have been formed. While the long duration processes have produced the mega-landforms, like the hills, pediments and pavements, other rocky planar surfaces, vast alluvial plains, high sand dunes, etc., the imprints of the short duration processes remain for few days to few tens of years. These often include the low transient features like

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the barchans, shrub-coppice dunes (nebkhas), low fence line sandy hummocks, other low sand streaks, rills and gullies, new flood plain deposits, scalding, etc. The short duration features are being formed now and, hence, these come into sharp focus during the land degradation studies.

The endogenic processes, including tectonic disturbances, are very rare and episodic in nature, but these can erase or drastically change, in a very short spell of time, the land features created by the exogenic processes through millennium of activities. The major examples are in and around the Great Rann of Kachchh, where a land mass, the "Allah Bund", was uplifted during the 1819 earthquake (Oldham, 1926). It also effected many changes in the drainage features in Kachchh mainland and the delta to its west (Kar, 1988 a, 1993 a). Similar earth movements through out the Quaternary period in Kachchh and Saurashtra areas have disturbed the delicate base level of the streams and are leading to vigorous stream erosion and gully development, especially along the major lineaments, and a consequent very high soil loss. The unequal movement of the land during each episode of tectonism is also causing unequal distribution in the spatial pattern of soil erosion. In the southern part of the Thar desert episodic earth movements have led to terracing and stream incision along the major streams, as well as development of small gully networks in the alluvial plains of the Luni drainage system. Even now the water and sediment transport along the streams in the Luni basin are strongly influenced by some major lineaments, as was noticed during the flood year of 1990 (Kar, 1994).

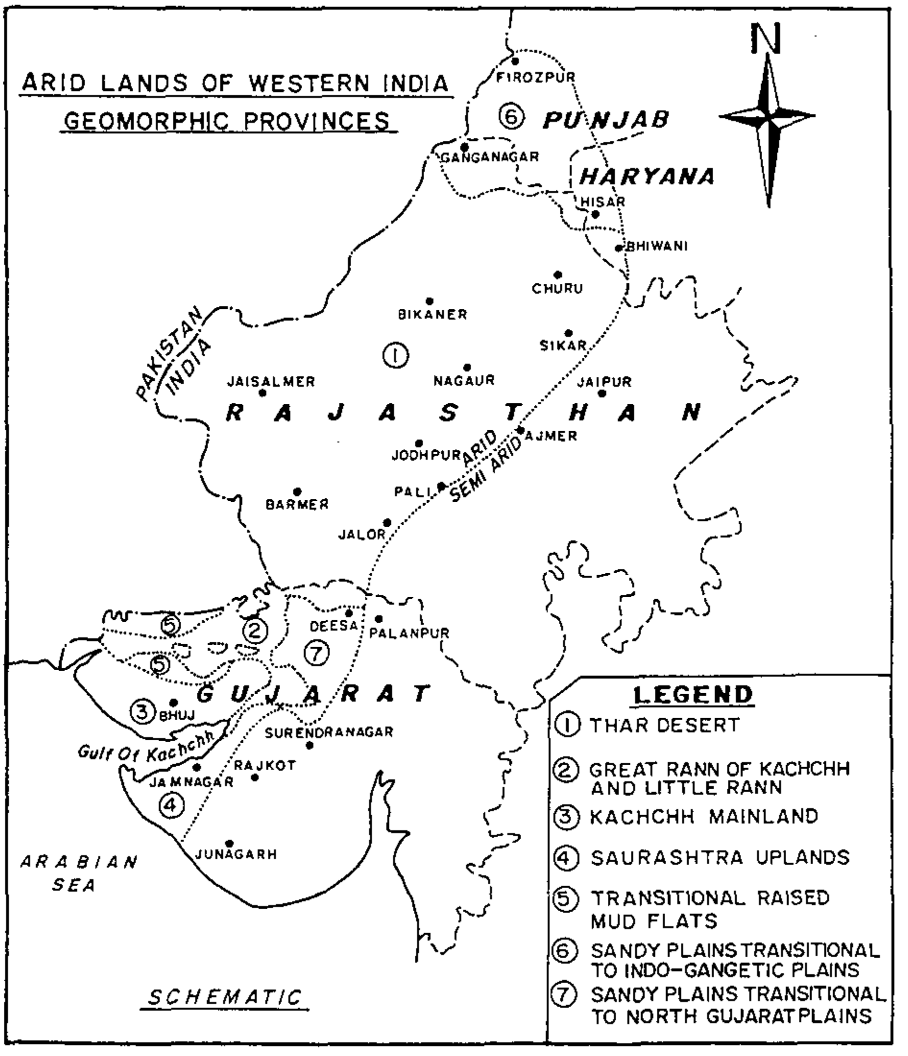

Fig. 1 Arid lands of western India : Geomorphic provinces.

3. Estimation of erosion potentials

(a) *Water Erosion Potentials*

The concept of potential erosion helped much in understanding the spatial distribution pattern of the erosion through water and wind. For water erosion, the Universal Soil Loss Equation (USLE) which is one of the best known examples of lumped parameter models and is applicable for field scale estimation only, has some limitations of its own. It needs point-based information on every parameter, and therefore, as the system becomes larger and the components start behaving in more complex manners, the paucity of data in the desert terrain makes the spatially lumped input data more unrealistic and it compounds the error of estimation (Pickup, 1988). Yet, Singh *et al.* (1985) suggested a rainfall erosion index of 300 along the eastern margin of the arid lands in India. It has not yet been successfully applied to the arid areas. There are other methods of estimating water erosion also, like the ANSWERS, which is a distributed process model and can accomodate spatial data from topographical sheet and remote sensing, but in areas of sparse basic data on water and sediment character in a desert it can lead to errors which, if the method is applied at regional scale, can compound to such an extent that the results can not be trusted. The search for a realistic model, suitable for regional-scale application in the arid lands should, therefore, continue.

Till such time that an universally acceptable method of estimating water erosion is found out, the pattern of water erosion could be deciphered from the sheet, rill and gully erosional features. These features are numerous along the eastern margin of the Thar desert where the average annual rainfall varies from 350 to 500 mm, but are very few to the west of the 250 mm isohyet. The most vulnerable landforms are the sandy lands near the Aravalli ranges, the medium to heavy textured alluvial plains and the sloping uplands and colluvial plains in between the Aravalli ranges (Kar, 1988 b). Although increased ploughing of the land and destruction of vegetation cover must have accelerated the erosion, it is a difficult proposition to find out how much of the gullying activity is due to human activities alone and how much is due to the natural processes, under the environmental set up of the region. As we have noted earlier, the accelerated water erosion in the arid Kachchh and Saurashtra is mostly due to base level changes related to neotectonism. Human activities are assisting the process, especially in the areas of shallow soils where the impact is felt much faster and in a more glaring fashion.

(b) *Wind Erosion Potential*

The potential wind erosion index for Thar desert was calculated on the basis of mean wind speed and PE values for the different meteorological stations in and around the desert. Since the aeolian entrainment and transportation are generally restricted here to the five summer months of March to July, the values were calculated using the long term climatic norms for those five months only (Kar, 1993 b; Table 1). The wind erosion index was found to be well explained by mean wind speed and PE (Fig. 2).

Table 1 Categories of wind erosion index (March-July) for Thar desert and meteorological stations in them

Wind erosion index (%)	Category	Station
480 & above	Extremely high	Jaisalmer
120-479	Very high	Phalodi
60-119	High	
30- 59	Moderate	Bikaner, Jodhpur, Pachpadra, Barmer
15- 29	Low	Ganganagar, Churu, Nagaur, Jaipur
1- 14	Very low	Hisar, Sikar, Sambhar, Ajmer, Erinpura

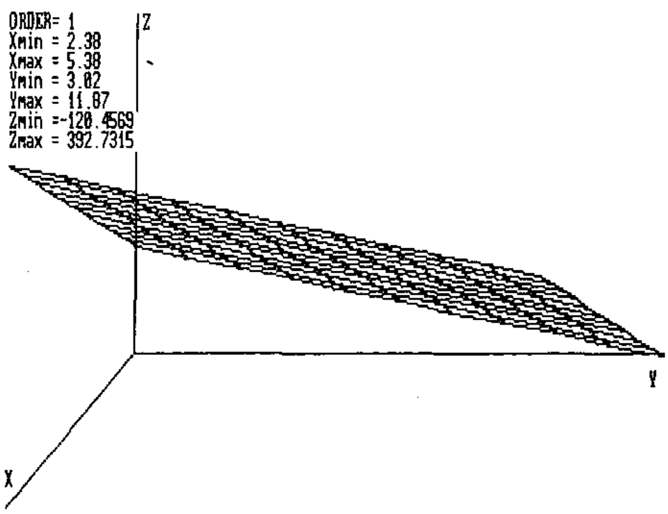

Fig. 2 Wind erosion index as a function of wind speed (X) and PE (Y) : March-July.

The results matched well with the observed pattern of the effects the wind erosion has on the terrain and also with the pattern of sand reactivation. For example the mobile dunes are forming under natural environment mostly to the west of 120 contour of the index (very high category), where even the soft sedimentary rocks are being constantly etched and grooved by the sand-surcharged SW wind to create, in extreme cases, some of the salt encrusted depressions (*Ranns*) of the region (Fig. 3). The high megabarchanoids occur further to the west, in the extremely high index zone (more than 480). The sandy terrain in both these areas are highly vulnerable to aeolian reactivation, even under the slightest human pressure. In the eastern part of the desert, on the other hand, the index is low to moderate, and it matches well with the much less aeolian perturbation of the old high dunes and sandy plains. New mobile dunes are rare. The sandy landforms in the eastern part, especially the high sand dunes have, however, been inheritted from a past dry climatic phase, as is the case with the high dunes elsewhere in the desert (Singhvi and Kar, 1992). Consequently, the erodibility of the terrain to wind is almost as high as in the west (Kar and Joshi, 1992). Fortunately, the higher rainfall in the east and better vegetation status of the sandy terrain there, have helped to restrict the sand mobility to the areas of high cultivation and grazing pressures. In other words, it is possible to identify the major areas vulnerable to wind erosion from the spatial distribution of landform types, wind erosion index and wind erodibility pattern (Fig. 4 and 5).

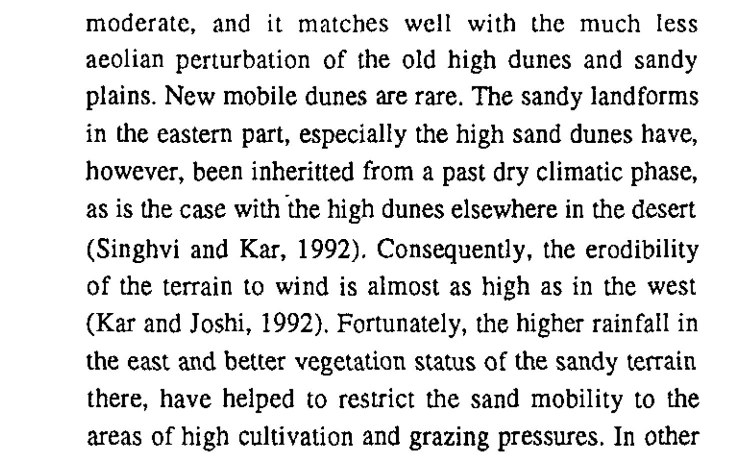

Fig. 3 Computer simulation of SW-facing escarpments in limestone and small depressions in their lee, formed by strong sand surcharged south-west wind near Kanod in western Thar.

4. Human influences and land degradation

As we have discussed earlier, isolation of the signatures of human influences alone on the terrain (through process acceleration) from that of the natural geomorphic processes is still a difficult proposition over major part of the region. This is especially true for some of the notable water eroded areas, both along the eastern part of the Thar desert and in the arid tracts of Kachchh and Saurashtra. In Kachchh and Saurashtra the youthful nature of the terrain is mostly due to tectonically controlled base level changes in the recent past and subsequent attempts of the stream networks to adjust to newer base levels. Often these are the areas of shallow soils and rill and gully activities. Estimation of areas affected by sheet wash is difficult and debated. Human activities must have accelerated the processes through cultivation on marginal lands, deep ploughing, etc., but no realistic estimate is available as to how much of 'degradation' through water is attributable to nature and how much to man. Discussion with the farmers bring to the fore another crucial point in the debate on land degradation. According to them the shallow soils which they cultivate are almost the same what they used to cultivate earlier. Even if there is some soil loss it hardly makes any difference to them. However, in many cases they use amendments in the soils for increased production from it, and also use their traditional wisdom in the conservation of moisture and soil. The soil column, for them, is still adequate to continue with.

Along the eastern part of the Thar desert gully erosion is prevalent along the western slope of the Aravalli hill ranges, where one also encounters huge obstacle sand dunes that were mostly inheritted from a past dry climate. Present high rainfall in the area (400-500 mm), coupled with the sandy soil and a relatively high slope are favourable to gully development. Because of the present cultivation and grazing pressures on these lands, it is believed that the gullies are progressing at a faster rate. Yet, there is very little supportive evidence. Gullies in the surrounding sandy plains often occur in the farmers' fields. The farmers are aware of headward progress of the gullies, but do not believe that their agricultural activities hasten the process, unless tractors are used to loosen the soil. Many of them believe that the agricultural crop residues which they leave in the field are good sand binders and whatever land is being lost through gully erosion is a slow natural

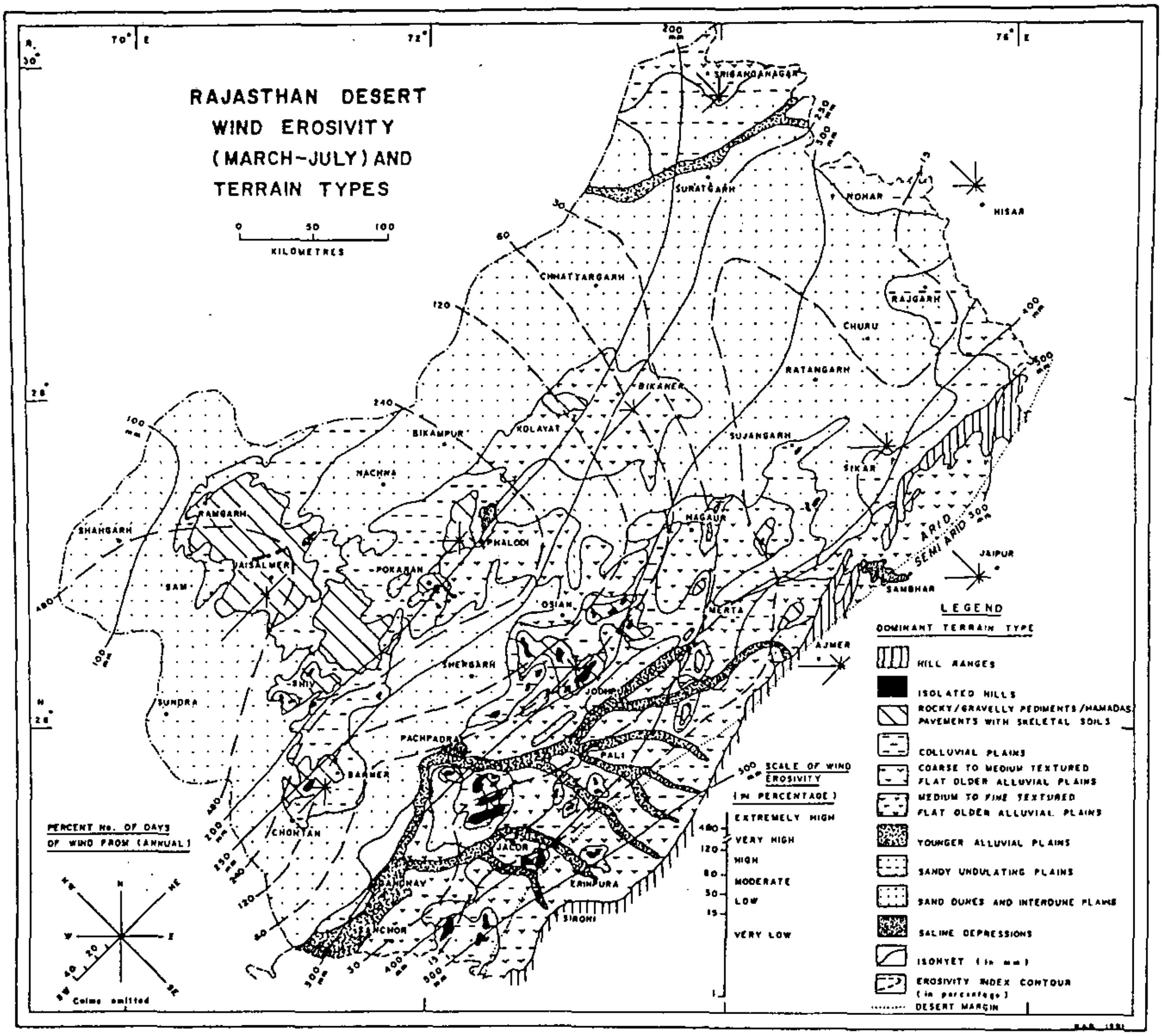

Fig. 4 Rajasthan desert : Wind erosivity (March-July) and terrain types.

phenomenon. In other words, we must have enough database before we apportion the blame to the stake holders in the affected areas. The socio-economic compulsions of the people residing in the areas affected add another dimension to the problem. This is echoed more by the dwellers of the Thar desert, as we will narrate in the next section.

In much of the Thar desert wind erosion is a major problem. The western limit of dryland cultivation in the Thar desert is almost co-terminous with the 240 contour of wind erosion index. To the east of this limit the sandy terrain is now increasingly put to tractor ploughing. This leads to more of sand blowing than earlier (Ghose *et al*., 1977; Dhir *et al*., 1992). Moreover, the traditional practices like keeping the land as fallow for long or short durations, rotational grazing, etc., are not popular now. Cultivation has also encroached upon the lands which earlier used to be reserved as common grazing lands. As a result more land is being subjected to sand reactivation (Singh *et al*., 1978). This is happening even in the wetter eastern margin of the desert which is potentially less vulnerable to wind erosional hazard (Kar, 1986). This is because, there is a limit to the capacity of sandy landforms to maintain a balance with the exploitative enterprises of man. Deep ploughing of the dune slopes and interdune plains, destruction of the traditional pasture lands and wanton destruction of the vegetation cover of the sandy terrain have loosened the structure of the sandy soil in its top few metres and have reactivated the erstwhile stable surface in certain pockets. Since human pressure is very high, people have no choice but to use their land continuously and suffer some degradation of their land. Use of tractor has gained dominance because it is more economical to hire a tractor for a day or two than to rear a draught animal for life. Moreover, the tractor can be used much faster than an animal to exploit the seasonal moisture.

Accelerated salinity-alkalinity hazard is dominant in the medium to heavy textured alluvial plains, especially because of irrigation with saline ground water. In the seaward margin of the coastal alluvial plains very high pumping of potable ground water has led to an intrusion of saline sea water into the aquifer. Since the farmers have no other choice as regards watering the crops, they continue to use the groundwater, even after its quality has been adversely affected by sea water intrusion. In the Indira Gandhi Canal Command (IGNP) area in the Thar desert, the problems of waterlogging and salinity-alkalinity are increasing at a faster pace. In the area covered within the Stage I of IGNP, the critical areas for waterlogging increased from 742 sq. km in 1981 to 1980 sq. km in 1990. This is mainly because the soil is followed at a shallow depth by a barrier of gypsum or calcium-rich formation (Singh and Kar, 1991). Such salinity build up has also been noticed in the command areas of small irrigation tanks in the south-central part of the desert and where the canals have crossed some salt-rich palaeochannels (Kar, 1992).

5. Mapping of land degradation

Visual interpretation of the standard False Colour Composites (FCCs) of Landsat TM and Indian Remote Sensing Satellite's (IRS) LISS 2 bands have provided valuable mappable information on the degradation processes and classes. It has been possible to successfully use the pixel by pixel radiance of the

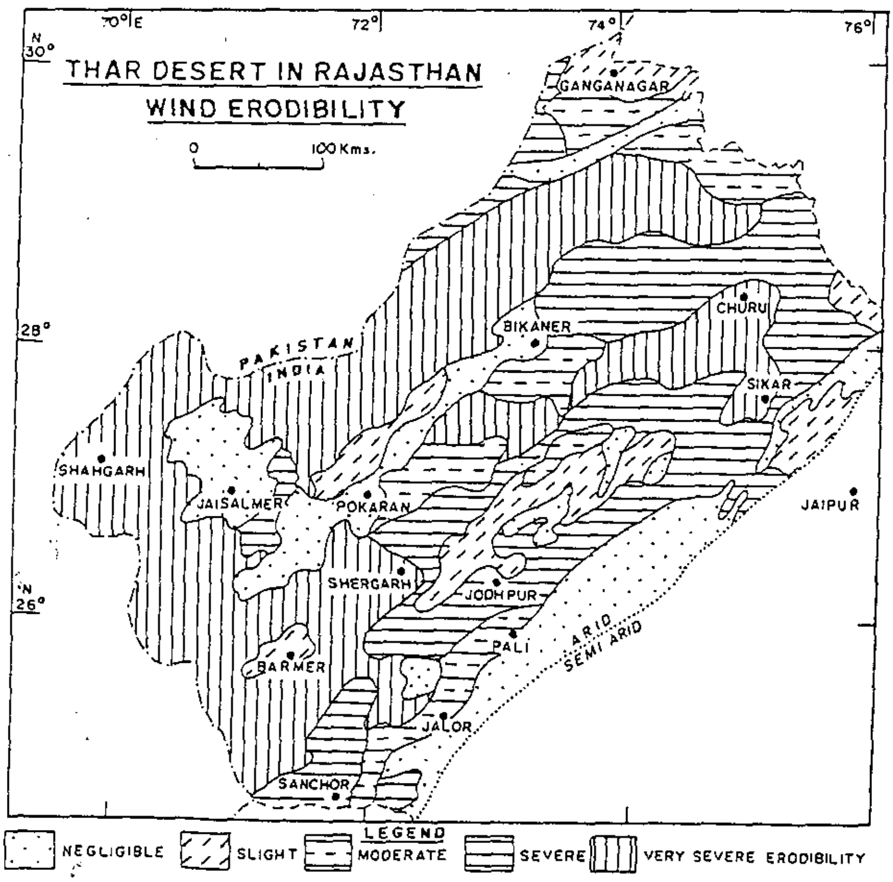

Fig. 5 Thar desert in Rajasthan : Wind erodibility.

manifestations of degradation on the landforms as surrogates for the degradation processes. The visual interpretation is, however, subjective. No two interpreter will, perhaps, agree to the severity of a degradation class, since value-based judgement is involved. Therefore, a quantifiable indicator is required. This was tried for the reactivated aeolian sand categories in the north-eastern fringe of the desert (Sen *et al.*, 1991). The spectral response characteristics of the sand in different wave length bands of Landsat MSS were processed using the following formulae:

0.43 band4 + 0.63 band5 + 0.59 band6 + 0.26 band7.

Termed as Soil Brightness Index (SBI), it helped to reduce the effects of vegetation and highlighted the different categories of sand reactivation. However, the signatures of the salt-affected areas and the riverine sand got mixed up with the areas of highly reactivated aeolian sand, thus leading to some misrepresentation. Therefore, a density slicing was carried out on the SBI output, on the basis of available ground information. This helped to substantially reduce the errors in classes. The salt-affected lands could be separated from the other classes as these were represented as the brightest areas. The highly reactivated aeolian sand and the riverine sand, however, could not be separated everywhere. Yet, the riverine sand could be visually separated as a separate unit, because of its linear, meandering trend on the image output. The other classes recognized were sands of low reactivation, the stable sand and the other miscellaneous class (Fig. 6).

Having received some degree of success, this technique is now being tried in other test sites in the desert also, using Landsat and IRS products. Experiments are also being carried out on the efficiency of other digital processing techniques like supervised classification, principal component analysis, band ratioing, etc., in the identification of aeolian sand provenance and sand mobility. The lower resolution of

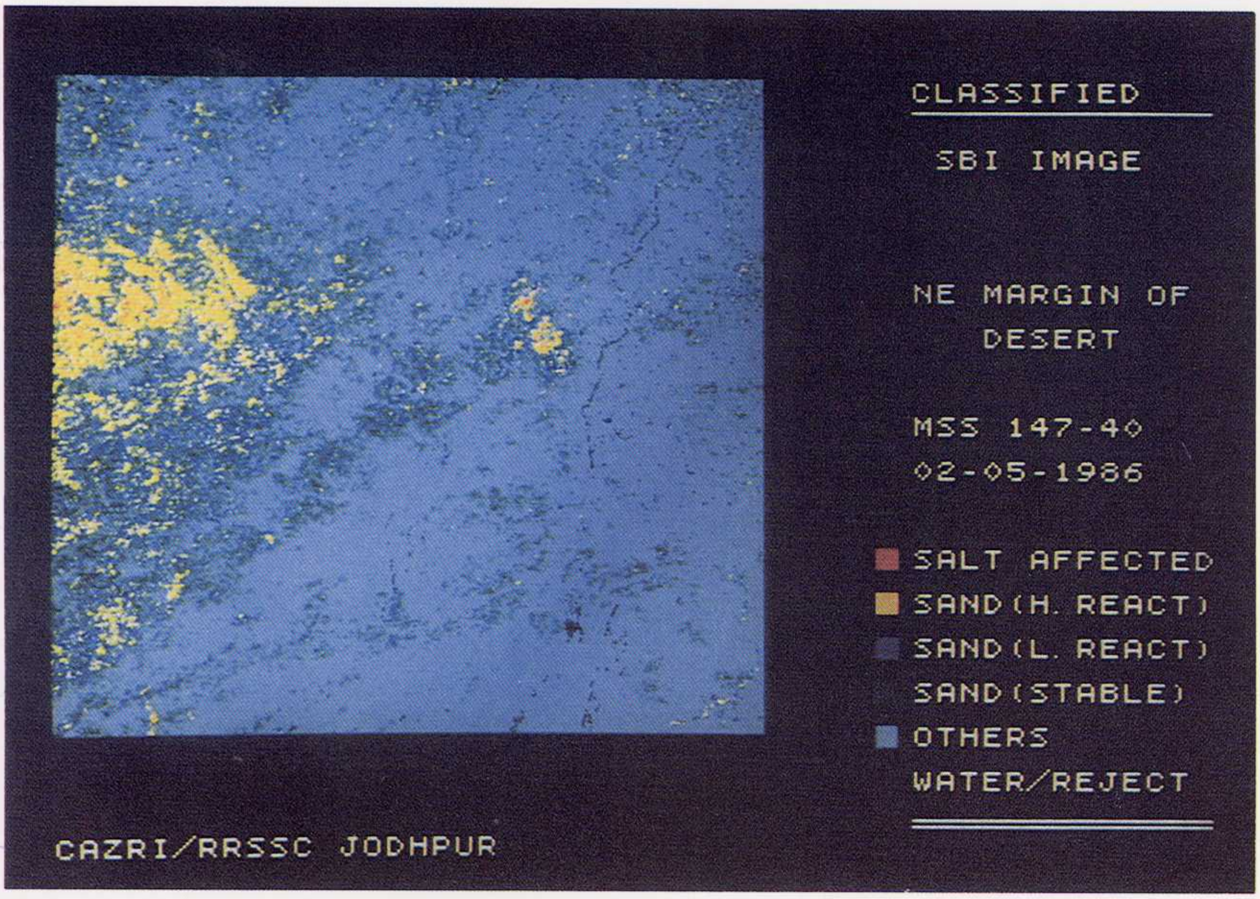

Fig. 6 Classified SBI image : NE margin of desert (MSS 147-40; 02-05-1986).

the MSS bands some time prove very useful in delineation of the degradation areas. For example, the moderate to severe water erosional zones along the small drainage lines in Saurashtra are very much prominent in the ERTS images of 1972 (MSS band 7, corresponding to MSS band 4 of the next generation Landsat images). The coarse resolution of the images suppressed most other information to highlight only the brighter eroded areas. Pickup and Chewings (1988) developed a model for forecasting soil erosion through fluvial processes in the arid Australia, using Landsat MSS digital data. Pilesjo (1992) on the other hand, found variations in estimation of soil loss from different satellite sensors (e.g. Landsat TM and Landsat MSS). For the mapping of salinity/alkalinity the standard FCCs of high resolution images are found to be useful.

On the basis of the available field information and satellite image interpretation attempts have been made to prepare a desertification status map for western Rajasthan (Singh *et al.*, 1992) and to catalogue the nature of the physical problems of desertification in the region (Singh *et al.*, 1994). We provide here a set of simplified field methods for assessing the wind and water erosional problems in the Thar desert (Tables 2 and 3).

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Table 2 Field criteria for assessing wind erosion/deposition in the Thar Desert

Topography	Rainfall zone(mm)	Major criteria for assessment	Severity
Flat sandy plains with dominantly loamy sand to sandy loam soil	100-550	Fresh sand sheeting upto 30 cm thick. New fence line hummocks upto 100 cm high	Slight
Moderately sandy undulating plains and sand dunes with loamy sand soils; thickly sand sheeted plains	Above 300	Presence of reactivated fresh sand of 50 to 150 cm thickness on stable dunes, sandy plains and fence line hummocks	Moderate
Moderately sandy undulating plains and sand dunes with sand to loamy sand soils	Below 300	Reactivated and fresh sandy undulations in the form of hummocks and sand ridges of 90-300 cm height. Sand sheets of 60-150 cm thickness between undulations. Reactivated stable dunes with fresh sand deposits of 70 to 200 cm thickness. Exposed plant roots to a depth of 40 to 100 cm in the sandy plains indicate erosion	Moderate
Moderate to strongly undulating sandy plains with closely spaced hummocks and high sand dunes with sand to loamy sand soils	100-550	Closely spaced sandy undulations in the form of hummocks and transverse and longitudinal ridges of 1 to 4 m height with fresh sand cover. Sand deposits of 100-300 cm thickness are usually present between undulations. Highly reactivated sand dunes are covered with fresh sand from all sides and superimposed by barchan dunes of 2 to 4 m height	Severe
Barchan dunes and very thick sand sheets with loose sand throughout the profile	100-550	Active and drifting sands in the form of individual and coalescing barchan dunes of 2 to 5 m height, encroaching upon roads, settlements and agricultural fields	Very severe

Modified after Singh *et al*. (1992)

Table 3 Field criteria for assessing water erosion in the Thar Desert

Topography	Rainfall zone(mm)	Major criteria for assessment	Severity
Plains with 30 to 90 cm deep medium to fine textured soils and good stand of tree vegetation.	Above 300	Sheet erosion imperceptible, but rills of 0.3 to 0.5 m depth and 0.4 to 0.9 m width are usually present.	Slight
Plains with 7 to 20 cm deep soils and poor stand of vegetation.	Below 300	Kankar exposed in pockets due to sheet erosion. Widely spaced rills are present.	Slight
Gently undulating plains with sand to loamy sand and sandy loam soils.	Above 300	Sheet erosion as evidenced by few pebbles and kankar on the surface. Soil depth is generally less than 30 cm.	Moderate
Hills, locky/gravelly plains and sandy undulating plains with sand, sand and gravel and loamy sand soils.	Below 300	Rills of 0.6 to 1.2 m depth and 1.0 to 1.7 m width. Widely spaced gullies of 4-8 m depth and 6-15 m width.	Moderate
Moderately sloping uplands, rocky/gravelly surfaces and gentle to moderately sloping plains with sand, sand and gravel and loamy sand to sandy loam soils.	Above 300	Exposed kankar and pebbles, suggesting complets stripping of soil through sheet wash. Gullies of 6-10 m depth and 7-25 m width with narrow interfluves.	Severe
Steeply sloping hill ranges, associated obstacle dunes and sandy undulating plains.	Above 300	Closely spaced gullies of 10-15 m depth and 20-40 m width. Almost no mappable interfluves.	Very severe

Modified after Singh *et al*. (1992)

References

Ahlcrona, E. 1988. *The Impact of Climate and Man on Land Transformation in Central Sudan.* Meddelanden Fran Lunds Universitets Geografiska Institutioner, No. 103; 140 p.

Cardy, F. 1994. Desertification. *Our Planet*, 6 (5): 4.

Dhir, R.P., Kolarkar, A.S. and Singh, H.P. 1992. Soil resources of the Thar. In, *Perspectives on the Thar and the Karakum* (Eds., A. Kar, R.K. Abichandani, K. Anantharam and D.C. Joshi). Ministry of Science and Technology, Govt. of India, New Delhi, pp. 60-85.

Dregne, H., Kassas, M. and Rozanov, B. 1991. A new assessment of the world status of desertification. *Desertification Control Bulletin*, 20: 6-18.

Ghose, B., Singh, S. and Kar, A. 1977. Desertification around the Thar - a geomorphological interpretation. *Annals of Arid Zone*, 16: 290-301.

Hellden, U. 1991. Desertification - time for an assessment. *Ambio*, 20: 372-383.

Hellden, U. 1994. Desertification - fact or fiction? *Our Planet*, 6 (5): 33.

Hellden, U. and Eklundh, L. 1988. *National Drought Impact Monitoring - A NOAA NDVI and precipitation data study of Ethiopia.* Lund Studies in Geography, No. 15, 55p.

Hentati, A. 1994. Taking effective action. *Our Planet*, 6 (5): 5-7.

Kar, A. 1986. Physical environment, human influences and desertification in Pushkar - Budha Pushkar lake region, India. *The Environmentalist*, 6: 227-232.

Kar, A. 1988 a. Evidence for neotectonism from the Thar desert. In, *Geomorphology and Environment* (Eds., Savindra Singh and R.C. Tewari). Allahabad Geographical Society, Allahabad, pp. 300-310.

Kar, A. 1988 b. Evaluation of present-day geomorphic processes in the Indian desert for assessing land degradation and naural hazards. *Ibid.*, pp. 643-654.

Kar, A. 1992. Morphological processes, human influences and land degradation in the Indian desert. In, *New Dimensions in Agricultural Geography*, vol. 2 (Ed., Noor Mohammad). Concept, New Delhi, pp. 123-150.

Kar, A. 1993 a. Neotectonic influences on morphological variations along the coastline of Kachchh, India. *Geomorphology*, 8: 199-219.

Kar, A. 1993 b. Aeolian processes and bedforms in the Thar desert. *Journal of Arid Environments*, 25: 83-96.

Kar, A. 1994. Lineament control on channel behaviour during the 1990 flood in the southeastern Thar desert. *International Journal of Remote Sensing*, 15: 2521-2530.

Kar, A. 1995. Geomorphology of arid western India. In, *Quaternary Environmentand Geoarchaeology in India* (Eds., S. Wadia, R. Korisettar and V.S. Kale). Memoir 32, Geological Society of India, Bangalore, pp. 168-190.

Kar, A. and Joshi, D.C. 1992. Prediction of land degradation hazards and risk assessment: the experience from Indian arid zone. *Proceedings, World Congress on Natural Hazard Reduction*, vol. 2, New Delhi, pp.11-23.

Oldham, R.D. 1926. The Cutch earthquake of 16 June, 1819, with a revision of the great earthquake of 12 June, 1897. *Memoir, Geological Survey of India*, 46: 71-147.

Olsson, L. 1993. Desertification in Africa - a critique and an alternative approach. GeoJournal, 31: 23-31.

Pickup, G. 1988. Modelling arid zone soil erosion at the regional scale. In, Fluvial *Geomorphology of Australia* (Ed., R.F. Warner). Academic Press Australia, Sydney, pp. 105-127.

Pickup, G. and Chewings, V.H. 1988. Forecasting patterns of soil erosion in arid lands from Landsat MSS data. *International Journal of Remote Sensing*, 9: 69-84.

Pilesjo, P. 1992. *GIS and Remote Sensing for Soil Erosion Studies in Semi-Arid Environments.* Meddelanden Fran Lunds Universitets Geografiska Institutioner, No. 114, 203 p.

Sen, A.K., Kar, A., Kumar, V. and Chatterji, D. 1991. Soil brightness index as a reliable tool for measuring the degree of aeolina hazard along the north-eastern margin of the Thar. *Abstracts, National Symposium on Remote Sensing of Environment*, Madras, pp. 47-48.

Singh, G., Babu, R. and Chandra, S. 1985. Research on the Universal Soil Loss Equation in India. In, *Soil Erosion and Conservation* (Eds., El-Swaify, W.C., Moldenhauer, W.C. and Lo, A.). Soil Conservation Society of America, Ankeny, pp. 496-508.

Singh, S., Ghose, B. and Kar, A. 1978. Geomorphic changes as evidence of palaeoclimate and desertification in Rajasthan desert, India (Luni development block - a case study). *Man & Environment*, 2: 1-13.

Singh, S. and Kar, A. 1991. Morphological characteristics of landforms and associated problems. In, Prospects of Indira Gandhi Canal Project (Eds., I.P. Abrol and J. Venkateswarlu). ICAR, New Delhi, pp. 11-18.

Singh, S., Kar, A., Joshi, D.C., Ram, B., Kumar, S., Vats, P.C., Singh, N., Raina, P., Kolarkar, A.S. and Dhir, R.P. 1992. Desertification mapping in western Rajasthan. *Annals of Arid Zone*, 31: 237-246.

Singh, S., Kar, A., Joshi, D.C., Kumar, S. and Sharma, K.D. 1994. Desertification problem in western Rajasthan. *Annals of Arid Zone*, 33: 191-202.

Singhvi, A.K. and Kar, A. (Eds.) 1992. *Thar Desert in Rajasthan*. Geological Society of India, Bangalore, 191 p.

Thomas, D.S.G. 1993. Sandstorm over a tea cup? Understanding desertification. *Geographical Journal*, 159: 318-331.

Warren, A. and Khogali, M. 1992. *Assessment of Desertification and Drought in the Sudano-Sahelian Region*, 1985-1991. UNSO/UNDP, New York, 102 p.

Desertification in Western Rajasthan - A Sociological View Point

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The arid region of India covers about 12 per cent of the country's geographical area and occupies over 0.32 million sq. km. of the hot desert of which 61 per cent comes under western Rajasthan. For centuries together people are living in the great Indian desert despite climatic vagaries. Over-exploitation of land, water and natural vegetation show the sign of man's activity on environment. Besides environmental problem, biotic interference on desert land like excessive pressure of human and animal population, low productivity, lack of diversified occupational base, traditional farming, etc., aggravate the vulnerable situation. The complexities of human population associated with desertification focuses the attention of social scientists worldwide (Berry and Kates, 1972; Caldwell, 1975; Kates 1972). Studies carried out in arid Rajasthan (Malhotra, 1976, 1977) reported that ecological deterioration and accentuation of desertification has been occurring in the region in recent times due to the growing number of human and livestock population, accompanied by inadequate development of resource base.

1. Population dynamics

The population in this region can be divided into two broad categories viz., sedentary and semi-nomadic or nomadic. The heterogeneous caste composition and the inter dependence of various caste/communities are the characters of desert dwellers. Caste stratification is strictly followed and all socio-economic activities are controlled by the institution of caste.

The desert region of India has relatively higher growth of population compared to other areas. By the arid zone standard the arid zone of Rajasthan is one of the thickly populated deserts of the world with a density of 83 persons per km^2 compared to 3 persons per km^2 in most of the deserts of the world. With the increasing population more and more marginal and sub-marginal lands have been put under cultivation, disturbing the entire ecosystem. Comparison of data on decennial growth rate of population (1901-1991) in arid zone of Rajasthan, Rajasthan state as a whole and India revealed an increasing trend of population. It is evident that starting with a base of roughly 3.40 million in 1901, the population in the arid region of western Rajasthan increased by more than five times in 1991 (Table 1). Similarly, the density of population has been increasing in all the successive years (Fig. 1). The percentage increase of population during each decade had been higher in arid Rajasthan. The factors responsible for higher growth rate of population were the early age at marriage, traditional beliefs and customs, illiteracy, especially the female illiteracy, gap between the birth and the death, inadequate family welfare measure, etc.

Table 1 Decennial Groth of Population in Arid Rajasthan, Rajasthan and India

	Arid Rajasthan			Rajasthan			India		
Year	Population	Growth Rate	Density of Popolation	Population	Growth Rate	Density of Population	Population	Growth Rate	Density of Population
1901	3,404,812		16	10,294,090		30	238,396,327		75
1911	3,688,458	8.33	17	10,983,509	6.69	32	252,093,390	5.74	76
1921	3,386,922	-8.17	16	10,292,648	-6.28	30	251,321,213	-0.3	76
1931	4,067,553	20.09	19	11,747,974	14.13	34	278,977,238	11	84
1941	4,940,596	21.46	23	13,863,859	18	40	318,660,580	14.22	97
1951	5,869,212	18.79	28	15,970,774	15.19	46	361,088,090	13.31	109
1961	7,644,382	30.24	36	20,155,602	26.2	58	439,234,771	21.64	133
1971	9,807,864	28.3	47	25,765,806	27.83	75	548,159,652	24.79	166
1981	13,483,022	37.47	64	34,261,862	32.97	100	685,184,692	25	208
1991*	17,437,655	29.33	83	43,880,640	28.07	128	843,930,861	23.16	256

Source: Diatrict Census Handbook, Rajasthan State and India
*1991 Figure is provisional

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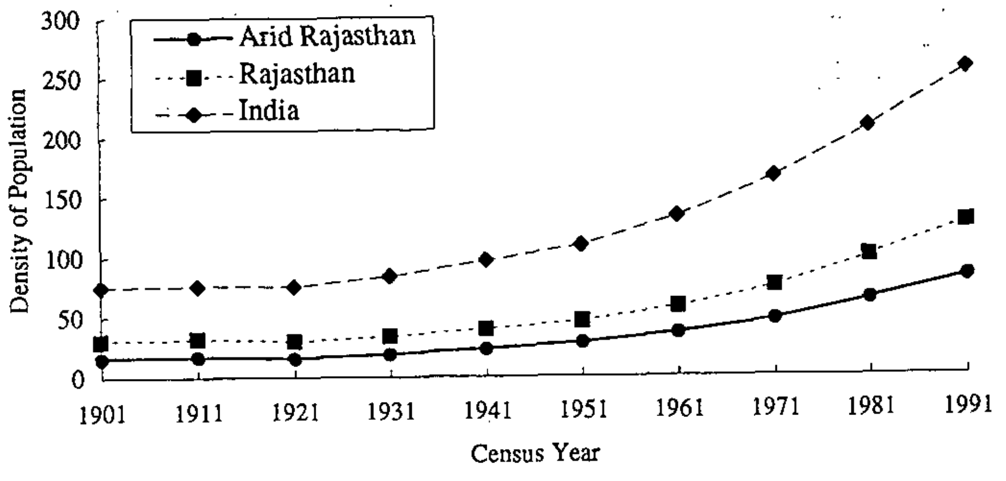

Fig. 1 Density of Population (persons per km^2).

The age and sex composition of population revealed a broad based pyramid having majority of population in the younger age group (0-34 years), which would substantially enhance the population. Early marriages and begetting of children are the integral parts of social lives of the desert dwellers although the actual consummation of marriage (*Muklawa*) starts when the girl reaches the age of puberty. The mean age of marriage for boys and girls of Rajasthan is low compared to all India average (Table 2). This region, moreover, had developed high fertility norms over the centuries due to high mortality. Although with the advancement in medical sciences the mortality rate has been checked, high fertility still continues. Data on birth and death rates revealed a wide gap between the births and deaths. The family planning program initiated in this region is slowly making its impact felt. However, it will take a longer time to control the population because the population base was already too large when the programs were initiated after Independence. It was observed that gender preference, at least for one male child if not more (which is considered sacrosanct, social security in old age, continuity of family) is quite dominant among the desert dwellers, which ultimately adds more children in family.

Table 2 Age of Marriage

	Mean age of marriage (years)	
	Rajasthan	India
Boys	19.3	23.2
Girls	14.6	18.33

Socio-cultural variables of this caste and tradition bound society, combined with better health care system, should be taken into consideration. A proper understanding of socio-economic, political and religious aspects, values and aspirations of the concerned society is also essential to visualize the problem of population control in a proper perspective.

Migration has played an insignificant role in the growth of population in the rural arid Rajasthan, as immigration from other states remained poor due to the paucity of productive lands and dearth of large scale industries. Similarly, out-migration from this region is significantly low because of backwardness, conservatism, traditional caste system, joint family system, early marriages, illiteracy, etc.

2. Literacy

The level of education or literacy is not high in the rural arid region of Rajasthan. Literacy has not spread rapidly here. Data on level of literacy (Table 3) of arid region of Rajasthan, Rajasthan State as a whole and India have been analyzed from 1951 to 1991. Although the percentage literacy in arid Rajasthan had increased from 1951, it was less than the state of Rajasthan and national average. The provisional figure of 1991 literacy level registered an upward trend compared to 1981. The picture of female literacy, on the other hand, is quite dismal. Some of the reasons for poor level of literacy are described below.

Table 3 Extent of Literacy (%) in arid Rajasthan, Rajasthan and India (1951-1991)

	Arid Rajasthan			Rajasthan			India		
Year	Male	Female	Total	Male	Female	Total	Male	Female	Total
1951	12.6	2.39	7.73	14.44	3	8.95	24.9	7.9	16.6
1961	22.94	5.63	14.68	23.71	5.84	15.21	34.4	12.9	24
1971	27.1	7.6	17.78	28.74	8.4	19.07	39.51	18.44	29.34
1981	33.04	9.61	21.8	36.3	11.42	24.38	56.37	29.75	43.25
1991*	42	15	29	55.07	20.84	38.81	63.86	38.42	52.11

Source: District Census Handbook (Rajasthan State and India)
*1991 Figure is provisional

As far as education of male children is concerned, quite a sizable part of respondents mention poor economy and the assistance needed from children in agriculture and animal husbandry activities which require family labor. The village community is not wholly responsible for the poor level of literacy as many-a-times proper infra-structure facilities could not be made available. A very few farmers are also of the opinion that after getting education the children may not like to continue agriculture or traditional occupation. The level of literacy among the female children is quite poor, mainly due to social customs and taboos. Among some castes it was not customary to send the girls to school. Moreover, early age at marriage is one of the important reasons for not sending them to schools. Daughters usually help in domestic and animal husbandry activities. Some of the farmers also think that if girls are educated they may not get a suitable match.

3. Occupational structure and farm practices

Agriculture and animal husbandry are the two principal sources of livelihood of the majority of population. However, people living in the arid region have been wholly dependent on subsistence agriculture. The majority of population depend absolutely on rainfed agriculture. For minimizing the risk of climatic vagaries farmers persist with some traditional system of cultivation like mixed cropping, crop rotation, fallowing of land, fragmentation of land, etc. The adoption of various high yielding varieties of seeds, chemical fertilizers and insecticides revealed a dismal picture (Table 4), as the adoption of different dry farming crops like HYV of oilseeds, pulses and legume grain was quite low (2-15%) compared to the cereal crops like pearl millet (36 %), which is called bajra in this region. The use of chemical fertilizers and insecticides were absolutely dependent on the availability of irrigation facilities. The risk of crop failure is one of the major constraints for adoption of various improved practices which could be mitigated by introducing crop insurance scheme. By introducing improved farming to a large extent, the over-exploitation of marginal and sub-marginal lands could be checked. Since the rainfall is quite poor and erratic, farmers keep large number of livestock for their survival i.e. at least in the event of crop failure they may get something from livestock which would ensure their survival. The livestock population far exceeded the human population and from 13.40 million in 1956, it went up to 23.32 million in 1983. Opinion survey (Saha and Singh, 1990) revealed that farmers prefer to keep large size of herd. Quality of breed is not preferred over quantity. A large number of farmers still consider that keeping more animal is a status symbol which raises socio-economic status. Such a large animal base means over-grazing and resultant degradation.

4. Conclusion

It is clear from the foregoing discussion that various socio-economic factors that are affecting the process of degradation should be studied at micro-level for better management. The Indo-Japan collaborative research project on desertification will not only help in analysing the various socio-economic parameters, accelerating the process of desertification, but will also help in eliciting the peoples perception towards desertification process.

Acknowledgements

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References

Berry, L. and Kates, R.W. 1972. Views on environmental problems inEast Africa. *The African Review*, 2 (3): 299-314.

Caldwell, J.C. 1975. The Sahelian drought and its demographic implications. *OLC Paper No. 8*. Overseas Liason Committee, American Council of Education, Washington D.C.

Kates, R.W. 1972. The hazard of drought. In, *Patterns and Perspectives in Environmental Science*. National Science Foundation, Washington D.C., pp. 218-221.

Malhotra, S.P. 1976. Opinion survey and desertification. *Proceedings, Development and Conservation of desert and Semi-Desert Lands*. Ashkhabad.

Malhotra, S.P. 1977. Socio-demographic factors and nomadism in the arid zone. In, *Desertification and its Control*. ICAR, New Delhi, pp. 310-323.

Saha, D.K. and Singh, U. 1990. People's perception towards Common Property Land (CPL) degradation in some arid areas of western Rajasthan. *Transactions of Indian Society of Desert Technology*, 15: 75-84.

Table 4 Extent of Adoption of various Agricultural Innonations in Arid Areas of Rajasthan

	Stages of Adoption (%)											
	Awareness				Trial				Adoption			
Type of Innovations	Upper Luni Basin	Barmer	Nagaur	Jalor	Upper Luni Basin	Barmer	Nagaur	Jalor	Upper Luni Basin	Barmer	Nagaur	Jalor
HYV of Bajra	89.0	81.0	85.0	88.0	24.0	38.0	30.0	56.0	16.0	15.0	16.0	36.0
HYV of Guar	8.0	9.0	-	56.0	1.0	0.7	-	13.0	-	0.3	-	6.0
HYV of Moong	5.0	7.8	-	41.0	3.0	0.3	-	6.0	-	0.1	-	4.0
HYV of Til	15.0	6.0	-	28.0	5.0	0.7	-	5.0	-	0.1	-	2.0
HYV of wheat	84.0	20.0	35.0	58.0	12.0	3.0	10.0	24.0	8.0	1.4	8.0	15.0
Chemical Fertilizer	85.0	43.0	74.0	71.0	22.0	6.0	17.0	38.0	10.0	3.0	1.3	24.0
Insecticide	75.0	19.0	40.0	56.0	6.0	4.0	8.0	21.0	4.0	1.0	6.0	11.0

HYV - High Yielding Varieties of seed

Upper Luni Basin - Areas partly covering districts - Jodhpur, Pali, Nagaur, Ajmer & Udaipur

Part III Desertification and Human Activities in China

Desertification in China - Its Characteristics in Asian Context

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1. Introduction

UNEP defines desertification as land degradation in arid, semi-arid and dry sub-humid areas resulting from adverse human impact. Here, land degradation implies reduction of land resource potential through soil erosion (wind and water erosion), salinization and decrease in production rate and biodiversity. However, land degradation occurs not only in these areas but also in other bio-climatic zones. For example, severe salinization problem can be observed in irrigated hyper-arid areas and, on the other hand, in cultivated wetlands in the humid tropics. Wide range of observation of desertification / land degradation phenomena is kept for establishing the method of combating desertification.

Asian Continent is characterized as a region with vast amount of desertified drylands. UNEP/GRID reported in 1991 that Asia contains nearly 2 billion ha or 32 % of the world drylands, which is almost the same amount reported in Africa. More than 70 % of Asian drylands are exposed to the threat of desertification. In addition, land degradation is significantly recognized in hyper-arid areas in Central Asia and in humid sub-tropics and tropics in East and Southeast Asia. It is quite obvious that the amount of irrigated lands is very high and ratio of desertified lands in irrigated lands is also high in Asia, which suggests one of the characteristics of desertification in Asia. Understanding of desertification in Asian context will highlight common and unique characteristics necessary for promoting world-wide comparative desertification studies.

China located in Central and East Asia has various bio-climatic zones from hyper-arid to humid areas. It has a long history of pastoral, agricultural and silvicultural landuses. Post-war land reform and land development under the leadership of communist party has brought drastic and unique change in quality and quantity of human impacts on these lands. For instance, land degradation was accelerated during the period of cultural revolution 1966 - 1976, when party leaders demanded people to learn from farmers and to expand arable lands as much as possible. The significance of selecting China as a study field for desertification and its control studies is that 1) it contains various bio-climatic zones and various land degradation phenomena can be seen, and 2) influence of human impacts on lands are easily evaluated through assessing landscape change in the recent decades.

2. Desertification process in the selected bio-climatic sites in china

2.1. Salinization caused by irrigation in hyper-arid areas in Xinjiang Uygur

Severe salinization is observed in Fukang area, located at the northern footslopes of Tianshan Mountains. Here arable lands with irrigation system was reclaimed in the 1960's by military settlers using meltwater coming from glacier at the top of Bogda Mountain. At present, wheat, cotton, rice and capsicum are major products. However, because of the advance of severe salinization caused by irrigating hyper-arid environment, abandoned lands have expanded. Comparison of satellite image in 1977 and aerial photo in 1987 shows that 61 % of arable lands are abandoned, mainly by the salinization of grassland soils (Fig. 1 & 2). Institute of Biology, Soil Science and Desert Research, Chinese Academy of Science is trying to improve degraded lands by introducing salt-tolerant crops and improving irrigation system by saving water and constructing underground canals.

2.2. Sand dune remobilization caused by deforestation and over-grazing in semi-arid areas in Inner Mongolia (Neimenggu)

Grasslands with patchy distribution of forests dominated by *Pinus-Quercus* and *Ulmus* woodlands have degraded through human impacts in Wulan-Aodu area, Inner Mongolia (Fig. 3 & 4). During the time of "Great Leap Forward" for promoting iron smelting announced in 1976 by the communist leader and the construction period of large reservoir in this area, trees were cut intensively for firewood, resulting in destroying forests and woodlands and induced accelerated sand dune remobilization. Gradual increase in population both people and domestic animals has also affected on the

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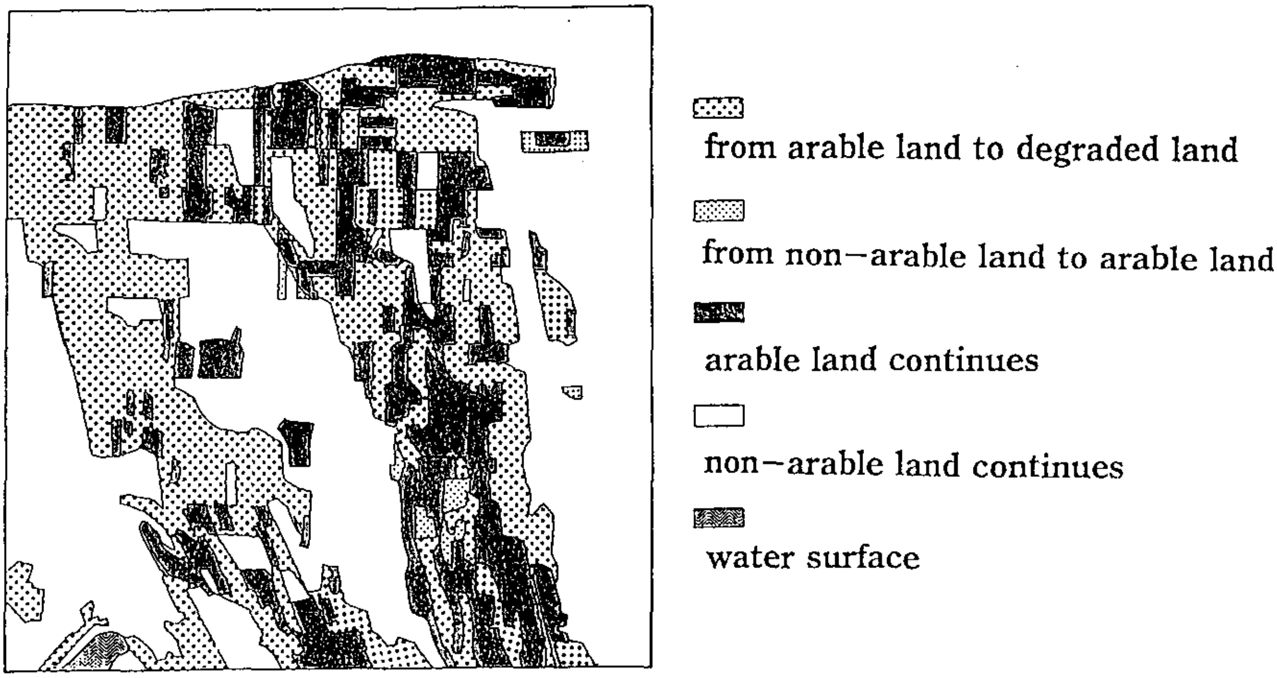

Fig. 1 Distribution of desertified lands in Fukang, Xinjiang 1976-1987.

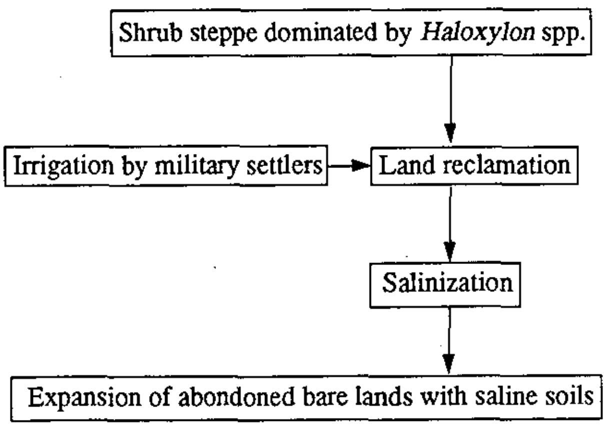

Fig. 2 Land degradation process in Fukang, Xinjiang (Hyper-arid zone).

land degradation. Over-grazing has brought rapid decrease of grassland biomass. Digging of salinized lowland soils for housing materials has brought the irreversible change in soil potential. Institute of Applied Ecology, Chinese Academy of Sciences is trying to rehabilitate desertified landscape by improving grasslands and planting trees to stabilize sand dunes.

2.3. Water erosion caused by deforestation in humid areas in Zhejiang

Lanxi area, Zhejiang is geomorphologically characterized by the hills and lowlands. Before World War II, weathered surface of the hills were stabilized by covering of *Pinus* woodlands and paddy fields were well developed on lowlands. Here, "Great Leap Forward" brought strong impact on woodlands, resulting in decrease of logging and increase of Bare hill surface (Fig. 5). As a result, accelerated soil erosion was occurred in the humid environment and the landscape called "red-colored desert" (degraded landscape of sub-tropic acid red soils) was appeared. Eroded soils were accumulated on lowland, which made lowland farming difficult. Increasing demand of firewood has caused soil erosion, too. Local government and farmers started land improvement such as reforestation and rehabilitation of lowland arable lands (Fig. 6, 7 & 8). At present, degraded lands are gradually decreasing. However, in Changshan area, west of Lanxi, deforestation of hills is still major problem causing floods : after heavy rainfall.

3. Toward the world-wide comparison of desertification

Chinese cases suggest there are strong relationships among bio-climatic zones, landuse systems and land degradation patterns (Table 1 & 2). These three factors are of course related with each other forming particular desertification/land degradation phenomena.

For the search of the way to combat desertification, these three factors are surveyed before adopting land improvement techniques. They are also suitable as indices for comparing desertification/land degradation

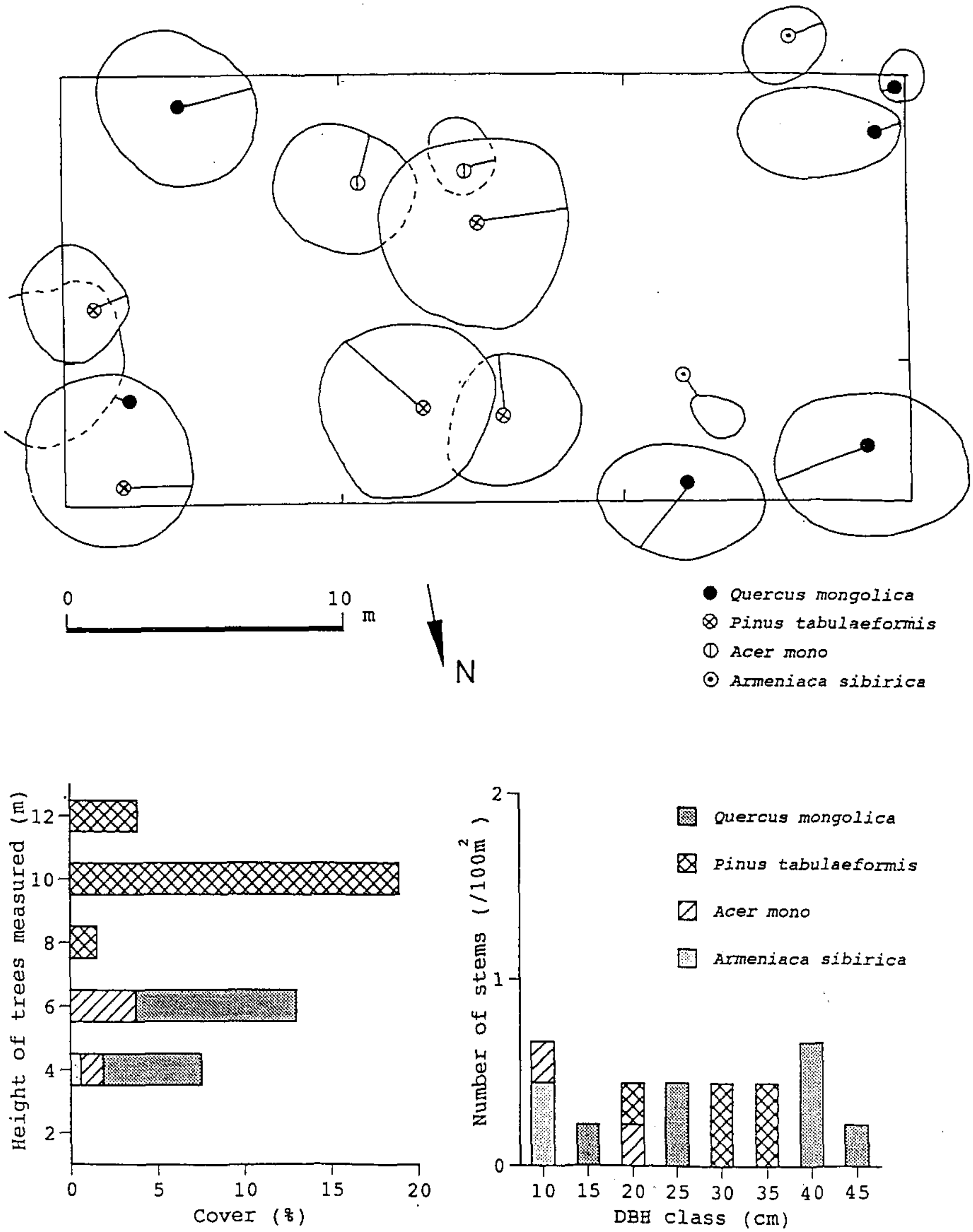

Fig. 3 Community Structure of *Quercus-Pinus* Forest.

processes in Asia. In the present research project, case studies in China, India and Thailand should be summarized based on this framework (Fig. 9). On the other hand, case studies in Africa will be used for continental-scale comparison of desertification.

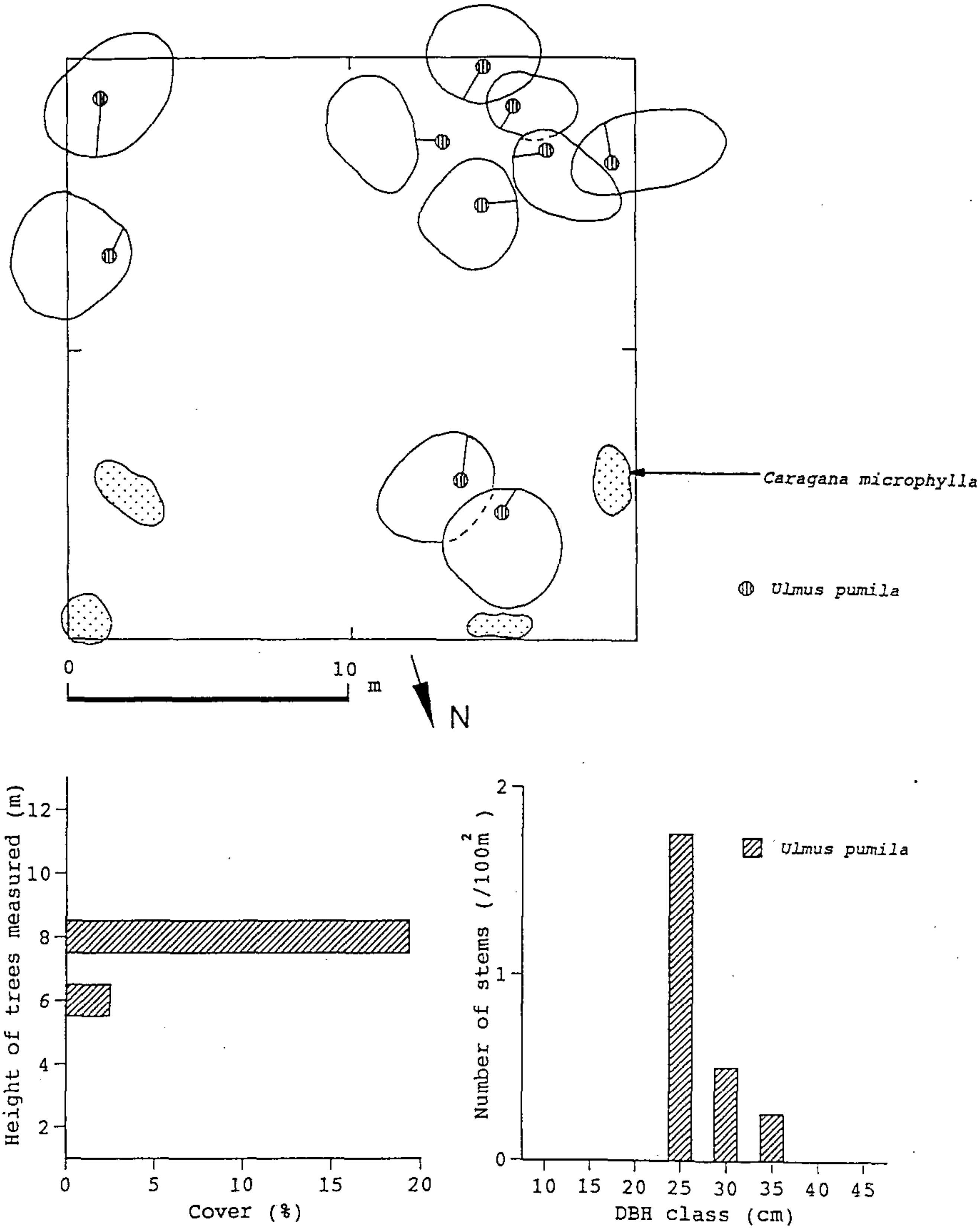

Fig. 4 Community Structure of *Ulmus* Woodland.

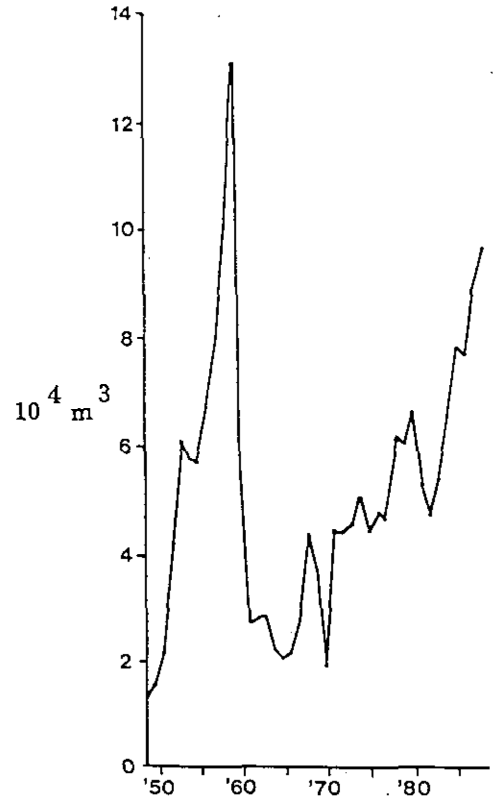

Fig. 5 Volume of logging in Lanxi 1949-1988.

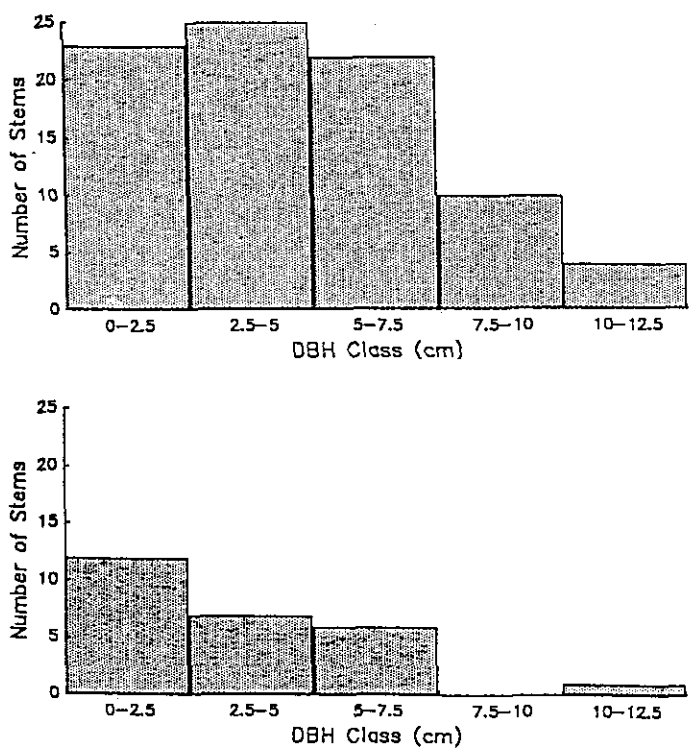

Fig. 6 Comparison of protected and non-protected *Pinus massoniana* forest. Upper:Protected Lower:Non-protected.

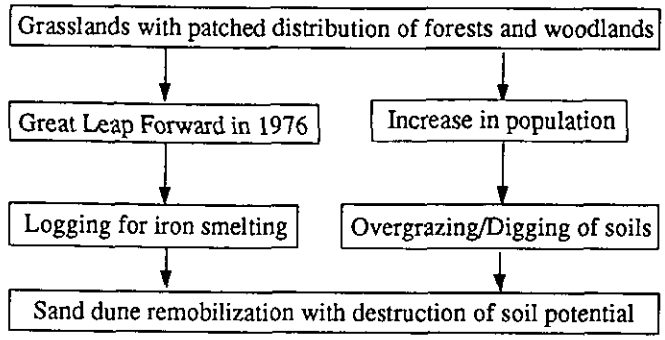

Fig. 7 Land degradation process in Wulan-Aodu, Neimenggu (Semi-arid zone).

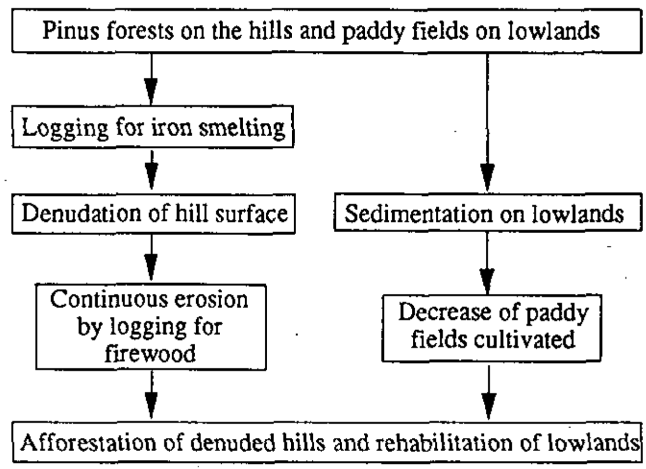

Fig. 8 Land degradation and rehabilitation in Lanxi, Zhejiang (Humid zone).

Table 1 Percentage of people recognizing as serious environmental problem in each surveyed area

Category of serious environmental problem	Shanshan Xinjiang	Tongbeihu Neimenggu	Changshan Zhejiang
Air pollution	26	6	37
Water pollution	14	6	33
Deforestation	14	6	37
Grassland degradation	7	25	0
Overuse of chemicals	19	0	8
Desertification	9	87	10
Soil and water erosion	7	0	47
Salinization	43	0	2

Table 2 People's consciousness of human impact on lands in each surveyed area

Percentage of positive and negative impact assessment		Shanshan Xinjiang	Tongbeihu Neimenggu	Changshan Zhejiang
Irrigation	Yes	4	12	16
	No	65	81	66
	Don't know	29	6	14
Logging	Yes	60	81	81
	No	29	12	6
	Don't know	12	6	14
Grazing	Yes	26	50	50
	No	31	12	25
	Don't know	41	12	20

Bioclimatic zone	Hyper-Arid	Arid	Semi-arid	Sub-humid	Humid
Dominant landuse	Nomad	Nomad Pasturage	Pasturage	Rainfed cropping	Cropping /Forestry
Land degradation	← Salinization → (Hyper-Arid to Humid) ← by irrigation → (Hyper-Arid to Semi-arid) ← by deforestation → (Sub-humid to Humid) ← Wind erosion → (Arid to Semi-arid) ← Water erosion → (Sub-humid to Humid) ← Decrease in production rate and biodiversity → (Hyper-Arid to Humid) ← Forest and scrub degradation → (Semi-arid to Humid) ← Grassland degradation → (Hyper-Arid to Semi-arid)				
Study field	Xinjiang Jisalmer	Jodhpur	Neimenggu Pali	Nyngxi	Zhejiang Thailand

Fig. 9 Relationship among environmental factors related to land degradation.

Research on Plant Ecology in Amelioration Process in Desertification of the Kerqin Sandy Lands

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The Kerqin Sandy Lands covers an area of 43,000km^2 with latitude 42°20' - 44°20'N and longitude 118°30' - 123°30'E. It is subordinate to Chifeng City (former Zhaowuda Allied City), Zhelimu Allied City of Inner Mongolia Autonomous Region, Jilin Province and Liaoning Province. The area is seriously threatened by desertification, alkalization and grassland degeneration, among which desertification is the most prominent. According to the statistics, the desertified area is 41 % in Chifeng and 52.57 % in Zhelimu. Because of the effects of natural conditions and human activities, the desertification process is relatively fast. Wengniute County, Chifeng City, for example, covers an area of 11,878 km^2, out of which 47.2 % is desertified land with average annual increase of 66.7 km^2 during the past 30 years and some years with 113.3 km^2. The desertification not only hinders the development of economy this region, but also affects global environment. Therefore, we have carried out scientific research works for more than 20 years to control desertification in Wulan - Aodu, the Kerqin Sandy Lands. The items on plant ecology in controlling desertification are as follows:

1. Natural environment and vegetation

Wulan - Aodu is located at 43°20'N latitude and 119°39'E longitude, with 429 m elevation. It is located in temperate zone with semi-arid monsoon climate, with annual average temperature 6.3°C, precipitation 340 mm, out of which 65 - 70 % is in June to August, and evaporation 2,500 mm. Annual average wind speed is 4 m/sec. In almost 80 days per an year strong wind (wind grade is more than 8) is recorded.

The topography is wave-shape of dune and low land, and somewhere remain relic hills. The depth of sand is usually more than 200 m. The sand is supplied incessantly from thick Quaternary stratification by weathering. The Sandy Lands can be divided into 5 types: moving dune, semi-fixed dune, fixed dune, even Sandy Lands and low land between dunes. The soils are mainly blown sand soil, meadow soil and alkali soil. The groundwater level is about 1 m in lowland and 2 m in other landforms.

The vegetation in the area shows the characteristics of forest-steppe transitional zone. At present, some *Pinus-Quercus* forests survive on relic hills, where such species as *Pinus tablaeformis, Quercus mongolia, Acer mono, Celtis bungeana,* are dominant. *Ulmus pumila* forests also remain in some even fields. Meanwhile, on most part of fixed dunes and even fields are covered by *Caragana microphylla* shrubbery and grass steppe which mainly consists of *Cleistogenes squarrose, Koeleria crista, Agropyron cristatum.* Various meadows and halophyte communities are distributed in lowland which mainly consists of *Arundinella hirta, Hemarthria japonica* and *Aneurolepidium chinese* and so on as dominant species. Annual species *Agriophyllum arenarium* community scatters on moving dunes. On semi-fixed dunes generally grows vermouth community in which *Artemisia halodendron* is dominant and sometimes *Salix flavida* distributes on part of the dune tops. *Salix* shrubberies usually grow in lowland between dunes in which *S. microstachya, S. mongolia,* and *S. flavida* are dominant. The vegetation succession series in this area include hygrosere, xerosere, halosere and psamosere. Relatively stable communities are *Pinus - Quercus* forest, *Ulmus* forest, *Caragana* shrubbery and grass steppe.

2. Natural vegetation change

Bio-ecological engineering measure, which is used to ameliorate the desertified land, mainly include fencing preservation of degraded vegetation and establishing artificial vegetation.

The degraded vegetation changes with fencing presentation as follows.

2.1. *Cleistogenes - koeleria* grassland:

Annual mixed with perennial grass species were main components of the plant communities before fencing preservation in overgrazed even Sandy Lands. After fencing presentation for 15 years, annuals (*Setaria*

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viridis, Digitaria sanguinalis, Pappophorum boreale and *Aristida adscensionis*) disappeared while rhizome grasses (*Pennisetum flacidum, Ameurolepidiumm chinese, Agriopyron cristatum*) and small-shrubs (*Lespedeza dahurica, L. hedysaroides*) gradually increased. And then on, cespitose grasses (*Cleistogenes squarrose, Koeleria crista*) gradually became dominant. This process is called cepitose grass steppilization (the process that vegetation changes into steppe from other communities). The average height of plant community after fencing preservation increased from 20 cm to 50 cm, the biomass from 450 kg/ha to 1,875 kg/ha, and the total coverage from 25 % to 80 %.

2.2. *Caragana* shrubbery:

On overgrazed wave-like fixed sand dunes, grew *Caragana* shrubbery community, with thin *Caragana microphylla* dominant in upper layer and annual plants dominant in lower layer. After fencing preservation for 6 years, the flora of the lower layer showed a evident change: annuals gradually disappeared while long rhizome grass - *Pennisetum flacidum* - became booming and other rhizomic grasses (*Agropyron cristatum, Aneurolepidium chinese*) and cespitose grasses (*Cleistogenes squarosa, Koeleria crista*) entered. This process is called cespitose grass steppelization of synusia. The height of upper shrub layer increased from 1 m to 1.5 m, lower grass layer from 20 cm to 50 cm, the coverage of grass layer from 15 % to 60 %, the biomass of shrubs increased up to 797 kg/ha from 558 kg/ha, and the grass layer up to 1,406 kg/ha from 270 kg/ha.

2.3. Vegetation on sand dunes

Nearly bear sand dunes, 15 - 30 m high, which were formed from fixed and semi-fixed sand dunes by repeated cutting or overgrazing, are similar to moving sand dunes except for the surviving species of their original vegetation. After 20 years' fencing preservation, vermouth sandy communities consisting of drought resistance shrubs (*Caragana microphylla, Hedysarum fluticosum*) have been established. The succession process of vegetation had three stages:

1) Annual-biannuals dominating stage, such as *Setaria virids, Corispermum* spp. *Artemisiia scoparia, A. sibersiana, Agriophyrum arenarium* and *Bassia dasyphylla*.

2) Long rhizome grasses dominating stage, such as *Pennisetum flaecidum Aneurolepidium chinese* and *Phragmites communis*.

3) Under-shrub vermouth stage. *Artemisia halodendron* is dominant species accompanied with *A. udanica,, A. sacrorum, A. capillaris, Caragana microphylla, Hedysarum fluiticosum*, etc.

This process is called psamophyte communitilization. During the succession, the height of community increased up to 65 cm from 30 cm, biomass up to 1,125 kg/ha from 21 kg/ha and the coverage up to 65 % form 57 %.

2.4. Vegetation in low land between dunes

In the low land, with lower topography, 1 m groundwater level and good water condition, there developed meadow soils and grew shrubbery communities dominated with *Salix* spp., primarily. After repeated cutting, the shrubberies degenerated into meadows mainly consisting of *Carex* spp. In Wulan-Aodu area, through 20 years' fencing preservation, exuberant *Salix* shrubbery community has been established. The succession process included three stages as:

1) *Carex duriscula* and other *Carex* species dominating stage.

2) Rhizome grasses (*Calamagrostis epigeios, Phragmites communis*) and other herbs stage. The herbs are mainly *Thalictrum simplex, Inula btarmica var. japonica, Taraxacum mongolica, Vicia amoena, Lathylus quinquenermus, Chrysanthemum zawarskii*, etc.

3) Shrubs dominating stage. The major shrub species are *Salix mongolica, S. microstachya, S. flavida* mixed with *Betula microphylla*.

This succession process is called shrubberization (the process of changing into shrubbery from other communities) in wet lowland. After the preservation, the height of shrubs increased up to 2 m from 0.7 m, the height of grasses up to 80 cm from 30 cm, the coverage of shrubs up to 85 % from 6 %, the coverage of grasses up to 60 % from 25 %, the biomass of shrubs up to 1,149 kg/ha from 178 kg/ha/year and the biomass of grass up to 2,700 kg/ha/year from 400 kg/ha.

3. The stability of artificial vegetation for fixing sand

In order to fix the moving sand dunes, we have established a large area of artificial plant communities, among which *Caragana* community is vast. It was set up by means of hole planting in 1 x 1 m^2 grass checks since 1985.

Comparing with physical engineering measures, bio-ecological engineering measures are enduring for slowing down wind, fixing sand, and gradually strengthening the effects on physical environment, furthermore, resuming and improving the ecological environment. However, the key problem of bio-ecological engineering is the stability of artificial community.

3.1. Adaptiveness to the physical environment

As an aboriginal species, *Caragana microphylla* can adapt to the general physical environment. But the key problem is whether it can grow normally to form community under the drought condition on the moving dunes. Based on many years' observation, *Caragana microphylla* community with coverage 15 % could grow well in both normal year (such as in 1987, with precipitation 330 m) and intermediately drought year (such as in 1989, 187.5 mm). However, the growth was hindered in seriously drought years (such as in 1988, 136.9 mm) with a lot of leaves withered, but in the next year this species grew well.

From the observation, it was found that the seasonal soil moisture, above 1 m depth, in the dunes covered with *Caragana microphylla* community is less than that in bare sand dunes because of plant transpiration (as Table 1). In normal years the soil water-storage capacity of the dunes with *Caragana* community is usually 20 - 30 mm during the growing season, which is less than that of moving dunes in seriously drought years. In seriously drought years, the soil water-storage capacity of dunes with *Caragana* community is only 8 - 13 mm, which is equivalent to that the lowest value of available soil water-storage capacity (The soil water field capacity is 5.5 %, volume weight is 1.6, specific gravity is 2.0, weighing coefficient of *Caragana* microphylla is 0.8 - 1.0 %). Based on studies of transpiration of *Caragana microphylla*, the precipitation and soil water-storage capacity only meet what *Caragana microphylla* transpiration need (as Table 2). Therefore, a lot of leaf withered.

3.2. Perfectness of the flora

The natural *Caragana microphylla* community shows species richness of 6 - 7, a total flora of 30, and a life-form table with Ph. 10 %, Ch. 7 %, H. 36 %, G. 20 %, Th. 27 %. At present, the artificial *Caragana* community has a total flora of 18, a life-form table with H. 4, G. 4, Th. 10, through which we can see that the annuals is dominant, and that the flora of the artificial *Caragana* community is still not perfect and needed to be further improved.

Table 2 Seasonal Changes of Transpiration Capacity of Caragana microphylla

Months	Transpiration Capacity per Leaf Weight (g/g)	Total Transpiration Capacity * (mm)
May	16.25	3.90
Jun.	12.78	18.02
Jul.	15.14	38.90
Aug.	14.16	42.20
Sep.	10.10	19.80
Total		122.82

*Notes: Transpiration capacity when coverage is 15 %.

3.3. The ability of self growing and regeneration

According to many years' observation, the growth of *Caragana microphylla* can be divided into infancy stage and mature stage. Infancy individuals, 1 - 4 years old, show vegetative and upward growth. Mature ones, 5 years old and older, do their thickening and reproductive growth. Under the condition of artificial

Table 1 Seasonal Changes of Soil Water-storage Capacity in Caragana community (C) and bear sand dunes (S)

(mm)

Month	May			Jun.			Jul.			Aug.		Sep.			Oct.	
Date																
Yr. Type	5	15	25	5	15	25	5	15	25	15	25	5	15	25	5	15
1987 C	50.5	38.6		26.8	27.2		29.7	20.0	17.1		24.5					
S	60.0	44.3		43.8	45.4		45.6	40.9			54.0					
1988 C	14.5		14.1			13.0			15.2	15.8				25.6	44.0	
S	41.5			31.7	35.2	25.4		29.6	20.0	30.1	25.1	23.0			34.2	
1989 C			13.4			12.1		9.1	9.2	12.0	11.5		9.5	12.5	13.1	9.5
S			37.8		37.5		32.0		42.2		42.0			52.5		59.4

community, *Caragana microphylla* can grow well, bloom and bear fruits. The biomass of various aged plants is also normal (as Table 3).

As to regeneration, new seedling can not be seen in artificial plant communities. But the ability of sprout regeneration is high. Based on experiments, the annual biomass of mature plants after branch - cutting was more than the total biomass of three years old ones (as Table 3). This indicates that the ability of regeneration of *Caragana microphylla* is high in artificial community.

Table 3 Changes of Caragana microphylla biomass above ground g/individual

Years aged	2	3	4	5	6	7	8	9	10	11	12
Biom. of individual	4.7	9.6	18.0	28.9	50.7	53.5	54.0	56.1	59.5	60.0	60.7
Annual biomass	2.7	7.8	11.0	10.2	13.3						12.2
Annual biom. after brunch-cutting	3.3	6.6	9.6	13.2	17.9						20.2

3.4. Effects upon the environment

The effects of artificial plant community upon the environment are mainly to slow down wind, to fix sand and to ameliorate soil condition. As there are lots of paper published on the effects of slowing down wind and fixing sand, we do not discuss about them in this article.

The effects of artificial plant community on the soil condition include those on the soil moisture and on the soil nutrition. The former has been discussed above. The soil nutrient materials of *Caragana microphylla* mainly come from dead roots and, especially, the litter. The amount of withered leaves and branches of *Caragana microphylla* with 6 - 7 years aged is 750 - 900 kg/ha yearly. Although only a part of them returns to soil because of wind blowing, the improvement of soil nutrient condition is remarkable in the soil surface (as Table 4).

Table 4 Soil Nutrient Materials in Caragana Microphylla Community and Bear Sand Dune

Nutrient Material in Soils	Humus (%)	Readily N (ppm)	Readily P (ppm)	Total N (%)	Total P (%)
Caragana Soil	0.18	50.75	4.029	0.013	0.010
Sand Dune	0.04	30.45	11.924	0.005	0.008

In the light of above, the artificial *Caragana* community is developing toward the stable vegetation. And also, because of high quality of nutrient materials (as Table 5) contained in the leaves and the brunches of *Caragana microphylla*, artificial *Caragana* community has great significance both in controlling wind, sand and in animal husbandry.

Table 5 Nutrient Material Content in Leaves of Caragana Microphylla (%)

Crude Protain	Sugar	Starch	P	Ca	Mg
25.1	2.1	7.1	0.24	1.48	0.3

Amelioration of Desertification and Construction of Sustainable Landuse System in Wulan-Aodu Area

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The Kerqin Sandy Lands, in the west of Northeast China, covers an area of 43,000 Km^2, within 118°30' - 123 °30'E Longitude, 42°20' - 44°20'N latitude. As it is in forest-steppe transition zone, there had been growing exuberant forests and steppes, therefore, it was traditional husbandry base.

Since the middle of the 18th century, especially from the last 40 years, because of rapid increasing of population and expanding of livestock without control, grassland has degraded, land has desertified and alkalized. Such processes hindered not only the development of regional economics, but also the lifting of living standard of the local people. Wulan-Aodu area, located at the west of the Kerqin Sandy Lands, is a typical example of the developing experience and land desertification processes.

Wulan-Aodu area, located at the north part of Nashihan Township, Wengniute County, Chifeng City, Inner Mongolia Autonomous Region, includes three villages, one of which is called Wulan-Aodu Village. Wulan-Aodu Village has an area of 7,350 ha, 170 families, 751 people with 98 % Mongolian, 7,567 livestock. In 1992, average income per a person was only 620 RMB with 90 % from livestock husbandry. The traditional habit for raising livestock is remained there. According to Nashihan Township, natural grassland was completely degraded; 90 % was desertified, 30 % of which has become bare to occur remobilized sand dunes. The reasons caused the severe state include richness of sand sources, frequent drought, and, especially, the human activities. (as Table 1).

Table 1 Changes of Population and Livestock in Wulan-Aodu Village

Year	Family	Population	Livestock	Note
1950	15	77	670	
1956	47	270	4,429	← 30 families migrated in
1960	62	313	10,935	
1966	85	448	14,259	
1970	97	547	10,715	
1976	103	616	10,390	← 40 knowledge youths from cities settled down
1980	105	591	8,961	
1986	126	659	7,932	
1990	149	697	7,557	
1993	170	751	7,567	

According to Table 1, the population in 1990 was nearly 10 times of that in 1950, the amount of livestock in 1990 was 11.3 times of that in 1950. In 1966, when the livestock number was the largest, it was 20 times as much as that in 1950.

Such human activities as house construction, animalfold building, firewood cutting, grassland ploughing for planting grain, overgrazing, etc., had seriously affected on the ecological environment. According to aged local villagers, in this area grew vast exuberant grassland, with average grass height 60 - 70 cm; only at livestockfolds and near watering sites there were desertified land, which was totally less than 1 % of the area in 1950's. However, in 1960, the population had expanded to more than 300 in Wulan-Aodu village. A lot of trees mainly including *Salix* spp. in low land and *Betula* spp. on sandy dunes had been cut down for house construction, livestockfold building and firewood. As a result the lowland between dunes became dry, grassland degraded obviously, and the proportion of the desertified area reached 10 %. With the time on, in 1966, the number of livestock reached the maximum (14,259), herds of animals consumed all the forage grass in the summer and autumn with nothing left for the following seasons, the desertified area increased up to 20 %. In the later decade, the population of animals was kept at more than 10,000, and the grassland had been universally degenerated; 60 % of the area was desertified. Since 1980s, although the number of animals was fluctuating 8,000, the animals suffered from lack of forage and grew badly, became of the worsened natural conditions and pasture deterioration. This situation indicated that controlling the regional population and livestock is of utmost importance to the frail ecological environment.

In degraded pastoral area, like Wulan-Aodu, where the local people live on livestock husbandry, the more degraded land resources provides the less support capacity, i.e., the worse grassland breeds the fewer and the more malnuturist animals, which makes the living standard lower. In return, lower living standard forces

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people to feed the more animals to improve their living, the more animals causes the grassland more degenerated. This process is a harmful feedback, which is deeply affects the sustainable use of the ecosystem.

In order to break the harmful feedback and to improve the local people's living, we have undertaken much research works and have organized many bio-ecological engineerings to ameliorate the worsened ecological environment and to establish a sustainable developing system of land use. By means of improving the degraded ecosystems optimizing the local landscape components and introducing new landscape components to construct a new landscape pattern with high heterogeneity and stability, we managed to establish an efficient and harmonious artificial-natural landuse system with higher economic benefit and higher ecological benefit than the primary landscape in Wulan-Aodu area.

Based on those principles, we optimized the vegetation by the following 4 measures:

1. Establishing Complicated Shelter-forest System

Forest has multiple functions such as slowing down, and fixing movable sand, water and soil conservation, regulating climate and improving environment. It provide a shelter for grass growth and husbandry development, and it can lay an important role for increasing the vegetation coverage and improving the original plant communities. We designed and planted various shelter-forests for such habitats as moving sand dunes, semi-fixed sand dunes, fixed sand dunes, hollow land and residential area. Belts, networks and tracts of shelters have been integrated into a complicated shelter-forest system. When shelter-forests were constructed, trees, shrubs and herbs were combined, and fencing to preserve the existing plants and planting new individuals were simultaneously carried out.

2. Developing Forage Forest

Leaves, twigs, flowers and fruits of trees and shrubs can be used as complementary forage of animals. Xyrophyta grows long and stably and is likely to stand fluctuation of natural conditions. The nutrient materials analysis of leaves of 48 species of xylophyta revealed that there are 14 woody plants with cryde protein more than 20 % and 20 plants with 15 - 20 % crude protein in the foliage. Consider that the protein content of corn is about 14%. In Wulan-Aodu area, suitable forage woody plants are *Caragana microphylla*, *Ulmus pumila*, *Salix matsudana*, *Hedysarum fruiticosum*, and so on.

3. Planting High Yield Forage Crops

Corn, beans and leguminous herbage can grow in hollow land between sand dunes and in the residential area where there are shelters and sheds to prevent the forage crops from wind, sand and animals. The yield of planted forage crops is 4 - 8 times as much as that in natural harvest grassland.

4. Controlling and Stabilizing the Number of Livestock, with Improvement of Animals' Quality

According to the forage-animal balance theory, strict control of the quantity of livestock, specially in winter and in spring, has universal significance in degenerated pastoral areas. In Wulan-Aodu area, out of the quantity of livestock, 50 - 60 % must be reproductive animals while 30 % must be sold out after the growth season. The strict control of the livestock population can reduce impact on the grassland. Furthermore, the quality of livestock can be improved and the time required for livestock growth can be shortened by the control.

As for the improvement of the habitats, we adopted the following 2 measures:

1. Regulating the Micro-climate

Drought, wind and sand drifting are the main calamities in Wulan-Aodu area. Establishing the complicated shelter-forest system was not only for improving the plant communities, but also for regulating the micro-climate of habitats. When shelterbelts were established, the micro-climate became better with the process of slowing down of wind and prevention of drifting sand.

2. Ameliorating the Soil Conditions

The grassland was hardened or desertified with the trampling of the over-loaded animals. In such grassland grass growth was hindered with not only poor yield but also disappearance of excellent forage species. Therefore, we adopted 2 approaches to ameliorate the soils:

1) Fencing, preserving, seeding, fertilizing and ploughing in desertified grassland.

2) Ploughing, fertilizing, spreading trace element chemicals, and planting herbs in alkali and / or hardened grassland.

We have finished several items of the bio-ecological engineerings and established a primary sustainable landuse system in Wulan-Aodu area since 1982. We have fixed 800 ha of remobilized sand dunes, by means of planting artificial vegetation. Vegetation coverage on the fixed dunes has increased from 20 % to 70 %. Shelter-forest systems have been established with 170 ha planted area and 3,200 ha shelter area. As a result have the forest coverage increased from 0.4 % to 5.3 %. It is more important that the systems have changed the previous grasslands into forest-grassland compound. At present 1,500 ha of grassland is preserved by fencing. Three thousand hectare of grassland have been improved so that hay harvest have increased from 1,500 - 2,000 kg/ha. Furthermore, we have founded 80 ha forage crop field, 20 ha forage forest and 150 ha forage shrubbery. All these works are examples of the engineering. We have no technical difficulties to spread the achievements abroad. We are difficulties, however, for funds for construction, and in obtaining local people's consciousness of sustainable development. As to funds for the construction, according to our example, to construct sustainable development system needs 1,500 RMB per hectare, whereas the government funds are only 15 RMB per hectare to do it.

Part IV Research in Indian Desert

Vegetation Coverage under Different Grazing Pressures in Arid and Semi-arid Areas in Thar Desert

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1. Introduction

Animal husbandry is one of the most important industries in arid and semi-arid areas in the world. The activities sometimes leads to the desertification due to overgrazing. Because of the burst of human population in these areas, the population of herbivores has been increased and the degraded area has been enlarged. Especially, Thar Desert (Great Indian Desert), is one of the most densely populated deserts of the world. According to the 1971 census, the population of this area is 19 million and an average density of 61 km^{-1} against the average density of 3 km^{-1} in other deserts. According to Ghosh *et al.* (1988), the census held in 1983, total livestock population in western Rajasthan part of the Thar was 23.3 million, an increase of nearly 4.2 million over the livestock population in 1977. Under these circumstances, it is necessary to clear the effect of grazing by herbivores on plant community to make a proper management of rangeland and to detect the mechanism of desertification.

The arid environment is characterized by severe abiotic factors of harsh drought stress, high fluctuation in rainfall, extreme high temperature, scarce soil nutrients and so on. Due to these physical or climatic conditions, the production of grassland in the desert area is lower than the that in temperate or tropical areas. Less production results in scarce vegetation coverage and poor spatial structure and floral composition. Under these circumstances, the irreversible changes in plant species composition or soil structure should occur if the grazing by animals is higher than the annual regeneration capacity of vegetation (Crawley, 1983).

Even under the conditions where no irreversible changes of vegetion coverage occur, grazing by animals changes plant community structures and dynamics through the different effects of grazing behavior of different animal species. Selective feeding influences dynamics of each component heterogeneously. The number and viability of certain plant species is reduced by feeding and another unpalatable or grazing-tolerant species is increased. For example, goat browse grasses or leaves of shrubs by standing and sheep browse grasses growing on the ground by bending their head. The different food preference and feeding behavior change the competitive relationships between the components of plant community.

Numerous attempts have been made to show the effect of grazing by herbivores on the grassland community in cool temperate grassland (Hill *et al.*, 1992; Painter *et al.*, 1989, 1993; Kemp 1937; Aarssen and Tukington, 1985; Perterson, 1962; Quinn & Miller, 1967), in tropical savanna (Pandy and Singh 1992a, b; Belsky, 1992). In contrast to these studies, most of studies on the effect of gazing by herbivores on desert plant communities are rather superficial. The effects of grazing were estimated by comparison between protected and non-protected area from grazing. Though, it is possible to show the qualitative effects of grazing on plant communities using this comparison method, it is impossible to detect the quantitative effects on grassland communities.

Our concern is to detect the quantitative effect of large mammals on plant communities in arid environment. In the present study, we observed the seasonal changes of grassland dynamics in four different grazing pressures (8, 6,3 sheep ha^{-1} and control) in two climatic zones (arid and semi-arid regions), to estimate the effect of glazing pressure on the population dynamics of arid and semi-arid grasslands.

2. Methods

Description of study site

This study was conducted on semi-arid and arid region in Thar desert (24. 0° -30. 5 °N; 70. 0°- 76. 2 °E).

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Two sites, semi-arid Pali and arid Chandan, were selected. There are three distinct seasons in both areas; hot summer, monsoon and winter. The growing season for plant species is restricted in monsoon season. Average annual precipitation (1900-1981) is 450 mm in Pali and 150 mm in Chandan (Shanker, 1983). In both areas, rainfall mainly occurs during monsoon season (from the end of June to the end of September). The land form is flat and aggregated with old alluvial plain and sandy undulating buried pediment, soil texture is clay loam in Pali and sandy in Chandan.

Both sites have been fenced by Central Arid Zone Research Institute for more than 20 years. Grassland community is dominated by perennial grass species, *Cenchrus setigerus* in Pali and *Lesiurus sindicus* in Chandan. The aboveground standing crops of these two dominant species are almost similar and are ca. 350 g m^{-2}. Both species grow in the form of tussocks, the average height are ca. 35 cm and 80 cm in Pali and Chandan, respectively. The vegetation coverage by these dominant species is 10% in Pali and 5% in Chandan, and the distribution of these tussocks were clumped.

In each of arid and semi-arid area, two 1 ha plots and two 2 ha plots were established in protected experimental field at the end of monsoon season in September, 1993. All plots were enclosed by barbed-wires to exclude livestocks. The vegetation coverage was measured by line-interception method in the end of December, 1993. From the beginning of July, 1994, we conducted the observation for thirty days intervals during monsoon season. We set ten 10 m long straight lines per ha in each treatment, at each line we measured the diameter of all plants which attached to the lines. Same lines were used continuously to observe the temporal change at one place, and the average of each line were used as a represent value of one treatment. All the values were divided by 10 m to use these values as per cent values, and summed up in each species coverage per line. Diversity was calculated as Shannon-Wiener function (Shannon and Weaver, 1949);

$$H = -\sum_{i=1}^{s} p_i \log 2 p_i$$

where p_i = the proportion of total number contributed by species i, s = total number of species observed in each line and season.

To create different intensity of grazing pressures, we introduced sheep in March 1994 with densities of 3 and 6 heads ha^{-1} (2 ha plot), 8 $heads^{-1}$ and zero for control (1 ha plot). To analyze temporal change of vegetation, the total coverage of all species were used in community level. In population level, to compare the dynamics of each species among treatments we used only species which appeared sufficiently in all plots. ANOVA was used to test for the differences in coverage due to treatment and season for each area separately.

3. Results

Floral composition

The grassland in semi-arid region (Pali) has richer flora than in arid region (Chandan), total number of species observed is 64 species in our experiment field in Pali, and 34 species in Chandan (Table 1). In Pali, non leguminous forbs are prevalent more than half (34 species), this value is more than double as that of Chandan. Grass species were more dominant (34%) in Chandan than in Pali (23%). In view of species number, the percentage of legumes, trees and shrubs and annual/perennial ratio is almost same in both area.

3.1. Seasonal change in coverage

The total coverage of grassland changed significantly in the course of season in both region (Fig. 1 & Table 2). Especially in arid region (Chandan), the change was conspicuous. Comparing the change in control plot, there is distinct difference between two area. In arid region (Chandan), the coverage increased rapidly from 5% to 35% from August to September then decreased quickly. On the contrary, in semi-arid region (Pali), there was no such tendency, the total coverage was steady around 15%. The reason for this difference was mainly owning to the coverage of legumes (Fig. 2). In Chandan, the coverage of legumes rose from 0% in January to 29% in August, it contributed 89% to total coverage. In Pali, legumes grew to only a few percentage. The coverage of grasses in Pali was more fluctuated than in Chandan, decreasing from January to September. The coverage of non leguminous forb was quite small and constant in Chandan, but that values in Pali gradually increased from January to September, then decreased in October.

In respect to the life form, there were same trends in differences (Fig. 2). In Chandan, perennials were quite stable, and change of annuals were conspicuous. On the other hands, the change of both annuals and perennials were not outstanding. The curves

3.2. The seasonal change in diversity

The diversity index increased quickly at the beginning of monsoon season in both arid and semi-arid region (Fig. 3). The values were higher in Pali than in Chandan throughout observation. During monsoon season, the value did not vary in semi-arid region, but in arid region, it had moderate peak in August.

Table 1a Coverage of all species occued in experimental field and peak coverage in four treatments in arid. The values in control and 8 sheep are the average of ten 10 m x 1 cm lines, for 3 and 6 sheep treatment average of 20 lines were used

SPECIES			TREATMENT			
			Control	3 sheep	6 sheep	8 sheep
Lasiurus sindicus	grass	p	5.40	4.50	6.40	5.20
Cymbopogon jawarncusa	grass	p	0.00	0.02	0.00	0.04
Cenchrus setigerus	grass	p	0.00	0.00	0.07	0.00
Aristida funiculata	grass	a	0.12	1.40	0.39	0.35
Brachiaria ramosa	grass	a	0.00	0.03	0.03	0.00
Cenchrus biflorus	grass	a	0.37	1.24	0.44	0.51
Cenchrus ciliaris	grass	a	0.00	0.10	0.15	0.03
Cenchrus prieurii	grass	a	0.00	0.02	0.00	0.00
Dactyloctenium sindicum	grass	a	0.04	0.00	0.00	0.00
Eragrostis poaeoides	grass	a	0.01	0.00	0.00	0.00
Latipes senegalensis	grass	a	0.06	0.17	0.10	0.04
Tragus roxburghii	grass	a	0.00	0.04	0.01	0.40
Boerhavia diffusa	forb	p	0.05	0.18	0.35	0.05
Cassia italica	forb	p	0.08	0.00	0.00	0.00
Cassia pumila	forb	p	0.00	0.00	0.01	0.00
Citrullus colochynthis	forb	p	0.00	0.12	0.00	0.10
Corchorus tridens	forb	p	0.40	0.51	0.49	0.48
Blepharis sindica	forb	a	0.02	0.17	0.34	0.17
Cleome viscosa	forb	a	0.00	0.08	0.09	0.00
Dicoma tomentosa	forb	a	1.00	0.30	0.09	0.04
Farsetia hamiltonii	forb	a	0.08	0.00	0.00	0.00
Gysekia pharnacoides	forb	a	0.26	0.63	0.23	0.62
Mollugo cerviana	forb	a	0.04	0.02	0.14	0.10
Tribulus terrestris	forb	a	0.13	0.79	0.16	0.32
Cucumis sp.	forb		0.00	0.00	0.00	0.03
Indigofera anabaptesta	legume	a	4.30	3.90	0.75	0.17
Indigofera cordifolia	legume	a	11.00	10.40	0.24	0.34
Indigofera hochstetteri	legume	a	8.95	2.20	0.63	0.00
Indigofera linifolia	legume	a	12.40	4.50	0.24	0.05
Tephrosia strigosa	legume	a	0.91	0.31	0.13	0.00
Aerva persica	shrub	p	0.00	0.00	0.00	0.02
Crotalaria burhia	shrub	p	0.81	0.00	0.11	0.05
Dipterygium glaucum	shrub	p	0.25	0.00	0.00	0.00
Polygala erioptera	shrub	a	0.19	0.10	0.06	0.11
Acacia nilotica	tree	p	0.00	0.01	0.00	0.00
Prosopis cineraria	tree	p	0.00	0.00	0.01	0.00

Table 1b Coverage of observed species in experimental field and peak coverage in four treatments in semi-arid area. The values in control and 8 sheep treatment plot (1ha) are the average for ten 10 m lines, in 3 and 6 sheep treatment (2ha) average for that of 20 lines

SPECIES			TREATMENT			
			Control	3 sheep	6 sheep	8 sheep
Cenchrus setigerus	grass	p	11.80	9.85	7.97	10.40
Dichanthium annulatum	grass	p	0.00	0.01	0.00	0.00
Eleusine compressa	grass	p	0.52	0.22	0.35	0.46
Eremopogon foveoratus	grass	p	0.44	0.56	0.82	0.38
Aristida spp	grass	a	0.38	0.15	0.76	1.00
Brachiaria ramosa	grass	a	0.11	0.15	0.09	0.02
Brachiaria sp.	grass	a	0.04	0.07	0.03	0.04
Cenchrus biflorus	grass	a	0.00	0.00	0.00	0.02
Dactyloctenium aegyptim	grass	a	0.00	0.00	0.00	0.00
Digitaria sp.	grass	a	0.00	0.00	0.01	0.00
Eragrostis ciliaris	grass	a	0.24	0.03	0.05	0.25
Eragrostis poaeoides	grass	a	0.00	0.01	0.00	0.00
Eragrostis tremula	grass	a	0.00	0.00	0.01	0.00
Tetrapogon sp.	grass	a	0.04	0.01	0.06	0.03
Tragus roxburghii	grass	a	0.03	0.04	0.04	0.01
Aerva persica	forb	p	0.21	0.00	0.00	0.00
Boerhavia diffusa	forb	p	0.08	0.17	0.63	0.62
Bouchea marrubifolia	forb	p	0.22	0.20	0.36	0.30
Cassia pumila	forb	p	3.10	4.35	4.72	1.30
Convolvulus rottlerianus	forb	p	0.00	0.00	0.02	2.20
Corchorus depressus	forb	p	0.01	0.02	0.34	0.02
Crotalaria medicagenia	forb	p	0.00	0.00	0.12	0.00
Evolvulus sp.	forb	p	0.00	0.00	0.04	0.00
Heliotropium marifolium	forb	p	0.45	0.98	0.35	0.17
Ipomoea sp.	forb	p	0.00	0.05	0.47	0.00
Phaseolus trilobus	forb	p	0.90	0.61	0.85	1.30
Sehima nervosum	forb	p	0.03	0.15	0.05	0.28
Ageyratum sp.	forb	a	0.13	0.15	0.07	0.37
Anticharis sp.	forb	a	0.15	0.04	0.05	0.03
Celosia argentia	forb	a	0.00	0.00	0.03	0.00
Cleome viscosa	forb	a	0.00	0.00	0.01	0.00
Corchorus tridens	forb	a	0.45	0.73	0.55	0.63
Dactyliandra welwitschii	forb	a	0.00	0.00	0.00	0.10
Dicoma tomentosa	forb	a	0.05	0.01	0.02	0.00
Digera sp.	forb	a	0.02	0.03	0.00	0.02
Echinops echinatus	forb	a	0.05	0.00	0.00	0.00
Euphorbia granulata	forb	a	0.02	0.03	0.06	0.07
Gracilia sp.	forb	a	0.00	0.00	0.01	0.01
Leucas sp.	forb	a	0.00	0.00	0.34	0.00
Polygala sp.	forb	a	0.53	0.69	0.21	0.30
Sesamum indicum	forb	a	0.00	0.00	0.02	0.00
Tribulus terrestris	forb	a	0.31	0.30	0.14	0.08
Trichodesma ampelxicaule	forb	a	1.60	1.80	2.22	2.10
Vernonia cinerea	forb	a	0.14	0.18	0.26	0.03
Vicoa sp.	forb	a	0.73	1.05	0.27	0.31
Cucumis sp.	forb		0.31	0.18	0.49	0.00
Peristrophe sp.	forb		0.00	0.00	0.00	0.07
Pulicaria sp.	forb		0.17	0.18	0.08	0.01
Alysicarpus sp.	legume		0.00	0.00	0.00	0.03
Heylandia sp.	legume	a	1.60	1.56	1.10	1.80
Indigofera anabaptesta	legume	a	0.22	0.31	0.49	0.29
Indigofera cordifolia	legume	a	0.63	1.42	1.75	2.50
Rhynchosia minima	legume	a	0.12	0.36	1.31	0.38
Tephrosia strigosa	legume	a	0.08	0.41	0.53	0.31
Calotropis procera	shrub	p	0.01	0.00	0.00	0.05
Cappari desidua	shrub	p	1.60	1.07	0.00	0.00
Lepidagethis trinevis	shrub	p	4.10	2.90	2.42	0.80
MImosa hamata	shrub	p	0.05	2.05	1.23	0.58
Pergularia daemia	shrub	p	4.40	4.10	4.92	3.10
Solanum albicaule	shrub	p	3.40	0.02	0.01	0.00
Zizypus sp.	shrub	p	4.00	4.20	4.65	1.60
Prosopis cinereria	tree	p	0.00	0.00	0.12	0.00
Prosopis juliflora	tree	p	0.00	0.00	0.04	0.00

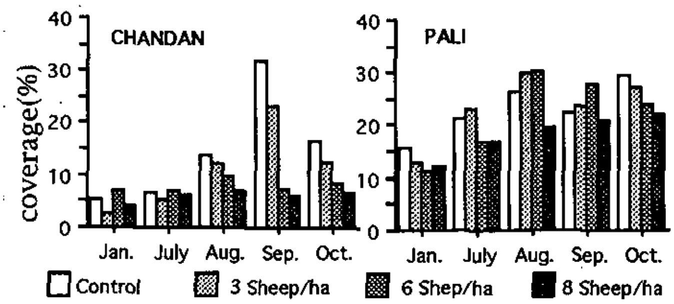

Fig. 1 The seasonal change of total grassland coverage and effect of grazing in arid (Chandan) and semi-arid region (Pari). The value were mean of ten lines (8 sheep/ha and control), 20 lines (3 and 6 sheep/ha).

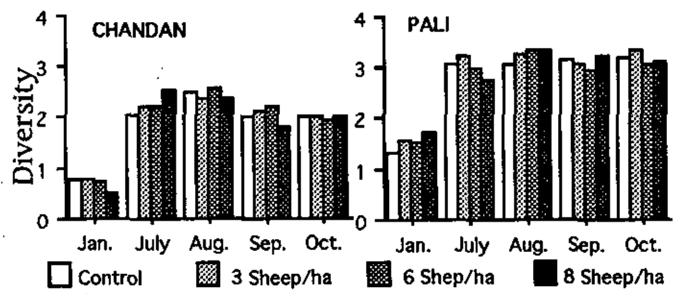

Fig. 2 The coverage dynamics of grassland community divided by the life forms. The values were the average for 10 lines (control and 3 sheep/ha plot) and 20 lines (3 and 6 sheep/ha plot).

3.3. Effect of grazing on coverage

The effect of grazing on coverage of grassland community was also significant in both region (Fig. 1& Table 2). In arid region grassland, the effect was more distinct, from August to October, the coverage of each month arranged from control to 8 sheep/ha. Particularly in September the value in 8 sheep/ha was less than one sixth of control plot. While the coverage in control plot rose immediately to the level of 32% from July to September then drop calmly, the value was steady at around 6% in 8 sheep ha^{-1} plot. In the view of composition, the differences among the treatments were contributed by legumes or annuals. The changes of total coverage consisted with that of legumes and annuals. And the coverage of grasses was not different among the treatments (Fig. 2). In semi-arid region, although there was a significant effect of grazing on grassland community, there was not clear trend in the effect of grazing on total coverage shown in arid region in each month. Though the coverage of three treatments arranged with gradient of grazing pressures in October, that of control plot was sometimes less than another treatments in other months. Comparing the component, there was not clear response to the grazing pressures neither in forbs nor grasses (Fig. 2). From the point of life cycle, there were effect of grazing on the coverage. The grazing reduced the annuals coverage in arid region, on the other hand, coverage of annuals gradually increased with the gradients of grazing intensity. The coverage of perennials in 8 sheep ha^{-1} plot was slightly less than that of control plot (Fig. 4).

Table 2 ANOVA *testing treatments (grazing pressures) and seasonal change in coverage*

CHANDAN	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	3	2513.063	837.688	17.573	<0.0001
Season	4	5085.046	1271.261	26.668	<0.0001
Treatment * Season	12	4590.905	382.575	8.025	<0.0001
Residual	279	13300.002	47.670		

PALI	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	3	925.041	308.347	6.889	0.0002
Season	4	6420.188	1605.047	35.858	<0.0001
Treatment * Season	12	1424.144	118.679	2.651	0.0022
Residual	277	12398.824	44.761		

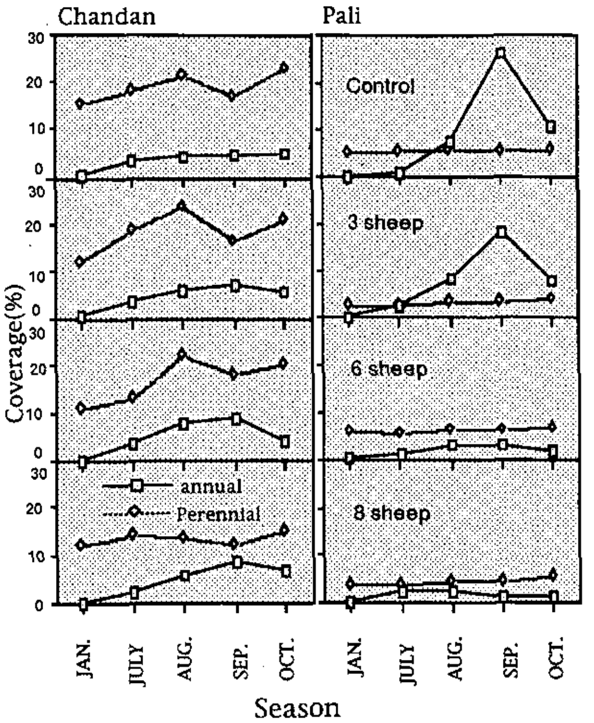

Fig. 3 The seasonal change and effect of grazing on diversity index of Shannon-Wiener in arid (Chandan) and semi-arid region (Pari). The value were the average of ten lines (8 sheep/ha and control) and 20 lines (3 and 6 sheep/ha plot).

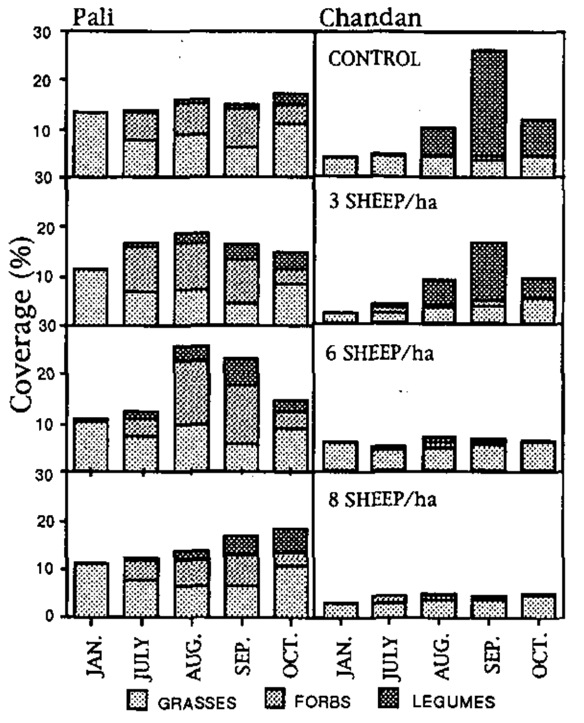

Fig. 4 The dynamics of coverage of grassland community divided by life cycle. The values were average for 10 lines (control and 8 sheep/ha plot) and 20 lines (3 and 6 sheep/ha plot).

3.4. Effect of grazing on diversity

In both region and throughout observation, grazing did not affect the diversity of grassland community (Fig. 3 and Table 3).

Table 3 ANOVA testing treatments (grazing pressures) and seasonal change of diversity in arid (Chandan) and semi-arid (Pali)

CHANDAN	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	3	0.284	0.095	0.363	0.7795
Season	4	90.593	22.648	86.998	<0.0001
Treatment * Season	12	3.230	0.269	1.034	0.4175
Residual	275	71.591	0.260		

PALI	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	3	1.094	0.365	1.452	0.2279
Season	4	107.599	26.900	107.162	<0.0001
Treatment * Season	12	3.184	0.265	1.057	0.3970
Residual	277	69.532	0.251		

3.5. Population dynamics

The coverage dynamics of plant populations differed among plants life forms and life cycles between regions (Fig. 5 & 6).

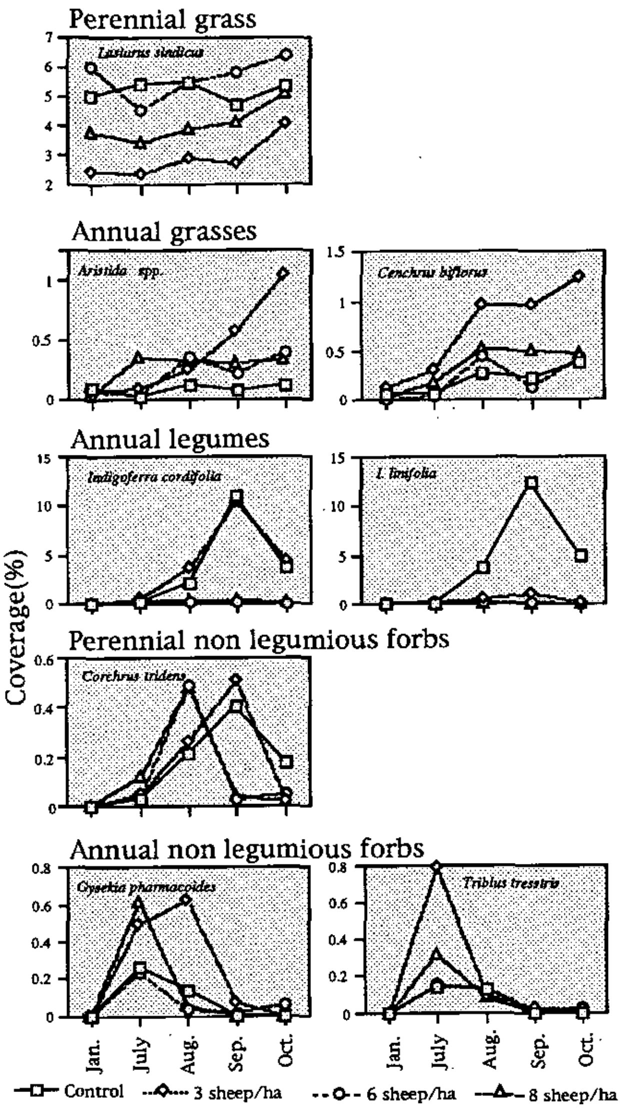

Fig. 5 Coverage dynamics of main species in arid region (Chandan). The values were average for ten lines (control and 8 sheep/ha) and for 20 lines (3 and 6 sheep plot).

Lesiurus sindicus and *Cenchrus setigerus* which were the dominant perennial grass species in arid and semi-arid regions respectively, showed different response to grazing. Though, *L. sindicus* did not show clear relationship between coverage change and grazing intensity, C. *setigerus* decreased with grazing gradient. In semi-arid region, two perennial grasses, C. *setigerus* and *Eremopogon fovoelatus* has same trend, they had rapid drop during hot summer (From January to July) and marked increase at the end of monsoon season. In some annual grass species, the values of control plot were lower than another treatment plots.

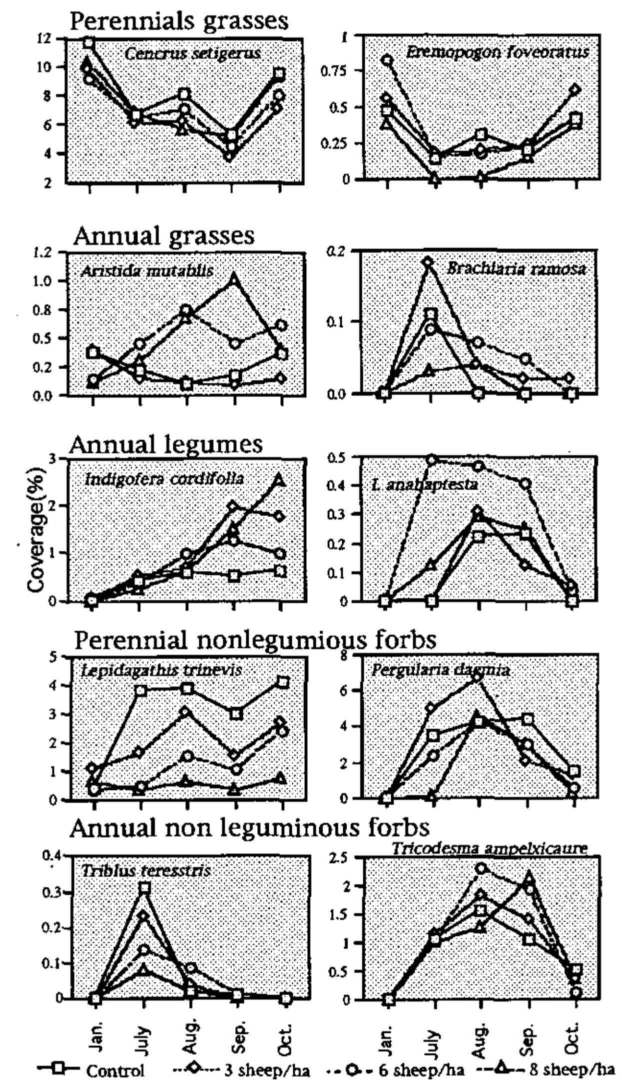

Fig. 6 The coverage dynamics of main species in semi-arid region (Pali). The values were the average for 10 lines (control and 8 sheep/ha) and for 20 lines (3 and 6 sheep/ha plot).

Two annual legumes, *Indigofera cordifolia* and *I. linifolia*, suffered most severe grazing in Chandan, but in semi-arid region *I. cordifolia* showed opposite response to grazing. Throughout the monsoon season, the coverage in control plot stable and smallest among all plots. The coverage of *Lepidagathis trinevis* showed clear negative response to the grazing, it decreased gradually with grazing increased. An annual non leguminous forb, Triblus terretris showed unique response to grazing. In arid region this species increased with increase of grazing intensity, on the contrary, it decreac,ed with increase of grazing in semi-arid region.

4. Discussion

In this study, we observed the effect of grazing on total plant coverage in both semi-arid and arid region. The effect was more marked in arid region, the coverage decreased with the increase of grazing intensity. Main reason of this decrease was owning to the decrease of annual legumes. Sheep showed selective grazing behavior, they grazed chiefly forbs, but grasses were not affected severely by grazing. Especially in arid region, *Indigofera cordifolia* and *I. Iinifolia* which dominant seasonally in monsoon period, were grazed severely. Without grazing, these species occupied 89 % of total coverage in September, then the value decreased to 72 % in 3 sheep/ha. In 6 and 8 sheep/ha treatment they grazed intensively, the values dramatically decreased to less than one tenth (8. 9 % and 7. 9 %). Annual grasses and forb species sometimes showed opposite response to grazing. The coverage of *Aristida mgtablis. Cenchrus biflorus* and *Triblus terrestris* increased with existence of sheep. On the contrary in semi-arid region, the effect of grazing less marked and sheep grazed less selectively as compared to arid region. Two perennial grasses, *Cenchrus setigerus* and *Eremopogon foveoratus,* perennial forb, *Lepidagathis trinevis* and *Triblus terrestris* decreased with the increase of grazing. It must be noted that the response of *I. cordifolia* was quite different in two region, and the dynamics of *Triblus terrestris* was opposite.

The response of grassland communities to grazing varied in different climatic condition. The difference was due to different dynamics of each population which consisted in different rate, and the different response of same species in different region. The competitive relationship between composition would have changed by grazing the degree that one species would increase in the expense of another. We should regard the coverage dynamics as the influence of both grazing and competition. But in arid environment competition is less important because of low total plant density. So we should think increase of one species as a direct effect of grazing. One possible suggestion might be change in soil condition by tramping. Grazing animals might promote the germination of some species by bring some seeds from deeper soil layer to surface.

In this study we observed only the population growth by measuring coverage in one growing season, but we have to consider effect of grazing on another stages such as reproduction or seed bank. Further detailed study must be done continuously.

References

Aarssen, L. W. and Turkington, R. 1985. Within species diversity in natural populations of *Holcus lanatus, Lolium perenne* and *Trifoliwn repens* from four different-aged pastures. *J. Ecol.* 73: 869-886

Belsky, A. J. 1992. Effect of glazing, competition, disturbance and fire on species composition and div-ersity in grassland communities. *J. Vegetation* Sci. 3: 187200.

Crawley, M. J. 1983. Herbivory. *The Dynamics of Animal-Plant Interaction*. Blackwell Scientific Publications, Oxford.

Gohsh, P. K., Bohra, H. C., and Goyal, S. P. 1988. *Desert Ecology*. Scientific Publishers.

Hill, M. O., Evans, D. F. and Bell, S. A. 1992. Long-t er m effects of excluding sheep from hill pastures in North Wales. *J. Ecology*. 80: 1-13.

Kemp, W. B. 1937. Natural selection within plant species exemplified in a permanent pasture. *J. Hered.* 28: 329-333

Painter, E. L., Detling, J. K. & Steingraeber, D. A. 1989. Effects of grazing history, defoliation, and fzquency-dependent competition on two North American grasses. *Am. Nat. Bot.* 76: 1368-1380

Painter, E. L., Detling, J. K. & Steingraeber, D. A. 1993. Plant morphology and gmzing History: Relationship between native grasses and herbivores. *Vegetatio*. 106: 37-62

Pandy, C. B., and Singh, J. S. 1992. Rainfall and grazillg effects on net primary productivity in a tropical savanna, *India. Ecology* 73(6): 2002-2021

Pandy, C. B., and Singh, J. S. 1992a. Influence of Rainfall and grazing on herbage dynamics in a seasonally dry tropical savanna, *Vegetatio* 102: 107-124

Peterson, R. A. 1962b. Factors affecting resistance to heavy grazing in needleandthreadgrass. *J. Range Manage.* 15:183-189

Quinn, J. A. and Miller, R. V. 1967. A biotic selection study utilizing Muhlenbergia montana. *Bull. TolleyBot.* Club94: 42432

Shanker, V. 1983. Depleted vegetation of the desertic habitat: Study on its natural regeneration. *CAZRI Monograph.* 21:1-30

Shannon, C. E and Weaver, W. 1949. *The mathematical theory of communication.* University of Illinois Press, Urbana.

Impact of Grazing on the Vegetation in the Thar Desert, India

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1. Introduction

Grazing based animal husbandry is the predominant occupation and the main stay of inhabitants of arid region in the Thar Desert in India. In the semi arid regions, however, dry farming is the major occupation and livestock rearing has a subsidiary role to contribute in the agricultural economy. This is reflected in the land coverage of grazinglands in the two regions. In the semi-arid zone the rangelands occupy 15 to 20 percent lands and are of small sizes located on marginal or often degraded lands earmarked as village community grazinglands. In the arid regions, the rangelands occupy on an average 45 percent land and in extreme arid tracts like Jaisalmer district of the state of Rajasthan. 95 percent of the total district area (41674.3 sq km) is used as grazinglands (Shankar and Kumar, 1987).

Both semi-arid and arid grazing lands bear the brunt of past misuse and present neglect (Mertia, 1992). The grazing pressure on the rangeland vegetation is estimated at 3.2 ACU/ha (Rekib, 1981). In the desert region, the accessible tracts are overgrazed and so, are generally of "poor" range conditions. As against carrying capacity of 0.2 to 0.5 ACU/ha (Raheja, 1966). The grazing pressure ranges from 1 to 4 ACU/ha. The vegetation in this region is commonly shaped by nomadic and sedentary forms of pastoral use. There is a wide range in the palatability to the livestock of he perennial and annual components of the vegetation from area to area. As such, the overstocking causes severe competition between the grazing animal species and there by leading to deterioration of more palatable grass species in the natural vegetation (Ahuja and Mertia, 1976; Mertia, 1984, 1985, 1989, 1992; Ahuja *et al.*, 1970; Gupta and Saxena, 1971).

The natural resources, land, water and vegetation, in the semi-arid and arid regions of Thar desert in India are getting overburdened due to increasing human and animal population. And also the thinly populated desert region of Thar desert in India are now being prospected as the future home of the man kind. In this paper, the gazing resources and the impact of grazing systems on natural vegetation are discussed in the context of primary productivity and their possible management systems for checking the environmental degradation in the Thar desert of India.

2. Environmental setting

Location

The Thar desert forms the eastern limit of a vast tract of arid region that encompasses the desert of Sahara the Arabia, Iran and Baluchistan in Africa and Asia. The eastern limit of the Thar is roughly coterminous with the Aravalli hill ranges - one of the oldest surviving in the world, while its western margin is along the fertile plains of the Indus in Pakistan. In the south it has a sharp natural boundary with the world's largest saline waste-the Great Rann of Kachh, while in the north the riparian sub Himalayan plains define its boundary.

It is situated between the latitudes of 24° 30'N and the longitudes of 69° 30'E. Within the territory of India the Thar forms a part of the country's sandy hot arid zone, spread over 0.32 M sq. km area. Western Rajasthan alone constitutes (61%), while in the state of Gujarat it covers 20% area and in the state of Punjab and Hariyana 9% area. The Southern states of Maharashtra, Andhra pradesh and Karnataka together contribute the rest 10% area.

Climate

The climate is arid, where precipitation over a greater part of the year is less than the potential evapotranspiration and meets less than one third of the annual water need (PE). A significant feature of the distribution of rain fall in the desert regions is that a major part of the rainfall is received during the south west monsoon period, June to September. The contribution of this seasonal rainfall to annual rainfall is quite high (91 to 96%) over whole of Gujarat and south and central parts of western Rajasthan (Ramakrishana *et al.*, 1992). Another interesting feature of the rainfall is the higher coefficient of variability in the annual rainfall which often exceeds 50 percent in NW Indian arid zone and is higher than 70 percent in the extreme regions of western Rajasthan where the annual

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rainfall is as low as 180mm. Such a poor rainfall performance is due lo low level divergence and associated subsidence of air up to 0.8 km, as also marked divergence at a height of 2 to 6 km over the region. Dust storms are frequent during hot weather season, especially in the month of May and June. The average wind speed during June is more than 25 Kmph in the western part of desert regions.

The mean diurnal variations of temperature is 14°C to 16°C. The mean maximum temperature during the season varies from 40°C to 42°C but in some years mercury has touched 50°C - 52°C. During the cold season minimum temperature varies from 3°C to 10°C. Frost occurs at all stations when temperatures touches - 2°C to 4°C, but its incidence varies from 5 to 20 days and is associated with the western disturbances bringing in cold.

Soil

Arid zone soils of India extends through an area of about 200,000 sq. km and these occur predominantly in the region of Thar desert in India. Ray Choudhari *et al.* (1963) described broadly the soils of arid zone as "Desert Soils" in the west and "Grey Brown Soils" in the south east. Roy *et al.* (1978) divided the soils in to "Desert soils" and "Sand dunes" because unlike "Desert soils", "Dune sands" did not show any lime concretionary zone in the profile and they occurred in association with "Red desert soils" also. Soils of arid regions of this region have further been put into six major groups by (Dhir, 1977).

Flora

Plant life in the Thar desert have evolved through many evolutionary phases. The occurrence of fossils of Callophyllum, Garcinia and Mesua (Lakhanpal and Bose, 1951) and Cocos (Kaul, 1951) in Tertiary (Eocene) sediments indicated humid environment of tropical rainforest. The changes in plant life from cool temperature of the Permo - carboniferous to tropical in the upper cretaceous suggests gradual northward movement of the Indian plate across the equator (Lukose, 1984). The sequence of events leading to the change from above to the Xerophytic form of the Holocene becomes difficult to trace as no paleobotanical records belonging to 50 million years that elapsed between those two epochs are available. It is, therefore, believed that "the present day flora was well established at the beginning of Holocene (10,000 year ago) and that subsequent changes in the post - glacial vegetation were more ecological than floristics" (Lakhapal and Singh, 1975). There has been a high intervention of biotic activities which has influenced true equilibrium of flora and climate. The present, physiognomy is, therefore, more xeric than the climate warrants (Shankar, 1994).

The flora of the Indian desert is constituted by the following life forms viz; (Th/40.1%, Ph/22.1%, Ch/18.9%, H/15.5%, Cr/3.4%) (Das and Sarup, 1951). The percentage of Therophytes further increases to 49% in the western hyper-desertic region (Mertia and Bhandari, 1991). The most characteristic life forms of the Indian desert are Chamaephytes (18.9%) which are the leading species, of most association. The main species are *Fagonia cretica, Tephrosia uniflora, Rhynchosia chimperii R. pulverulento, Alysicarpus longifolius, A. moniliter* etc.

Vegetation

The vegetation is highly sparse with limited number of trees and shrubs (Mertia and Bhandari, 1978). Xerophytic annuals constitute about 60 percent of the species. The area under forest is negligible being 0.68 percent. Broadly there are three ecological zones in Western Rajasthan viz, (1) The south and south east of the region near the Aravalli mountains, but not strictly in the desert (2) Semi-arid region about 160 km parallel to the first region where plants of xerophytic types are found, and (3) arid region in the extreme north and west of the region and here the vegetation is very poor. Balatter and Halberg (1918 - 1921) recognised five formations from western Rajasthan. The plant life varies in its magnitude from 100 mm zone in the west to wetter eastern part. Later on, Champion (1936) classified the arid zone vegetation into four main types which subsequently (Champion and Seth, 1964) reclassified into eight forest types. Gupta (1975) enlarged the five vegetation types of Satyanarayan (1964) into six types which were, later on, slightly modified by Saxena (1977) but the original SiX types have been maintained. The six vegetation types are: (1) mixed xeromorphic thorn forest, (2) mixed xeromorphic woodland, (3) mixed xeromorphic riverine thorn forest, (4) Lithophytic scrub desert, (5) Psammophytic scrub desert and (6) Holophytic scrub desert.

Grazing resources of Thar

Major portion of Thar desert (60%) lies in the Western Rajasthan and over (20%) in the Western part of Gujrat state. Grazing resources of arid and hyper arid regions have been well documented by the Scientists of Central Arid Zone Research Institute by conducting research at 52 Rangemanagement and soil conservation centers over last forty years. The rangelands in this desert includes grasslands, forest grazing areas and wastelands of various categories (Table 1) and these generally support different species of perennial grasses with scattered thorny trees, bushes and shrubs and some of them have high forage value. The area under grazingland have declined by 23.78 per cent from 1951 to 1971-72 and is estimated to have further declined during last 20 years with a increasing pressure on grazing resources. Mertia (1992) have clearly demonstrated on the basis of 20 years of research on rangeland improvement and utilization that grazing conducted on basis of carrying capacity can increase the productivity from poor to good over a period of 15 years even in the hyper arid regions of Thar desert.

Grazing lands

The first country wide survey report of the grazingland was published by the ICAR in the form of a book entitled "Grass covers of India", authored by Dabadghao and Shankarnarayan (1973). Five major grass covers, their aerial extent and herbage yield had been described by them. The tropical Sehima - Dichanthium cover is the largest followed by sub - tropical Dicanthium - Cenchrus - Lasiurus, Pharagmites - Sacharum - Imperata and Themeda - Arundinella and temperate and alpine meadows in the Himalayas and Nilgiris. The only climatic climax of grassland vegetation in India is the temperate alpine meadow which are largely dominated by festuwid grasses. The tropical and sub tropical grasslands are derived tertiary seral communities, (Whyte, 1964) where the successional processes are arrested due to continued biotic interferences viz, grazing and or burning (Champion, 1936). The flora of grazinglands is dominated by Therophytes, Mertia (1976) and Mertia and Bhandari (1992). The preponderance of therophytes results from strong periodicity in tropical monsonic climate. The trees and shrubs are usually associated with grasslands.

The growth of vegetation in the Indian desert starts with the onset of monsoon in the end of June or beginning of July, each year. The top growth is attained in September or October and then it declines upon maturity as most of ephemerals has very short life cycles. The period of active growth depends mainly on distribution of rain and production depends on species composition.

The above ground production in the semi-arid regions in Jodhpur (350 mm/yr) has been estimated at 1.2 -2 t/ha yr where as in the driest region, Jaisalmer (180 mm/yr) the dry herbage yield of 2 -2.5 t/ha has been recorded (Mertia, 1992).

Impact of Grazing systems

In the Indian desert plant growth is limited to a short period due to eco-climatic conditions. There is an alarming trend in the increase of animal population which are maintained on grazinglands. Under natural conditions an interrelationship prevails between available palatable plants and the number of consumers

Table 1 Grazing resources of different district in West Rajasthan (1,000 ha)

Districts	Total Geographical Area	Forests	Pastures	Misc. Trees Crops & groves	Waste lands	Fallow lands	Total grazing Resources
Jaisalmer	3840	182	101	198	2822	168	3471
Barmer	2817	18	208	-	290	543	1057
Jodhpur	2256	5	122	5	55	544	726
Nagaur	1764	14	76	2	11	322	425
Junjunu	593	33	44	-	8	36	121
Churu	1686	5	46	-	30	216	297
Ganganagar	2063	391	23	60	82	28	584
Total	15019	646	620	205	3298	1857	6681

in a given ecosystem. Natural process operates in an efficient way to provide herbage and allow plants to regain vigor regardless of defoliation, but only up to a critical level of feed demand versus supply. This equilibrium is under continuous disturbance because of increase in number of animals. High variation in forage production from year to year and due to decreasing trends in the grazinglands.

The best way of utilization of vegetation in the grasslands is through grazing based on carrying capacity. The type of animal to be grazed should depend on the kind of forage which is available in the rangeland. The animals may prefer some plants more in comparison to other plants depending on nutrient content, taste, odour and their morphology. The stages of plant growth also influences preference and use eg. *Blepharis sindicus* in preferred by sheep when it is tender and by camels at maturity. Similarly *Cenchrus biflorus* and *Aristida funniculata* are grazed by sheep either in preflowering stage or after seed shedding where as perennial grasses *Lasiurus sindicus* and *Cenchrus ciliaris* are readily grazed at all stages of growth but preference of cattle and sheep varies. Results of the various studies conducted on the impact of grazing using different conventional grazing systems are described and discussed in this paper.

The grazing systems viz, (i) continuous, (ii) deferred and (iii) deferred rotational were mainly used and management practice of partial harvesting and heavy intensity of grazing stress were also studied.

Grazing conducted either by sheep or cattle using continuous v/s deferred rotational grazing revealed that with cattle, change in the percent basal cover due to treatments was highly significant in all the years where as frequency was affected over the years (Table 2). The percent basal cover of *L. sindicus* indicated decline over the years. Being a tall, tussocky perennial grass, cattle obviously have an easy access to it. Under deferred rotation the grasses get sufficient time to produce seeds which helps in natural seeding of grasslands and it produce fresh biomass through vegetation growth (Chakravarty *et al.*, 1970; Mertia, 1987).

While assessing the impact of this system with sheep as a grazing animal it also revealed that perennial species like *L. sindicus* declined over the years under the continuous grazing and increased under all the rotational grazing treatments. Population of *Aristida funniculata* and *Cenchrus biflorus*, whose awns and burrs cause great discomfort to the grazing animals (Ahuja *et al.*, 1970), indicated decrease in their basal cover because utilization of these less desired species was higher in rotational grazing system as compared to continuous grazing. It is clearly indicated that, when these grasslands are allowed a rest period, they regenerate by self seeding and assume normal vigour and cover. Rotational grazing which allows this rest period naturally favours the growth and preponderance of *L. sindicus* and *E. compressa* (Mertia, 1984; Bawa *et al.*, 1988). Similar findings have also been reported by Sharma (1988) and Mertia (1991) from the rangelands in semi-arid regions dominated by *Cenchrus ciliaris* and *Dicanthium annulatum.*

In a similar study with continuous versus partial

Table 2 Percent basal cover of six species in the initial and final year under different grazing systems

Species	Continuous grazing		Deferred rotational grazing							
	T1		T2		T3		T4		T5	
	Initial Year	Final Year	Initial Year	Final Year	Initial Year	Final Year	Initial Year	Final Year	Initial Year	Final Year
Lasiurus sindicus	1.37	0.90	0.50	1.64	0.83	0.91	1.50	2.80	0.02	0.02
Eleusine compressa	0.18	0.30	0.05	0.21	0.01	0.12	0.08	0.29	0.72	0.75
Dactyloctenium sindicum	0.11	0.03	0.02	0.03	-	-	-	-	0.02	0.02
Aristida funniculata	0.06	0.02	0.13	0.01	0.14	0.14	0.00	0.01	0.37	0.07
Cenchrus biflorus	0.28	0.19	0.24	0.01	0.61	0.21	0.55	0.12	0.33	0.08
Indigofera cordifolia	0.31	0.01	0.75	0.07	0.20	0.00	0.11	0.02	0.39	0.00

harvesting of pasture every year at preflowering stage coupled with continuous controlled grazing was distinctly superior (2.100 t/ha) over the continuous controlled grazing (1.306 t/ha) in terms of forage production (Table 3). This was mainly because of better vegetative growth of harvested pasture (Mertia, 1992). Similar results were also arrived by Mauria *et al.* (1989) in semi-arid region on rangeland dominated by *Cenchrus ciliaris* grass.

Table 3 Effect of grazing treatment on dry forage production (t/ha) of major grass species

Species	T1	T2	X	%
Lasiurus sindicus	1.020	1.830	1.42	83.53
Eleusine compressa	0.057	0.013	0.04	
Dactyloctenium sindicum	0.029	0.020	0.02	
Cenchrus biflorus	0.081	0.083	0.08	
Aristida funniculata	0.082	0.135	0.11	
Indigofera cordifolia	0.027	0.027	0.03	
Total dry matter	1.306	2.108	1.70	

In a mixed grazing systems which involved five grazing combinations of cattle and sheep on continuous basis revealed the similar results as indicated by cattle and sheep alone. Cattle affected adversely the perennial grass species where as sheep adversely affected most palatable species like *Indigogera cordifolia* (Mertia, 1991). Similar observation were earlier reported by Chakravarty *et al.* (1970) that *Indigogera* species being legume is preferred much by sheep till it is green.

Seasonal grazing of rangeland have revealed that the availability of the grass to the animals during summer season (April to June) is about 33 percent of the estimated production (Table 4). The seasonal carrying capacity varies significantly during different years. It has been noticed that rate of growth of animals remain higher in monsoon season and lowest in the summer season. Similar stocking rate throughout the year severely damages the perennial vegetation. It causes uprooting of grass tussocks from soils, compaction of soil and arrests the regeneration of perennial grasses Ahuja *et al.* (1970) and Mertia (1992).

Table 4 Dry forage yield (t/ha) during different seasons in a year

Year	T1	T2	T3	T4	Mean	SEm±	C.D.at 5%	C.D.at 5%
1	1.88	1.91	1.70	1.29	1.69	0.0372	0.1059	0.1415
2	1.64	1.29	0.99	0.60	0.13			
3	0.67	0.94	0.47	0.27	0.99			
Mean	1.39	1.38	1.05	0.72				

Effect on Forage production

The forage production is significantly affected by different intensities of grazing. Medium and light intensities do not affect the forage production adversely but the heavy or severe grazing affected the forage production of perennial grasses.

Heavy intensity of grazing stress at initial stages of grazing has indicated 86.5% utilization of pasture (Sharma, 1987). In another study in semi-arid rangeland indicated that heavy intensities of grazing led to 86.59 % utilization of edible species (Table 5; Ahuja and Mertia, 1976). The species viz, *Tephrosia purpurea* an unpatable species could not be eliminated even by heavy intensity of grazing.

Shankarnarayan *et al.* (1977) have also reported that forage yield generally increased with decreases in grazing intensity which could be attributed to higher growth rates observed in medium and light grazing as judged by the efficiency index value of (Blackman, 1919). There is a favorable shoot apex development which is damaged in heavy grazing.

Effect on growth form of vegetation

The impact of overgrazing is more pronounced on the perennial grasses and trees and shrubs having suitable height for browse by camels and goats. The dominat grasses, *Lasiurus sindicus, Panicum turgidum, P. antidotale, Cenchrus ciliaris* and *C. setigerus* which grow erect and acquire 'bakket' shape and grows extensively but under heavy intensity of grazing their form is turned into 'saucer' shape. Similarly browsing combined with lopping and felling in the early phases of growth of dominant species like *Ziziphus mauritiana, Prosopis cineraria, Capparis decidua* and *Salvadora oleoides* are turned into bush form which otherwise are small size trees. This phenomina is operative due to heavy brows by camels and goats which never allow them to attain their natural form. Pandey (1964) observed that it is the intensity of grazing which is the decisive factor in shaping the physiognomy and structure of the grassland vegetation.

Common Grazinglands

Common property lands (CPLs) consisting mainly of barren lands and long fallow have been declining at the rate of 2.24 and 1.93 percent per annum in the regions of Thar desert. The present average forage production has been estimated 0.295 t/ha. The house hold figures revealed that stocking rates at farm level were larger by 24 to 32 percent compared to optimum on different sizes of farms (Anantha Ram, 1993).

The main reasons of degradation of (CPLs) include (i) permanent grazing of animals by landless and small farmers (ii) Overgrazing and heavy trampling by animals every day while coming for drinking water and shelter for some period. In fact no grass species grows to the stage of maturity in these lands due to very heavy stocking, which has converted these lands into highly degraded conditions. The most palatable *C. setigerus, Dactyloctenium sindicum, Cenchrus biflorus* and *Eleusine compressa* are grazed to ground level and are even uprooted and have disappeared completely. The common unpalatable species viz; *Tephrosia purpuria, Aerva persica* and *Leptadaenia pyrolechnica* are found. Trees viz; *Ziziphus rotundifolia, Prosopis cineraria, Maytenus emarginatus, Salvadora oleoides* and *Capparis decidua* are commonly growing on such sites.

3. Summary

The ever increasing trend in the livestock and human population has put heavy grazing pressure and continuous decrease in the area of land available for grazing. Due to these factors, over 60% of grazinglands are in poor condition; 14 percent in fair, 13 percent in good and 2-3 percent in excellent state. Low and erratic rains and frequent droughts restricts the vegetative and self seeding period of natural vegetation. The different conventional grazing experiments has provided useful information about the impact of grazing on rangelands of Indian desert. It has been observed that continuous grazing led into reduction in the density, basal cover and forage production of many palatable perennial species and increases of unpalatable species. The rotational and deferred rotational grazing systems are superior over the continuous controlled grazing. It has been observed that these systems provide rest to the perennial species which can assume their growth and vigour and produces high biomass and also these systems provide better opportunities to the grazing animals for utilizing annuals and those species which become less palatable after maturity (Ahuja *et al.* 1970; Gupta and Saxena, 1991; Mertia, 1992).

Grazing based on carrying capacity aiming at (70%) utilization has proved better, because during sub-normal and drought years moderate and heavy intensities has caused heavy utilization and mortality of palatable species. The heavy intensities have shown adverse effect

Table 5 Effect of heavy stress of grazing on % botanical composition and dry forage yield kg/ha

Plant Communities	Botanical Composition %			Forage Yield kg/ha		
	Before Grazing	After Grazing	Difference	Before Grazing	After Grazing	Difference
High perennials	8.1	6.3	1.8 (22.2)	872	145	727 (83.37)
Low perennials	17.4	3.4	14.0 (80.5)	396	24	372 (93.94)
Annual grasses	34.6	17.4	17.2 (49.7)	351	48	303 (86.3)
Total edibles	60.1	27.1	33.0 (54.9)	1619	217	1402 (86.59)
Non edibles	0.8	0.5	0.3 (37.5)	116	80	36 (31.03)
Grand total	60.9	27.6	33.3 (54.7)	1735	297	1438 (82.88)

Figures in parenthesis is percentage utilised by grazing animals.

on palatable species on both protected and on free common grazinglands. It is therefore, important to know the type of animal to be grazed on rangeland and to decide the stocking rate on year long basis or seasonal basis to avoid any deterioration which may otherwise lead to complete eradication of palatable perennial species.

References

Ahuja, L.D., M.C. Prajapat, K.K. Vyas and G.R. Abbasi, 1970: Growth under different systems of grazing in *Aristida-Eleusine* pastures in arid regions of the Rajasthan. *Ann. Arid. Zone*, 9: 266-271.

Anantha Ram, K, 1993. Carrying capacity thresholds as regulatory feed back devices for common property lands management in Arid Rajasthan. In *Proceedings International workshop on Common Property Resources and crisis of Pastoralism in Thar Desert.*

Blatter. E and Hallberg, F. 1918-1921. The flora of the Indian desert (Jodhpur and Jaisalmer). *J. Bombay nat Hist Soc*, 27: 40-47, 270-279, 506-519.

Bawa, A.K., I.C. Gupta and B.D.Sharma 1988. Natural resources and their Management in rangelands of western Rajasthan. *Curr. Agric* Vol.12:33-56.

Chakravarty, A.K., Ram Ratan and K.C. Singh 1970. Grazing studies in the arid and semi-arid zone of Rajasthan. VIII. Utilization of vegetation cover, grazing behaviour of sheep and seasonal variation Of crude profein contents of crude profein contents of planst of different pastures. *Ann. Arid Zone*, 6: 10- 18.

Champion, H.G. 1936. A preliminary survey of the forest types of India and Burma. *Indian Forest records. Mimeo.*

Champion, H.G. and Seth, S.K. 1964. A revised survey of the forest types of India. *Mimeo, Dehradun*, 653 P.

Dabadghao, P.M. and K.A. Shankarnarayan 1973. *The grass cover of India ICAR*, New Delhi 718 P.

Das, R.B. and Sharup S. 1951. Flora Lin Rajputata studies. *Bio-Sci*, 1 :36-42.

Dhir, R.P. 1977. Western Rajasthan soil their characteristics and properties. Desertification and its control, *ICAR*, pp. 102- 115.

Gupta, R.K. and Saxena, S.K. 1971. Ecological studies on the protected and overgrazed rangelands in the arid zone of western Rajasthan. *J. Ind. Bot.* Soc. 50.

Gupta, R. K. 1975. *Plant life in the Thar desert. In:Environmental analysis of the Thar desert (Eds. R.K. Gupta and I Prakash)*, English book Depot, Dehradum, pp 202-236.

Kaul, K.N. 1951. A palm found from Kapurdi (Jodhpur-Rajasthan desert) Cocos sahnii sp. nov *Curr.Sic.* 20:138.

Kumar, M and MM Bhandari 1992. Impact of protection and free grazing on sand-dune vegetation in the Rajasthan desert, India. *Land degradation and rehabilitation*, Vol. 3: 215-227

Lakhanpal, R.N. and Bose, M.N. 1951. Some tertiary leaves and fruits of Guttiferae from Rajasthan. *J. Indian. Bot. Soc*. 30: 131-139

Lakhanpal, R.N. and Singh, Gurdip 1975. Palesbotanical history. In: *Environmental analysis of Thar desert. (Eds. R.K. Gupta and I Prakash)*, English Book Depot, Dehradun, pp. 38-47.

Lukose, N.G. 1984. How far the palynological evidences supports the drift of the Indian subcontinent-a case study, In *Evolutionary botany and Biostratigraphy (A.K. Sharma, G.C. Mitra and M. Bener jee, eds)*. Todays and Tomorrows pnnteers, New Delhi, pp. 683-694.

Mauria, S. and L.N. Harsh 1984. Performance of heifers on controlled continuous grazing versus continuous grazing with supplementation of hay during the lean period *Ann. Arid Zone*, 23(4) : 359-362.

Mertia. R.S. 1976. Study on the floristic composition of extreme arid regions of Rajasthan. *Ph.D. Thesis University of Jodhpur Rajasthan. India.*

Mertia, R.S. 1984. Effect of different systems of grazing by sheep on the botanical composition of *Lasiurus eleusine* grazinglands. *Forage Res*. 10(1): 15-18.

Mertia, R.S. 1985. Growth performance of heifers grazing on Cenchrus - Aristida grassland. *Ann. Arid Zone*, 24(4): 358-360.

Mertia, R.S. 1987. Effect of selective grazing on the botanical composition of *Lasiunns sindicus* grassland. *Ann. And Zone*, 26(4): 293-295.

Mertia, R.S. 1989. Seasonal carrying capacity of rangeland in western Rajasthan. *Indian J. Range*

Mgmt.,10(1): 67-69.

Mertia, R.S. 1991. Pasture and animal productivity from grazingland under rotational grazing system in semi-arid regions of India. *Range Mgmt & Agroforestry*, 12(2): 133-137

Mertia, R.S. 1992. Studies on improvement, and utilization of rangelands of Jaisalmer region. *CAZRI Monograph*, 38: pp.1-45.

Mertia, R.S. and M.M. Bhandari 1992. Vegetational adaptation in the extremely arid region of the Indian desert. In *Inter Natl. Symp. Arid Zone Research and Development.* pp 155-164. Scientific Publisher Jodhpur.

Pandey, S.C. 1964. Ecology of grasslands of Sagar, Madhya Pradesh II. A composition of fenced associations. Indian *J. Bot. Soc.* 43 : 577-605.

Paroda, R.S., H.S. Mann and C.M.Verma 1980. Management of Indian arid rangelands. *CAZRI Tech. Bulletin*, No.4 38.

Raheja, P.C. 1966. Rajasthan desert can bloom with forage. *Indian farming*, 15 : 47.

Ramakrishna, Y.S., Agnihotri, C.L. and Rao, R.S. 1992. Climatic resources of Thar desert and adjoining arid areas of India. In: *perspective of Thar and Karakum (Eds. Amalkar, R.K., Abichandani, K.Anantha Ram and D.C. Joshi)*, DST. Govt of India. New Delhi, pp.10-20.

Ray Choudhuri, S.P. Aggarwal, R.K. Gupta, N.K. and Thomas, P.K. 1963. *Soils of India ICAR*, New Delhi - 495 p.

Rekib, A. 1981. Some aspects of livestock feeding on herbage in Bundelkhand (U.P.). Paper presented at *National Seminar on Rainfed Agriculture and farm forestry with special reference to Bundelkhand Region*, held at IGFRI Jhansi during Dec. 17-19, 1981.

Roy, B.B., Dhir, R.P. and Kolarkar, A.S. 1978. Soils of Rajasthan desert and their characteristics. *Proc. Winter School on Development of Rajasthan Desert*, CAZRI. Jodhpur.

Satyanarayan, Y. 1964. Habitat and plant communities of Indian desert. *Proc. Symp. Problems of Indian Arid Zone*, Ministry of Education, Govt. of India. UNESCO; pp. 59-68.

Shankar, Vinod and Suresh Kumar 1987. Grazing resources of Jaisalmer. *Ecology and Developmental planning with special reference to sewan grasslands*. Pub. No. 28 CAZRI. Jodhpur.

Shankar, Vinod, 1994. Vegetation of the Indian Arid Zone. In *sustainable development of the Indian, Arid Zone. (Eds. R.P. Singh and Surendra Singh)*, Scientific publisher Jodhpur, India, pp. 49-53.

Saxena, S.K 1977. Vegetation and its succession in the Indian desert. In: *Desertification and its control (Ed. P.L. Jaiswal)*, Model press (P) Ltd. New Delhi, pp. 176-192.

Sharma, S.K. 1987. Improvement and grazing management of arid rangelands at Samdari and Jodhpur. *CAZRI. Monograph*, No.30 pp.39.

Whyte, R.O. 1964. *Grassland and Fodder resources of India*. ICAR, New Delhi, 533 pp.

Desert Mapping using NOAA/AVHRR in the Thar Desert, India

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Abstract

The study aims at making land cover classification based on the phenological characteristics using NOAA/AVHRR image data in Rajasthan, India. The satellite data used in the study were NOAA-11/AVHRR LAC mode imageries, January 8, 1989 and October 7, 1989, which are corresponding to winter (dry season) and post-monsoon season (post-rainy season) respectively. The land cover could be classified into nine types by clustering. The area of each land cover type of each district of Rajasthan State was computed. The study found out the NOAA/AVHRR images useful for regional scale mapping of certain land cover types in the desert and the distribution of the land cover types was clarified using two-temporal images.

1. Introduction

1) Study area

The Thar Desert spreads over 0.32 million km^2 and much of it lies in the western part of the Rajasthan State, India (Fig. 1). The physical geography of Rajasthan is dominated by the existence of Aravalli range, extending from south-west to north-east. It allows the monsoon wind to blow from Arabian Sea to Himalayas and it brings monsoon rainfall to Rajasthan.

Rajasthan could be divided into arid, semi-arid and sub-humid regions and broadly rainfall is lower in west and north-west and higher in south-east. Arid region consists of districts of Jaisalmer, Barmer, Bikaner, Ganganagar, Churu, Jhunjhunu, Sikar, Nagaur, Jodhpur, Pali and Jalor (Fig. 2). The normal annual rainfall at meteorological station is 164 mm at Jaisalmer, 366 mm at Jodhpur, 466 mm at Sikar. Semi-arid region consists of districts of Alwar, Jaipur, Bharatpur, Ajmer, Tonk, Sawai Madhopur, Bhilwara, Bundi, Kota, Chittorgarh, Udaipur, Sirohi, Dungarpur and parts of Jhalawar. The normal annual rainfall is 557 mm at Ajmer, 842 mm at Kota and 660 mm at Udaipur. Sub-humid region contains parts of Jhalawar and Banswara district. The normal annual rainfall is 1023 mm at Jhalawar (Rao, 1992).

Its weather pattern could broadly be classified into the four seasons: winter (December - February), summer (March - June), monsoon season (July - September), and post-monsoon season (October - November) .

The agriculture of Rajasthan has Kharif season (monsoon season) and Rabi season (dry season). In Kharif season, the most preferred crop is Bajra (Pearl Millet) followed by kharif pulses constituting Moong, Moth, Urd and Cowpea. They rely on the monsoon rainfall. In rabi season, the cereals are mostly cropped under irrigation facilities. Gram is grown in the largest area and followed by wheat and rape-mustard etc. (Khurana, 1992).

2) Technical background

Satellite remote sensing could be a great tool for wide area desert mapping, because it can collect data widely, repeatedly, continuously and constantly. Moreover, in desert area, it is often difficult to carry out field investigation. Therefore, satellite remote sensing is now used more often.

With respect to usage of NOAA/AVHRR in the field of desert mapping or desertification monitoring, Tucker *et al.* (1985) carried out African land cover classification based on seasonal land cover changes using NOAA/AVHRR data. Potdar *et al.* (1993) investigated the response of vegetation in the Thar Desert to the monsoon rainfall using multi-temporal NOAA AVHRR data of post-monsoon period and meteorological data. Yasuoka *et al.* (1993) produced NDVI mosaic map of south-east Asia including Rajasthan using NOAA AVHRR LAC images.

Land-use in Rajasthan is strongly related to agricultural practices and it has significant contrast in two seasons of Rabi season and Kharif season. The study aims to make land cover classification based on the phenological characteristics using NOAA/AVHRR and map desert area, using dry season and post-monsoon

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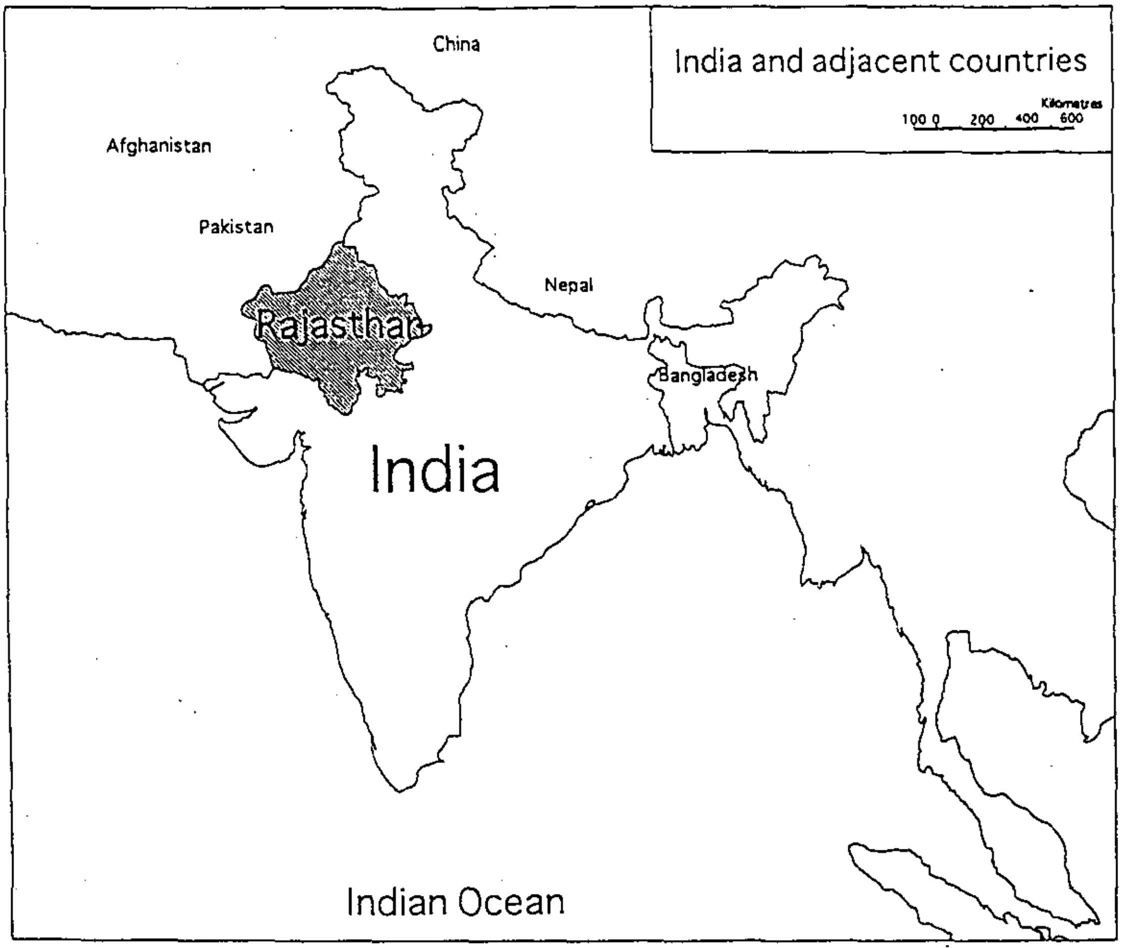


Fig. 1 Location of Rajasthan State, India.

season when wide-area cloud free images can be gained.

2. Materials and methods

The satellite data used in the study are NOAA-11/AVHRR LAC mode imageries (Band 1-5), January 8, 1989 and October 7, 1989, which are corresponding to winter (dry season) and post-monsoon season (post-rainy season) respectively.

"Global Historical Climatology Network: Long-Term Monthly Temperature, Precipitation, Sea level pressure, and Station pressure data" (GHCN data, by Vose, R. S. *et al.*) was used to examine the weather conditions of the data acquisition period. Following image processing were carried out for two satellite images.

1) Geometric correction: Each image was overlaid onto the longitude/latitude coordinates through geometric correction. The third order polynomial decided by the tick mark information was used for converting the image coordinate to the longitude/latitude coordinate.

2) Affine transformation: Even after geometric correction described above, still two images had a few pixel difference. So Affine transformation was performed to adjust two images perfectly.

3) Extraction of Rajasthan area: The 1024 x 1024 pixels containing all Rajasthan State were extracted from two images.

4) Radiometric correction: Two images were radiometrically calibrated using CCT value of water area (sea etc.) with constant low value and bare land area with constant high value to make it possible to compare two images with each other.

5) False color imaging: Two false color maps were imaged through false color composite; Band 1 (Near-infrared red channel)=RED, Band 2 (Visible channel)= GREEN and BLUE. Two images were radiometrically enhanced using saturating linear contrast enhancement method with the same maximum and minimum

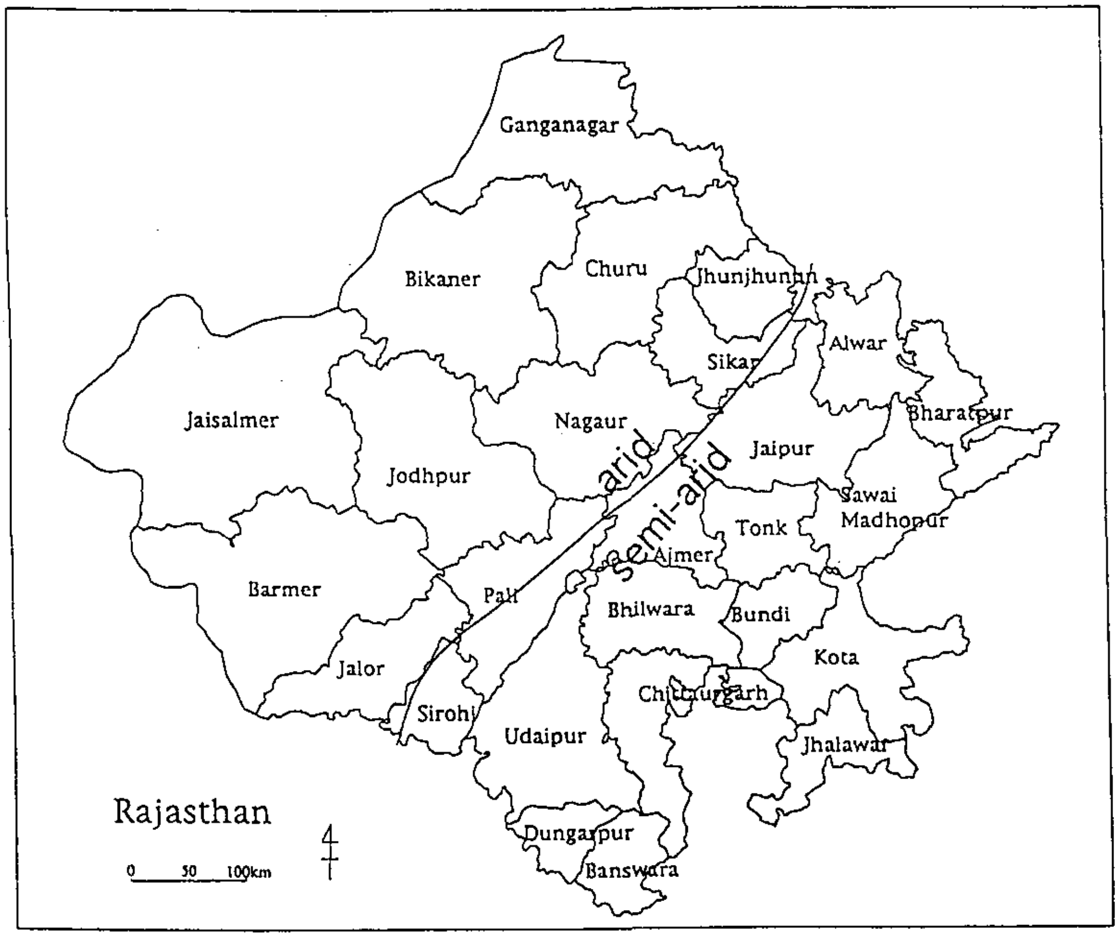


Fig. 2 Districts of Rajasthan State and the boundary between arid and semi-arid areas.

brightness values.

6) NDVI mapping: The Normalized Difference Vegetation Index (NDVI) was calculated using following formula.

NDVI=(Band 2 - Band 1) / (Band 2 + Band 1)

7) Clustering: Four variable data of two images with Band 1 and 2 were clustered using the isodata algorithm and the cluster map was produced.

8) Digitizing of Rajasthan map: The map of "Rajasthan (1978)" (scale 1 : 1 million) was digitized using ARC/INFO as vector type data and converted to ERDAS raster type data.

9) Map projection converting: The AVHRR images were converted to the Polyconic projection and were overlaid onto the Rajasthan map.

10) Area calculation: After the image processing described above, the area of each cluster of each district of Rajasthan State was computed. The area was calibrated using districtwise area data obtained from a census.

3. Results

1) Weather conditions of 1989 (Fig. 3, Fig. 4)

Compared to 1985-1988, the weather conditions of 1989 in Rajasthan had average temperature and a little bit more precipitation at Bikaner and less precipitation at Jodhpur.

2) False color map of January (Fig. 5a)

Judging from the January map, Aravalli range located at the south part of Rajasthan and irrigated cropped area around Alwar are represented in red. In the north-west, Indus river and its drainage area can be seen. Because few crops are growing in the field at the period, the surrounding area of Indus river is represented in dark blue. In the south-west, Rann of Kutch can be seen, which is a salt flat and in case of drying-up, the land surface is covered with white salt which has very strong reflection similar to cloud. In the Luni basin area in the south-west and areas to the south of it, some red parts can be seen. These are irrigated areas, using mainly tube wells and tank water.

3) False color map of October (Fig. 5b)

The surrounding area of Indus river is represented in strong red, indicating canal irrigation with high crop productivity. Also, some parts in Ganganagar district are shown in red, indicating irrigated field using the canal water. The east half of Rajasthan is more reddish than that on January map.

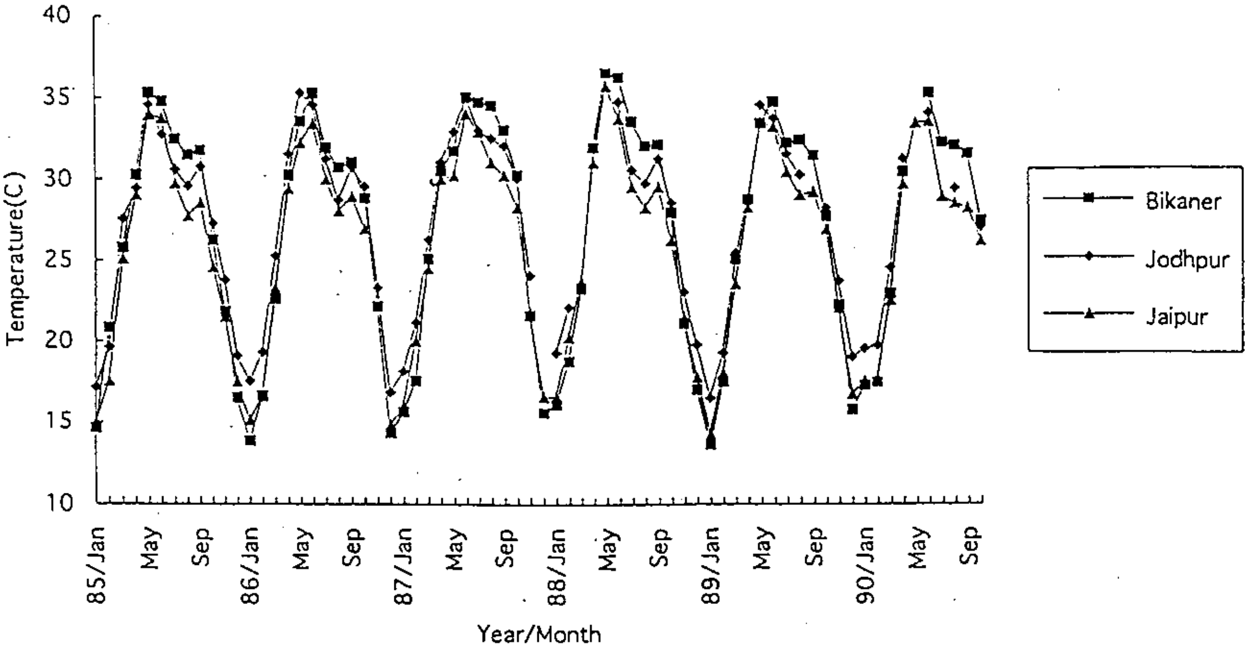


Fig. 3 Monthly temperature from January 1985 to October 1990.

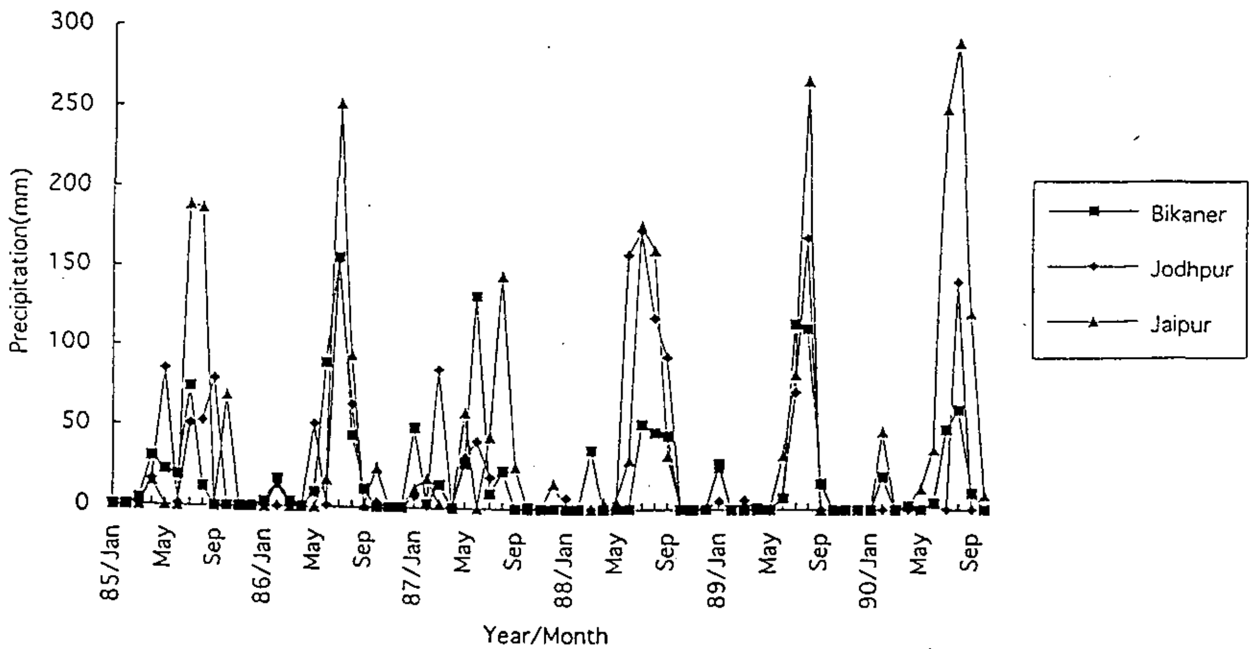
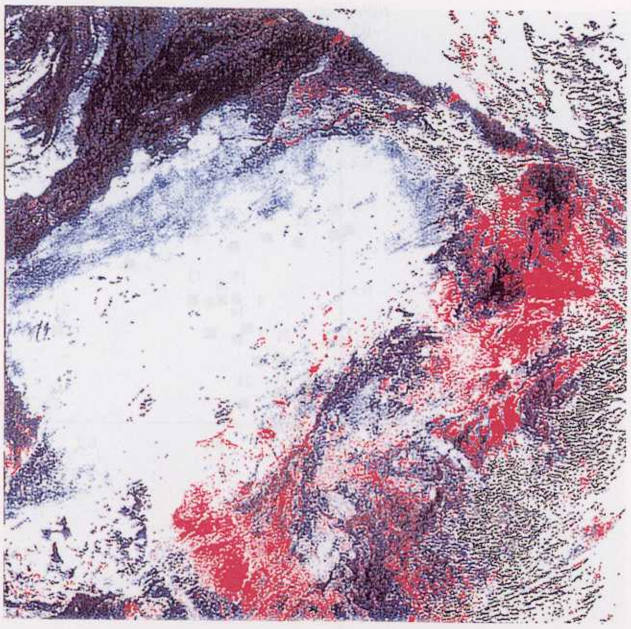


Fig. 4 Monthly precipitation from January 1985 to October 1990.

(a)



(b)

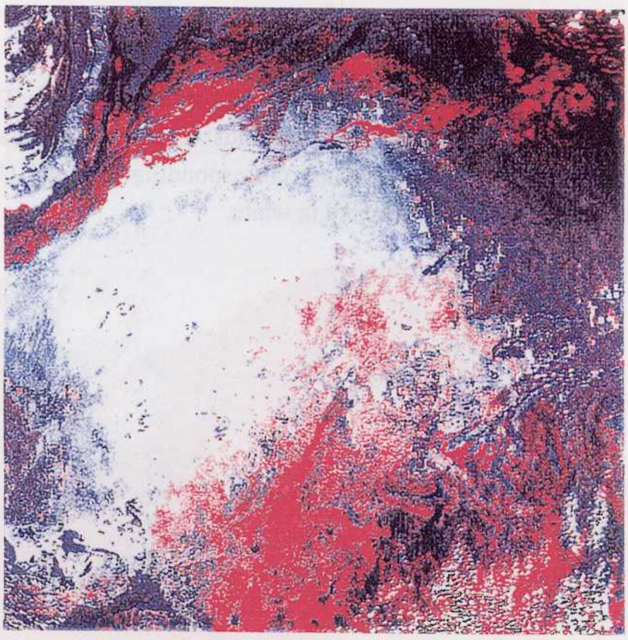


Fig. 5 NOAA/AVHRR false-color composite image of (a) January 8, 1989, (b) October 7, 1989. In original image, red=band2, green=band1, blue=band1. Two images are calibrated geometrically and radiometrically for mutual comparison. The Desert is represented in white at the center-left part.

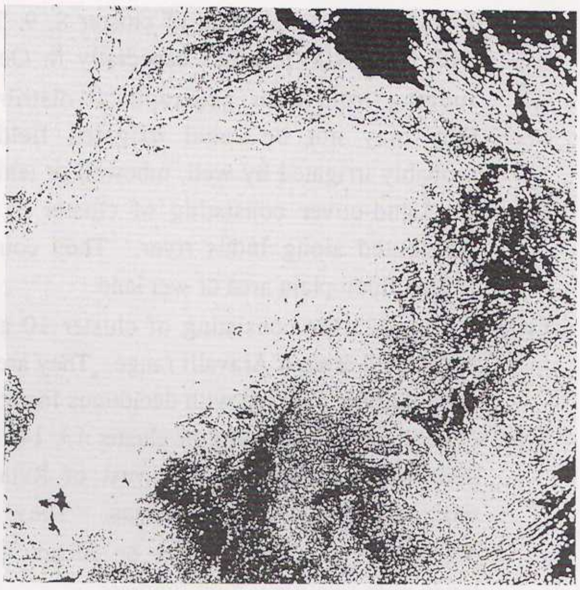
4) NDVI map of January (Fig. 6a)

In the NDVI map, the area with low NDVI value is represented in white and high NDVI value in dark grey, and the area covered with cloud is masked in black. The west half of Rajasthan is shown in white (low NDVI). The northern part of Aravalli range and the irrigated field located at the west of Aravalli range have high NDVI values.

5) NDVI map of October (Fig. 6b)

The irrigated field along Indus river has much higher NDVI than that of January. Also, the surrounding area of Aravalli range has higher NDVI. The sparse vegetation area indicated by low NDVI is shifted from south-east to north-west, compared to January map.

(a)



(b)

Fig. 6 NOAA/AVHRR NDVI image of (a)January 8, 1989, (b)October 7, 1989. The area with low NDVI value is represented in white and high NDVI value in dark grey, and the area covered with cloud is masked in black.

6) Cluster map and land cover classification (Fig. 7, Fig. 8, Table 1 & Table 2)

The land cover could be classified into nine types by clustering.

Type I: Land-cover consisting of cluster 5-7 distributed along Indus river and the northern part of Aravalli range with very high NDVI values. They could be judged densely vegetated area such as irrigated field and deciduous forest of Aravalli range.

Type II: Land-cover consisting of cluster 8, 9, 11, 15 with high NDVI values especially in October. Judging from their geographical distribution, they may not be canal irrigated field, but probably irrigated by well, tubewell or tank.

Type III: Land-cover consisting of cluster 3 and 4 distributed along Indus river. They could be judged flood plain area or wet land.

Type IV: Land-cover consisting of cluster 10 and 12 distributed around Aravalli range. They are hilly area partially covered with deciduous forests.

Type V: Land-cover consisting of cluster 13, 14, 17, 18 distributed from center to west of Rajasthan with around 0.1 NDVI values. They could correspond to open pasture or current fallow lands with relatively high biomass.

Type VI: Land-cover consisting of cluster 19-22 distributed west part of Rajasthan with low NDVI values less than 0.05. They could correspond to open pasture or current fallow lands with low biomass.

Type VII: Land-cover consisting of cluster 24 distributed mainly in Jaisalmer. It has similar NDVI values to cluster 20, but its albedo values of Band 1 and 2 are much higher than any other clusters except Type XI clusters influenced by cloud. They may be open pasture or current fallow lands with very low biomass.

Type VIII: Land-cover consisting of cluster 1 and 2 have very low albedo values in Band 1 and 2. They could be classified as water body such as lake, river and tank.

Type IX: Cluster 16, 23, 25-30 have very high albedo values in Band 1 and 2. They are judged cloud or dried-up Rann.

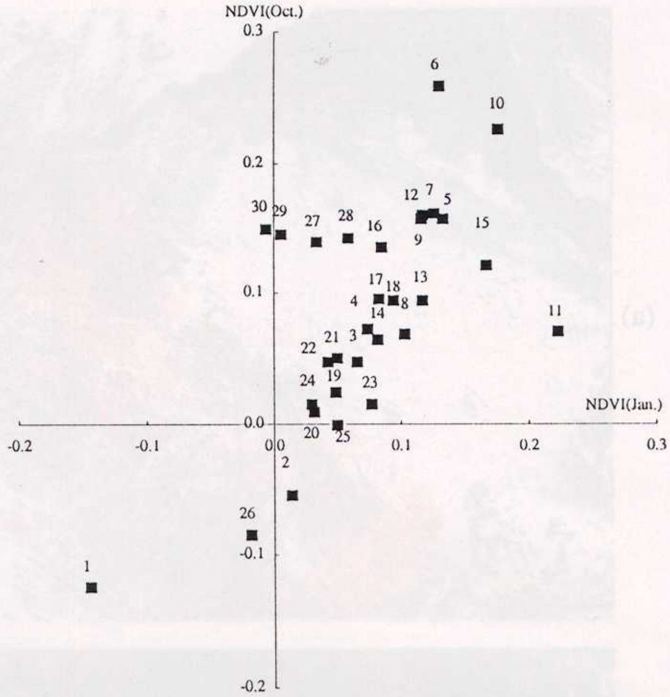


Fig. 7 Geographical distribution of cluster-class. The number in the map corresponds to the cluster-class number. The cluster-class corresponding to cloud (16, 23, 25-30) is represented in white.

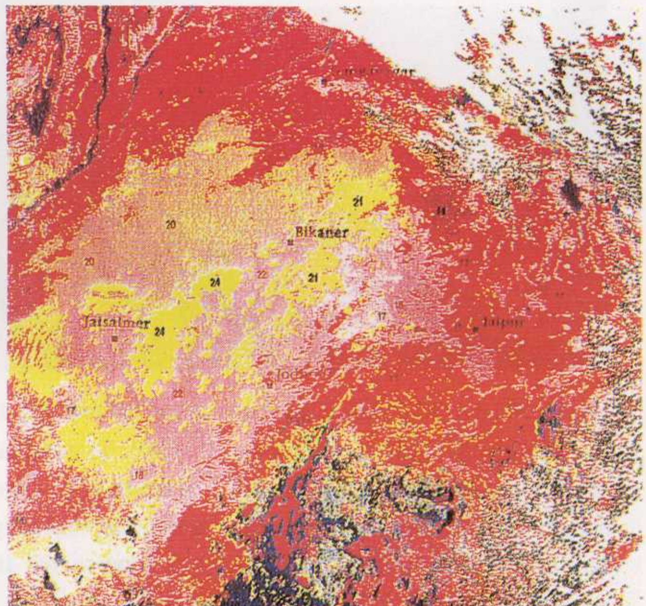


Fig. 8 Scattergraph of NDVI value of each cluster - January 8, 1989 and October 7, 1989 -. The number in the figure means the cluster-class (See Table 1).

4. Concluding remarks

4.1. Desert mapping methodology

The study found the NOAA/AVHRR images useful for regional scale mapping of certain land cover types in the desert. This was because the maps obtained by digital image processing could be explained clearly by the land cover conditions which were mainly depending on the agricultural practices. But at the same time, the calculated area turned to have some differences from other statistical information, for example, the area that were thought to be classified into irrigated area was different from that of existing statistics. The main reason is considered to result from AVHRR's spatial resolution of approximately 1.1 km, which may be too large for detection of small-scale land cover such as tubewell irrigated field.

Table 1 Calibrated CCT value of Band 1, 2 and NDVI of each cluster-class - January 8, 1989 and October 7, 1989 -

Cluster	8-Jan Band 1	8-Jan Band 2	7-Oct Band 1	7-Oct Band 2	8-Jan NDVI	7-Oct NDVI
class 1	103	77	118	92	-0.144	-0.124
class 2	143	147	144	129	0.014	-0.055
class 3	114	130	152	167	0.066	0.047
class 4	113	131	167	193	0.074	0.072
class 5	108	139	138	191	0.126	0.161
class 6	110	143	127	216	0.130	0.259
class 7	118	149	150	206	0.116	0.157
class 8	126	155	164	188	0.103	0.068
class 9	124	162	140	192	0.133	0.157
class 10	122	174	135	214	0.176	0.226
class 11	117	184	167	192	0.223	0.070
class 12	139	176	150	207	0.117	0.160
class 13	128	162	178	215	0.117	0.094
class 14	145	171	176	200	0.082	0.064
class 15	135	189	171	218	0.167	0.121
class 16	167	198	148	194	0.085	0.135
class 17	160	189	176	213	0.083	0.095
class 18	154	186	189	228	0.094	0.094
class 19	154	170	200	210	0.049	0.024
class 20	166	177	219	223	0.032	0.009
class 21	172	190	200	221	0.050	0.050
class 22	178	194	215	236	0.043	0.047
class 23	138	161	258	266	0.077	0.015
class 24	194	206	236	243	0.030	0.015
class 25	172	190	360	359	0.050	-0.001
class 26	340	328	313	264	-0.018	-0.085
class 27	245	262	149	197	0.034	0.139
class 28	201	226	148	197	0.059	0.142
class 29	311	315	145	194	0.006	0.145
class 30	407	402	143	193	-0.006	0.149

With respect to application of NDVI, because the geographical pattern of NDVI was recognized similar to that of rainfall distribution, NDVI can be used for macroscopic understanding of arid conditions. But for example, though cluster 20 and 24 have similar NDVI values, because their albedo values and geographical distribution were significantly separated, they were thought to represent different land cover type. Therefore, in case of land cover classification, we should use not only NDVI values, but also albedo values.

4.2. Desert geography

The total area of land cover type V, VI and VII which would corresponds to open pasture or current fallow land which was the typical land-use in the desert, was the largest in Jaisalmer (38,000 km^2), followed by Barmer (28,000 km^2), Bikaner (27,000 km^2), Jodhpur (22,000 km^2) and Ganganagar (19,000 km^2) in a decreasing order.

The comparison of January image and October image shows some differences. Macroscopically, the line where NDVI = 0.05 locates around Nagaur in January. In October, the line shifts from south-east to north-west, around the north-west part of Jodhpur. In addition to the macroscopic movement, other local differences are mosaiced into the large scale difference. The local differences appear with canal irrigation practiced in Ganganagar and Kota, tank irrigation in Bhilwara and Pali, well and tubewell irrigation in Alwar and Jaipur. Moreover, the deciduous forest of Aravalli range represents seasonal changes due to its phenology such as leaves-falling. But it will be necessary to analyze more multi-temporal NOAA AVHRR images for further understanding of the seasonal changes.

Acknowledgments

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Table 2 Districtwise area of each land cover classification

	Type I	Type II	Type III	Type IV	Type V	Type VI	Type VII	Type VIII	Type IX	Total
Cluster Class	5, 6, 7	8-9, 11, 15	3, 4	10, 12	13-14, 17-18	19-22	24	1, 2	16, 23, 25-30	
Ganganagar	* 452	518	238	265	6781	12342	1	22	15	20634
	** 2	3	1	1	33	60	0	0	0	100
Blkaner	0	5	4	1	647	25003	1536	2	46	27244
	0	0	0	0	2	92	6	0	0	100
Churu	0	4	3	0	7380	9443	0	0	0	16830
	0	0	0	0	44	56	0	0	0	100
Jhunjhunun	19	459	85	20	4659	679	0	0	7	5928
	0	8	1	0	79	11	0	0	0	100
Alwar	1359	5003	195	65	1756	1	0	0	2	8380
	16	60	2	1	21	0	0	0	0	100
Bharatpur	48	5641	93	45	1786	16	0	3	469	8100
	1	70	1	1	22	0	0	0	6	100
Sawal Madhopur	287	5835	39	137	3429	159	0	6	635	10527
	3	55	0	1	33	2	0	0	6	100
Jalpur	231	4657	53	154	8746	209	0	10	8	14068
	2	33	0	1	62	1	0	0	0	100
Slkar	29	817	7	6	6435	438	0	0	0	7732
	0	11	0	0	83	6	0	0	0	100
Ajmer	720	1368	13	811	5545	17	0	7	0	8481
	8	16	0	10	65	0	0	0	0	100
Tonk	51	2778	19	340	3927	64	0	10	7	7194
	1	39	0	5	55	1	0	0	0	100
Jaisalmer	0	2	1	0	715	30225	7437	0	22	38401
	0	0	0	0	2	79	19	0	0	100
Jodhpur	0	718	2	16	6146	13989	1969	2	8	22850
	0	3	0	0	27	61	9	0	0	100
Nagaur	6	2546	14	742	11809	2442	31	41	88	17718
	0	44	0	4	67	14	0	0	0	100
Pali	955	3135	41	3938	4166	126	0	20	6	12387
	8	25	0	32	34	1	0	0	0	100
Barmer	19	126	89	10	4931	22458	703	1	50	28387
	0	0	0	0	17	79	2	0	0	100
Jalor	39	1978	21	152	6555	1716	15	0	165	10640
	0	19	0	1	62	16	0	0	2	100
Sirohl	1040	1147	13	2189	707	1	0	13	26	5136
	20	22	0	43	14	0	0	0	0	100
Bhllwara	719	3051	40	4205	2370	2	0	51	17	10455
	7	29	0	40	23	0	0	0	0	100
Udaipur	4108	2145	15	10805	124	0	0	73	9	17279
	24	12	0	63	1	0	0	0	0	100
Chittaurgarh	2756	2652	37	4879	188	0	0	328	17	10856
	25	24	0	45	2	0	0	3	0	100
Dungarpur	404	282	55	2858	14	3	0	120	33	3770
	11	7	1	76	0	0	0	3	1	100
Banswara	1955	997	98	1736	87	0	0	139	26	5037
	39	20	2	34	2	0	0	3	1	100
Bundl	1037	1305	51	932	2103	93	0	29	2	5550
	19	24	1	17	38	2	0	1	0	100
Kota	2322	2835	175	3261	1429	18	2	54	2340	12436
	19	23	1	26	11	0	0	0	19	100
Jhalawar	1507	991	205	1042	449	23	8	13	1981	6219
	24	16	3	17	7	0	0	0	32	100
Total	20062	50993	1606	38608	92884	119465	11701	940	5979	342239
	6	15	0	11	27	35	3	0	2	100

* area in km²
** area in percentage of each district.

References

Khurana, G. P. 1992. Soil, climate, land use characteristics and associated features for agricultural production in Rajasthan, In *Geographical facets of Rajasthan*, Sharma, H. S. and Sharma, M. L., eds, Kuldeep Publications, Ajmer, 123-139.

Potdar, M. B., Pokharna, S. S. and Sridhar, V. N. 1993. Response of vegetation in the Thar Desert to monsoon rainfall: an investigation using NOAA AVHRR and meteorological data, *Journal of Arid Environments*, 25, 19-26.

Rao, A. S. 1992. Climate, Climatic changes and Paleo-climatic aspects of Rajasthan, In *Geographical facets of Rajasthan*, Sharma, H. S. and Sharma, M. L., eds, Kuldeep Publications, Ajmer, 38-44.

Tucker, C. J., Townshend, J. R. G. and Goff, T. E. 1992. African land-cover classification using satellite data, *Science*, 227, 369-375.

Yasuoka, Y., Yamagata, Y., Otoma, S., Miyazaki, T. and Takeuchi, S. 1993. Vegetation mapping and change analysis in south-east Asia from NOAA AVHRR LAC imageries, In *Proceedings of 1993 International Geoscience and Remote Sensing Symposium*, Tokyo, Vol. IV, 1683-1684.

Vose, R. S. *et al.* "Global Historical Climatology Network: Long-Term Monthly Temperature, Precipitation, Sea level pressure, and Station pressure data" (digital data set).

Desertification - A Study in Khabrakalan Village in Western Rajasthan

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1. Introduction

Desertification is defined as "Land degradation in arid, semiarid and dry sub-humid areas resulting from various factors including climatic variations and human activities". The principal desertification processes are degradation of vegetative cover, water and wind erosion, soil compaction and salinization and waterlogging, (Dregne, 1983).

In the arid zone of Rajasthan, the most important facets in the process of desertification are:

(1) unscientific land use practices like cultivation of sand dunes and other marginal lands;

(2) uncontrolled grazing and indiscriminate cutting of trees and shrubs; and

(3) non-judicious use of surface and ground water leading to waterlogging and salinity.

It has been estimated that 23,882 Sq.km. area in Thar Desert of Rajasthan is affected by desertification. The dominant process of desertification here is the expansion of sand cover and sand dune formation. About 76% of the desert is affected by high to medium vulnerability and 20% of desert area is susceptible to medium to light vulnerability, (Venkateswarlu, *et al.*, 1992).

The socio-economic aspects of desertification process were studied in some details in a representative village (Khabrakalan) in Jodhpur district of Rajasthan by a multi-disciplinary Indo-Japan research team. The results are discussed below.

Khabrakalan village in Osian tehsil of Jodhpur district is dominated by a sandy terrain. A sample of 64 households were selected at random. The households were then stratified into marginal, small, medium and large, according to the owned size of land holdings. The number of households in each size group came to 18, 13, 9 and 24 in marginal, small, medium and large size groups, respectively.

The data relating to land use, livestock holdings, crop production, input use, cultivation practices, fuel use for cooking, perception of desertification process etc. were recorded on pre-tested household schedule by personal interview and discussion. The data were analyzed with the help of ratios, means and other simple statistical tools. The process of desertification is discussed with reference to cultivation pressure, grazing intensity, fuel use intensity and local perception of desertification of cause, consequence and control measures.

1.1. General background

Khabrakalan has a geographical area of 16.529 km^2 with a population 1,253 in 1991. The density of population is 76 persons/km^2. Only 19% of the total population is literate. The total number of households is 182 and the settlement is scattered. Five major communities inhabit the village. Each one of them settled in different groups according to caste/ community affiliation. Most of the land in the village is owned by three dominant caste groups viz. Rajputs, Vishnoi and Jats. One side of the village has a chain of huge sand dunes and the other remaining sides have sandy plains with sandy soils. Seventy percent of the area of the village (1,165 ha.) was sown to crops in the reference year (1992-93). The total area sown to crop one time or other formed 87%, if the area under fallows are added to the net sown area. This leaves about 209 ha. under other uses like, pastures (2%), barren waste (2%) and culturable waste (8.5%). The total number of livestock in the village was 4,126 in 1992. The composition of livestock was bovines (20.7%), ovines (78%) and others (1.3%). The draught power (males over 3 yrs.) was 74 or 37 pairs of bullocks. The livestock in adult cattle units (ACUs), numbered 1,254 in the village. The density of livestock on grazing lands was 4.28 ACU/ha Animal units per ha of net sown area was 1.07. Net sown area per pair of bullocks was 31.48 ha.

2. Results and discussions

2.1. Land use changes

Crop lands

Changes in land use as a primary indicator of desertification is to be reflected in the amount of

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cultivated land abandoned, expansion of dry land farming to former pastoral lands and fallow periods. In Khabrakalan the per capita land available was 1.32 ha out of which net area sown to crops was 1 ha. thus leaving little area for other uses. This, in other words, means that there has been rampant encroachment of grazing lands for cropping. It has been estimated that 64% land in Jodhpur district and 79% of arid Rajasthan is unsuitable for cropping (Dhir, 1977; Jodha, 1982). Fallowing under rainfed farming is a function of rainfall and relative size of land and the capacity of this size to fulfill the basic consumption requirement of the population. Due to pressure of consumption demand, fallowing of crop lands, in the village varied along with the rainfall pattern only. Lower the rainfall, higher the fallow lands and vice versa

Consumption supplies depends, among other things, on the per capita land area and yield. The per capita land available and the corresponding per capita area sown to crops in different size groups are presented in Table 1. It reveals that the per capita area sown to crops was less than a hectare in three out of four size groups. Bajra (pearlmillet) which is the staple food crop of the village has an average long term yield of 0.20 to 0.25 tonnes per hectare (Mruthyunjaya *et al.*, 1983). The subsistence needs are considered to be about 250 Kgs of cereals per capita per year including seed reserve (Le' Houerou, 1977). In the Indian conditions the annual per capita consumption requirement of cereals is considered to be 144 Kgs (Sukhatme, 1962). By the above standards, the per capita land sown to crops is just about the barest minimum in the first three size groups. Given the high co-efficient of variation of yields (49%) and crop failure due to drought, the inhabitants of the village continue to raise crops year after year to eke out a living. Continuous crop cultivation is not that harmful if the crops are well nourished so that the soils are not depleted. But in this aspect also the inhabitants were found to be wanting firstly because the use of farm yard manure (FYM) on the sample farms amounted to an average of 0.108 t/ha Atleast in case of FYM use, marginal farmers with a use of about 0.230 t/ha were found to be better as compared to other size groups. However, it was not enough to keep the land in productive condition for continuous annual cropping.

Table 1 Agro-Economic Attributes of Sample Households of Khabra Kalan Village

	Marginal	Small	Medium	Large	Total
CROP LAND					
No. of Households (No)	18	13	9	24	64
Household members (No)	131	90	79	274	572
Acreage per capita (Ha)	0.33	0.76	0.94	1.70	1.13 *
Area cropped per capita (Ha)	0.31	0.65	0.66	1.07	0.77 *
LIVESTOCK					
Draught power (No)	3	5	2	12	22
Milk cows and Buffaloes (No)	34	49	30	181	294
Sheep and Goats (No)	123	108	94	371	696
Total livestock (No)	160	162	126	564	1012
Livestock in ACUs (No)	-	-	-	-	347
Per capita cattle (No)	0.28	0.60	0.80	1.64	0.55 *
Sheep and Goats (No)	0.94	1.20	2.35	3.14	1.21 *
Total (No)	1.22	1.80	3.15	4.78	1.76 *
DUNG USE					
Availability of Dung (T)	33.3	48.6	23.8	173.7	284.4
FYM used for crops (T)	9.40	5.00	0.98	32.5	47.88
Dung cake used as Fuel (T)	18.61	17.15	15.69	30.66	82.11
FYM use per Ha. (T)	0.230	0.085	0.018	0.112	0.108
FUEL USE					
Fuel wood (Kg/PC/Day)	0.98	1.10	0.60	0.96	0.94 *
Dung cake (Kg/PC/Day)	0.39	0.52	0.54	0.31	0.39 *
Crop waste (Kg/PC/Day)	0.21	0.21	0.14	0.23	0.21 *
Total (Kg/PC/Day)	1.58	1.83	1.28	1.50	1.54 *
Primary energy (MJ/PC/Day)	28.2	32.4	21.6	27.0	27.3 *
Useful energy (MJ/PC/Day)	2.26	2.59	1.73	2:16	2.18 *

NOTE: * Refers to average; (T) Tones; (MJ) Mega Joules; (PC) Per Capita

To plough a hectare of land under dry land crops, a pair of bullocks takes 2.5 days (Rao and Singh, 1977). In Khabrakalan the availability of draught power was short, considering that the net area sown per pair of bullocks was 31.48 ha. Due to short rainy season (about 8-17 rainy days) (Rama Krishna *et al.*, 1992) it is humanly impossible to plough the land in time for sowing with the available draught power. The use of tractors for ploughing is therefore widespread in the village. All the sample farmers reported the use of tractors for ploughing although there was only one household owning the tractor. Even the households having draught power did not use it for ploughing purposes. The plus point for tractor use is that the operations can be carried out timely soon after the first rains and probably maintaining bullock power would work out much more costly compared to hiring of tractor, particularly for small and marginal farmers.

The socio-economic compulsions coupled with short rainy season dictate the inhabitants to extend the cropping to unsuitable area. The small acreage at individuals disposal makes it to be cultivated year after year, not allowing the land to recoup by fallowing. The nutrients removed in the process of crop growing is not replaced adequately by supplies of plant nutrients in the form of FYM or chemical fertilisers. The use of heavy tractors in place of draught power exerts a pressure equivalent to 1.4 to 2.1 Kg cm^{-2} (Heady, 1975) and contributes to subsoil compaction and crusting leading to water erosion and top soil erosion by wind, besides uprooting of the perennial shrubs and grasses (Jodha, 1974).

Grazing lands

About 80-90% of rangelands in arid zone of Rajasthan are under poor to very poor condition class. (Raheja, 1962). The average airdried forage yield from poor and very poor grazing land is 0.5 and 0.2 t/ha, respectively. The poor condition class rangelands can support an animal population of 13, measured as adult cattle units (ACU) per 100 ha (Bhimaya and Ahuja, 1969). This means that at the grazing land productivity of 0.5 t/ha, the grazing area required is about 6 ha per ACU. In Khabrakalan the grazing land per ACU was 0.23 ha In other words there were 4.28 ACUs per ha of grazing land in the village. The composition of livestock was bovines (20.7%), Ovines (78.0%) and others (1.3%). In terms of number therefore the ovines (sheep and goats) were in larger number. The per capita bovines and ovines in the sample households reveals that there were about 3.5 animals for every two persons in the village, consisting roughly of one bovine and 2.5 ovines (Table 1). The size of herd in a smilar setting was estimated to be 26 to 32 percent higher in different size groups (Anantha Ram *et al.*, 1992). The distribution of animals among size groups reveals that medium and large size farms had more than three animals per head. The size of bovines and ovines was larger in these size of holdings compared to that in the marginal and small farms. It is difficult to supply the required 2.5 t/annum of dry matter equivalent per ACU with 0.23 ha. of grazing land per ACU with an yield of 0.5 t/ha and a crop residue 0.6 to 0.8 t/ha from 0.93 ha. of crop lands per ACU. The result is overgrazing of the depleted grazing lands. The denuded grazing lands are further subjected to soil compaction by the hooves of cattle, sheep and goats which is reported to exert a pressure equivalent to 0.65 to 1.7 kg cm^{-2} respectively. If the crusting is hard, seedling emergence is impaired. The result of overstocking is a progressive reduction in vegetation cover, increased wind erosion, trampling, sealing, increased runoff and desertification.

2.2. Cooking fuel use

The daily per capita minimal wood consumption for domestic use is about a kilogram, but is often more than three times this figure (Le' Houerou, 1977). In the sample households of the village the average per capita daily consumption of fuel wood was 0.94 kg. along with dung cake (0.39 Kg) and crop waste (0.21 Kg). The useful energy derived from a like order of non-commercial fuel is short of requirement due to inefficient cooking devices, (Anantha Ram *et al.*, 1990). Fuelwood, dung cake and crop wates accounted for 61, 25 and 14 percent of total fuel use respectively for cooking in the sample households. Apparently the fuelwood use looks reasonable. Considering the fact that the village has no forest land and 70 percent of the total area is sown to crops the supply of 0.343 t fuelwood per capita per year, was obtained largely from grazing lands, which is a common property resource (CPR). The major source of fuelwood being CPR, the indiscriminate cutting of trees and bushes has resulted in a short supply of fuelwood, leading to lower consumption consequently dung cake supplemented the fuelwood for cooking purposes. The per capita daily dung cake use in the sample households ranged between 0.31 Kg and 0.54 Kg. The average was 0.39 Kg for all size groups. The annual dung cake use in the sample households worked out to 82 tonnes. If we take an average of 80% of dung cake as dung proper, then the amount of dung burnt to cook food works out to 65.6 t. This is more than the dung used in the form of farm yard manure (FYM) on the sample farms Table 1. The use of dung as fuel not only deprives the soil of the nutrients, but also the organic material that helps to preserve the soil structure and the fertility needed for productive farming. Use of fuelwood and the dung cake in the sample farms are exploitative and help the process of desertification.

2.3. Perception of desertification and control

It is generally agreed that man and his actions are primarily responsible for desertification. The villagers were asked to mention the three most important causes, consequences of desertification and measures to control them. Among the respondents 89% opined that over cultivation is the major cause, followed by 76% suggesting ploughing by tractor and 56% as indiscriminate cutting of trees and bushes. As to consequences the thinking was as follows: occurrence of famine and malnutrition (94%), deterioration of living conditions (72%) and shortage of fodder for livestock (67%). As for control measure of desertification, 65% felt that control of population was necessary, while 75% mentioned soil conservation and 59% agro-forestry practices.

The results show that the villagers are aware of the problems and consequences of their actions to a large extent. Still they persist with what they are doing, because of the socio-economic setting in which they have to eke out a living. The alternatives for making a living in the system are limited and so the desertification process continues with all the attendant risks.

3. Summary and conclusion

The socio-economic aspects of desertification process were studied in Khabrakalan village. A total of 64 households were randomly selected which were later grouped in to four distinct size groups on the basis of size of land holdings. Desertification process was analysed with reference to agricultural land use, grazing, fuel use for cooking and local perception on desertification. Extension of dryland farming to marginal lands (formerly grazing lands) was found to be a major factor associated with desertification, as 70% of the total area was sown to crops in the reference year and 87% of the total area was under cultivation one time or the other. The per capita land available, coupled with low productivity of this land, compelled the inhabitants to go for continuous cultivation to fulfil their minimum consumption requirement. Nutrient loss from soils due to crop raising is not compensated by using fertiliser or farm yard manure. The use of FYM on sample farms avarged a meager 0.108 t/ha, depriving the soil binding organic matter and thus exposing the soil to wind and water erosion.

Added to this, the widespread use of tractors for ploughing adds to the erosion hazard. The availability of grazing land per adult cattle unit (ACU) was 0.23 ha, whereas the requirement is about 6 ha/ACU, given the poor condition class of the grazing lands in the village and the region. The result is overgrazing and exposure of denuded grazing lands to wind and water erosion hazards. The per capita annual consumption of fuel wood and dung cake was 343 and 142 Kg, respectively. The fuelwood was largely obtained from common perperty grazing lands which are subject to indiscriminate exploitation. The fuelwood use and the use of dung cake as fuel accelerate the process of desertification through destruction of vegetation and deprivation of soil of organic matter. Majority of the people are aware of the causes and consequences of desertification and control measures, but the process of desertification continues because the alternatives to eke out a living are limited in the system.

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References

Anantha Ram, K; Bhati, G.N. and Daulat Goyal, 1990. The Economics of cooking energy scenario in arid Rajasthan, *Annals of Arid Zone* 29(4) 333-338.

Anantha Ram, K, Goyal, Daulat and Vyas, K.K. 1992. Resource degradation; An analysis of grazing land degradation in Arid Zone of Rajasthan *J. of Rangemanagement and Agroforestry*, 13(1)36-39.

Bhimaya, C.P. and Ahuja, L.D. 1965. Criteria for determining condition class of range lands in Western Rajasthan, *Annals of Arid Zone* 8(1) 73-79.

Dregne, H.E. 1983. *Desertification of Arid lands - Advances in Desert and Arid Land Technology and Improvement, Vol. 3* Harwood Academic Publishers, New York.

Dhir, R.P. and Bhola, S.N. 1977. Land use capability classification In *Desert eco-system and its improvement*, Ed. H.S. Mann, Central Arid Zone Research Institute, Jodhpur 111-114.

Heady, H.F. 1975. Range Land Management, Mc Graw-Hill, New York, quoted In *Arid Land-Their use and abuse*, Heathcote, R.L. Longman, London P.98.

Jodha, N.S. 1982. The role of adiminstration in desertification: Land tenure as a factor in the historical ecology of Western Rajasthan; In *Desertification and Development*. Ed. Spooner, Brain and Mann, H.S. Academic press. New York 333-350.

Jodha, N.S. 1974. A case of process of Tractorisation, *Eco. and Pol. Weekly*, 9(52) A- 111A- 118.

Le'Houerou, H.N. 1977. *The nature and cause of degradation in and around Arid lands*, Ed. Michael H. Glantz, West view press, Boulder, Colarado 17-38.

Mruthyunjaya, Anantha Ram K. and K.K. Vyas 1983. Pace and Problems of growth of coarse grain and Kharif pulses in Arid areas of Rajasthan, *Annals of Arid Zone* 22(3) 177-185.

Rao, A.R. and Singh, I.J. 1977. Bullock - The Mainstay of farm power in India, In : *Agriculture and Energy*. Ed. Lockeretz, William, Academic press, London, 597-606.

Rama Krishana, Y.S., Agnihotri, C.L. and Rao, A.S. 1992. Climatic resources of the Thar desert and adjoining arid areas of India, In *Perspectives on the Thar and the Karakum*

Ed. Amal Kar, Abhichandani R.K., Anantha Ram, K. and Joshi, D.C. *Department Science and Technology*, Govt. of India, New Delhi 10-20.

Raheja, P.C. 1962. Range management, *Gosamvardhan* 10: 1-6.

Sukhatme, P.C. 1962. The food and Nutrition situation in India, Indian Journal of Agril. *Economics* Vol. 17, (2,3), 24.

Venkateswarlu, J., Sen, A.K. and Gupta, J.P. 1992. Desertification and its control in the Thar. In *Perspectives on the Thar and the Karakum*, 307-316.

Status of Water Resources in the Arid Zone of Rajasthan, India

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1. Introduction

Indian arid zone or Thar desert is characterised by sparse and highly variable precipitation, extreme variation of diurnal and annual temperature and high evaporation. It covers about 12 per cent of the country's geographical area and is a water deficit region (Fig. 1). The most acute problem of water within this zone is, however faced within the hot arid belt of Rajasthan which accounts for 62 per cent of the country's arid zone and is spread over eleven districts of the state. The chief source of replenishing the water resources in this region is rainfall which is also very low and the distribution is erratic, especially in the north-western sector. A large proportion of rainfall goes back to the atmosphere through evaporation and transpiration resulting in inadequate replenishment of water resources and improper utilization of land. Ground water here is generally associated with the joints, fissures and cavities in hard rocks and extensive alluvial and aeolian deposits.

The inhabitants of this region are dependent upon the development of water as resource. The surface collection and temporary storage of rain runoff permit

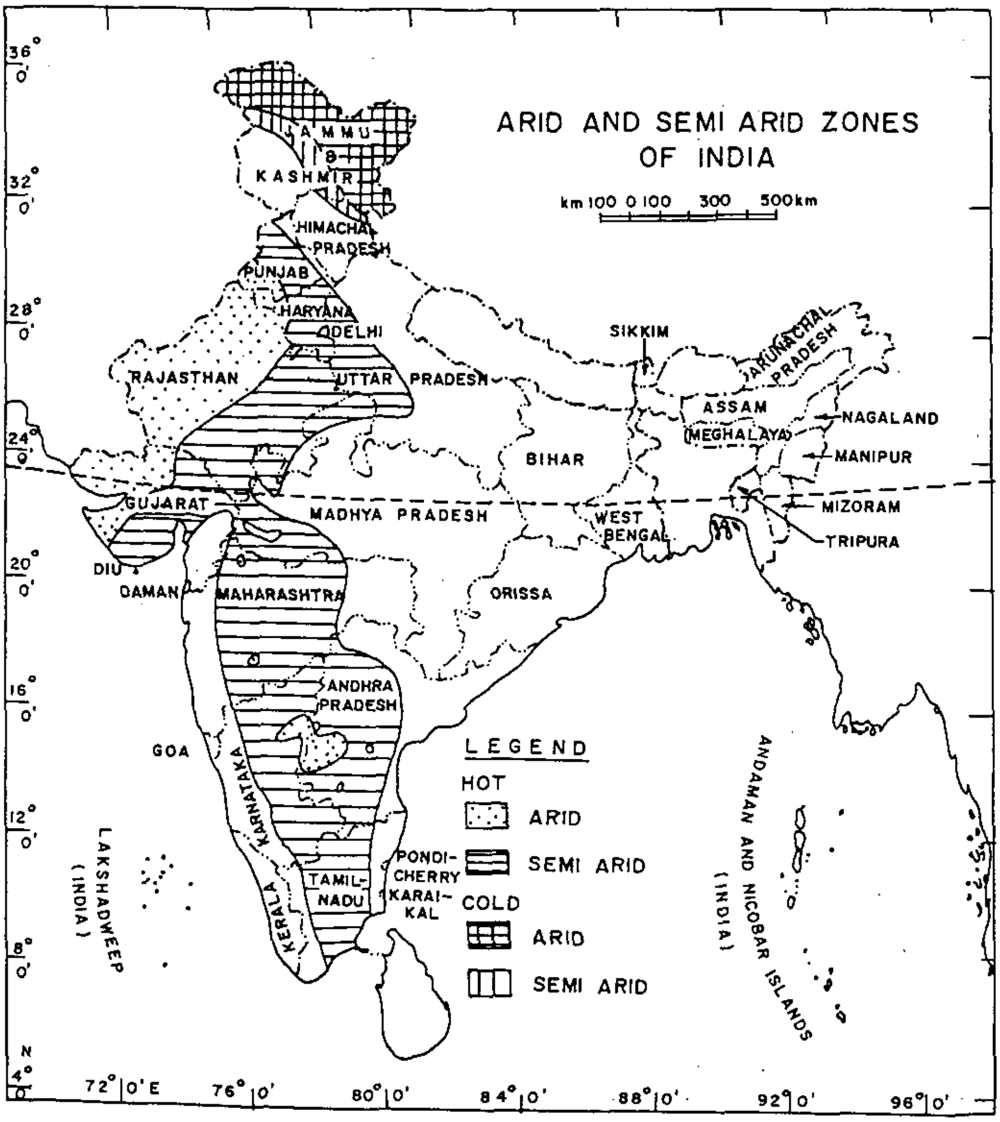

Fig. 1 Arid and semi arid zones of INDIA.

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seasonal settlement and trant-humant livestock herding. Facilities for year round storage, further more, make possible permanent settlement and intensification of cultivation through irrigation of winter crops.

2. Hydrological features

The arid zone of Rajasthan is classified as vast sandy undulating plains dotted with isolated hills and separated by north-east treading Aravalli ranges. The rainfall within this region is highly variable in space and time. The mean annual rainfall varies from less than 100 mm in the extreme western part of Jaisalmer to 600 mm in the south-east sector (Fig. 2). Much of it (78 to 96 per cent) is received during the south-west monsoon season (July to September).

The topographic features show wide variation in different tracts. The eastern part has generally sloping topography with high relief in Aravalli hill ranges. The hill slopes because of excessive erosion in most of the places have very shallow soil. The central and western parts covering an area of 1,48,600 km^2 have generally flat topography. The area is covered with sand interspersed by sand dunes, plateau and bosses of granite and rhyolite. The soil in general is high textured with high rate of infiltration and permeability and poor water storage capacity.

The Luni with its 10 tributaries is the only organised drainage system in this region. It rises in the Aravalli hills near Ajmer and is lost in the Rann of Kachchh. The streams are ephemeral and remain dry in non-monsoonal period. Even during monsoon period stream flow is of very short duration. In the central and western regions, there is no defined drainage system. Catchments with sandy soils and sand dunes do not produce any runoff. Runoff occures only in localised areas from catchments with isolated hills or shallow soils with impervious basement. The water yield from such area is collected in stock water tanks for human and livestock consumption.

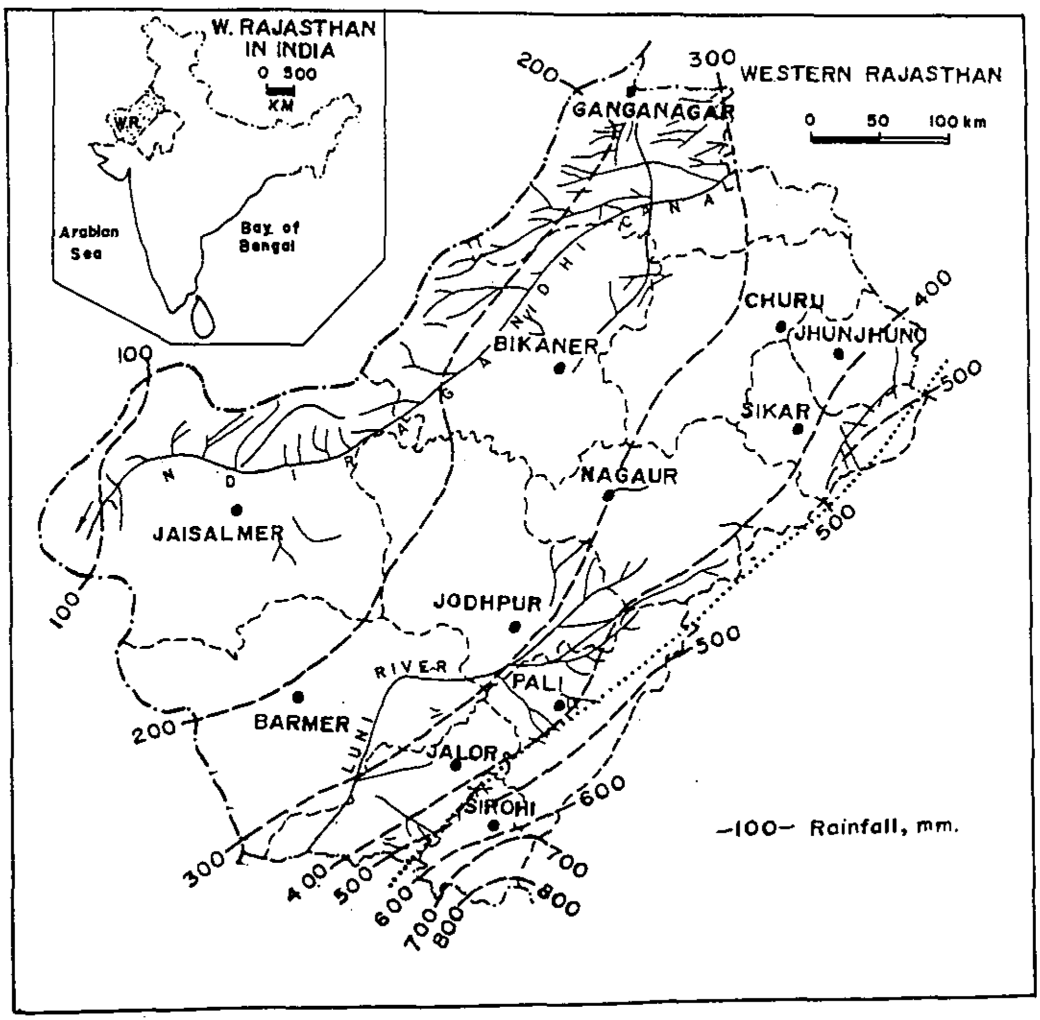

Fig. 2 Mean annual rainfall, mm (--), stream characteristics (-) and Eastern boundary (.....) of arid zone of Rajasthan.

In the north-west of arid zone of Rajasthan nearly 11 per cent area is occupied by the canal network. The terrain of this zone is of sandy nature and therefore seepage losses are very high. At many places alluvial and interdunal plains having gypsiferous sediment and clay barriers are found at varying depth which restrict vertical movement of water.

3. Hydrogeological set up

The major hydrogeological formations in this region belong to Delhi super group, Vindhyan super group, Mesozoic and Tertiary group and Quaternary era (Sharma & Dubey 1993). The crystalline igneous and metamorphic formations are characterised with very poor porosity and low yield of water. Vindhyan and Marwar super group sandstones and limestones occupying part of Jodhpur and Nagaur districts are promising aquifers with moderate to high yield. Among the semi-consolidated formations the Lathi sandstone (Mesozoic) occupying part of Barmer, Bikaner and Jaisalmer districts are moderate to high productive aquifer with fresh ground water. Though alluvium formations covering part of Churu, Ganganagar, Jalore, Barmer and Jaisalmer constitute most productive aquifer, the quality of ground water in it varies widely. The blown sand also forms moderately potential aquifer at places. The valley fills along the stream channels often contains productive aquifer with limited ground water potential.

4. Assessment of water resources

4.1. Surface water resources

The availability of surface water resources in the arid zone of Rajasthan is limited due to hostile climatic conditions and poor water yielding efficiency of the sandy terrain. According to Mehta and Kashyap (1970) surface water potential of this region is 1,132 x $10^6 m^3$. At present there are 550 surface water storage tanks in the capacity range of less than 1.5 x 10^6 to 208 x $10^6 m^3$ in the region (Anonymous, 1990). The total utilisable capacity of these tanks is nearly 1,169 x $10^6 m^3$ for providing irrigation in over 1,00,000 ha lands and to meet the domestic water demand (Table 1). The major surface tanks and reservoirs are Jawai, Sardar Samand, Hemawas, Kharda etc. (Table 2).

Jawai, the biggest storage reservoir (207 x $10^6 m^3$) in the region was constructed in 1956 (1845-1956) to meet the drinking water demand of Jodhpur and Pali cities beside developing irrigation facility in more than 22,700 ha command area. The water from the reservoir to Jodhpur city is regulated through a 150 km lined canal with discharge of 0.5664 cumec and impounded in Takhatsagar. An other important reservoir is Sardar Samand (88 x $10^6 m^3$), constructed in the year 1994 at the confluence of Sukri and Guhiya rivers, the tributaries of river Luni. The reservoir's water is used mainly for irrigation in 13,239 ha command area and domestic water supply on limited scale. Hydrological studies conducted from 1988 to 1993 revealed that the reservoir received

Table 1 Districtwise distribution of Reservoir / Tanks and storage capacity in western Rajasthan*

District	Capacity Range in Million Cubic Metres												Total	
	> 30		15 - 30		6 - 15		3 - 6		1.5 - 3		< 1.5		No.	Storage capacity (mcm)
	No.	T.C.	No.	T.C.	No.	T.C.	No.	T.C.	No.	T.C.	No.	T.C.		
Pali	4	389.89	2	44.9	9	68.8	10	40.4	16	33.69	50	30.75	91	608.35
Sirohi	1	39.08	1	22.7	3	27.1	8	30.7	14	28.02	15	8.70	42	156.20
Jalore	1	33.98	-	-	5	47.1	11	38.9	18	38.28	60	28.72	95	187.05
Barmer	-	-	1	20.7	-	-	1	4.65	1	2.27	59	15.12	62	42.77
Nagaur	-	-	-	-	1	8.52	-	-	6	11.91	52	23.64	59	44.07
Jodhpur	1	52.82	1	21.7	1	6.60	2	8.77	2	4.40	49	13.02	56	107.26
Jaisalmer	-	-	-	-	-	-	1	4.90	-	-	138	13.03	139	17.93
Bikaner	-	-	-	-	-	-	-	-	2	4.43	4	1.22	6	5.65
Total	7	515.77	5	110	19	158	33	128	59	123.10	427	134.20	550	1169.28

* Source : Irrigation Dapartment, Govt. of Rajasthan

* T.C. : Total CApacity in MCM

30 to 40 per cent less water from its catchment. This is mainly due to the degradation in the catchment through human intervention (Khan *et al.*, 1990).

Table 2 Major surface tanks and reservoirs

S. No.	Name of structure	Tehsil	Location District	Capacity ($10^6 m^3$)	Catchment areas (km^2)
1	Hemawas	Pali	Pali	62.55	1124.05
2	Sardarsamand	Sojat	Pali	88.00	1634.11
3	Kharda Bandh	Pali	Pali	18.81	181.29
4	Baniawas	Pali	Pali	8.51	634.54
5	Mithari	Bali	Pali	8.71	77.07
6	Luni	Raipur	Pali	12.55	375.03
7	Rajsagar (Chopra)	Sojat	Pali	8.16	113.96
8	Jawai Dam.	Bali	Pali	207.78	787.35
9	Bankli Bundh	Ahore	Jalore	33.98	1610.97
10	Chawarcha	Ahore	Jalore	7.93	93.57
11	Bandi sendra	Bhinmal	Jalore	12.57	429.93
12	Chithalwana	Sanchore	Jalore	12.24	667.45
13	Meli Bundh	Siwana	Barmer	4.65	233.09
14	Golia Bundh	Barmer	Barmer	0.83	446.26
15	Bajana Bundh	Barmer	Barmer	0.69	6.99
16	Bhakarpura Bundh	Barmer	Barmer	0.86	78.65
17	Chandra Bundh	Barmer	Barmer	0.71	25.38
18	Bhakri	Degana	Nagaur	8.52	320.12
19	Bherunda	Degana	Nagaur	2.07	62.16
20	Harsoere Bundh	Degana	Nagaur	2.52	77.70
21	Pundlao	Merta	Nagaur	1.82	219.24
22	Jhalora	Parbatsat	Nagaur	1.30	139.85
23	Gagrana	Merta	Nagaur	2.22	154.49
24	Jaswant Sagar	Bilara	Jodhpur	52.82	1336.70
25	Surpura	Jodhpur	Jodhpur	21.65	31.08
26	Bisalpur	Jodhpur	Jodhpur	6.60	924.62
27	Kailana	Jodhpur	Jodhpur	4.73	84.00
28	Takhat Sagar	Jodhpur	Jodhpur	6.00	-
29	Umed Sagar	Jodhpur	Jodhpur	7.79	27.00
30	Balsamand	Jodhpur	Jodhpur	1.38	13.50

The oldest lake of Jodhpur is Balsamand, constructed in the year 1126 AD and subsequently extended from time to time to increase water storage capacity. With the increasing demand of water over time more such structures namely Umedsagar (1800 AD), Kailana (1872 AD), Takhatsagar (1832 AD) and Umedsagar (1931 AD) were constructed. The total capacity of these lakes is 18.60 x $10^6 m^3$ and sufficient to support about 8,00,000 population for 8 months. However, in recent years due to mining and adoption of soil and water management techniques in the catchments these lakes do not receive proportionate water during normal rainfall years.

The maximum surface potential in the arid zone of Rajasthan is in the eastern tract which runs parallel to Aravalli hills comprising the drainage basin of Luni river. Dhir and Krishanmurthy (1952) reported that nearly 518 x $10^6 m^3$ surface water is available in Luni basin. Dhurvanarayan *et al.*, (1974) computed surface water potential of Luni basin as 517 x $10^6 m^3$ using monsoon rainfall of the region and Strange's constants. According to an other estimate the surface water potential of Luni basin is 858 x $10^6 m^3$, out of total 700 x $10^6 m^3$ is utilizable potential (Anonymous, 1980). Studies conducted in Sukri and Guhiya basins, tributaries of Luni river between 1988 and 1992 revealed that the basin outflows were highly variable. The peak flow, ranged from 23.50 to 227.5 cumec and 25.50 to 529.0 cumec and the annual flow volume ranged from 3.612 to 35.616 x $10^6 m^3$ and 2.654 x $10^6 m^3$ to 62.34 x $10^6 m^3$ in Sukri and Guhiya, respectively (Table 3; Khan, 1993). In the upper Luni basin 1184 *nadis* (village ponds) in different size group are functional with utilizable capacity of 69.666 x $10^6 m^3$. Sizewise distribution of *nadi* revealed that 41.81 per cent *nadis* are in the small group, 22.21 per cent in medium size group and 35.98 per cent are in big size group (Table 4). The stored *nadi* water is generally used for human and livestock consumption (Shankarnarayan and Kar, 1993).

Table 3 Water potential in Sukri and Guhiya Basins

Year	Sukri		Guhiya	
	Peak flow (Cumec)	Volume (x $10^6 m^3$)	Peak flow (Cumec)	Volume (x $10^6 m^3$)
1988	100.00	18.905	32.00	2.654
1989	23.50	3.612	262.00	29.164
1990	227.50	13.122	529.00	62.340
1991	37.70	2.193	36.50	3.428
1992	227.50	35.616	25.50	3.981
Mean	-	14.690	-	20.313

Surface water potential, except in canal command area is very low in the central and western parts. The runoff caused in response to some high magnitude rain storms get collected in short channel lengths and lost in transmission or disappear in sand dunes. However, the inhabitants in the region have evolved their own system of harnessing rainwater from hilly/rocky catchments for domestic and livestock consumptions and for biomass production. The system include *tanka* (cistern) *nadi* (dugout pond) and *khadin*. Accordingly to Jain (1968) the surface water available annually for utilization in these parts is nearly 580 x $10^6 m^3$.

Table 4 Status of nadi in different size group in upper Luni basin

Name of catvhment	Small ($< 0.01x10^6m^3$) No.	Small Volume (10^6m^3)	Medium ($0.01-0.03x10^6m^3$) No.	Medium Volume (10^6m^3)	Large ($> 0.03x10^6m^3$) No.	Large Volume (10^6m^3)	Total No.	Total Volume (10^6m^3)
Guhiya	29 (2.45)	0.146	61 (5.15)	1.209	101 (8.53)	22.023	191 (16.12)	23.378
Upper Luni	10 (0.84)	0.059	38 (3.21)	0.769	211 (17.82)	30.715	259 (21.87)	31.543
Jojri	295 (24.91)	1.325	70 (5.91)	1.288	39 (3.29)	2.576	404 (32.12)	5.189
Bandi	161 (13.60)	0.942	94 (7.94)	1.636	75 (6.34)	6.978	330 (27.88)	9.556
Grand Total	495 (41.81)	2.472	263 (22.21)	4.902	426 (35.98)	62.292	1184 (100.00)	69.666

Figure in parenthesis are per cent of total nadis.

4.2. Canal water

The Indira Gandhi canal is a major canal network in the region. It originates in Harika Barrage at the confluence of Beas and Sutlej rivers in Punjab to transport 9,856 x 10^6m^3 of water through Punjab and Haryana in Rajasthan. In Rajasthan the canal passes through Ganganagar, Bikaner and Jaisalmer districts (Fig. 3). The length of feeder canal is 204 km with capacity of 524 cumec at canal head. The length of main canal in stage I is 189 km, in stage II 256 km and distribution system at full development is 8,190 km with culturable command area (CCA) of 1.543 x 10^6 ha. The water requirement for irrigation, drinking and industrial use in the canal command area is 9,640 x 10^6m^3. The canal project has been planned to develop irrigation potential of 1.393 x 10^6 ha, of which 0.301 x 10^6 ha shall be through lift irrigation of upto 60 m (Table 5). At present 0.7 x 10^6 ha land is being irrigated, of which 0.62 x 10^6 ha is in stage I and remaining 0.08 x 10^6m^3 in stage II (Anonymous, 1994). The flow volume of the main canal varies from 1,727 x 10^6m^3 to 2,961 x 10^6m^3 in different season. The average annual water flow at the head of the main canal between 1982 and 1986 was 4,567 x 10^6m^3 (Anonymous, 1988).

Indira Gandhi canal project was planned to bring about a significant transformation in the desert ecosystem. However, intensive canal irrigation, poor canal maintenance and mismanagement have created adverse effect in the command area. The dominant problems are waterlogging and consequent salt infestation, and formation of new dunes in the cultivated fields. The problem of waterlogging is related to the gypsiferous hard pan and ill-drained clay beds within the alluvial plains, which are the inherent limiting factors in the region. Seepage of water from the canal bed and sides is the added dimension to the problem. It is estimated that 7.3 per cent of the project area of 7,000 km^2 in stage I has become waterlogged and 24 per cent area is in danger if the present trend continues (Bithu, 1984). In stage II with the intensive irrigation over 3,000 km^2 area is vulnerable to waterlogging (Fig. 4).

4.3. Ground water resources

Essentially contribution to ground water in the arid zone of Rajasthan is precipitation. The aquifer exists in patches with varying hydrological properties. According to Sharma & Dubey (1993) in this region utilizable ground water resources for irrigation is 2435.43 x 10^6m^3 and 2957 x 10^6m^3 is the mean gross recharge. The development of ground water is considerably low i.e. below 5 per cent in Bikaner, Jaisalmer and Churu districts whereas it is moderate i.e. between 25 to 50 per cent in Ganganagar, Barmer, Jodhpur and Pali districts. In case of Nagaur, Sikar, Jalore and Jhunujhunu districts the development of ground water has shown considerable growth i.e. between 8 per cent and about 124 per cent (Table 6).

The status of ground water reveals that 45,632 km^2 (22.72%) area is over exploited, 44,728 km^2 moderately developed and poorly developed area is

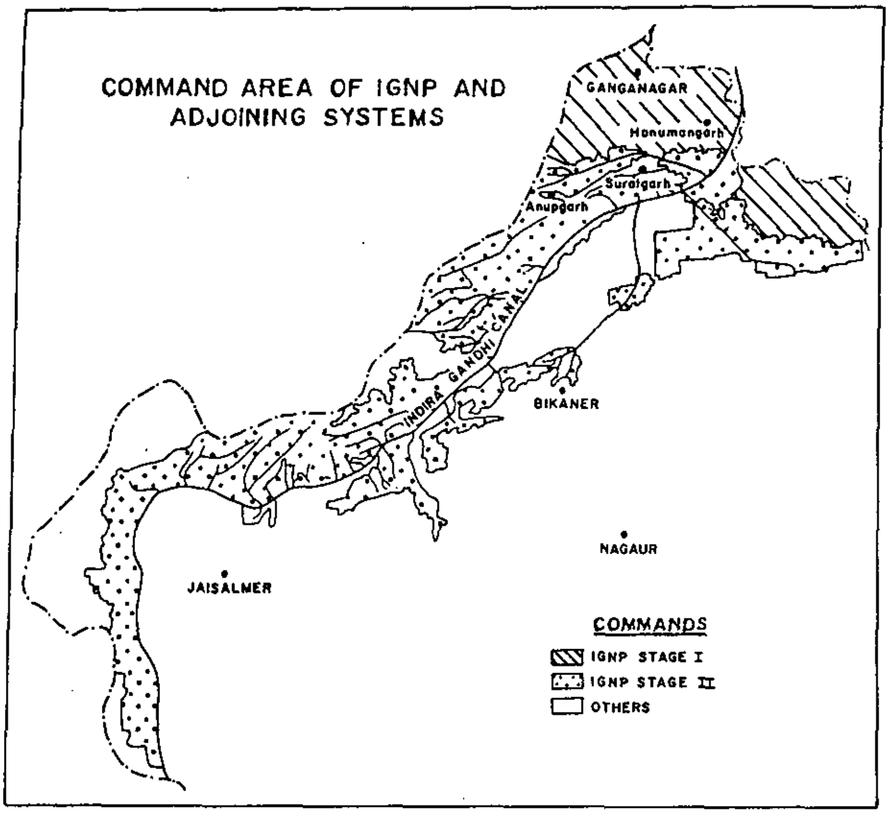

Fig. 3 Command area of IGNP and adjoining systems.

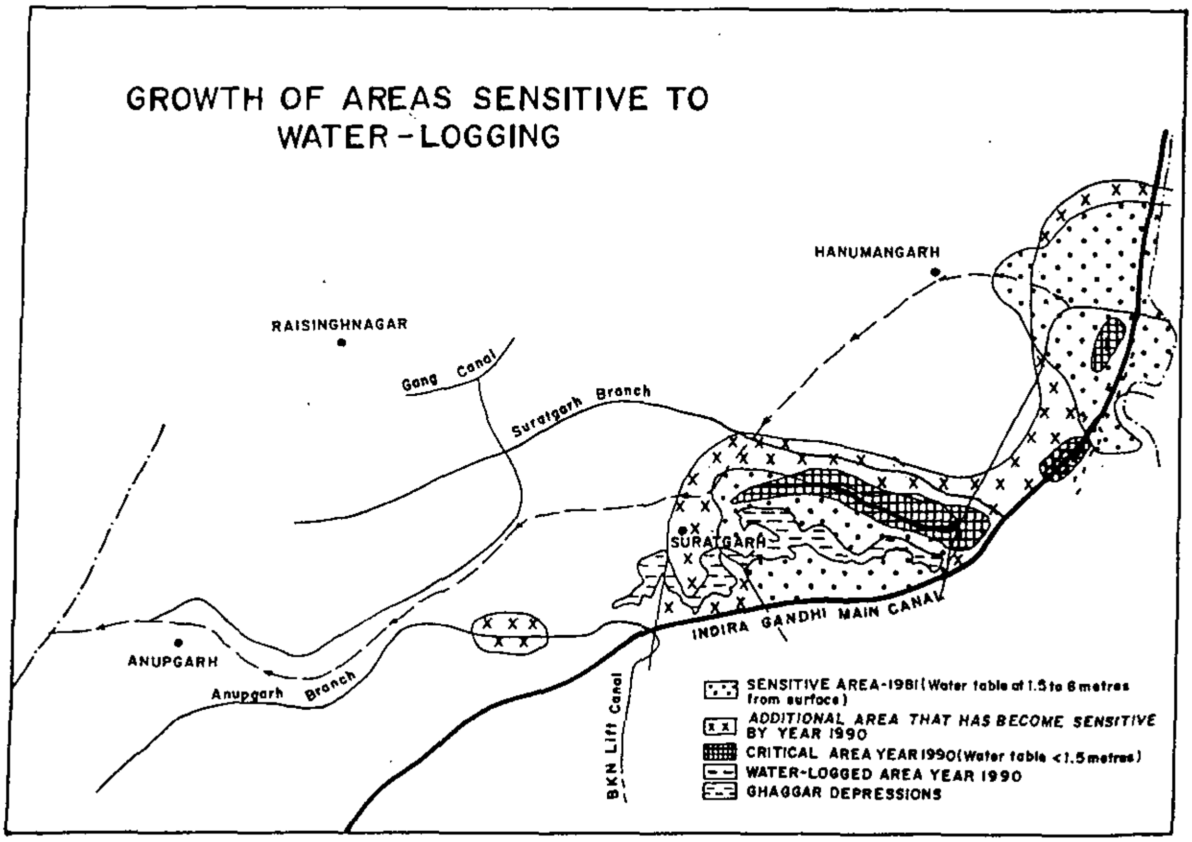

Fig. 4 Growth of areas sensitive to water-logging.

Table 5 Features of Indira Gandhi canal project

Particulars	Stage I	Stage II	Total
A. Main canal			
i) Length of feeder (km)	204	-	204
Canal capacity at head (cumec)	524		-
ii) Length of feeder (km)	189	256	445
Discharge at head (cumec)	515	283	-
Discharge at 189 km (end of Stage I) (cumec)	-	283	-
Discharge at 445 km (cumec)	-	136	-
iii) Length of distribution System at full development			
Flow areas (km)	2743	3155	5898
Lift areas (km)	3332	1960	2292
Total (km)	3075	5115	8190
B. Culturable Command Area (CCA)			
Flow irrigation (10^6 ha)	0.479	0.706	1.185
Lift irrigation (10^6 ha)	0.046	0.312	0.358
Total (10^6 ha)	0.525	1.018	1.543
C. Irrigation Potential at			
Full Development	0.527	0.565	1.092
Flow areas (10^6 ha)	0.051	0.250	0.301
Lift areas (10^6 ha)	0.578	0.815	1.393
Total (10^6 ha)			
D. Water Requirement			
Irrigation (10^6m^3)	4500	4080	8580
Drinking and industrial use (10^6m^3)	268	792	1060
Total (10^6m^3)	4768	4872	9640

Source: Approach paper on arrest of desertification, CAZRI, Jodhpur, March 1994.

1,10,468 km^2 (Fig. 5; Sharma and Paliwal, 1993). The trend of utilization of ground water is a reflection of irrigation practices in the different districts. In Jaisalmer, Bikaner and Barmer and Churu districts ground water is utilized mainly for domestic purposes.

Ground water in western Rajasthan is inherited by the diversity of quality problems. Ground waters are sodic in character due to high SAR or RSC values. The SAR ranges from 0.15 to 176.8 with an average value of 13.9. In the districts of Barmer, Bikaner and Jaisalmer more than 33.3 per cent water have SAR more than 18. High RSC generally occures in low to medium salinity water and ranges from nil to 68 m meL^{-1} with an average value of 3.1 meL^{-1}. The districts Jhunjhunu, Nagaur and Sikar have high RSC in ground water (Gupta, 1991).

5. Management of water resources

At present water resources in the arid zone of Rajasthan is inadequate to meet the growing demand in the region. The ground water is largely saline with total idsolved solid contents over 3000 ppm and deep seated. In some parts ground water is being over-mined for short term gain. The existing water bodies are inadequate and vulnerable to high water losses through evaporation and seepage, heavy sedimentation from the degraded catchments, and water contamination (Khan

Table 6 Districtwise ground water status in western Rajusthan (as on 1.1.1992)

District	Geographical area (sq.km)	Net area suitable for ground water recharge (sq.km)	Mean gross recharge (10^6m^3)	Utilizable ground water resource for irrigation (10^6m^3)	Total Draft (10^6m^3)	Net irrigation Draft (10^6m^3)	Ground water balances (10^6m^3)	Stage of ground water development (%)
Barmer	28387	12951.16	277.99	233.67	147.40	77.52	146.15	34.66
Bikaner	27244	11561.00	174.28	147.55	15.34	0.19	147.36	0.13
Churu	16830	6440.24	132.36	107.07	20.08	1.88	105.19	1.76
Ganganagar	20634	2836.10	702.13	596.80	272.34	186.68	410.11	31.28
Jaisalmer	38401	8718.64	39.36	33.01	2.52	0.11	32.91	0.33
Jalore	10640	8128.10	575.93	489.47	641.47	432.55	56.99	88.36
Jhunjhunu	5928	5273.69	104.94	78.05	162.10	96.56	-18.51	123.72
Jodhpur	22850	16606.52	232.29	191.44	165.30	67.84	123.61	35.40
Nagaur	17718	15106.37	191.92	124.39	213.10	102.36	22.62	82.30
Pali	12387	7362.54	404.35	342.78	253.85	169.68	173.11	49.50
Sikar	7732	7263.46	121.91	101.13	136.06	84.55	16.58	83.61
	208751	102247.92	2957.46	2435.43	1979.56	1219.92	1253.14	

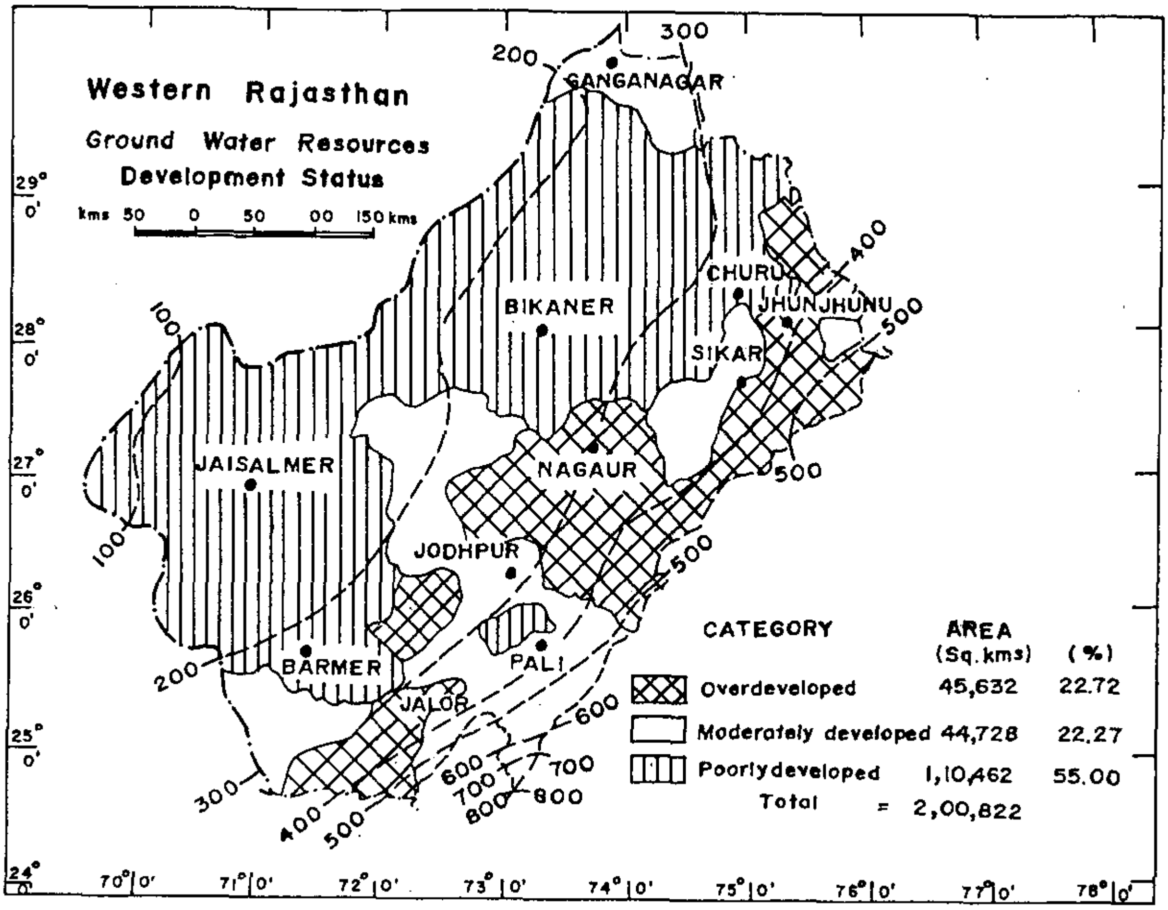

Fig. 5 Western Rajasthan ground water resources development status.

and Bohra, 1990). It is therefore of primary importance to manage this precious resource for maximising its availability in the region. This can be achieved by adopting suitable water harvesting and recharge techniques such as *tanka* (Fig. 6), *nadi* (Fig. 7), *khadin* (Fig. 8), anicut, percolation tank, sub-surface barrier etc. on large scale. The improved designs of *tanka* for capacities ranging from 10,000 to 6,30,000 litres developed by CAZRI, Jodhpur have great potentiality in this region and it takes care of losses both by evaporation and seepage (Fig. 9). *Tanka* may be constructed at any location. It is best suited near the settlements. *Nadi* may also be set up in most cases in this region. However, where the soils are highly permeable, *Nadi* may be provided with lining of polyethylene sheet (LDPE) (Fig. 10) or soil cement or any cheap material. The surface to volume ratio may possibly be kept below 0.3 to minimise evaporation losses (Khan, 1989). Field investigation in Guhiya and Sukri basins indicated that it is possible to establish medium size storage tanks on large scale in this tract (Khan *et al.*, 1990).

For increasing the crop production, *Khadin* system of water harvesting and runoff farming and other soil and water conservation practices including water spreading, bunding and furrowing have great scope in this region. In areas, where the upper portion of the catchments are hilly and rocky, the runoff causes soil erosion. By installing suitable structures such as anicuts and gully plugs across the gullies it is possible to reduce the erosion. Such practices also serve several objectives such as regeneration of grasses, greater forage production and recharging the ground water in near vicinity.

The main source of replenishment to ground water reservoirs is infiltration from precipitation. While this is inadequate or where ground water draft exceeds normal annual replenishment, artificial recharge of ground water is necessary. This may be achieved by water spreading and injection methods. Percolation tanks and sub-surface barriers are better methods for areas where the surface formations possess good

Fig. 6 Tanka(cistern) - A traditional rainwater harvesting system for drinking water.

ermeability. Studies conducted on artificial recharge through percolation in different river basins revealed that the rate of percolation ranges from 10 to 50 mm/day in physiographic settings (Khan, 1996). With the construction of sub-surface barrier at Chauri-Kallan in Jodhpur district the annual rate of depletion of ground water has been reduced from 1.0 m to 0.30 m and 1.0 m to 0.23 m, respectively (Table 7; Das Gupta and Batra, 1993).

Recharge by injection is the only method for artificial recharge of confined aquifers or deep seated aquifers with poorly permeable over burden. The recharge is instantaneous and water losses in negligible. Injection method is also very effective in case of highly fractured hard rocks and karstic limestone. However,

Fig. 7 Nadi (Village tank) - A traditional rainwater harvesting system for domestic water supply and livestock consumption.

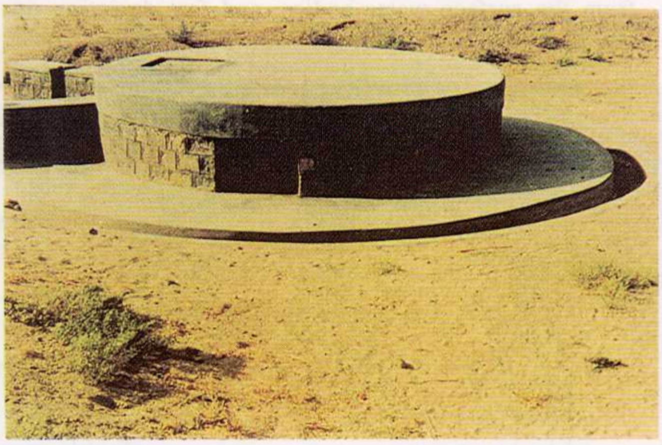

Fig. 9 An improved tanka of 21,000 litres developed by CAZRI.

Fig. 8 Khadin - A traditional rainwater harvesting system for crop production.

requirement of extreme purity of the source water to be injected is the necessary pre-requisites to prevent-clogging of injection structures.

Studies conducted in the northern Gujarat revealed that the recharge from injection wells was an average 72000 m^3/well/year in aquifers with average transmissivity of 200 m^2/day (Phadtare, 1987). In an other study the recharge rate using injection well technique was 590 litres per min at an efficiency of 56%, aquifer permeability of 70 m/day and aquifer transmissibility of 540 m^2/day (Sharma, 1987).

6. Conclusion

The availability of water in the arid zone of Rajasthan is inadequate to meet the growing demand of the society. High rate of evaporation and seepage losses from the surface water bodies, and fast depletion of

Table 7 Effect of sub-surface barrier (SSB) on ground water recharge

Item	Kalawas		Chauri-kalan	
	Before SSB	After SSB	Before SSB	After SSB
Av. rate of depletion in ground water (m/year)	1.00	0.30	1.00	0.23
Yield in wells (m^3/day)	80-120	100-145	60-90	80-120
No. of tubewells	-	5	-	-
Increase in command area (ha)	-	10	-	15
Rate of infiltration to ground water (%)	10	15	12	37
Benefited area (m)				
i) Upstream side	-	400	-	350
ii) Downstream side	-	700	-	500
iii) Right bank	-	180	-	160
Iv) Left bank	-	125	-	125

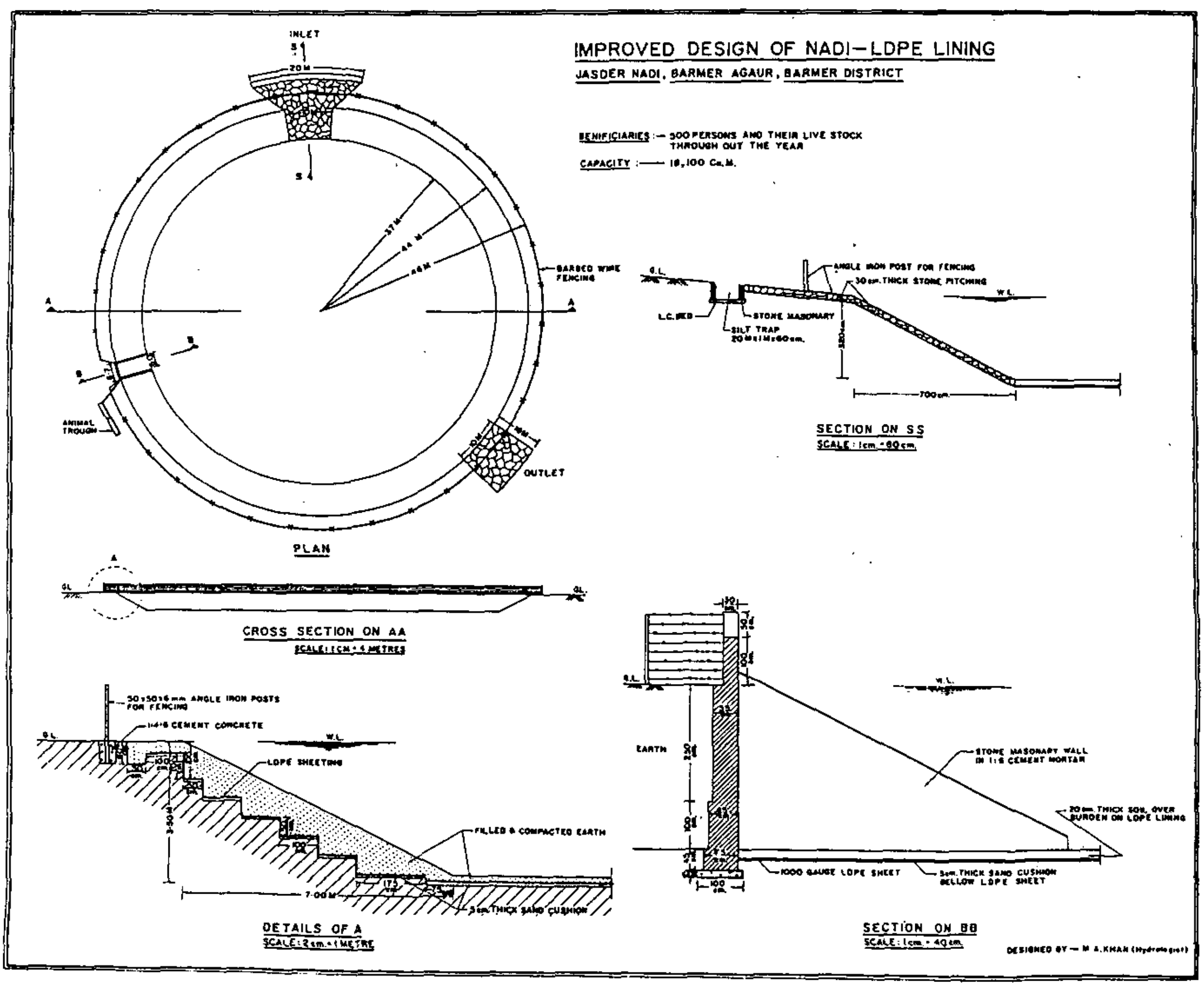

Fig. 10 Improved design of nadi with LDPE lining developed by CAZRI, Jodhpur.

ground water reservoir due to over mining in many areas, restrict the developmental activities in the region.

Management of rain runoff by adopting suitable water harvesting and recharge techniques using scientific inputs should be taken up on large scale to maximise water availability in the region. Inducement of ground water recharge will also help in improving the water quality particularly in saline aquifers.

References

Anonymous 1980. *Master Plan of Luni River Basin.* Irrigation Deptt. Jodhpur, 217 p.

Anonymous 1988. Water management strategy for Indira Gandhi Nahar Project. *ORG Report,* Baroda, 62 p.

Anonymous 1990. *Inventory of irrigation tanks, western Rajasthan.* Irrigation Department, Govt. of Rajasthan, 59 p.

Anonymous 1994. *Approach paper on arrest of desertification,* CAZRI, Jodhpur, p. 160.

Bithu, B.D. 1985. Environmental impact assessment of water resources project in arid region. In : *Proc. International Seminar on Environmental Impact Assessment of Water Resources Projects, Roorkee,* pp. 62-87.

Das Gupta, P.K. and Batra, P.K. 1993. Evaluation study of subsurface barrier for artificial recharge in ground water, Jodhpur district. In : *Proc. National Seminar on Ground Water Investigation,* pp. 273-297.

Dhir, R.D. and Krishnamurthy, K.V. 1952. The Hydrology of Rajasthan desert. In : *Proc. Symp. Rajputana desert, Nat. Inst. Sci. Ind*. p. 211.

Dhurvanaraya, V.V., Shir Niwas & Murthy, K.N.K. 1974. Efficient use of water resources in Indian Arid Zone. In : *Proc. Symp. Problem of Indian Arid Zone,* New Delhi, pp. 25-27.

Gupta, S.C. 1991. Quality classification of ground water of western Rajasthan. *Annals of Arid Zone,* 30 : 315-321.

Jain, J.K. 1968. *Resources and potentialities of Rajasthan.* Ph.D. Thesis, University of Jodhpur, 278 p.

Khan, M.A. 1989. Upgraded village pond-nadi to ensure improved water supplies in arid zone. *Water and Irrigation Review,* Israel, pp. 20-22.

Khan, M.A., Issac, V.C. and Bohra, D.N. 1990. Hydrological characteristics of Sardar Samand reservoir in arid Rajasthan. *Annals of Arid Zone,* 29 : 87-92.

Khan, M.A. and Bohra, D.N. 1990. Water-loss studies in the Sardar Samand Reservoir. *Jour. of Arid Environment,* London, pp. 245250.

Khan, M.A. 1993. Rainfall-runoff-sediment relationship in two desert rivers. *Unpublished Report.*

Khan, 1996. Inducement of ground water recharge for sustainable development. In: *Proc. 28th annual convention, Indian Water Works Association,* Jodhpur, 147-150.

Mehta, H.S. and Kashyap, S. 1970. Water potential of Rajasthan. In : *A search for Water.* Sarjana Prakashan Publication, Jaipur, pp. 29-36.

Shankarnarayan, K.A. and Kar, A. 1993. *Upper Luni Basin - An integrated analysis of natural and human resources for development planning.* CAZRI, Jodhpur, p. 577.

Sharma, S.C. 1987. Artificial recharge of ground water in Gujarat. In: *Proc. Ist National Water Convention* CBIP, New Delhi, 145-150 (II).

Sharma, D.C. and Dubey, J.C. 1993. Rajasthan : Ground water resources and assessment current approach and problem. In : *Proc. National Seminar on Groundwater Investigation and Application of Remote Sensing in Rajasthan* pp. 137-150.

Sharma, D.C. and Paliwal, S.C. 1993. Status of ground water resources and need for its judicious use. In : *Proc. National Seminaron Ground Water Investigation and Application of Remote Sensing in Rajasthan,* pp. 198-214.

Part V Research in Chinese Desert

Some Characteristics of Desertification and Its Recent Trends in Eastern China using Landsat Data

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1. Introduction

The term "desertification" in its technical sense has a broader meaning than simply describing the phenomenon occurring in peripheral areas of deserts. Therefore, "desertification" has been redefined in Agenda 21 as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities". The term "desertification" is used now to refer not only to surrounding deserts areas, but also to some major food producing zones in the semi-arid and subhumid regions (Kadomura, 1991).

Even in East Asia, where the arid zone occupies a small surface we can see that the new definition brings this problem closer to home. In particular, in Eastern China, which comprises 50% of the land surface and over 90% of the population, climatic conditions are changing from the semi-arid regions in the north to the subtropical, subhumid areas in the south. Zhu *et al.* (1992) estimated that desertification in China was induced by water and wind erosion, affecting 1.483 million km^2, or about 15% of China.

The purpose of this study is to clarify the characteristics of desertified areas, and by using Landsat data, to understand how desertification has progressed over the last 10-20 years in some reference areas where different types of desertification is occurring.

2. Some desertification characteristics in eastern china

Some characteristics of desertification in Eastern China are mentioned bellow:

Desertification by wind erosion occurs in arid and semi-arid regions where soil surface layer consists of sand size materials. Areas where desertification is already pronounced are mainly seen in the lower reaches of inland rivers at western latitudes than 105° E, and in oases surrounding areas. Such regions account for 2/3 of the decertified region in northern China. A typical landscape consists of reactivated moving sand dunes, caused by overgrazing, overcultivation, and cutting of natural vegetation. This has been occurring for the past 100 years. In addition, similar phenomenon are also observed in semi-arid and sub-humid regions where sand deposits form the soil surface layer, such as the northeast plains, the middle reaches of the Changjiang (Yangtze) River, and the coastal plain.

Water erosion mainly affects the middle reaches of the Huanghe (Yellow) River in the loess region, mountainous areas of southwestern, and hilly areas in northeast China. The major landscapes consists of 1) ridge and badlands areas formed by water erosion in semi-arid and subhumid loess plateau; 2) badlands in humid areas, where runoff has affected granite and laterite landscapes, 3) rocky, desert-like landscape in limestone areas of mountain regions; and 4) gravel desert-like landscape in humid areas where debris flows in mountainous regions have led to the blanketing of valley floors with sand and gravel.

In this study, we have selected the three reference areas described below (Fig. 1).

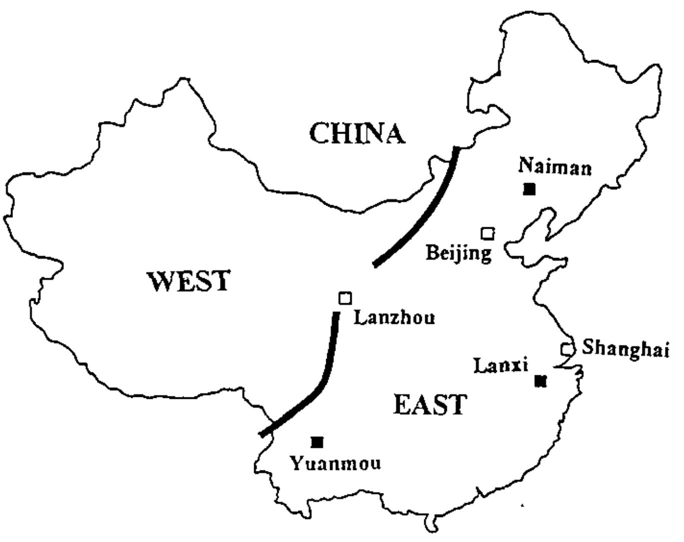

Fig. 1 The study area.

The first was Naiman area in the Inner Mongolia Autonomous Region selected as a region typifying

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desertification caused by wind erosion. Second was Lanxi in Zhejiang Province, as an example degradation caused by runoff erosion. Third was Yuanmou in Yunnan Province, as an example of severe gully erosion resulting in badlands.

(1) Naiman (Inner Mongolia Autonomous Region)

Naiman is located about 400km NE of Beijing. This semi-arid region has an annual average rainfall of 372 mm and annual average temperature of 6.4 °C. Quaternary lacustrine sediments are the main surface deposits in this region. Sand dunes, formed in an earlier dry period are widely distributed. They have been fixed and became covered by soil and vegetation in a more humid climate. On fixed sand dunes and in the lowlands between dunes, field crops are cultivated, especially corn and sorghum. In addition grasslands have been extensively developed in northeastern Naiman.

Desertification has been caused by the destruction of natural vegetation and about 1-2 m of topsoil. It begins with the movement of unconsolidated sand by a strong wind of 5 m/s (18 km/h) that often blows during the spring in this region. LANDSAT images have shown wavelike patterns on the ground surface facing the dominant wind direction, with widely distributed sand dunes extending from west to east. The movement of sand is inversely related to particle size, i.e., the smaller the sand particles, the greater the movement. Annual dune movement of 5 m/yr has been observed. Furthermore, in the grassland sections we can confirm points where sand spots have been expanding in elliptical patterns around ponds. At present, measures have been put into practice to stop sand movement and in some peripherical areas vegetation has already invaded. However, in some areas the dune sand is being collected as material for bricks, encouraging desertification.

(2) Lanxi (Zhejiang Province)

Lanxi, about 300km west of Shanghai, is located in the northeastern section of a long basin which runs east to west. The climate is subtropical monsoon, with annual precipitation of 1360 mm, half of which falls in April, May, and June. Autumn is a dry period, and the annual evapotranspiration rate of 1493 mm is somewhat higher than the annual precipitation. The physiography of this basin is roughly divided into alluvial plain and hilly areas, with desertification progressing in most of the latter. The soils of the hilly areas are red soils of the Quaternary. Originally, the soil cover consisted of a top layer of about 2-3m of red soils underlain a 7-8 m of "tiger stripe" clayey sediment containing 2 gravel layers.

Desertification in this region is caused by the clearing of forested slopes for cultivation. After the land has been denuded, rainfall causes sheet erosion of the surface layer, and the red soils are washed away. For this reason, the density of rills and gullies in desertified hills is relatively low, and convex slopes have been preserved. This type of landscape, which has been called "red desert," can be seen on a much larger scale in Nanchang, 200 km to the west. LANDSAT images show distinctive areas of bare, red ground surface. The area has been misused several times in the past, even, it is said, 200-300 years ago. However, it is believed that most of the serious desertification has occurred within the past 30 years.

Vegetation experiments on denuded land have shown that bamboo forests, tea plantations, etc., reduce erosion at nearly zero, and efforts are being made to preserve the land.

(3) Yuanmou (Yunnan Province)

Yuanmou, about 200 km NW of Kunming, is located in the bottom of a long, narrow basin which runs north to south. Its elevation is 1250-1 350m mean sea level. Due to the influence of the foehn which comes over the Transverse Mountains, annual precipitation is only 613 mm while annual evapotranspiration is 3847.8 mm, making this a very dry place. The mountains surrounding this basin are still undergoing upheaval. The valley floor itself is not necessarily flat, and there is a mixture of valleys and the hilly uplands that they dissect. Desertification is progressing in the uplands, where the dry, red, porous soil becomes soft and susceptible to landslides when suddenly saturated with water. The rate of vegetation cover is less than 20%. Flash floods coming immediately after the dry season cause considerable gully erosion, and a badlands landscape is forming. Even LANDSAT images indicate that a meshed pattern of gullies is encroaching on the uplands. The shrublands and forests in the mountains on the eastern fringe of the basin provide a stark contrast to the pastures in the western mountains.

In the remaining flat surface of uplands, irrigated sugar cane fields spread out, but in the surrounding areas gully erosion is progressing, apparently having reached a depth of 7-8 m over the past 30 years. Furthermore, in some places gullies are regressing at a rate of 6 m/yr, causing damage to sugar cane fields. Severe erosion has continued over the past several years. Thirty years ago, flooding occurred two or three times every ten years. Recently, about 2-3 floods apparently have been occurring every ten years.

3. Methods for understanding the desertification processes

Using LANDSAT data, we identified decertifying regions by the following methods:

(1) A vegetation index was used to identify unvegetated regions.

For LANDSAT TM data (TM 4 - TM 3) / (TM 4 + TM 3)

For LANDSAT MSS data (MSS 7 - MSS 5) / (MSS 7 + MSS5)

Low values of this index represented unvegetated areas. Comparisons were made with composite images to derive the threshold values, then unvegetated areas were identified. To consider seasonal variations in vegetation, common areas were identified in autumn and spring data.

(2) Water bodies and man-made structures such as settlements, which were included in the non-vegetated regions, had to be removed. For that purpose, the ratio:

(TM 5 - TM 1) / (TM 5 + TM 1)

was obtained. Since bare land in this band ratio was higher than water bodies and man-made structures, it was possible to separate the two. Therefore, the index derived from this ratio was named the structure index. Since there was no MSS sensor corresponding to TM band 5, old data were masked by water bodies and man-made structures derived from the new images.

(3) Using the redness index (TM3 - TM1) / (TM3 + TM1) which reflects the amount of iron oxides contained in the soil, desert areas were identified by the ground color in each region.

(4) Finally, desertified areas identified from data of different years were superimposed to obtain yearly changes.

4. Recent trends of desertification

30 square km sections, for each one of the three studied areas, were selected as reference districts, and were analyzed for desertification patterns over the last 10-20 years using the methods mentioned above. Desertified regions have low vegetation indexes. Areas showing the soil colors of the respective areas (white for Naiman, red for Lanxi and Yuanmou) were identified, the results from analysis of old and new images were superimposed to clarify the changes (Table 1 & Fig. 2).

Table 1 Recent trends of desertification in three model districts of the study area

Lanxi (ha)

73 \ 92	desert (red desert)	non-desert
desert (red desert)	2,109 (1.7 %)	1,518 (1.2 %)
non-desert	1,186 (0.9 %)	121,567 (96.2 %)

(Total Area : 126,380 ha)

Naiman (ha)

82 \ 91	desert (active dun	non-desert
desert (active dune)	32,808 (29.2 %)	13,526 (12.3 %)
non-desert	13,442 (12.0 %)	52,562 (46.8 %)

(Total Area : 112,338 ha)

Yuanmou (ha)

76 \ 92	desert (badlands)	non-desert
desert (badlands)	7,982 (8.4 %)	5,538 (5.8 %)
non-desert	6,339 (6.7 %)	75,003 (79.1 %)

(Total Area : 94,862 ha)

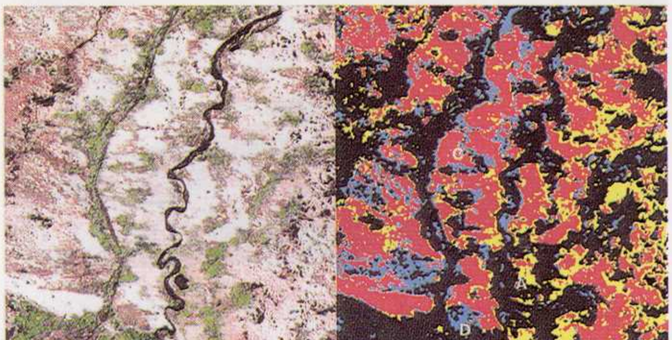

Fig. 2 Composite photo of Landsat TM (left) and recent trend of desertification (1982-1991) in Naiman, Inner Mongolian Autonomous Region.

The areal proportions of the three reference districts undergoing desertification were, respectively, roughly 40% in Naiman, 3% in Lanxi, and 15% in Yuanmou. However, the area of reclaimed land and the area of newly desertified land were roughly the same in all districts, indicating that the areal extent of desertification in all three districts is almost constant.

In Naiman, the areas around the settlements and along the N-S running road and railway in the eastern part of the town showed some recovery from 1982-91, in contrast to outlying areas, where desertification continued. This trend was also evident in the other two regions. For example, in Yuanmou from 1976-92, the trend of land reclamation around the town and desertification in outer areas was clearly manifested. The same kind of result was also obtained from Lanxi for 1973-92.

The above results show that desertification does not proceed unilaterally regardless of the state of degradation; rather, thanks to some sort of measures implemented when relatively easy to do so, the progress of desertification could be restrained.

5. Ground truth of the state of desertification

Field work was conducted in Naiman to verify the results of the analysis.

(1) "A" point (42° 49' 56"N, 120° 45' 15"E; Fig. 3)

Fig. 3 An example of deserified area in Naiman (A in Fig. 2).

This site, situated at about 10 km of fixed sand dunes in eastern Naiman, is an area which LANDSAT data analysis showed to be decertifying from 1982-1991. According to a desertification process map compiled by the Chinese Academy of Science, cropland that had been cultivated by dry farming method was classified as abandoned farmland in 1958 and as shrubland in 1974, and shrublands of willow were seen in the area. There was no trace of cultivation on the forest floor, just a scant covering of grass, and sand dunes had begun to encroach on some parts of the area. This condition corresponded well with the results of LANDSAT data analysis. Moreover, on the surface of what were believed to be the original encroaching dunes were patches of shami (Gramineae) and nothing else, indicating that the sand had been moving within the past several years. Strong winds which can easily move the sand particles was evidenced by the fact that all the willows at the shrubland were leaning in the same direction and that their root systems were exposed.

A possible reason for desertification was thought to be overgrazing, as evidenced by personal interviews and scattered livestock droppings found during a field survey.

(2) "B" point (42° 49' 8"N, 120° 47' 33"E; Fig. 4)

Fig. 4 An example of deserified area in Naiman (B in Fig. 2).

This site, located about 8 km SSE of "A" point, was also judged to have been decertifying from 1982-91. According to the desertification process map, this area was classified as grassland in both 1958 and 1974, but a comparison of the two years shows a vast reduction in areal extent and a transformation into semi-fixed sand dunes. A field study revealed scant traces of cultivation in depressions, but the ground was nearly covered by sand, and the sand dunes had begun to move again.

According to personal interviews, this had been a grassland containing some willow. However, the willows were cut to make room for grass, and allowing increasing the animals population to a density of one head per 20 hectares. Overgrazing resulted in the onset of desertification. Afterwards, an attempt was made to grow wheat in the depressions, but there was little hope for worthwhile yields, as only about 25 kg/ha was obtained in the best area, considerably less than the 350 kg/ha harvested in surrounding areas which have not been subject to desertification.

(3) "D" Point (420 51' 2"N, 1200 42' 11"E; Fig. 5)

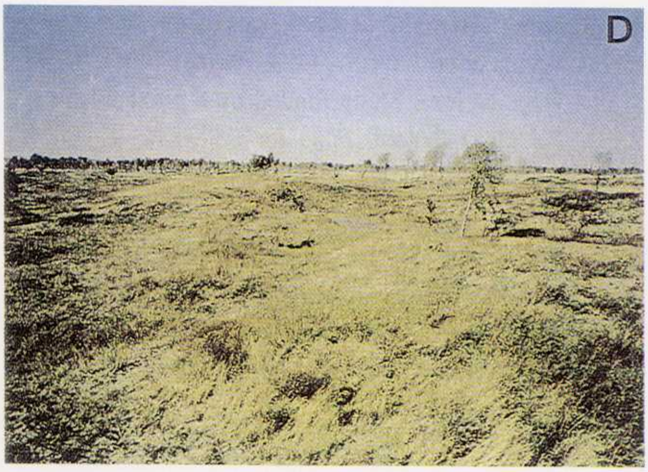

Fig. 5 An example of recoverd area in Naiman (D in Fig. 2).

This site differs from the two previous ones in that it was reclaimed land from the desert in 1982-91. This is an area of sand dunes about 5km east of Naiman. The desertification process map showed the surrounding area to be one of moving and semi-moving sand in 1958; by 1974, the central area had become a moving sand area, with the surrounding area consisting of fixed sand dunes.

In the 1991 LANDSAT images, this area clearly differs from the white color of the moving sand dunes, leading us to assume that vegetation in the area has recovered. Moreover, the topography of the area consists of small patches of undulating moving dunes (maximum size 7-8 m), but most of the ground surface has vegetation cover such as grasses of the Artemisia family and young willows and other scrub. The sand dunes have also been observed to be fixing. This is the result of a prohibition on grazing enacted about 5 years ago. In addition to naturally recovering grasses, poplar groves have also been planted in part of the area. Moreover, cultivation has also began in limited areas, with crops including not only wheat but Chinese cabbages, carrots, watermelons, and corn, providing a yearly net income of about 4000 yuan for some of the more prosperous farmers. Groundwater is used for irrigation and is brought up from a depth of about 20m.

The resulting field work for these three sites roughly corresponds to the results of the image analysis.

6. Evaluation of the desertification processes

Regions of gully erosion

As it has become possible to gain a spatial understanding of the decertifying regions, we must now evaluate the processes of desertification. For this purpose, we have attempted to evaluate Yuanmou Province, an area typified by badlands caused by gully erosion.

Gullies are trenches with steep sloping walls, that produces shadows which can be detected in the LANDSAT images.

At the LANDSAT observation time (about 9:30 a.m.) in this region the shadows of the linear structures are very pronounced in the south and east directions. Therefore, directional filtering processing was used to identify these shadows .

After giving to this data set binary values, further filter processing was conducted and only shadows with a minimum of 3 continuous pixels (90m) in all directions were kept (Fig. 6). Then these binary images were processed using the "Ultimage" software on a Macintosh computer.

However, the lineaments so derived may not always indicate gullies, since the shadows of roadside trees and structures may also be included. Therefore, using the results of land use classification, we masked forests, cultivated lands and bush, and left only the sections of bare land and grassland. This became our gully density map.

Finally, we took the 3 X 3 pixels of the evaluated sites, and, based on the pixel of the lineaments, evaluated the degree of land degradation as follows (Fig. 6):

None	Light	Moderate	Heavy	Severe
0	1-2	3	4	5-9

As a result, we found that in the west there is a large area of mountainous slopes used as grasslands which are not prone to gully erosion due to the smooth relief. On the other hand, in the hilly sections on the bottom of the basin are only scattered, narrow areas of flat surfaces, indicating that a meshed pattern of gullies is developing. This is in accordance with data obtained from field studies and existing topographic maps.

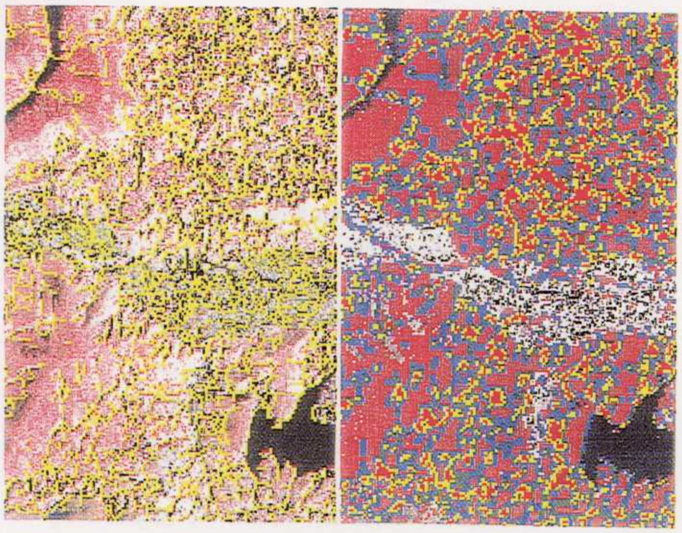

Fig. 6 An examples of gully (yellow line) extracted by texture analysis (left) and degree of desertification estimated by gully density in Yuanmou, Yunnan Province (red:Severe, yellow:Heavy, green:Moderate, biue:Light, brown:None).

7. Conclusion

The results we have obtained allows the following conclusions:

(1) Desertification in eastern China is characterized by reactivation of fixed sand dunes at Naiman, surface erosion of the topsoil at Lanxi, and severe gully erosion resulting in badlands at Yuanmou.

(2) No significant changes in areal extent of desertification were observed in any of the analyzed regions of Naiman, Lanxi, and Yuanmou. Land management around major settlements, roads, railway lines, etc., in all these regions was relatively good, and desert land has been reclaimed. However, in outlying regions where inadequate management practices are used, new desert land is appearing.

(3) Vegetation, structure, and soil redness indexes, combined with temporal analyses, were very effective for understanding the spacial extent of desertification, .

(4) The processes of desertification in Yuanmou Province, where gully erosion is prominent, were anlysed.

Acknowledgements

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References

Kadomura, Hiroshi 1991. Research Problems Associated with Observation of Land Degradation. Study funded by a grant from the FY 1990 General Fund for Scientific Research (A) 63302068 *Research Report "Comparative Studies of Land Degradation Observation"*; Tokyo Metropolitan University, pp.5-32.

Zhu, Zhenda *et al.* 1992. China: Desertification Mapping and Desert Reclamation. Form "*World Atlas of Desertification,*" UNEP. pp.46- 49.

Desertification in North China

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Abstract

In North China there are abundant natural resources and a great potential for sustainable development. However, most of regions in the area have been seriously suffered from desertification / land degradation, which has became a very important restricting factor for economic and social development. On the basis of research and practice over many years, we belive that the desertification is land degradation resulting mainly from adverse human impact. The degraded land is desertified land. It's indicators are mainly presented by wind erosion, water erosion and salinization, and its processes lead to a rapid decline in the biomass production and the potential productivity of land, and even loss of land resource, which created the problem not only in natural environment but also in economic and social environment According to recent study the situation of desertification become more and more servers in North China. But some good examples have proved that the adopted measures for land conservation are feasible and the process of desertification has effectively been controlled in typical areas. The potential productivity of cultivated land and rangeland have gradually been restored.

1. Status and process of desertification

Desertification is a serious economic and environmental problem which is now facing many countries. China is one of the countries suffering from severe decertification, which mainly caused by the excessive human economic activities and the process of wind erosion, water erosion and salinization. For example, the desertified land through wind erosion, what we called as sandy desertification has increased from 137,000 sq.km in 1950's to 176,000 sq.km in middle of 1970's (Table 1), and continued to spread to 197,000 sq.km in late of 1980's in Northern China (Table 2). Those sandy desertified land are mainly distribute at, (1) interlocking areas between cultivated and grazing lands in semi-arid zone, about 40.5% of sandy desertified land ; (2) undulating desert steppes in semi-arid zone, about 36.5% and (3) marginal oases and lower reaches of interior rivers in arid zone, about 23% (Fig. 1) (Zhu Zhenda and Wang Tao, 1990). Most of sandy desertified land come from the Gansu Province and Inner Mongolia. Ningxia, and Xinjiang Autonomous Regions. As apresent results of research in Goughe Basin of Qinghai and middle part area of Tibet, the sandy desertified land have reached to 12,670 sq.km and 1,860 sq.km respectively in late of 1980's. So the total area of sandy desertified land is about 211,530 sq.km in North China. Table 3 shows the different human causes of sandy desertification in China (Zhu zhenda, et al, 1989).

The processes of sandy desertification are mainly activities of wind erosion after vegetation has been destroyed. When wind eroded on the farmland and rangeland, the top soil will be transported anywhere, then the cases would begin to appear : a. the shifting sands accumulate at the leeward side and gradually develop to the occurrence of dense mobile dunes; b. the original features of the surface will be changed to roughness and eroded terraces and deflated fields. These processes destroy the structure of soil which allows for the rapid decline the biomass production and the potential productivity of land, and even the loss land resources.

The desertification which exacerloated by the processes of water erosion could be found in Sichuan and Yunnan Province. The salinazation mainly appeared in continental river basin in Xinjian because of misuse of water resources. So the dynamic process of desertification in North China can be expressed as shown in Fig. 2 (A) and (B).

2. Strategies and measures for controlling desertification

Chinese government has paid much attention for combating desertification for last four decades, which resulting about 12% of desertified land has been checked from expanding and 10% has been rehabilitated.

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Table 1 *Distribution of Desertifified Land in North China (sq.km. 1970's)*

Regions	Total areas	Different types of desetification land Moderate type	Severe type	Most severe type
Hulun Buir	3799	3481	275	43
Lower part of Nenjiang	3564	3286	278	
West Jilin	3374	3225	149	
East fringe of Da Hinggan Ling Mt.	2335	2275	60	
Horqin Steppe (Jirem Prefecture)	21567	16587	3805	1175
Northwest of Liaoning Prov.	1200	1088	112	
Xar Mulun River (Former Zhao Uda Prefecture)	7475	3975	1875	1625
North parts of Weichang, Fengning, Hebei Province	1164	782	382	
North of Zhangjiakou, Hebei Province	5965	5917	48	
Xilin Gol and Qahar Steppes	16862	8587	7200	1075
Ulan Qab Pref. Inner Mongolia (Beyond Daqing Mt.)	3867	3837	30	
Ulan Qab Pref. Inner Mongolia (Da Qing Mt. area)	784	256	320	208
Noethwest of Shaanxi Prov.	52	52		
North of Shanxi Prov.	21686	8912	4590	8184
Ordos Plateau (Ih Ju, Ulan Qab Prefectures)	22320	8088	5384	8848
North of Ulan Buh Desert and the Great Bay of Yellow River	2432	512	912	1008
North of Langshan Mountain	2174	414	1424	336
Central and southeast of Ningxia	7687	3262	3289	1136
West piedmont plain of Helan Mt.	1888	632	1256	
South border of Tengger Desert	640		640	
Lower reach of Ruoshui River	3480	344	2848	288
Central of Alxa Pref.	2600	392	2208	
Oases border in Hexi Corridor	4656	560	2272	1824
Piedmont Plain in Qaidam Basin	4400	1136	1824	1440
Gurban Tunggut Desert border	6248	952	5296	
Taklimakan Desert border	24223	2408	14200	7615
Total	176442	80960	60677	34805

Table 2 The development of sandy desertification in typical areas in the nokkrth China (unit:sq.km)

Regions	Areas of monitored regions km² %	Desertified land middle of 1970's km²	%	Desertified land middle of 1980's km²	%	Annual Increased Area km²	growth rate %	Period
Horqln Sandy Land In Jlrem League	112,000	21,567	19.25	23,800	21.25	186	0.82	1975-1987
Chlfeug (In Horqln Sandy Land)	34,680	7,405	21.35	9,051	26.10	137	1.69	1975-1987
Bashang reglon In Hobel Province	51,300	2,613	5.09	4,515	8.79	159	4.66	1975-1987
Houshan reglon In Inner Mongolla	48,530	13,770	28.40	23,000	47.40	769	4.37	1975-1987
Mu Us Sandy Land In lh Ju League In Inner Mongolla	49,100	43,407	88.30	45,973	93.60	257	0.59	1975-1987
Qahar steppe In XIlln Gol League Inner Mongolla	12,770	3,669	28.70	5,541	43.40	156	3.50	1975-1987
Yanchi Countly, Nlgxia	6,760	1,369	20.20	1,846	27.30	48	3.00	1975-1987
Yulln reglon, Shanxi	21,530	15,308	71.10	13,219	61.40	-232	-1.6	1975-1987
Xlnlln Gol steppe, Inner Mongolla	111,780	13,194	11.80	16,409	14.67	268	1.0	1975-1987
Lower reach reglon of Roushui River, Westem part of Alxa, Inner Mongolla	32,200	3,480	10.81	5,955	18.49	225	5.0	1975-1986
Pledmont Plaln of Kunlun Mt. In Qaldam Basln, Qlnghal	7,920	4,400	55.60	5,573	70.40	117	2.4	1976-1986
Shugul Lake Reglon In Central Alxa	16,200	1,172	7.23	1,308	8.07	13	1.1	1974-1984
Total	504,770	131,354	26.02	156,190	30.94	2,103		

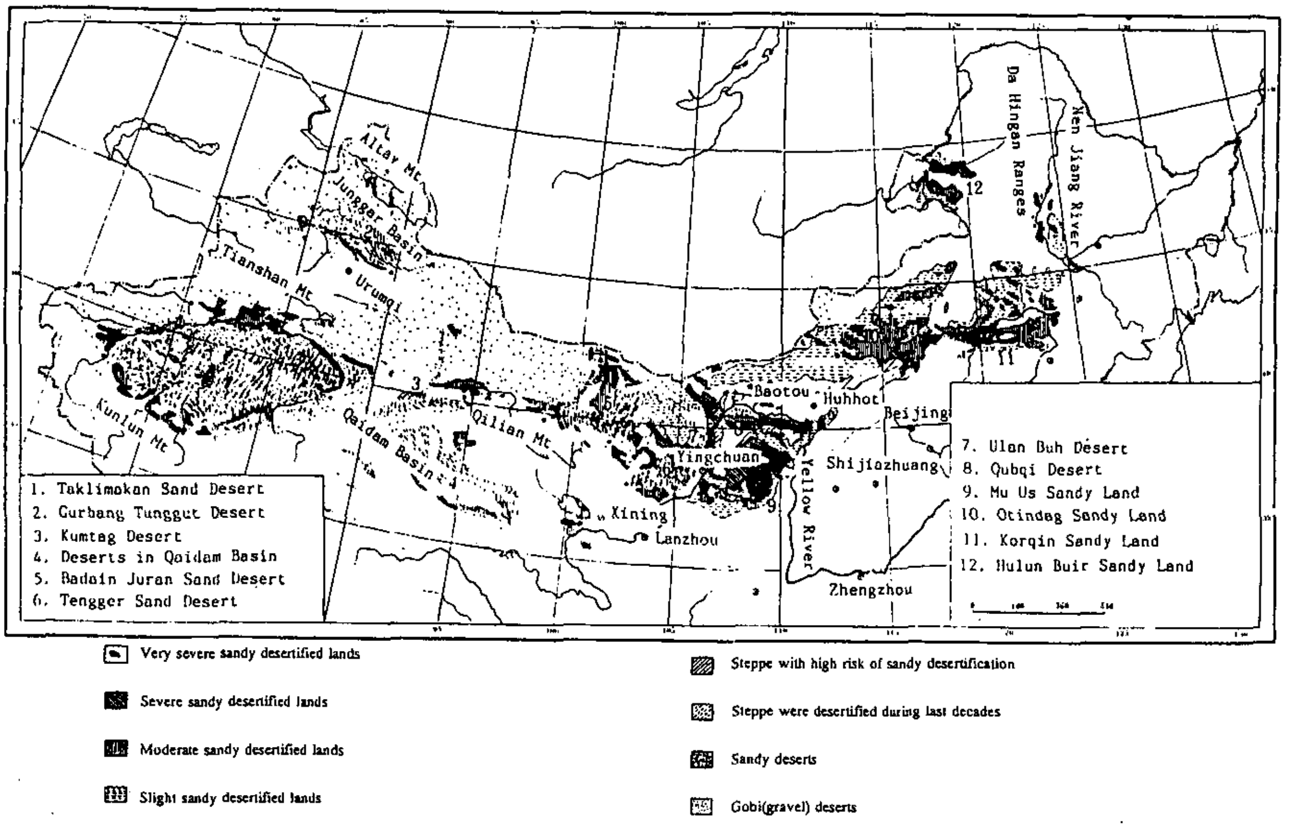

Fig. 1 Distributions of deserts and sandy desertified lands in North China.

Table 3 Different human causes of sandy desertification in China

Causes of desertification	Percentage in the total area of sandy desertification (%)
Over cultivation on the steppes	25.4
Over grazing on the steppes	28.3
Over collection of fuelwood	31.8
Misuse of water resources	8.3
Total	93.8

desertification in a very arduous and even complicated one. Enormous work should be handled and accomplished. According to the characteristics of natural resources and social-economics in the desertified land area and on the basis of existing problems during the utilization and the experience on the combating desertification in typical areas, the principles of the uniting ecological and economic benefits should be observed during controlling, the exploitation and utilization of resources should be combined with the control and protection of environment. The major strategies contain as follows:

1. To adhere to develop properly the animals husbandry and forestry, limit to reclamation;
2. To control effectively the growth of population and to reduce the pressure of human on desertified land:
3. To reform rural energy structure in desertified land, especially the structure of fuelwood for cooking and heating.

Observing these strategies, we can develop the concrete measures to restore the farmland and rangeland from desertified land.

1. As point out above mentioned that the occurrence and spread of sandy desertification were impacted by the fragility of ecosystems and the excessive human economic activities, so under semi-arid

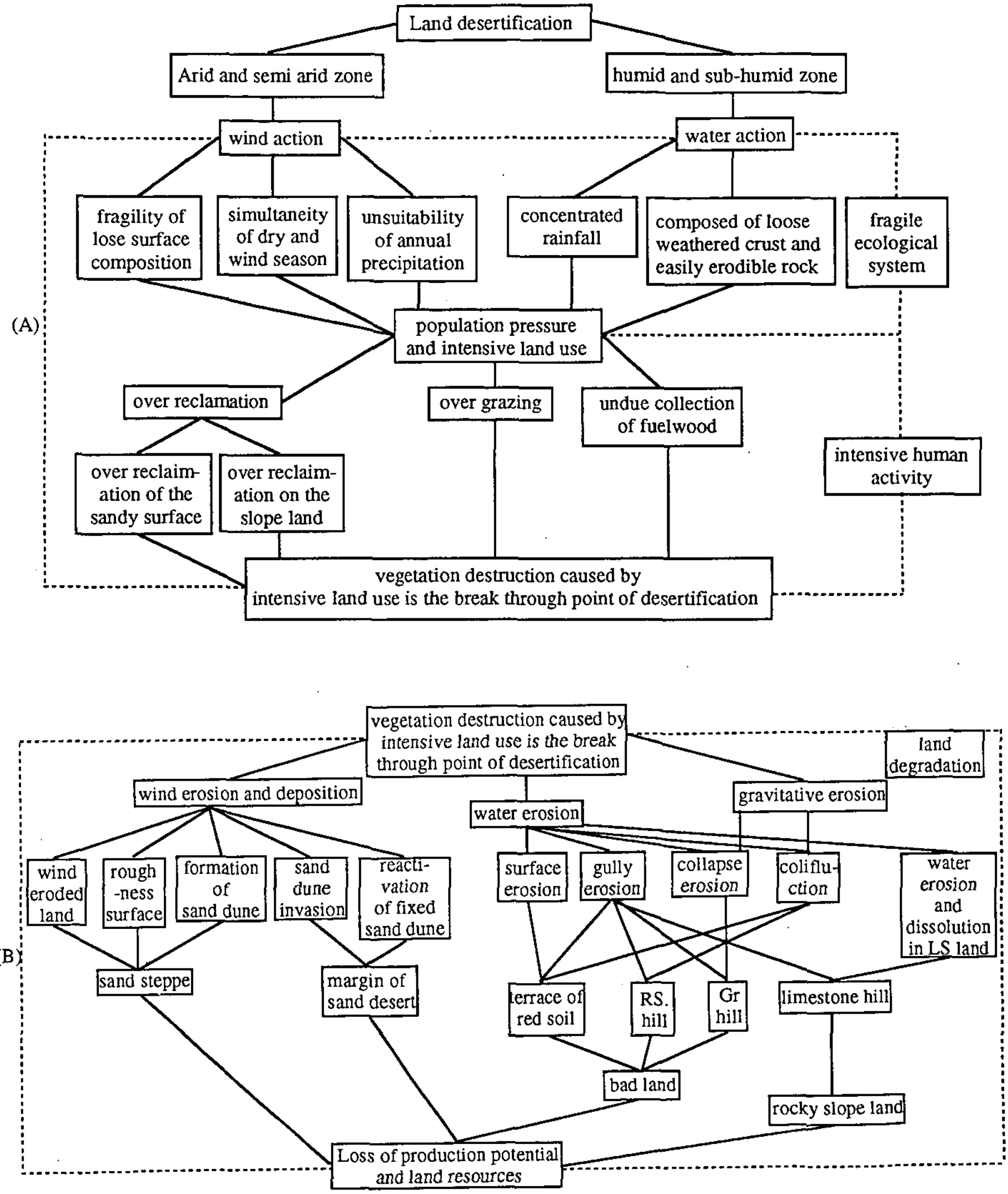

Fig. 2 The Processes of Desertification in China.

eco-environment, as soon as the human interruptions of excessive economic actives stop, the process of desertification will be gradually ended and the semi-arid eco-environment will be restored by its potential ability of natural reversing. Fencing to conservation is an effective way to limit the spread of desertified land which now adopt widely under the natural condition in semi-arid area. After fenced some years, the vegetative coverage and biomass both were increased.

2. To regulate the existing landuse patterns at the marginal area of farmland and rangeland, i.e. to change the existing extensive cultivation and turn the dry-farming land aimed to produce food grains into grazing and woodland and to obtain double benefit of ecological and economic. The key point of the regulation of landuse develop the intensive manage of flat fields with better soil and water condition in basin or along river valley. Some practices in sandy desertified land can exemplify the success of regulation of regulation of landuse pattern. For instance, the Huanghuatala village in Naiman country, Inner Mongolia, was an undulant sandy rangeland and annual precipitation is 360 mm. Owing to the overcultivation and undue collection of fuelwood, the area of desertification spread rapidly and 81% of the total area was desertified. Mean annual grain yield was only 420 kg/ha. Since the middle of 1970's, the proportion of landuse of dry farmland was regulated, the area of plantation and grazing land were enlarged. Shelterbelts, protective network and woodland which are composed of tree, bush and grass have been established. The cropping field under the threat of sandy desertification was gradually reduced. The plantation was combined closely with natural conservation. At present, the proportion of landuse is regulated as that the cropping land occupied 21%, plantation area occupies 27% and pasture 52% respectively. The sandy desertified land has been initially controlled. The total yield of food grain, increased 436% comparing with that before the process of desertification was reversed. Table 4 and Table 5 show two successful examples.

Another example is the Belgian village, Fengning Country, Hebei Province, the area of village is 16,870 ha., there were 6,800 ha. farmland, 770 ha. land and 8,930 ha. in 1984. In 19-87, after regulated the landuse pattern, there were 4,000 ha. farmland, 1900 ha. forest land and 10,600 ha. grassland. Because of the intensive manage the farmland with better quality soil and water condition, although the farmland decreased about 41.2%, the total yield increased 30% because of the increased of per ha. yield. The former 1,300 ha. farmland was planted trees and brush or grass, the sandy desertificational process was controlled, the ecological environment was improved and the livestock farming developed, too.

Table 4 Achievement of combating desertification in Yoledianzi, Naiman Banner, Hoeqin Sandy Land, Inner Mongolia

	1984	1994
Shifiting sand areas	1,000 ha.	170 ha.
Farmland	200 ha.	100 ha.
Grain yield	140,000 kg.	470,000 kg.
	(700kg.ha.)	(4,700 kg./ha.)
Personal income	174 yuan/y	1,290 yuan/y

3. To increase the rates of plantation and pasture. Except the increase of the proportion of the land for plantation and pastures, on the aspect of the development of livestock farming, steppe grazing and indoor or semi-indoor feeding system (for the purpose of intensive collection of manure) should be popularized. Proportional artificial grassland and forage farms should be built as supplementary source of natural grassland. The undulant sandy lands or gentle semi-fixed dunes can be vegetated through conservation or artificial plantation of forage grass (including the small pieces of fields and pasture), to obtain the aim to increase the linkage between livestock farming and cropping fields, straws and green manures can be used so a

Table 5 Some good change since combated desertification in the Yanchi Countly, Ningxia

	Before combat in 1980	After combat in 1989
Shifting	53,400 ha.	19,600 ha.
woodland	13,520 ha.	77,060 ha.
Grass yield	1,040 kg/ha.	4,380 kg/ha.
Grain yield	100%	320%
Average of personal income	200 yuan/year	1,170 yuan/year

supplementary. In the rangeland area, except the proportional determination of domestic animals carrying capacity, rotation grazing, artificial pasture and forage farms in the desertified land the reasonable replacement of drinking wells and rearrangement of grazing spots and the construction of paves road on rangeland are important steps to comrol the spread of sandy desertification.

To summarize, the measures for combating desertification can be showed in Fig. 3.

References

Zhu Zhebda and Wang Tao 1990. An analysis on the trend of Land Desertification in Northern China during the last decade based on examples from some typical areas (in Chinese). *Acta Geogr. Sin.* 45, Science Press, Beiling. 430-440.

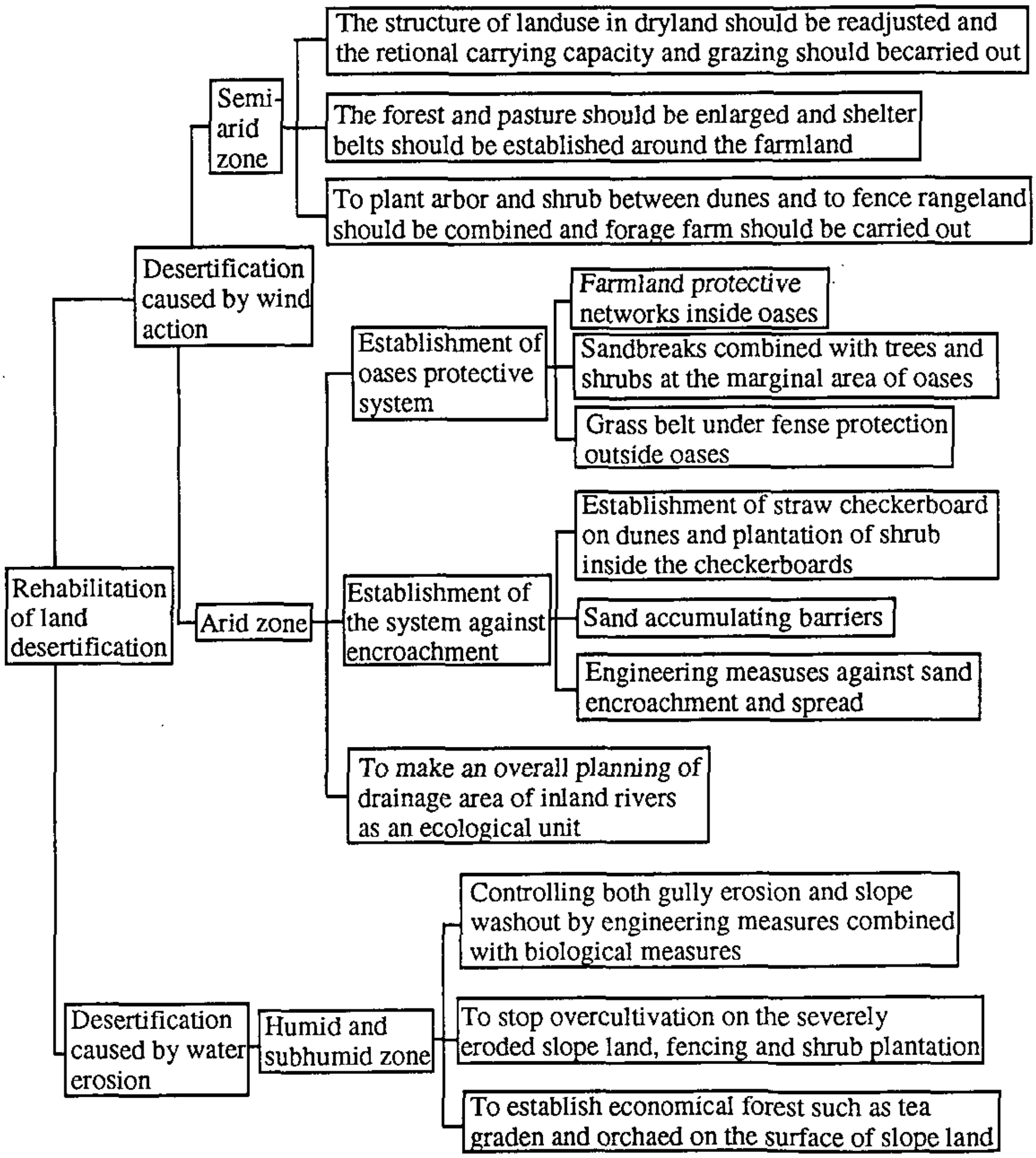

Fig. 3 The Measures for Combating Desertification in China.

Vegetation Cover Change in Desertified Kerqin Sandy Lands, Inner Mongolia

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Abstract

Historical and recent land degradation has been caused by human activities in semi-arid Kerqin Sandy Lands, Inner Mongolia. The purpose of the present study is to outline the process of land degradation in this area and to assess the efficiency of desertification control measures on recuperating process of vegetation cover. Historical documentation and field evidence suggest a long history of land degradation in Kerqin Sandy Lands where Quaternary sand deposits with a depth of some 200m are widely distributed. Remnant forest patches dominated by *Quercus mongolica* and *Pinus tablaeformis* on isolated hills and *Ulmus pumila* on sand dune fields provide evidence of the previous landscapes in the forest-steppe transitional bioclimatic vegetation zone. In addition to the historical vegetation degradation, rapid expansion of denuded landscapes since World War II is obvious. Comparison of maps shows remobilized sand dune fields to have expanded 2.3 times in area in the last 50 years. Demographic data for the Wulan-Aodu settlement area at the center of the western Kerqin Sandy Lands shows that human and livestock population drastically increased in the 1950-60s, and this is thought to be the main cause of land degradation in this area. Livestock population has decreased since the 1970s but land degradation has continued because of a period of dry climate which started in 1971. Land use management such as grazing control is a most effective countermeasure against land degradation. Wulan-Aodu Grassland Ecosystem Research Station, Institute of Applied Ecology has set up fenced experimental fields on remobilized sand dunes and in interdune depressions within which grazing has been controlled. Remarkable vegetation restoration can be observed in fields conserved for about five years, though appearance of woody species is still insufficient even after 20 years' protection. Spatial variation in vegetation between sand dunes and interdune depressions can be observed in the protected area: *Caragana microphylla* and *Artemisia halodendron* are typically dominant on dunes and Typha minima and Salix spp. are frequently dominant in interdune depressions. In unprotected area *Caragana microphylla* and *Setaria viridis* dominate on dunes and in flat lowlands, respectively. Therefore, the effectiveness of grazing control on vegetation restoration is indicated, though on dune ridges, where sand movement is very active, other strategies such as artificial revegetation works are also desirable to support and promote vegetation restoration.

Key words: desertification, sand dune remobilization, vegetation restoration, grazing control, Inner Mongolia

1. Introduction

In June 1994 an International Convention to Combat Desertification in Countries Experiencing Serious Drought and/or Desertification, particularly in Africa, was ratified in Paris. This Convention defines the term desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities". Desertification is now recognized by the international community as a serious global environmental issue to be solved through establishing sustainable resource management systems and land use systems.

Decrease in vegetation cover is a significant phenomenon in desertified lands. Recent studies have been carried out to further understanding of the process of vegetation cover change and to find ways for conserving and/or restoring vegetation. Studies in African savanna areas have revealed that grazing control is important for restoring vegetation (e.g., Backeus *et*

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al., 1994; O'Conner, 1994). Generally, heavy grazing or "overgrazing" is considered a major reason of vegetation (e.g., van Vuren and Coblentz, 1987); appropriate control of grazing is therefore recognized as an important effort to maintain vegetation (Agarwal *et al.*, 1993).

When we consider the problem of desertification and associated vegetation cover change, the Asian Continent is worthy of note. It is characterized as a region with vast areas of desertified drylands. UNEP/GRID reported in 1991 that Asia contained nearly two billion ha or 32% of the world's drylands, which was almost the amount reported in Africa (Dregne *et al.*, 1991). More than 70% of Asian drylands are exposed to the threat of desertification/ land degradation. Therefore, the preparation of action programs based on scientific and technological knowledge to combat desertification in Asia is highly recommended. For this purpose, Environment Agency, Japan has started in 1992 desertification control studies in India and in China with the cooperation of national research institutes such as the National Institute for Environmental Studies and the National Institute for Agro-Environmental Sciences. The authors in this paper joined in this research project and selected China as their study region.

The possibility of natural restoration of vegetation varies for different areas. Therefore, it is important to understand how vegetation will change in each region after disturbances such as grazing cease. If sufficient individual studies of vegetation restoration are accumulated, it will be possible to evolve a general theory. In the present study, the authors selected semi-arid sandy land in northeastern China. It has a long history of pastoral, agricultural and silvicultural land uses. Post-war socialistic land reform and land development have resulted in unique characteristics in land use changes.

The significance of selecting northeastern China as a field for the studies of desertification and its control is that the influence of natural and human impacts on the land can easily be evaluated through assessing the drastic landscape changes in the recent decades with reliable records. Since the 1970s the Chinese government and many local governments have managed land use so as to control soil erosion and to restore vegetation (Zhu ed., 1988). Today recovery of vegetation can be observed in many plots, though large area are still left with poor vegetation. This situation is just suitable to evaluate the efficiency of desertification control measures. In this paper desertification status and vegetation restoration are studied on Kerqin (or sometimes referred to as "Horqin") Sandy Lands, Inner Mongolia, wherein typical land degradation phenomena as indicated by sand dune remobilization are observed.

2. Objective of the study and the features of the study area

Objective of the study

Sand dune remobilization is one of the most significant phenomena of desertification worldwide. In Africa desert encroachment was seriously recognized in the Sudano-Sahelian zone in the early 1970s, and this stimulated establishing desertification control strategies (Grantz ed., 1977). However, sand dune remobilization has also been observed in other continents. For example, Toya *et al. ed.* (1985) summarized the extensive sand dune remobilization caused by European settlement in Australia. In Asia fixed sand dune fields occur in semi-arid zones mainly in India and those in China. They also suffer from sand dune remobilization problem. A case study in China, therefore, can present another example of sand dune remobilization and associated vegetation cover change.

China is characterized as an area having a long history of desertification. However, recent land use change caused by increase in population and alteration in social structure have drastically transformed the land cover. Denuded and/or degraded landscapes have expanded on settled semi-arid zones where vegetation cover used to be sustainably maintained. Especially, in Inner Mongolia, intensive sand dune remobilization has occurred because of various human impacts. It is worth studying this area to understand the process of desertification and change in vegetation cover. In this paper the authors try to understand the actual status of vegetation cover and process of its change, brought by recent desertification / land degradation, and to assess the efficiency of desertification control measures taken in this area. Wulan-Aodu Grassland Ecosystem Research Station, Institute of Applied Ecology, Chinese Academy of Sciences, located at the center of western Kerqin Sandy Lands has been selected as the base of the present study. Field surveys were performed as joint research work between the University of Tokyo and the Institute of Applied Ecology in 1992-1994 in Wulan-Aodu and its surrounding area.

Physical setting

In China the term "sandy lands" is different from the term "desert" and is used for the extensive sand dune fields bioclimatically covered with vegetation. However, because of historical and recent desertification / land degradation; vegetation cover on sandy lands has decreased rapidly. Kerqin Sandy Lands located in the western part of Northeast China is one of the largest sandy lands in China. It covers an area of 43,000km^2, within 118° 30' to 123° 30'E longitude, 42° 20' to 44° 20'N latitude, and is considered to be in the forest-steppe transition zone (Kou, 1994). The origin of aeolian sands are thought to be alluvial and lacustrine deposits with a thickness of some 200m (more than 200m in Wulan-Aodu) along the Shilamulin / Xiliao Ho (River) formed in the Middle and Late Pleistocene period, and fixed dunes were formed associated with soil development during the Holocene period (Zhu *et al.*, 1988), which made vegetation growth possible.

The Kerqin Sandy Lands are located in an arid to semi-arid temperate climatic zone. Annual rainfall in Kerqin Sandy Lands is about 300mm in the west and 500mm in the east. Mean annual rainfall in Wulan-Aodu is 340mm, 70% of which concentrates in the period June-August with 2,500mm of mean annual evaporation (Nan, 1994). Mean annual temperature is 6.3°C, but the annual variation is very large because of continental inland climate. In summer mean temperature is over 20°C, while in winter often below -10°C. A climatic diagram based on the data 1981-1984 (Fig. 1) shows that rainfall is enough for vegetation growth but a relatively dry period appears in autumn, which stimulates the withering of herbaceous plants from the middle of September.

Relatively long term climatic records are stored in Wutan Meteorological Station that is close to the study area. Variability of mean annual rainfall is high, with a range of 229-564mm (Fig. 2-a), but does not immediately present evidence of climatic fluctuation. However, the residual mass (RM) graph shows the existence of a wet period from 1958 to 1970 and a dry period from 1971 to 1985 (Fig. 2-b). The RM graph can reveal continuous dry or wet period and turning points between them, and it is often used for the analysis of long-term rainfall records in arid and semi-arid Australia (Iwasaki, 1985). The RM graph is given by plotting Xi, which is calculated by the following equation, against the time scale.

$$X_i = 1000 \times \sum_{n=1}^{i} \left(\frac{r_n - \bar{r}}{\bar{r}} \right)$$

where r_n is the annual rainfall for the n-th year of the record. In the present study the mean annual rainfall $\bar{r}$ was computed for the 34 years period from 1957 to 1990.

Wind records from 1957 to 1990 are also stored in Wutan Meteorological Station. Average wind speed in Wutan is 3.1m/sec. In spring before plants start growing wind speed is relatively high (Fig. 3), which is considered to cause the active sand drift, in particular on denuded sand dune surfaces. Wind direction in spring is northwest, which corresponds with longitudinal sand dune direction.

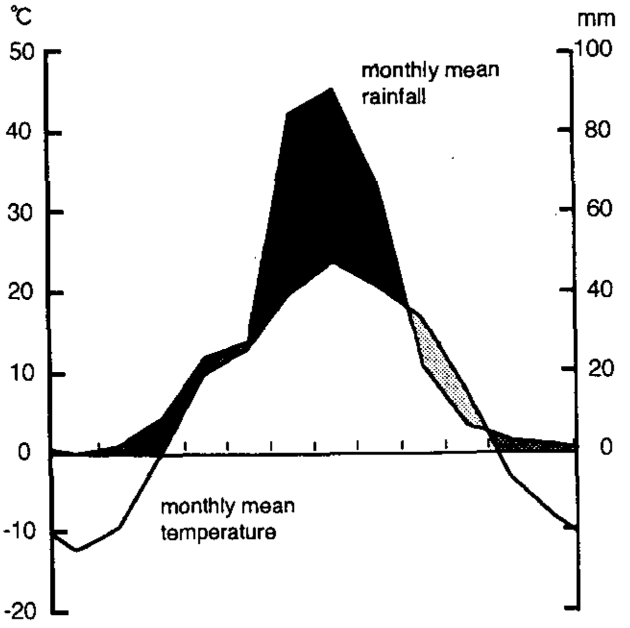


Fig. 1 Climatic diagram of Wulan-Aodu based on the data 1981-1984.

Human activities

The eastern part of Kerqin Sandy Lands is a marginal zone between the Mongolian grazing zone and the Chinese agricultural zone, while land use in the western part of the Lands is dominated by Mongolian

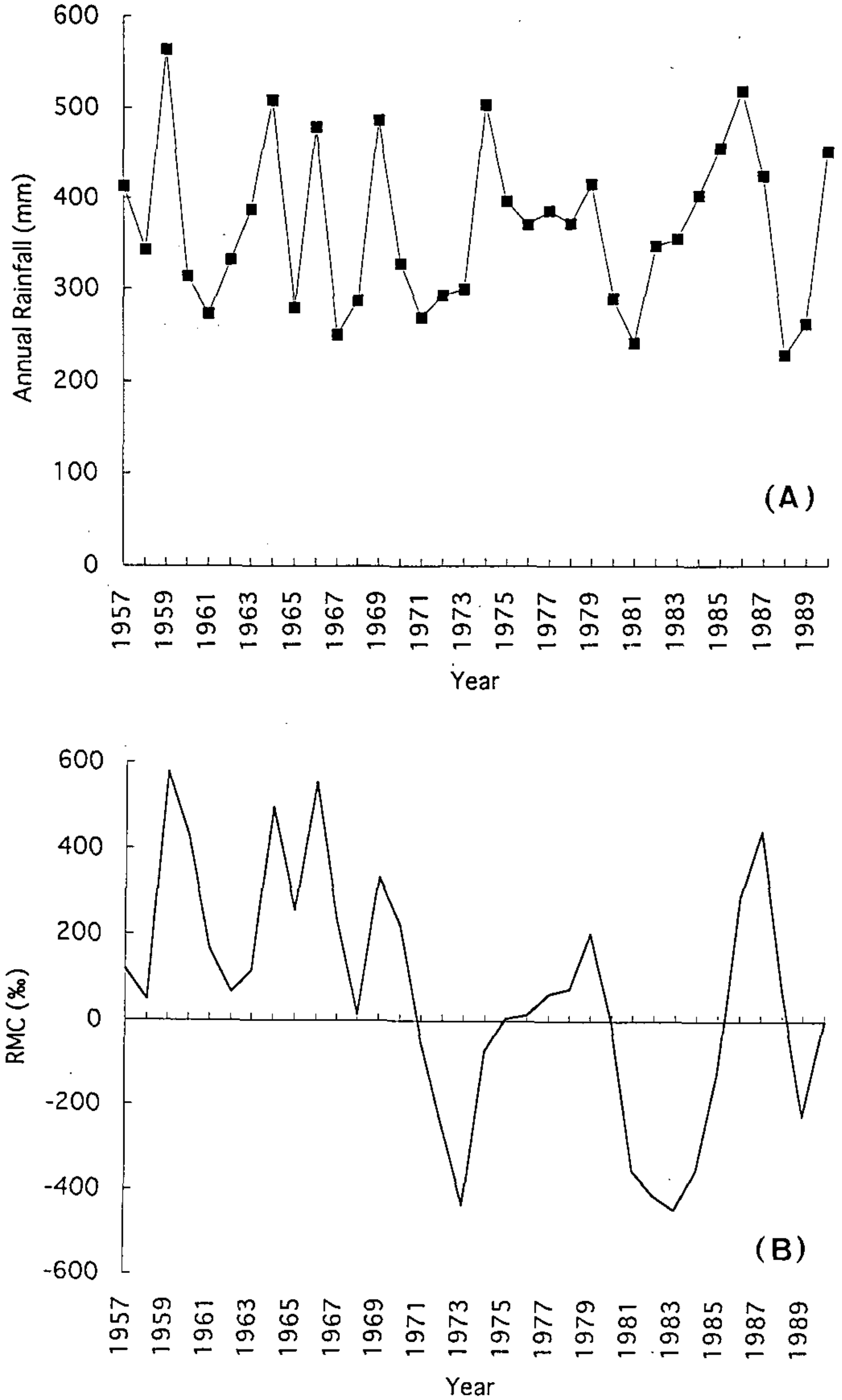


Fig. 2 Mean annual rainfall (above) and residual mass graph (below) in Wutan from 1957.

grazing. Formerly nomads, people have settled after the World War II, following the Chinese governmental land policy.

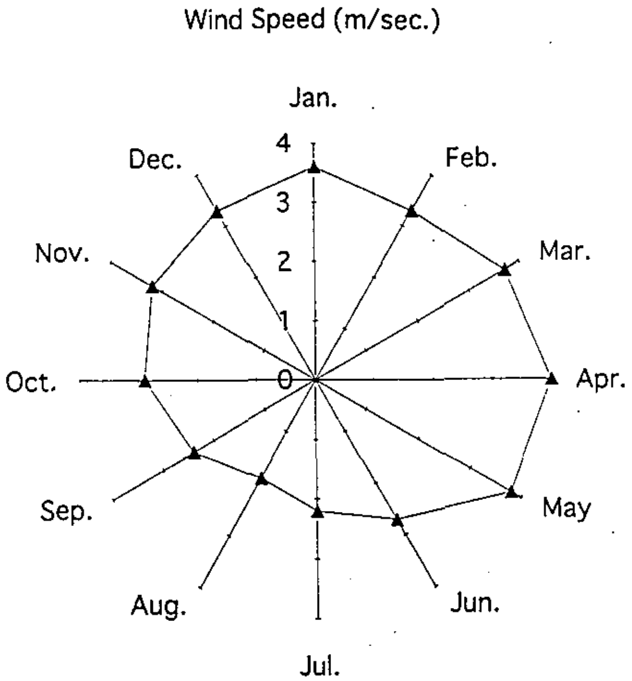


Fig. 3 Monthly change in wind speed in Wutan Human activities.

Wulan-Aodu Village, belonging to Nashihan Township, Wengnuite County, Chifeng City, has an area of 7,350 ha, 170 families, 751 people of whom 98% are Mongolian, and 7,567 livestock (Kou, 1994 & Fig. 4). Ninety percent of family income comes from livestock husbandry. Livestock dung is used for fuel, which is different from the Chinese custom of using firewood as fuel. However, during the time of the "Great Leap Forward", when iron smelting was promoted and the construction of Hongshan Reservoir was taking place from 1958 to 1961, great amount of trees were cut intensively for firewood, and this is said to have caused the decrease in vegetation cover.

3. Process of vegetation cover change

Historical change in vegetation

No scientific records exist of the floristic composition of the vegetation cover of the Kerqin Sandy Lands before the overexploitation started. It is believed, however, that the area was covered with rich grassland vegetation and partly with woodlands. Zhu *et al.* (1988) have summarized past human activities in the Kerqin Sand Lands since the Neolithic Age, some 4,000 to 5,000 years ago. Near the Hongshan settlement, a deflation plain is revealed because of recent sand drifts. There are many artificial stone flakes, wood fragments and animal bones scattered on a dark semi-consolidated sand layer formed during the period of Hongshan Culture (Fig. 5 & Fig. 6).

Fig. 4 Settlement of Wulan-Aodu. Mongolians are collecting forage grasses and animal dropping at home garden. Tall trees behind the settlement were planted by the Institute of Applied Ecology. Far behind remobilized dune fields are observed.

Several dark colored semi-consolidated sand layers are widely distributed in Kerqin Sandy Lands and are considered to be a relict soil layer (Zhu *et al.*, 1988). Soil analysis by the authors, however, shows that even the darkest layer distributed in the Wulan-Aodu area contains 0.439 of C and 0.0338 of N, and C/N ratio is 13.0, which is insufficient to conclude that the layer is relict soil. Further investigation is required about the origin of the sand layers.

Before the recent expansion of desertified lands, forests and woodlands are said to have distributed widely on isolated hills and sand dune fields. There are some remaining remnant forest/woodland patches in the Wulan-Aodu area. Fig. 7 shows the vegetation structure of a *Quercus-Pinus* forest patch remaining on an isolated hill in this area. Fig. 8 shows the vegetation structure of *Ulmus macrocarpa* woodland developed on sand dune fields (Fig. 9; Takeuchi, unpublished data). Because of the influence of intensive grazing there was no evidence of regeneration in either the forest or the woodland

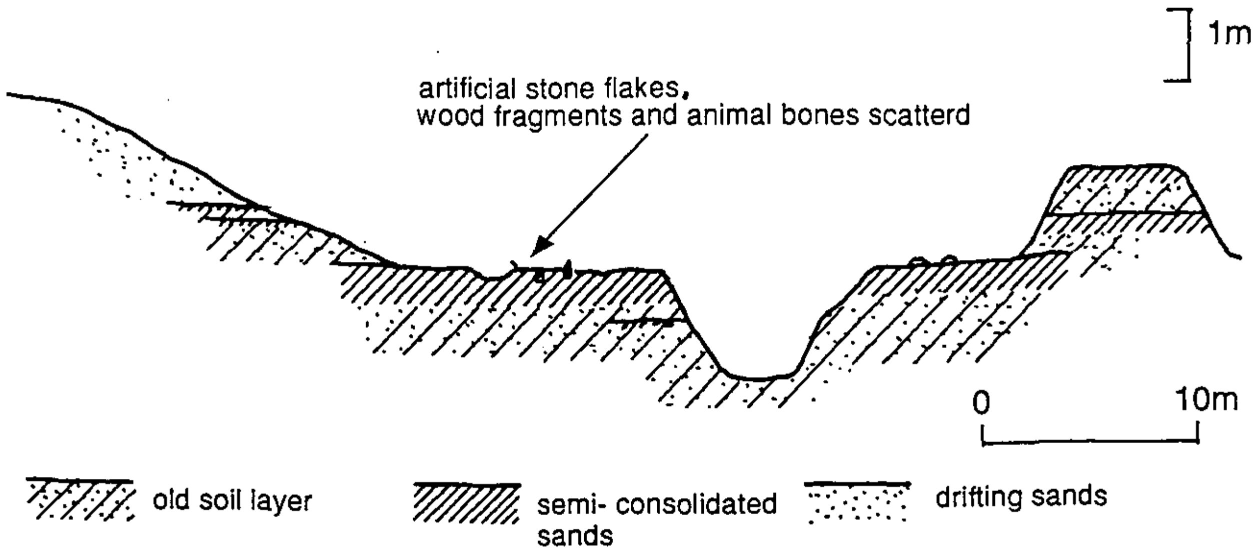


Fig. 5 Distribution of dark semi-consolidated sand layer at the deflation plain near Hongshan.

patches. So the maintenance of such vegetation in the future is not guaranteed.

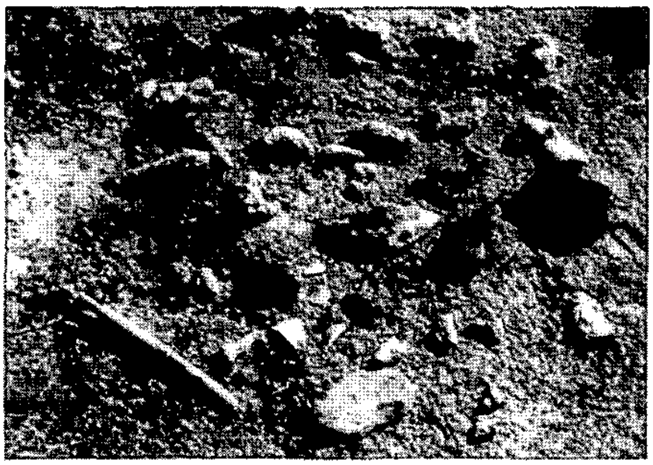


Fig. 6 Artificial stone flakes, cemented wood fragments collected on dark semi-consolidated sand layer.

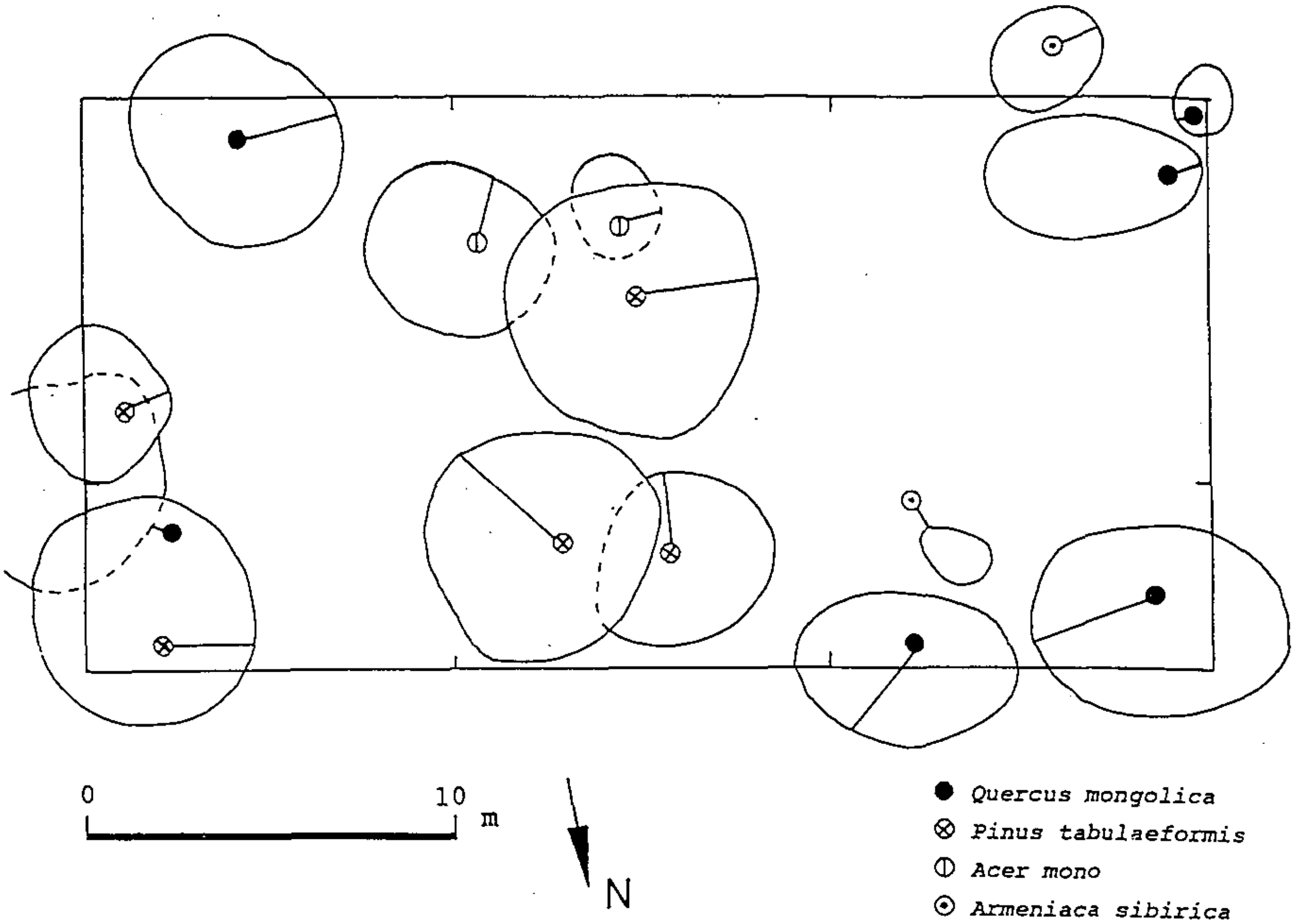
Recent vegetation cover change

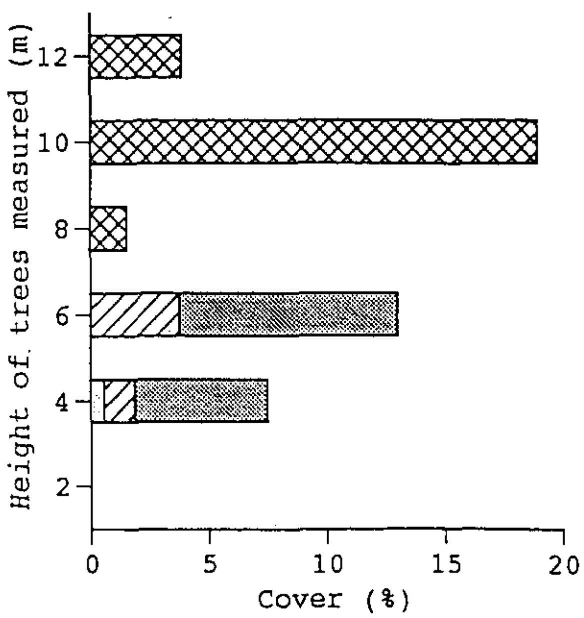
It is said that desertification / land degradation has escalated since World War II. To understand the magnitude of post-war expansion of remobilized dune fields, two maps in which the study field is drawn were compared. One is a topographic map at 1:100,000 made in 1935 by the former Japanese Army who invaded Northeastern China at that time. The other is a desertification hazard map at 1:500,000 made in 1985 by the Institute of Desert Research, Chinese Academy of Sciences.

An overview figure was obtained as shown in Fig. 10. The result shows that the area of remobilized dune fields comprised 1,160 km^2 in 1935, and 2,710 km^2 in 1985. Remobilized dune fields in 1985 are 2.3 times in area than in 1935, which shows that recent sand dune remobilization is very active. Fig. 11 shows the scheme of the recent expansion of remobilized dune fields. Here peat bed developed along a small stream is being overlaid by active sand drifts.

The main cause of the sand dune remobilization in the Wulan-Aodu area is an increase in population, both human and livestock (Fig. 12). Kou (1994) has summarized the history of vegetation cover change. He says that population had expanded to more than 300 persons by 1960 (Fig. 10) and a lot of trees mainly *Salix* spp. in interdune depressions and *Betula* spp. on sand dunes had been cut down for housing construction, buildings for livestockfold and so forth, with the consequence that has become 10% of the area desertified, whereas it was less than 1% in the early 1950s. Cutting of trees for firewood during the time of the "Great Leap Forward" and construction of the Hongshan Reservoir may have accelerated this degradation process. Desertified lands increased up to 20% in 1966 when the number of livestock peaked (Fig. 13).

Livestock population decreased rapidly from 1970 to 1986. Nevertheless, Kou (1994) reported that desertified lands continued to expand to occupy 60% of





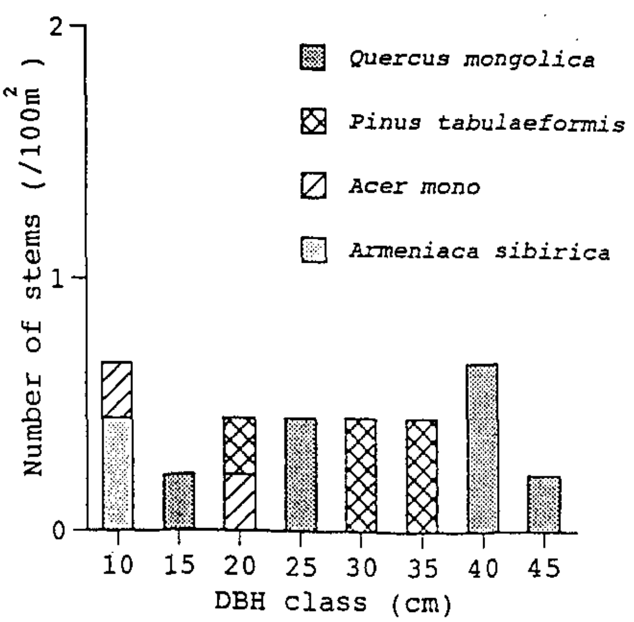


Fig. 7 Vegetation structure (crown projection diagram, crown projection cover and DBH class) of *Pinus-Quercus* forest remained on relict hills.

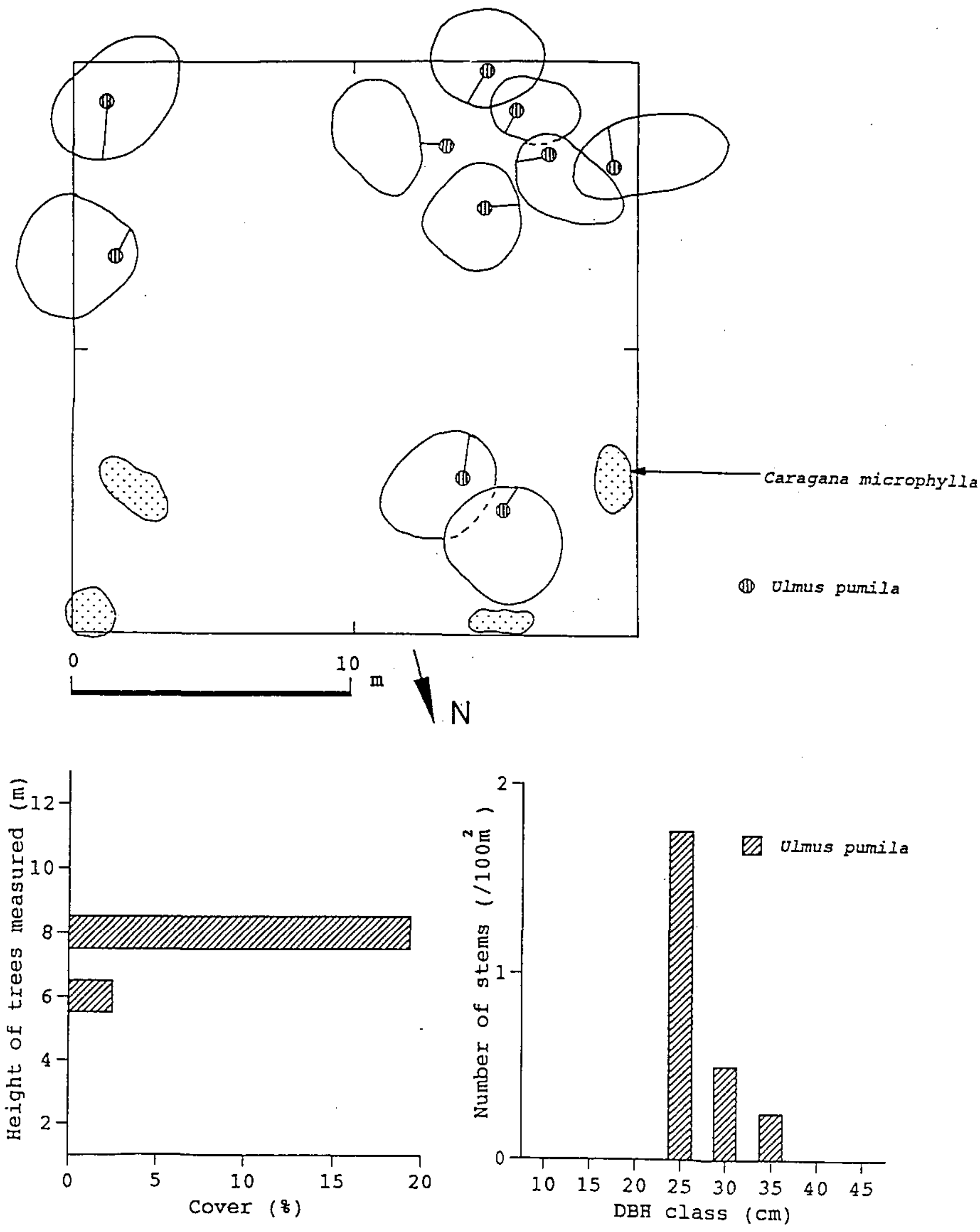


Fig. 8 Vegetation structure (crown projection diagram, crown projection cover and DBH class) of *Ulmus* woodland remained on sand dune fields.

the area. The period corresponds to the period of dry climate already mentioned. Therefore, climatic change is considered to have accelerated the desertification and associated vegetation cover change in this area.

The shape of the remobilized sand dunes is Barchan type and they move in a southeast wind direction (Fig. 16). The remobilized dune ridges are often higher than 15m. Steep slopes are formed on the leeward side of dunes. Dune movement is 3-5 m/year and often buries roads, which are most important lifelines in this area (Fig. 14).

As presentative measure the Wulan-Aodu Grassland Ecosystem Research Station started grazing control and revegetation works along the roads in the 1970s. Grazing has been basically inhibited in the controlled fields to conserve vegetation, though from November to April the inhibition has been loosened in lowland controlled fields. In the controlled fields on sand dunes grazing has been inhibited throughout a year, therefore the vegetation there is just protected. As a result, remarkable vegetation restoration can be observed, details of which is explained in the next chapter. The vegetation cover on sand dunes protected since 1977 is evaluated by aged local villagers to be similar to the standard of vegetation cover in the 1950s (Fig. 15).

4. The effectiveness of grazing control on vegetation restoration

Method of field survey

Field surveys were carried out in the summers of 1993 and 1994. Eight transacts were placed on seven sand dunes taking care to cover various periods of grazing control by fencing (Table 1). Each transect was set from sand dune ridge to interdune depression, or from one dune ridge to another. The length of each transect was 30 to 100m. Along each transect 10 to 30 quadrats (2m x 2m) were set to obtain vegetational data. In addition to them, vegetation in flat lowlands was surveyed with 49 quadrats (1m x 1m or 0.5m x 0.5m, according to vegetation height). Twenty of them were located in unprotected area. Five, fifteen, and nine quadrats were in enclosed areas where grazing has been inhibited for 2, 5 and 20 years, respectively. For each quadrat, all species present were recorded with their coverage. Topography was also measured along each transect in order to draw sections.

Method of data analysis

Species compositional data were analyzed by means of Detrended Correspondence Analysis (Hill, 1979). Species which appeared in more than four quadrats were included in the analysis. This kind of treatment enhances analytical performance without any loss of important information (e.g., Orlóci and Mukkatu, 1973). Major trends in compositional change were then estimated. The effect of grazing control was evaluated by comparison of DCA scores among the transects or quadrats that differed in the duration period of control. The relationship between topographic location and species composition was also analyzed in the same manner.

Results of the analysis

General attributes of vegetation

Table 2 indicates the average vegetation height, species richness and dominant species for each quadrat group classified by protected period (see Table 1) and topography. On sand dunes the species richness has a tendency to decrease with the length of protected period, presumably because of the dominance of *Salix* spp. The increase in average vegetation height with the length of protected period is also observed indicating that woody species such as *Caragana microphylla* and *Salix* spp. grow to larger size in controlled area. In lowlands and interdune depressions both species richness and vegetation height seem to fluctuate with no relation to the length of conserved period, though the vegetation conserved for twenty years and located in lowlands (group G and H) contained larger number of species.

The difference concerning topographic variation is mainly observed in dominant species. For example, *Caragana microphylla is* dominant only on dunes. Compositional variation is further analyzed in the following sections by means of ordination technique.

Detrended Correspondence Analysis

The results of DCA are shown by scatter plots of the first and second axes (eigenvalues were 0.867 and 0.780, respectively). Fig. 17 and 18 indicate the sample (i.e., quadrat) scores and species scores, respectively.

The ordination of the quadrats shows a minor overlap between the vegetation controlled (conserved or protected) for different periods. As for the quadrats in

Fig. 9 Remnant *Ulmus pumila* woodland patch distributed on sand dune fields with Caragana microphylla on disturbed land surface.

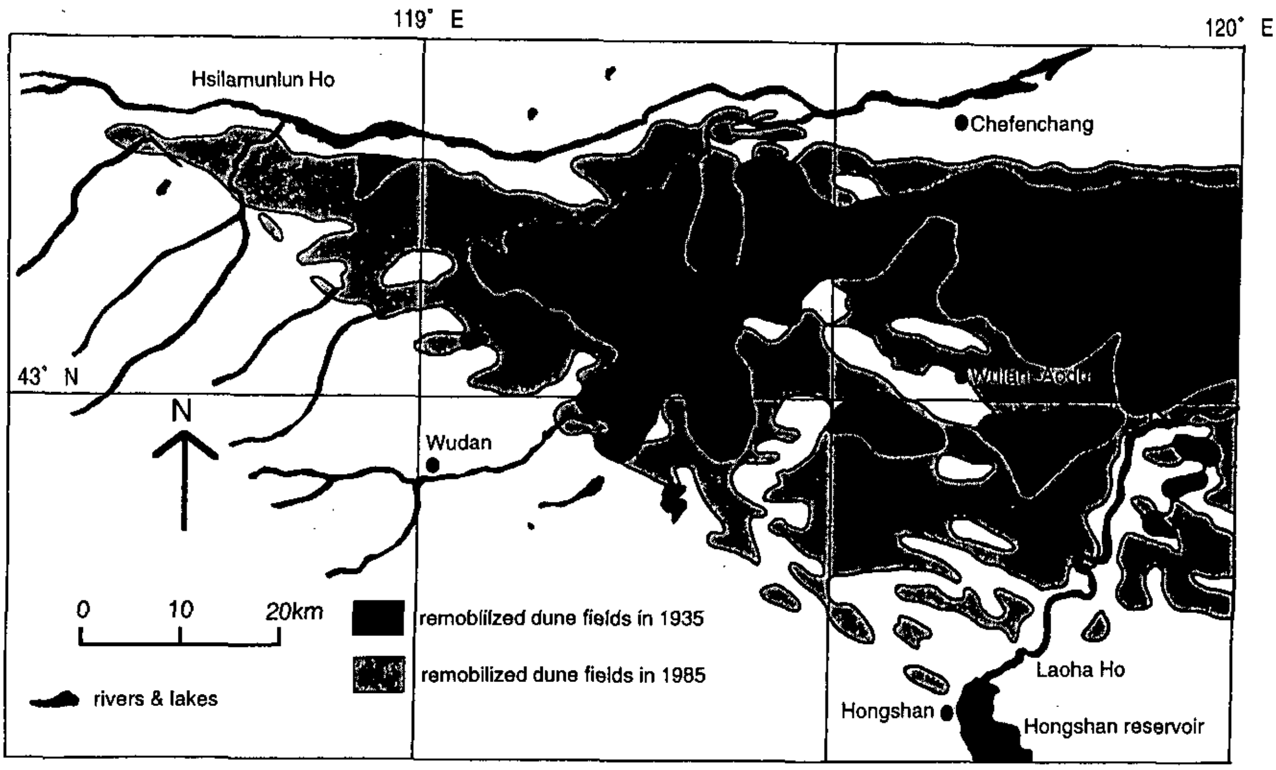


Fig. 10 Expansion of remobilized dune fields in western Kerqin Sandy Lands in a recent 50 years period, 1935-1985.

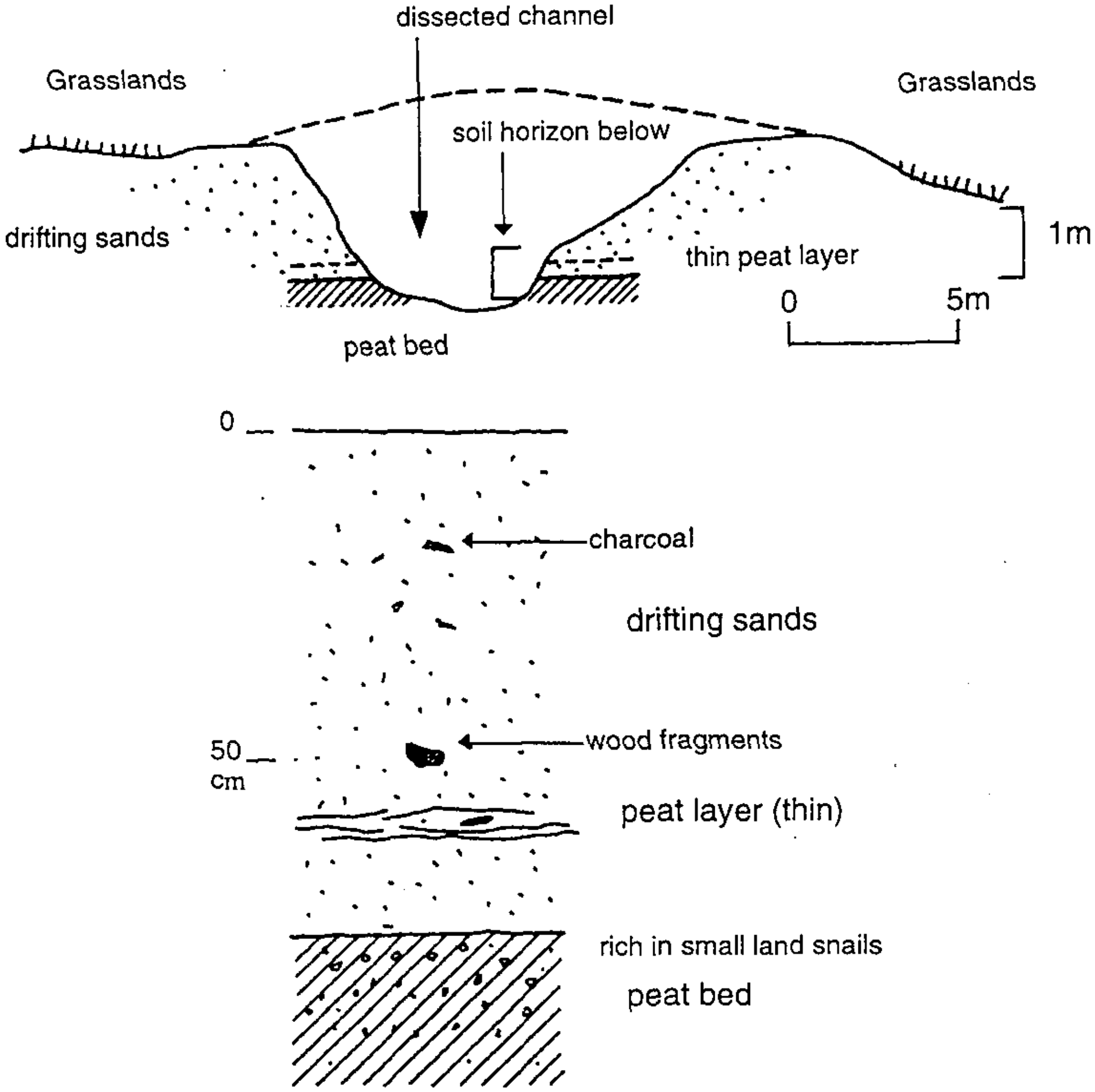


Fig. 11 Peat bed overlaid by drifting sands at the northern margin of the western Kerqin Sandy Lands along the Hsilamunlun Ho.

Fig. 12 Overgrazing of livestock brings land degradation.

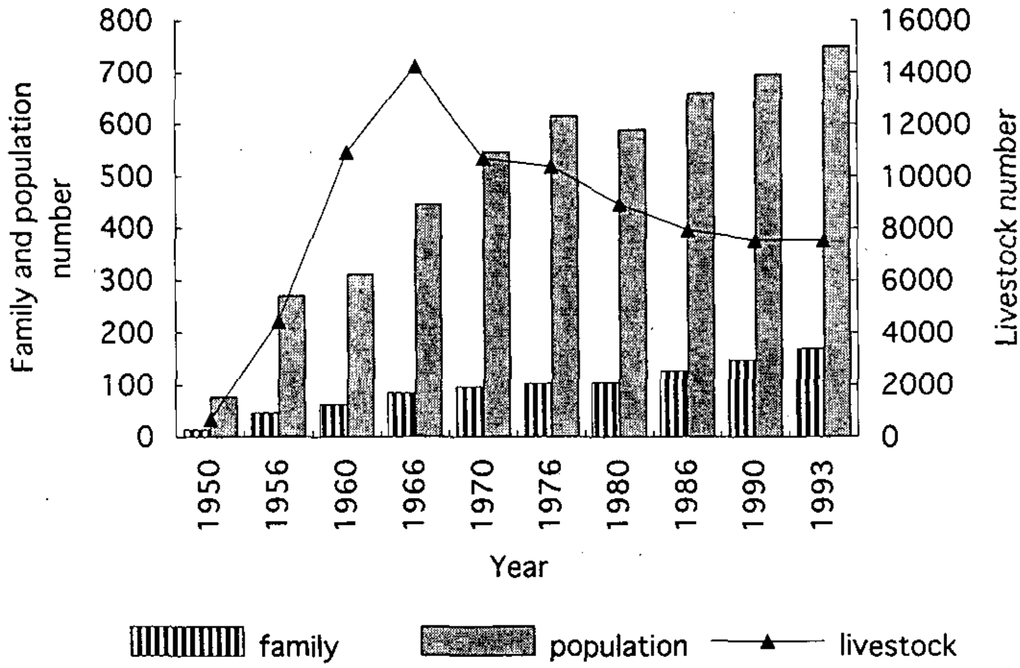


Fig. 13 Change in number of families, population and livestock in Wulan-Aodu Village since 1950 (after Kou 1994).

Fig. 14 Remobilized sand dunes often interrupt traffic Former road was recently buried beneath the remobilized.

Fig. 15 Present situation of dune fields protected since 1977. Woody species such as *Betula microphylla* start growing. *Phragmites communis* community develops on interdune depression.

the controlled areas minor overlap is also observed between topography types. The quadrats in uncontrolled areas, however, are plotted closer to one another. These results indicate that grazing control mainly influences species composition and that restored vegetation by grazing control will vary depending on topography.

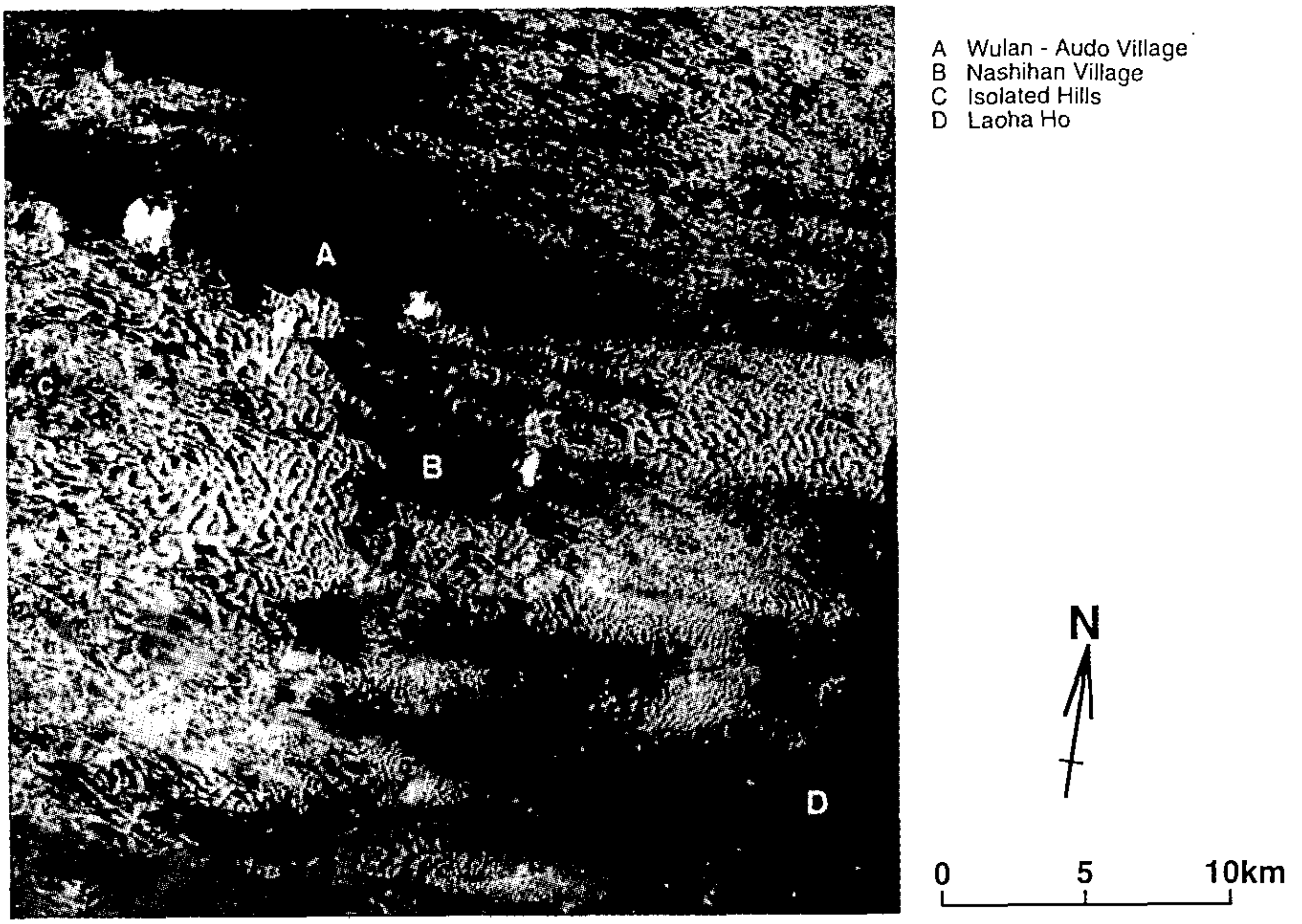


Fig. 16 Landsat image showing the actual status of desertification / land degradation in Wulan-Aodu and its surrounding area in 1992 (compiled by the National Institute of Aero-Environmental Sciences).

Table 1 Characteristics of the surveyed quadrats

Quadrat group	Number of quadrat	Length of transect (m)	Topography	Controlled period (years)
A	12	-	Lowland	0
B	8	-	Lowland	0
C	5	-	Lowland	2
D	5	-	Lowland	5
E	5	-	Lowland	5
F	5	-	Lowland	5
G	5	-	Lowland	20
H	4	-	Lowland	20
DA	21	100	Dune	0
DB	10	50	Dune	0
DC	30	50	Dune	2
DD	20	40	Dune	0
DE	15	30	Dune	13
DF	15	30	Dune	11
DG	15	30	Dune	10
DH	15	30	Dune	17

* Objectively determined in the field.

The compositional difference associated with the length of controlled period is mainly reflected by the first axis, especially in the case of the quadrats in lowlands. Therefore, the first axis can be interpreted as the axis of degree of vegetation restoration. The compositional difference of controlled vegetation associated with topography is observed along the second axis, which can be recognized as the axis of topographic variation.

As for the quadrats on dunes, compositional difference between controlled and uncontrolled vegetation is not so clear. On the dunes *Caragana microphylla* dominantly occurs from the earliest stage of the succession (dwarf *Caragana* community) to later stages (*Caragana* or *Artemisia* communities), while in interdune depressions and in lowlands species composition changes quickly with controlled period (Table 2). This fact is the reason for the relatively large overlap between the ordination of the controlled and uncontrolled vegetation on dunes.

Table 2 Vegetation structure in each quadrat group

Quadrat group	Species richness	Dominant species (Number of quadrats in which the species was most dominant)	Vegetation height(cm)
A	5.8	*Setaria viridis* (6), *Phragmites communis* (5), *Aneurolepidium chinensis* (1)	10
B	10.9	*Phragmites communis* (6), *Lactuca tatarica* (1), *Equisetum arvense* (1)	40
C	18.6	*Calamagrostis epigeios* (5)	70
D	8.4	*Aneurolepidium chinense* (5)	30
E	5.8	*Setaria viridis* (4), *Phragmites communis* (1)	20
F	8.6	*Aneurolepidium chinense* (4), *Carex duriscula* (1)	30
G	14.2	*Puccinellia tenuiflora* (4), *Carex duriscula* (1)	60
H	18	*Adenophora tetraphyra* (2), *Hemerocallis minor* (2)	90
DA	6	*Caragana microphylla* (14), *Setaria viridis* (6)	80
DA(ID)*	7	*Oxytropis myriophylla* (1)	5
DB	13.5	*Caragana microphylla* (5), *Setaria viridis* (1), *Echinops gmelinii* (1)	70
DB(ID)*	4.7	*Caragana microphylla* (3), *Setaria viridis* (1)	60
DC	5.5	*Corispermum theregium* (6), *Pennisetum flaecidum* (5), *Senecio* sp.(5), *Caragana microphylla* (1)	20
DC(ID)*	11.3	*Typha minima* (7), *Salix flavida* (3), *Salix microstachya* (1), *Carex duriscula* (1), *Senecio* sp.(1)	190
DD	10.5	*Agriophyllum arenarium* (5), *Caragana microphylla* (4), *Pennisetum flaecidum* (2), *Calamagrostis epigeios* (1), *Corispermum thregium* (1)	30
DD(ID)*	5.9	*Calamagrostis epigeios* (3), *Halerpestes ruthenica* (1), *Setaria viridis* (1), *Carex duriscula* (1), *Agrostis trinii* (1)	20
DE	7.4	*Caragana microphylla* (8), *Pennisetum flaecidum* (2), *Lespedeza dafurica* (1)	130
DE(ID)*	7.8	*Salix microstachya* (4)	170
DF	8	*Caragana microphylla* (3), *Artemisia halodendron* (3), *Setaria viridis* (2), *Messerschmidia sibirica* (1), *Pennisetum flaecidum* (1)	90
DF(ID)*	6.2	*Artemisia halodendron* (3), *Artemisia siversiana* (1), *Phragmites communis* (1)	140
DG	3.9	*Corispermum theregium* (4), *Salix flavida* (3)	140
DG(ID)*	4.9	*Salix mongolica* (4), *Salix microstachya* (2), *Halerpestes ruthenica* (1), *Lactuca tatarica* (1)	220
DH	6.1	*Artemisia halodendron* (5), *Caragana microphylla* (3), *Cleistogenes squarrosa* (3), *Salix flavida* (1), *Phragmites communis* (1)	120
DH(ID)*	9	*Phragmites communis* (1), *Artemisia sacrorum* (1)	110

*(ID) : interdune depressions.

By visual criteria, the quadrats having high values of the first axis, i.e., the quadrats in the controlled area, can be classified into three groups. The first is the group having low values of the second axis characterized by the dominance of species such as *Halerpestes ruthenica* and *Puccinellia tenuiflora*. The quadrats belonging to this group are mostly those located in the 20 years protected lowland. Another group is composed of quadrats showing intermediate values of the second axis, characterized by the dominance of *Typha minima* and observed only in the protected interdune depressions. The quadrats having high scores of the second axis belong to the third group. The quadrats in this group are mainly dominated by *Salix flavida* (on protected dunes), *S. microstachya* and S. *mongolica* (in protected interdune depressions).

Fig. 19, showing the relationship between the altitude of each quadrat from the bottom of its neighboring interdune depression and the first axis score of DCA, indicates that vegetation is almost constant along the transects located in the unprotected area, while developed vegetation can be observed on the protected interdune depression. Composional change in protected interdune depressions is apparently observed at an altitude of 1m or less from the bottom (Fig. 19). Some of the quadrats located on the protected dunes have higher scores of the second axis (Fig 17). Within these quadrats *Artemisia halodendron* or *Salix flavida is* dominant (compare Fig. 17 with Fig. 18 or see Table 2).

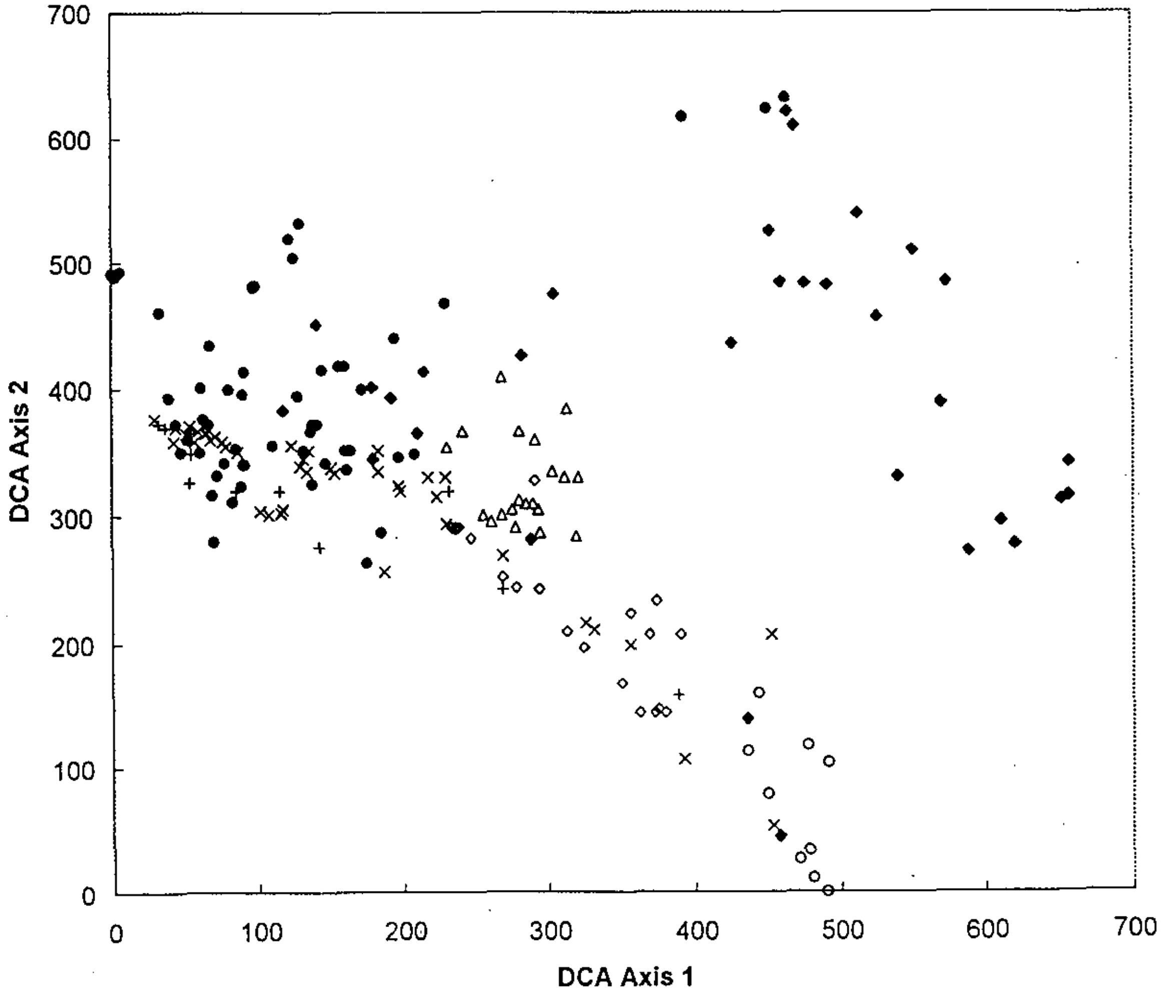


Fig. 17 Scatter diagram of the DA first and second axes indicating sample (quadrat) ordination. Open triangles: Unprotected lowland, Open diamonds: 2 to 5 years protected lowland, Open circles: 20 years protected lowland, x: Unprotected dune, Close circles: Protected dune, +: Unprotected interdune depression, Close diamond: protected interdune depression.

The above mentioned results indicate that vegetation can readily be restored under grazing control in interdune depression and lowland where underground water level is high and soil moisture is appropriate to vegetation growth. It is also indicated that vegetation restoration is slow and/or difficult on dunes probably because of dry and degraded soil condition, and that restored vegetation is different between dunes and interdune depressions.

Discussion on Vegetation Restoration

Based on the results, it is concluded that grazing control is the key factor in promoting plant succession in the study area. Past studies concerning the effect of grazing on vegetation can be divided into two categories. One comprises studies in which grazing is a useful method to maintain vegetation in species rich status (Smith and Rushton, 1994; Bullock *et al.*, 1994). The other comprises studies in which grazing is a harmful factor, damaging vegetation restoration (*e.g.*, Backeus *et al.*, 1994; O'Conner, 1994). As for the present study field of Kerqin Sandy Lands, grazing does affect vegetation cover and should be limited or inhibited in order to restore vegetation cover. However, on sand dunes species richness actually increases under grazing because the dominance of *Salix* spp. is prevented by grazing. On dunes in this area development of vegetation cover is more desirable than increase of species richness to control dune activity. Therefore, grazing should be controlled on sand dunes even at the expense of species

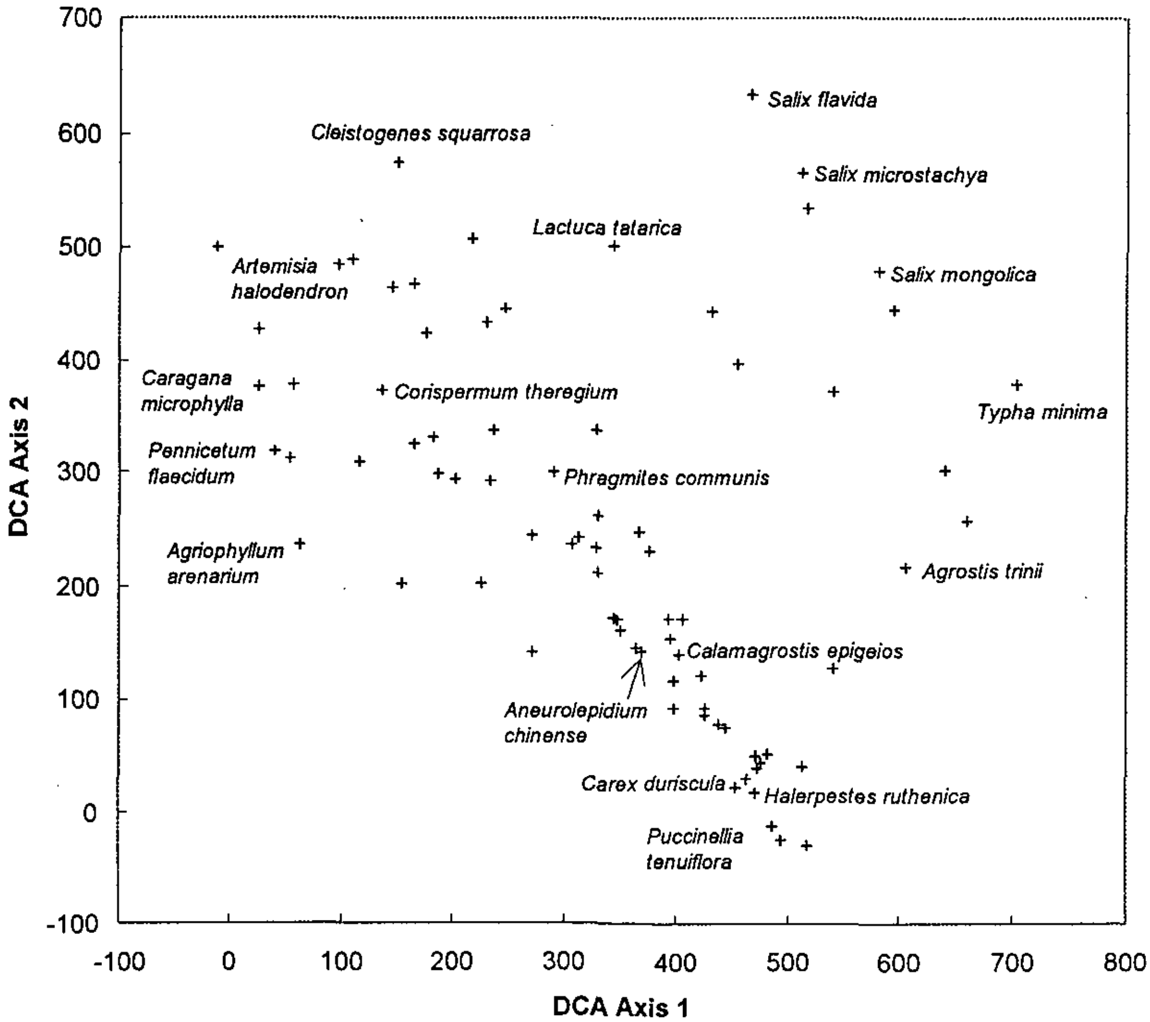


Fig. 18 Scatter diagram of the DA first and second axis indicating species ordination.

richness/diversity.

It can be noted that the observed vegetation is different among topography types in the controlled area. This fact indicates that factors influencing vegetation vary according to topographic gradient and that the control strategy should be different depending on topography.

It appears that vegetation restoration is more difficult on dunes than in depressions and lowland. The reason is probably the lack of soil moisture and the advance in soil degradation on dunes. It has been reported that soil degradation slows vegetation recovery (Backeus et al., 1994).

In lowland and interdune depressions, fencing is an effective strategy for vegetation restoration. Vegetation has been observed to restore itself spontaneously after the beginning of the grazing control. However, the authors cannot decide the minimum length of grazing control period for vegetation restoration. In some depressions, two years of control allows the development of tall, dense and species rich *Typha minima* community (Table 2). In other depressions, however, 10 to 15 years of grazing control is sometimes insufficient for vegetation restoration (Fig. 17, Table 2). In lowlands, five years control is not enough to restore well-developed grassland such as has been observed in areas protected for 20 years (Fig. 2), though tree species are still rare even in such areas.

From the point of view of vegetation structure,

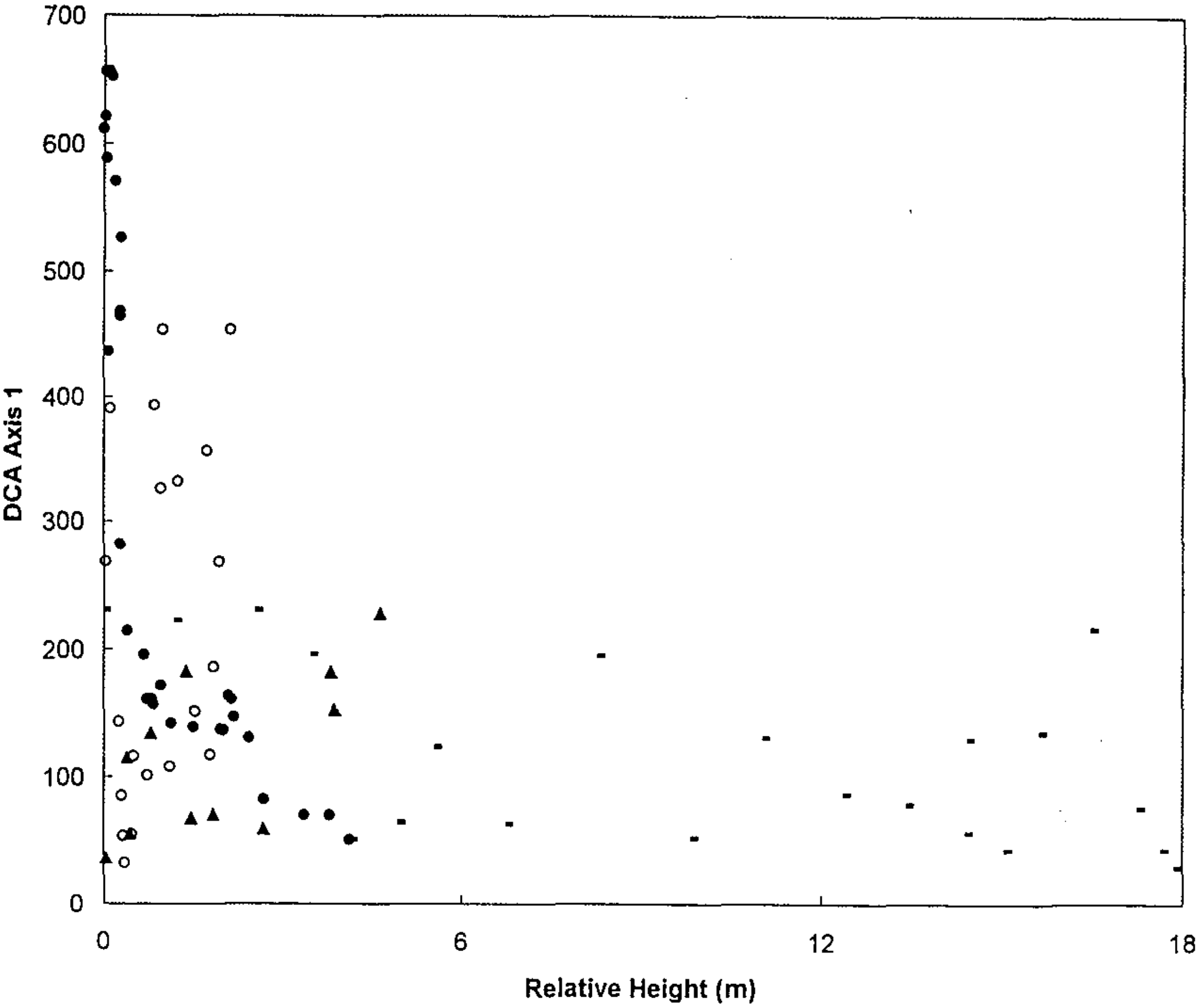


Fig. 19 The spatial variation of vegetation along topographic gradient. Vegetational variation and topographic condition are indicated by the scores of the DA first axis and relative height from depression bottom, respectively. -: Transect DA (unprotected), Close triangles: Transect DB (unprotected), Close circles: Transect DC (protected for 2 years), Open circles: Transect D (unprotected but wetter in soil moisture than the Transacts DA and DB.

the *Calamagrostis epigeios* community observed in the two-years controlled lowland comprises many (average 18.6) species and grows tall (average 0.7m, Table 2). If species composition, soil degradation and sand dune remobilization do not need to be considered, grazing control for two years is almost enough for restoring grassland vegetation in lowlands in the study area.

On dunes, fencing or enclosure is not always so effective. In this case plantation is a possible way of vegetation restoration. In the present study field plantation of *Caragena microphylla,* which is a dominant shrub species on dunes, has been carried out by Wulan-Aodu Grassland Ecosystem Research Station, Institute of Applied Ecology. Nan (1994) reported that this plantation is quite effective in lowering wind effects and in fixing soil. The efficiency of the plantation, including other species than *Caragana microphylla,* on vegetation restoration should be further analyzed in order to complete the restoration strategy for this area.

5. Concluding Remarks

Overuse of the semi-arid fragile environment has changed fixed dune fields to remobilized dune fields in Kerqin Sandy Lands. Vegetation cover has been rapidly depleted. It is concluded that the main cause of recent dune remobilization in Wulan-Aodu is overgrazing by livestock. However, climatic fluctuation seems to have accelerated the land degradation process. A similar case was reported in the Sudano-Sahelian zone where livestock population increased during a wet period of climate, causing severe damage to the environment when followed by a dry period (Grantz ed., 1977). These facts support the thesis that desertification is a phenomenon caused by both natural and man-induced causes.

The results of the survey on vegetation restoration suggest that grazing control is the most effective way of desertification control in this area. Revegetation works can help the progress of plant succession. Similar experiments have already been done in various semiarid zones in the world. The problem is how to establish sustainable land use system that can support human population.

One solution to this problem is to construct a land use zoning system. In this area, topography (soil moisture, and nutrient concentration and soil texture, maybe) are the major descriptors classifying land use zones. In lowland and depressions in this area vegetation structure can develop to some extent in a few years. In lowland and depressions with appropriate soil moisture, grazing control can be loosened from today's level to adopt a rotation system allowing people to use recovered vegetation cover periodically. It should be noticed, however, that an alkalization problem accompanied by too much moisture, which can also be observed in this area and other soil degradation should be taken into account (Kou 1994). On sand dunes strict grazing control is essential and in some cases artificial revegetation works are also desired to support and promote vegetation restoration.

These criteria are still too abstract and idealistic to be applied to realistic problems. To show a model of a sustainable land use system adaptable to this region will be our next theme.

Acknowledgement

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References

Agarwal, M., Shukla, A. and Pal, V. N. 1993. Grazing of forested grassland and its conservation. *Ecological Modelling* 69: 57-62.

Backeus, I., Rulangaranga, Z. K. and Skoglund, J. 1994. Vegetation changes on formerly overgrazed hill slopes in semi-arid central Tanzania. *Journal of Vegetation Science, 5,* 327-336.

Bullock, J. M., Clear Hill, B., Dale, M. P. and Silvertown, J. 1994. An experimental study of the effects of sheep grazing on vegetation change in a species-poor grassland and the role of seedling recruitment into gaps. *Journal of Apttied Ecology,* 31, 493-507.

Dregne, H., Kassas, M. and Rosanov, B. 1991. A new assessment of the world status of desertification. *Desertification Control Bull., 20, 6-18.*

Grantz, M.H., ed. 1977. *Desertification: Environmental degradation in and around arid lands.* Westview Press, Boulder, 346p.

Hill, M.O. 1979. *DECORANA: A FORTRAN program for detrended correspondence analysis and reciprocal averaging.* Cornell University, Ithaca.

Iwasaki, K 1985. Regional classification of climatic change and variability in Australia since 1840. Toya, H., Takeuchi, K. and Ohmori, H. eds.: *Studies on environmental changes due to human activities in the semi-arid regions of Australia,* Dept. Geogr., Tokyo Metropol. Univ., 19-27.

Kou, Z. 1994. Amelioration of desertification and construction of sustainable landuse system in Wulan-Aodu area. *The 2nd International Symposium on Desertification,* Tsukuba, 5p.

Nan, Y. 1994. Research on plant ecology in ameriolation process in desertification of Kerqin Sandland. *The 2nd International Symposium on Desertification,* Tsukuba, 8p.

O' Conner, T. G. 1994. Comparison and population responses of an African savanna grassland to rainfall and grazing. *Journal of Applied Ecology, 31,* 155-171

Orloci, L. and Mukkattu, M. M. 1973. The effect of species number and type of data on the resemblance structure of a phytosociological collection. *Journal of Ecology,* 61, 37-46.

Smith, R S. and Rushton, S. P. 1994. The effects of grazing management on the vegetation of mesotrophic (meadow) grassland in Northern England. *Journal of Applied Ecology,* 31, 13-24.

Toya, H., Takeuchi, K. and Ohmori, H. eds. 1985. *Studies of environmental changes due to human activities in the semi-arid regions of Australia.* Dept. Geogr. Tokyo Metropol. Univ., 317p.

van Varen, D. and Coblentz, B. E. 1987. Some ecological effects of feral sheep on Santa Cruz Island, California, USA. *Biological Conservation 41*: 253-268.

Zhu, Z., ed. 1988. *Desertification and rehabilitation in China.* The International Centre for Education and Research on Desertification Control, Lanzhou, 222p.

Zhu, Z., Zou, B., Di, X., Wang, K., Chen, G. and Zhang, J. 1988. *Desertification and rehabilitation - Case study in Horqin Sandy Land.* Institute of Desert Research, Academia Sinica, Lanzhou, 113p.

Part VI Research on Soil Degradation

Comparative Study of Desertification (Soil Degradation)

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1. Introduction

Desertification can be defined as land degradation induced by human activities and experienced under humid climate as well as semi-arid and arid climate. Human activities include not only agriculture and/or grazing but the construction of roads and/or water ways, mining operation, etc. Land degradation involve the integrated deterioration of land cover, which is detected as the reduction of vegetation coverage of the land surface, the change of the type of plant communities, soil erosion and the decline of soil fertility. This paper focuses on the desertification from soils point of view, i.e. soil degradation. Some examples of soil degradation observed somewhere in the world are described and compared in terms of its type, causes and impact on human welfare.

2. Soil Degradation

Lal and Stewart (1990, 1992) classified the processes of soil degradation into the following three categories;

1) physical processes such as the deterioration of soil structure (slaking and the formation of surface crust), the increase in bulk density (compaction), the changes of soil water and temperature regime,

2) chemical processes such as leaching, acidification and elemental imbalances (salinization, deficiency or toxicity of a specific element, laterite formation),

3) biological processes such as the depletion of soil organic matter, the decrease of bio-diversity and the increase in soil-borne pathogens.

These processes are usually not independent but work together and make the problems more serious and complicated (Lal, 1990). These processes are affected by natural factors (e.g. climate, hydrology, topography, parent material, vegetation, etc.) as well as socio-economic, even political, factors (e.g. population pressure, land use, roads and water-ways construction, waste disposal, agricultural practices, land tenure, etc.). They can be initiated by natural causes as well as anthropogenic causes. Natural causes are soil characteristics such as an effective soil depth, clay mineralogy type and texture. Anthropogenic causes include mismanagement in farming systems (e.g. deforestation, tillage and rotation method, application of agro-chemicals and fertilizers, pest control measures, erosion control practices, etc.) and socio-political problems (e.g. land tenure, properties rights, legislation, etc.). In most of the cases of soil degradation in the world, the anthropogenic cases play more important roles than the natural ones. Followed are some examples of the analysis on the type, causes and impact of soil degradation observed in the world.

3. Soil degradation in the world

Case in Northeast Thailand

Type of soil degradation

In Thailand, forest occupied 53% of the total land area in 1961 and decreased to 28% in 1987. Forest in Northeast Thailand is 12.7% of that region, which is far less than the average. Two types of soil degradation are encountered, i.e. soil erosion on hilly lands and salinization in the depression. According to Department of Land Development, almost 90% of Northeast Thailand are more or less subjected to soil erosion and about 30% of them is moderately eroded soils. Mitsuchi *et al.* (1986) and Miura *et al.* (1990) reported that 17% of the lowlands are salt-affected soils.

Causes of soil degradation

Northeast Thailand receives about 900mm per annum and has potential evapotranspiration of 1800mm, thus, the climate of this region is sub-humid. Precipitation is concentrated in two rainy seasons (May through June and September) and dry season in November though February is quite severe. Thai farmers have traditionally been working for lowland rice cultivation in the valley bottoms and/or flood plains and, thus, uplands under forest vegetation in that region have been used for supplemental crop production. Due to the population growth of their own and immigrants from mountainous areas in and adjacent to Northeast Thailand, forest, however, has been cleared for the development of upland farms since 1960s. New farmers settled on the hill slopes started upland rice cultivation and moved to cassava and corn after the decline of soil

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fertility. Soils in this region are mostly sandy and their inherent fertility is very low. Deforestation for the development of upland farm decreases the amount of water evaporated through vegetation, resulting in the increase of surface run-off as well as percolation water through soil bodies. The former induced soil erosion, while the latter contributed to higher water table, which transported salts from soil bodies up to soil surface, in other words, salinization started. The soils in this region inherently include high percentages of NaCl in soil bodies (Sinanuwong and Takaya, 1974; Furukawa, 1992). Major reasons of soil degradation here are population growth, immigration from the surrounding areas, scarcity of farm land for subsistent agriculture, low inherent soil fertility, rise of ground water level and high salt-containing soil material.

Impacts and countermeasures

Soil erosion on the lower part of hill slopes tends to contribute not only to the deterioration of upland farm but the expansion of salt-affected soils near the edges of the depressions. Both of soil erosion and salinization lead the decline of crop yield, which may produce more peasant farmers. Among countermeasures, mulching and forestation of Eucalyptus seems to be promising. Eucalyptus with grass mulch grows fast and contributes to the protection against soil erosion on the hill slopes, to supplying fuel wood and can be sold for pulp industry. Eucalyptus also evaporates a lot of water, contributing to lowering the water table in the lowlands as well as the upland, which is expected to reduce salinization hazard in the lowlands. Schematic diagram depicting causes and impact of soil degradation in Northeast Thailand is shown in Fig. 1 .

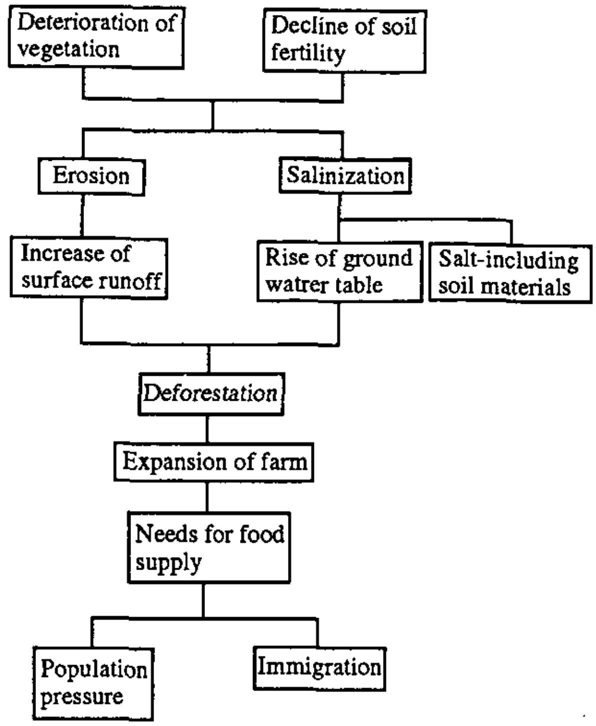

Fig. 1 Causes and impact of soil degradation of NE Thailand.

Case in East Africa

Type of soil degradation

Rwanda and the eastern part of Zaire are located in the area of Great Rift Valley of East Africa. Most of the area is more than 1,000m above sea level. This region is mountainous and steep topography, although the climate is quite mild. Soils are derived from basaltic lava and very fertile, if compared to those in other parts of Africa. Almost all hill slopes are permanent farms and utilized for staple food production, mainly banana, kidney beans, cassava, sorghum, sweet potatoes and maize. Soil degradation encountered in this region is sheet erosion and the subsequent decline of soil fertility.

Causes of soil degradation

As mentioned above, soils are very fertile here, thus, the area is very densely populated since before the independence. Although we do not have detail census data, it is even said that the population density in this region is over 800 persons/km^2 and the population is still rapidly increasing. Jurion and Henry (1969) reported that the farms were originally rotated with long fallow (about 20 years). They are now, however, split into small pecies and continuously cultivated. Some farms may have a short fallow period (2 to 3 years). The farmers tend to open new farms on steep hill slopes and/or swamps which have not yet fully utilized before.

The area has quite high rainfall (ca. 1,400mm per annum) with cool temperature (17 to 19°C). Although natural vegetation was forest, some part of it was cleared for the cultivation of cinchona and chrysanthemum as exporting cash crops at the time of Belgian occupation. Such plantation farms were managed with contour cropping with rows of elephant grass against soil erosion on the steep slopes. They were, however, reformed into the farm for staple food crops after the independence and some rows were removed, where we now observe serious erosion problem. Major reasons of soil degradation here are high population pressure, scarcity of farm land for subsistent agriculture, high rainfall, steep topography and mismanagement of farms in terms of erosion control.

Impact and countermeasures

Erosion induces the loss of not only fine soil particles but nutrient cations and organic matter, causing deterioration of soil fertility as well. Deforestation for the development of new farms to feed the increasing population may accelerate soil erosion with the increase of surface runoff. Swamps and lowland shall be utilized more intensely and we must develop an appropriate technology for efficient utilization of lowland, since no one have yet taken serious consideration on lowland in this region.

Although the farm on the hill slopes are subjected to serious erosion, hill tops near housing compound have been carefully managed against soil erosion as well as soil fertility decline. These areas are planted with banana, which is very important cash crop in this region. They produce and sell banana beer, thus, they take very much care of banana farms with applying organic manure made of kitchen waste and animal dung and mulching with weed grasses and banana leaves. Kitchen gardens planted to vegetables are also managed in a same manner in terms of erosion and fertility control. These farms are very rich in nutrient status with favorable soil physical condition. Hence, the author recommends to reallocate of farm plots for erosion and fertility control, so that banana grove be on the slopes and farm for food crop be on the hill tops, because banana grove is very efficient for protecting eroded soil materials. Contour belt with banana grove on sloping farm may also contribute to the protection of nutrient losses in soil solutions as well as mass movement (Kosaki and Kyuma, 1989). Schematic diagram depicting causes and impact of soil degradation in Great Rift Valley area is shown in Fig. 2.

Case in Kazakhstan

Type of soil degradation

In North and Central Asia is distributed 200 million hectares of salt-affected soils under arid and semi-arid climates. The former Soviet Union has developed large-scale irrigation scheme for the production of cotton and rice in Central Asia since 1960s. Environmental problems due to irrigation practices for the last three decades in this area have been recently reported, which include the shrinkage of inland lakes, such as Aral Sea and Lake Balkhash. Farms and surroundings are also affected to show salt-accumulation on the soil surfaces. Rozanov (1984) reported 1 million hectares of irrigated land was lost in Central Asia because of erroneous irrigation practices. According to Khakimov (1981), the percentage of moderate to severe salinized soils in that area reached 60 to 70% and crop yield decreased by 30 to 33%. Soil degradation observed in this area is salinization due to irrigation under the dry climates.

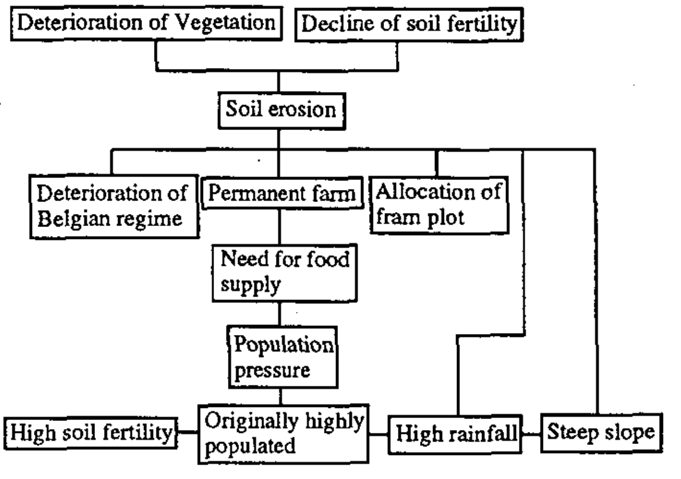

Fig. 2 Causes and impact of soil degradation of Great Rift Valley.

Causes of soil degradation

This area is characterized with very low precipitation (ca. 150mm per annum) and cool temperature (9 °C, average). The original vegetation is semidesert shrub of Haloxylon spp. and land was used for grazing cattle before irrigation schemes were constructed. Population density is very sparse. Soils are more or less sandy and include calcium carbonates and sulfates in the subsoil.

Most of the desert soils have some salt accumulating layers in the soil bodies. In natural condition, such salt accumulation layers can be observed in the subsoil but not in the surface soils. This is because even a very limited amount of precipitation can dissolve salts in soil bodies and let them move down to some depth from the surface. Thus, ordinary upland does not pose salinity problem. Only in the depression with high water table salts are encountered on the soil surface.

Irrigation, however, changes the water regime of upland soils. Once the farm is irrigated, irrigation water percolates through soil solum and raise the level of ground water, if drainage is not very much efficient. Where the ground water table is high capillary connects the ground water and the soil surface. Under the arid climates, evaporation rate is very high and the ground water moves upward. Moving up through capillary, the ground water dissolves salts accumulated in the subsoil and transport them to the soil surface, where only water evaporates and the salts are crystallized on the soil surface. High salts contents in the surface soils may disturb the normal growth of plants and destroy vegetation cover if the situation is serious. Soil degradation (salinization) is due to mismanagement in the application of irrigation water.

Impact and countermeasures

High rate of salts accumulation may induce reduction in crop yield and, if the farms are severely affected, they may turn into barren lands that can not be used for crop cultivation forever. Once salts are accumulated on the soil surface, it is almost impossible to wash or leach salts from the soil bodies with a very limited amount of rainfall and/or irrigation water with good quality.

To avoid the disastrous outcome mentioned above, good drainage system be guaranteed, good quality of irrigation water be used and minimum amount of irrigation water be applied to the plants. All are indispensable in order to keep the salt content in soil solution at minimum and to break capillary between ground water and soil surface.

Cropping system may help to some extent. In the study area, the farms are cultivated with rotation of rice, barley and alfalfa. Only for rice cultivation irrigation water was introduced into farms and not for barley and alfalfa. Salt accumulation is much less in the farm than the surrounding virgin lands as well as in rice farms than barley or alfalfa farms. This is due to regular washing of salts during rice cultivation. Rice cultivation can mitigate salt accumulation in the farms but may accelerate it in the surroundings (Kosaki *et al.*, 1992). Although it is expected that the cultivation of salt accumulating plants may reduce the salts contents in the surface soils, there are still a lot to study in the future. Schematic diagram depicting causes and impact of soil degradation in Kazakhstan is shown in Fig. 3.

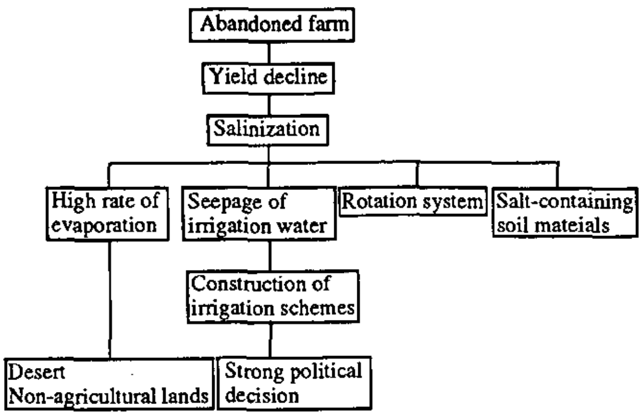

Fig. 3 Causes and impact of soil degradation of Kazakhstan.

4. Conclusions

All the examples of soil degradation described here are induced by human activities, mismanagement of land use. Although some long term changes in local and/or global climate may affect the type and extent of soil degradation, human activities seem to contribute more drastically and may cover the climatic factors. The type, causes and impact of soil degradation varies from one place to another, thus the countermeasures against soil degradation should be surveyed, tested and evaluated with taking account of physical as well as socio-economic conditions in an individual situation. The application of a given countermeasures without detail analysis of the problem site may result in disastrous and irreversible changes in our environment and terminate our life.

References

Furukawa, H. 1992. Finalized working documents on "*Application of reforestation and agro-forestry to soil management in Korat Plateau*" submitted to the Mekong Secretariat.

Jurion, F. and Henry, J. 1969. Can Primitive Farming Be Modernised? *INEAC*, Bruxelles.

Khakimov, F.I. 1981. Soil melioration conditions of desertification of deltas. *Puschino*, Moscow.

Kosaki, T. and Kyuma, K. 1989. Soil fertility of arable land in Zone de Kabare in the Lake Kivu area. In *Agriculture and Soils in Zaire (ed. by Hirose, S.)*, Nihon University.

Kosaki, T., Tsujimura, S. and Ishida, N. 1992. Where and how does salinization take place under large-scale irrigation agriculture in Central Asia? A case study in Kazakhstan., *The Proceedings of the International Workshop on Classification and Management of Arid-Desert Soils.*, Academia Sinica.

Lal, R. and Stewart B.A. (eds.) 1990. Soil Degradation. *Advances in Soil Science*, vol. 11, Springer-Verlag, New York.

Lal, R. 1990. Soil erosion and land degradation, The global risks. *Advances in Soil Science*, vol. 11, 129-172.

Lal, R. and Stewart, B.A. (eds.) 1992. Soil Restoration. *Advances in Soil Science*, vol. 17, Springer-Verlag, New York.

Mitsuchi, M., Wichaidit, P. and Saeree, J. 1986. Outline of soils of the northeast plateau, *Thailand, their characteristics and constraints. Technical paper No. 1. Agricultural Development Research Center in Northeast Thailand, Khon Kaen.*

Miura, K., Wichaidit, P. and Subhasaram T. 1990. Genetic features of the major soils in northeast Thailand. *Technical paper No. 8, Agricultural Development Research Center in Northeast Thailand, Khon Kaen.*

Rozanov, B.G. 1984. Principles of the doctrine on the environment. *IGU.* Moscow.

Sinanuwong, S. and Takaya, Y. 1974. *Simple and feasible technique to suppress salinization and to cultivate plants in moderately to strongly salt affected areas on northeast Thailand.* pp232-240.

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Towards solving the global desertification problem (4)
-Research on the evaluation of interaction
between desertification and human activities-

砂漠化問題の解決に向けて（４）
一砂漠化と人間活動の相互影響評価に関する研究一

Edited by Tadakuni Miyazaki and Atsushi Tsunekawa

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