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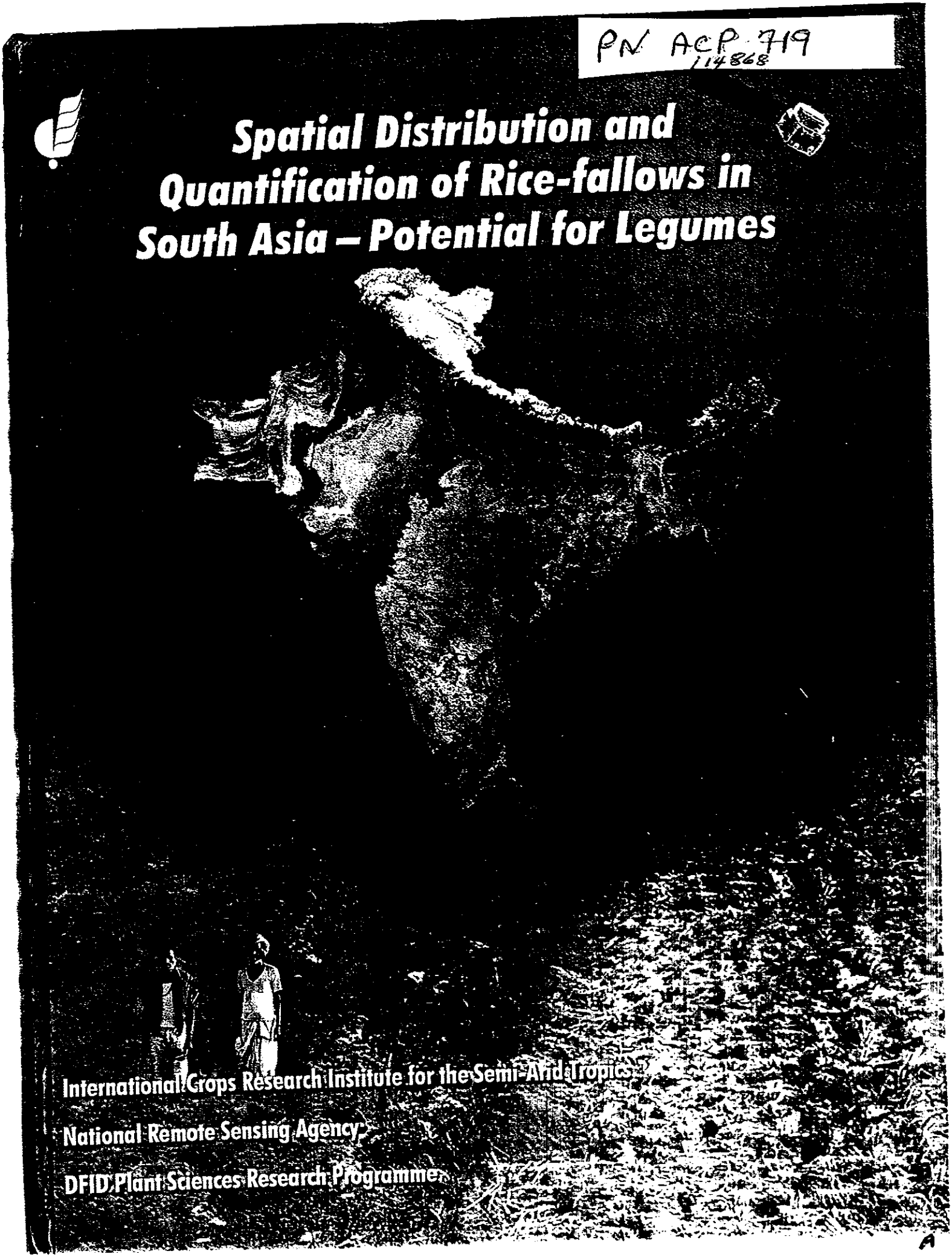
Spatial Distribution and Quantification of Rice-fallows in South Asia – Potential for Legumes



International Crops Research Institute for the Semi-Arid Tropics

National Remote Sensing Agency

DFID Plant Sciences Research Programme

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Abstract

Rice, the most extensively grown crop in South Asia, is cultivated on approximately 50 million ha. Despite growing demands for food production because of an increasing population in South Asia, there is little scope for expansion of cropping into new areas and therefore an increase in cropping intensity, along with raising of yields, needs to take place on existing agricultural lands. Rice-fallows present considerable scope for crop intensification and diversification if the appropriate technology is applied. But there has been limited information on the area of rice-fallows available and on the potential technologies that could be implemented.

This book describes the use of satellite remote sensing and geographical information systems (GIS) technology to develop an accurate and updated quantification and spatial distribution of rice fallow lands and a corresponding classification of their potential and constraints for post-rice legumes cultivation in South Asia (Bangladesh, India, Nepal and Pakistan). These rice-fallows represent diverse soil types and climatic conditions and most of theseareas appear suitable for growing either cool-season or warm-season legumes. Introducing appropriate legumes into rice-fallows is likely to have significant impact on the national economies through increased food security, improved quality of nutrition to humans and animals, poverty alleviation, employment generation and contribution to the sustainability of these cereal-based production systems in South Asia.

This book would provide guidance to policy makers and funding agencies to identify critical research areas and to remove various bottlenecks associated with effective and sustainable utilization of rice-fallows in South Asia.

Cover: False color composite of South Asia taken by Indian Remote Sensing Satellite for the rabi season 1999/2000 (top); chickpea grown after rice (bottom left), and rice-fallow (bottom right).

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Preface

South Asia is one of the major rice-producing regions of the world, having about 50 million ha under this crop. Much of this area has a single crop per year, usually rainy season rice, and no crop is grown after the rains. The large and growing population of the region requires ever-increasing quantities of locally available food grains; so these large areas of land that lie fallow for much of the year are a particular cause for concern in South Asia. They are a major under-utilized resource that could contribute to food security and improve farmers' livelihoods. Moreover, continuous rice cropping can lead to reduced productivity over time and increasing legume cultivation, by replacing fallow, in these rice production systems could contribute to the long-term sustainability of the cropping system.

Precise estimates of rice-fallows and their spatial distribution were not available. The project reported here, supported by DFID Plant Sciences Research Programme, UK, has attempted to quantify rice-fallows in South Asia, by using satellite image analysis, and to document their spatial distribution. Over 14 million ha were found to lie fallow following the 50 million ha of rainy season rice. A GIS (geographical information systems) analysis of these fallow lands has indicated that they represent diverse soil types and climatic conditions. A review of existing technologies indicates that it is possible to productively cultivate legumes (warm season or cool season depending on the location) in most of the rice-fallows that were identified. This study further showed that introducing legumes to replace the rice-fallows could have a considerable impact on the rural economy. An additional legume crop will generate employment opportunities, contribute to poverty alleviation and better food security, and improve the quality of nutrition of humans and animals. An overall improvement in soil health could substantially contribute to the sustainability of these production systems in South Asia.

I am confident, this information will prove invaluable to planners, administrators, and scientists in helping farmers put to productive use the vast potential of rice-fallows in South Asia.

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1. Executive Summary

Rice is the most extensively grown crop in South Asia (Bangladesh, India, Nepal, and Pakistan; Sri Lanka is not included in this study, even though it is part of South Asia), occupying nearly 50 million ha. Much of it is grown in the kharif (rainy) season. A substantial part of this area remains fallow during the rabi (postrainy) season because of several limitations, the prime one being limited availability of soil moisture. Precise estimates of rice-fallows and their spatial distribution are not available. Since rice is grown on some of the most productive lands of this region, there is substantial scope to increase cropping intensity by introducing a second crop during the rabi season. This project has attempted to quantify rice-fallows in South Asia by using satellite image analysis and document their spatial distribution. Using geographical information systems (GIS) tools, we have overlaid the spatial distribution of the rice-fallows on to the climatic and soil information data to understand the soil types and climatic conditions of these lands. This information is critical for developing strategies to utilize these lands for short-season crops that are suitable to the climatic and soil conditions of this region. Legumes such as chickpea, khesari, lentil, mung bean, and black gram are potential crops for rice-fallows. These crops may not require supplemental irrigation and contribute substantially in enriching the fertility status of these soils by fixing atmospheric nitrogen and adding organic matter. In addition they may help in sustaining the rice-based systems by breaking pest and disease incidence associated with sole rice systems. Similarly, they could enhance the microbiological activity and thereby nutrient availability of the soils following rice.

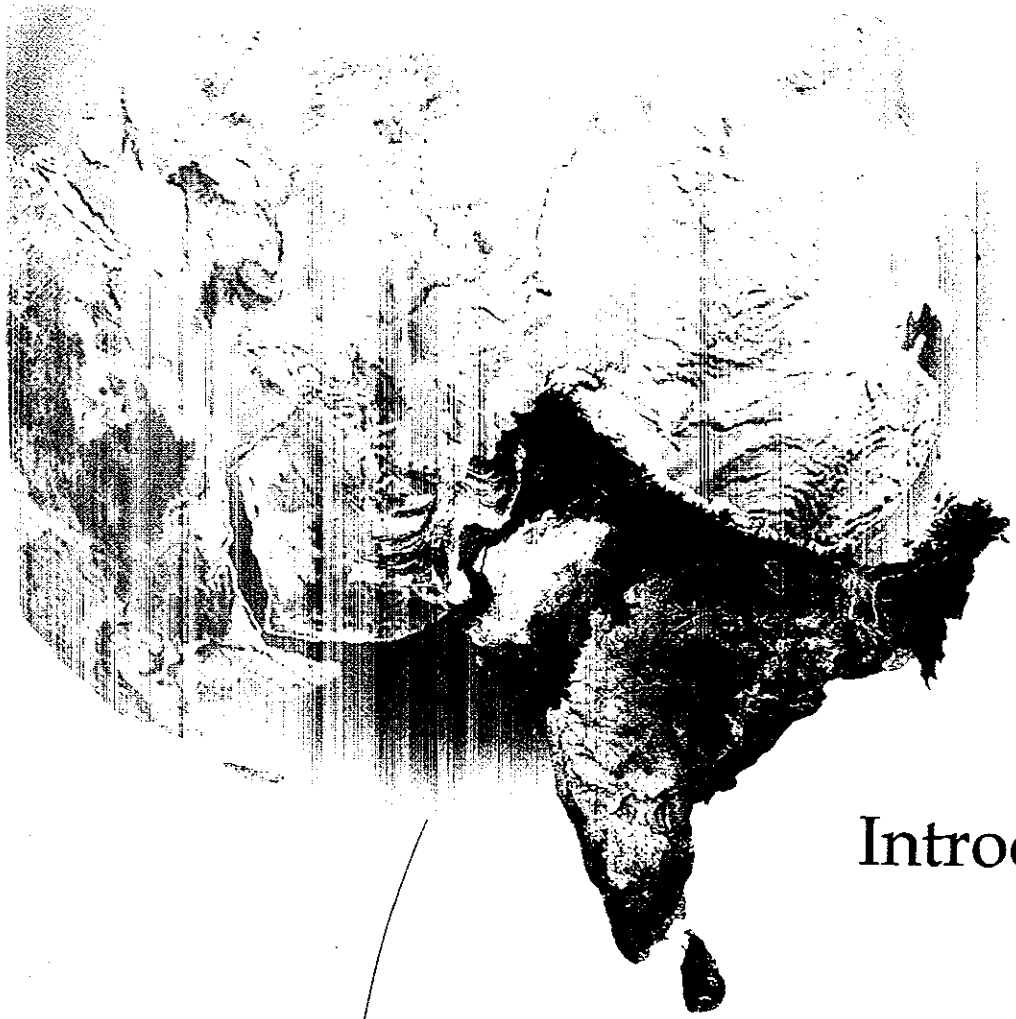
Satellite image analysis estimated that rice area during 1999 kharif season was about 50.4 million ha (Table 1.1). Rice-fallows during 1999/2000 rabi season were estimated at 14.29 million ha. This amounts to nearly 30% of the rice-growing area. These rice-fallows offer a huge potential niche for legumes production in this region. Nearly 82% of the rice-fallows are located in the Indian states of Bihar, Madhya Pradesh, West Bengal, Orissa, and Assam. The GIS analysis of these fallow lands has indicated that they represent diverse soil types and climatic conditions; thus a variety of both warm season legumes (such as soybean, mung bean, black gram, pigeonpea, groundnut) and cool season legumes [such as chickpea, lentil, khesari (lathyrus), faba bean, pea] can be grown in this region. Available soil water-holding capacity (1 m soil profile) for most of these lands ranges from 150 mm to 200 mm. If it is assumed that the soils in these lands are fully saturated during most of the rice growing season, the residual moisture left in the soil at the time of rice harvest will be sufficient to raise a short-season legume crop.

A number of abiotic (soil acidity, salinity, alkalinity, and terminal drought), biotic (diseases and insect pests), and socioeconomic (social unrest, lack of awareness among farmers of legume technologies, and lack of effective policy initiatives to promote legumes) constraints contribute to the lack of cropping during this period in this region. These will have to be addressed by appropriate research and policy initiatives in addition to developing suitable legume varieties that have targeted adaptation to these rice-fallows.

Table 1.1. Estimates of rice areas during the 1999 kharif season, and rice-fallows during the rabi season of 1999/2000 based on satellite image analysis.

Country	Kharif rice area (million ha)	Rice-fallow (million ha)	Rice-fallow as % of rice area	% total rice-fallow in South Asia
Nepal	1.45	0.39	26.9	2.7
Bangladesh	6.36	2.11	33.2	14.8
Pakistan	2.45	0.14	5.7	1.0
India	40.18	11.65	29.0	81.5
Total	50.44	14.29	28.3	

A review of existing technologies indicates that it is possible to productively cultivate legumes in most of these identified rice-fallows. An economic analysis has shown that growing legumes in rice-fallows is profitable for the farmers with a benefit-cost ratio exceeding 3.0 for many legumes. Also, utilizing rice-fallows for legume production could result in the generation of 584 million person-days employment for South Asia (66.7 in Bangladesh, 503 in India, 10.2 in Nepal, and 3.6 in Pakistan; values are in million person-days). Thus, introducing legumes into these rice-fallows will have a multi-faceted impact on the economy through employment generation, poverty alleviation, food security, quality of nutrition to human and animal population, and contribution to the sustainability of these production systems in South Asia.



Introduction

2. Introduction

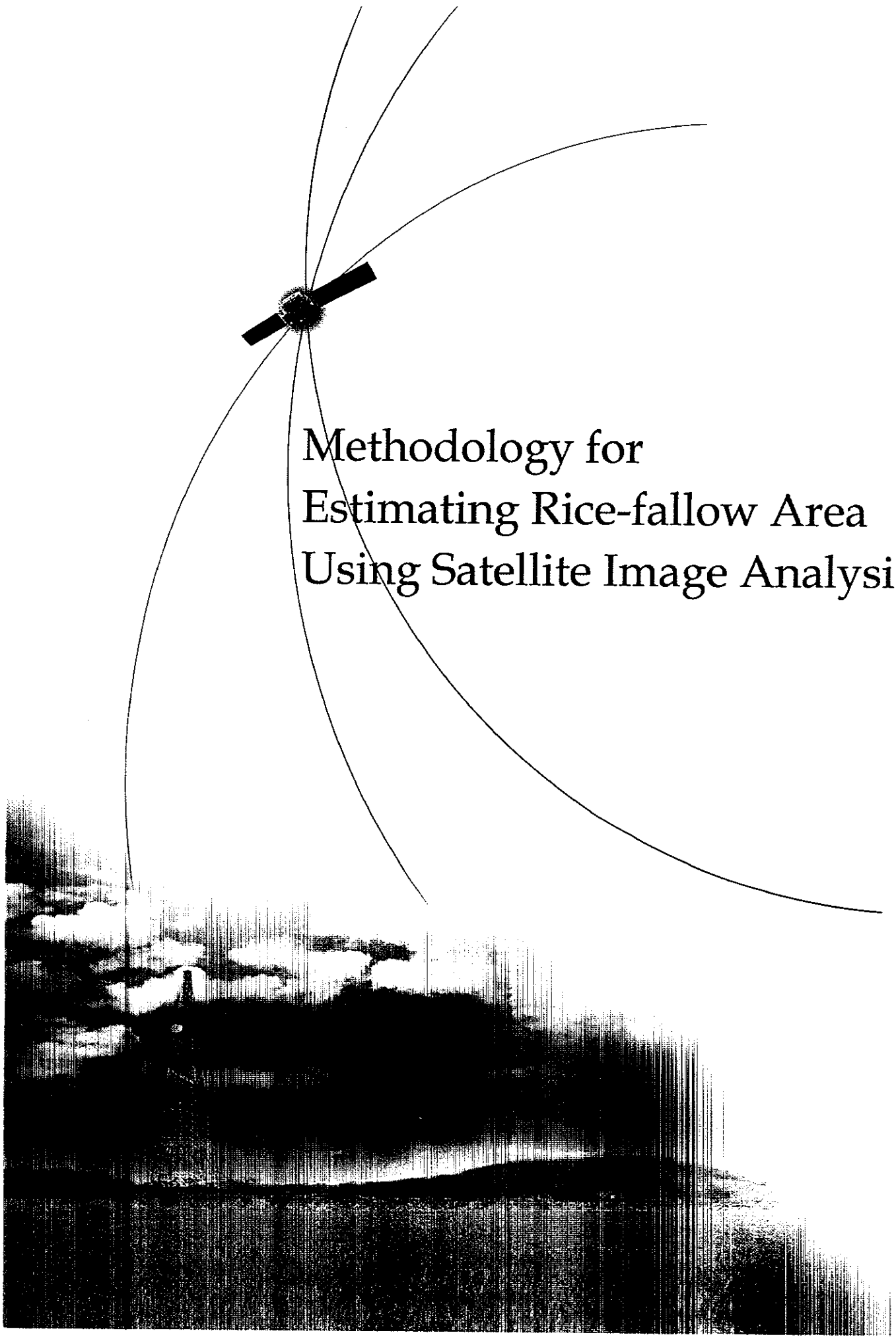
South Asia is one of the major rice (*Oryza sativa* L.) producing regions of the world, with around 50 million ha under this crop. A substantial proportion of this area is under only a single crop, usually kharif (rainy) season rice, with the land remaining fallow during the following rabi (postrainy) season. This situation largely occurs for rainfed rice, where irrigation facilities for either rice itself or a post-rice crop are not available. Nevertheless, residual soil moisture, derived from the previously flooded rice fields that could support growth of a crop after rice, remains available well into the rabi season. Large areas of land lying fallow for a considerable proportion of the calendar year are particularly cause for concern in South Asia, for two main reasons. Firstly, the large and growing population of the region requires ever-increasing quantities of locally available food grains and fallow lands on which crops could potentially be grown represent under-utilization of agricultural land resources. Secondly, continuous cereal cropping, in this case rice, is unsustainable over time and some form of crop rotation or diversification is desirable for agricultural production system sustainability (Paroda et al. 1994, Hobbs and Morris 1996).

It would be desirable to increase the cultivation of legumes, which are already to some extent cultivated after rice in South Asia (Johansen et al. 2000b), in these rice-fallows for several major reasons. Firstly, there are growing shortages of legume grains in the region, as indicated by increasing imports. Secondly, legumes have ameliorative effects in cereal-based cropping systems and thus contribute to their long-term sustainability (Kumar Rao et al. 1998). The constraints and opportunities for legume cultivation in subtropical South Asia, including cultivation after rice, have recently been reviewed (Johansen et al. 2000b). Various technologies, including appropriate cultivars, are now available that would increase feasibility of legume cultivation after rice. Examples of application of these technologies to increase legume cultivation in rice-fallows are available, such as use of seed priming to promote chickpea (*Cicer arietinum* L.) cultivation after rainfed rice in the High Barind Tract of Bangladesh (Musa et al. 1999).

To assess the scope for increasing cultivation of legumes in rice-fallows of South Asia, better quantification of rice-fallow areas than is now available is required. Estimates currently available are derived from government-recorded crop statistics, by subtracting areas of rabi crops from area of kharif rice. This procedure can only indirectly approximate actual rice-fallow areas. Advances in the application of satellite imagery to quantify land use patterns have made it feasible to estimate more precisely areas of

fallow lands after kharif season rice (Venkataratnam 1999). Further, geographical information systems (GIS) technology can be combined with satellite imagery to relate spatial and temporal distribution of rice-fallows with the various climatic and edaphic variables that would determine legume adaptation and constraints to their cultivation. By incorporating socioeconomic information relating to legume cultivation after rice it is thereby possible to assess suitability of particular legumes for specified rice-fallow situations. This approach is attempted in the project described in this report. The South Asian countries of Bangladesh, India, Nepal, and Pakistan have been chosen for this study and recommendations for better utilization of rice-fallows through legume cultivation have been derived for these countries.

Methodology for Estimating Rice-fallow Area Using Satellite Image Analysis



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3. Methodology for Estimating Rice-fallow Area Using Satellite Image Analysis

Satellite remote sensing is now considered as an appropriate tool for deriving information in spatial and temporal domains by providing multi-spectral reflectance data at regular intervals in a synoptic mode. Also, satellite data are amenable to geo-referencing, thus making it compatible with analysis by GIS. The rice acreage and production at district, state, and national levels are being routinely generated with the techniques developed and tested under Crop Acreage and Production Estimation (CAPE) project using single date Linear Imaging Self Scanning Sensor (LISS-I/II) data of Indian Remote Sensing Satellites (IRS 1A/1B) (Parihar et al. 1990).

The second generation Indian Remote Sensing Satellites (IRS-1C & 1D) have three sensors on-board, viz., the Panchromatic Camera (PAN), the LISS-III, and the Wide Field Sensor (WiFS). The PAN data is of high resolution at 5.8 m in a single spectral band of 520 to 750 nm, and is mainly useful in micro-level planning, e.g., for infrastructure development. The LISS-III provides reflectance data in green, red, and near-infrared bands at 23.5 m spatial resolution and at 24 days re-visit, covering a swath of about 141 km. This data is found to be useful for identification of cash crops such as chili (*Capsicum annuum* L.) and tobacco (*Nicotiana tabacum* L.) grown in small land holdings and for improved discrimination of different crops grown under multiple crop situations (Krishna Rao et al. 1997).

The WiFS sensor provides reflectance data in red and near-infrared bands at 188 m spatial resolution and at 5 days re-visit, covering a swath of about 812 km, and is useful in deriving regional level crop information. High frequency of the availability of the WiFS data due to the short re-visit period also facilitates the monitoring of crops (Kasturirangan et al. 1996). WiFS data was found to be suitable for deriving regional information on the spatial distribution of rabi rice crops grown in the Godavari delta of East Godavari and West Godavari districts and pulse crops cultivated in the kharif rice-fallow fields of the Krishna delta of Krishna and Guntur districts of Andhra Pradesh, India (Navalgund et al. 1996). National level wheat (*Triticum aestivum* L.) production forecast using multi-date WiFS data is operational under the Forecasting Agricultural Output using Space, Agrometeorology and Land-based Observations (FASAL) project (SAC 1999). Also, the procedures were developed and are operational to estimate rice cropped area using microwave data from RADARSAT (Chakraborty et al. 1997) under FASAL to overcome the problem of non-availability of cloud-free optical satellite data during the kharif season.

In the present study, WiFS data of the 1999 kharif and the rabi 1999/2000 seasons was used to derive the regional level information on the spatial distribution of the kharif rice and rabi rice-fallow lands in the South Asian countries of Bangladesh, India, Nepal, and Pakistan.

Scientific Rationale of the Approach

Remote sensing is largely concerned with the measurement of surface reflectance of energy (from the sun) from objects and drawing inference from such reflectance for identification of objects of interest (Colwell 1983). In response to the incident solar radiation, different objects on the earth's surface characteristically exhibit different spectral reflectance patterns, which enable their identification/discrimination. The satellite sensors capture this reflected energy and transmit the signal to ground stations, which is subjected to processing, analysis, and interpretation. An understanding of the physical properties and the physiological processes and their interaction with incident solar radiation is the key element in the discrimination of different land and vegetation types. Plant parameters such as leaf structure, pigmentation, exposure to the illumination source, phyllotaxy, turgidity, and nutritional status influence the reflectance pattern.

Typical spectral reflectance patterns of green leaf

Leaves have both diffuse and specular characteristics. The diffuse leaf reflectance emanates primarily from the interior of the leaf through multiple scattering. The specular character of leaf reflectance at the surface of the leaf is primarily affected by topography of the cuticular waxes and leaf hairs. The green plant has spectral reflectance characteristics, which are quite distinct from most other objects on the earth's surface. The reflection of the sun's radiation by green leaves is relatively low in the visible portion of the electro-magnetic spectrum (EMS), in the 400–700 nm region. A high proportion of the incident sunlight energy is in the blue part (400–500 nm). The red part (600–700 nm) of the spectrum is absorbed by leaf pigment (chlorophyll) to be chemically transformed in the process of photosynthesis. Light energy in the green part of the spectrum is reflected to a slightly higher degree and the human eye perceives the green color of the plant as the dominant color. A healthy plant reflects radiation energy in the infrared part (700–900 nm) of the spectrum to a much higher degree than most other objects. The high reflectance in infrared is due to the internal structure of the leaves. In the spectral region of 1300–2700 nm (near thermal infrared), the main water absorption zones are 1450 nm, 1950 nm, and 2600 nm (Hoffer 1978).

Reflectance pattern of rice crops and rice-fallow fields

The reflectance spectra of plant canopies are a combination of the reflectance spectra of the plants and of the underlying soil (Guyot 1990). When a plant canopy grows, the soil contribution progressively decreases. Thus, during the active vegetative growth phase, the visible and middle infrared reflectance decreases and the near infrared reflectance increases. During senescence, the reverse phenomenon occurs. Maximum reflectance from the vegetation is sensed when the crop canopy fully covers the ground, which coincides mostly with the beginning of the reproductive phase. Hence, in this study, satellite data corresponding to this stage were selected to discriminate the rice crop in the kharif season.

After the harvest of kharif rice, the land will be either left fallow or cultivated with a suitable crop in the following rabi season. The time gap between the harvest of the kharif rice and the cultivation of the rabi crop depends upon the suitability of the prevailing weather, availability of water, etc. Satellite data of the period soon after the harvest of kharif rice crop will depict large area under fallows though these lands are sown with rabi crop because of poor manifestation on the image leading to an over-estimation of the fallow lands. In order to properly estimate the post-kharif rice-fallows, the satellite data of rabi period was selected based upon the prevailing cropping pattern of the region, and coinciding with the likely maximum vegetative stage of the dominant crop when the crop is manifested clearly and discernable on the satellite data.

Methodology

The methodology essentially consisted of selection of the datasets, processing of the satellite data, incorporation of ground information, analysis of the satellite data, and generation of the output products in hard and soft formats. Various steps used in the analysis are depicted in Figure 3.1.

Selection of the satellite datasets

Agronomic information is essential and is utilized in the selection of satellite datasets to identify and best discriminate the rice crop from other agricultural land covers. The crop calendar, which provides information on the staggering in the transplantation operations of the paddy crop across the study area, was utilized in the selection of the appropriate satellite data. Efforts were also made to have a uniform database across the study area so as to obtain the standardized estimates as well as to optimize the number of satellite datasets required for the investigation. In case of administrative regions (e.g., state in India) occupying large width, greater than the WiFS swath of 812 km, multiple

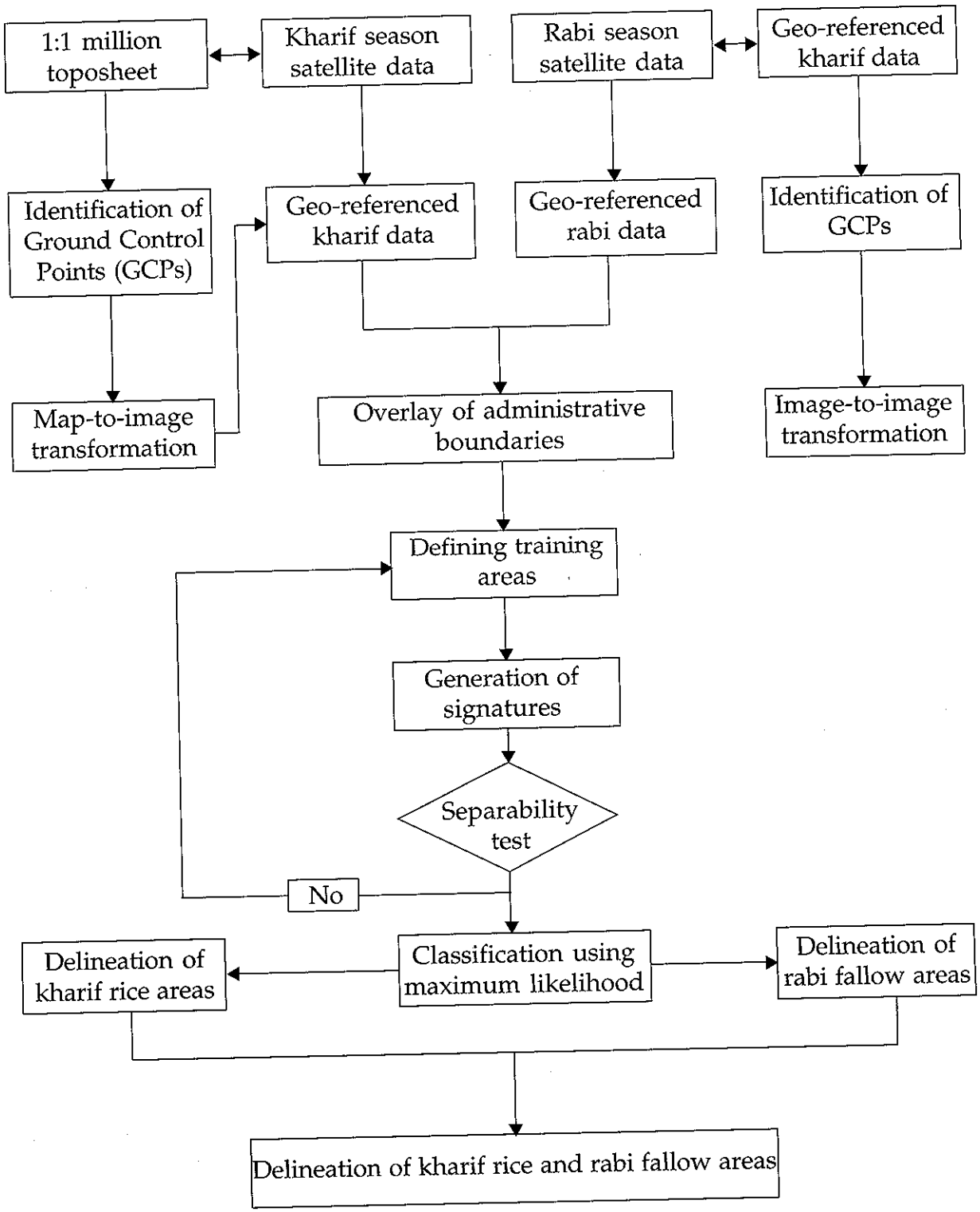


Fig. 3.1. Methodology for delineation of kharif rice and rabi fallows using satellite data

(2 to 3) satellite datasets within a season were used. Subsets of the satellite data, to the extent of the administrative region coverage, were extracted and the analysis was carried out at individual administrative region level. The corresponding datasets were mosaicked and the administrative boundaries were overlaid. The satellite datasets used in the study are provided in Table 3.1.

In general, IRS-WiFS data corresponding to the peak biomass stage of rice during the kharif 1999 season (October to November) and the data of the rabi 1999/2000 (January to March) were used. The state-specific crop calendar information was utilized in this step considering the variations of rice cropping period within the kharif rice season across regions. This was also essential as the post-kharif season would also vary as influenced by the actual rice-growing period during the kharif season.

In Bangladesh, use of several images from early February to March were required to differentiate lands remaining fallow throughout the winter. Some rabi crops, such as mustard (*Brassica* sp) and lentil (*Lens culinaris* Medic.) were harvested during February and thus their vegetative signatures can only be obtained in early February. In some areas boro rice is planted during February and thus its signatures can only be obtained in March. Hence, satellite data of March acquisition was considered optimal and used for analysis in deriving the post-kharif rice-fallows. Therefore, rice-fallows were calculated by subtracting areas shown as cropped in February but fallow in March from the area shown as fallow in March.

Processing of the satellite data

Geo-referencing of the datasets. Toposheets generated by Survey of India on 1:1,000,000 scale were used in the study, which were geo-referenced to polyconic Everest projection and subsequently used for geometric correction of the satellite datasets. The first date satellite data of kharif or rabi seasons were registered with these projected toposheets using an affine transformation technique followed by re-sampling to obtain the geo-referenced image, which was subsequently considered as the master image. In this step, adequate number of well-distributed ground control points (GCPs) were identified and used to minimize the errors in registration of the datasets. The satellite data of the subsequent dates were co-registered with this master image. ERDAS – IMAGINE 8.0v (ERDAS 1999) was used in geo-referencing of the data. Polyconic projection was applied uniformly to all the datasets with graticular (latitude/longitude) information in degrees. Common central meridian points and origins were used in developing models for geo-referencing of wider regions, which were not covered in a single swath of WiFS; this enabled efficient geo-referencing while mosaicking and facilitated easier import into GIS via ArcInfo software.

Table 3.1. Satellite datasets used in the study.

Satellite	Path/Row	Date of pass	Coverage
IRS-1D	100-56	01-11-1999	Madhya Pradesh, Maharashtra – India
IRS-1D	100-59	01-11-1999	Madhya Pradesh, Maharashtra, Andhra Pradesh – India
IRS-1D	95-50	02-09-1999	Punjab, Haryana, Uttar Pradesh – India
IRS-1D	96-49	30-08-1999	Punjab, Haryana, Uttar Pradesh – India
IRS-1D	93-50	03-10-1999	Pakistan; Punjab, Haryana – India
IRS-1D	83-52	08-10-1999	Pakistan
IRS-1D	89-47	20-09-1999	Pakistan
IRS-1D	89-52	20-09-1999	Pakistan
IRS-1D	99-52	10-10-1999	Nepal; Uttar Pradesh – India
IRS-1C	103-53	10-10-1999	Nepal; Uttar Pradesh, Bihar, Madhya Pradesh – India
IRS-1D	99-56	10-10-1999	Madhya Pradesh – India
IRS-1C	103-56	10-10-1999	Madhya Pradesh, Bihar, Orissa – India
IRS-1D	97-51	16-10-1999	Nepal; Uttar Pradesh, Rajasthan – India
IRS-1D	95-50	18-10-1999	Punjab, Haryana, Uttar Pradesh – India
IRS-1C	95-60	18-10-1999	Maharashtra, Karnataka – India
IRS-1D	95-55	18-10-1999	Maharashtra, Rajasthan – India
IRS-1C	101-54	24-10-1999	Nepal; Uttar Pradesh – India
IRS-1C	106-54	25-10-1999	Bangladesh; West Bengal, Assam – India
IRS-1D	110-54	27-10-1999	Bangladesh; Assam – India
IRS-1D	107-59	11-10-1999	Bangladesh; Assam – India
IRS-1C	96-61	16-11-1999	Karnataka, Kerala, Andhra Pradesh – India
IRS-1C	100-62	12-11-1999	Andhra Pradesh – India
IRS-1C	100-67	12-11-1999	Tamil Nadu, Kerala – India
IRS-1C	92-57	27-10-1999	Gujarat – India
IRS-1D	113-52	12-11-1999	Assam – India
IRS-1D	113-56	12-11-1999	Bangladesh; Assam – India
IRS-1C	97-59	01-02-2000	Madhya Pradesh, Maharashtra – India
IRS-1C	103-66	02-03-2000	Tamil Nadu – India
IRS-1D	90-47	14-02-2000	Pakistan
IRS-1D	90-52	14-02-2000	Pakistan
IRS-1C	100-66	16-02-2000	Tamil Nadu, Kerala – India
IRS-1D	104-53	22-02-2000	Nepal; Uttar Pradesh, Bihar – India
IRS-1D	94-50	27-02-2000	Punjab, Haryana, Rajasthan – India
IRS-1D	94-55	27-02-2000	Punjab, Haryana, Rajasthan – India
IRS-1D	111-56	22-03-2000	Bangladesh
IRS-1C	108-55	17-03-2000	Bangladesh; West Bengal, Assam – India
IRS-1C	99-52	06-03-2000	Nepal; Uttar Pradesh – India
IRS-1C	99-57	06-03-2000	Maharashtra – India
IRS-1C	104-58	07-03-2000	Orissa, West Bengal – India
IRS-1C	92-57	31-01-2000	Gujarat – India
IRS-1D	113-53	26-01-2000	Assam – India
IRS-1D	100-62	5-03-2000	Andhra Pradesh, Karnataka – India
IRS-1C	103-61	2-03-2000	Andhra Pradesh, Madhya Pradesh, Orissa – India

Overlaying of the administrative boundaries and forest masks. The administrative boundaries of the countries were overlaid on the satellite data to generate country level information and to develop the output products. In case of India, state-wise boundaries were overlaid. Forest masks were also generated and were excluded in the classification of satellite data.

Ground truth information

Ground information is essential, right from the selection of the data to the verification of the results at various intermediate steps such as defining the training areas, generation of spectral signatures, testing the separability, and classification of the satellite data. Since the analysis was carried out corresponding to the postharvest period of these crops, real time ground truth was not used in this project. Hence, ground information as available in the form of published literature was used to derive the information on the growing period and distribution of crops in India.

Ground information for Pakistan and Bangladesh was provided by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) for use in the analysis. In case of Nepal, the ground information of Uttar Pradesh and Bihar states of India was extrapolated because of the spatial contiguity of these two regions.

Post-classification verification/validation

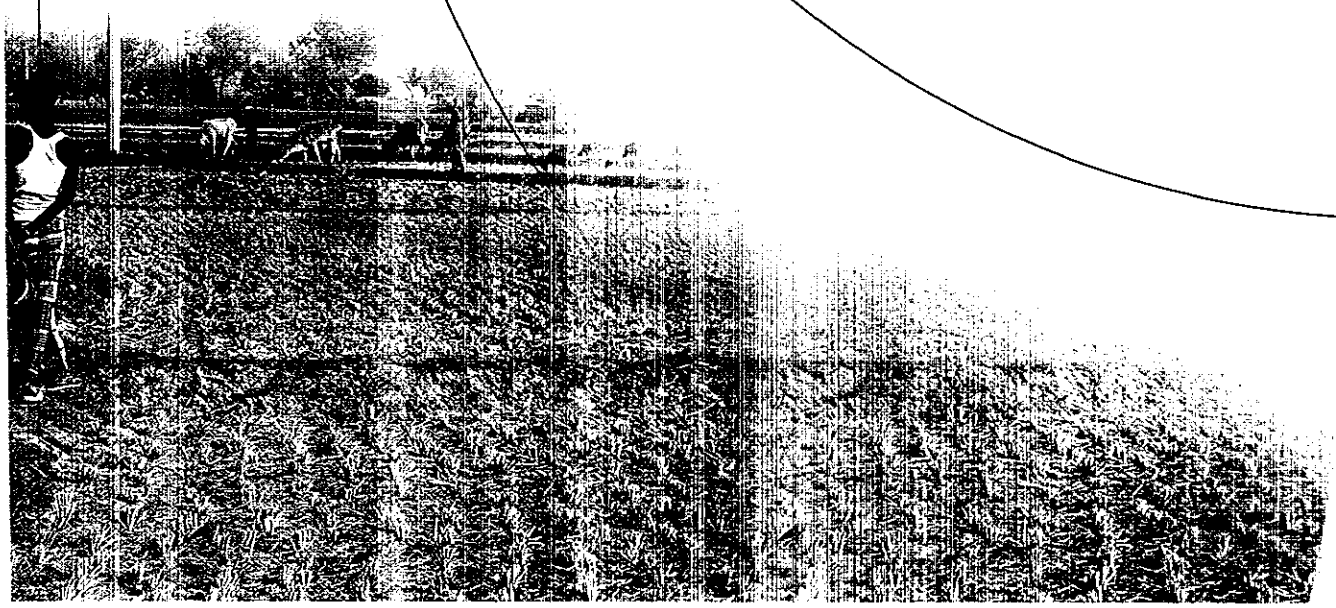
The classified outputs of kharif 1999 showing the cropped areas and the rice-fallows of rabi 1999/2000 of Bangladesh were provided to ICRISAT for verification of the cropping pattern. The feedback enabled the labeling of different crop classes properly. Also, it was possible to discriminate early and late transplanted rice crops due to their characteristic variations in the spectral reflectance patterns.

The kharif rice area estimates using RADARSAT data and wheat area estimates using WiFS data of the national level rice and wheat production estimation projects under the ongoing FASAL project were also used in verifying the classification results for the estimation of kharif rice and the wheat area in the following rabi season.

Use of GIS for Rice-fallow Characterization

The GIS was used to create simple overlays of pedo-climatic variables along with the rice-fallow data generated from remote sensing satellite. The rice-fallow data were vectorized and used as a layer for overlay. ArcView software from ESRI (Environmental Systems Research Institute, California, USA) was used to make the overlays. The pedo-climatic variables were obtained from different sources [soils from the Digital Soil Map of the World (DSMW) (FAO 1996), climatic variables as gridded surfaces from the International Water Management Institute (IWMI), Sri Lanka]. A soil water balance model (WATBAL - Keig and McAlpine 1974) was used to estimate the available soil water spatially (2.5 arc minutes = 4.5 km approximately) and temporally (monthly) using the above pedo-climatic datasets. The program coded in Fortran, used in running the water balance model, was developed by P. Jones of Centro International deAgricultura Tropical (CIAT), who patterned it after the Basic-Plus example by Reddy (1979). The program was modified to suit the available data. The input data for the WATBAL model are precipitation and potential evapotranspiration (PE) as gridded interpolated surfaces from point data. The interporlated climatic surfaces are available at monthly temporal resolution. The maximum soil water-holding capacity (SWHC) is extracted from DSMW and its derived soil properties (FAO 1996). The SWHC is the upper bound of the moisture storage capacity class with highest percent value under the mapping unit. These raster surfaces, which are a matrix of grid cell values, were converted to ASCII format for the purpose of faster processing and used as inputs to the model. The model estimates the available soil water at each grid cell for each month as the sum of soil water storage of the previous month and the precipitation during the month minus the soil water loss as actual evapotranspiration (AE) during the month. The AE during the month is calculated as the ratio of AE/PE multiplied by PE. The ratio of AE/PE was taken as equal to 1.0 for soil moisture percentages from 100% down to X% and decreases linearly to 0 thereafter, where X is calculated from a square root function, 3+3.868*(SQRT(SWHC)), that fits the three values of X supplied by Reddy (1979); i.e., 30, 50, 70 for soil holding capacities of 50, 150, 300 mm, respectively. The outputs in the ASCII format are again converted into raster surfaces using ArcInfo GIS. This averaging process was intended only to give an overall impression at a national level of spatial and temporal variations in soil water availability parameters. It would not necessarily be sufficiently rigorous to accurately simulate soil water status at a given point in space and time.

The Rice-fallow Environment



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4. The Rice-fallow Environment

Although it is obviously desirable to cultivate legumes, or other crops, after rice, rather than leaving the land fallow, there are several major reasons why farmers refrain from doing this. The more generic abiotic, biotic, and socioeconomic constraints to cultivation in rice-fallows, common across most rice-fallows in South Asia, are summarized below. They will be discussed more specifically in relation to agro-environmental conditions elaborated in each country section but it is intended here to provide a general background to the target environment of this study.

Agronomic requirements for paddy cultivation such as puddling and the requirement of standing water create unfavorable conditions for legume cultivation after the harvest of rice. Puddling of rice soils results in a massive structure-less top soil, underlain by a plow-pan or compaction layer (generally between 15 cm and 20 cm deep), which is deliberately created for rice cultivation to limit percolation and reduce drainage (Parihar et al. 1985, Cass et al. 1994). Drying of surface soil and compaction of the plow-pan layer constrains seed germination and seedling establishment (Ramakrishna et al. 1992). Also, significant changes in soil reaction and nutrient availability occur due to the wetting and drying in paddy fields. These adverse soil physical conditions limit subsequent root growth and supply of air, water, and nutrients to roots, which results in poor adaptation of legumes to rice-fallows in general (Cook et al. 1995, Nasr and Selles 1995).

If the soil remains saturated after harvest of rice, as commonly occurs in the high rainfall eastern parts of the Indo-Gangetic Plain, waterlogging may constrain germination of legume seeds and seedling establishment. Many legumes are highly sensitive to soils at or near saturation during the germination stage, which is mostly due to lack of sufficient oxygen for the germinating seed (Richard and Guerif 1988) as well as susceptibility to fungal diseases. Crops such as pigeonpea (*Cajanus cajan* (L.) Millsp.), groundnut (*Arachis hypogaea* L.), and soybean (*Glycine max* (L.) Merr.) are particularly sensitive to waterlogging during germination and early seedling stages, and thus are not suitable for relay planting with rice. By contrast, black gram (*Vigna mungo* (L.) Hepper), lentil, and khesari (*Lathyrus sativus* L.; lathyrus, grass pea) are relatively tolerant of excess water at germination and early seedling stages and are thus better suited for relay planting with rice.

Optimum soil moisture content in the seedbed is critical for germination, crop establishment, and initial crop growth. Tillage of these soils can result in rapid loss of surface soil moisture, resulting in poor plant stand establishment (Hadas 1985). Thus, in general, legume crops that cannot be relay sown with paddy will have a very limited optimum period of sowing

for successful crop establishment. Deep sowing (i.e., 15 to 20 cm deep) places seeds in soil with adequate soil moisture content for germination, but delays emergence of the shoot above the soil surface (Mohammad et al. 1989). This is a common practice for legumes such as chickpea in light-textured upland soils because this crop has the ability to emerge from deeper soil layers. However, deep sowing is usually not practical after rice due to clayey surface soil and hard pan development. Also, as for excess soil moisture, soil moisture deficit in the seedbed can predispose seeds to damage by pathogenic organisms, which can then affect the plant stand establishment (Hadas and Russo 1974).

Soil puddling enhances soil bulk density and thus the pressure seedlings need to exert to penetrate the soil, which is one of the constraints to seedling emergence of legumes in paddy soils (Cook et al. 1995). The mechanical impedance of the drying puddled soil may limit root growth (Vepraskas 1988). Although there are some differences among legumes in their ability to grow roots in a drying puddled soil, root growth rates sharply decrease at 1 to 3 MPa (Taylor and Gardner 1963, Taylor et al. 1966, Taylor and Ratliff 1969), depending on the soil type. The root limiting bulk densities for the clay, clay loam, sandy loam, and loamy sand textural classes are approximately 1.4, 1.5, 1.65, and 1.75 Mg m^{-3}, respectively (Vepraskas 1994). Impeded root penetration can result in moisture deficits at later stages of crop growth, rendering crops particularly vulnerable to terminal drought stress (Greenland 1985, So and Woodhead 1987).

The flooded soil condition during the period of the rice crop lowers soil rhizobial populations (Kumar Rao et al. 1982, Rupela and Saxena 1987), thus adversely affecting nodulation and hence nitrogen (N) nutrition of subsequently grown legumes. There may also be similar adverse effects of flooding on soil mycorrhizal populations, which would limit the plants' nutrient acquisition ability, but we are not aware of any quantification of this effect. The calcareous, alkaline soils of the western and central Indo-Gangetic Plain are subject to constraints of alkalinity and salinity, to which most legumes are particularly susceptible. Alkaline soil conditions particularly predispose crops to zinc (Zn) deficiency. Soils in high rainfall zones, particularly in eastern India and Nepal, suffer from soil acidity (pH <5.5) to which legumes, and particularly their N-fixing ability, are sensitive (Chong et al. 1987). Acid soil conditions predispose legumes to deficiencies of phosphorus (P), molybdenum (Mo), and boron (B).

Seedling fungal diseases, such as collar rot caused by *Sclerotium rolfsii*, are particular problems for legumes grown after rice due to the moist conditions and the presence of rice stubble that acts as a substrate for these saprophytes. Where soil conditions remain moist during the growing period, either due to residual soil moisture in rice paddies or winter rainfall,

foliar diseases, such as ascochyta blight (*Ascochyta rabiei*) in the western Indo-Gangetic Plain and botrytis gray mold (BGM) (*Botrytis cinerea*) in the eastern Indo-Gangetic Plain affecting chickpea, are a severe threat to cultivation of legumes after rice. Legume pod borers, particularly *Helicoverpa armigera*, can severely limit yields of legumes in all ecosystems.

Fields remain fallow after rice primarily through lack of irrigation facilities to support following crops. Such rice lands are usually cultivated by the poorest of rice growing communities, whether as small-holder farmers or share-croppers on lands owned by absentee landlords. Their crop income is essentially limited to one rice crop per year, a crop dependent on rainfall and therefore subject to climatic vagaries, adding further uncertainties to the farmers'situation. However, even with reliable and reasonably high rice yields there would be a limit to income improvement imposed by reliance on rice alone, due to the relative long-term decline in prices of rice grain and the ever-increasing cost of inputs required to maintain rice yields. Therefore, crop diversification offers a means of breaching the ceiling imposed by rainfed rice cultivation. However, investment capabilities of poorer rice farmers are negligible, even those required for the limited inputs necessary for successful grain legume cultivation. Thus, even if reasonable legume yields are possible after rice, the decision of a farmer to proceed is tempered by limited investment capability and the well-known risks associated with legume cultivation. Availability of time to plant legumes is also a problem as this coincides with the time of rice harvest. Generally, little mechanization is available and the crop transition period is very demanding of available human and animal labor. Further, unlike in well-developed irrigated areas, the infrastructure to support legume cultivation after rice is generally lacking. Major components of this infrastructure include ready and affordable availability of required inputs, price support for grain, ready access to markets, and organized marketing ensuring fair farm-gate prices and grain/seed storage capability. Thus although legume cultivation after rice can be demonstrated to be agronomically feasible, it may be socioeconomically too difficult for farmers to attempt.

Despite the hostile environment generally encountered when trying to cultivate legumes after rice, outlined above, there are reasons to believe that this is now becoming more agronomically and socioeconomically feasible. Further, it is becoming more necessary to consider this option so as to meet ever increasing and more diversified food requirements of the South Asia region and to tackle long-term sustainability of rice-based cropping systems. Improved technologies for legume cultivation, including after rice, are now available, making economically viable, and relatively reliable, yields of grain legumes achievable (Johansen et al. 2000b). Further possibilities for making legume cultivation after rice a more feasible proposition for resource-poor rainfed rice farmers in South Asia are presented in later sections of this report.

Results and Outputs

5. Results and Outputs

5.1. Bangladesh

Introduction

Crop production in Bangladesh is a highly intensive activity because of high annual rainfall (varying from 1200 mm to 6000 mm), favorable temperature regimes for both tropical and temperate crops, generally fertile soils, and the high population density. The production system is mostly rice-based, where transplanted (T.) aman rice is traditionally grown during the kharif season and a range of crops is grown with or without irrigation during the rabi season. However, there are substantial rabi rice-fallow areas available particularly in the northwest and in the northern districts, but the spatial distribution of these rice-fallows has not been precisely quantified. The length of rabi growing period ranges from 105 days to 145 days depending on the region, and the rabi season begins during 12 to 21 October (Rahman et al. 2000). Cereal cultivation receives high priority in Bangladesh, particularly to achieve food security for the ever-increasing population (Rahman et al. 2000). If irrigation is available during the rabi season, farmers prefer rice-rice or rice-wheat cropping systems, and thus legumes are being continuously relegated to marginal lands. The area and production of some legumes such as lentil and chickpea have decreased over the past decade (Razzaque and Sattar 1998). Pulses production has been nearly stagnant in the country for the last two decades (Rahman et al. 2000). With the increase in population, the per capita availability of pulses has been decreasing significantly (Rahman et al. 2000). Utilizing rice-fallows for the production of short-season pulses during rabi season could substantially contribute to increased pulses production in the country. Also, this would contribute to soil fertility maintenance, and other beneficial factors associated with crop rotation with legumes in this predominantly rice-based production system. This section assesses, quantifies, and documents the distribution of rice-fallows in Bangladesh using a combination of satellite image analysis and GIS tools. The potential of introducing suitable legumes into these rice-fallows is evaluated in the context of various biotic, abiotic, and socioeconomic factors limiting production of grain legumes in rice-fallows.

Total Rice Area

During 1996/97, the area under T.aman rice was recorded in official statistics as 5.735 million ha (BBS 1997). The satellite image analysis estimated T.aman rice area for 1999 at 6.36 million ha, which is within the expected range of T.aman rice area for Bangladesh. The unclassified (i.e., raw) and classified satellite images of kharif 1999 are given in

Figure 5.1.1 (see Table 3.1 of Section 3 for details of the dates of satellite images used for quantifying T.aman rice area).

Rice-fallow Estimates

Based on the satellite images taken during January, February, and March 2000 (Table 3.1 of Section 3), the rice-fallow area was estimated. Due to the complex rabi cropping pattern in Bangladesh, it was necessary to deduce fallow areas using images taken at several times during January to March. Those taken in late January or during February detected as fallow land that would be later planted to boro (winter, irrigated) rice. However, those taken in March detected boro rice but included as fallow fields that had contained rabi crops that were harvested in February, such as mustard or lentil. Thus, by accounting for both boro rice and early-harvested rabi crops, the satellite image analysis during rabi 1999/2000 indicated that 2.11 million ha of rice-fallows were available amounting to 33% of the T.aman rice area. The spatial distribution of rice-fallows is given in Figure. 5.1.2, which indicates large tracts of rice–fallows in northwestern (Barind), northern, and coastal parts of the country.

Edaphic and Climatic Features of Rice-fallows

Using soils database of the Food and Agriculture Organization of the United Nations (FAO), IWMI-climatic database, and GIS, the spatial distribution of rice-fallows was superimposed on the soils and climatic data as shown in Figure 5.1.3. Rice-fallows in northwestern and northern districts have various soil types: Eutric Cambisols in districts Panchagar, Thakurgaon, and parts of Dinajpur, and the rest of the northwestern and northern districts (where the Barind region is located) are mostly Eutric Gleysols (Fig. 5.1.3). Parts of Barind (i.e., Rajshahi and Nator) and most of the Gangetic river floodplain are comprised of Calcaric Gleysols that range from loamy to clayey soils (Fig. 5.1.3). Rice-fallows located in the southern districts of Pirojpur, Jhalkati, Patuakhali, Borguna, and Bhola mostly have Eutric Gleysols and Calcaric Fluvisols. Soils of rice-fallows in Bhola districts and Laksmipur and Noakhali are Calcaric Fluvisols (Fig. 5.1.3). The spatial distribution of these rice-fallows in relation to agro-ecological regions of Bangladesh are presented in Figure 5.1.4. The available soil water-holding capacity of these rice-fallows is around 200 mm in 1 m soil profile (Fig. 5.1.5). The annual rainfall ranges from 1500 mm in the northwest to about 6800 mm in the east (Fig. 5.1.6). Summer rainfall (June to October) ranges from 1255 mm to 5164 mm (Fig. 5.1.7). Winter rainfall (November to February) ranges from 33 mm to 116 mm (Fig. 5.1.8). A major portion of the rice-fallows are located in the annual rainfall zone of 1500 mm to 2500 mm (Fig. 5.1.6). Relatively small areas of rice–fallows are found in the eastern region where annual

rainfall exceeds 3000 mm (Fig. 5.1.6). Annual mean maximum and minimum temperatures range from 26°C to 29°C, and 17°C to 21°C respectively (Figs. 5.1.9 and 5.1.10); mean summer maximum and minimum temperatures range from 27°C to 31°C, and 21°C to 25°C respectively (Figs. 5.1.11 and 5.1.12); mean winter maximum and minimum temperatures range from 23°C to 26°C, and 11°C to 16°C respectively (Figs. 5.1.13 and 5.1.14).

Spatial distribution of monthly available soil water (in 1 m profile), derived from rainfall only, which is based on WATBAL soil water balance model (Keig and McAlpine 1974), and integrated with GIS is presented in Figure 5.1.15. It appears that nearly 200 mm of water is available in the soil profile of 1 m depth from June to October for most of Bangladesh (Fig. 5.1.15). In November, the available soil water levels begin to decline progressively to be almost depleted in many soils of Bangladesh during January and February (Fig. 5.1.15). This is particularly so for the rice-fallows located in the north and northwestern districts of Bangladesh. However, rice-fallows in the High Ganges River Floodplain, Ganges Tidal Floodplain, and Young Meghna Estuarine Floodplains may not experience water deficits during the rabi-growing season (Fig. 5.1.15). Also, AE/PE (actual evapotranspiration/potential evapotranspiration) ratios further support this analysis as the ratio is between 0.5 and 1.0 until December, indicating adequate soil water status for the winter legumes in these rice-fallows (Fig. 5.1.16). In the north and northwest, AE/PE ratio is between 0 and 0.2 from January to March, indicating that rabi legumes are likely to face severe water deficits from January if grown entirely on stored soil moisture (Fig. 5.1.16). Thus, supplemental irrigation (of one or two) or winter rain may be necessary for optimum legume yield, particularly in February or March when legume crops are in their active reproductive stage. Rice–fallows in South (Borguna, Jhalkati, Patuakhali, Bhola, Laksmipur, and Noakhali) are unlikely to experience water deficits even during January to March (Figs. 5.1.15 and 5.1.16). In rice-fallows of Laksmipur and Noakhali, waterlogging could be a potential limiting factor for introducing legumes during winter (Fig. 5.1.5).

Legumes Suitable for Rice-fallows

In Bangladesh, most of the pulses cultivation is concentrated in the Gangetic floodplain (Rahman et al. 2000). Lentil, black gram, and mung bean (*Vigna radiata* (L.) Wilczek) are grown mainly on high and medium highlands and moderately well to poorly drained light-textured soils. Chickpea and khesari are grown mostly on medium highlands and lowlands and poorly drained heavy-textured soils. Soils of these areas are calcareous and range from loamy to clayey. The length of rabi-growing period in these regions

ranges from 105 days to 145 days beginning around the middle of October. These regions receive relatively low rainfall of about 1500–2500 mm, and the rice-fallows in eastern parts of Bangladesh fall in the high rainfall zone (Fig. 5.1.6). The cool period (minimum temperature <15°C) lasts for 50 to 110 days and normally begins during 20 November to 6 December. The legumes suitable for rice-fallows in Bangladesh are discussed.

Khesari

Khesari is cultivated as a relay crop with the main season rice (T.aman rice) in the medium highlands and lowlands (Rahman et al. 2000). It is broadcast on the saturated soil by the end of October to mid-November, about 2 to 4 weeks before the rice harvest. It is the hardiest crop among pulses and can thrive under both excess moisture and extreme drought conditions. It has no major disease or insect problems; hence it can give stable yields with minimal inputs. A major portion of the khesari production is concentrated in the southern districts (Pirojpur, Jhalkati, Patuakhali, Bhola, and Borguna) and also the central districts (Faridpur, Rajbari, Dhaka, and Manikganj) (Rahman et al. 2000). Substantial rice-fallows have been found in these districts. Thus khesari could be a candidate for logical extension into these new production areas. In Satkhira, Laksmipur, and Noakhali districts, substantial rice-fallows were found; these are likely to be waterlogged (Fig. 5.1.5). Khesari should be the ideal crop for such production niches as well. Some rice-fallows are found in Chittagong, where khesari can be introduced as a winter legume. Rice-fallows were also found in the eastern districts of Sunamganj, Habiganj, Sylhet, and Moulvibazar, where khesari can be introduced. Substantial rice-fallows in the western districts (Nator, Rajshahi, Chapai Nawabganj, and Naogaon) and northern districts (Panchagar, Thakurgaon, Dinajpur, Nilphamari, Lalmonirhat, Rangpur, and Kurigram) may also be suitable for khesari cultivation. Rice-fallows found in districts of Sherpur and Mymensingh are the potential niches for this crop. One of the main limiting factors for the extension of khesari into rice-fallows is the fear of lathyrism that is associated with the consumption of this pulse as a staple food. Recent development of low-toxin genetic stocks such as 'Barikhesari 2' can minimize/eliminate the problem of lathyrism (Table 5.1.1) (Rahman et al. 2000). Thus, awareness of the availability of these low-toxin lines of this crop can be a critical factor for adoption of the crop in rice–fallows. It is also important that the low-toxin or non-toxin varieties should be easily distinguishable from toxic varieties of khesari, so that the farmers can avoid growing the latter.

Table. 5.1.1. Pulses varieties recommended or released in Bangladesh.

Crop	Variety	Year of release/registration
Lentil	Barimasur 1 (Uthfala)	Released in 1991
	Barimasur 2	Released in 1993
	Barimasur 3 (BLX-8405-36)	Registered in 1996
	Barimasur 4	Registered in 1996
Chickpea	Hyprosola	Released in 1981
	Nabin (Barichhola 1)	Released in 1987
	Barichola 2	Released in 1993
	Barichola 3	Released in 1993 (for Barind only)
	Barichola 2	Released in 1994
	Barichola 4 (ICCL 85222)	Registered in 1996
	Barichola 5 (RBH 228)	Registered in 1996
	Barichola 6 (ICCL 83149)	Registered in 1996
	Barichola 7	Registered in 1999
	Barichola 8	Registered in 1999
Khesari	Barikhesari 1	Registered in 1995
	Barikhesari 2 (no. 8603)	Registered in 1996 (low-toxin line)
Black gram	Barimash	Released in 1990
	Barimash 1	Released in 1994
	Barimash 2 (BMAX-90233)	Registered in 1996
	Barimash 3 (BMAX-90235)	Registered in 1996
Mung bean	Mubarik	Released in 1982
	Kanti	Released in 1987
	Binamung 3 (BMX-842243)	Released in 1996
	Binamung 4 (BMX-841121)	Registered in 1996
	Binamung 5 (NM-92)	Registered in 1997
Cowpea	Barifalon 1	Released in 1993
	Barifalon 2	Registered in 1996
Groundnut	Dhaka 1	Recommended
	DG2	Recommended
	Jhinga badam	Recommended
	DM1	Recommended
	ICGS (E) 55	Released in 1995

Source: Rahman et al. (2000).

Lentil

Most of the lentil is grown in the aus rice (upland, direct-seeded rice grown in summer during April to July)/jute (*Corchorus capsularis* L.)-fallow-lentil cropping pattern and is usually sown in early November. Some lentil is also grown in the broadcast (B.) aman rice-lentil cropping pattern, where it is sown during the latter part of November and is

considered as a late-sown crop (Rahman et al. 2000). Most of the lentil production is concentrated in the Ganges floodplain (i.e., in districts of Jessore, Jhenaidah, Chuadanga, Meherpur, Kushtia, Rajbari, Faridpur, Magura, and Narail). Most of these districts showed substantial areas of rice-fallows during March, particularly in districts Meherpur, Chaudanga, and Rajbari. From many of these fallows observed, lentil was already harvested in February (Fig. 5.1.3). Rice-fallows are found in the eastern districts of Sunamganj, Habiganj, Sylhet, and Moulvibazar, where lentil can be a potential crop during winter. Also, substantial rice-fallows are found in the western (Nator, Rajshahi, Chapai Nawabganj, and Naogaon) and northern districts (Panchagar, Thakurgaon, Dinajpur, Nilphamari, Lalmonirhat, Rangpur, and Kurigram), where lentil is a potential winter legume. Also, lentil can be introduced as a winter legume in rice-fallows found in districts of Sherpur and Mymensingh. Most local cultivars suffer from rust and stemphylium blight especially under late planting conditions. The loss caused by these diseases may be minimized, by early planting (in October), if T.aman rice is harvested in time. Also, yield of lentil can be increased significantly, by early planting with a higher seed rate to achieve a plant stand of 33.3 plants m^{-2} (Ahlawat et al. 1982, 1983, Saxena et al. 1983).

Chickpea

Nearly 60% of the chickpea is grown on relatively heavier soils under the aus-rice/jute-fallow-chickpea cropping pattern, where it is sown in November (Rahman et al. 2000). The remaining (40%) chickpea area is under T.aman rice-chickpea cropping pattern, where it is sown in late November or early December as a late-sown crop (Rahman and Mallick 1988). Until 1997, chickpea production was mostly confined in Faridpur, Gopalganj, Narail, Jessore, Jhenaidah, Magura, Chuadanga, Meherpur, Kushtia, and Rajbari districts. A substantial decline in chickpea area has occurred in recent years due to BGM epidemics (Rahman et al. 2000). Substantial rice-fallows were found in some of these districts where chickpea was traditionally grown: Pabna, Rajbari, Faridpur, Jhenaidah, Chaudanga, and Meherpur (Fig. 5.1.3). Thus utilization of these rice-fallows for chickpea production is possible if BGM can be effectively managed.

Substantial rice-fallows are found in the Barind region (i.e., three northwestern districts). Nearly 0.8 million ha in the High-Barind Tract in northwestern Bangladesh remains fallow in winter after harvest of T.aman rice (Raisuddin and Nur-E-Elahi 1984). This was further confirmed by satellite image analysis (Fig. 5.1.3). It was demonstrated that chickpea can yield >1 t ha^{-1}, if planted by early November (Kumar et al. 1994). In this case, the local long-duration rice cultivars need to be replaced by short-duration varieties

such as BR-1, BR-14, BARIdhan 32, and IR-50. The relatively less humid climate in the Barind area is not favorable for BGM (which is a major threat to chickpea in the traditional areas), and thus chickpea will have potentially high adaptability and also yield potential in this region.

Land remains fallow after the harvest of T.aman rice in some parts of eastern Bogra, Rangpur, and Dinajpur districts (Fig. 5.1.3). The soils are silty-loam with high soil moisture-holding capacity. Chickpea grows vigorously on these soils, but sets fewer pods. On-station studies indicate that chickpea yield of more than 1 t ha^{-1} can be obtained by applying 0.5 kg B ha^{-1} (C. Johansen, ICRISAT, unpublished). If parts of these areas are brought under chickpea cultivation, total area and production of this pulse crop can be greatly increased. Also, the other northern districts, namely, Panchagar, Thakurgaon, Nilphamari, Lalmonirhat, and Kurigram, have substantial rice-fallows (Fig. 5.1.3) where chickpea is a potential winter crop.

Mung bean

Nearly 70% of the mung bean is grown in the T.aman rice-mung bean-aus rice cropping pattern in the southern region of Bangladesh. Mung bean varieties that are recommended for Bangladesh are given in Table 5.1.1. The southern districts of Jhalkati, Patuakhali, Borguna, and Bhola have substantial areas of rice-fallows, potentially suitable for mung bean cultivation (Figs. 5.1.3 and 5.1.4). Since the area is under Ganges Tidal Floodplain, seawater salinity during rabi season (because of seawater inundation) could be a potential limitation for introducing mung bean into these rice-fallows (Rahman et al. 2000). Tolerance to salinity, particularly during early seedling stage will be necessary for mung bean to utilize this production niche.

Groundnut

Groundnut is cultivated in pockets throughout the country (Rahman et al. 2000). In the north, duration of this crop is 120 to 130 days; groundnut growth and development is inhibited at temperatures below 20°C. This crop is therefore mainly distributed in regions with milder winter temperatures. Groundnut varieties that are recommended for Bangladesh are presented in Table 5.1.1. Traditionally, groundnut is grown in the riverbed areas, planted in October to November and harvested in March to April. Rice-fallows in southern districts (Patuakhali, Borguna, and Bhola), central districts (Rajbari, Kushtia, and Faridpur), and the southwestern districts of Laksmipur are suitable for introducing groundnut during winter after the harvest of T.aman rice (Fig. 5.1.3). Also, rice-fallows found in Chittagong are suitable for introducing groundnut. There is

potential for expansion of rabi groundnut in char (river basin) lands without much competition from other crops. Substantial rice-fallows found in the following districts Lalmonirhat, Gaibandha, Sirajganj, Jamalpur, Tangail, Kushtia, Faridpur, Dhaka, Narayanganj, Munshiganj, Noakhali, Patuakhali, and Bhola are suitable for groundnut production. Parts of Thakurgaon, Panchagar, and Nilphamari districts, in the northwest region of the country are also suitable for groundnut cultivation, provided irrigation is available during winter. This is mainly due to the low temperatures in these northern districts (Fig. 5.1.14), which prevents planting of groundnut until early January. Thus the groundnut-growing season extends into April or May, and requires irrigation.

Constraints to Legumes Production

Abiotic constraints

A number of climatic and soil factors can limit yields of legumes when introduced into the rice-fallows.

Excess soil moisture and humidity. Waterlogging during seed germination and initial seedling growth phases can be a constraint for legumes that are introduced into rice-fallows of southern districts. High humidity during vegetative growth stages (particularly during November to January) makes certain legumes (e.g., chickpea and lentil) susceptible to diseases such as BGM. This can happen in some years, where excessive rainfall occurs during winter that can encourage excessive vegetative growth leading to lodging, and also encourage development of various leaf and root diseases. If rainfall occurs at reproductive stage it will not only physically damage the flowers and developing pods/ seeds, but also encourage foliar diseases such as BGM in chickpea, rust and stemphylium blight in lentil, downy mildew in khesari, and late leaf spot in groundnut.

Drought. Rapid drying of tilled soil after harvest of rice can adversely affect germination of legume seeds subsequently sown and emergence of seedlings. Since the winter rainfall during rabi season is low (<5% of the total rainfall), legumes will have to rely mainly on stored soil moisture at the time of planting to meet their growth requirements. Rabi crops grown under these conditions are prone to terminal drought stress, particularly during active reproductive phase of growth that usually coincides with raising temperatures and declining soil water levels from February. The WATBAL soil water balance model indicates that crops grown during the rabi season are likely to experience water deficits from January, but more severe water deficits from February (Figs. 5.1.15 and 5.1.16). This is particularly relevant in Barind region and also for the districts of northern Bangladesh (Figs. 5.1.15 and 5.1.16).

Temperature extremes. Low winter temperatures encountered during December to February particularly in the northern and western districts of Bangladesh (Fig. 5.1.14) can minimize vegetative growth, abort flowers, and thus delay pod setting and pod filling in crops such as chickpea and lentil. This normally leads to extension of growing season into March and April, when terminal drought stress is a serious constraint for realizing the yield potential in these legumes.

Soil factors and nutrient deficiency. The Ganges floodplain soils where substantial rice-fallows are found are calcareous and alkaline (Figs. 5.1.3 and 5.1.4). Surface soil acidity is one of the limiting factors in some parts of Barind (see Section 4). Soils of rice-fallows in Young Meghna Estuarine Floodplains agro-ecological region (Fig. 5.1.4) have high clay content; thus plow-pan formation is one of the serious constraints for root development in legumes following rice. This is particularly important as it makes legumes highly sensitive to water stress because of shallow rooting forced on them in these rice-fallows. Sulfur (S) deficiency is likely to be a problem in the rice-fallows of western and northern districts (Rahman et al. 2000), but not in the Gangetic floodplains, where Zn deficiency is likely to be a problem (Rahman et al. 2000). In the Tista floodplain area of northern Bangladesh (Fig. 5.1.4), B deficiency could be a serious limiting factor for chickpea and lentil (BARI 1987, 1993, Miah 1995). Thus, when legumes are introduced into these rice-fallows, care should be taken to address these possible factors limiting plant nutrition through appropriate fertilization.

Biotic constraints

Diseases. Details of the major diseases that infect legumes are given in Table 5.1.2. Among chickpea diseases, BGM, fusarium wilt, dry root rot, and collar rot are most important (Rahman et al. 2000). These are widespread over most of the chickpea growing regions where rice-fallows are located. In lentil, out of 16 diseases reported (Table 5.1.2), stemphylium blight and rust are most serious in the lentil-growing regions where rice-fallows are located (Bakr and Ahmed 1993). Collar rot and vascular wilt can also cause serious damage to lentil. Yellow mosaic, cercospora leaf spot, and powdery mildew are the major diseases of mung bean and black gram that could affect the production if introduced into rice-fallows (Rahman et al. 2000). The other diseases which could be relatively less important are given in Table 5.1.2. Powdery mildew and downy mildew are the major diseases of khesari that can cause significant yield losses in the rice-fallows. At least 18 diseases of groundnut are reported, of which late leaf spot, rust, and sclerotium stem and root rot are major diseases (Rahman et al. 2000) (Table 5.1.2).

Table 5.1.2. Recorded diseases of legumes suitable for rice-fallows in Bangladesh.

Crop/Disease	Causal organism	Status
Chickpea		
Botrytis gray mold	*Botrytis cinerea*	Major
Fusarium wilt	*Fusarium oxysporum* f. sp *ciceris*	Major
Collar rot	*Sclerotium rolfsii*	Major
Dry root rot	*Macrophomina phaseolina* (sclerotial state *Rhizoctonia bataticola*)	Minor
Alternaria blight	*Alternaria alternata*	Minor
Stunt	Bean (pea) leaf roll virus	Minor
Rust	*Uromyces ciceris-arietini*	Minor
Root-knot	*Meloidogyne javanica, M. incognita, Belonolaimus* sp	Minor
Lentil		
Stemphylium blight	*Stemphylium* sp	Major
Rust	*Uromyces viciae-fabae*	Major
Collar rot	*Sclerotium rolfsii*	Major
Vascular wilt	*Fusarium oxysporum* f. sp *lentis*	Major
Damping-off	*Pythium* sp	Minor
Cercospora leaf spot	*Pseudocercospora cruenta*	Minor
Root-knot	*Meloidogyne javanica, M. incognita*	Minor
Mung bean		
Yellow mosaic	Yellow mosaic virus	Major
Cercospora leaf spot	*Pseudocercospora cruenta*	Major
Powdery mildew	*Oidium* sp, *Erysiphe polygoni*	Major
Anthracnose	*Colletotrichum lindemuthianum*	Minor
Sclerotinia blight	*Sclerotinia sclerotiorum*	Major
Leaf blight	*Leptosphaerulina trifolii, Phoma* sp	Minor
Nematode disease	*Helicotylenchus* sp, *Hoplolaimus indicus*	Minor
Black gram		
Powdery mildew	*Erysiphe polygoni, Oidium* sp	Major
Cercospora leaf spot	*Pseudocercospora cruenta*	Major
Yellow mosaic	Yellow mosaic virus	Major
Anthracnose	*Colletotrichum caulicola*	Minor
Seed rot and seedling blight	*Macrophomina phaseolina*	Minor
Root-knot	*Meloidogyne javanica, M. incognita, Aphelenchoides* sp	Minor
Target spot	*Corynespora cassicola*	Minor
Leaf crinkle	Leaf crinkle virus	Minor
Leaf blight	*Leptosphaerulina trifolii*	Minor
Khesari		
Downy mildew	*Peronospora viciae*	Major
Powdery mildew	*Oidium* sp	Major
Leptosphaerulina blight	*Leptosphaerulina trifolii*	Minor
Leaf curl	Leaf curl virus	Minor
Groundnut		
Late leaf spot	*Phaeoisariopsis personata*	Major
Rust	*Puccinia arachidis*	Major
Crown rot	*Aspergillus niger*	Major
Sclerotium stem and root rot	*Sclerotium rolfsii*	Major
Early leaf spot	*Cercospora arachidicola*	Minor
Rhizoctonia leaf blight/seedling rot	*Rhizoctonia solani*	Minor
Seed rot	*Aspergillus flavus*	Minor

Source: Rahman et al. (2000).

Insect pests. Nearly 30 insect pests affect legumes grown in rice–fallows (Table 5.1.3). Aphids are common on lentil, khesari, and mung bean and cause significant damage and yield losses. *Helicoverpa armigera* (pod borer) is a major pest of chickpea and black gram (Rahman 1989). *Spilosoma* (*Diacrisia*) *obliqua* (hairy caterpiller) is a major pest of black gram, mung bean, and groundnut. *Euchrysops cnejus* (hair-streak blue butterfly pod borer), *Monolepta signata* (monolepta beetle), and *Bemisia tabaci* (whitefly) are the major insect pests of mung bean and black gram. *Agrotis ipsilon* (cutworm) is a common, major pest of chickpea; and it also attacks lentil and black gram (Karim and Rahman 1991). Thrips are also a major pest of mung bean. Weather conditions determine the level of infestation of these pests that varies over space and time.

Priorities for alleviation of abiotic and biotic constraints

A number of crop management practices for legumes, if adopted for rice-fallows, can substantially reduce the abiotic and biotic constraints that can limit their yield expression.

- Adoption of short-duration rice varieties particularly for the Barind region, could facilitate planting of chickpea and lentil by early November. This could substantially improve productivity of these crops by limiting initial and terminal drought stress effects.
- Adoption of appropriate tools (e.g., rotovator for rapid turnaround time and using seed-drills for planting) for land preparation, particularly after the harvest of rice for legume planting could substantially improve the plant stand. Seed dibbling should be explored for chickpea and other legumes by practicing zero tillage. This may permit relay planting with rice (similar to lentil and khesari), which could conserve soil moisture, and thus provide the legume crop maximum advantage from stored soil moisture. Cornell University, USA in collaboration with the Bangladesh Rice Research Institute (BRRI) and farm machinery dealers in Bangladesh have adapted a planter that can drill chickpea on the day of paddy harvest. This technology, if widely adopted, can reduce the turnaround period and improve plant stand of chickpea, which is a critical requirement for high yield in these production environments.
- Chickpea varieties that have the ability to emerge and establish under excessive soil moisture should be developed to facilitate relay planting with rice. This would permit early planting and crop establishment in the beginning of November.
- Seed priming has shown positive effects on plant growth and yield of chickpea in rice–fallows of the Barind region (Musa et al. 1999). The efficiency of seed priming should be evaluated for other rice–fallows, and for other legumes.

Table 5.1.3. Recorded insect pests of legumes suitable for rice-fallows in Bangladesh.

Insect pest	Nature of damage	Status
Chickpea		
Helicoverpa armigera	Bore into pods and feed on seeds and foliage	Major
Agrotis ipsilon	Cut the young seedlings	Minor
Callosobruchus chinensis, C. maculatus	Damage seed in storage	Major
Alcidodes collaris	Bore into pods and feed on seeds	Minor
Aphis craccivora	Suck sap from foliar parts	Minor
Pachynerus chinensis	Bore into pods and feed on seeds	Minor
Lentil		
Callosobruchus chinensis, C. maculatus	Damage seed in storage	Major
Aphis craccivora	Suck sap from shoots and pods	Minor
Spodoptera exigua	Cut the plant or plant parts	Minor
Helicoverpa armigera	Bore into pods and feed on seeds and shoots	Minor
Nezara viridula	Suck sap from shoots and pods	Minor
Black gram		
Spilosoma (Diacrisia) obliqua	Feed on leaves	Major
Helicoverpa armigera	Bore into pods and feed on seeds, young stems, and leaves	Major
Agromyza phaseoli	Bore into stem	Major
Callosobruchus maculatus	Damage stored seeds	Major
Monolepta signata	Feed on leaves	Major
Euchrysops cnejus	Bore into pods and feed on seeds	Major
Aphis craccivora	Suck sap and transmit virus	Minor
Maruca vitrata	Bore into pods and feed on seeds	Minor
Bemisia tabaci	Suck sap and transmit virus	Minor
Mung bean		
Bemisia tabaci	Suck sap and transmit virus	Major
Euchrysops cnejus	Bore into pods and feed on seeds	Major
Agromyza phaseoli	Bore into stems and feed on internal tissue	Major
Aphis craccivora	Suck sap and transmit virus	Major
Spilosoma (Diacrisia) obliqua	Feed on leaves	Major
Nezara viridula	Suck cell sap	Minor
Monolepta signata	Feed on leaves	Major
Callosobruchus chinensis	Damage to stored seeds	Major
Megalurothrips distalis	Cause flower drop	Major
Khesari		
Aphis craccivora	Suck sap from leaves, twigs, and branches	Major
Groundnut		
Spilosoma (Diacrisia) obliqua	Feed on leaves	Major
Odontotermis sp	Feed on pods and underground plant parts	Major
Empoasca kerri	Suck sap from foliage of plants	Minor
Scirtothrips dorsalis	Scrape leaf surface, suck sap; cause leaf curl and stunting of plants	Minor
Anarsia ephippias	Roll young leaves and feed inside	Minor

Source: Rahman et al. (2000).

- Chickpea cultivars or other suitable legumes having better ability to produce grain under terminal drought and high temperature stress should be developed for this region as these stresses appear to be an integral feature of most of the rice-fallows.
- Chickpea varieties that have the ability to set pods at cold temperatures (<5°C) should be developed particularly for the northwestern districts where temperatures are particularly cold during winter. If chickpea could set pods during December and January, rapid pod filling can occur during February when temperatures are closer to optimum. The crop would then mature by early March and thereby escape terminal drought and heat stress.
- Boron deficiency appears to be a problem in many of the rice-fallows, particularly in the floodplains of northern Bangladesh. Thus, application of B fertilizer should be encouraged when introducing legumes into these rice–fallows.
- Host plant resistance (HPR) is available for diseases such as fusarium wilt in chickpea, yellow mosaic in *Vigna* spp, and leaf spots in groundnut. Varieties with the relevant resistances need to be disseminated.
- Collar rot is a particular problem for legumes in rice-fallows but little HPR has so far been identified. Therefore, seed treatment with fungicide and appropriate crop rotation is needed to combat this problem.
- For foliar diseases such as BGM, integrated management strategies are available that can minimize crop damage (Pande et al. 1998). These include combinations of less susceptible genotypes, use of fungicidal sprays, prevention of dense crop canopies and seed health priorities.
- Integrated pest management strategies are needed to combat the major insect pests (Ranga Rao and Shanower 1999). These should be based on effective monitoring of pest incidence and use of biocontrol agents, rather than reliance on chemical insecticides.

Socioeconomic constraints

The major socioeconomic constraints faced by the Bangladeshi farmers are discussed below.

Lack of seed availability. Seeds of improved varieties, particularly those having resistance to some of the major abiotic and biotic stresses, are not available to the farmers. Therefore, farmers use their own seeds of local varieties, which are often of low quality, preserved under traditional storage structures, less viable, and contaminated with various seedborne diseases. Use of low quality seeds results in poor plant stand, damage to crops at the initial stages of growth, and poor yields (Miah et al. 1991).

Lack of cash and credit. Most farmers do not have enough cash on hand to buy quality seeds or inputs, even if they would wish to. Credit facilities are not available for legume crops in the same way that they are for other major crops such as rice, cotton (*Gossypium* sp), and sugarcane (*Saccharum officinarum* L.) (Hossain 1993).

Lack of support price and marketing. Cereal crops such as rice and wheat enjoy minimum support prices, but grain legumes do not. Pulses are also susceptible to storage pests, forcing farmers to sell pulses soon after harvest. Because of the small number of processing mills in Bangladesh, there is evidently a certain traders' monopoly in the pulses marketing process (Elias 1991). The traders buy the grains from the farmers at a low price. About 74% share of the profit goes to traders and only 26% to the farmers. More processing mills in the intensive pulse-growing areas would help to increase employment, reduce marketing costs, and break the traders' monopoly.

Consumer preference. Bangladeshi consumers prefer mung bean>lentil>chickpea>black gram>khesari. Some pulses are regionally preferred; for example, black gram is most preferred in northwestern Bangladesh and hence it is not widely grown in other parts of the country (Rahman et al. 2000).

Low response to improved management. The existing local cultivars of different pulses are not very responsive to improved management but a few high-yielding cultivars, such as Nabin (chickpea), showed very high yield potential (>2 t ha^{-1}) with improved management practices in farmers' fields.

Lack of adequate postharvest and processing technologies. Although effective storage procedures for pulses are available, that can be used at village level, there is a general lack of knowledge of these. Thus bruchid damage and loss of seed quality remains a problem (Miah et al. 1991).

Economic Feasibility of Growing Legumes in Rice-fallows

Farming systems research conducted at BRRI, Bangladesh Agricultural Research Institute (BARI), Bangladesh Jute Research Institute (BJRI), and Bangladesh Agricultural Research Council (BARC) during the 1980s and 1990s studied the feasibility of growing chickpea, lentil, and khesari in different areas of Bangladesh after T.aman rice. A review of the National Coordinated Cropping Systems Research project in Bangladesh (BARC 1985) showed that cultivation of lentil and khesari after T.aman rice is agronomically feasible and economically viable in medium-highlands and highlands of Brahmaputra Floodplain. Multilocation testing conducted at different farming systems research sites of BARI showed that cultivation of khesari under rainfed condition in Jamalpur and medium to medium-high lowland areas of Tista floodplain is possible (Abedin and Hossain 1991).

Rahman and Kar (1988) reported that mung bean can be grown in Barind (where about 82% farmers grow only a single crop of T.aman) with yield around 450 kg ha^{-1} after T.aman rice (variety BR-11). In 3 out of 5 years in the Barind, chickpea in the green manure (GM)-T.aman-chickpea cropping pattern produced good yields, and an acceptable yield in one year. The crop could not be established in one year due to depletion of soil moisture at sowing time. Results of experiments conducted by BARI and BRRI for growing chickpea in Rajshahi showed that production of chickpea is economically profitable (Tables 5.1.4 and 5.1.5). Cultivation of chickpea provided more than Tk. 11,000 per hectare to the farmers of Rajshahi.

Table 5.1.4. Performance of chickpea in rabi season at different locations of Rajshahi, Bangladesh.

Description	Alimganj	Alimganj	Saroil
Reference year	1991	1991	1989/90
Management practice	Farmers'	High	Farmers'
Yield (t ha^{-1})	0.40	0.83	1.00
Cost (Tk. ha^{-1})	757	912	-
Net return (Tk. ha^{-1})	1643	4068	-
Benefit-cost ratio (BCR)	3.17	5.46	-

Source: BRRI (1992), BARI (1989–90).

Table 5.1.5. Per hectare cost and returns from chickpea cultivation in High Barind region in Bangladesh.

Description	Unit	Quantity	Amount (Tk.)
Human labor	day	49	2112
Animal power	pair-day	19	1413
Seed	kg	49	1053
Manure	kg	259	54
Fertilizers	kg		1036
Urea	kg	16	
Triple superphosphate	kg	30	
Muriate of potash	kg	11	
Single superphosphate	kg	2	
Insecticide			26
Irrigation			21
Interest on operating capital			36
Total cost			5231
Gross return			16615
Net return			11384
Benefit-cost ratio (BCR)			3.18

Source: Karim et al. (1998).

Another BARI study (BARI 1997–98, p. 279) found that cultivation of mung bean, black gram, and cowpea (*Vigna unguiculata* (L.) Walp.) after T.aman rice is feasible at Dumuria, Khulna. During 1994–98, average grain yield of mung bean, black gram, and cowpea were 800 kg ha^{-1}, 850 kg ha^{-1}, and 1697 kg ha^{-1} (Table 5.1.6). Due to high market price, the highest benefit-cost ratio (BCR) was found with mung bean production and farmers are interested to grow mung bean in the fallow season. BARI also tested the feasibility of T.aman-khesari-fallow cropping pattern in the medium-highland of Bil Dakatia, Dumuria during 1997/98. Results revealed that additional grain yield of 845 kg ha^{-1} of khesari was obtained if the crop was grown in fallow period relayed with T.aman rice (Table 5.1.7). BARI tested B. aus rice-T.aman rice-khesari cropping pattern against the farmers' pattern B. aus rice-T.aman rice-fallow at Lalmonirhat and T. aus rice-T.aman rice-fallow at Nilphamari multilocation testing sites in the medium highlands of Bonarpara-Imadpur soil series under rainfed condition (BARI 1989–90, p. 321). The objectives of the study were to increase productivity and profitability of the pattern by replacing the local varieties, improving management practices, and introducing an additional crop of khesari as relay using residual soil moisture. Local varieties of rice were replaced with the modern varieties and recommended rates of fertilizers were used against the farmers' doses of 37 kg N ha^{-1}, 15 kg P_2O_5 ha^{-1}, and 11 kg K_2O ha^{-1} for B. aus rice and 46 kg N ha^{-1}, 35 kg P_2O_5 ha^{-1}, and 11 kg K_2O ha^{-1} for T.aman rice. The yield of B. aus and T.aman rice increased by 24% and 52%, respectively, with the change of varieties and high fertilizer doses. An additional yield of 0.79 t ha^{-1} of khesari was also obtained from the alternative cropping pattern. The return above variable cost (RAVC) in the alternative cropping pattern at Lalmonirhat and Nilphamari increased by 33% and 29%, respectively. The BCR (2.93) from alternative cropping pattern was also higher than that in the farmers' pattern (2.41).

Information reported so far has shown that cultivation of legumes after rice in kharif season is agronomically feasible and economically viable. The data reported above is old and price of

Table 5.1.6. Performance of different pulses at the multilocation testing site Dumuria, Khulna in Bangladesh during 1994, 1996, and 1998 (mean of 3 years).

Year	Grain yield (kg ha^{-1})		
	Mung bean	Black gram	Cowpea
1994	621	730	-
1996	1130	885	1994
1998	650	935	1400
Mean	800	850	1697
Benefit-cost ratio (BCR)	2.21	1.88	2.07

Source: BARI (1997–98).

Table 5.1.7. Performance of khesari in rice-fallow cropping pattern in Bangladesh.

Location	Crop year	Cropping pattern[1] (aus-aman-boro)	Yield (t ha^{-1})			Gross return (Tk. ha^{-1})	Total cost (Tk. ha^{-1})	RAVC[2] (Tk. ha^{-1})	BCR[3]
			Crop 1	Crop 2	Crop 3				
Lalmonirhat, Rangpur	1989/90	B.aus-T.aman-fallow	1.63	2.83	-	27227	11501	15726	2.36
Lalmonirhat, Rangpur	1989/90	B.aus-T.aman-khesari	2.13	4.23	0.70	43089	15329	27760	2.81
Nilphamari, Rangpur	1989/90	B.aus-T.aman-fallow	1.90	2.97	-	29602	12066	17536	2.45
Nilphamari, Rangpur	1989/90	B.aus-T.aman-khesari	2.24	4.60	0.87	47118	15522	31596	3.04
Bagherpara, Rajshahi	1989/90	Relayed khesari after B.aman	1.01	-	-	3873	2537	1336	1.53
Daudkandi, Comilla	1981/83	Relayed khesari after B.aman	-	-	0.80	-	-	-	-
Bil Dakatia, Khulna	1997/98	Fallow-T.aman-fallow	-	2.80	-	22150	7458	14690	2.97
Bil Dakatia, Khulna	1997/98	Fallow-T.aman-khesari[4]	-	2.80	0.85	30074	9684	20389	3.11
Bil Dakatia, Khulna	1997/98	Relayed khesari[4] after T.aman	-	-	0.85	7924	2226	5699	3.56

1. T = Transplanted; B = Broadcast.
2. RAVC = return above variable cost.
3. BCR = benefit-cost ratio.
4. Cultivar BARI Khesari 1.

Source: BARI (1989–90), BARI (1993), BARI (1997–98).

different inputs as well as that of outputs have changed. Therefore, we have estimated likely costs and benefits from growing chickpea, lentil, and khesari. These will indicate the likely benefit and investment requirements by individual farmers. Also, it provides indications on the total benefit from the introduction of legumes in fallow land to the national economy of Bangladesh in terms of employment creation and increase in output. Results of the economic feasibility analysis are provided in Tables 5.1.8, 5.1.9, and 5.1.10. Cultivation of chickpea would provide Tk. 13,150 per hectare with estimated BCR of 3.48, indicating that each taka invested in chickpea production will provide three taka and forty eight paisa (Table 5.1.8). Cultivation of lentil in one hectare of land will provide a BCR of 3.37 and net return of Tk. 9,600 (Table 5.1.9). On the other hand, khesari will provide Tk. 6,240 as net return with a BCR of 3.01 (Table 5.1.10). Thus, economic feasibility analysis showed that chickpea would provide highest return followed by lentil, and khesari.

Table 5.1.8. Cost per hectare and returns from cultivation of chickpea in rice-fallows in Bangladesh.

Description	Unit	Unit price (Tk.)	Quantity	Amount (Tk.)
Inputs				
Labor	day			1550
Land preparation and sowing	day	50	12	600
Weeding and cultural operations	day	50	9	450
Harvesting and threshing	day	50	10	500
Bullock labor	pair-day			600
Land preparation	pair-day	50	9	450
Threshing	pair-day	50	3	150
Seed	kg	30	50	1500
Fertilizer				1250
Diammonium phosphate	kg	9	100	900
Boric acid	kg	70	5	350
Pesticides	number of sprays	200	2	400
Total cost				5300
Outputs				
Grain yield	kg	21	800	16800
Fodder yield (byproduct)	kg	1	1500	1500
Green vegetable consumption				150
Returns				
Gross return				18450
Net return				13150
Benefit-cost ratio (BCR)				3.48

Table 5.1.9. Cost per hectare and returns from cultivation of lentil in rice-fallows in Bangladesh.

Description	Unit	Unit price (Tk.)	Quantity	Amount (Tk.)
Inputs				
Labor	day			1550
Land preparation and sowing	day	50	12	600
Weeding and cultural operations	day	50	9	450
Harvesting and threshing	day	50	10	500
Bullock labor	pair-day			600
Land preparation	pair-day	50	9	450
Threshing	pair-day	50	3	150
Seed	kg	50	30	1500
Fertilizer				
Single superphosphate	kg	6	100	600
Boric acid	kg	70	5	350
Pesticides	number of sprays	200	2	400
Total cost				4050
Outputs				
Grain yield	kg	25	500	12500
Fodder yield (byproduct)	kg	1	1000	1000
Green vegetable consumption				150
Returns				
Gross return				13650
Net return				9600
Benefit-cost ratio (BCR)				3.37

Table 5.1.10. Cost per hectare and returns from cultivation of khesari in rice-fallows in Bangladesh.

Description	Unit	Unit price (Tk.)	Quantity	Amount (Tk.)
Inputs				
Labor	day			1000
Sowing	day	50	1	50
Weeding and cultural operations	day	50	9	450
Harvesting and threshing	day	50	10	500
Animal power	pair-day			150
Threshing	pair-day	50	3	150
Seed	kg	20	35	700
Fertilizer				1100
Single superphosphate	kg	7.50	100	750
Boric acid	kg	70	5	350
Pesticides	number of sprays	80	2	160
Total cost				3110
Outputs				
Grain yield	kg	1200	600	7200
Fodder yield (byproduct)	kg	100	2000	2000
Green vegetable consumption				150
Returns				
Gross return				9350
Net return				6240
Benefit-cost ratio (BCR)				3.01

In a labor surplus economy like Bangladesh, scope for employment generation is always an opportunity for the farm households and national economy. It is estimated that cultivation of chickpea or lentil would create an employment opportunity of 31 person-days per hectare while khesari would provide 20 person-days work. On an average, cultivation of legumes in one hectare of fallow land would generate more than 27 person-days working opportunity and about Tk. 1,350 remuneration as labor wage. If all the rice-fallow areas (2.43 million ha) can be brought under legume cultivation then additional employment creation in the Bangladesh economy will be 66.7 million person-days (Table 5.1.11).

Table 5.1.11. Potential employment generation through introduction of legumes in rice-fallows of Bangladesh.

Crop	Labor requirement (person-days ha^{-1})
Chickpea	31.0
Lentil	31.0
Khesari	20.0
Mean (legumes)	27.5
Total rice-fallow area (ha)	2,426,093
Potential employment creation (person-days)	66,717,558

Concluding Remarks

The population of Bangladesh has probably crossed 132 million during 2000 and is estimated to be 153 million by 2010, and 173 million by year 2020 (BARC 1995). The current production of pulses is 0.532 million t (BBS 1997). If the present rate of per capita consumption of about 12 g day^{-1} (which itself is only one-third of the proposed requirement) is to be maintained in the year 2010, the requirement for pulse grains would be 0.672 million t. This means the total production of pulses needs to be increased by about 28% during the next decade, with an average annual growth rate of 2.2%.

There are increasing concerns about the long-term sustainability of cereal-cereal monocropping systems. It is generally considered as undesirable to indefinitely continue with these systems. Legumes are considered as ameliorative crops from a sustainability perspective to break continuous monocropping of cereals (Kumar Rao et al. 1998). Soil aggregation, soil structure, permeability, fertility, and infiltration rate are reported to improve with the inclusion of pulses in the cropping system (Yadav et al. 1997).

The major grain legumes, i.e., chickpea, mung bean, khesari, lentil, black gram, and groundnut occupy about 0.76 million ha in Bangladesh. If one third of the 2.11 million ha of rice-fallows are utilized for introducing these legumes, this could double the area for grain legume cultivation in the country. Thus production and per capita availability of these legumes could be doubled. Since no cereal is competing in this production niche (because of lack of irrigation facilities for the rabi season as limits to irrigation are being approached) and grain legumes have a natural adaptation to exploiting stored soil moisture in the rabi season, this production niche should be more fully exploited to improve the per capita legume availability in the country. The agronomic and economic feasibility of introducing short-season legumes into rice-fallows has been indicated during this study. Utilization of rice-fallows for the production of short-season legumes can have potentially large impacts on legumes production and per capita availability, and contribute to the sustainability of these production systems. Also, our estimates indicate that utilizing rice-fallows for legumes production could result in the creation of about 66 million person-days employment, which can contribute substantially to poverty alleviation in the country.

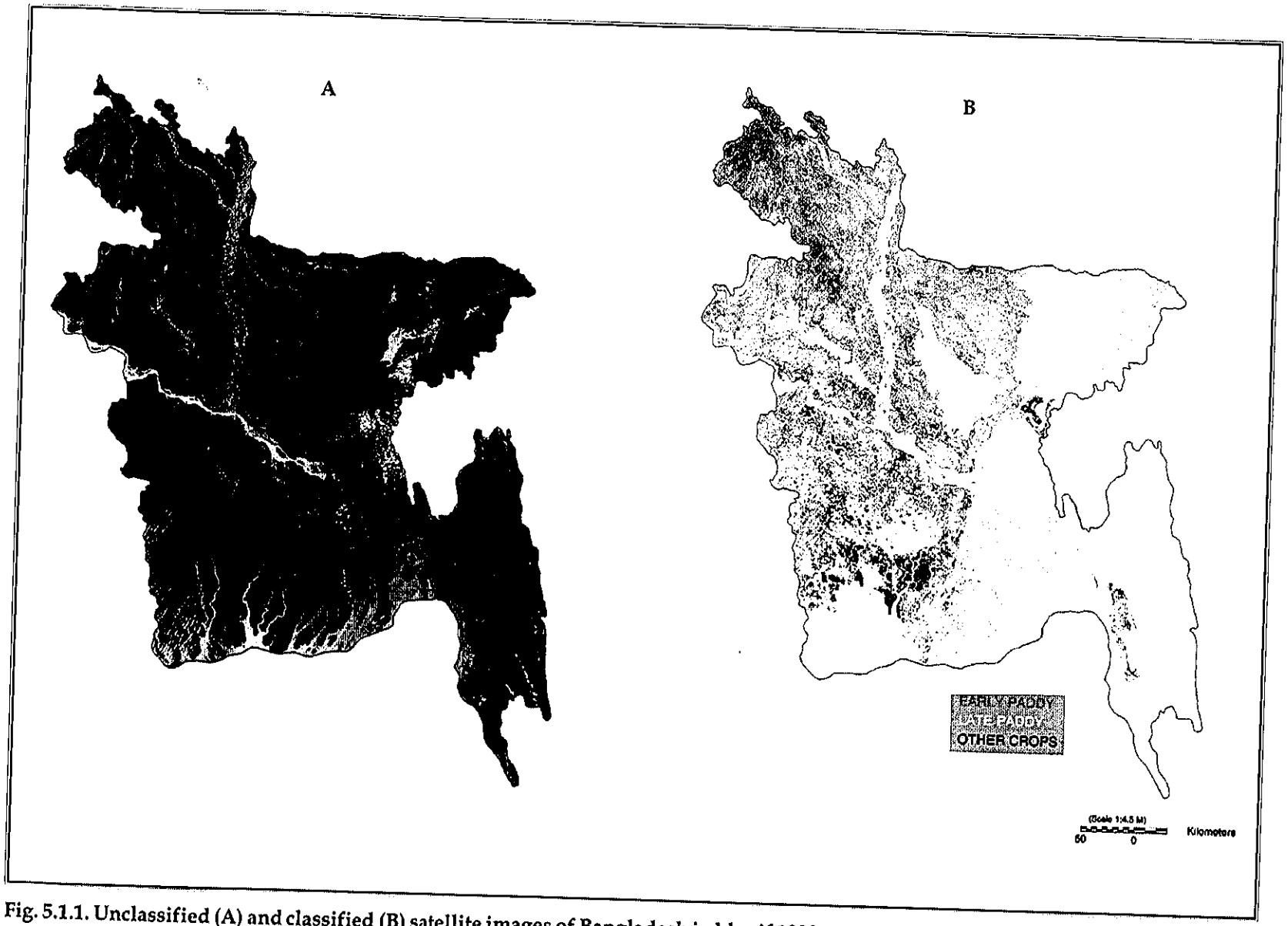


Fig. 5.1.1. Unclassified (A) and classified (B) satellite images of Bangladesh in kharif 1999

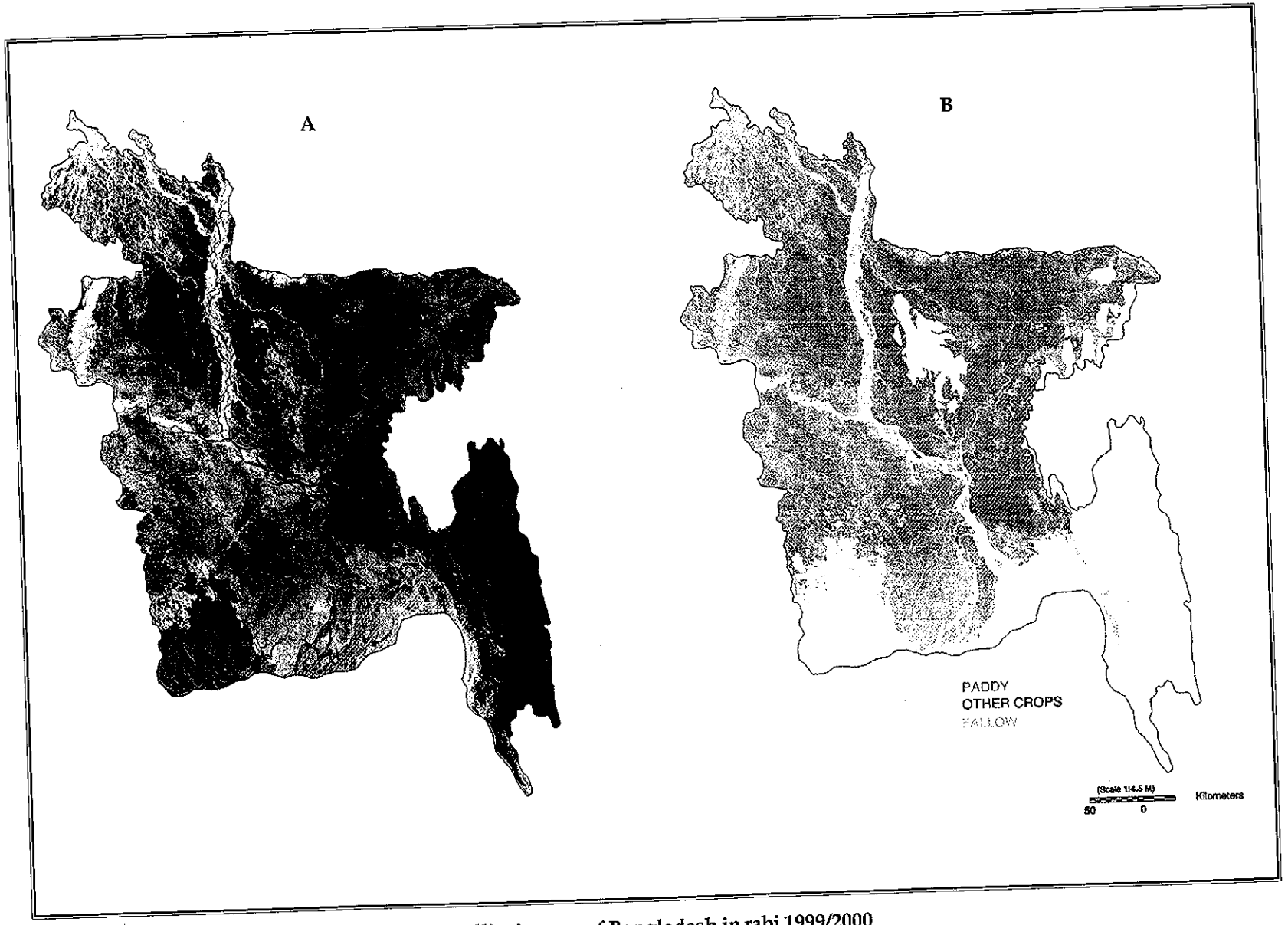


Fig. 5.1.2. Unclassified (A) and classified (B) satellite images of Bangladesh in rabi 1999/2000

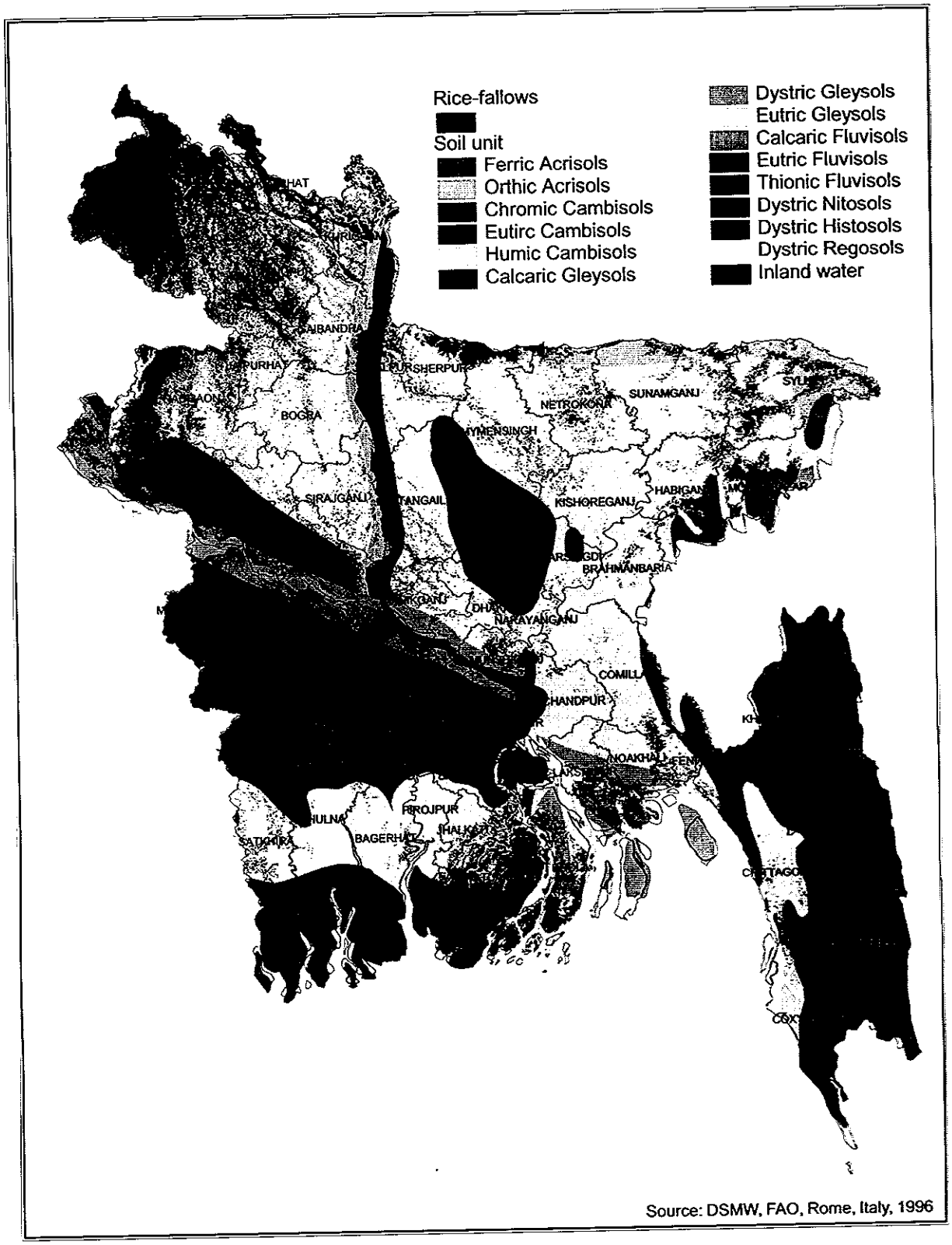


Fig. 5.1.3. Soils of Bangladesh

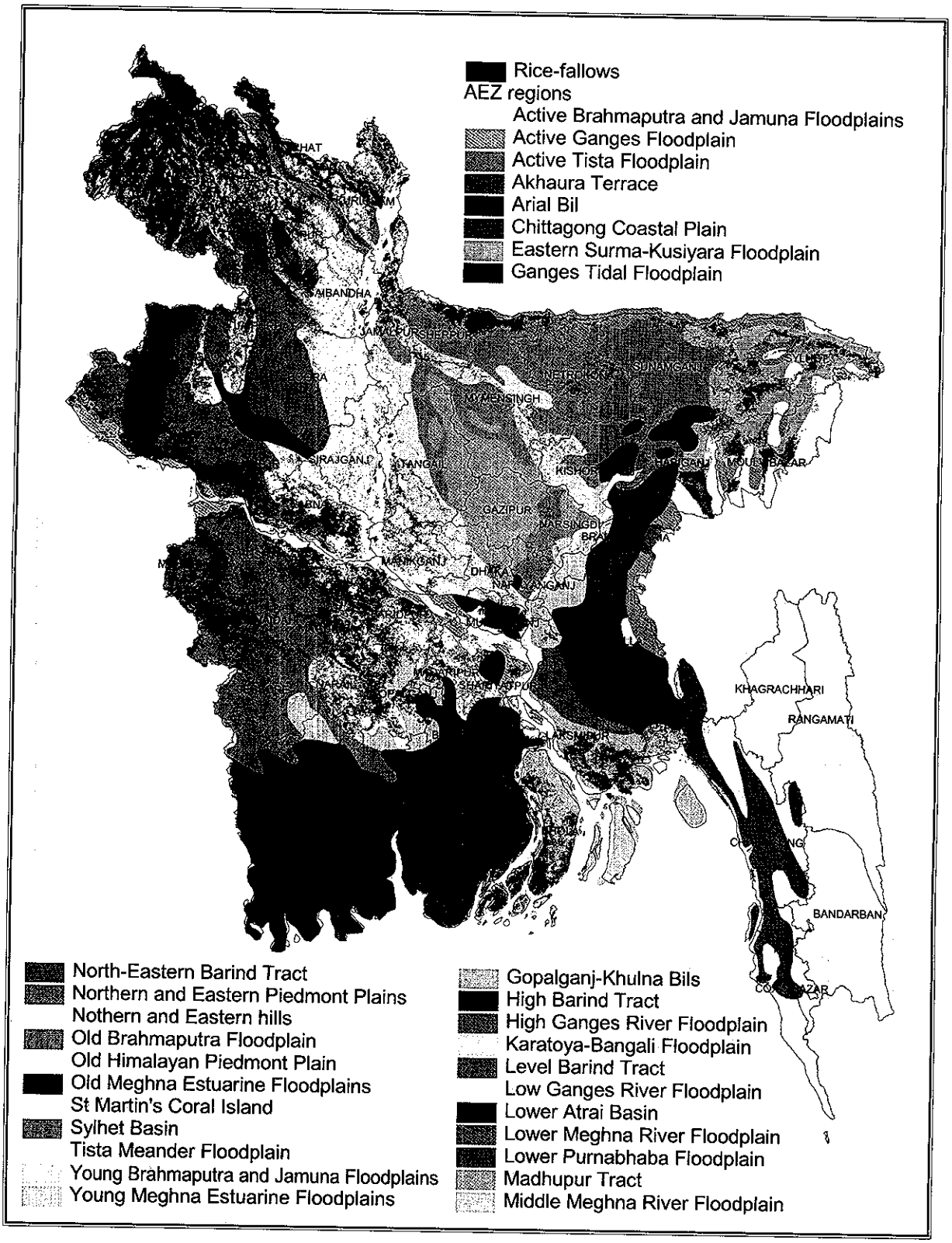


Fig. 5.1.4. Rice-fallows in different agro-ecological zones (AEZs) of Bangladesh

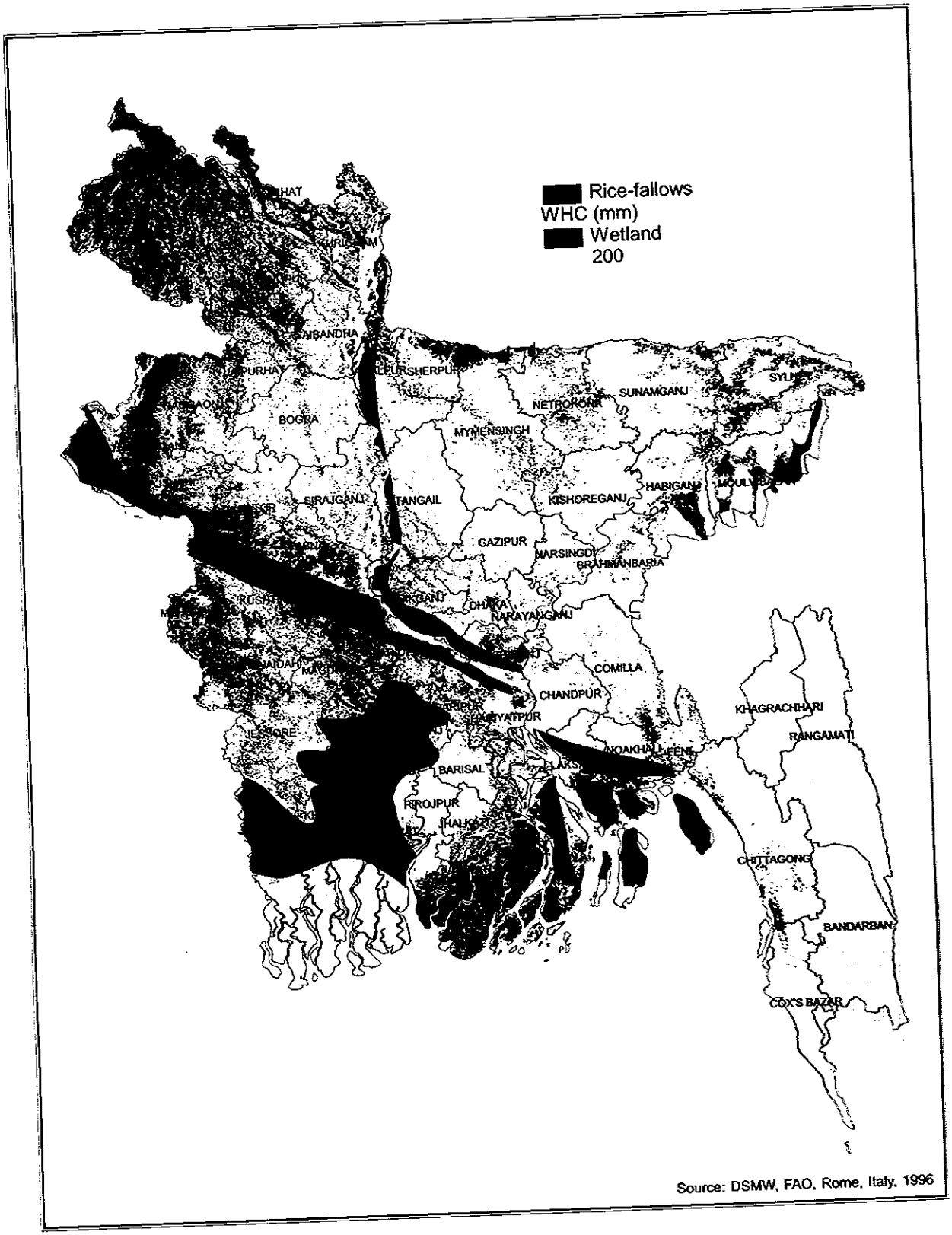


Fig. 5.1.5. Available soil water-holding capacity (WHC) in Bangladesh

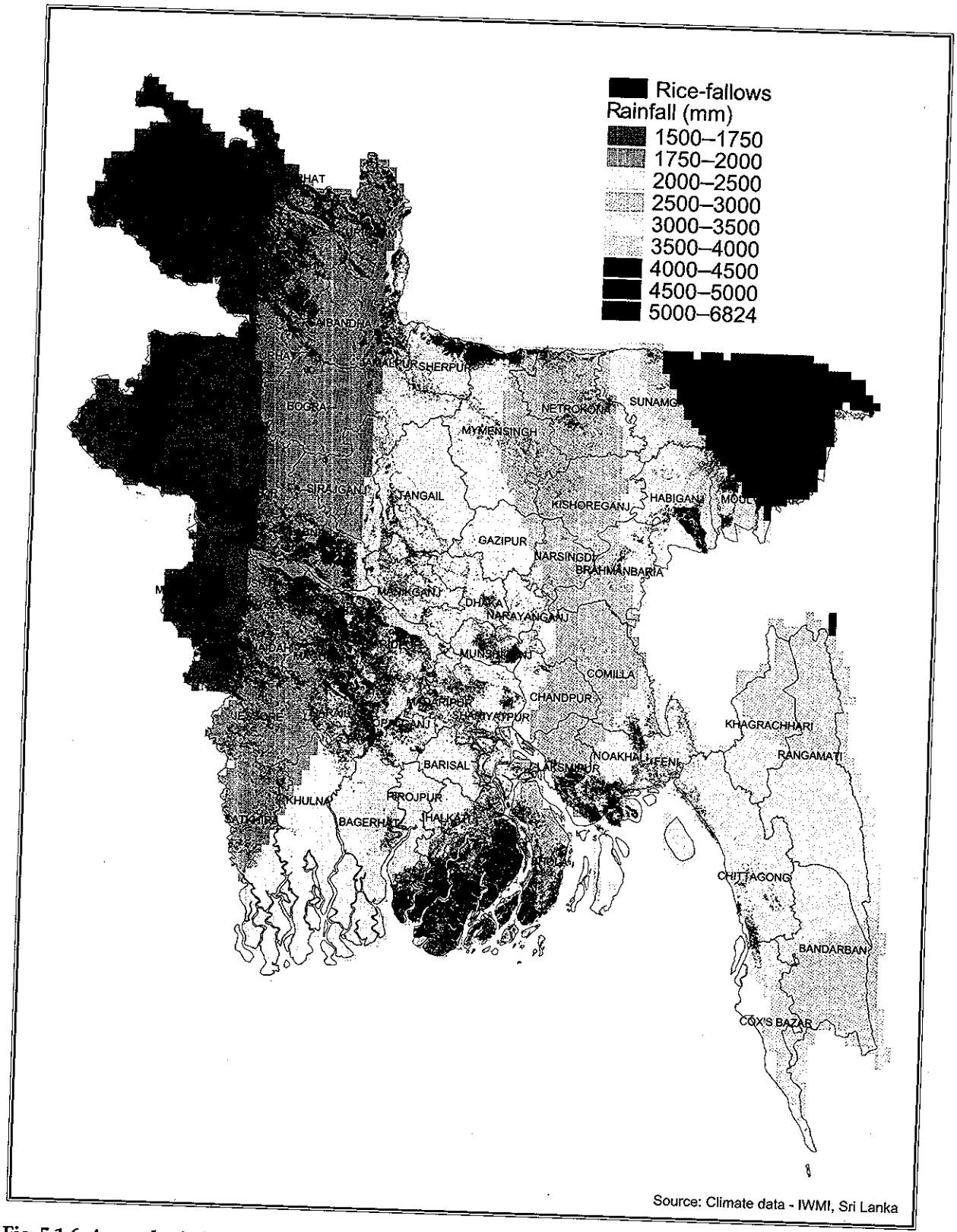


Fig. 5.1.6. Annual rainfall in Bangladesh

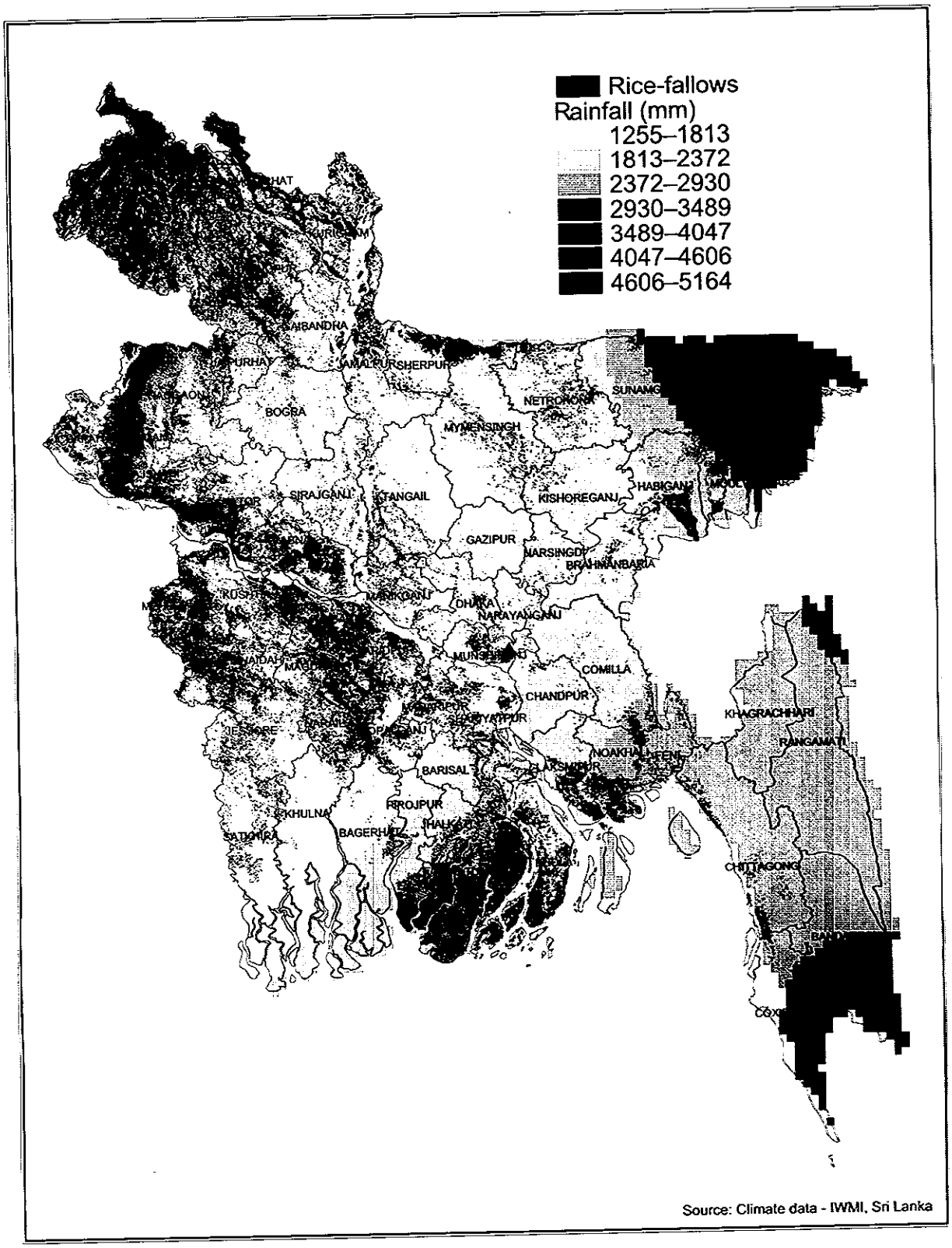


Fig. 5.1.7. Rainfal during summer (June-October) in Bangladesh

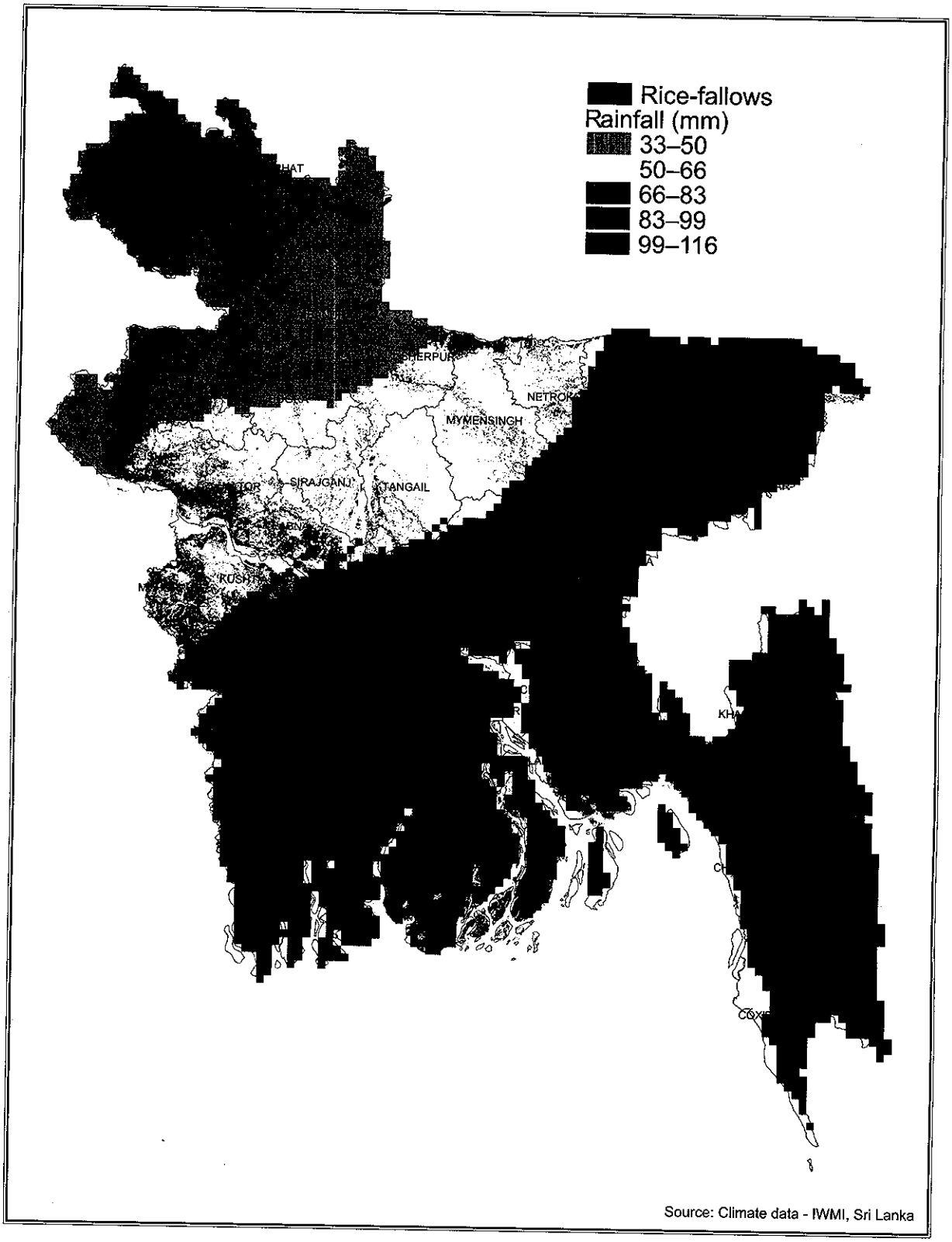
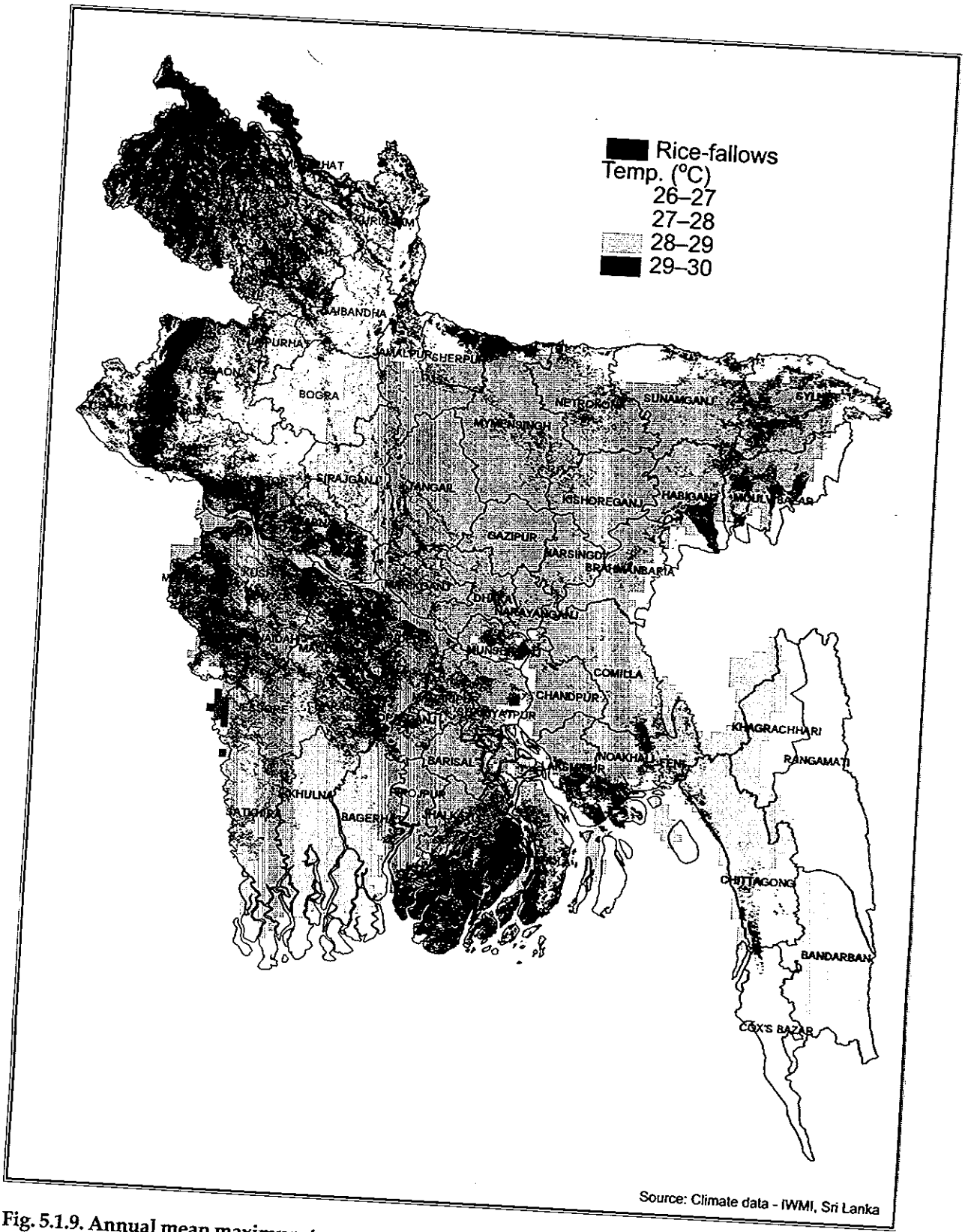


Fig. 5.1.8. Rainfal during winter (November–February) in Bangladesh



Source: Climate data - IWMI, Sri Lanka

Fig. 5.1.9. Annual mean maximum temperature in Bangladesh

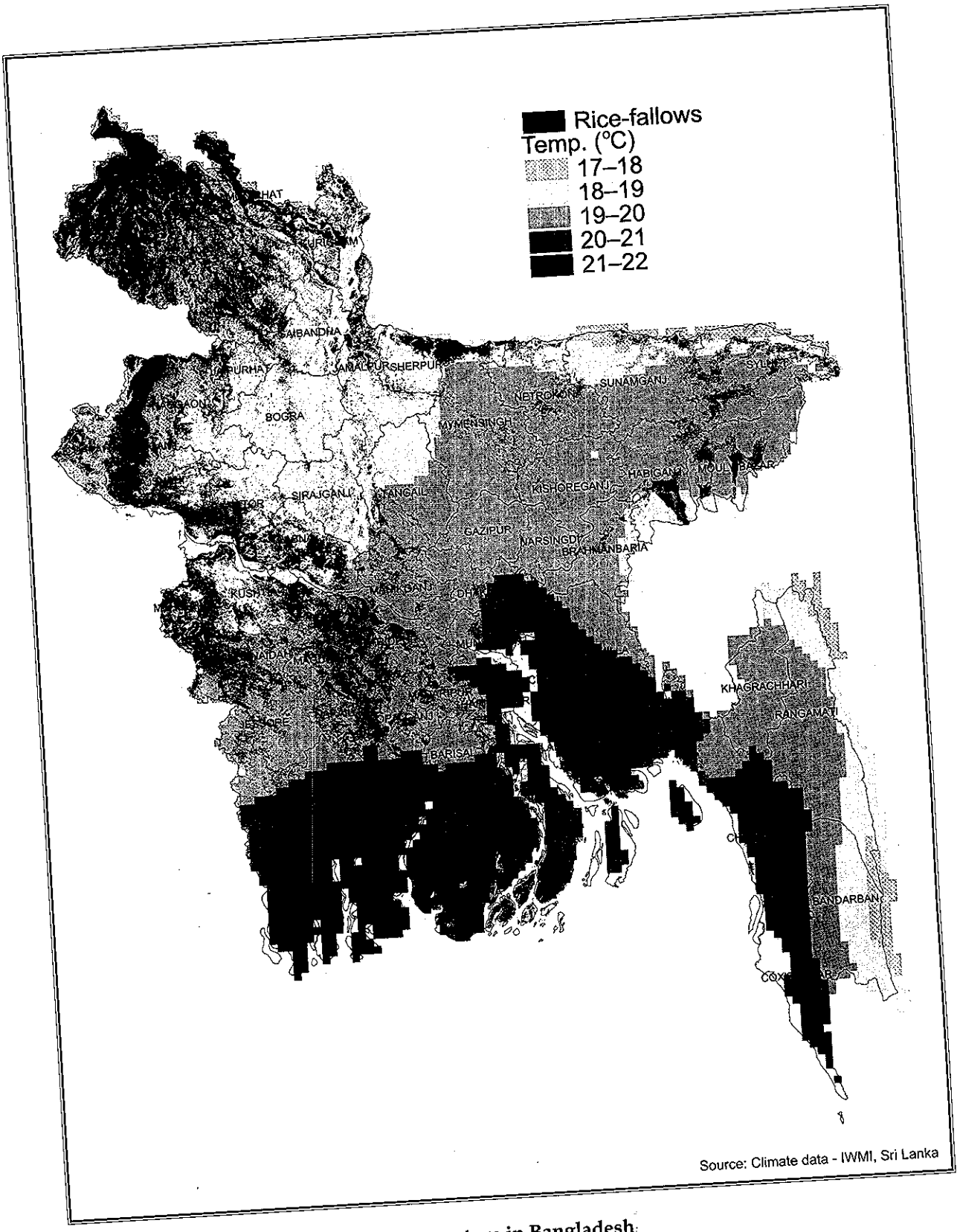


Fig. 5.1.10. Annual mean minimum temperature in Bangladesh

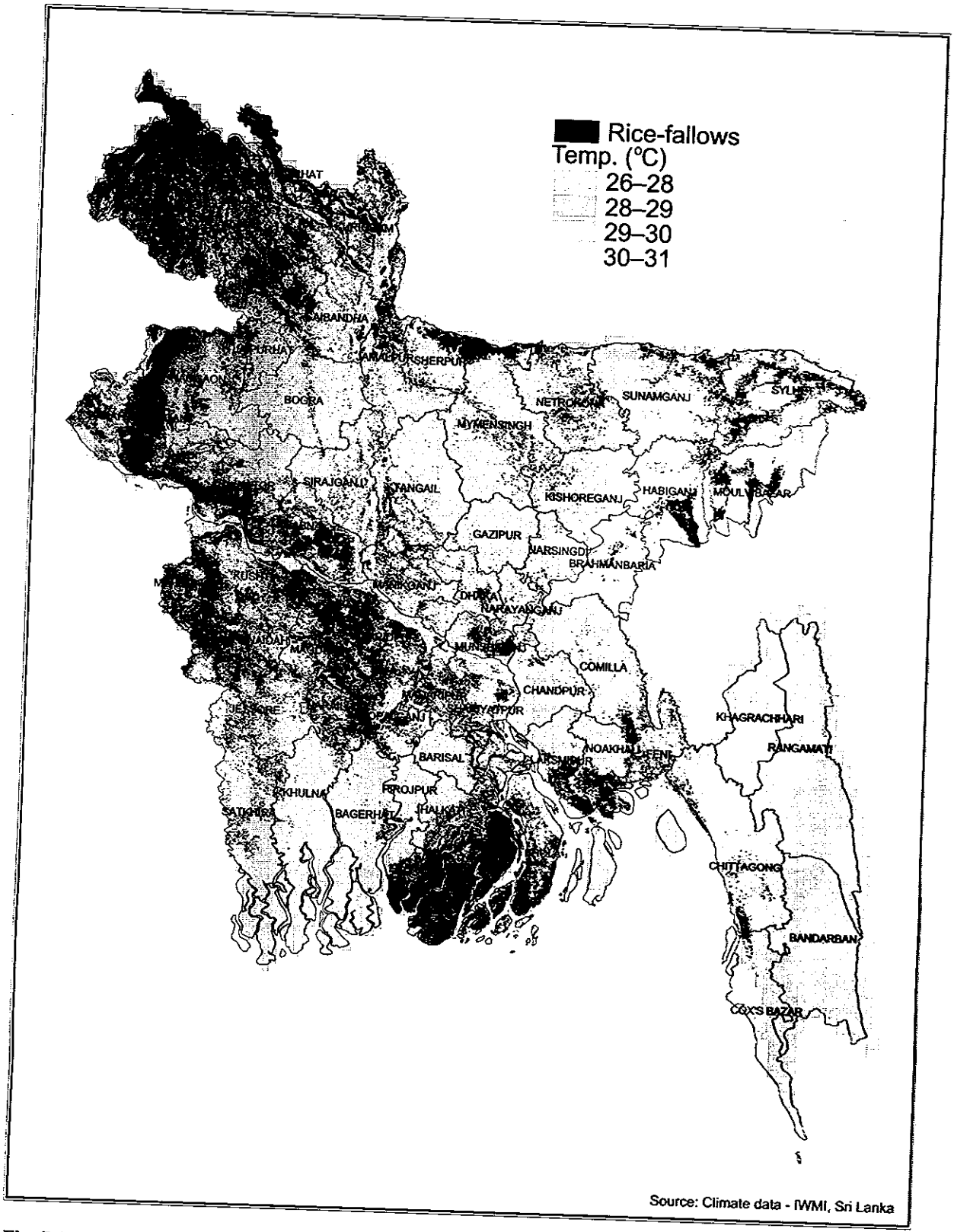


Fig. 5.1.11. Mean maximum temperature during summer (June–October) in Bangladesh

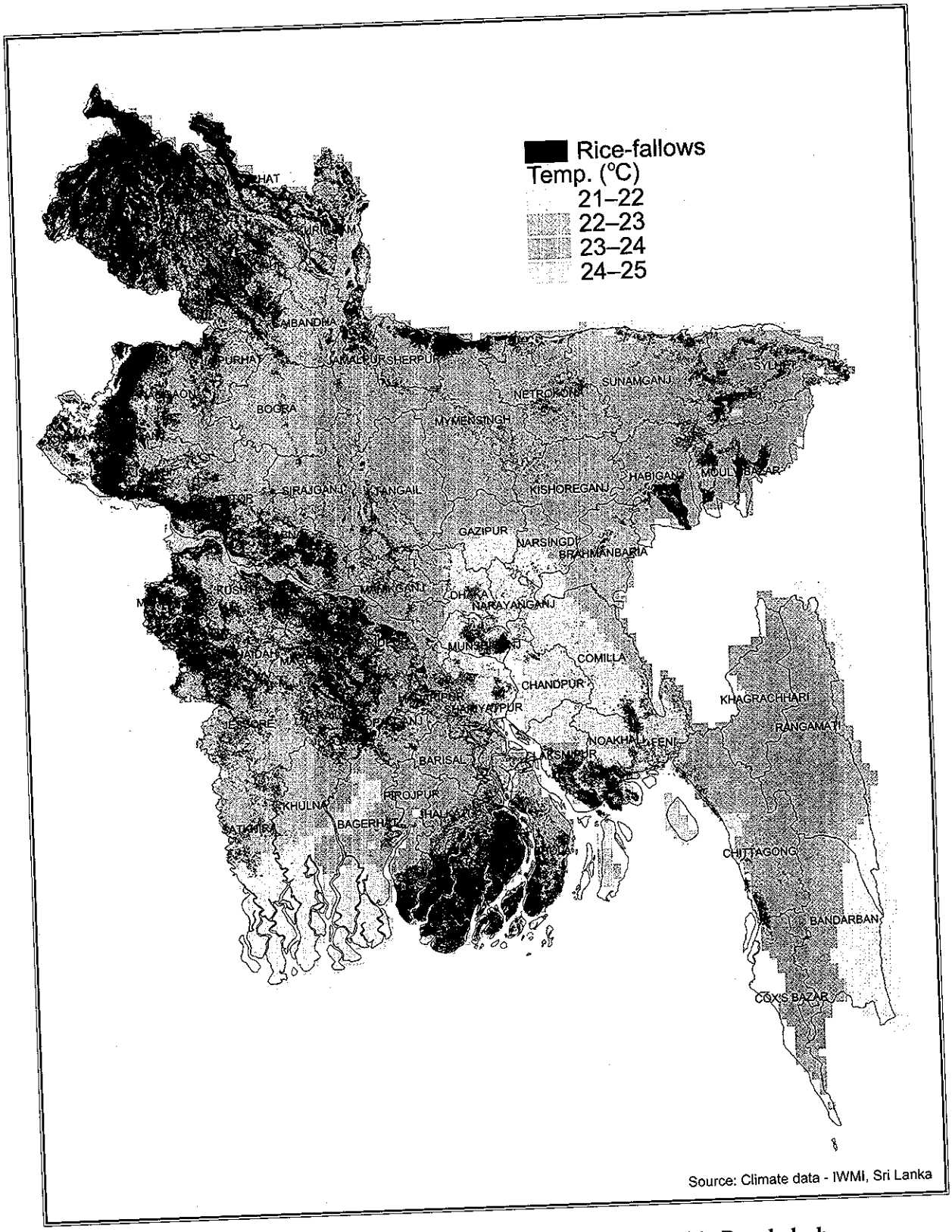


Fig. 5.1.12. Mean minimum temperature during summer (June–October) in Bangladesh

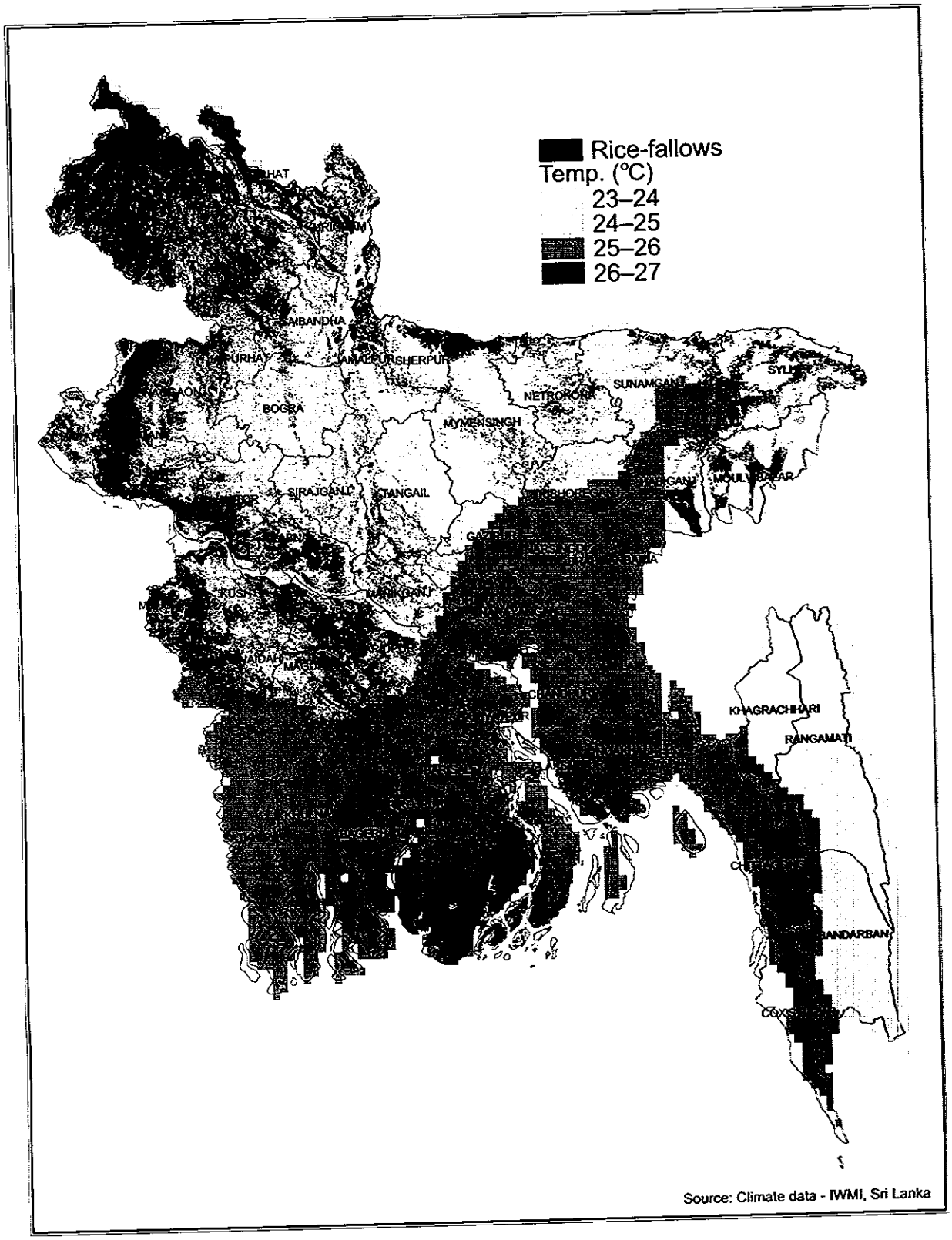


Fig. 5.1.13. Mean maximum temperature during winter (November–February) in Bangladesh

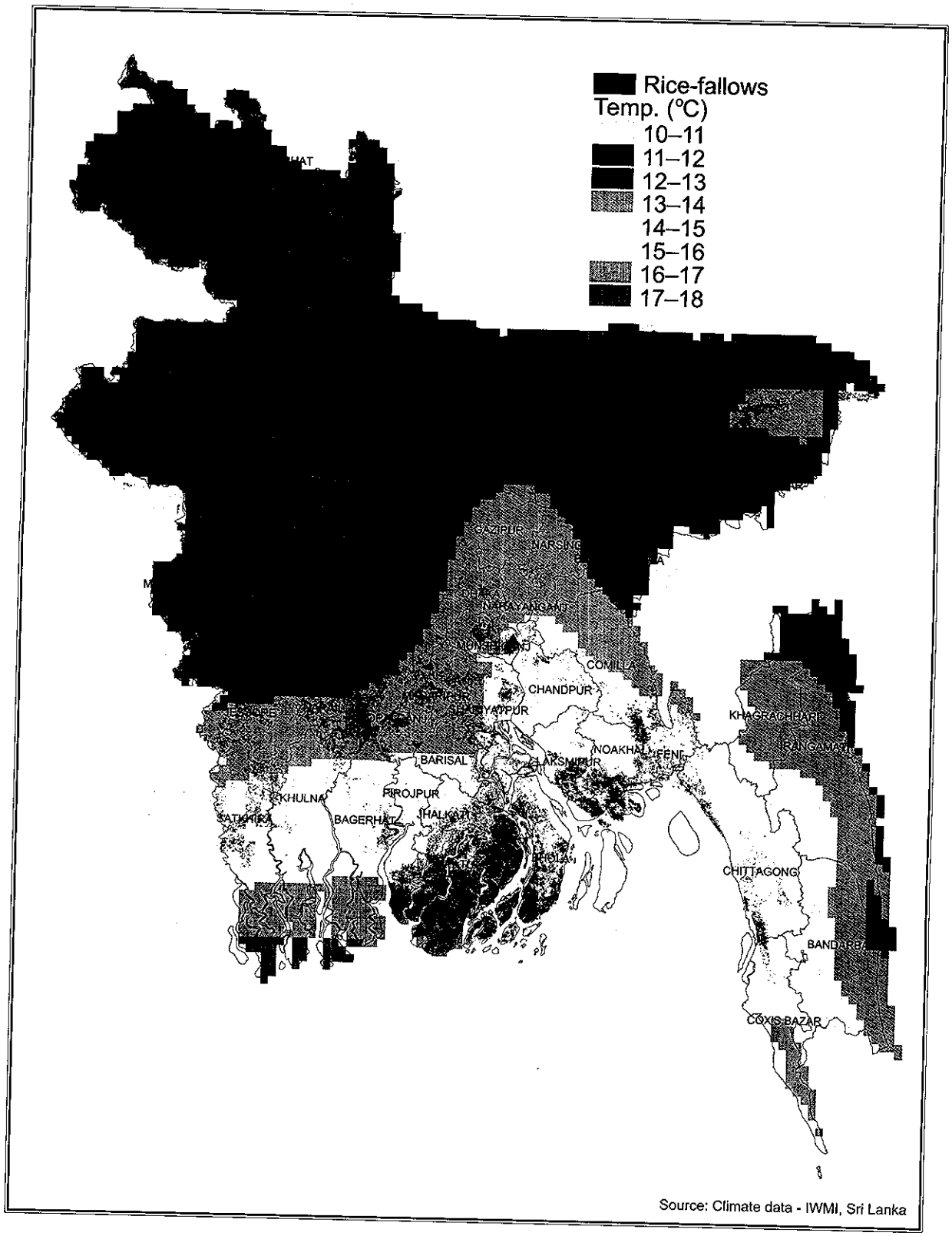


Fig. 5.1.14. Mean minimum temperature during winter (November–February) in Bangladesh

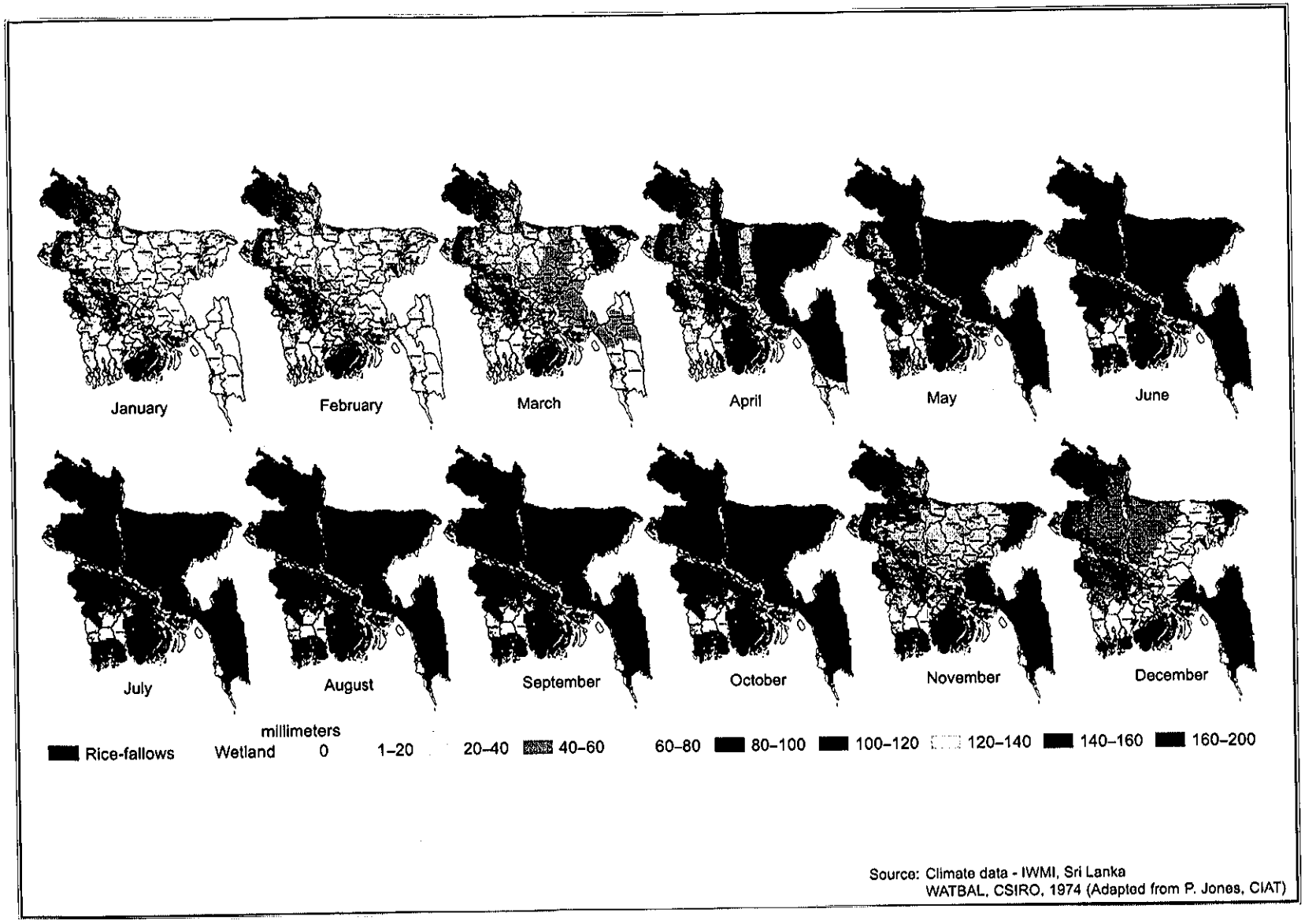
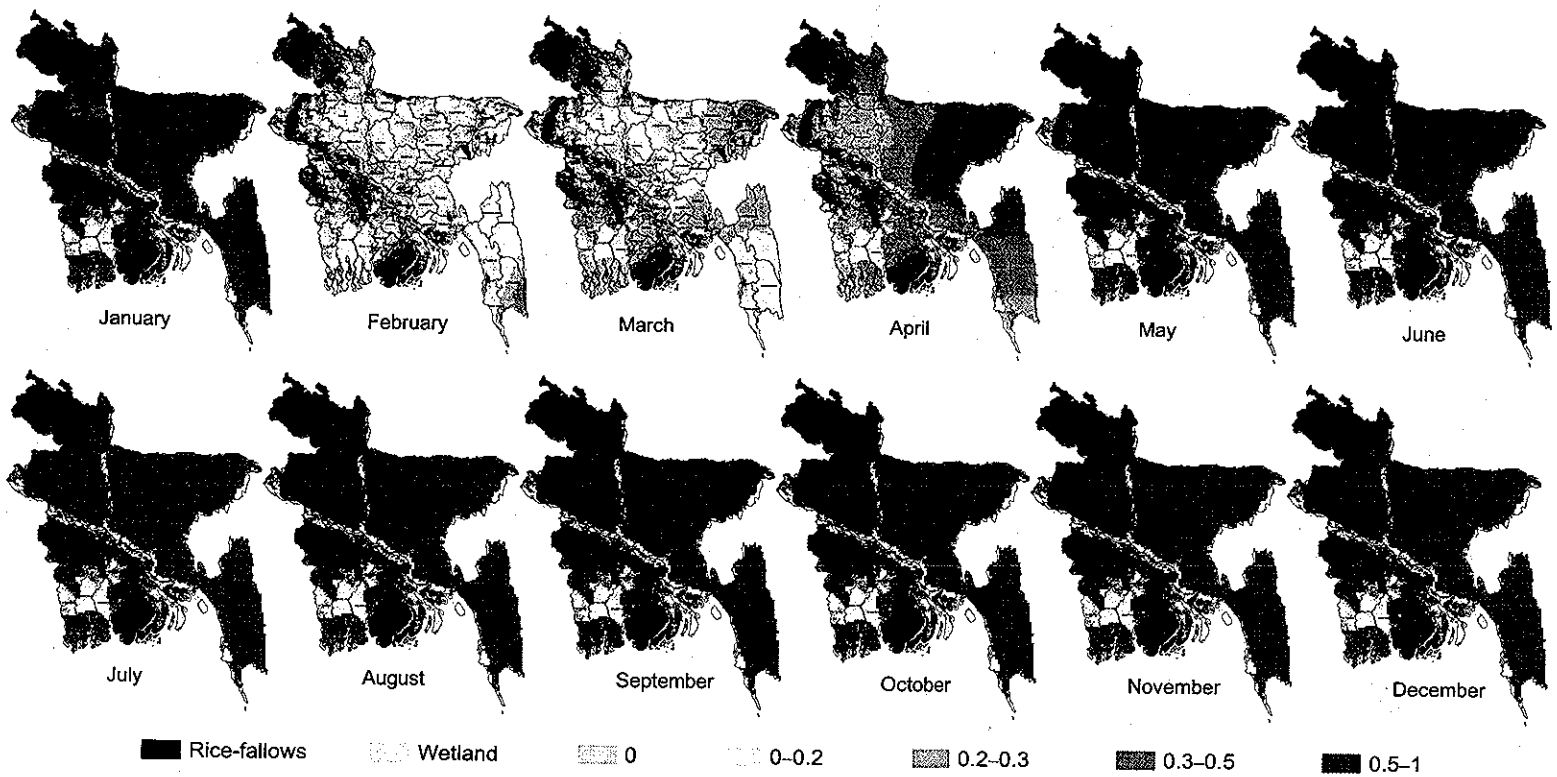


Fig. 5.1.15. Monthly available soil water in Bangladesh



Source: Climate data - IWMI, Sri Lanka
WATBAL, CSIRO, 1974 (Adapted from P. Jones, CIAT)

Fig. 5.1.16. Monthly actual evapotranspiration/potential evapotranspiration in Bangladesh

5.2. India

Introduction

There are nearly 40 million ha under rice production in India, which is the largest rice-growing area in South Asia. Much of this area remains fallow during the rabi season after the harvest of kharif rice. Increased cultivation of legumes in this predominantly cereal-based production system, wherever feasible, could substantially improve total legumes production in this region. It could also contribute to the sustainability of these rice-based production systems through the beneficial effects of legumes on subsequent rice crops. The per capita availability of pulses in India has been decreasing over the last few decades (Ali et al. 2000), which has largely been due to the expansion of irrigation facilities into the traditional legume growing areas (Joshi et al. 1994; Joshi 1998). Legumes are increasingly being replaced by rice during the kharif season and wheat during the rabi season. Thus legumes are being pushed into marginal areas less suitable for their cultivation and this has contributed to a substantial decrease in their production in traditional areas, and per capita availability. Introduction of short-duration legumes in rice-fallows, wherever feasible, during the rabi season could reverse this trend as these usually prime lands can be used for legume production without disrupting cereal production. A first step in this regard is to accurately quantify the extent of rice-fallows available in India and map their spatial distribution. Using GIS, we have overlaid the spatial distribution of rice-fallows on climatic and edaphic data to assess their suitability for legume cultivation during rabi season. This section summarizes the extent and spatial distribution of rice-fallows in India and their suitability for legume cultivation during the rabi season.

Rice Area Estimation

Based on crop statistics, 44.6 million ha of rice area was reported for India during 1999 (FAO 2001). Satellite image analysis has estimated that the rice area was 40.18 million ha during 1999 kharif season in the major rice-growing areas of India comprising 15 states (Table 5.2.1). Not all states of India were studied as the study was limited to states having considerable rice and rice-fallow areas. Also, some new states were recently created from Madhya Pradesh, Uttar Pradesh, and Bihar. The unclassified (raw) and classified satellite images of the 12 states where rice-growing areas are demarcated from other vegetation are presented in Figures 5.2.1 to 5.2.24.

Table 5.2.1. Estimates of rice area during kharif 1999 and rice-fallow area during rabi 1999/2000 based on satellite image analysis for major rice-growing states in India.

State	Kharif-rice area ('000 ha)	Rabi-fallow area ('000 ha)	Rabi-fallow area as % of kharif rice area	% of total rabi-fallow area
Andhra Pradesh	2657	305	11.5	2.6
Assam	2234	539	24.1	4.6
Bihar	5974	2196	36.8	18.9
Gujarat	469	83	17.7	0.7
Haryana	1109	0	0.0	0.0
Karnataka	984	182	18.5	1.6
Kerala	241	0	0.0	0.0
Madhya Pradesh	5596	4382	78.3	37.6
Maharashtra	1762	629	35.7	5.4
Orissa	3879	1219	31.4	10.5
Punjab	2498	0	0.0	0.0
Rajasthan	214	25	11.7	0.2
Tamil Nadu	1695	20	1.2	0.2
Uttar Pradesh	6255	353	5.6	3.0
West Bengal	4617	1719	37.2	14.8
Total	40184	11652	29.0	100.0

Rice-fallow Area Estimations

Based on satellite image analysis, the rice-fallows were estimated and demarcated for their spatial distribution. As described for Bangladesh, due to the complexity of the rabi cropping pattern in the eastern Indo-Gangetic Plain, in West Bengal and Assam, satellite images taken during January–March were used to differentiate land remaining fallow throughout the rabi season from land sown late to boro rice or from which rabi crops were harvested in February. The resultant unclassified and classified satellite images for the rabi season are given in Figures 5.2.1 to 5.2.24. Total rice-fallows for India are estimated at 11.7 million ha. Bihar, West Bengal, Orissa, Madhya Pradesh, Maharashtra, and Assam contribute a major portion of rice-fallows in India. In Madhya Pradesh, nearly 80% of the kharif rice area remains fallow during the rabi season and this amounts to nearly 4.4 million ha, accounting for nearly a third of total rice-fallows in India (Table 5.2.1).

Edaphic and Climatic Features of Rice-fallows

In India, rice is grown under diverse soil conditions. Large areas under rice crops are found along the banks of rivers, as water availability rather than soil is the more important factor in deciding on the suitability of an area for growing rice. Though rice is grown in almost all types of soils in India, the soils most suited to rice cultivation are heavy soils and clays or clay loams. Such soils, with high water-holding capacity, are found under tank irrigation conditions and river delta basins, and crops on these soils produce high yields. The most important groups of soils under which the crop is grown in India are the alluvial soils, red soils, laterite and lateritic soils, black soils, saline and alkaline soils, and peaty and marshy soils (Raychaudhuri et al. 1963). Since rice-fallows are distributed across the country, the edaphic and climatic factors of the major states where rice-fallows are found are discussed. The states of Andhra Pradesh, Assam, Bihar, Madhya Pradesh, Maharashtra, Orissa, and West Bengal together account for about 95% of the rice-fallows in the country.

Andhra Pradesh

In Andhra Pradesh, rice is grown mostly in East Godavari, West Godavari, Krishna, and Guntur districts. The soils in these four districts form mainly the deltas of the Krishna and Godavari rivers. Soils in West Godavari, Krishna, and Guntur are alluvial in nature and clayey in texture. The spatial distribution of rice-fallows and the soils they represent are shown in Figure 5.2.25, which is based on overlaying the rice-fallow areas on the FAO soil database. Though rice is grown in nearly 2.7 million ha in Andhra Pradesh, only 11.5% of this area remains as fallow during the rabi season (Table 5.2.1). Rice-fallows are mostly concentrated in the districts of Medak, Adilabad, Rangareddy, Visakhapatnam, Vizianagaram, and Srikakulam (Fig. 5.2.25). Rice-fallows of Adilabad, Medak, and Rangareddy have Chromic Vertisols, and Pellic Luvisols; rice-fallows in Vizianagaram and Srikakulam have Eutric Nitosols (Fig. 5.2.25). The available soil water-holding capacity of rice-fallow soils ranges from 150 mm to 200 mm in 1 m soil profile (Fig. 5.2.26). Most of the rice-fallows in Vizianagaram and Srikakulam have red soils. Red soils in Andhra Pradesh are brown to red in color and are mostly shallow, ranging from 15 cm to 60 cm depth; these soils vary in texture from sandy to loamy, are well drained, have a low salt content and pH ranging from 6.5 to 7.5. Also, these soils are low in humus, N, and P (Raychaudhuri et al. 1963).

The climatic features of rice-fallows in Andhra Pradesh are as follows. The annual rainfall ranges from 924 mm to 1392 mm (Fig. 5.2.27). The annual maximum and minimum temperatures are 25–30°C and 19–23°C, respectively (Figs. 5.2.28 and 5.2.29).

Rainfall during the kharif season ranges from 628 mm to 1036 mm (Fig. 5.2.30). During the kharif season, the maximum and minimum temperatures range from 28°C to 34°C and 21°C to 25°C, respectively (Figs. 5.2.31 and 5.2.32). During the rabi season (i.e., October to March), the rainfall varies from 204 mm to 546 mm (Fig. 5.2.33) and the maximum and minimum temperatures range from 25°C to 31°C and 15°C to 21°C, respectively (Figs. 5.2.34 and 5.2.35).

Assam

In Assam, rice is mainly grown on alluvial soils in the Brahmaputra and Surma valleys, and laterite soils in the mountainous regions of the northeastern parts of the state. The Brahmaputra valley is an alluvial plain, 720 km long and about 80 km broad. Soils of the valley are mostly sandy and sandy loams. Some red-loam soils are found in the districts of Karimganj, Hailakandi, and Cachar (Raychaudhuri et al. 1963). However, most of the soils are clayey, and some of them have fairly heavy clay soils. Being situated in the heavy rainfall region, the soils are highly leached, low in lime content and thus acidic in nature. The soils along the river banks are the most fertile tracts in the valley, fairly high in N and potassium (K). Rice, jute, and other crops are grown. In general, most soils in Assam have adequate levels of K, N, and organic matter. Rice-fallows are spread in most of the rice-growing regions of Assam, but nevertheless concentrated in the districts of Marigaon, Naogaon, and Lakhimpur (Fig. 5.2.36). Rice-fallows represent soil types of Eutric Cambisols, Orthic Acrisols, Ferric Acrisols, and Eutric Gleysols. But a major portion of rice-fallows are of Orthic Acrisols and Ferric Acrisols, which are of alluvial and laterite types respectively (Fig. 5.2.36). The available soil water-holding capacity in the 1 m soil profile of these rice-fallows is about 200 mm, with the exception of rice-fallow soils located in Karimganj, Hailakandi, and Cachar, where the soils usually remain waterlogged (Fig. 5.2.37). The most important characteristic of the soils in Assam is their acidic nature. The acidity increases with rainfall; thus soil acidity increases from west to east and from north to south. Therefore, the rice-fallows located in west and north are relatively less acidic compared to those in south and east.

Assam is a very high rainfall zone in India; total rainfall varies from 2040 mm to 6216 mm, and rice-fallows are present in most of these rainfall zones (Fig. 5.2.38). Kharif rainfall (June to September) varies from 1400 mm to 4400 mm in the rice-growing regions of Assam (Fig. 5.2.39). Rainfall during the rabi season (October to March) varies from 270 mm to 612 mm where these rice-fallows are located (Fig. 5.2.40). Annual maximum and minimum temperatures range from 22°C to 28°C and 16°C to 22°C, respectively (Figs. 5.2.41 and 5.2.42). Maximum and minimum temperatures in the kharif season

range from 28°C to 35°C and 22°C to 28°C, respectively (Figs. 5.2.43 and 5.2.44). Maximum and minimum temperatures in the rabi season range from 22°C to 28°C and 13°C to 17°C, respectively (Figs. 5.2.45 and 5.2.46).

Bihar

Bihar has the second largest rice-growing area (i.e., 5.97 million ha) in India. Nearly 37% of this area remains fallow during the rabi season (Table 5.2.1). Soils in Bihar can be broadly grouped into three groups: (a) alluviums in north of the Ganges; (b) alluviums in south of the Ganges; and (c) red and brown soils (Sarkar et al. 1998). Rice is grown in all of these soil types across the state. The alluvial soils north of the Ganges vary from clay loams to sandy loams and are neutral to alkaline in reaction. Alluvial soils south of the Ganges are heavier and finer in texture than those of the northern part. Red-loams occur in most of southern Bihar (includes districts of Palamu, Aurangabad, Gaya, Hazaribag, Lohardaga, Ranchi, Gumla, Giridih, Deoghar, Dumka, Sahibganj, and Dhanbad) and are mostly acidic (pH ranging from 5.0 to 6.8), poor in fertility status, and low in water-holding capacity (Raychaudhuri et al. 1963, Sarkar et al. 1998). Soils in Purbi Singhbhum and Pashchimi Singhbhum are of mixed types of Alfisols and Vertisols, and have problems of aluminium toxicity (Raychaudhuri et al. 1963).

Using the FAO-soils database, and GIS, the spatial distribution of rice-fallows was overlaid on the soil data to depict the soil types they represent (Fig. 5.2.47). Rice-fallows were found in most of the rice-growing areas of Bihar, but a major portion of these rice-fallows are concentrated in the southern part of Bihar, recently renamed as Jharkhand state. Most of the rice-fallows are concentrated in the districts of Aurangabad, Gaya, Deoghar, Dhanbad, Ranchi, Purbi Singhbhum, and Pashchimi Singhbhum. Rice-fallows are mostly Eutric Fluvisols in Kishanganj district; Orthic Luvisols and Ferric Luvisols in districts of Aurangabad and Gaya; and mostly Lithosols in districts of Deoghar, Bhagalpur, Godda, and Dumka. Rice-fallows in Dhanbad district are Ferric Luvisols. Large areas of rice-fallows are found in districts of Lohardaga, Gumla, and Ranchi, and these are Dystric Nitosols. Rice-fallows in Purbi Singhbum and Pashchimi Singhbhum are Chromic Vertisols. The available soil water-holding capacity of these rice-fallows (1 m depth), representing a wide range of soil types in Bihar, range from 150 mm to 200 mm (Fig. 5.2.48). Soils in Kishangang district, where substantial rice-fallows are located appear to be waterlogged (Fig. 5.2.48). The watertable varies in depth from 1 m to 3 m in most of the districts in Bihar where rice-fallows are located (Raychaudhuri et al. 1963).

Annual rainfall in these rice-fallows varies from 1200 mm to 1644 mm (Fig. 5.2.49), and rainfall increases from west to east (from 1176 mm in west to 1644 mm in east), and also from north to south (1176 mm in north to 1464 in south). A major portion of rice-fallows fall in the rainfall range of 1176 mm to 1344 mm. Nearly 80% of this rainfall occurs during the kharif season (i.e., from June to September), which ranges from 960 mm to 1280 mm (Fig. 5.2.50). About 20% of the total rainfall comes during the rabi season (October to March), which ranges from 126 mm to 204 mm where rice-fallows are located (Fig. 5.2.51). Rice-fallows located in western Bihar receive relatively less rabi-season rainfall (126 mm) compared to those in the eastern region (i.e., 200 mm) (Fig. 5.2.51). Annual temperature varies in the rice-fallows; the maximum temperature ranges from 23°C to 28°C (Fig. 5.2.52) and minimum temperature ranges from 14°C to 20°C (Fig. 5.2.53). During the kharif season, maximum temperature varies from 26°C to 33°C (Fig. 5.2.54); the minimum temperature varies from 18°C to 25°C (Fig. 5.2.55). Maximum and minimum temperatures during the rabi season vary from 23°C to 28°C and 9°C to 16°C respectively (Figs. 5.2.56 and 5.2.57).

Gujarat

Rice is grown in a relatively small area in Gujarat, on an area of about 0.47 million ha, of which only 0.08 million ha remains fallow during the rabi season (Table 5.2.1). Most of the rice is grown in the eastern part of Gujarat, which has Eutric Cambisols and Chromic Vertisols (Fig. 5.2.58). Rice-fallows are mostly located in the districts of Kheda, Vadodara, Panch Mahals, and Sabar Kantha, where Eutric Cambisols and Chromic Vertisols are the predominant soil types. Rice-fallows in Vadodara and Kheda have mostly alluvial soils while those in Panch Mahals district have medium black soils. The available soil water-holding capacity of most of these rice-fallow soils varies from 100 mm to 200 mm (Fig. 5.2.59). Annual rainfall varies from 996 mm to 1284 mm (Fig. 5.2.60). The annual maximum and minimum temperatures vary from 29°C to 31°C and 18°C to 21°C, respectively (Figs. 5.2.61 and 5.2.62). Kharif rainfall ranges from 924 mm to 1124 mm (Fig. 5.2.63). Maximum and minimum kharif season temperatures range from 30°C to 34°C and from 23°C to 24°C, respectively (Figs. 5.2.64 and 5.2.65). During the rabi season, the total rainfall ranges from 48 mm to 66 mm (Fig. 5.2.66); the maximum and minimum temperatures range from 28°C to 30°C and 14°C to 16°C, respectively (Figs. 5.2.67 and 5.2.68).

Karnataka

Rice is grown on nearly 0.98 million ha, of which about 18% remains fallow during the rabi season (Table 5.2.1). Rice-fallows are on Chromic Vertisols and Eutric Nitosols in

Belgaum district; Chromic Luvisols and Eutric Nitosols in Dharwad district; Eutric Nitosols in Shimoga district; and Chromic Luvisols in Mysore district (Fig. 5.2.69). Medium black soils and laterite soils are the most predominant soil types in rice-fallows in Belgaum district. In Dharwad, rice-fallows have mostly mixed red and black type, and laterite soils; in Shimoga and Mysore mostly red soils occur. The available soil water-holding capacity of the soils in rice-fallows ranges from 150 mm to 200 mm in the 1 m soil profile (Fig. 5.2.70). The climatic conditions where rice-fallows are located are as follows: annual rainfall ranges from 1392 mm to 2832 mm (Fig. 5.2.71); annual maximum and minimum temperatures range from 24°C to 30°C and 16°C to 20°C, respectively (Figs. 5.2.72 and 5.2.73). During the kharif season, rainfall ranges from 1152 mm to 2076 mm (Fig. 5.2.74); the maximum and minimum temperatures range from 24°C to 31°C and 16°C to 22°C, respectively (Figs. 5.2.75 and 5.2.76). During the rabi season, the rainfall ranges from 240 mm to 492 mm, but most of the rice-fallows fall in the rainfall zone of 240–360 mm (Fig. 5.2.77). The maximum and minimum temperatures during the rabi season range from 25°C to 31°C and 15°C to 19°C, respectively (Figs. 5.2.78 and 5.2.79).

Madhya Pradesh

Rice is grown mostly in the eastern and central regions of Madhya Pradesh. The major soil types found in these areas are alluvial, shallow black soils, medium black soils, mixed red black soils in north, and red-yellow soils in the eastern and central regions. The spatial distribution of rice-fallows and the soils they represent indicate that in the districts Panna, Bewa, and Satna, soils are Chromic Luvisols, which are mixed red and black (Fig. 5.2.80). The red soils are light-textured, and usually devoid of lime concretions and free carbonates. The most common form of soil is sandy clay. These soils are usually deficient in N, P, organic matter, and lime (Raychaudhuri et al. 1963).

In Betul district, rice-fallows lie on Vertic Cambisols, which are shallow black soils with clay loams having 15–30% clay. Rice-fallows in the districts Senoi, Chhindwara, Jabalpur, and Mandla have Chromic Vertisols. These are medium black soils, although patches of light-colored and reddish soils are often found. These black soils are generally deficient in N, P, and organic matter, but rich in K, iron, lime, aluminium, calcium (Ca), and magnesium carbonate (Raychaudhuri et al. 1963).

Most of southern and eastern Madhya Pradesh where rice is predominantly grown have soil types of Chromic Vertisols, as in the districts of Balaghat, Mandla, and Shahdol. In the districts of Sidhi, Surguja, Raigram, Bilaspur, Rajnandagaon, Durg, Raipur, and

Bastar, where a major portion of the rice-fallows (>75%) are located, soil types are Chromic Vertisols, Ferric Luvisols, and Chromic Luvisols. These soils are red and yellow in color, and generally considered light sandy soils; they occupy nearly 36% of the state's area and belong to the soil order Oxisols. They range from clay loam to loam and silty loam to silty clay loam and are poor in P (0.02 to 0.07%), humus, N, K, lime, and Ca. Sulfur deficiency is quite prevalent in the red soils zone of this state. In Bastar district, soils are usually acidic. The chemical and physical analyses of soil samples obtained from rice fields at Billori village, Jagdalpur, southeastern Madhya Pradesh are given in Table 5.2.2. Soils of rice-fallows have available water-holding capacity ranging from 150 mm to 200 mm in 1 m soil profile (Fig. 5.2.81).

The climatic variables of rice-fallows are as follows: the annual maximum and minimum temperatures range from 25°C to 29°C and 15°C to 21°C, respectively (Figs. 5.2.82 and 5.2.83); annual rainfall ranges from 900 mm in the western districts to 1476 mm in the eastern districts (Fig. 5.2.84). Rainfall during the kharif season (June to September) ranges from 900 mm to 1200 mm (Fig. 5.2.85). The maximum and minimum temperatures during the kharif season range from 27°C to 33°C and 20°C to 25°C, respectively (Figs. 5.2.86 and 5.2.87). During the rabi season, the rainfall ranges from 100 mm in northern districts to 180 mm in the southern districts (Fig. 5.2.88). Maximum and minimum temperatures in the rabi season vary from 23°C to 29°C and 11°C to 19°C, respectively (Figs. 5.2.89 and 5.2.90).

Table 5.2.2. Chemical and physical analyses of soil samples obtained from rice fields at Billori village, Jagdalpur, Madhya Pradesh, India.

Soil type	Sample depth (cm)	pH	EC (dS m^{-1})	Org. C (%)	Available P (ppm)	NO_3-N (ppm)	NH_4-N (ppm)	Coarse sand (%)	Fine sand (%)	Clay (%)	Silt (%)
Upland	0–15	5.38	0.02	0.59	0.1	4.5	8.1	7.83	14.00	41.70	36.50
	15–30	5.55	0.01	0.49	0.1	4.7	6.5	4.98	9.68	38.31	47.02
	30–45	5.28	0.02	0.35	0.1	6.2	8.0	6.85	11.73	35.90	45.53
Medium	0–15	5.25	0.03	0.73	0.1	4.5	8.5	12.28	17.76	33.23	36.73
	15–30	5.26	0.02	0.53	0.1	5.1	7.5	9.33	12.46	30.22	47.99
	30–45	5.17	0.02	0.44	0.1	5.7	7.4	13.77	9.61	29.60	47.01
Lowland	0–15	5.75	0.05	0.64	0.1	4.9	14.9	15.84	14.54	22.63	46.99

Source: C. Johansen, ICRISAT.

Maharashtra

Rice is a relatively minor crop in Maharashtra. It is grown in about 1.76 million ha, and nearly one third of this is left fallow during the rabi season (Table 5.2.1). The crop is mostly grown in coastal alluvium, medium and deep black soils. Rice-fallows in the districts of Dhule, Amravati, Chandrapur, Bhandara, Nagpur, and Nanded have mostly deep and medium black soils (Raychaudhuri et al. 1963). Deep black soils are calcareous, neutral to mild alkaline in reaction (pH 7.2 to 8.5), high in clay content (59%) and cation exchange capacity (Raychaudhuri et al. 1963). These soils are low in organic matter content. Medium black soils have a depth of about 1.5 m, are comparatively less clayey (about 43%) and have higher calcium carbonate ($CaCO_3$) content. Organic matter levels are very low (about 1.5%), but the soils are rich in K. The P levels are very low (Raychaudhuri et al. 1963). The spatial distribution of rice-fallows and the soils they represent are shown in Figure 5.2.91. A major portion of the rice-fallow soils is Chromic Vertisols and Lithosols. Such fallow-lands are mostly located in eastern Maharashtra. Rice-fallows in district Dhule have Haplic Phaeozem soils, and these are Dystric Nitosols in districts Ratnagiri and Shidhudurg in southern Maharashtra (Fig. 5.2.91). Available soil water-holding capacity of these rice-fallow soils varies from 150 to 200 mm in 1 m of the soil profile (Fig. 5.2.92).

The climatic features of rice-fallows in Maharashtra are as follows: the total rainfall in the rice-fallow regions varies from 948 mm to 2688 mm; the total rainfall increases from east to west (Fig. 5.2.93). A major portion of the rice-fallows are located in the eastern portion, where the annual rainfall is about 1235 mm (Fig. 5.2.93). The annual maximum and minimum temperatures range from 26°C to 30°C and 17°C to 22°C, respectively (Figs. 5.2.94 and 5.2.95). Kharif rainfall ranges from 724 mm to 2424 mm (Fig. 5.2.96); the maximum and minimum temperatures during the kharif season range from 26°C to 32°C (Fig. 5.2.97) and 20°C to 24°C, respectively (Fig. 5.2.98). During the rabi season (October to March), the total rainfall ranges from 84 mm to 180 mm, and most of the rice-fallows are located in the rainfall zones of around 140 mm (Fig. 5.2.99). The maximum and minimum temperatures range from 28°C to 31°C and 13°C to 21°C, respectively, during the rabi season (Figs. 5.2.100 and 5.2.101).

Orissa

Orissa has about 1.22 million ha rice-fallows during the rabi season amounting to 31.4% of kharif season rice area. Most of the rice-fallows in Orissa have soil types of Ferric Luvisols, Eutric Fluvisols, Lithosols, Dystric Nitosols, and Chromic Luvisols. Ferric Luvisols are the most predominant soil type in rice-fallows of Orissa (Fig. 5.2.102).

Available soil water-holding capacity in the top 1 m of soil in these rice-fallows ranges from 150 mm to 200 mm (Fig. 5.2.103). A major portion of these rice-fallows in the districts of Kalahandi, Bolangir, Sambalpur, Sundargarh, Dhenkanal, and Kheonjar have red soils (Raychaudhuri et al. 1963). These red soils are neutral in reaction, poor in organic matter and plant nutrients, and vary from loamy to sandy and are rarely clayey. The districts in the central plateau, Sambalpur, Bolangir, and parts of Dhenkanal have large areas under rice-fallows. Though rice-fallows have predominantly red soils, some rice-fallows have alluvial soils. Rice-fallows in the districts of Puri, Cuttack, Baleswar, and Mayurbhanj have laterite soils. These soils are generally loamy in texture, and rice-fallows in Cuttack and Puri are part of the Mahanadi delta. Soils in Mahanadi delta are the most fertile area of this state (Raychaudhuri et al. 1963). These are composed of alluvial deposits varying in texture and containing 30% to 50% clay. Also, these soils are low in soluble salt content and pH varies from 5.0 to 8.0 (Raychaudhuri et al. 1963).

The climatic conditions of rice-fallows in Orissa are as follows: the annual rainfall varies from 1140 mm to 1716 mm (Fig. 5.2.104), and the rainfall increases from west to east. Most of the rice-fallows in Orissa fall in the rainfall zones of 1452 mm to 1716 mm (Fig. 5.2.104). Maximum temperatures during the year range from 24°C to 29°C (Fig. 5.2.105); minimum temperatures during the year range from 17°C to 22°C (Fig. 5.2.106). Rainfall during the kharif season varies from 804 mm to 1324 mm in the rice-growing regions (Fig. 5.2.107). During the kharif season maximum temperatures vary from 26°C to 32°C (Fig. 5.2.108) and minimum temperatures range from 19°C to 25°C (Fig. 5.2.109). During the rabi season (October to March), rainfall varies from 180 mm to 264 mm in these rice-fallows (Fig. 5.2.110). Maximum temperatures vary from 24°C to 30°C, and minimum temperatures vary from 14°C to 20°C (Figs. 5.2.111 and 5.2.112).

Rajasthan

Rajasthan has about 214,000 ha under rice cultivation, of which only 25,000 ha remains fallow during the rabi season. The spatial distribution of these rice-fallows and the soils they represent are shown in Fig. 5.2.113. A major portion of the rice-fallows is located in the southern part, and it is represented by Chromic Luvisols and Chromic Vertisols (Fig. 5.2.113), with an available soil water-holding capacity ranging from 150 mm to 200 mm in 1 m soil depth (Fig. 5.2.114). The climatic features of these rice-fallows are as follows: annual rainfall ranges from 768 mm to 972 mm (Fig. 5.2.115); annual maximum and minimum temperatures range from 29°C to 31°C and 17°C to 19°C, respectively (Figs. 5.2.116 and 5.2.117). During the kharif season rainfall ranges from 704 mm to 880 mm (Fig. 5.2.118); maximum and minimum temperatures range from 32°C to 38°C and 22°C to 24°C, respectively (Figs. 5.2.119 and 5.2.120). During the rabi season rainfall

ranges from 48 mm to 84 mm (Fig. 5.2.121); maximum and minimum temperatures range from 27°C to 30°C and 13°C to 15°C, respectively (Figs. 5.2.122 and 5.2.123).

Tamil Nadu

Tamil Nadu has about 1.70 million ha under rice cultivation during the kharif season, of which only 20,000 ha remains fallow during the rabi season (Table 5.2.1). The spatial distribution of these rice-fallows and the soils they represent are given in Figure 5.2.124. A major portion of these rice-fallows has soils of Chromic Luvisols and Orthic Luvisols (Fig. 5.2.124), with an available water-holding capacity of about 200 mm in the 1 m soil profile (Fig. 5.2.125). The climatic features of these rice-fallows are as follows: total annual rainfall ranges from 1560 mm to 1800 mm (Fig. 5.2.126); annual maximum and minimum temperatures range from 27°C to 30°C and 21°C to 23°C, respectively (Figs. 5.2.127 and 5.2.128). Mean kharif rainfall ranges from 1740 mm to 3648 mm (Fig. 5.2.129); the maximum and minimum temperatures during kharif season range from 30°C to 34°C and 21°C to 25°C, respectively (Figs. 5.2.130 and 5.2.131). During the rabi season rainfall ranges from 552 mm to 660 mm (Fig. 5.2.132); the maximum and minimum temperatures range from 27°C to 31°C and 17°C to 22°C, respectively (Figs. 5.2.133 and 5.2.134).

Uttar Pradesh

Uttar Pradesh has the largest rice-growing area in India, of about 6.26 million ha, of which only 6% of the area remains fallow during the rabi season (Table 5.2.1). A major portion of this rice area is used for wheat production during the rabi season. Rice-fallows in Uttar Pradesh account for 3% of the total rice-fallow area in India (Table 5.2.1). The spatial distribution of these rice-fallows and the soils they represent are shown in Fig. 5.2.135. Rice-fallows have Eutric Cambisols soils in the districts of Kheri, Gonda, Pilibhit, Agra, and Etawah (Fig. 5.2.135). In districts Jalaun, Jhansi, Hamirpur, and Banda, rice-fallows are on Chromic Luvisols (Fig. 5.2.135). In districts Mirzapur and Sonbhadra, rice-fallows are on Chromic Luvisols, Ferric Luvisols, and Eutric Cambisols. The available soil water-holding capacity for most of these rice-fallow soils is about 200 mm in the 1 m soil profile (Fig. 5.2.136). A major portion of rice-fallows is concentrated in districts Kheri and Mirzapur (Fig. 5.2.135). Rice-fallows in Pilibhit and Kheri districts are likely to have saline, alkaline soils (B.B. Singh, Narendradeva University of Agriculture & Technology, Faizabad, India, personal communication). Also, rice-fallows in districts Agra, Mainpuri, Farrukhabad, Jalaun, Jhansi, Hamirpur, and Banda are likely to be on sodic soils, which can be a limiting factor for rabi season crop production (B.B. Singh, Narendradeva University of Agriculture & Technology, Faizabad, India, personal communication). In the districts of Bahraica and

Gonda, rice-fallows are on alluvial soils. In Mirzapur district, most of the rice-fallow soils are red. In Hamirpur and Banda districts, the rice-fallows have mainly mixed red and black soils. Rice-fallows in Agra, Etawah, and Mainpuri have alluvial soils (Fig. 5.2.135).

The climatic features of rice-fallows in Uttar Pradesh are as follows: annual rainfall ranges from 816 mm to 1260 mm (Fig. 5.2.137); and annual maximum and minimum temperatures range from 25°C to 30°C and from 15°C to 20°C respectively (Figs. 5.2.138 and 5.2.139). Rainfall during the kharif season ranges from 712 mm to 1040 mm (Fig. 5.2.140); maximum and minimum temperatures during kharif season range from 32°C to 37°C and 25°C to 28°C, respectively (Figs. 5.2.141 and 5.2.142). During rabi season, the rainfall ranges from 84 mm to 204 mm (Fig. 5.2.143); maximum and minimum temperatures range from 22°C to 27°C and 9°C to 14°C, respectively (Figs. 5.2.144 and 5.2.145).

West Bengal

Rice is grown in most parts of the state, and in soils ranging from laterite, red to alluvial soils. The spatial distribution of rice-fallows and the soil types they represent are given in Figure 5.2.146. Rice-fallows in Kooch Bihar have Dystric Nitosols and Eutric Gleysols. In Jalpaiguri, rice-fallows are of Eutric Cambisols and also Dystric Regosols. In West Dinajpur, rice-fallows have Calcaric Gleysols, Eutric Gleysols, Orthic Solonchaks, and Eutric Cambisols. Rice-fallows in Kooch Bihar and most of West Dinajpur are alluvial soils, which generally are deficient in N (range from 0.02% to 0.09%), and P levels vary from 0.1% to 0.15% (Raychaudhuri et al. 1963). The pH of these soils ranges from 7.0 to 8.0. Rice-fallows in the southern part of West Dinajpur have red soils and some of them extend into Maldah district. Soils in Jalpaiguri mostly are of alluvial soils, which are sandy, raw humus type, and deep black to gray black. These soils are acidic, poor in available bases and also very poor in nutrients. A major portion of these rice-fallows are concentrated in the western districts of West Bengal that include Purulia, Bankura, Medinipur, and Barddhaman where Dystric Nitosols are the predominant soil type. Three soil types are predominant in these rice-fallows: (a) red soil; (b) laterite soil; and (c) alluvial soil. Red soils are mildly acidic and poor in Ca, N, and available P. Laterite soils are yellow-gray on top and red below. Organic matter, N, available P, and Ca are low and the soils are acidic (pH ranging from 5.5 to 6.5). The alluvial soils in general are deficient in N (range from 0.02% to 0.09%), and phosphate in the soils vary from 0.1 to 0.15%; pH varies from 6.0 to 7.5, and K levels vary from 0.1 to 0.4% (Raychaudhuri et al. 1963). Rice-fallows in South 24 Paraganas have Dystric Cambisols, which are deltaic alluvial soils, and rich in Ca and magnesium. In Birbhum, most of the rice-fallows are of Ferric Luvisols, which are deltaic alluvial soils. Available soil water-holding capacity in these rice-fallows is about 200 mm in 1 m soil profile (Fig. 5.2.147) and soils in South 24 Paraganas and rice-fallows located in the eastern portion of West Dinajpur are wetlands (FAO 1996) (Fig. 5.2.147).

The climatic features of the rice-fallows in West Bengal are as follows: annual rainfall ranges from 1416 mm to 2136 mm, and the rainfall increases from west to east and also from north to south; rice-fallows in Purulia are in the rainfall zone of around 1400 mm, compared to rice-fallows in North 24 Paraganas which are in the rainfall zone of around 1800 mm (Fig. 5.2.148). Annual maximum temperature ranges from 21°C to 28°C (Fig. 5.2.149) and annual minimum temperature ranges from 16°C to 23°C (Fig. 5.2.150). During the kharif season, rainfall ranges from 1172 mm to 1620 mm (Fig. 5.2.151); maximum temperature ranges from 25°C to 32°C (Fig. 5.2.152) and minimum temperature ranges from 14°C to 25°C (Fig. 5.2.153). During the rabi season (i.e., October to March) rainfall ranges from 174 mm in northern districts to 290 mm in southern districts. The rabi season rainfall is lowest in the western districts and highest in the eastern districts (Fig. 5.2.154). The maximum temperature during the rabi season varies from 25°C to 28°C (Fig. 5.2.155), and the minimum temperature during the rabi season varies from 12°C to 20°C (Fig. 5.2.156).

Legumes Suitable for Rice-fallows and their Biotic Constraints

Cool-season legumes

Most cool-season legumes have temperature optima for most growth and development processes within the range of 15°C to 25°C, with a base temperature of 0°C (Johansen et al. 2000b). Some of the possible cool season legumes that can fit into these rice-fallows are discussed below.

Chickpea. Chickpea is one of the major grain legumes widely grown in India, and is suitable for rice-fallows of Uttar Pradesh, Rajasthan, Madhya Pradesh, Bihar, West Bengal, Assam, Orissa, Maharashtra, Gujarat, Andhra Pradesh, Karnataka, and Tamil Nadu. The average national chickpea yields have increased from 700 kg ha^{-1} in 1980/81 to 970 kg ha^{-1} in 94/95 (Ali et al. 2000). However, chickpea area has declined by more than 1 million ha during the past 15 years (Ali et al. 2000). Chickpea is not a major crop in rice-based production systems in peninsular India, but has potential for expansion especially in the rice-fallows in Andhra Pradesh, Karnataka, Orissa, Madhya Pradesh, and Bihar. Chickpea genotypes or sowing technologies that permit establishment under high initial moisture conditions should be developed to facilitate relay planting. The following fungal diseases are important for chickpea production in rice-lands (Ali et al. 2000): ascochyta blight (*Ascochyta rabiei*), BGM (*Botrytis cinerea*), fusarium wilt (*Fusarium oxysporum* f. sp *ciceris*), dry root rot (*Rhizoctonia bataticola*), wet root rot (*Rhizoctonia solani*), black root rot (*Fusarium solani*), and collar rot (*Sclerotium rolfsii*). Pod borer, semilooper, and bruchids are some of the important insect pests (Table 5.2.3).

Table. 5.2.3. Some important insect pests and nematodes of grain legumes in India.

Crop	Insect pest	Nematode
Chickpea	Pod borer (*Helicoverpa armigera*) Semilooper (*Autographa nigrisigna*) Bruchids (*Callosobruchus* sp)	Root-knot (*Meloidogyne* spp)
Groundnut	White grubs (*Lachtosterna* sp) Termites (*Microtermes, Odontotermes*) Tobacco caterpillar (*Spodoptera litura*)	Root-knot (*Meloidogyne* spp)
Lentil	Aphids (*Aphis craccivora*) Pod borer (*Etiella zinckenella*) Bruchids (*Callosobruchus chinensis, C. maculatus*)	Root-knot (*Meloidogyne* spp)
Pea	Leaf miner (*Phytomyza atricornis*) Stem fly (*Ophiomyia phaseoli*)	Root-knot (*Meloidogyne* spp) Cyst (*Heterodera goettingiana*)
Pigeonpea	Pod borer (*Helicoverpa armigera*) Podfly (*Melanagromyza obtusa*) Legume pod borer (*Maruca vitrata*) Blister beetle (*Mylabris pustulata*)	Cyst (*Heterodera cajani*) Lesion (*Pratylenchus* spp) Root-knot (*Meloidogyne* spp)
Soybean	Leaf folder (*Lamprosema omiodes indica*) Girdle beetle (*Oberopsis brevis*) Blister beetle (*Mylabris* sp)	Cyst (*Heterodera glycines*) Root-knot (*Meloidogyne* spp) Reniform (*Rotylenchulus reniformis*)
Vigna spp (black gram, mung bean and cowpea)	Hairy caterpillar (*Spilosoma (Diacrisia) obliqua*) Thrips (*Megalurothrips distalis*) Whitefly (*Bemisia tabaci*) Aphids (*Aphis craccivora*)	Root-knot (*Meloidogyne* spp) Cyst (*Heterodera* spp)

Source: Pande et al. (2000)

Lentil. Lentil is one of the major grain legumes grown extensively in India. Lentil is suitable for rice-fallows in Uttar Pradesh, Rajasthan, Madhya Pradesh, Bihar, Orissa, West Bengal, and Assam. Bihar and Uttar Pradesh are the major growing areas for lentil. Among fungal diseases, seedling rots (*Fusarium moniliforme*), black root rot (*Fusarium solani*), pythium root rot (*Pythium ultimum*), vascular wilt (*Fusarium oxysporum* f. sp *lentis*), collar rot (*Sclerotium rolfsii*), wet root rot (*Rhizoctonia solani*), dry root rot (*Rhizoctonia bataticola*), and sclerotinia stem rot (*Sclerotinia sclerotiorum*) are economically important (Ali et al. 2000). The major foliar diseases are: ascochyta blight (*Ascochyta fabae* f. sp *lentis*), rust (*Uromyces viciae-fabae*), downy mildew (*Peronospora lentis*), and gray mold (*Botrytis cinerea*). Anthracnose (*Colletotrichum truncatum*), alternaria blight (*Alternaria alternata*), and stemphylium blight (*Stemphylium botryosum*) are the other diseases that can affect lentil. Among viral diseases, yellow mosaic (bean yellow mosaic

virus) and cucumber mosaic (cucumber mosaic virus) are important for lentil production (Makkouk et al. 1993). Aphids, bruchids, and pod borer are the main insect pests of lentil (Table 5.2.3).

Khesari. Khesari is a robust legume commonly grown after rice in eastern India (Pande and Joshi 1995). It is suitable for rice-fallows in Uttar Pradesh, Madhya Pradesh, Bihar, West Bengal, and Assam. Khesari area has declined rapidly during the past two decades in India (Ali et al. 2000). It is grown extensively in central, southern, and eastern parts of Madhya Pradesh, where a major portion of rice-fallows is located. Khesari has wide adaptability to grow in paddy soils and is a very hardy crop in general with few pests or disease constraints. While it responds to good moisture conditions, it suffers much less as compared to other pulses such as chickpea in adverse conditions of soil moisture, both excess or deficit. Also, this crop is not injured by the cracking of black soils. It thrives best on low-lying water retentive heavy soils. Most of the khesari is grown as a relay crop, where the seed is broadcast into the standing rice crop before its harvest (about 3 to 4 weeks). At the time of rice harvest, the khesari crop is already established; and thus has an early advantage in establishing crop cover quickly, which further contributes to its adaptability to rice-based systems and also in escaping from terminal drought stress. A number of varieties such as 'Pusa-24', developed at the Indian Agricultural Research Institute (IARI), New Delhi contain low neurotoxin concentrations and have yield potential similar to the high-yielding local cultivars with high neurotoxin levels (Gadkari and Laxman Singh 1979). The improved genetic stocks such as P24-1-A, and 24-4-a-B isolated as single plants from a bulk of P-24 have neurotoxin concentrations of 0.2% and 0.16% respectively, whereas the local varieties have neurotoxin concentrations higher than 0.5% and up to 2% in some cases (Gadkari and Laxman Singh 1979). Recently Biol-212, a line almost free from neurotoxin was developed through somaclonal variation (Mehta and Santha 1996). Studies at the Nutrition Research Laboratory, Hyderabad have shown that 0.2% neurotoxin or less can be concluded as safe for human consumption (Gadkari and Laxman Singh 1979). Excessive consumption of khesari is believed to cause an incurable human disease called lathyrism. This is characterized by muscular weakness and paralysis of the lower legs. It affects chiefly males. It was observed that this paralysis appears only after protracted consumption of this grain.

Rust (*Uromyces fabae*), powdery mildew (*Erysiphe polygoni*), downy mildew (*Peronospora lathyri palustris*), and wilt (*Fusarium oxysporum* var. *lathyri*) are some of the important diseases of khesari (Ali et al. 2000). Aphids can be a serious pest of this crop.

Faba bean. Faba bean (*Vicia faba* L.) is mostly cultivated in western Uttar Pradesh, and is suitable for rice-fallows in Bihar, Uttar Pradesh, Rajasthan, Madhya Pradesh, West Bengal, and Assam. Among foliar diseases, chocolate spot (*Botrytis fabae*), ascochyta blight (*Ascochyta fabae*), and rust (*Uromyces viciae-fabae*) are the major diseases (Ali et al. 2000). Root rot (*Fusarium solani*) can also cause considerable yield losses in faba bean (Liu 1984).

Pea. Pea (*Pisum sativum* L.) is adapted to a wide range of soil types and environments and is suitable for rice-fallows in Bihar, Uttar Pradesh, northern Madhya Pradesh, West Bengal, and Assam. Seedling rot (*Rhizoctonia solani*), and pythium seed and seedling rot (*Pythium ultimum*) are important seedling diseases of pea (Ali et al. 2000). Fusarium root rot (*Fusarium solani* f. sp *pisi*), aphanomyces root rot (*Aphanomyces euteiches*), and fusarium wilt (*Fusarium oxysporum* f. sp *pisi*) are important soilborne diseases of pea. Powdery mildew (*Erysiphe pisi*) and downy mildew (*Peronospora viciae*) are the two most important foliar diseases of this crop. Among viral diseases, leaf roll, pea seedborne mosaic, and pea streak are important.

Aphids (*Acyrthosiphon pisum, Aphis pisum, Aphis craccivora*), stem fly (*Ophiomyia phaseoli*), leaf miner (*Phytomyza atricornis*), pea leaf weevil (*Sitona lineatus*), and pod borers (*Etiella zinckenella, Laspeyresia nigricana, Helicoverpa armigera*) are important (Table 5.2.3).

Warm-season legumes

The optimum temperature for growth and development of most tropical legumes is within the range of 25°C to 35°C, with a base temperature of 10°C (Johansen et al. 2000a).

Pigeonpea. Pigeonpea is suitable for rice-fallows in tropical environments where the winter temperatures are above 15°C. It can be grown in Orissa, southern Madhya Pradesh, Maharashtra, Andhra Pradesh, Tamil Nadu, and Karnataka. Although, pigeonpea is widely grown in peninsular India, its cultivation in rice-based systems is not common. With the development of photoperiod-insensitive, short-duration, new plant types, pigeonpea can now be introduced into rice-fallows during the rabi season in peninsular India. However, the crop is particularly susceptible to waterlogging during early stages of growth. Thus, genetic stocks that have tolerance to waterlogging need to be developed to improve adaptability to rice-fallows. Preliminary evaluations with short-duration pigeonpea genotypes indicate that yield levels of 1 t ha^{-1} can be obtained in rice-fallows of coastal Andhra Pradesh (Satyanarayana et al. 1988).

Fusarium wilt (*Fusarium udum*), sterility mosaic, phytophthora blight (*Phytophthora drechsleri* f. sp *cajani*), cercospora leaf spot (*Cercospora* spp), and alternaria blight (*Alternaria* spp) are economically important diseases of pigeonpea (Ali et al. 2000). Pod borers are the most important insect pests of pigeonpea. Other important pests are pod sucking bugs and blister beetle (Table 5.2.3).

Groundnut. Groundnut is traditionally grown during the kharif season. However, it is gaining importance as a rabi season crop in several states of India, particularly in Orissa and West Bengal. Since the mid-1970s, production of irrigated rabi groundnut has expanded in India, to now cover 17% of the total 8 million ha sown area (Reddy et al. 1992). Rabi groundnut is sown in October/November and harvested during March/ April. Low winter temperatures (<20°C) can limit growth of groundnut; also summer temperatures of >40°C can be deleterious (Reddy 1988). Groundnut is grown with irrigation or residual soil moisture in former water courses or after rice. However, there is a paucity of groundnut genotypes of appropriate duration and with low temperature tolerance to exploit the vacant rice-fallows and exposed water courses that abound in Bihar, West Bengal, and Assam during winter (Ali et al. 2000). The average pod yield in India is around 1 t ha^{-1} during the kharif season and 1.7 t ha^{-1} for the rabi season. Orissa is currently the leading state for postrainy season groundnut. Although groundnut is widely grown in peninsular India, the extent of its cultivation in rice-based systems is not common (<5%) (Ali et al. 2000). Groundnut can be a suitable crop for rice-fallows in Orissa, Madhya Pradesh, Maharashtra, Gujarat, Andhra Pradesh, Tamil Nadu, and Karnataka.

Seedling diseases caused by *Pythium*, *Rhizoctonia*, *Fusarium*, and *Macrophomina*, early leaf spot (*Cercospora arachidicola*), rust (*Puccinia arachidis*), stem rot (*Sclerotium rolfsii*), and aflatoxin contamination (*Aspergillus flavus*, *A. parasiticus*) are some of the economically important diseases of groundnut (Ali et al. 2000). Among viral diseases, groundnut rosette, bud necrosis, peanut mottle, and peanut stripe are important. More than 100 species of insects are known to feed groundnut and integrated pest management strategies are advocated to deal with the major pests (Ranga Rao et al. 1996).

Soybean. Soybean production is mostly confined to western Uttar Pradesh and western Madhya Pradesh as a kharif season crop. Soybean has a natural adaptability to grow in paddy soils, and is also tolerant to waterlogging during early stages of crop growth. It is ideally suited for rice-fallows, particularly in Maharashtra and in peninsular India. Compared with other legumes in the region, soybean is less constrained by insect pests and diseases, but is more susceptible to drought stress and is less adapted to local rhizobia.

The major abiotic constraints to soybean production in India are terminal drought and also specific nutrient deficiencies, particularly micronutrients (S, Zn, B). Another major constraint is lack of agro-processing facilities; agro-processing should be encouraged for wider acceptance by the farmers in new areas.

Some of the most important diseases that can limit soybean production when grown in rice-lands are: fungal diseases – rust (*Phakopsora pachyrhizi*), pythium root and seedling rot (*Pythium ultimum* and *P. debaryanum*), fusarium root rot (*Fusarium oxysporum*), rhizoctonia root rot (*Rhizoctonia solani*), phytophthora root and stem rot (*Phytophthora sojae*), charcoal rot (*Rhizoctonia bataticola*), and anthracnose (*Colletotrichum truncatum* and *C. destructivum*); viral diseases – soybean mosaic, yellow mosaic, and bud blight (Goodman and Nene 1976); bacterial diseases – bacterial blight (*Pseudomonas syringae* pv. *glycinea*) and bacterial pustule (*Xanthomonas campestris* pv. *glycines*) (Allen 1983).

The most important insect pests of soybean are leaf folder (*Hedylapta indicator*), girdle beetle (*Obereopsis brevis*), blister beetle (*Mylabris pustulata*), green bug (*Nezara viridula*), and tobacco caterpillar (*Spodoptera litura*) (Singh and Singh 1993) (Table 5.2.3).

Mung bean. Mung bean is mostly grown as a kharif crop and extensively cultivated in Bihar, Uttar Pradesh, Madhya Pradesh, and also in peninsular India. It has good adaptability to paddy soils; hence it is suitable for rice-fallows in Orissa, Madhya Pradesh, Bihar, Maharashtra, Andhra Pradesh, Tamil Nadu, and Karnataka.

Among 26 diseases recorded on mung bean, three are considered to be economically important (Pande et al. 2000): yellow mosaic (mungbean yellow mosaic virus), cercospora leaf spot (*Pseudocercospora cruenta*), and powdery mildew (*Erysiphe polygoni* and *Oidium* sp). Yellow mosaic is more severe in Chhatisgarh and Balaghat districts of Madhya Pradesh.

Galerucid beetle (*Madurasia obscurella*), hairy caterpillar (*Spilosoma (Diacrisia) obliqua*), thrips (*Caliothrips indicus*), jassids (*Empoasca kerri*), semiloopers (*Plusia* sp), whitefly (*Bemesia tabaci*), leaf folder (*Anartia* sp), blue beetle fly (*Lampides boeticus*), and pod borer (*Adisura atkinsoni*) are important pests of mung bean (Table 5.2.3).

Black gram. Black gram is extensively grown after rice in peninsular India during the rabi season. It is grown as a kharif crop in Uttar Pradesh, Bihar, and West Bengal. It has good adaptation to paddy soils and it is also tolerant to waterlogging during the early phases of crop growth. Black gram is suitable for rice-fallows in Orissa, Madhya Pradesh, Maharashtra, Andhra Pradesh, Tamil Nadu, and Karnataka during the rabi season.

Anthracnose (*Colletotrichum* sp), bacterial bean blight (*Xanthomonas phaseoli*), dry root rot (*Macrophomina phaseolina*), leaf spots (*Cercospora cruenta* and *C. dolichi*), powdery mildew (*Erysiphe polygoni*), rust (*Uromyces appendiculatus*), and yellow mosaic are some of the important diseases of this crop (Ali et al. 2000). Of these diseases, yellow mosaic is a serious problem in several parts of Madhya Pradesh, where this crop is grown. Wilt is most important in the Krishna delta region of Andhra Pradesh. Corynespora leaf spot and rust are problems in Andhra Pradesh and Tamil Nadu, while powdery mildew is a problem throughout the region.

The important insect pests recorded are: galerucid beetle (*Madurasia obscurella*), jassids (*Empoasca kerri*), whitefly (*Bemisia tabaci*), leaf folder (*Anartia*), blue butterfly (*Lampides boeticus*), pod borer (*Adisura atkinsoni*), green semilooper (*Plusia orichalcea*), tilhawk moth (*Acherontia styx*), tobacco caterpillar (*Prodenia litura*), and hairy caterpillar (*Spilosoma (Diacrisia) obliqua*) (Table 5.2.3).

Cowpea. Cowpea is mostly grown as a kharif crop, but can be grown as a rabi crop in peninsular India. It may be suitable for rice-fallows in Orissa, Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka, and Tamil Nadu. Fusarium wilt (*Fusarium oxysporum* f. sp *tracheiphilum*), cercospora leaf spot (*Cercospora canescens* and *Pseudocercospora cruenta*), brown rust (*Uromyces appendiculatus*), brown blotch (*Colletotrichum capsici*), and powdery mildew (*Erysiphe polygoni*) are important fungal diseases of cowpea (Ali et al. 2000). Bacterial blight (*Xanthomonas campestris* pv. *vignicola*) is the only bacterial disease that is important in cowpea. Cowpea golden mosaic and aphid-borne cowpea mosaic are the two most important viral diseases of cowpea. Insect pests of cowpea are similar to those of mung bean and black gram (Table 5.2.3).

Horse gram. Horse gram (*Macrotyloma uniflorum* (Lam.) Verdc.) is grown across several states of India mostly as a postrainy season crop, and is suitable for rice-fallows in Madhya Pradesh, Maharashtra, Orissa, Andhra Pradesh, Karnataka, and Tamil Nadu. This crop is hardy and suitable for marginal areas. The crop suffers from anthracnose (*Glomerella lindermuthianum*), leaf spot (*Cercospora dolichi*), and rust (*Uromyces appendiculatum*) (Ali et al. 2000). Yellow mosaic virus is one of the major constraints for its cultivation in peninsular India. The crop also suffers from root rot (*Pellicularia filamentosa*) and dry root rot (*Macrophomina phaseolina*).

Lablab bean. Lablab bean (*Lablab purpureus* (L.) Sweet) is suitable for rice-fallows in Maharashtra, Madhya Pradesh, Andhra Pradesh, Tamil Nadu, and Karnataka.

Abiotic Constraints to Legumes Cultivation

Several abiotic constraints to legumes cultivation that are common to rice-fallows (see Section 4) and are relevant for the rice-fallows in India are:

- Waterlogging during early stages of plant growth (universal to rice-fallows across the region).
- Poor plant stand (universal).
- Terminal drought (universal).
- Micronutrient deficiencies (S, B, Mo) (location specific).
- Soil acidity problems (location specific).
- Soil salinity/alkalinity problems (location specific).
- Low soil organic matter status (location specific).

A number of crop management practices associated with land preparation and sowing can improve plant stand in rice-fallows (see Section 4). Terminal drought can be addressed by using genetic stocks of legumes that can mature early, and thus can escape drought stress during the pod-filling stage (Subbarao et al. 1995). Also, another critical feature in addressing this issue is to use short-duration rice cultivars to facilitate early planting of legumes (i.e., by October) which could further improve the productivity of legumes when introduced into rice-fallows. Soil acidity problems can be addressed by using acid tolerant legumes, such as soybean, or acid tolerant varieties of other legumes, coupled with soil amendments and seed treatment such as lime pelleting. Also, improving soil organic matter levels can further minimize the adverse effects of soil acidity. Soil salinity can be addressed either by using relatively tolerant legume species or legume varieties. Severe nutrient deficiency can limit legumes such as lentil and chickpea (Sarkar et al. 1998). Nutrient deficiency can be corrected by application of appropriate fertilizers, and this is particularly relevant for the micronutrient deficiencies that are reported to be widespread in rice-fallows across many regions in India.

Socioeconomic Constraints to Legumes Cultivation in Rice-fallows

Major socioeconomic constraints faced by the Indian farmers wishing to cultivate legumes in rice-fallows are discussed below.

Lack of awareness and knowledge among farmers. Most of the farmers in Madhya Pradesh and Bihar, where large areas of rice-fallows are located, are not aware of the potential economic benefits of using fallows for legume cultivation. Nigam (1980) concluded that farmers mostly had a low level of knowledge on pulse production technology. In many cases, the farmers were found to have not only inadequate but

also incorrect information about recommended pulse production technology. Kennedy et al. (1990) reported that lack of technical knowledge regarding improved pulses cultivation is the top ranked constraint cited by the farmers of Guntur district of Andhra Pradesh.

Lack of seed availability. Non-availability of adequate quantities of quality seed of improved varieties in time is one of the major constraints in pulse production (Bolaria 1982, Singh 1995). Therefore, farmers use their own seed of local varieties, which are often of low quality due to preservation under defective storage systems. Use of low quality seed results in poor plant stand, susceptibility to seedling diseases, and ultimately poor yields; hence there is less motivation for cultivation in fallow lands after rice.

Lack of cash and credit. Credit is a key element for enabling small and marginal farmers to purchase the necessary inputs. But input mobilizing power of farmers is low because of relative high cost of technological inputs. Small land holdings make such inputs less viable. Credit facilities are not available for legume crops in the same way that they are for other major crops such as wheat, rice, cotton, and sugarcane (Lal 1984). Radha et al. (1989) focused on the greater need for credit facilities in a survey of 50 farms in Krishna district of Andhra Pradesh.

Marketing. Markets for legumes are thin and fragmented in comparison with rice and wheat (Byerlee and White 1997). It is generally perceived that the government procurement for legumes is not as effective as it is for rice and wheat, and often, farmers do not realize the minimum prices announced by the government. Also, the price spread (i.e., the market margin) for legumes is much higher than that of rice and wheat (Joshi and Pande 1996). Because of this, farmers do not benefit by the higher market prices of legumes, as most of the profits go to the traders, rather than to the farmers. Also, for certain legumes such as khesari, there is a lack of demand for consumption in general; the demand is localized. Because of the fear of lathyrism, khesari consumption is not encouraged. Lack of awareness/availability of low-toxin khesari genetic stocks is one of the major constraints for the adoption of the crop in rice-fallows (Joshi et al. 2000). Traditionally, the farm-gate prices of pulses have been low. Marketing arrangements for small quantities in interior areas have been inadequate leading to exploitation by middlemen (Bolaria 1982).

Low response to improved management. The existing local cultivars of different pulses are not very responsive to improved management practices. But improved varieties have high yield potential (>1.5 t ha^{-1}) with the adoption of improved management practices in farmers' fields.

Economic Feasibility of Growing Legumes in Rice-fallows

Experiments conducted in research stations to grow pulses in fallow lands after rice showed that it is agronomically feasible and economically viable (Table 5.2.4). Based on cost and returns analysis from lentil cultivation in rice-fallows of northeast Bihar (data collected from 100 farmers from various areas of Saharsa, a major lentil-growing district, during 1992/93), Singh and Singh (1995) concluded that lentil growing is profitable. The above mentioned data are old and the prices of different inputs and prices of outputs have changed. Therefore, we have estimated likely costs and benefits from growing chickpea, mung bean, lentil, khesari, and pea on per hectare basis using recent prices. This will assist understanding of the likely benefits and investment requirements by individual farmers and also give indications on the total benefit from introduction of legumes in rice-fallows to the national economy of India in terms of employment creation and increase in output. Results of the economic feasibility analysis are provided in Tables 5.2.5 to 5.2.11. Chickpea would provide the highest net return of Rs. 17,850 ha^{-1} with a BCR of 3.20 among the legumes assessed (Table 5.2.5). Returns for the other legumes would then be in order: lentil (Rs. 8,350; BCR = 2.33), pea (Rs. 6,670; BCR = 2.05), khesari (Rs. 6,180; BCR = 2.95), cowpea (Rs. 5,020; BCR = 2.04), black gram (Rs. 4,730; BCR = 2.21), and mung bean (Rs. 2,820; BCR = 1.70) (Tables 5.2.6 to 5.2.11).

In a labor surplus economy like India, scope for employment generation is always an opportunity for the farm households and the national economy. It is estimated that cultivation of chickpea, mung bean, pea, khesari, black gram, cowpea, and lentil would create an employment opportunity of 48, 38, 54, 38, 38, and 48 person-days per hectare, respectively. On an average, cultivation of legumes in one hectare of fallow land would generate more than 43 person-days working opportunity and more than Rs. 2,500 remuneration as labor wage. If all the rice-fallow areas (11.65 million ha) can be brought under legume cultivation then additional employment creation in Indian agriculture will be 502.7 million person-days (Table 5.2.12).

Table 5.2.4. Profitability of growing legumes after rice in India.

Description	Location of trial			
	Pattambi (Kerala)	Pattambi (Kerala)	Siruguppa, (Kurnool, AP)	Konkan Maharastra
Source	Joy et al. (1986)	Joy et al. (1986)	Setty and Channabasavanna (1993)	Shinde et al. (1992)
Year	1985/86	1985/86	1991/92	1985–87
Cropping pattern	Relayed black gram after rice	Relayed cowpea after rice	Chickpea after rice	Cowpea after rice
Grain yield (kg ha^{-1})	920	470	1515	1445
Total cost (Rs.)	NA[1]	NA	3169	5674
Gross return (Rs.)	NA	NA	12120	7557
Net return (Rs.)	NA	NA	8951	1883

1. NA = Data not available.

Table 5.2.5. Cost and returns (per hectare) from cultivation of chickpea in rice-fallows of India.

Description	Unit	Unit price (Rs.)	Quantity	Amount (Rs.)
Inputs				
Labor	day			2520.00
Land preparation	day	60.00	3	180.00
Sowing	day	60.00	3	180.00
Weeding and cultural operations	day	50.00	20	1000.00
Harvesting	day	50.00	20	1000.00
Threshing	day	80.00	2	160.00
Bullock labor	pair-day			450.00
Land preparation	pair-day	150.00	3	450.00
Machine cost	hour			500.00
Threshing	hour	200.00	3	500.00
Seed	kg	40.00	75	3000.00
Fertilizer	kg			980.00
Diammonium phosphate	kg	9.80	100	980.00
Pesticides	number of sprays	650.00	1	650.00
Total cost				8100.00
Outputs				
Grain yield	kg	25.00	1000	25000.00
Fodder yield (byproduct)	kg	2.00	400	800.00
Green vegetable consumption	kg			150.00
Returns				
Gross return				25950.00
Net return				17850.00
Benefit-cost ratio (BCR)				3.20

Table 5.2.6. Cost and returns (per hectare) from cultivation of mung bean in rice-fallows of India.

Description	Unit	Unit price (Rs.)	Quantity	Amount (Rs.)
Inputs				
Labor	day			2020.00
Land preparation and sowing	day	60.00	6	360.00
Weeding and cultural operations	day	50.00	10	500.00
Harvesting	day	50.00	20	1000.00
Threshing	day	80.00	2	160.00
Bullock labor	pair-day			450.00
Land preparation and sowing	pair-day	150.00	3	450.00
Machine cost	hour			200.00
Tractor/Power tiller for land preparation	hour			0.00
Threshing	hour	1.00	200	200.00
Seed	kg	20.00	10	200.00
Fertilizer	kg			660.00
Single superphosphate	kg	3.30	200	660.00
Pesticides	number of sprays	500.00	1	500.00
Total cost				4030.00
Outputs				
Grain yield	kg	11.00	600	6600.00
Fodder yield (byproduct)	kg	1.00	100	100.00
Green vegetable consumption	kg			150.00
Returns				
Gross return				6850.00
Net return				2820.00
Benefit-cost ratio (BCR)				1.70

Table 5.2.7. Cost and returns (per hectare) from cultivation of pea in rice-fallows of India.

Description	Unit	Unit price (Rs.)	Quantity	Amount (Rs.)
Inputs				
Labor	day			3000.00
Land preparation	day	60.00	3	180.00
Sowing	day	60.00	3	180.00
Weeding and cultural operations	day	50.00	20	1000.00
Harvesting	day	50.00	20	1000.00
Threshing	day	80.00	8	640.00
Bullock labor	pair-day			450.00
Land preparation	pair-day	150.00	3	450.00
Machine cost	hour			0.00
Threshing	hour			0.00
Seed	kg	40.00	40	1600.00
Fertilizer	kg			330.00
Single superphosphate	kg	3.30	100	330.00
Pesticides	number of sprays	500.00	2	1000.00
Total cost				6380.00
Outputs				
Grain yield	kg	16.00	800	12800.00
Fodder yield (byproduct)	kg	1.00	100	100.00
Green vegetable consumption	kg			150.00
Returns				
Gross return				13050.00
Net return				6670.00
Benefit-cost ratio (BCR)				2.05

Table 5.2.8. Cost and returns (per hectare) from cultivation of khesari in rice-fallows of India.

Description	Unit	Unit price (Rs.)	Quantity	Amount (Rs.)
Inputs				
Labor	day			1410.00
Land preparation	day	60.00	0	0.00
Sowing	day	60.00	1	60.00
Weeding and cultural operations	day	50.00	9	450.00
Harvesting	day	50.00	10	500.00
Threshing	day	80.00	5	400.00
Bullock labor	pair-day			150.00
Land preparation	pair-day	50.00	0	0.00
Threshing	pair-day	50.00	3	150.00
Machine cost	hour			0.00
Threshing	hour			0.00
Seed	kg	20.00	35	700.00
Fertilizer	kg			750.00
Single superphosphate	kg	7.50	100	750.00
Pesticides	number of sprays	80.00	2	160.00
Total cost				3170.00
Outputs				
Grain yield	kg	12.00	600	7200.00
Fodder yield (byproduct)	kg	1.00	2000	2000.00
Green vegetable consumption	kg			150.00
Returns				
Gross return				9350.00
Net return				6180.00
Benefit-cost ratio (BCR)				2.95

Table 5.2.9. Cost and returns (per hectare) from cultivation of black gram in rice-fallows of India.

Description	Unit	Unit price (Rs.)	Quantity	Amount (Rs.)
Inputs				
Labor	day			1860.00
Land preparation	day	60.00	3	180.00
Sowing	day	60.00	3	180.00
Weeding and cultural operations	day	50.00	10	500.00
Harvesting	day	50.00	20	1000.00
Threshing	day	80.00	2	160.00
Bullock labor	pair-day			450.00
Land preparation	pair-day	150.00	3	450.00
Machine cost	hour			200.00
Threshing	hour	200.00	1	200.00
Seed	kg	25.00	10	250.00
Fertilizer	kg			660.00
Single superphosphate	kg	3.30	200	660.00
Pesticides	number of sprays	500.00	1	500.00
Total cost				3920.00
Outputs				
Grain yield	kg	14.00	600	8400.00
Fodder yield (byproduct)	kg	1.00	100	100.00
Green vegetable consumption	kg			150.00
Returns				
Gross return				8650.00
Net return				4730.00
Benefit-cost ratio (BCR)				2.21

Table 5.2.10. Cost and returns (per hectare) from cultivation of cowpea in rice-fallows of India.

Description	Unit	Unit price (Rs.)	Quantity	Amount (Rs.)
Inputs				
Labor	day			2020.00
Land preparation	day	60.00	3	180.00
Sowing	day	60.00	3	180.00
Weeding and cultural operations	day	50.00	10	500.00
Harvesting	day	50.00	20	1000.00
Threshing	day	80.00	2	160.00
Bullock labor	pair-day			450.00
Land preparation	pair-day	150.00	3	450.00
Machine cost	hour			300.00
Threshing	hour	200.00	2	300.00
Seed	kg	20.00	20	400.00
Fertilizer	kg			660.00
Single superphosphate	kg	3.30	200	660.00
Pesticides	number of sprays	500.00	2	1000.00
Total cost				4830.00
Outputs				
Grain yield	kg	12.00	800	9600.00
Fodder yield (byproduct)	kg	1.00	100	100.00
Green vegetable consumption	kg			150.00
Returns				
Gross return				9850.00
Net return				5020.00
Benefit-cost ratio (BCR)				2.04

Table 5.2.11. Cost and returns (per hectare) from cultivation of lentil in rice-fallows of India.

Description	Unit	Unit price (Rs.)	Quantity	Amount (Rs.)
Inputs				
Labor	day			2520.00
Land preparation	day	60.00	3	180.00
Sowing	day	60.00	3	180.00
Weeding and cultural operations	day	50.00	20	1000.00
Harvesting	day	50.00	20	1000.00
Threshing	day	80.00	2	160.00
Bullock labor	pair-day			450.00
Land preparation	pair-day	150.00	3	450.00
Machine cost	hour			500.00
Threshing	hour	200.00	3	500.00
Seed	kg	40.00	30	1200.00
Fertilizer	kg			980.00
Diammonium phosphate	kg	9.80	100	980.00
Pesticides	number of sprays	650.00	1	650.00
Total cost				6300.00
Outputs				
Grain yield	kg	25.00	500	12500.00
Fodder yield (byproduct)	kg	2.00	1000	2000.00
Green vegetable consumption	kg			150.00
Returns				
Gross return				14650.00
Net return				8350.00
Benefit-cost ratio (BCR)				2.33

Table 5.2.12. Potential employment generation through introduction of legumes in rice-fallows of India.

Crop	Labor requirement (person-days ha^{-1})
Chickpea	48.00
Mung bean	38.00
Pea	54.00
Khesari	38.00
Black gram	38.00
Cowpea	38.00
Lentil	48.00
Mean (legumes)	43.14
Total rice-fallow area (ha)	11,652,000
Potential employment creation (person-days)	502,700,571

Concluding Remarks

Rice-fallows offer some of the most productive lands for legume production; if suitably integrated into rice-production systems, this can revolutionize pulses production, and thus per capita availability of pulses in India. Adequate policy support from the government is necessary for support price, strengthening of extension agencies, and also by providing the needed inputs and credits to the farmers to encourage legumes production. Declining total factor productivity is a serious concern in the rice-wheat systems of South Asia (Kumar et al. 2000) and the same may be true with rice-fallow systems. Thus introducing legumes into rice-wheat production systems and rice-fallow production systems may contribute to sustainability of these cereal-based cropping systems (Kumar Rao et al. 1998). Preliminary trials have shown that rice-fallows can support high yields of legumes during the rabi season. For example, legume cultivation involving chickpea and lentil in rice-fallows of Madhya Pradesh have indicated that grain yields up to 2.5 t ha^{-1} can be achieved (Johansen et al., ICRISAT, unpublished). This shows the enormous potential niche these rice-fallows can offer for the production of legumes. However, there are several abiotic, biotic, and socioeconomic constraints outlined in this report that need attention to optimally utilize this potential niche for legumes production. Also, utilization of rice-fallows for legumes production can have enormous employment generation potential in the country, amounting to 503 million person-days, and thus having a dramatic effect on the economy and also contributing substantially to poverty alleviation.

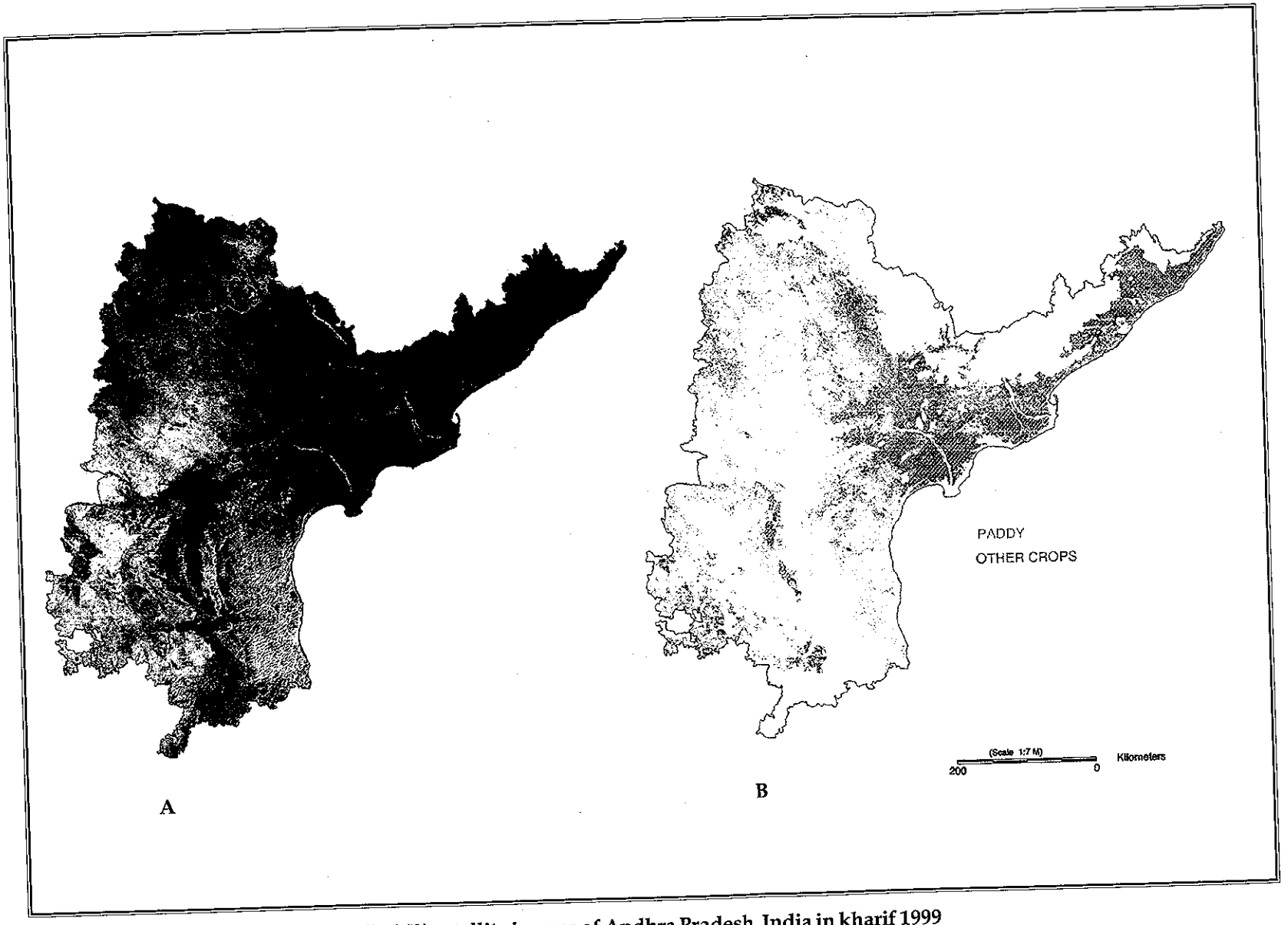


Fig. 5.2.1. Unclassified (A) and classified (B) satellite images of Andhra Pradesh, India in kharif 1999

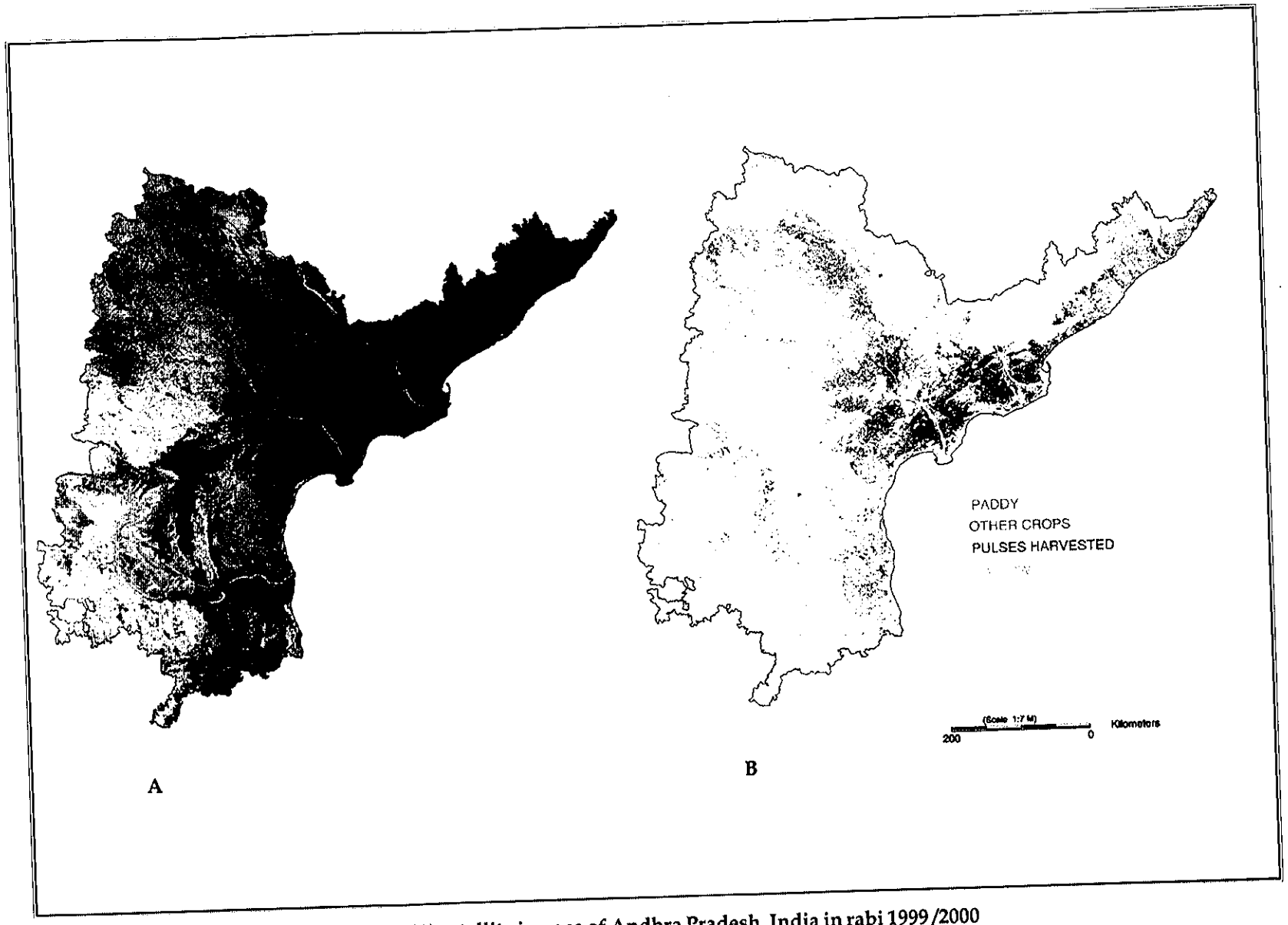


Fig. 5.2.2. Unclassified (A) and classified (B) satellite images of Andhra Pradesh, India in rabi 1999/2000

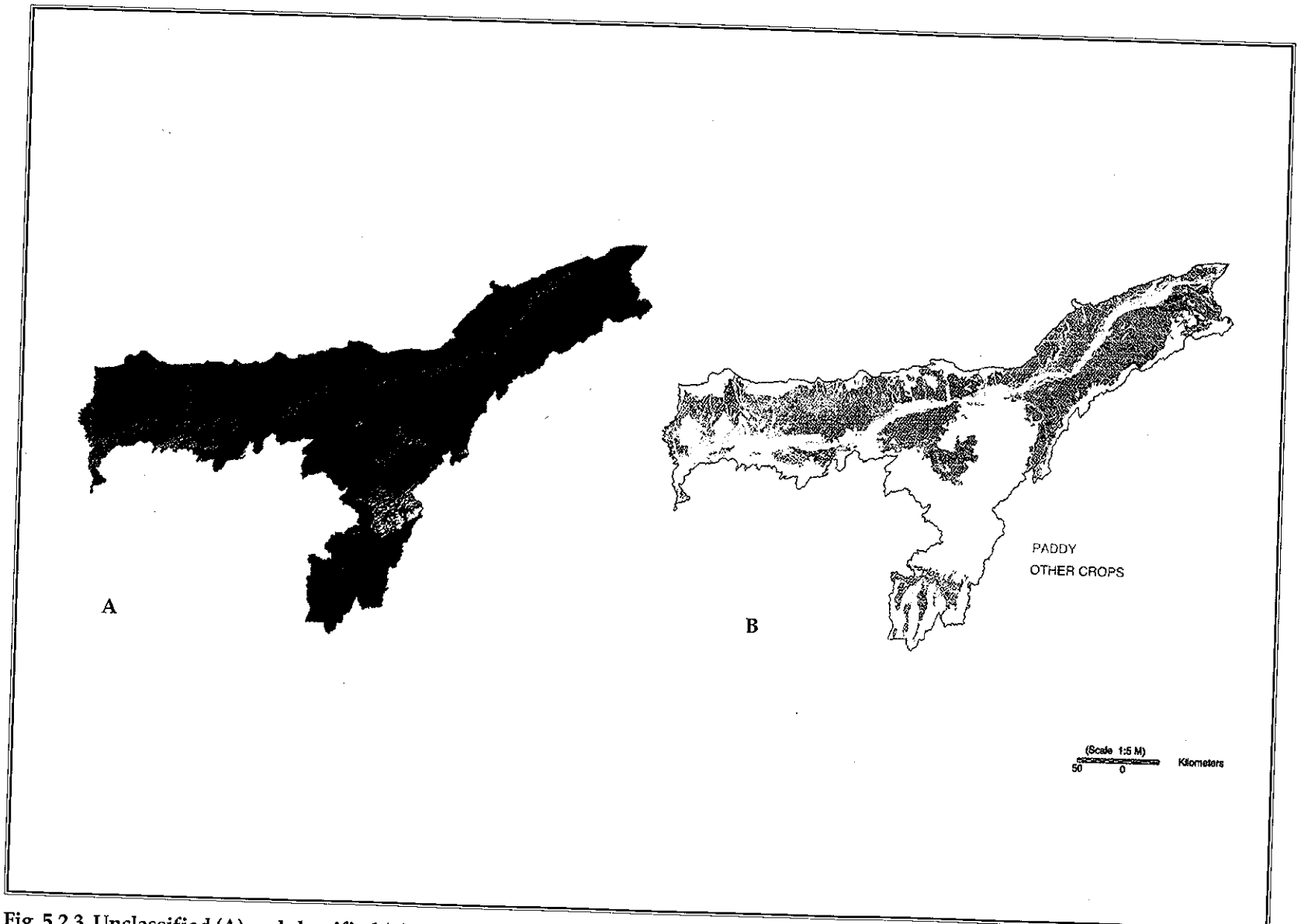


Fig. 5.2.3. Unclassified (A) and classified (B) satellite images of Assam, India in kharif 1999

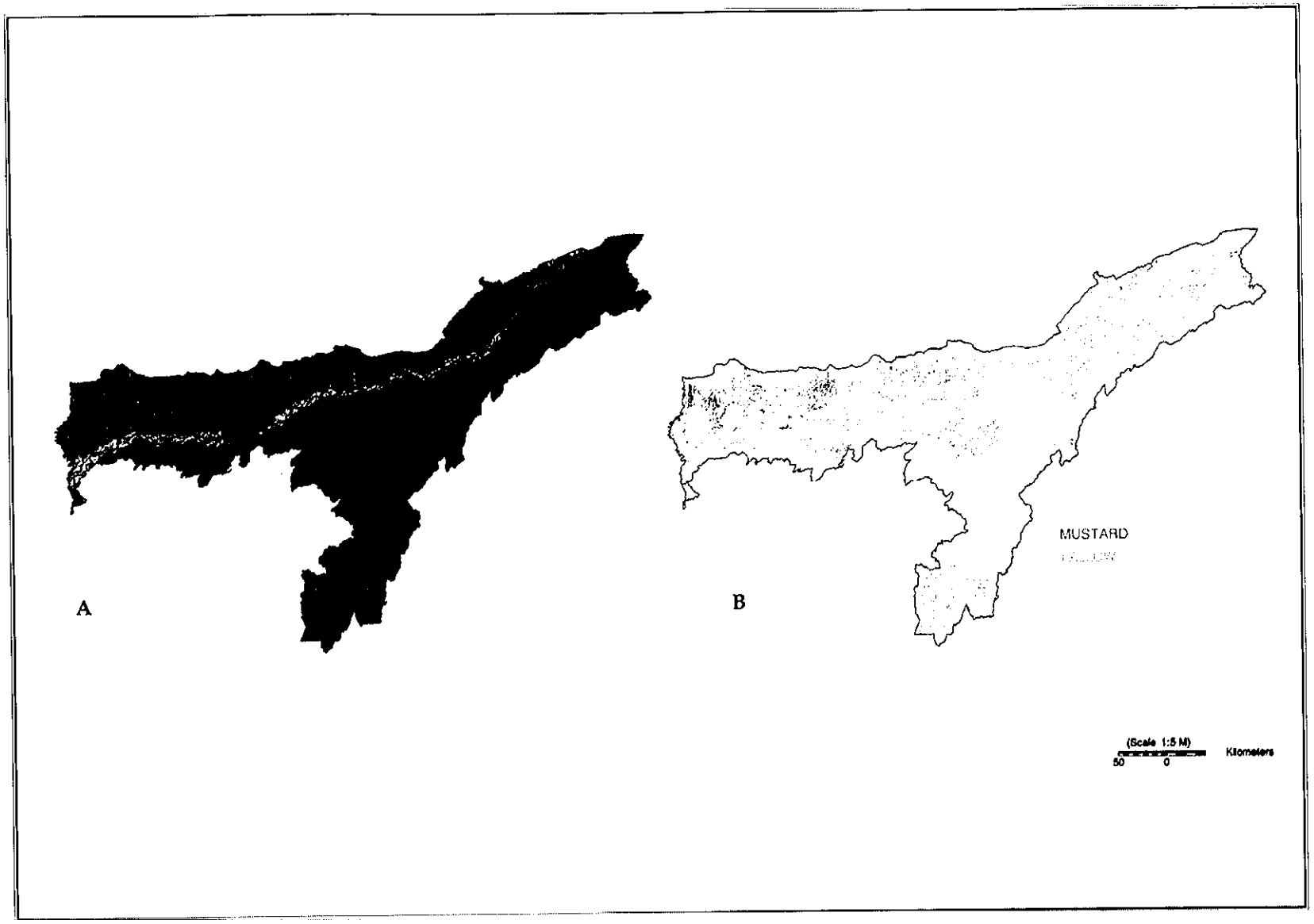


Fig. 5.2.4. Unclassified (A) and classified (B) satellite images of Assam, India in rabi 1999/2000

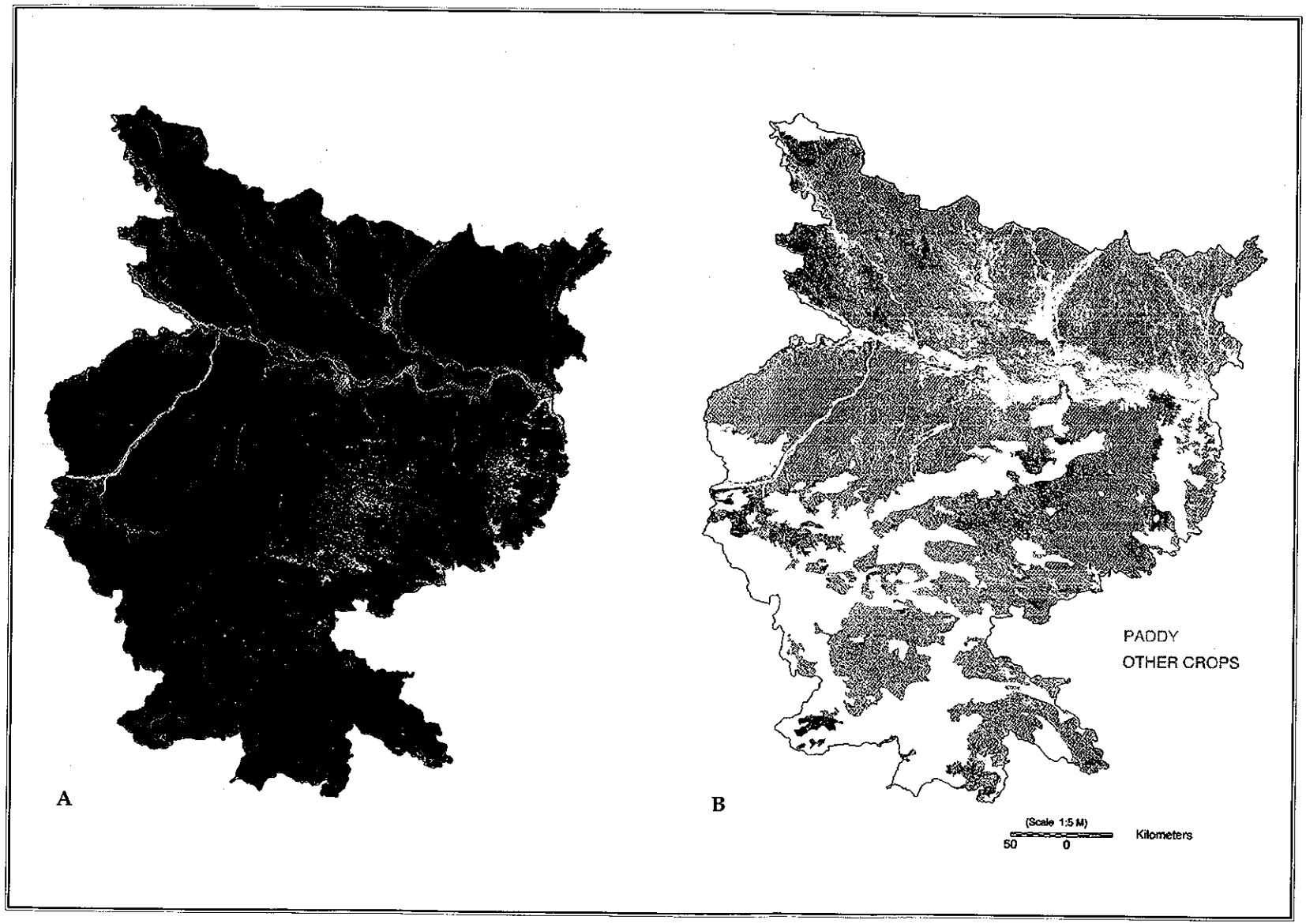


Fig. 5.2.5. Unclassified (A) and classified (B) satellite images of Bihar, India in kharif 1999

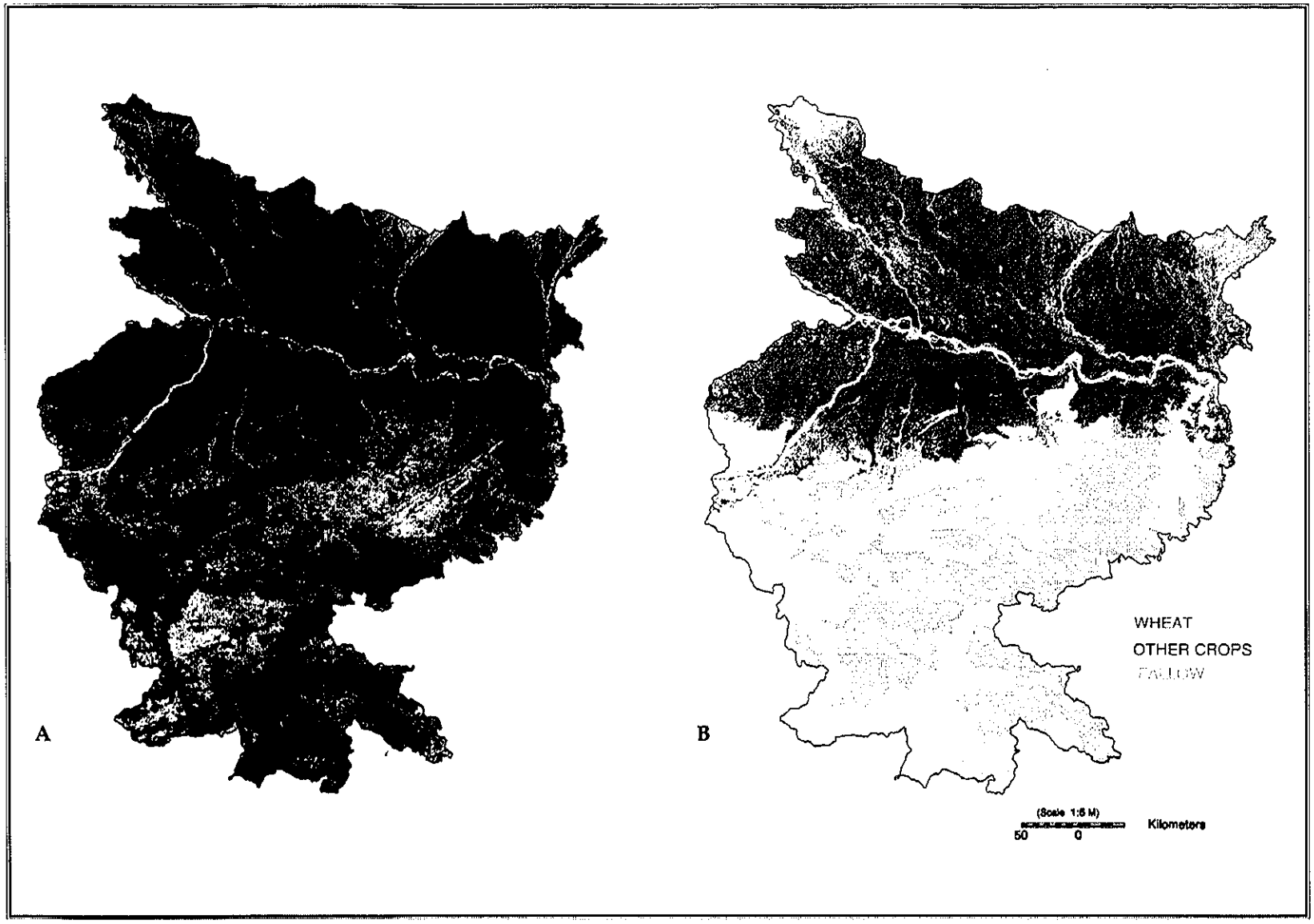


Fig. 5.2.6. Unclassified (A) and classified (B) satellite images of Bihar, India in rabi 1999/2000

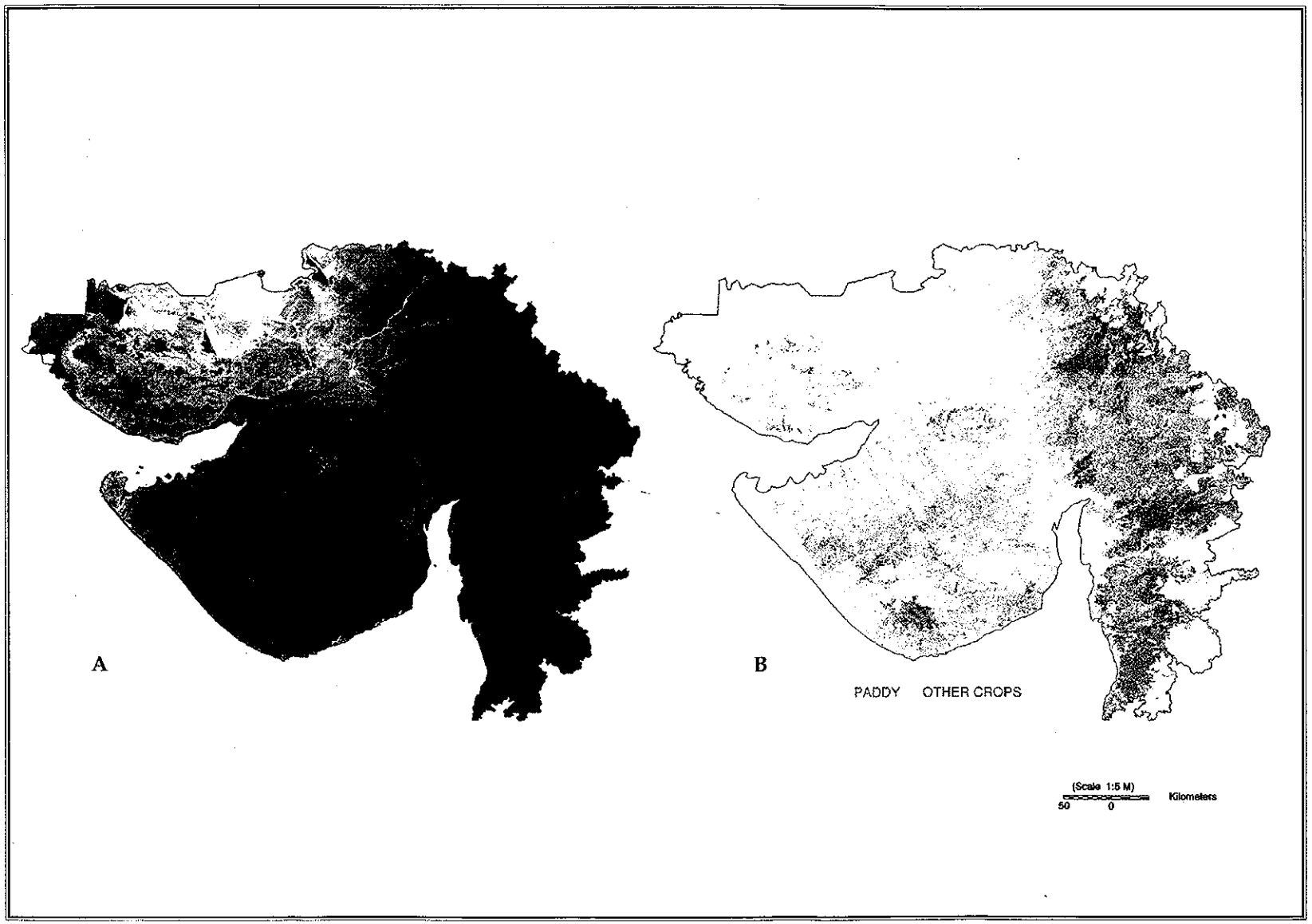


Fig. 5.2.7. Unclassified (A) and classified (B) satellite images of Gujarat, India in kharif 1999

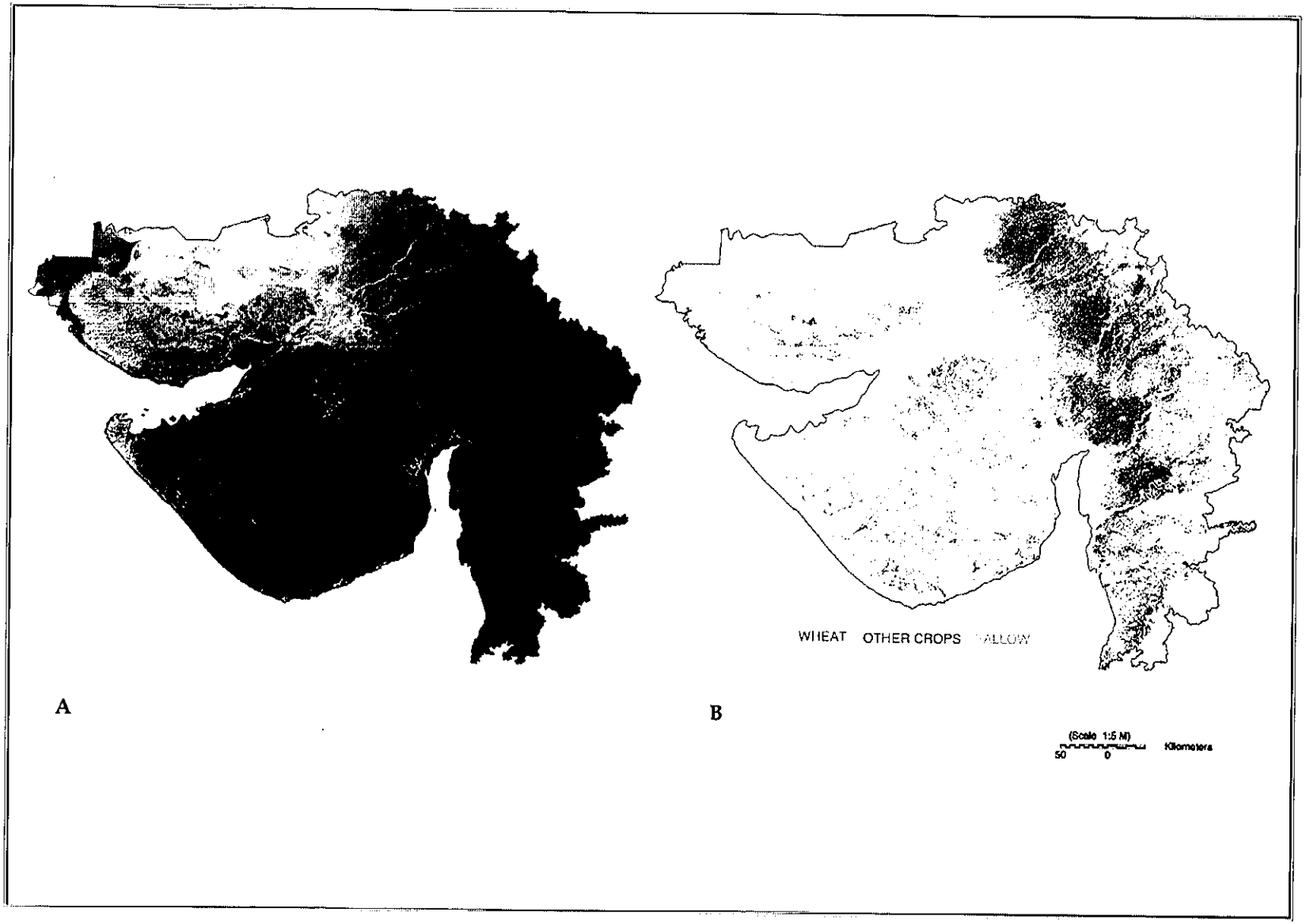


Fig. 5.2.8. Unclassified (A) and classified (B) satellite images of Gujarat, India in rabi 1999/2000

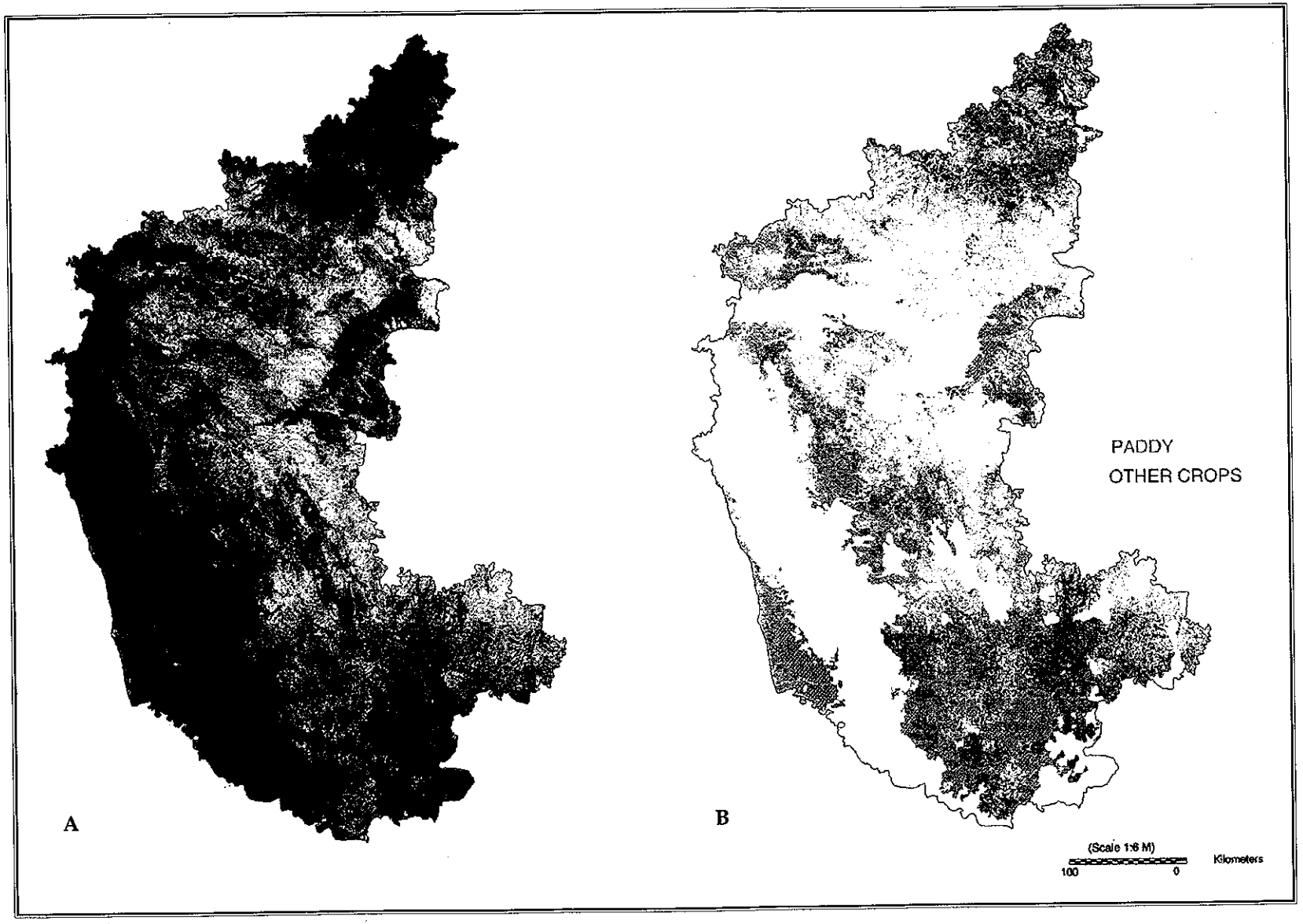


Fig. 5.2.9. Unclassified (A) and classified (B) satellite images of Karnataka, India in kharif 1999

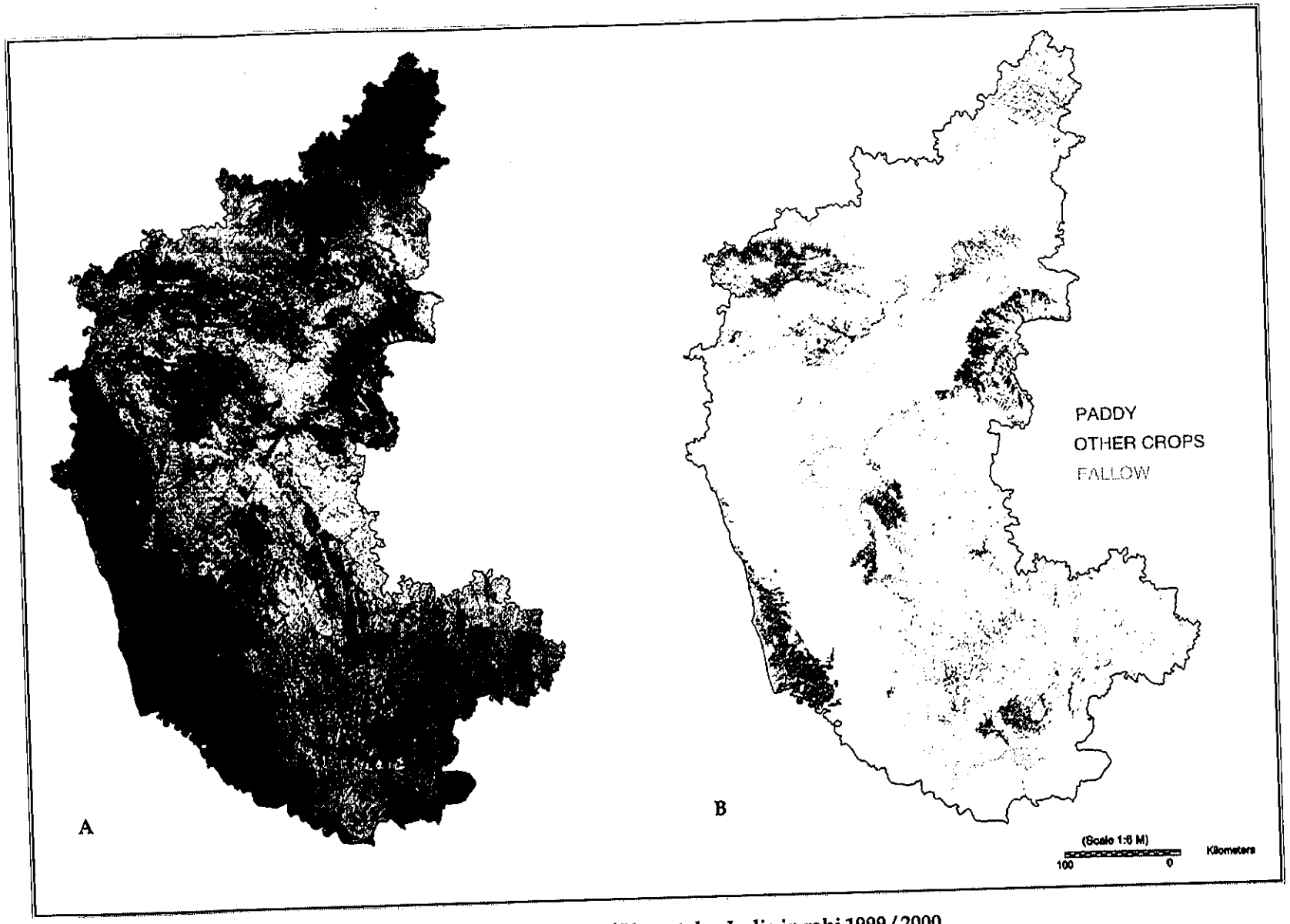


Fig. 5.2.10. Unclassified (A) and classified (B) satellite images of Karnataka, India in rabi 1999/2000

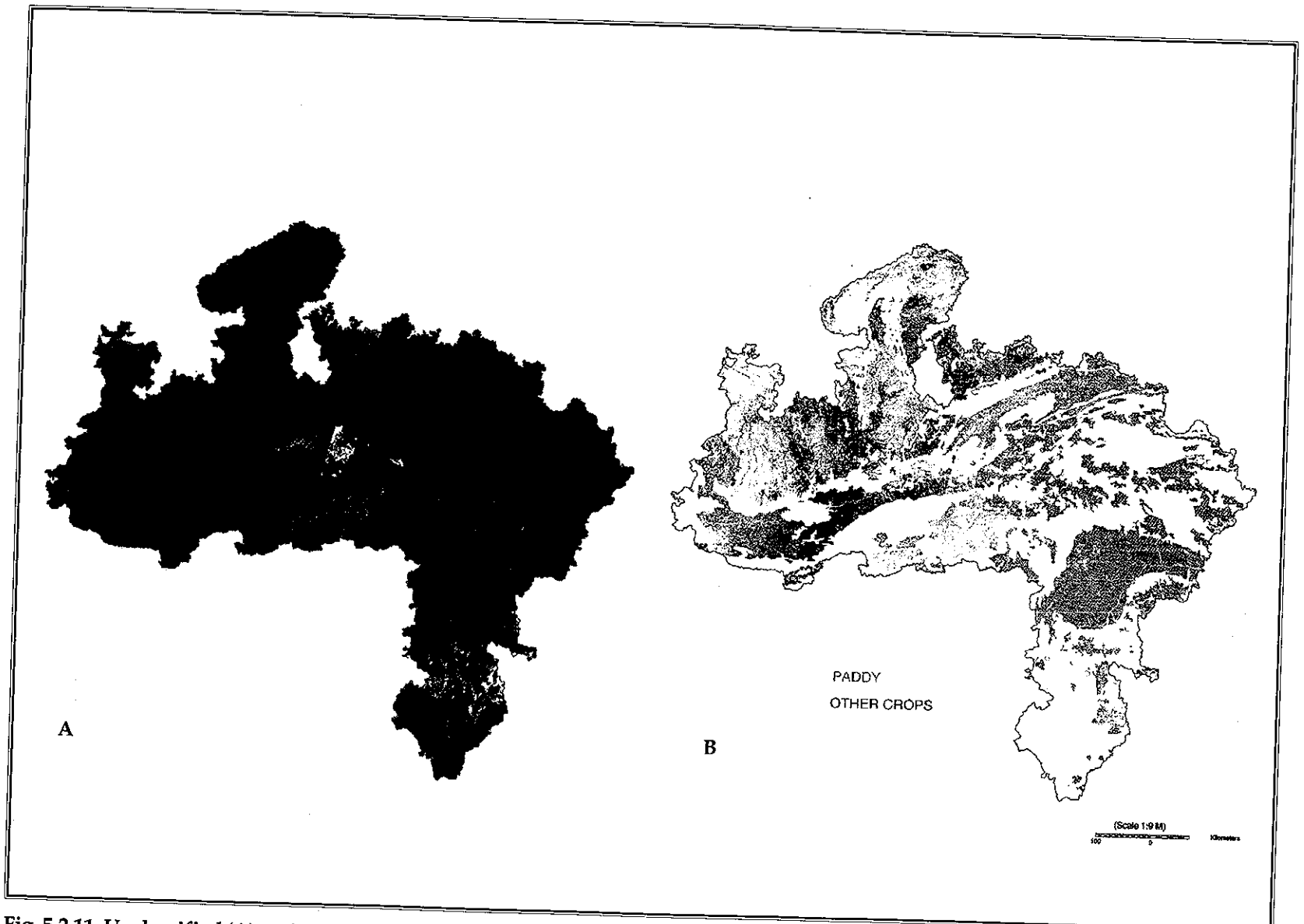


Fig. 5.2.11. Unclassified (A) and classified (B) satellite images of Madhya Pradesh, India in kharif 1999

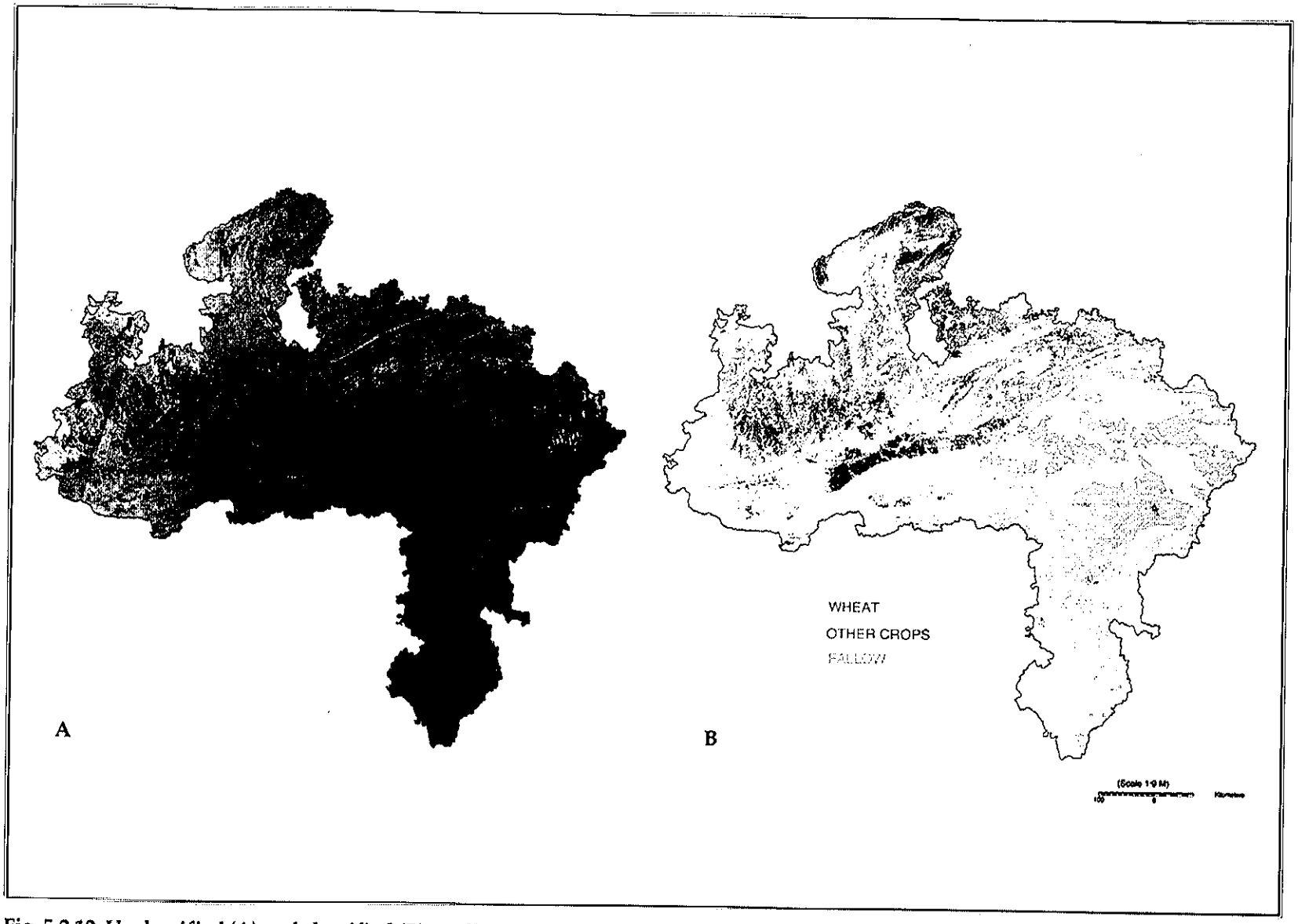


Fig. 5.2.12. Unclassified (A) and classified (B) satellite images of Madhya Pradesh, India in rabi 1999/2000

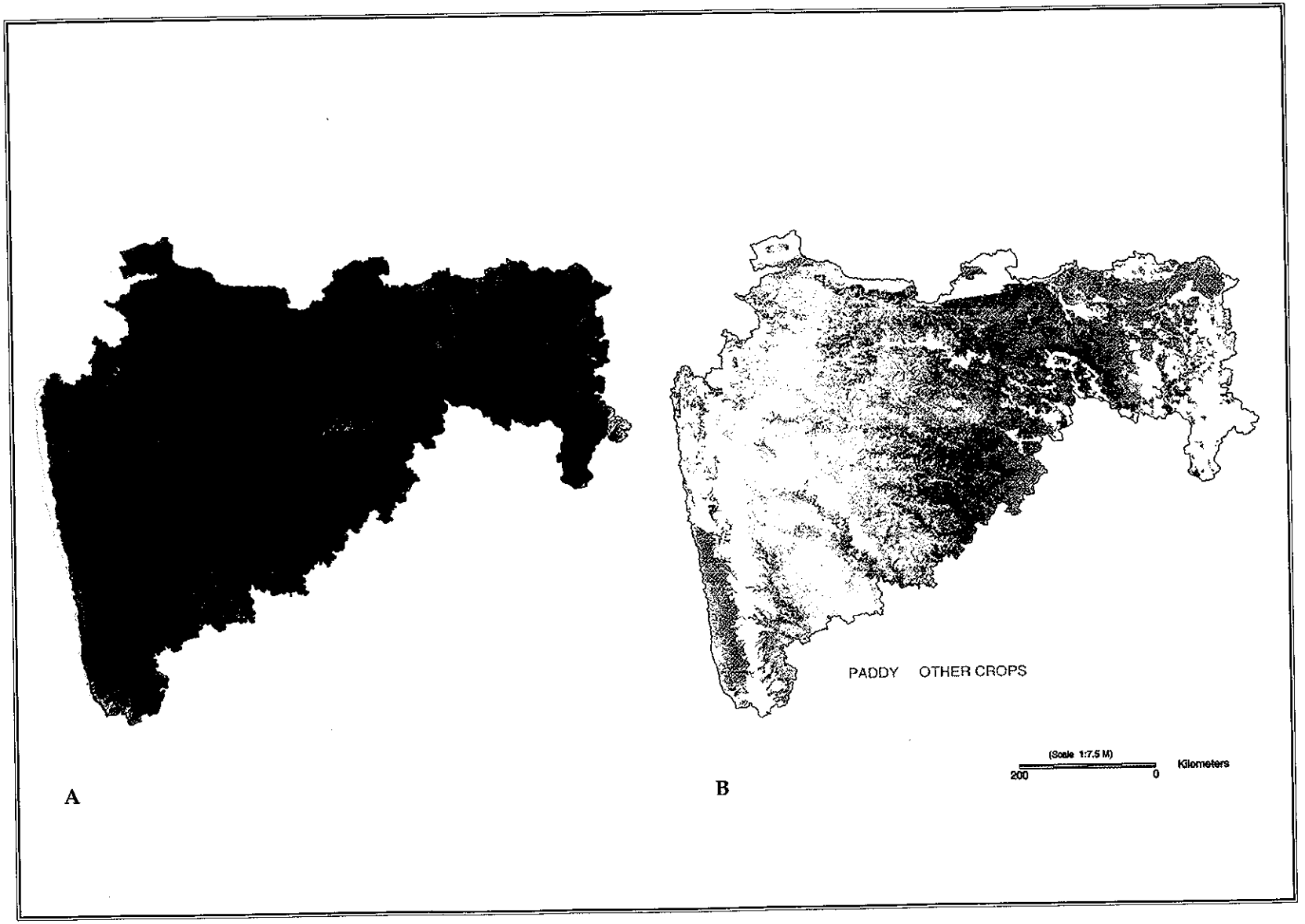


Fig. 5.2.13. Unclassified (A) and classified (B) satellite images of Maharashtra, India in kharif 1999

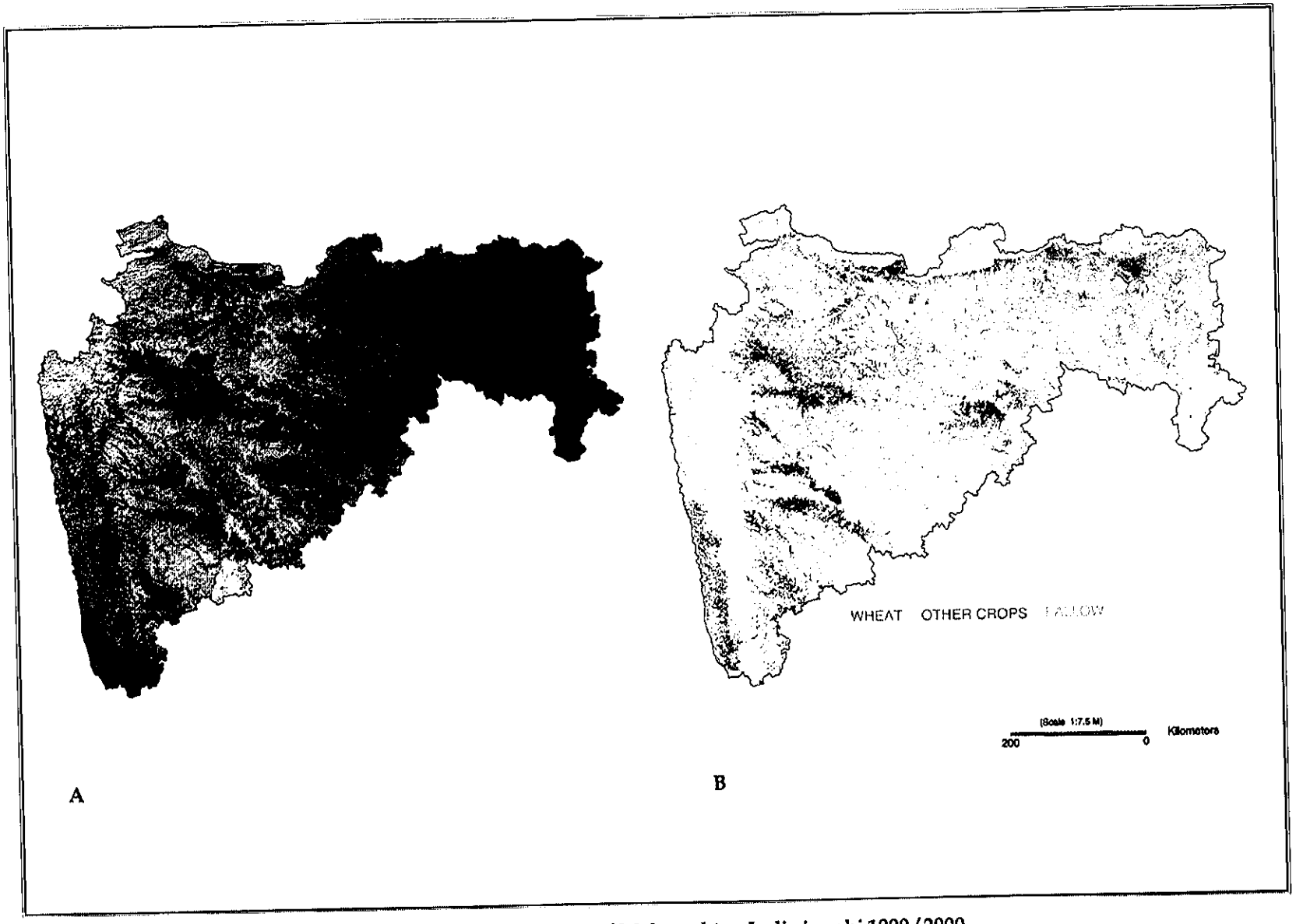


Fig. 5.2.14. Unclassified (A) and classified (B) satellite images of Maharashtra, India in rabi 1999/2000

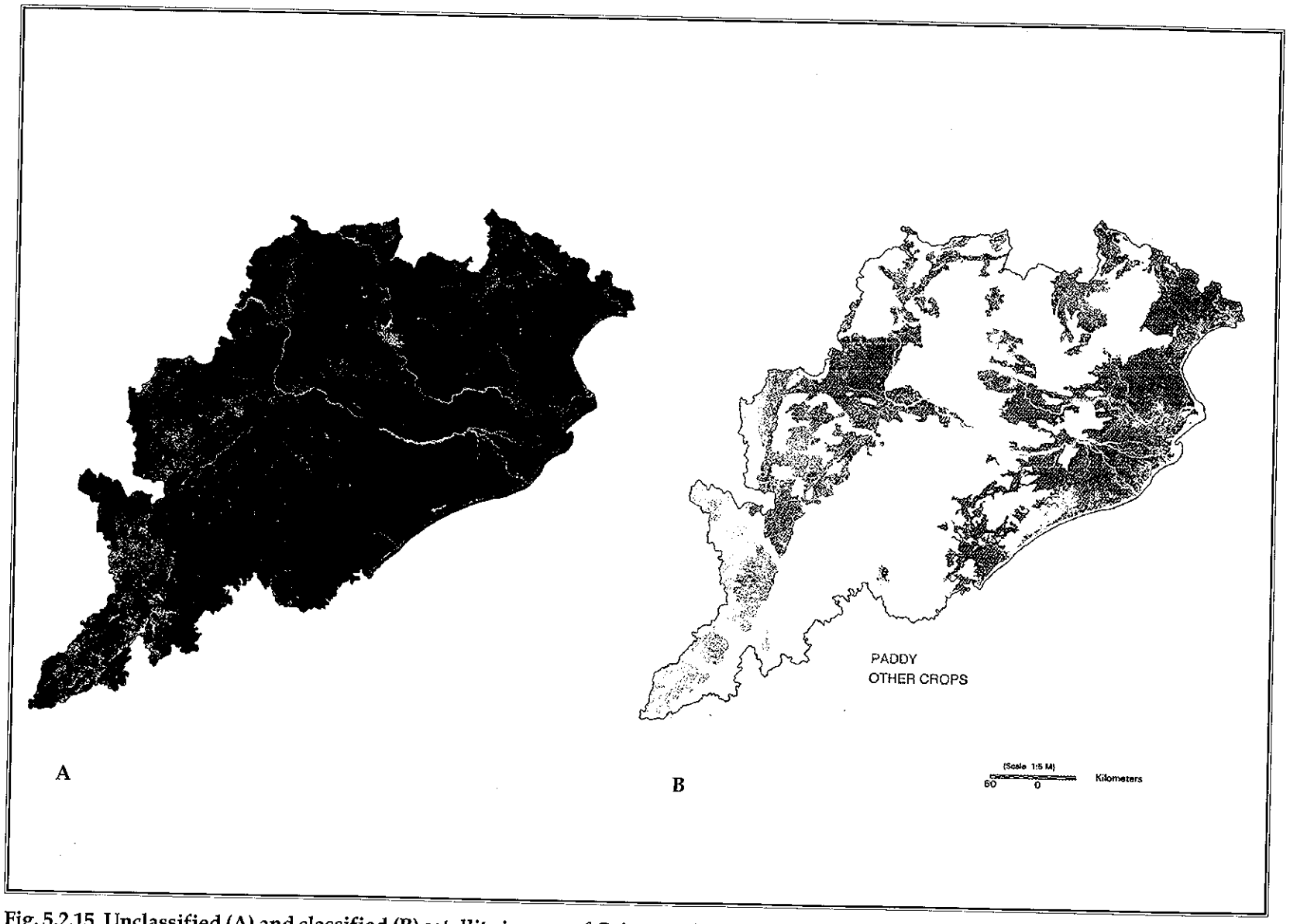


Fig. 5.2.15. Unclassified (A) and classified (B) satellite images of Orissa, India in kharif 1999

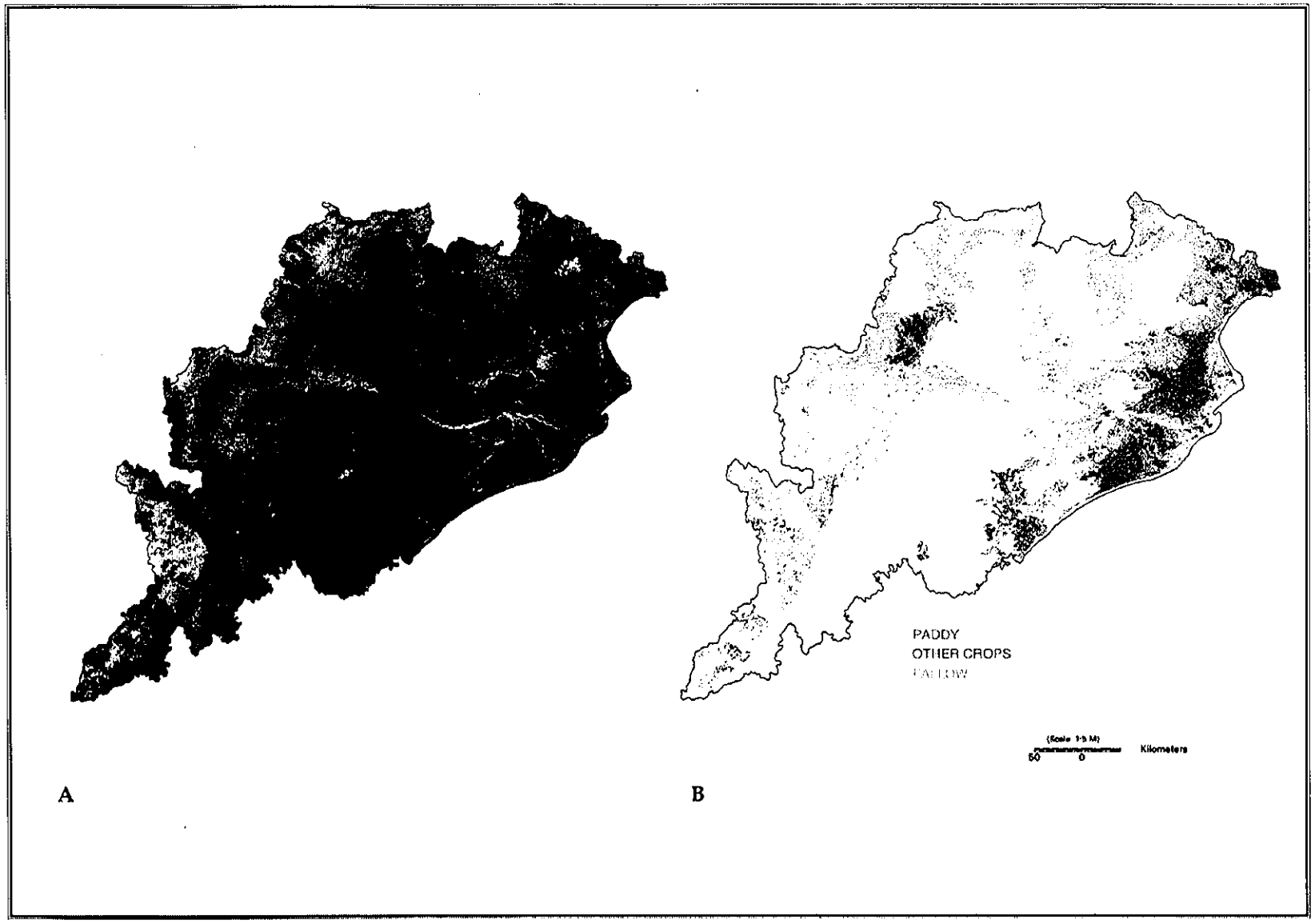


Fig. 5.2.16. Unclassified (A) and classified (B) satellite images of Orissa, India in rabi 1999/2000

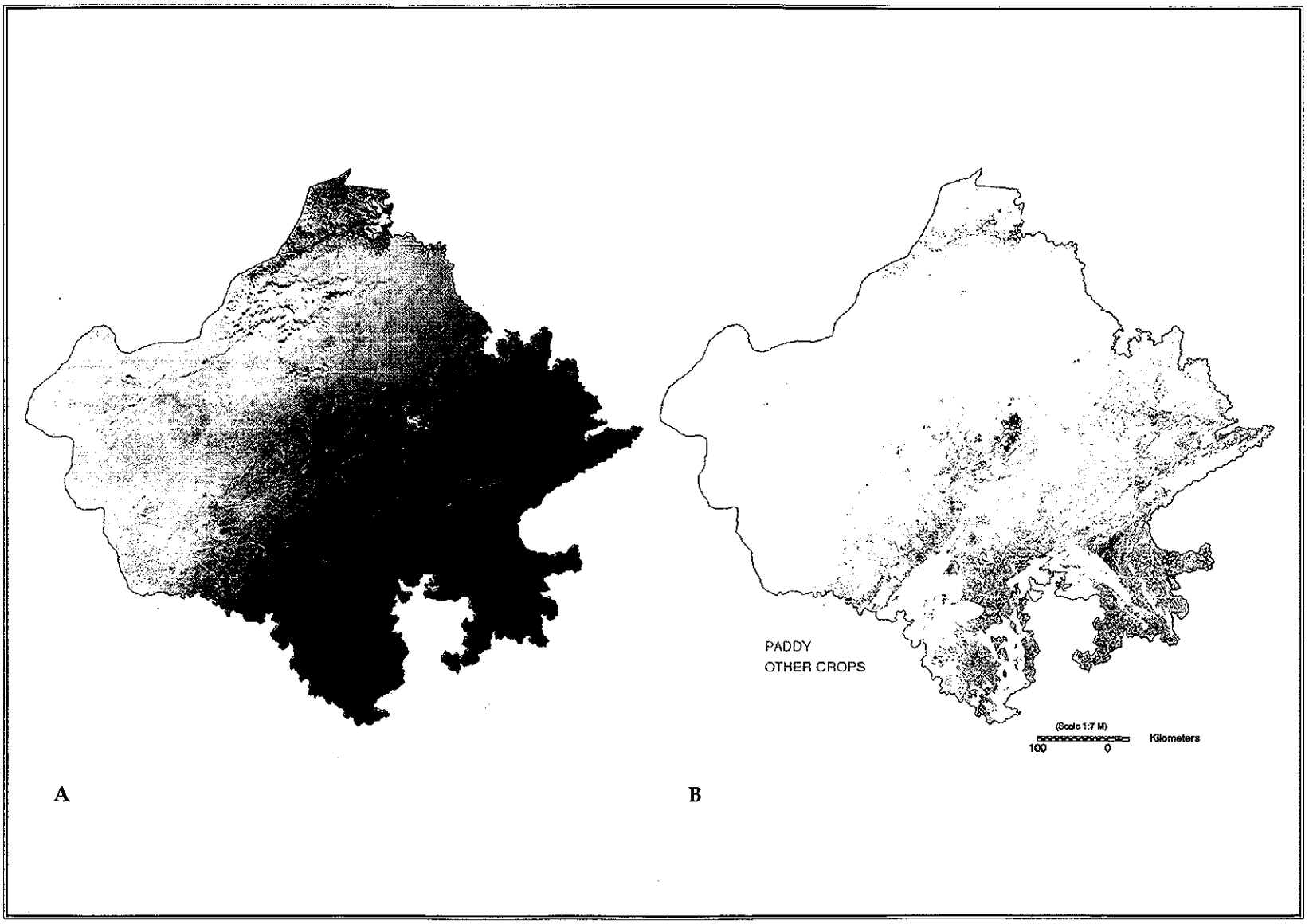


Fig. 5.2.17. Unclassified (A) and classified (B) satellite images of Rajasthan, India in kharif 1999

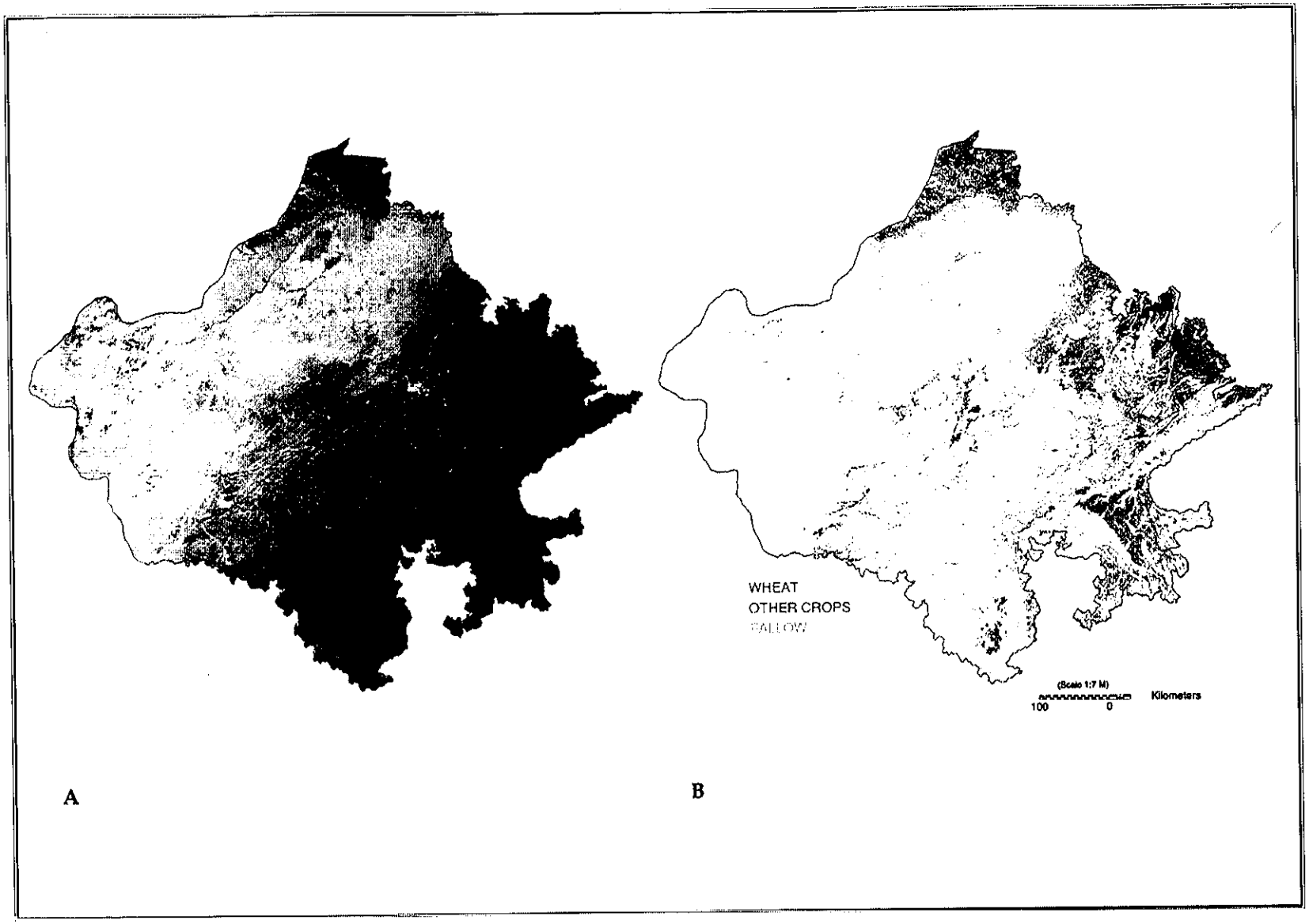


Fig. 5.2.18. Unclassified (A) and classified (B) satellite images of Rajasthan, India in rabi 1999/2000

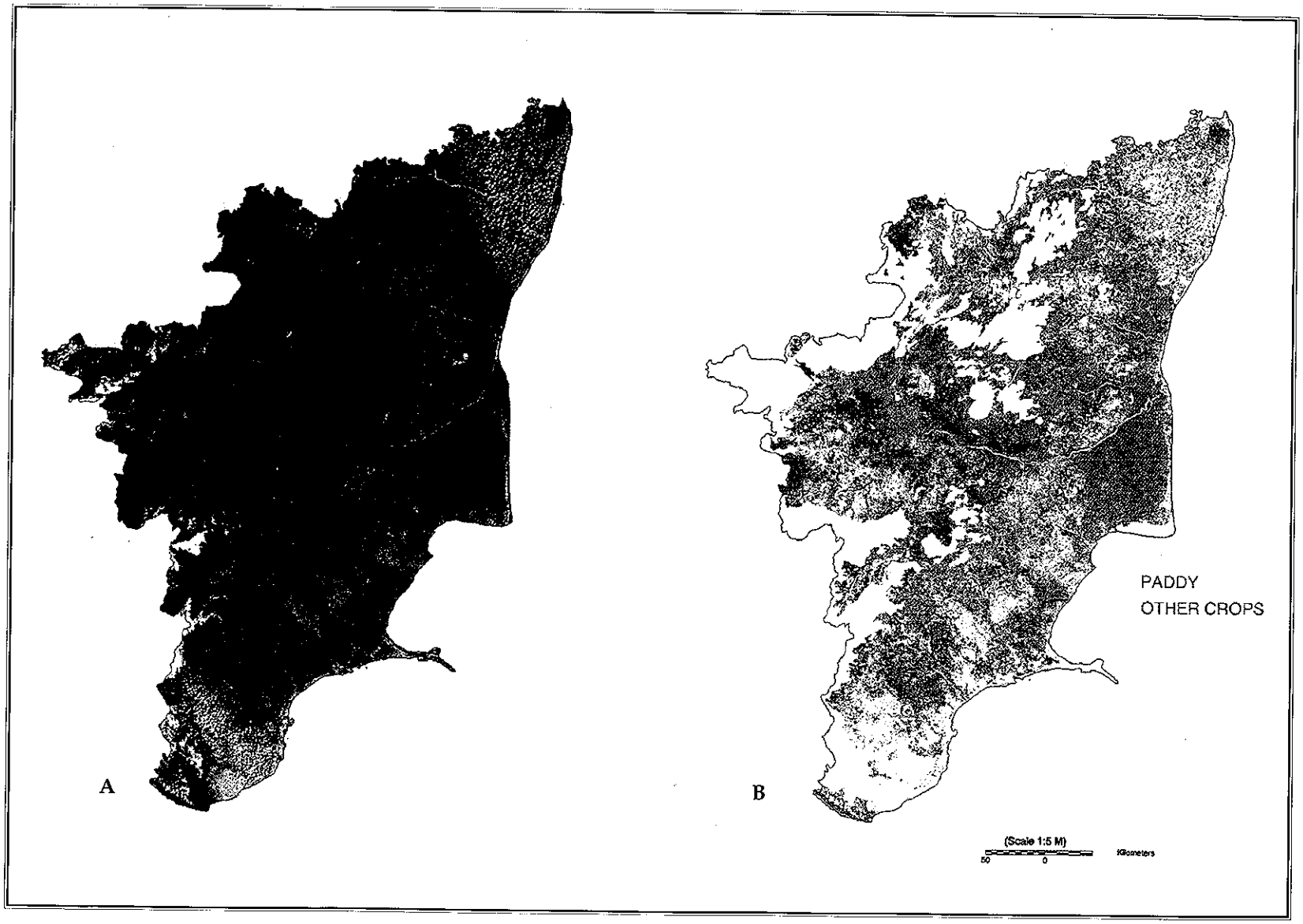


Fig. 5.2.19. Unclassified (A) and classified (B) satellite images of Tamil Nadu, India in kharif 1999

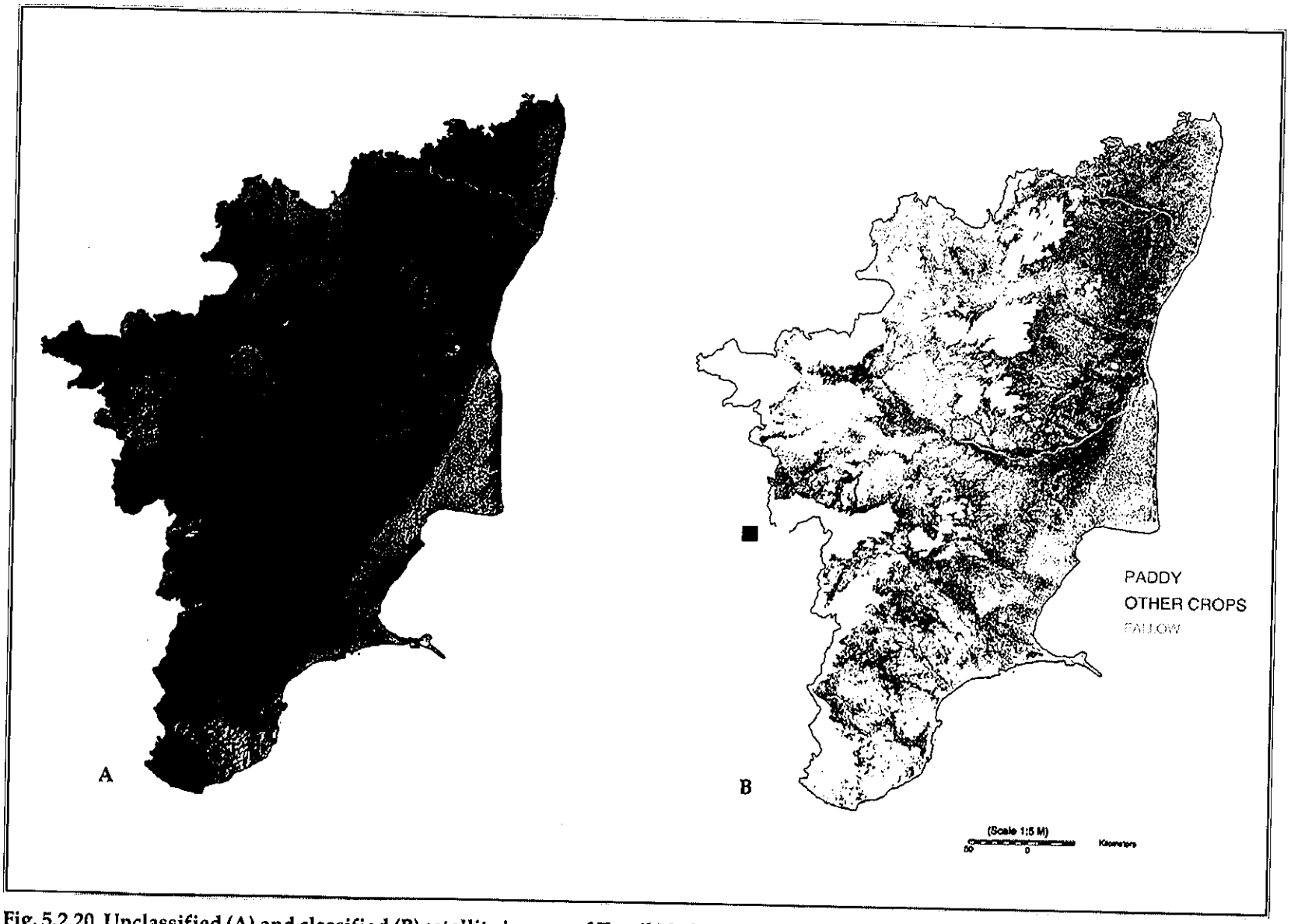


Fig. 5.2.20. Unclassified (A) and classified (B) satellite images of Tamil Nadu, India in rabi 1999/2000

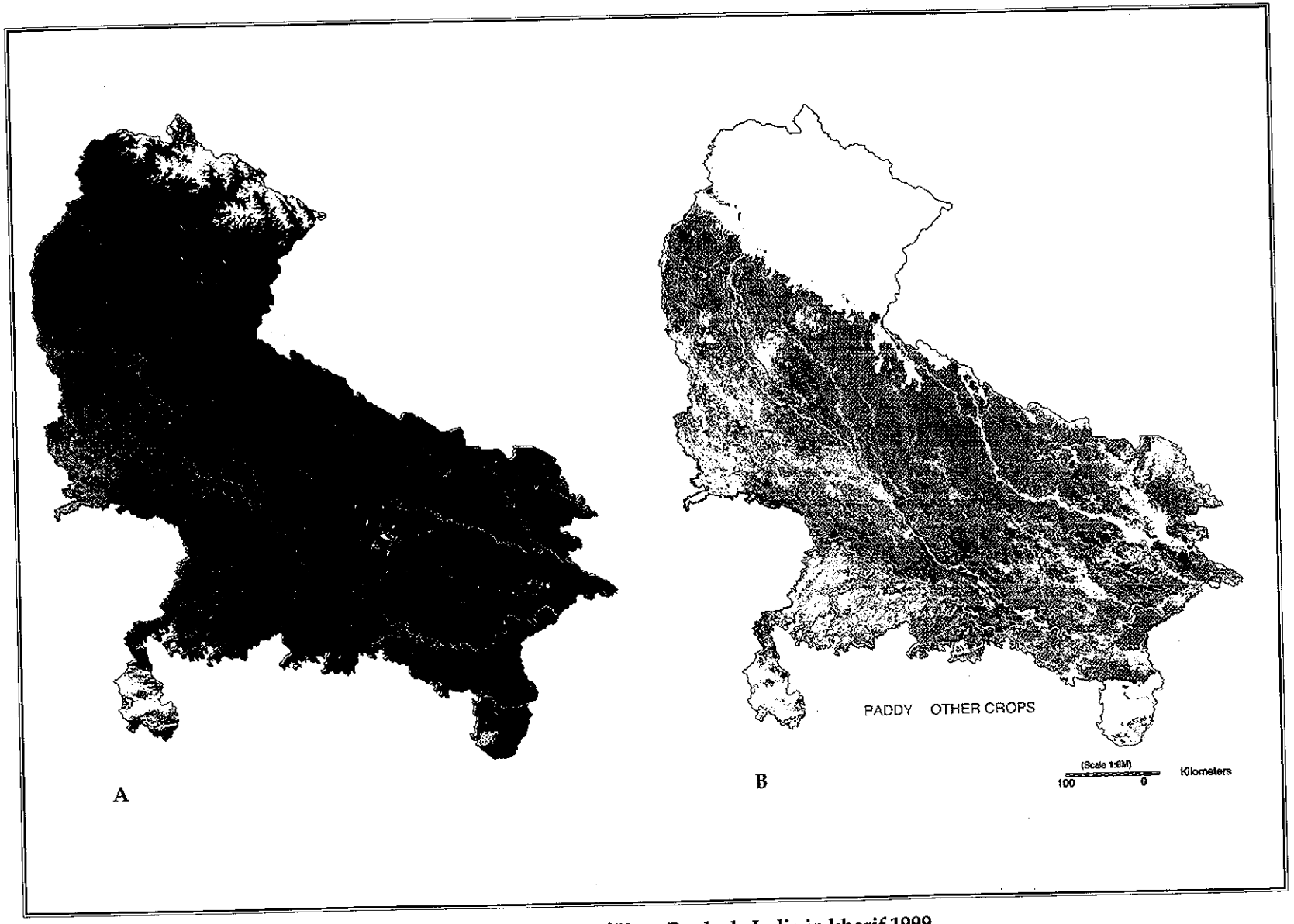


Fig. 5.2.21. Unclassified (A) and classified (B) satellite images of Uttar Pradesh, India in kharif 1999

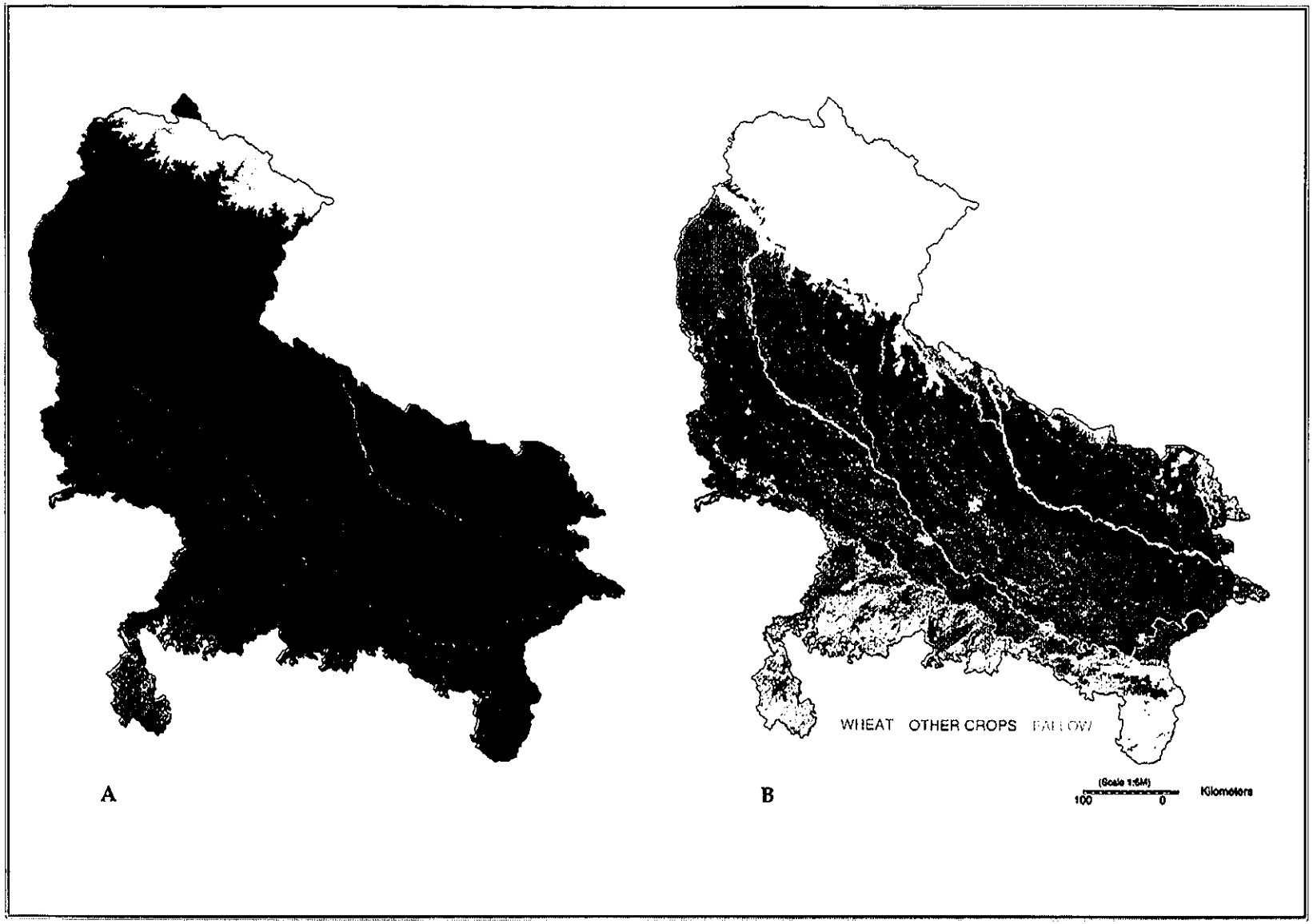


Fig. 5.2.22. Unclassified (A) and classified (B) satellite images of Uttar Pradesh, India in rabi 1999/2000

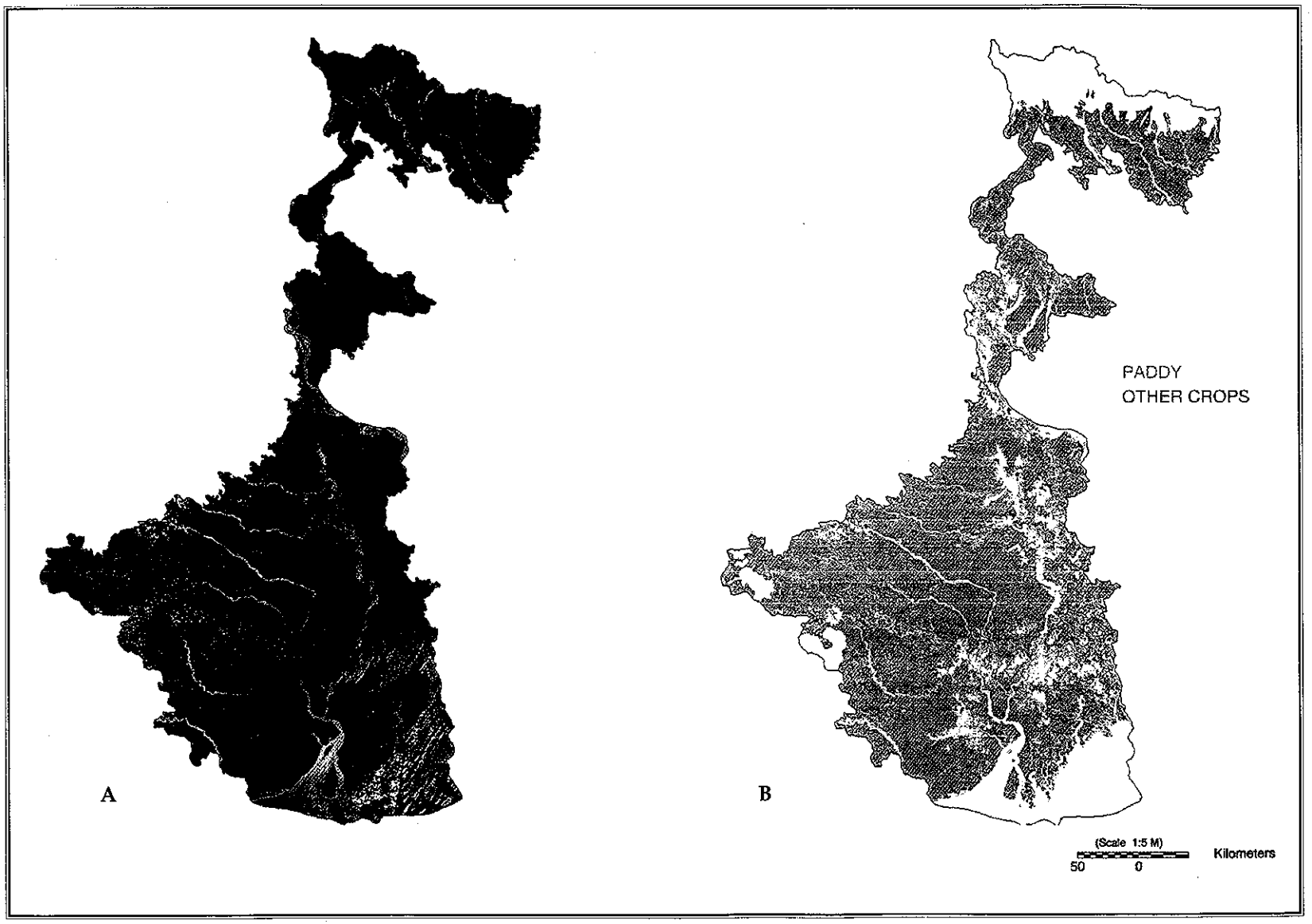


Fig. 5.2.23. Unclassified (A) and classified (B) satellite images of West Bengal, India in kharif 1999

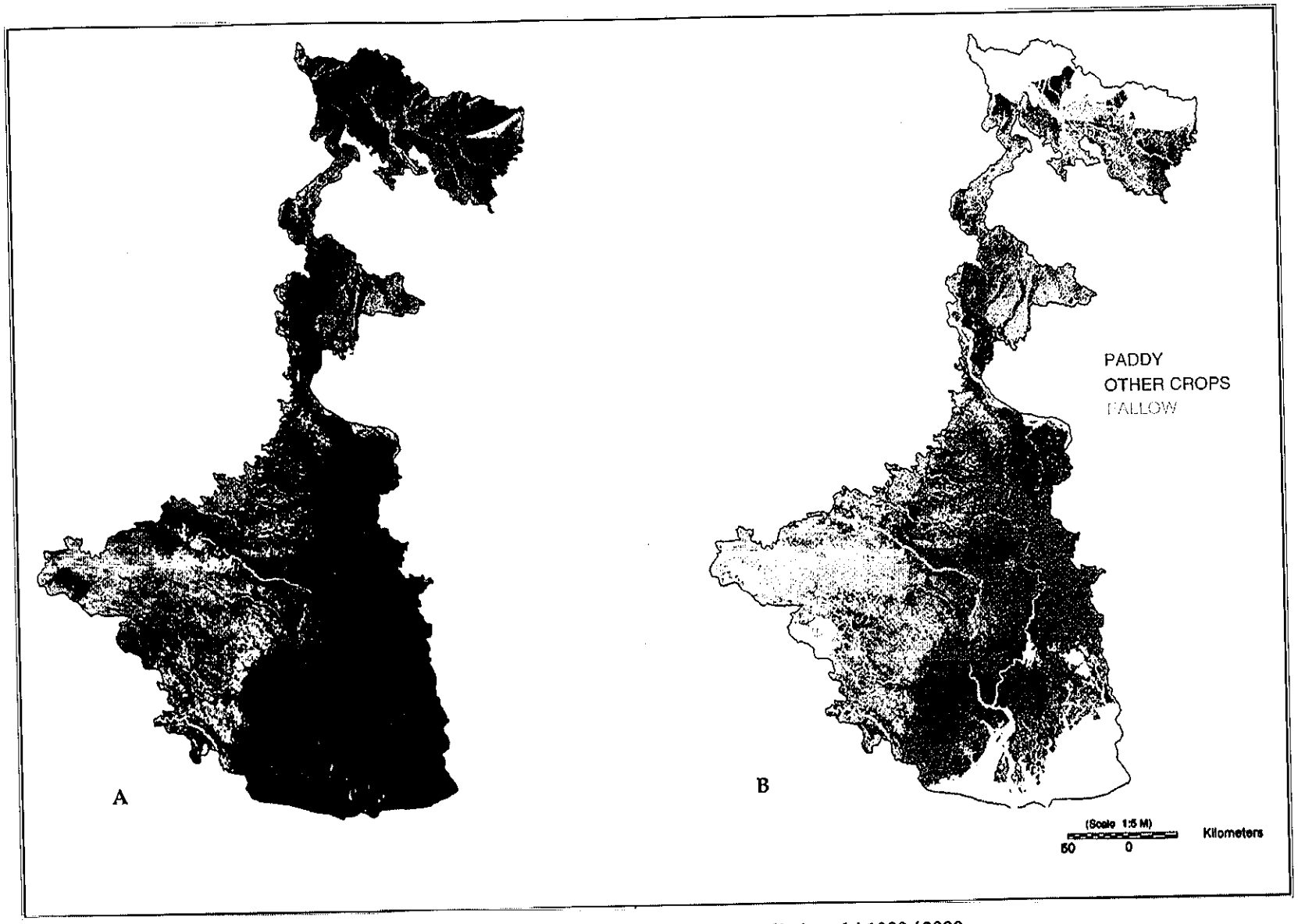


Fig. 5.2.24. Unclassified (A) and classified (B) satellite images of West Bengal, India in rabi 1999/2000

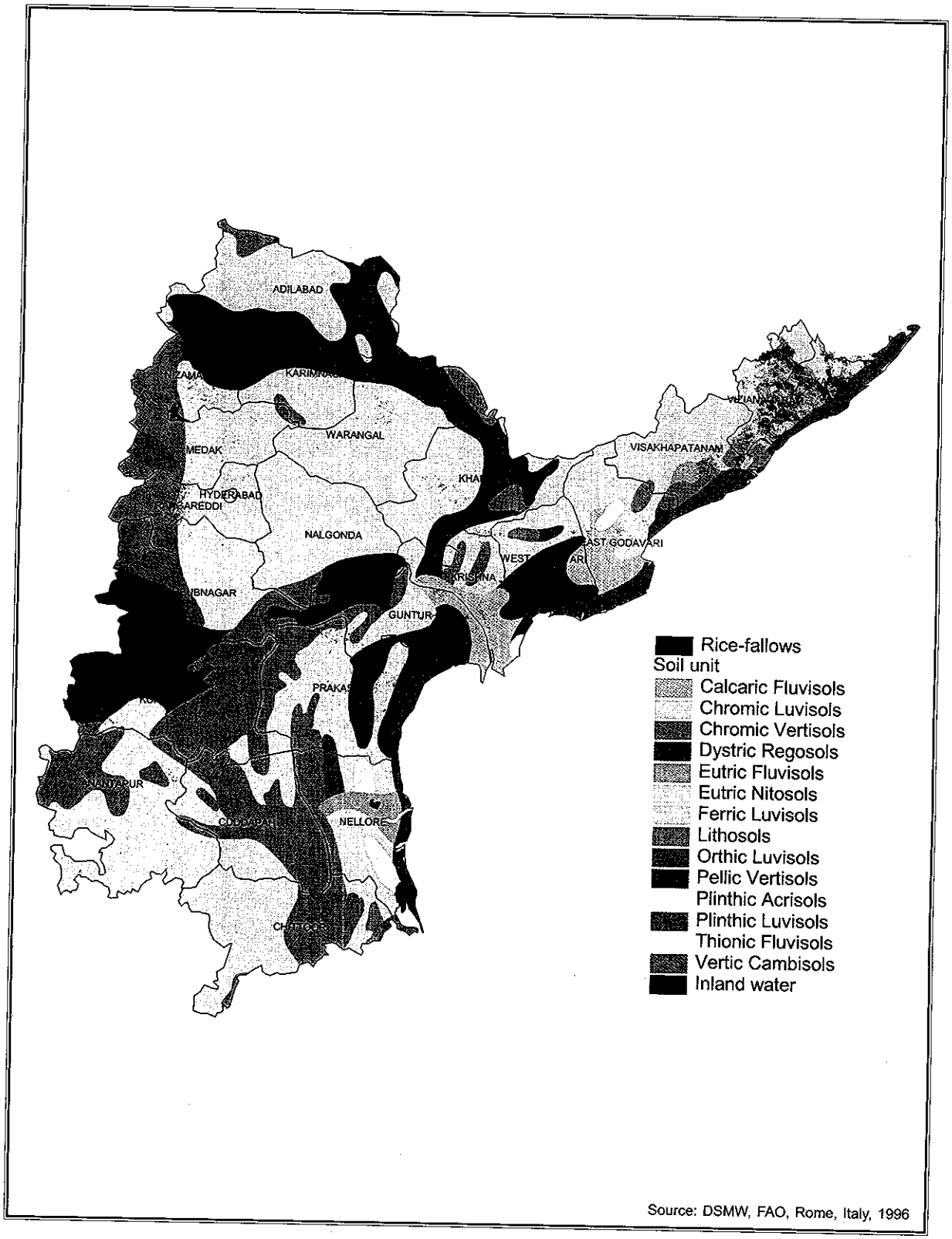


Fig. 5.2.25. Soils of Andhra Pradesh, India

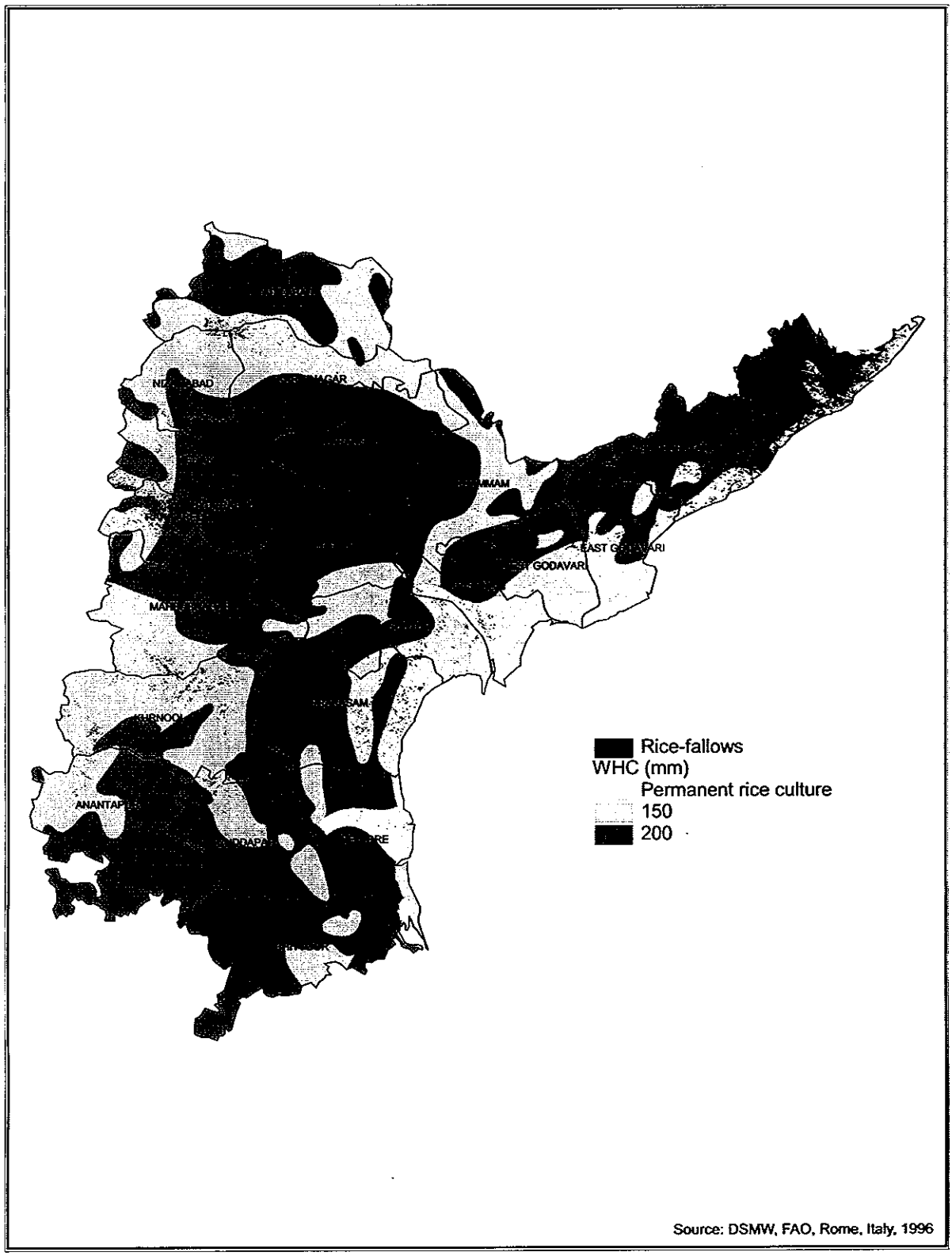


Fig. 5.2.26. Available soil water-holding capacity (WHC) in Andhra Pradesh, India

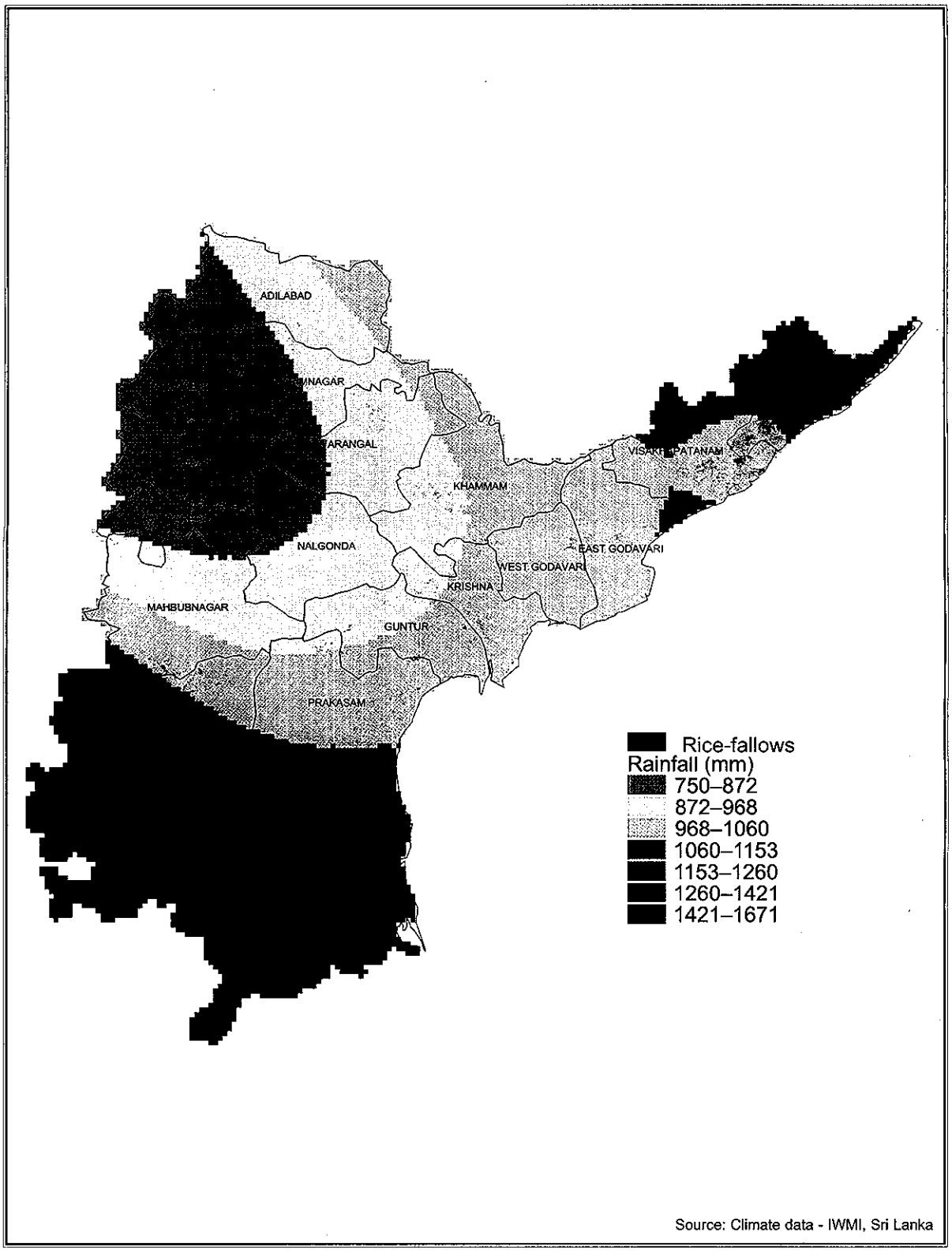


Fig. 5.2.27. Annual rainfall in Andhra Pradesh, India

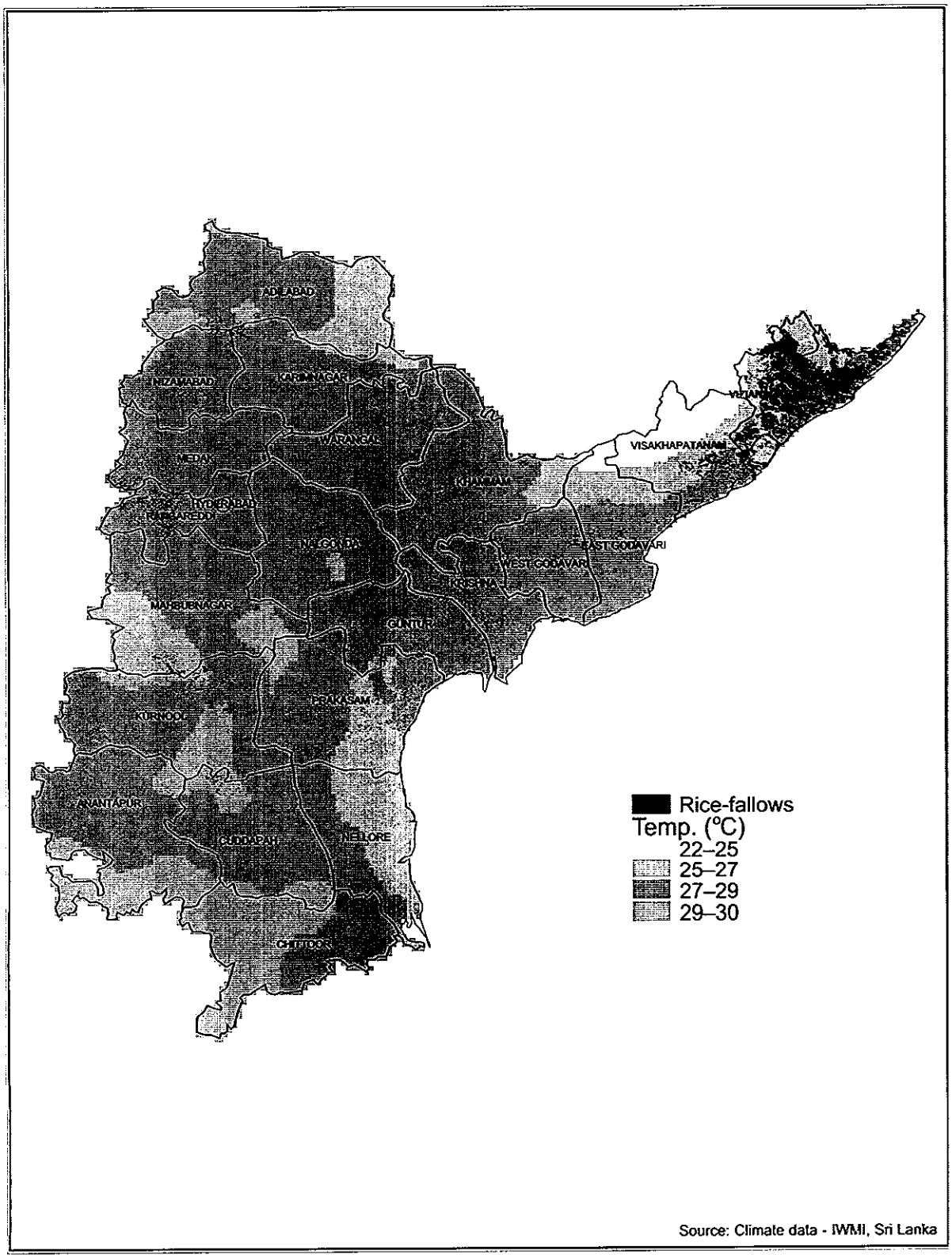


Fig. 5.2.28. Annual mean maximum temperature in Andhra Pradesh, India

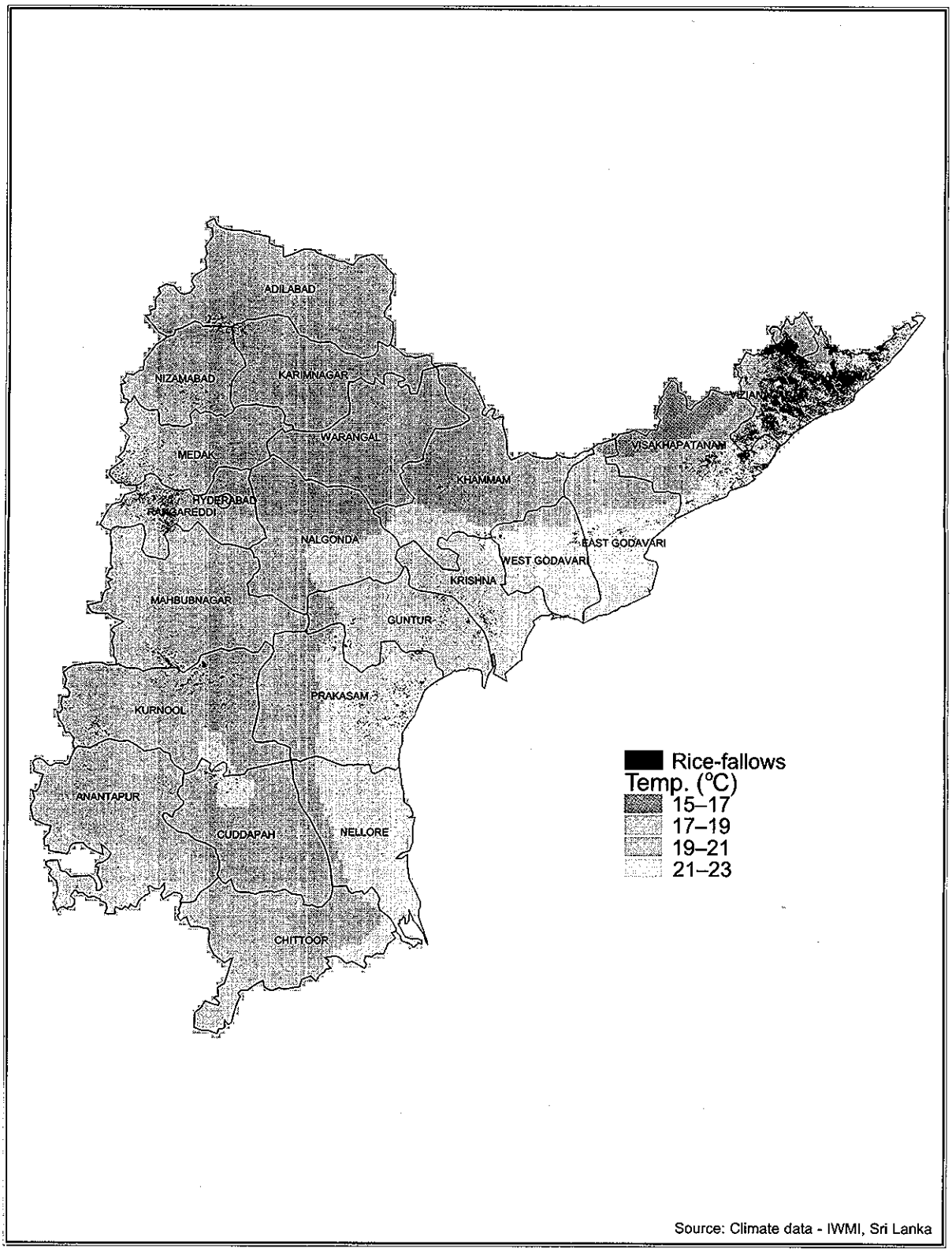


Fig. 5.2.29. Annual mean minimum temperature in Andhra Pradesh, India

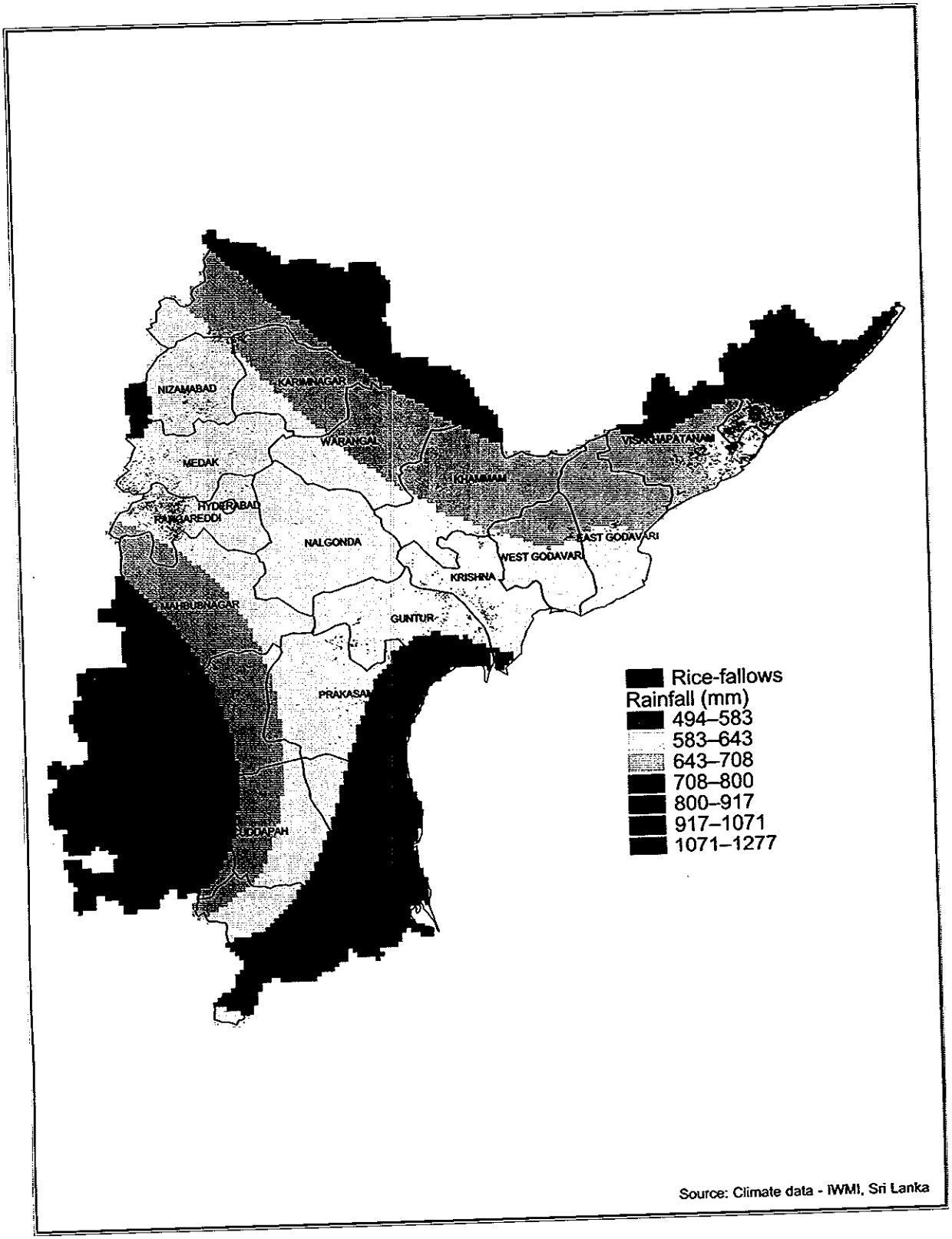


Fig. 5.2.30. Rainfall during kharif (June–September) in Andhra Pradesh, India

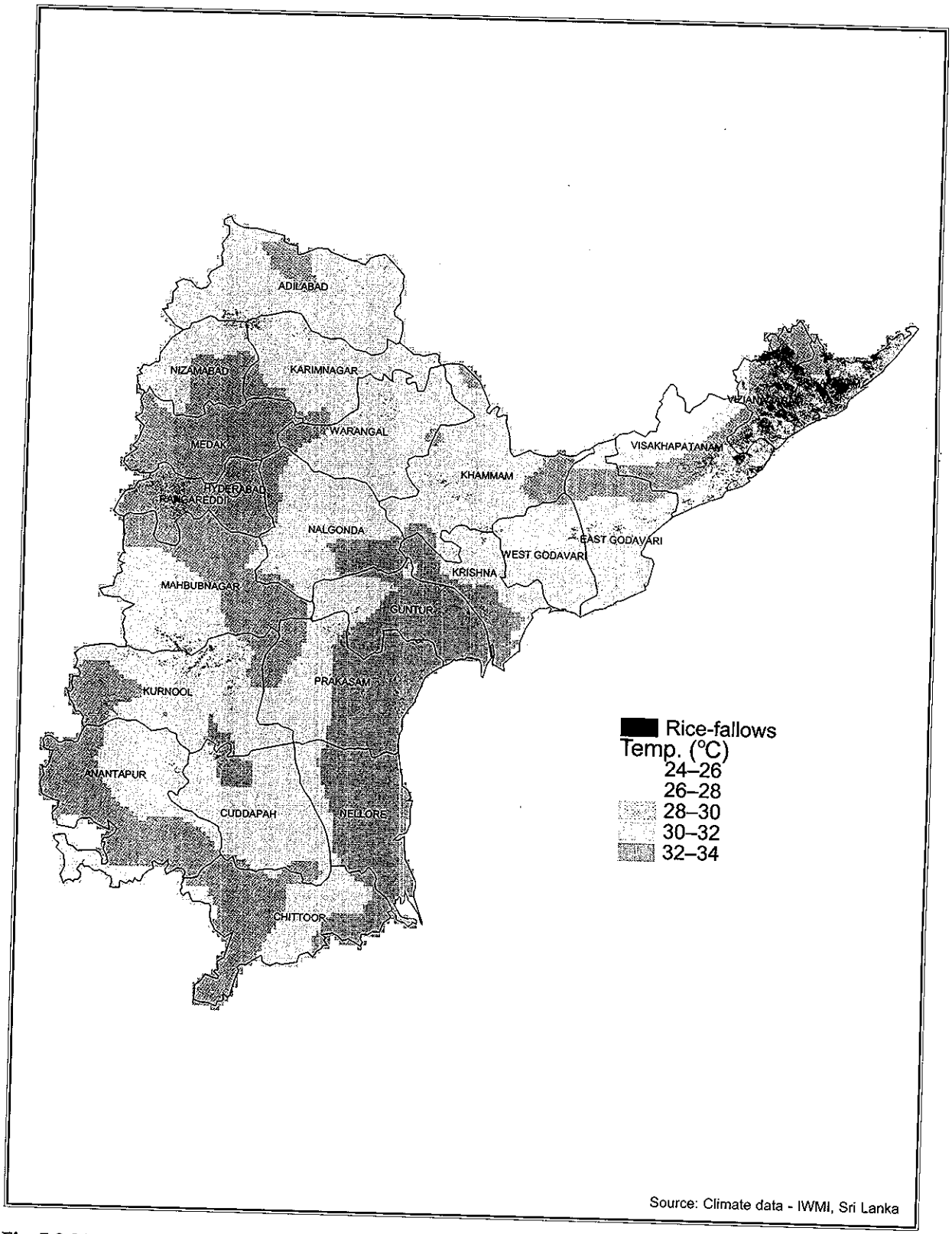


Fig. 5.2.31. Mean maximum temperature during kharif (June–September) in Andhra Pradesh, India

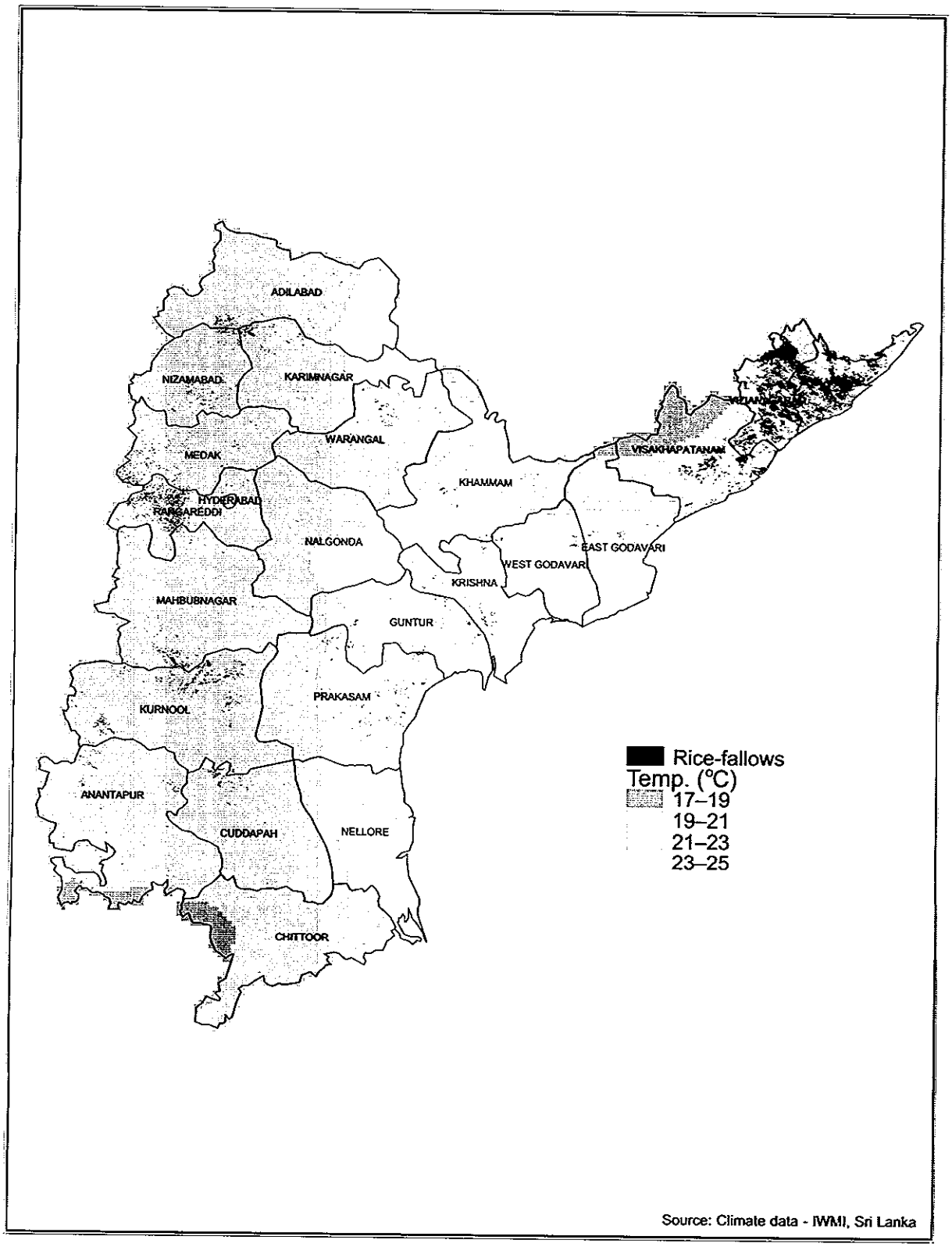


Fig. 5.2.32. Mean minimum temperature during kharif (June–September) in Andhra Pradesh, India

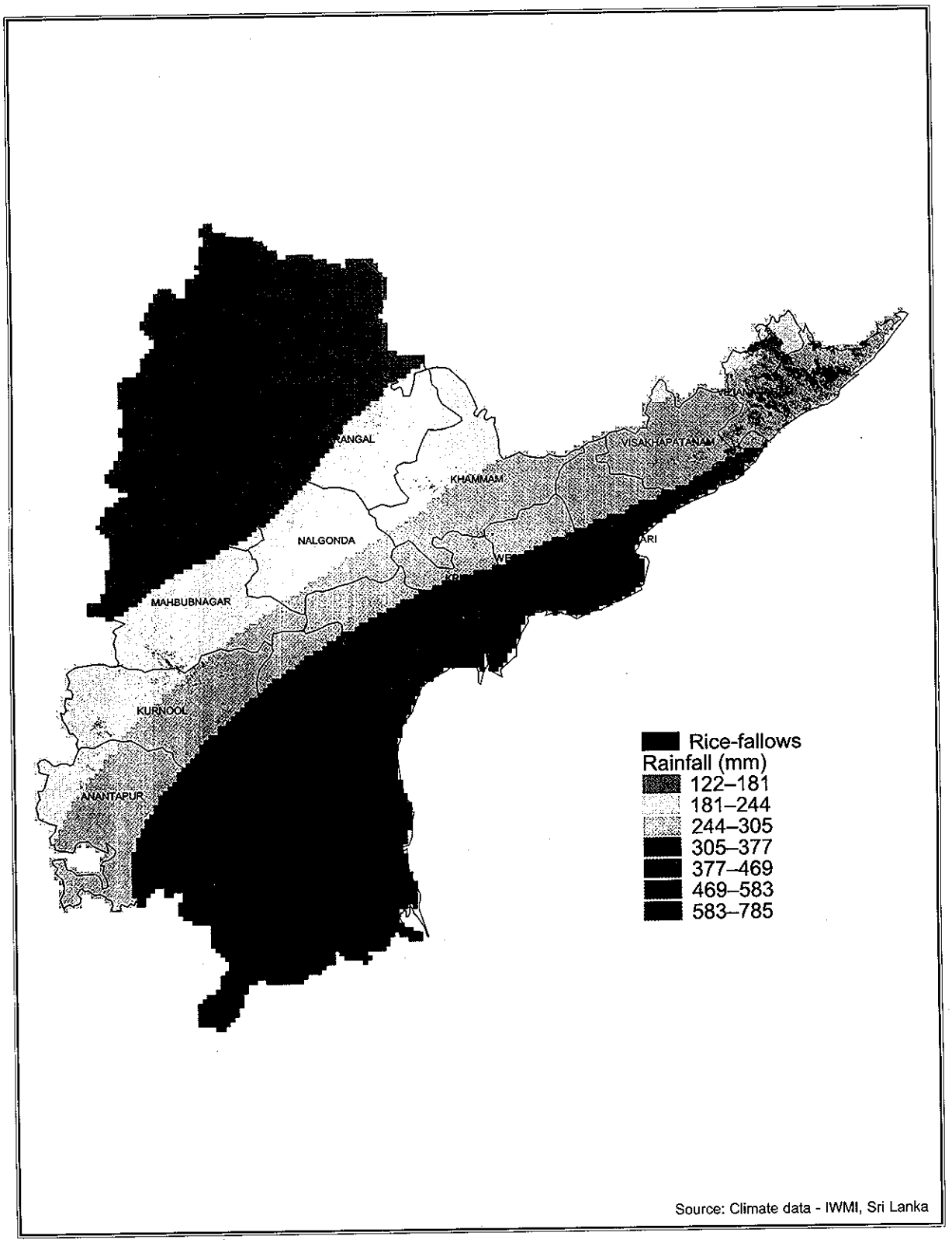


Fig. 5.2.33. Rainfall during rabi (October–March) in Andhra Pradesh, India

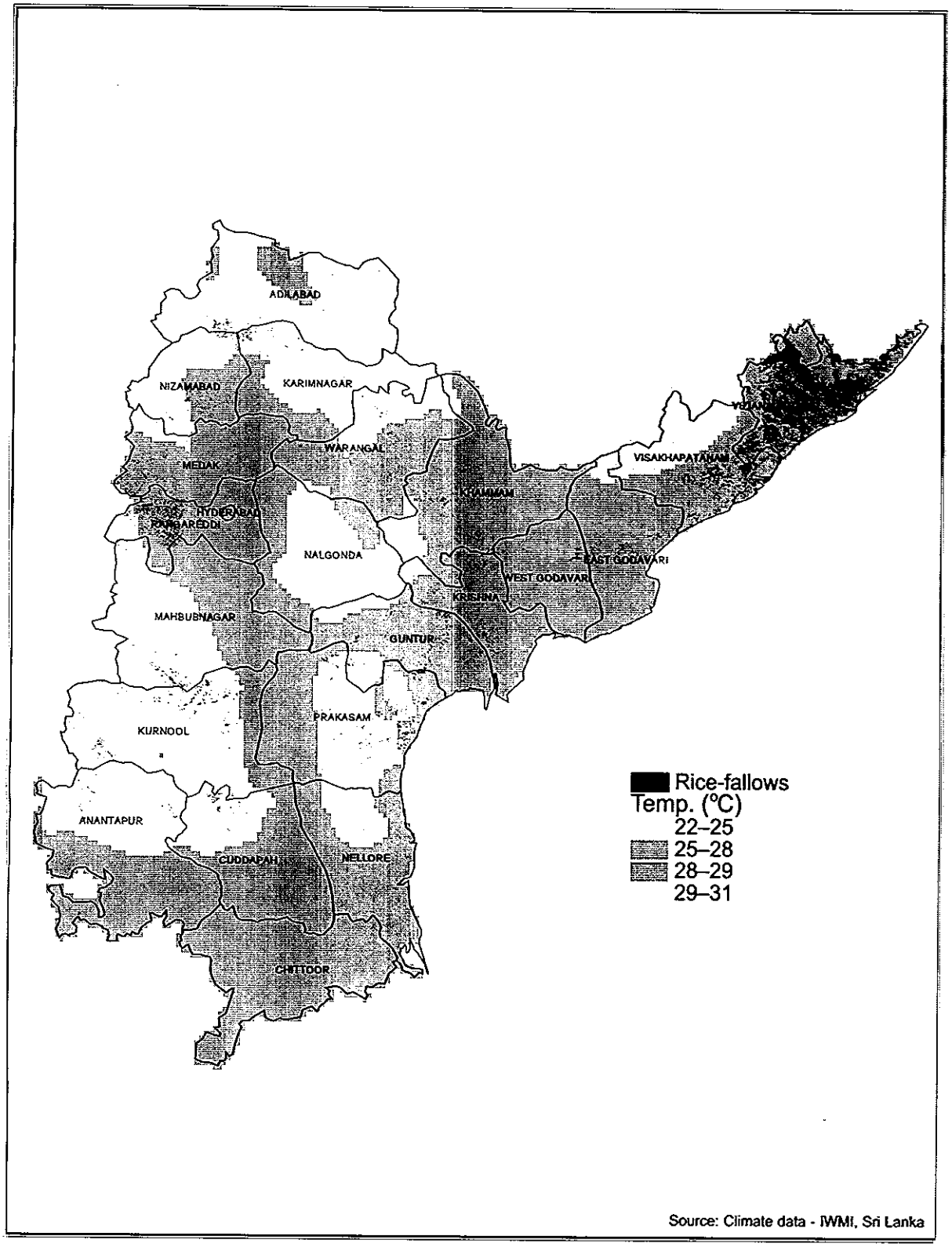


Fig. 5.2.34. Mean maximum temperature during rabi (October–March) in Andhra Pradesh, India

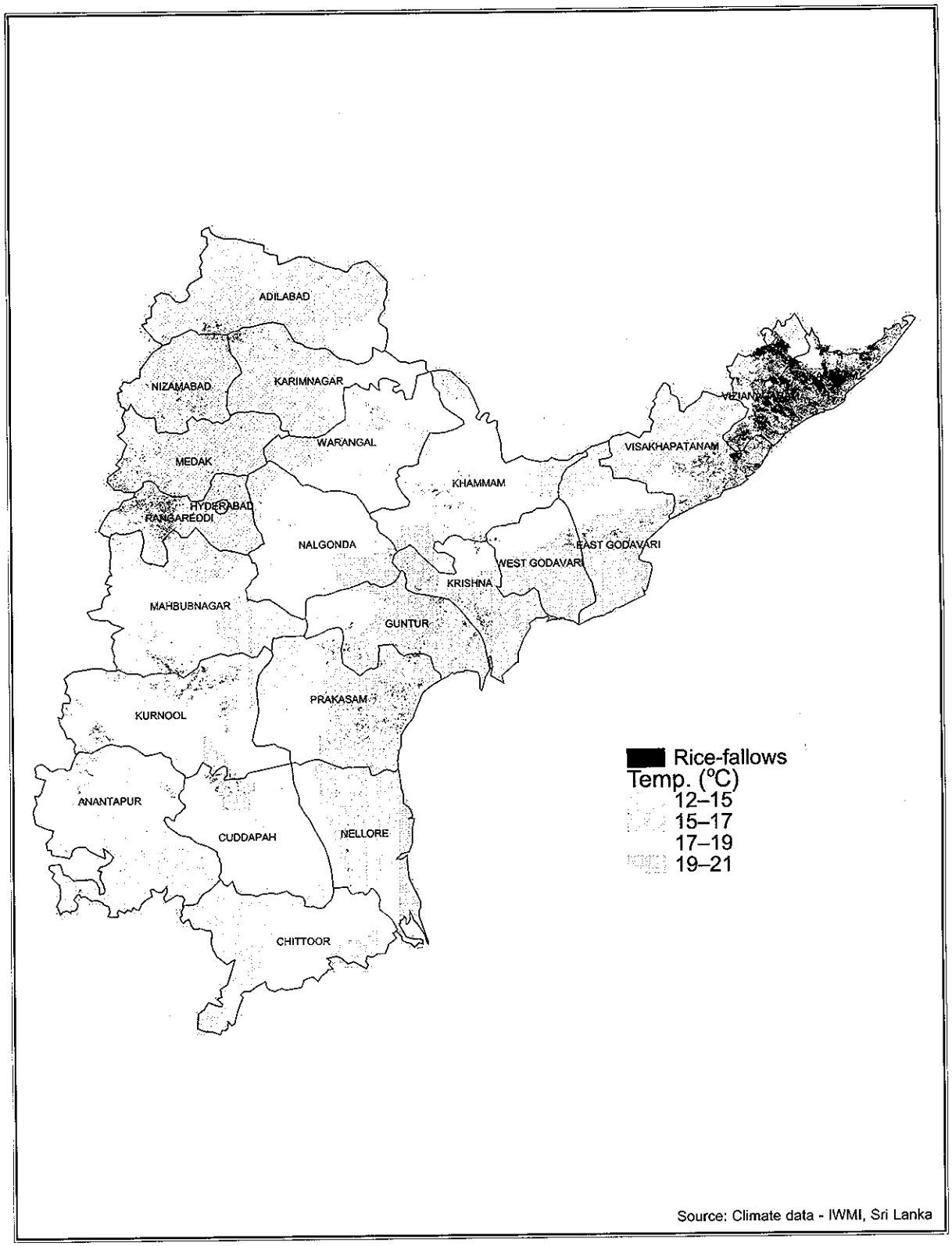


Fig. 5.2.35. Mean minimum temperature during rabi (October–March) in Andhra Pradesh, India

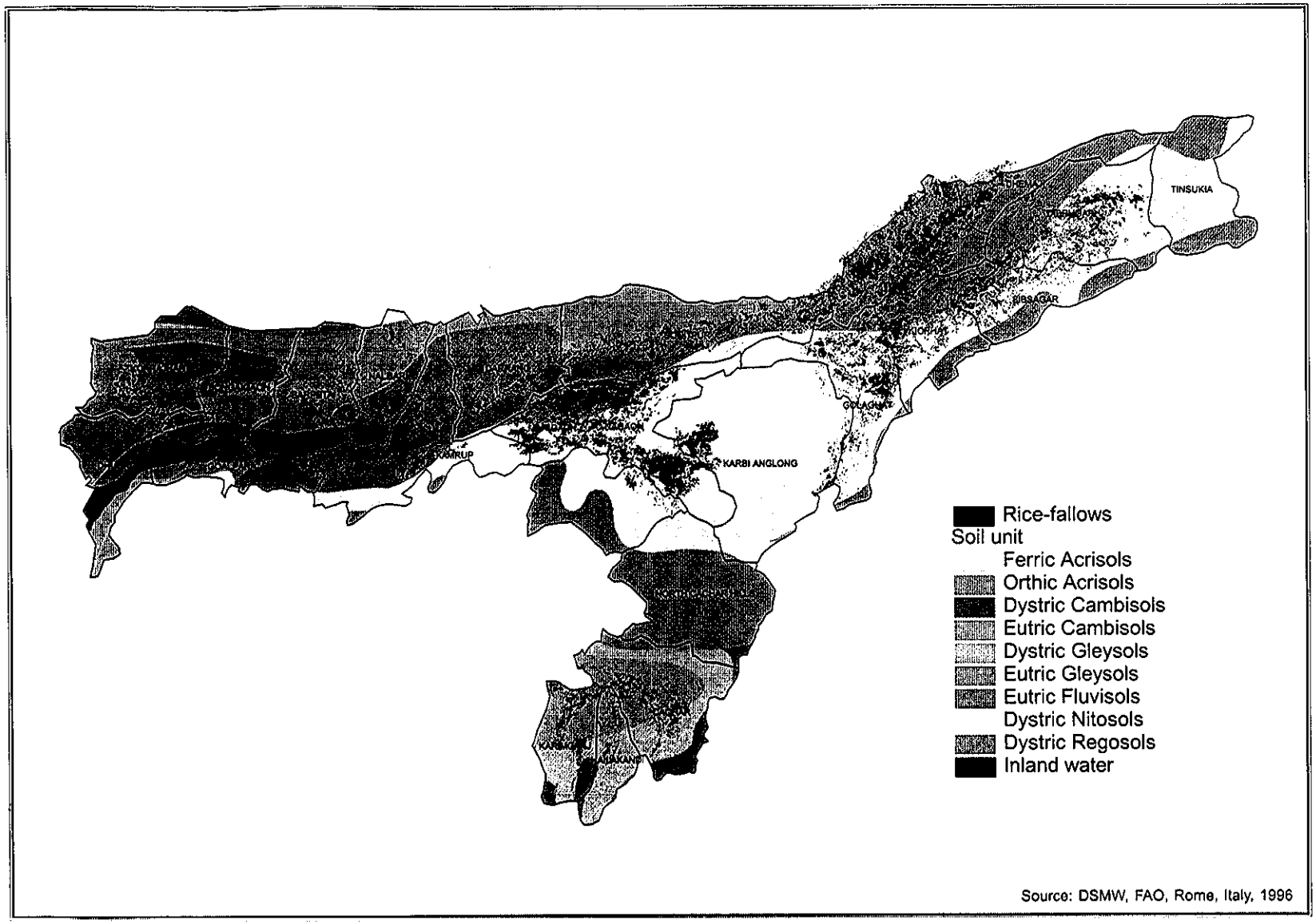


Fig. 5.2.36. Soils of Assam, India

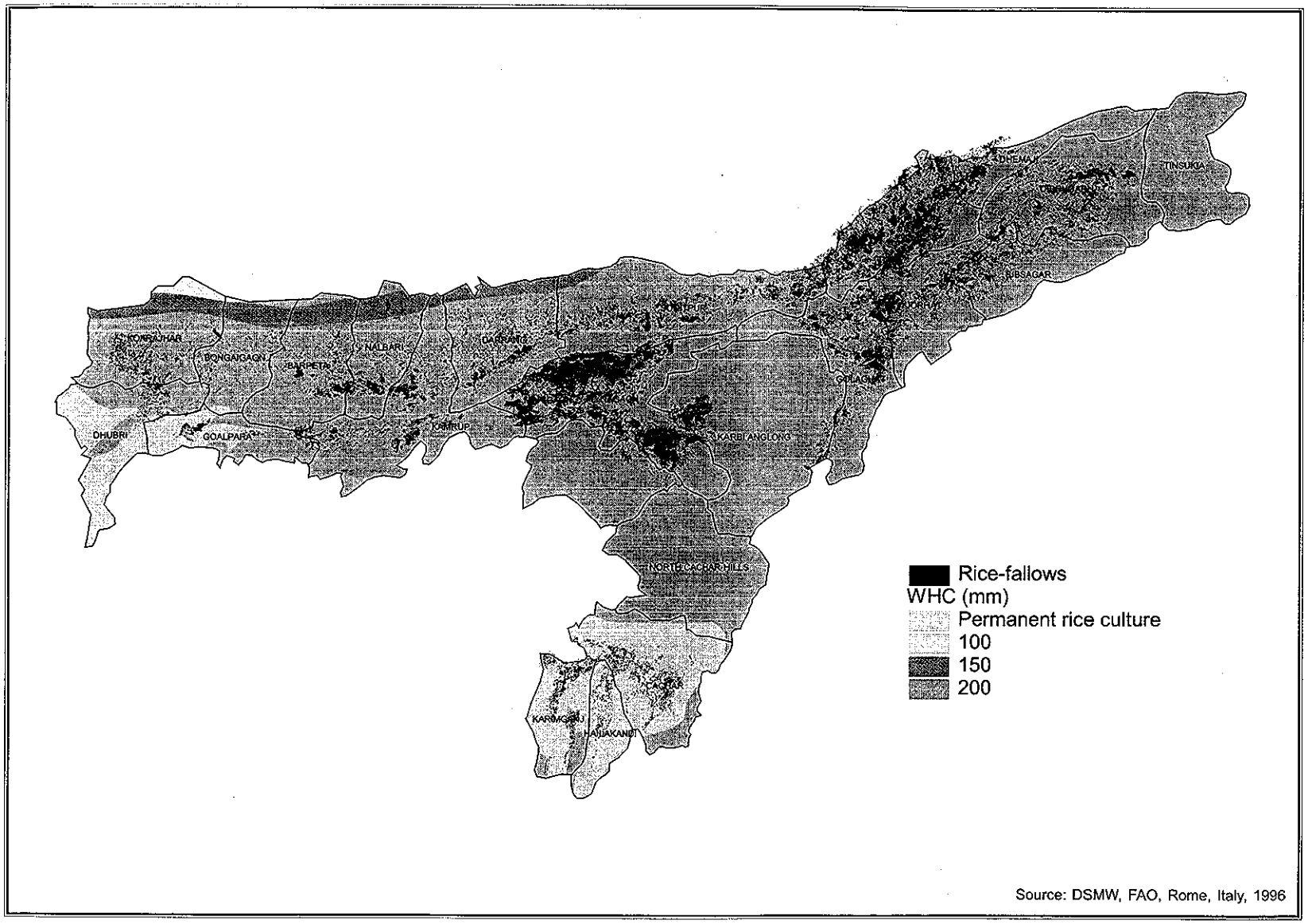


Fig. 5.2.37. Available soil water-holding capacity (WHC) in Assam, India

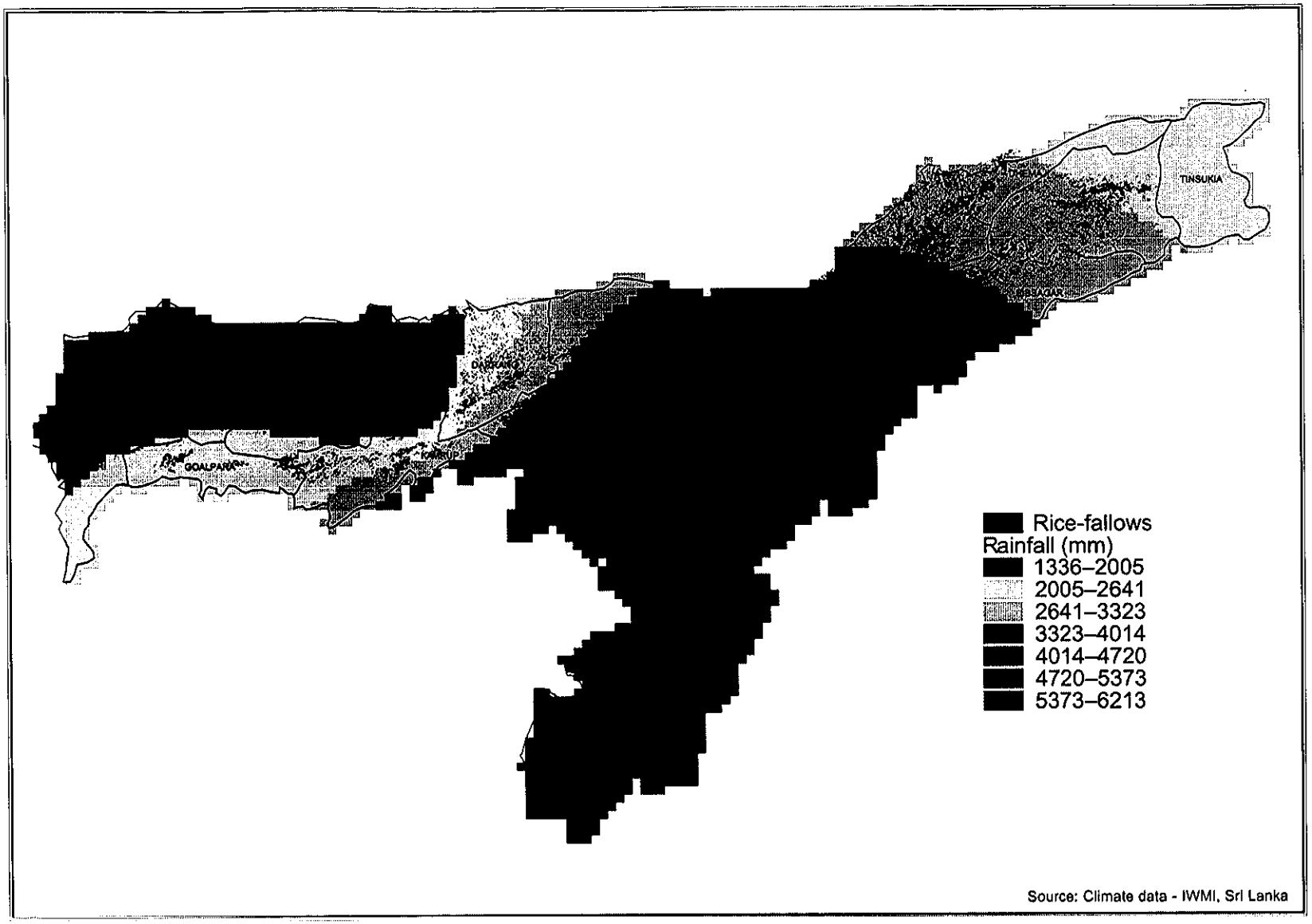


Fig. 5.2.38. Annual rainfall in Assam, India

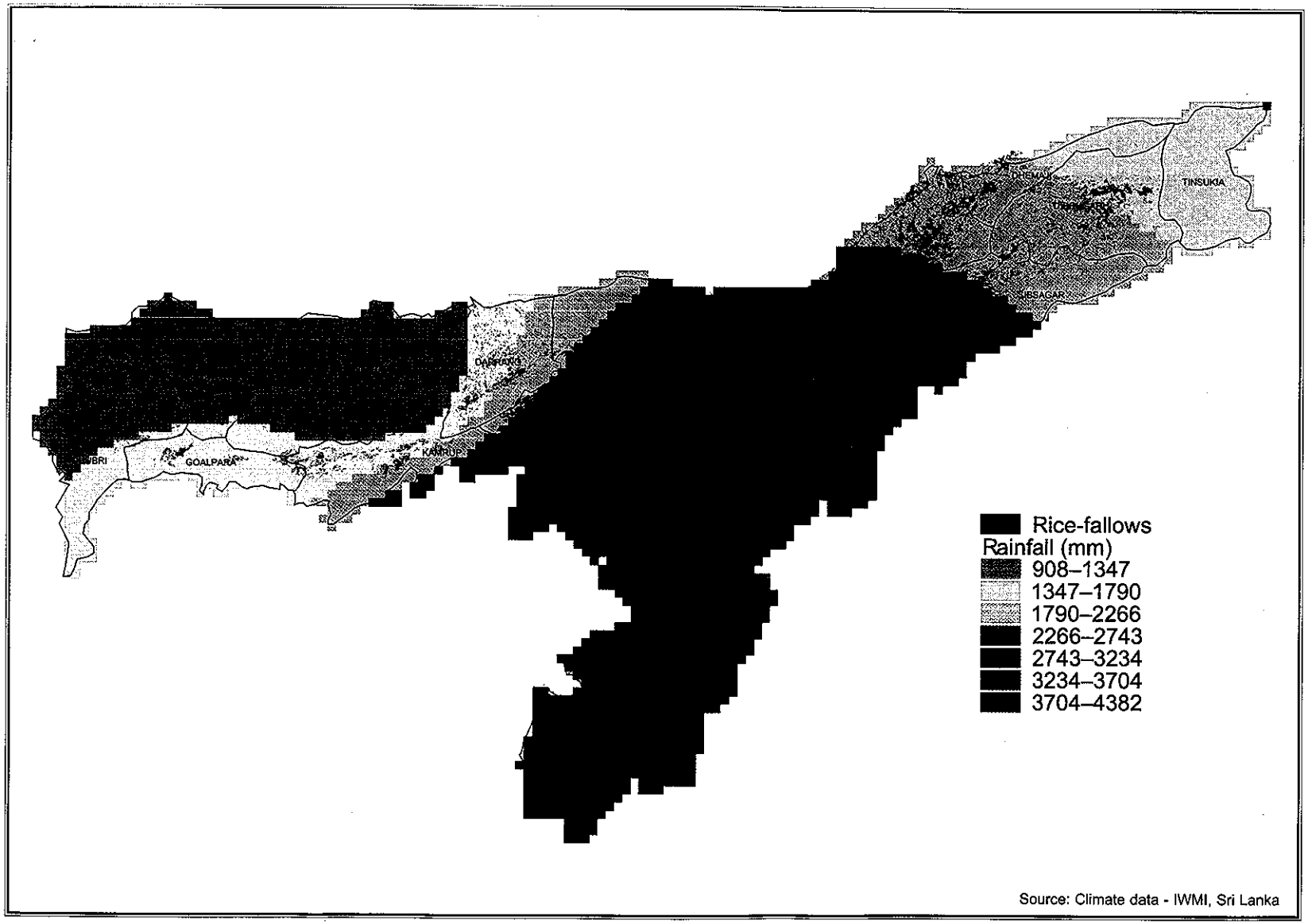


Fig. 5.2.39. Rainfall during kharif (June–September) in Assam, India

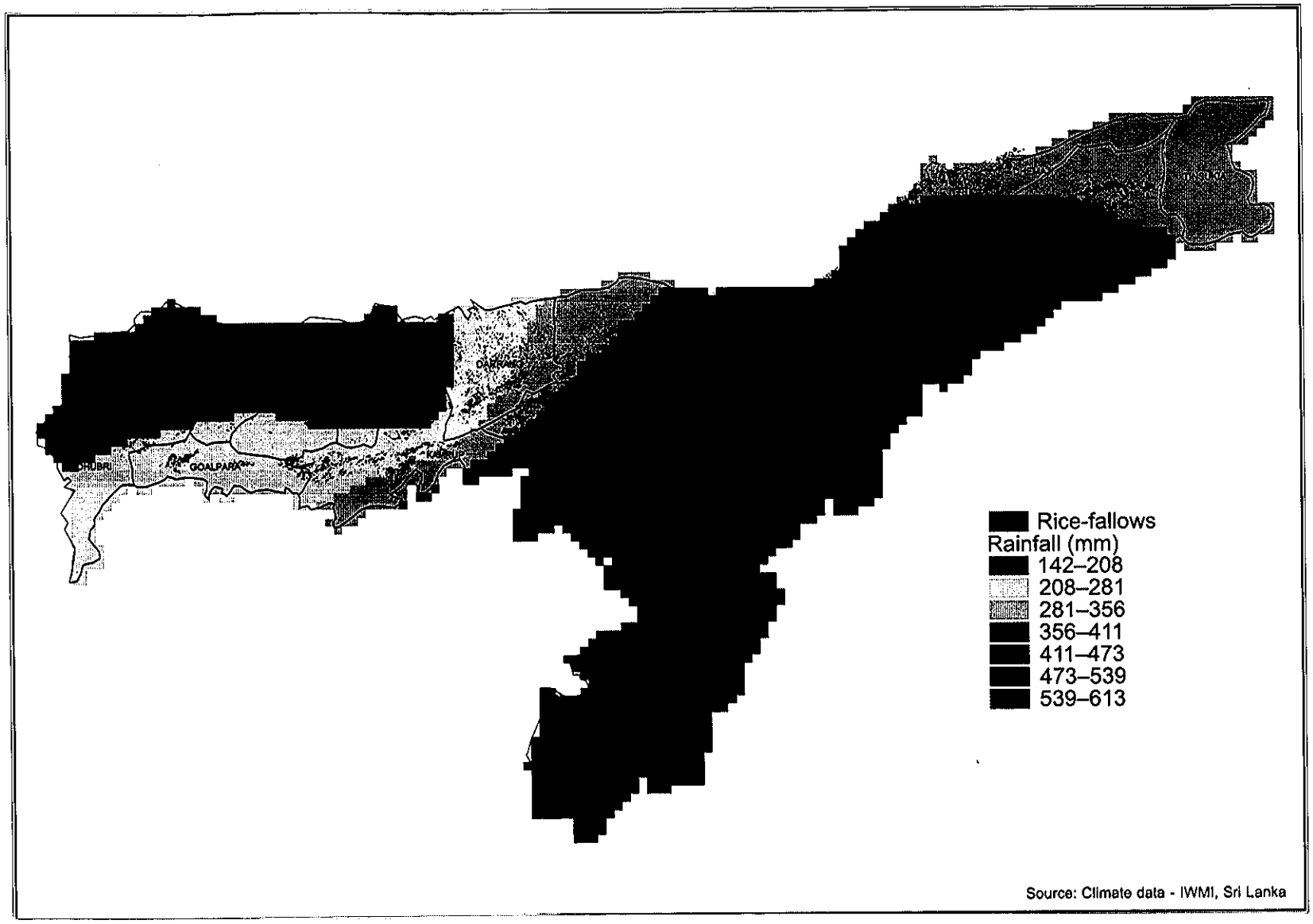


Fig. 5.2.40. Rainfall during rabi (October–March) in Assam, India

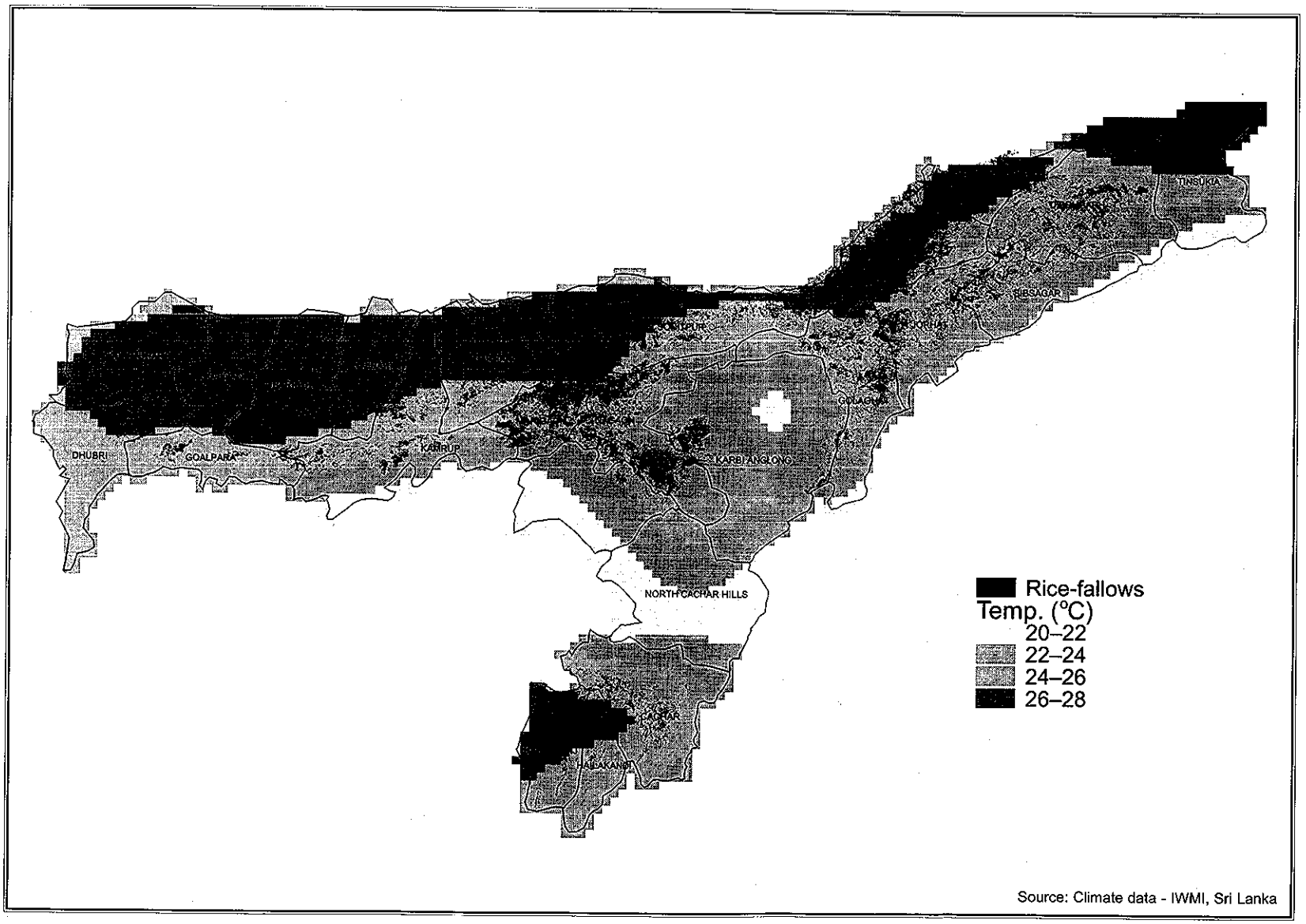


Fig. 5.2.41. Annual mean maximum temperature in Assam, India

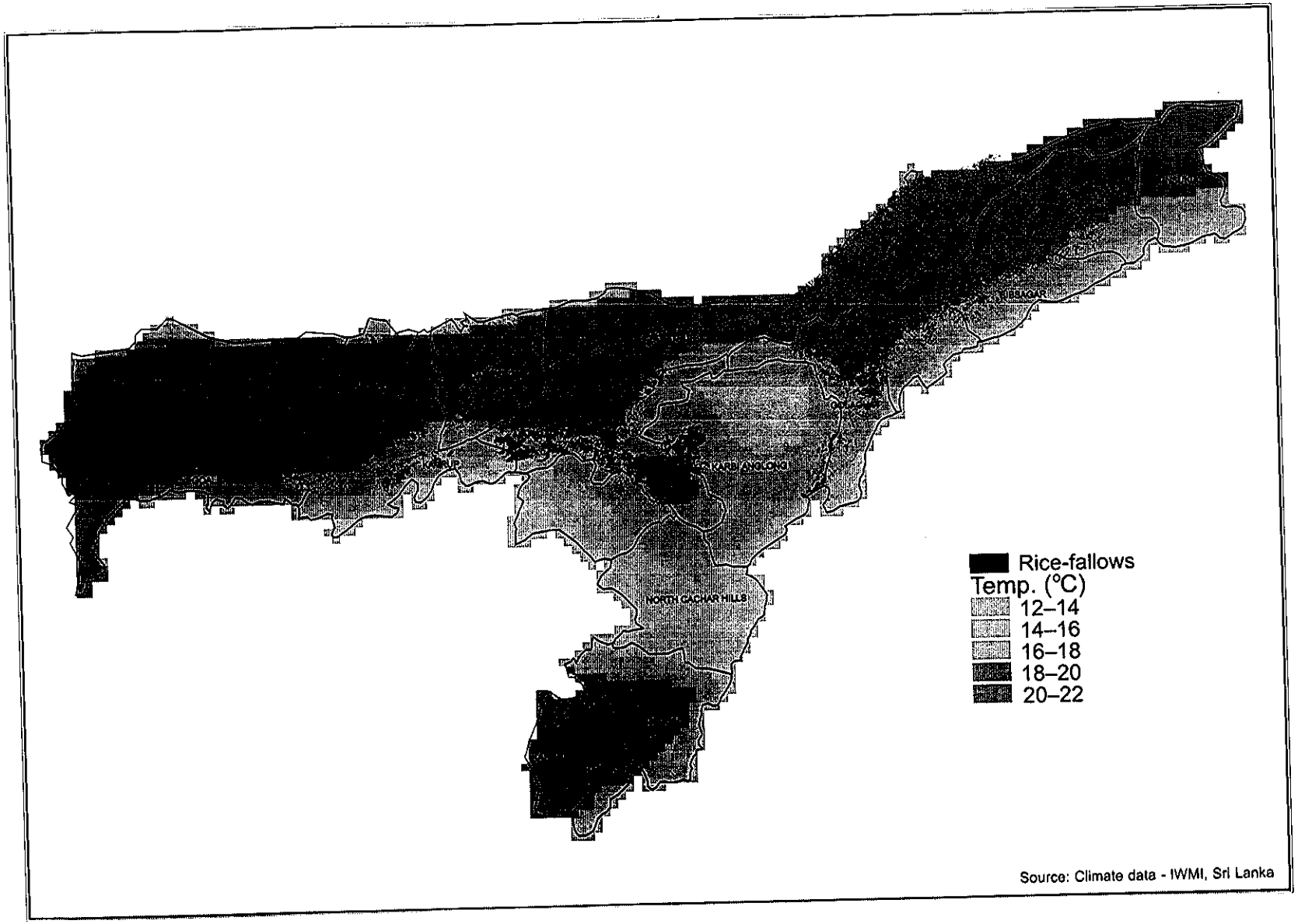


Fig. 5.2.42. Annual mean minimum temperature in Assam, India

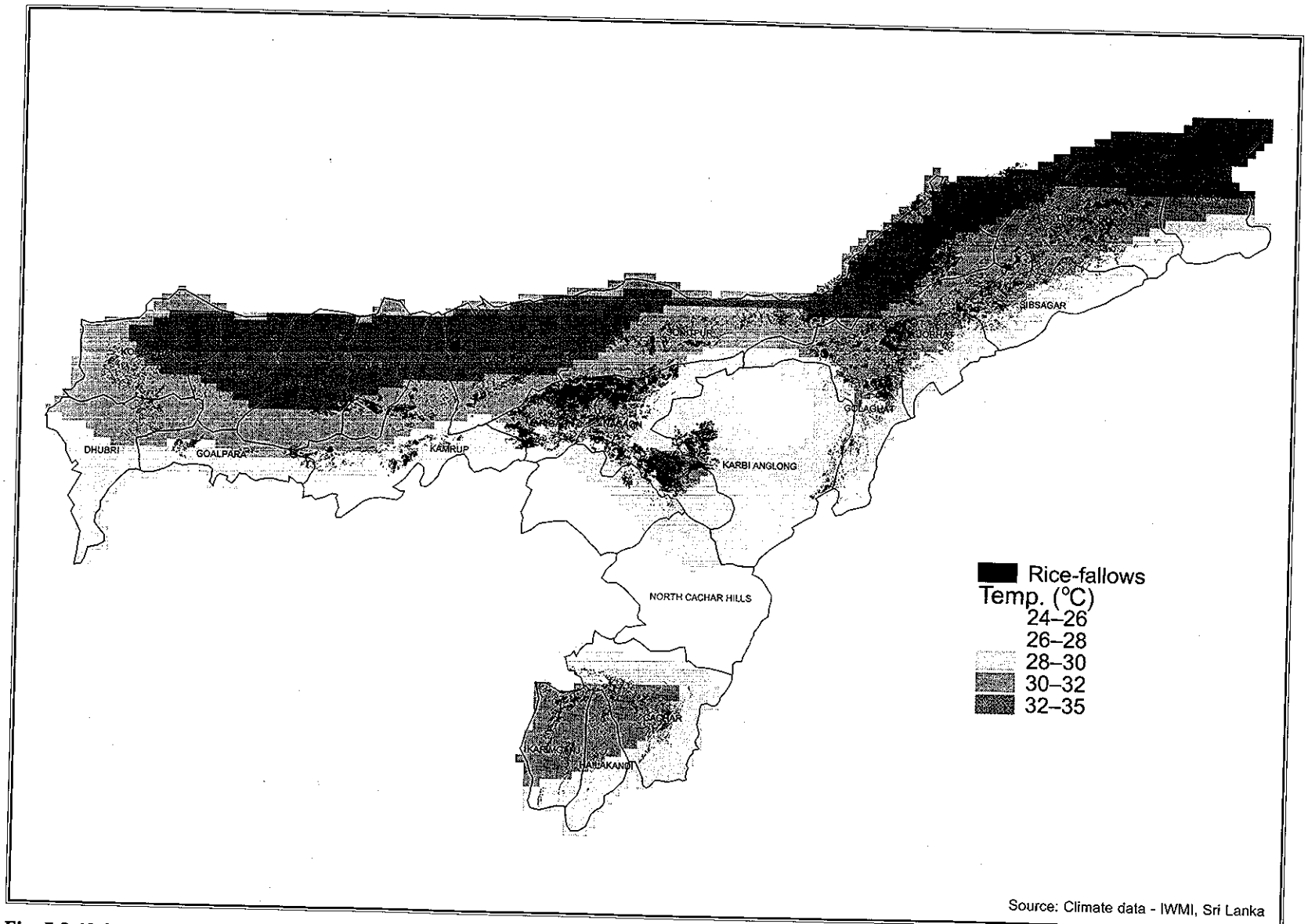


Fig. 5.2.43. Mean maximum temperature during kharif (June–September) in Assam, India

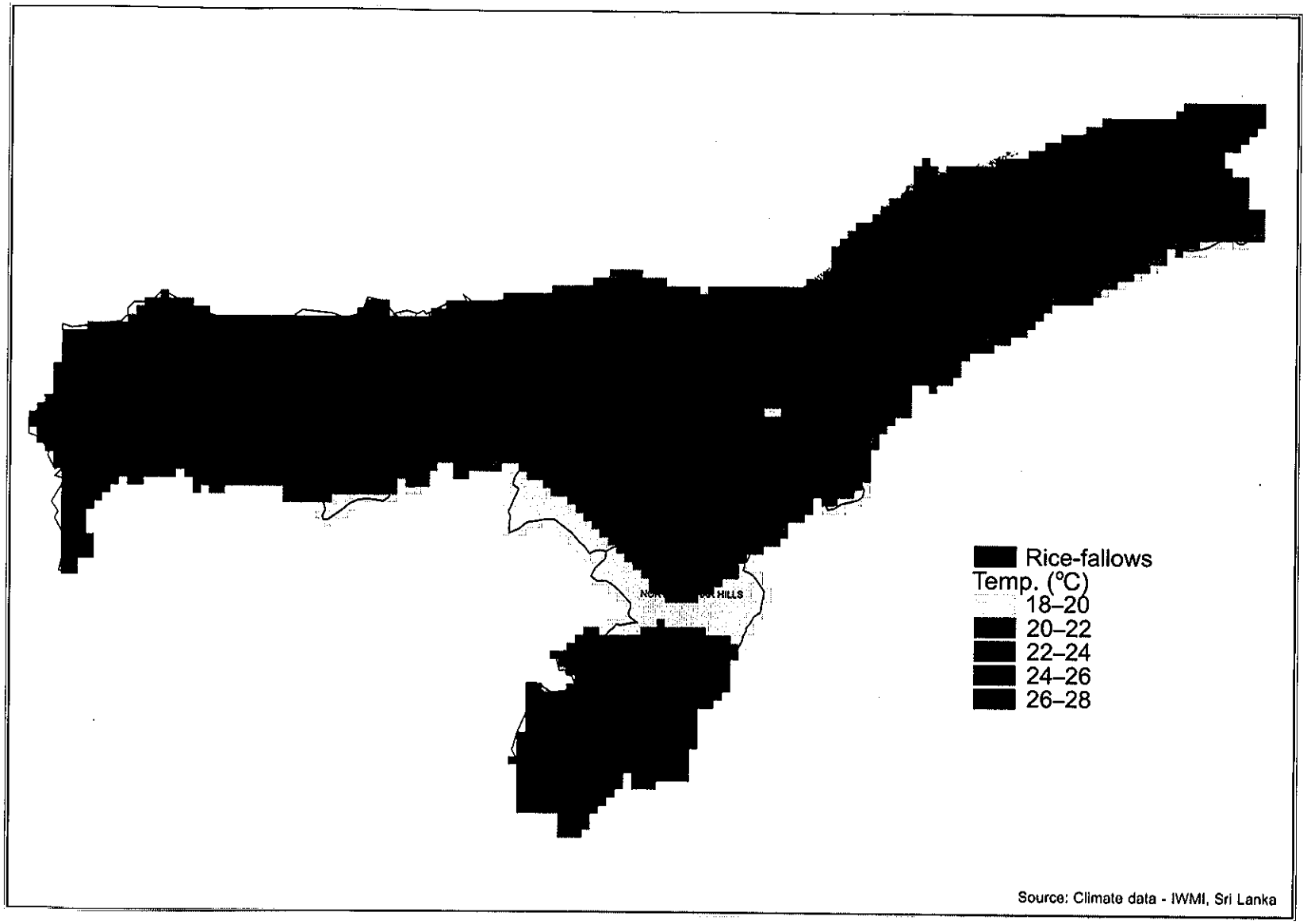


Fig. 5.2.44. Mean minimum temperature during kharif (June-September) in Assam, India

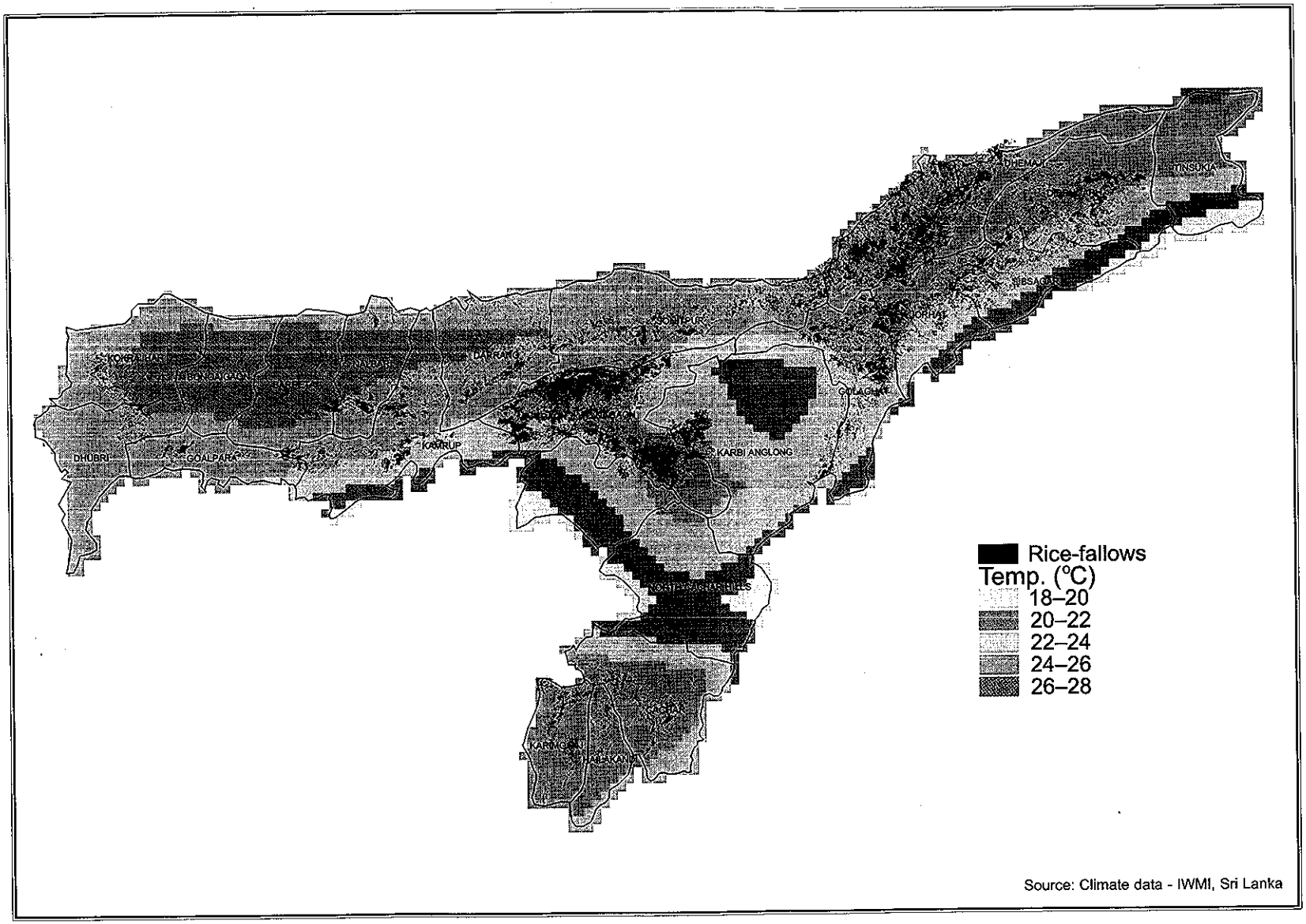


Fig. 5.2.45. Mean maximum temperature during rabi (October–March) in Assam, India

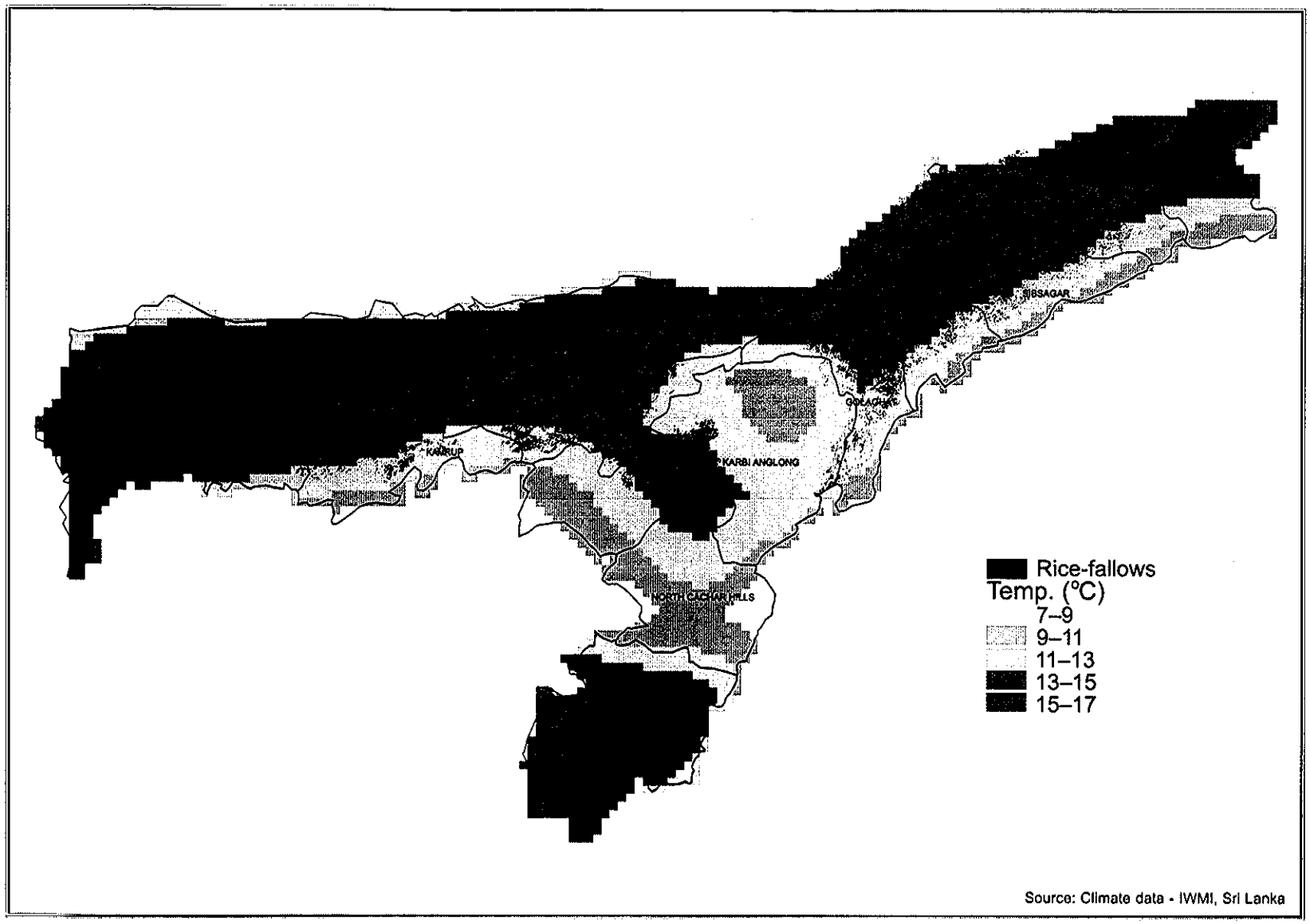


Fig. 5.2.46. Mean minimum temperature during rabi (October–March) in Assam, India

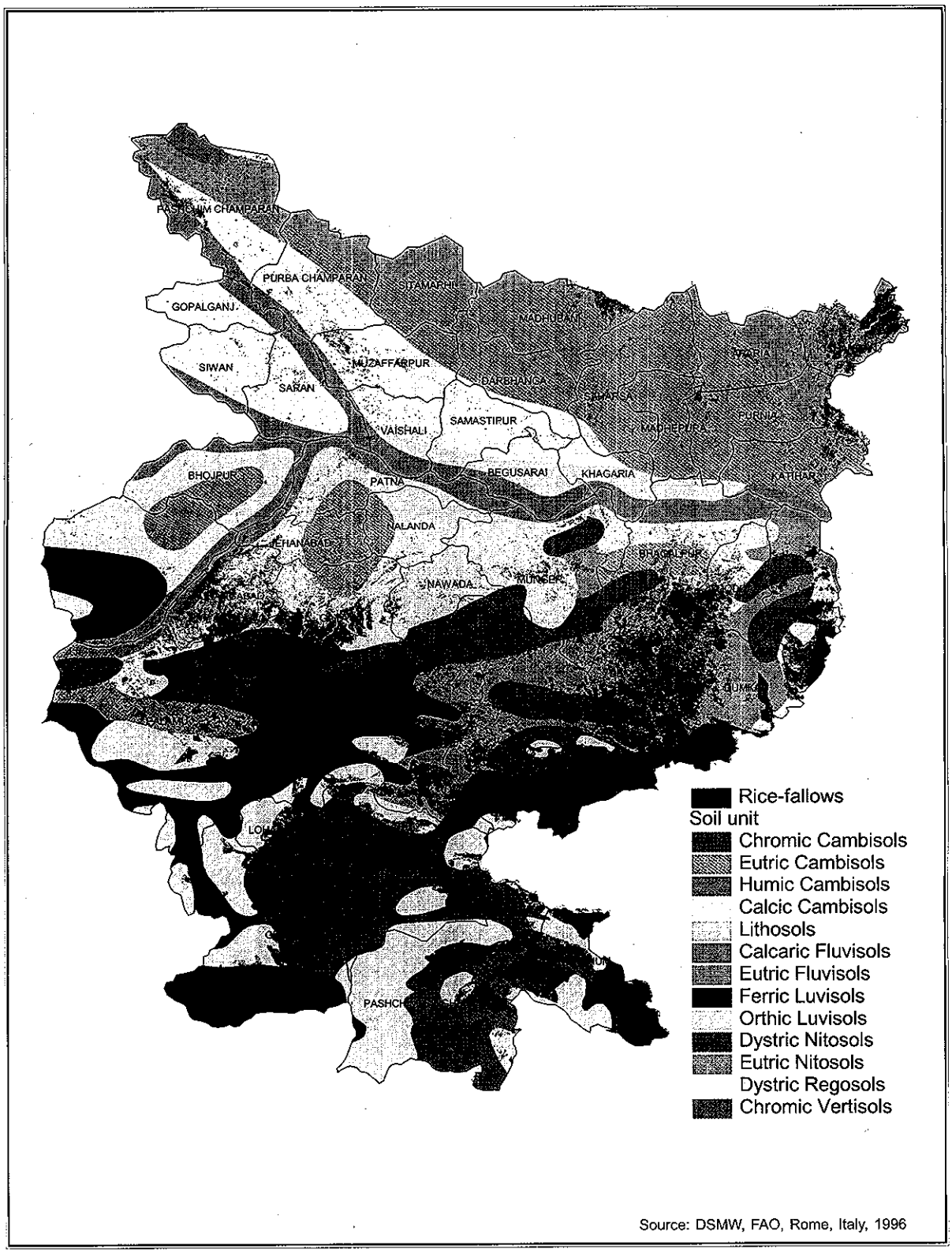


Fig. 5.2.47. Soils of Bihar, India

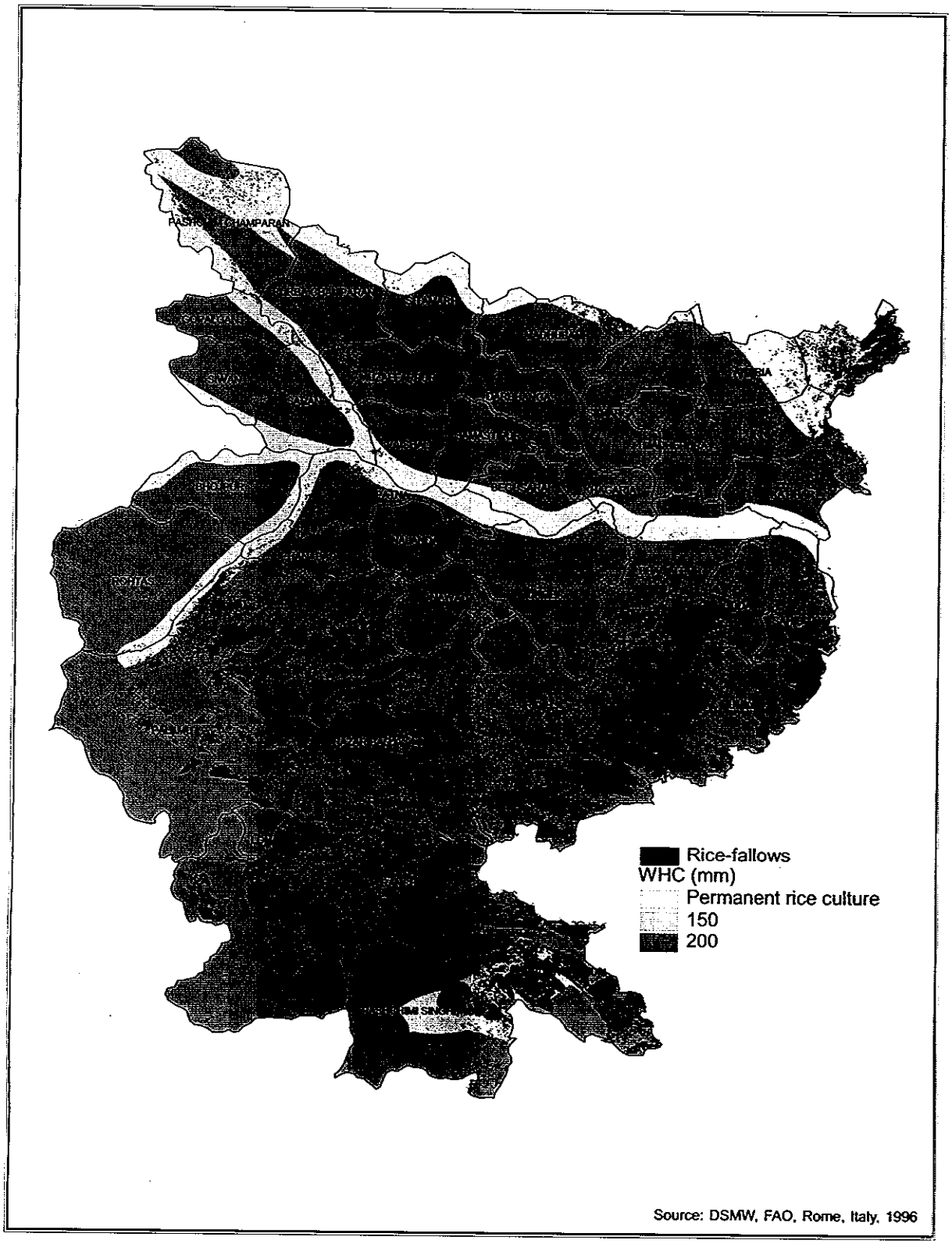


Fig. 5.2.48. Available soil water-holding capacity (WHC) in Bihar, India

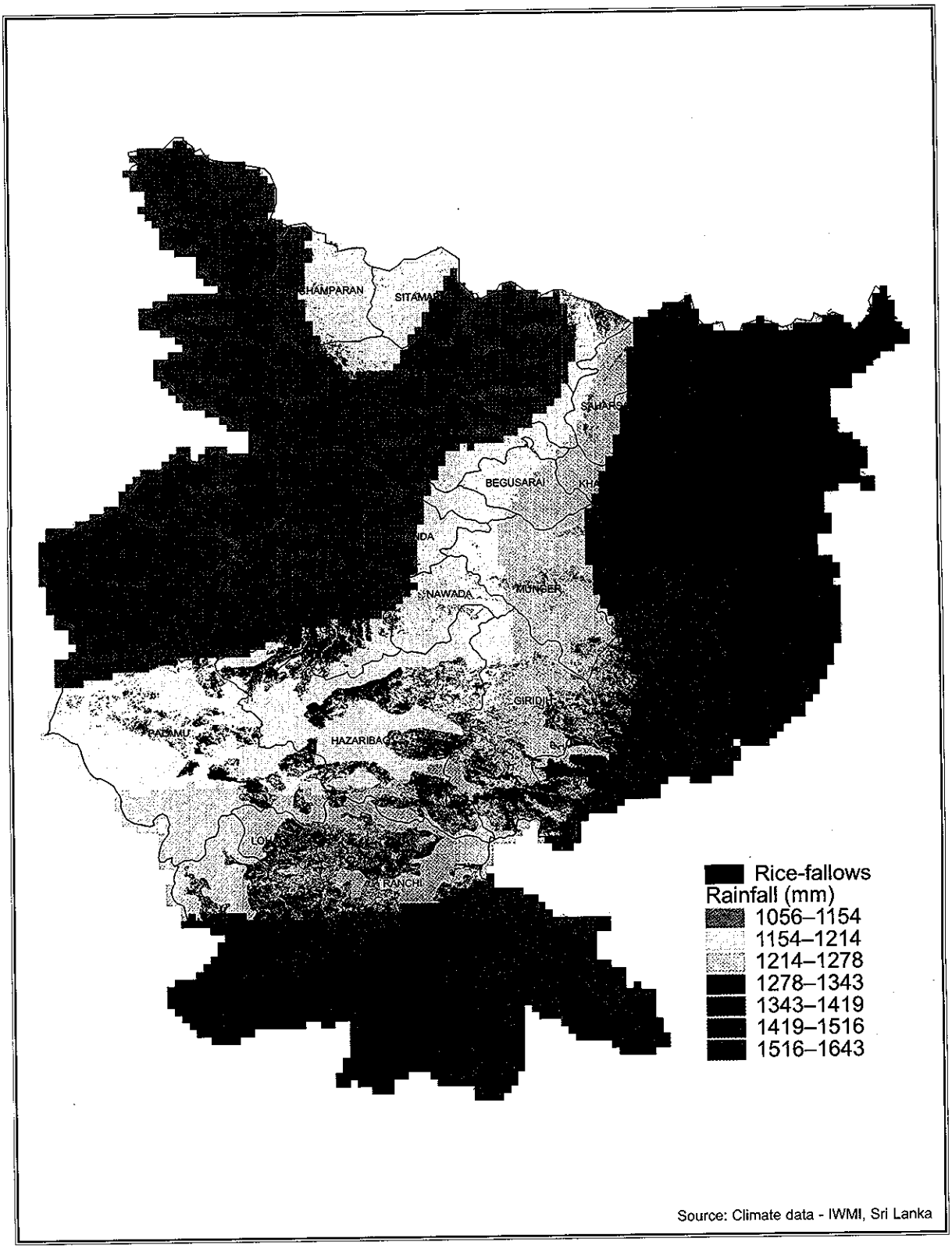


Fig. 5.2.49. Annual rainfall in Bihar, India

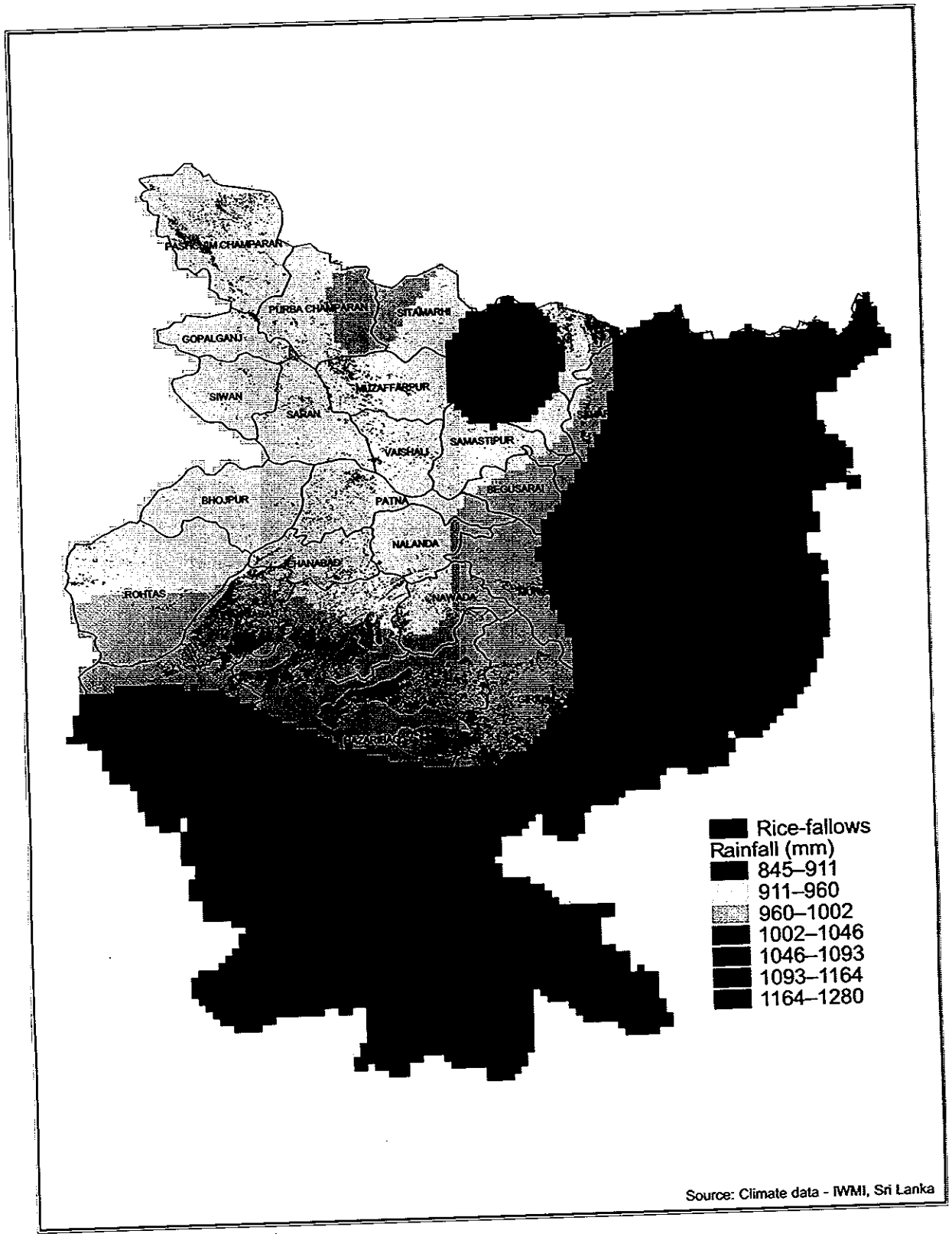


Fig. 5.2.50. Rainfall during kharif (June–September) in Bihar, India

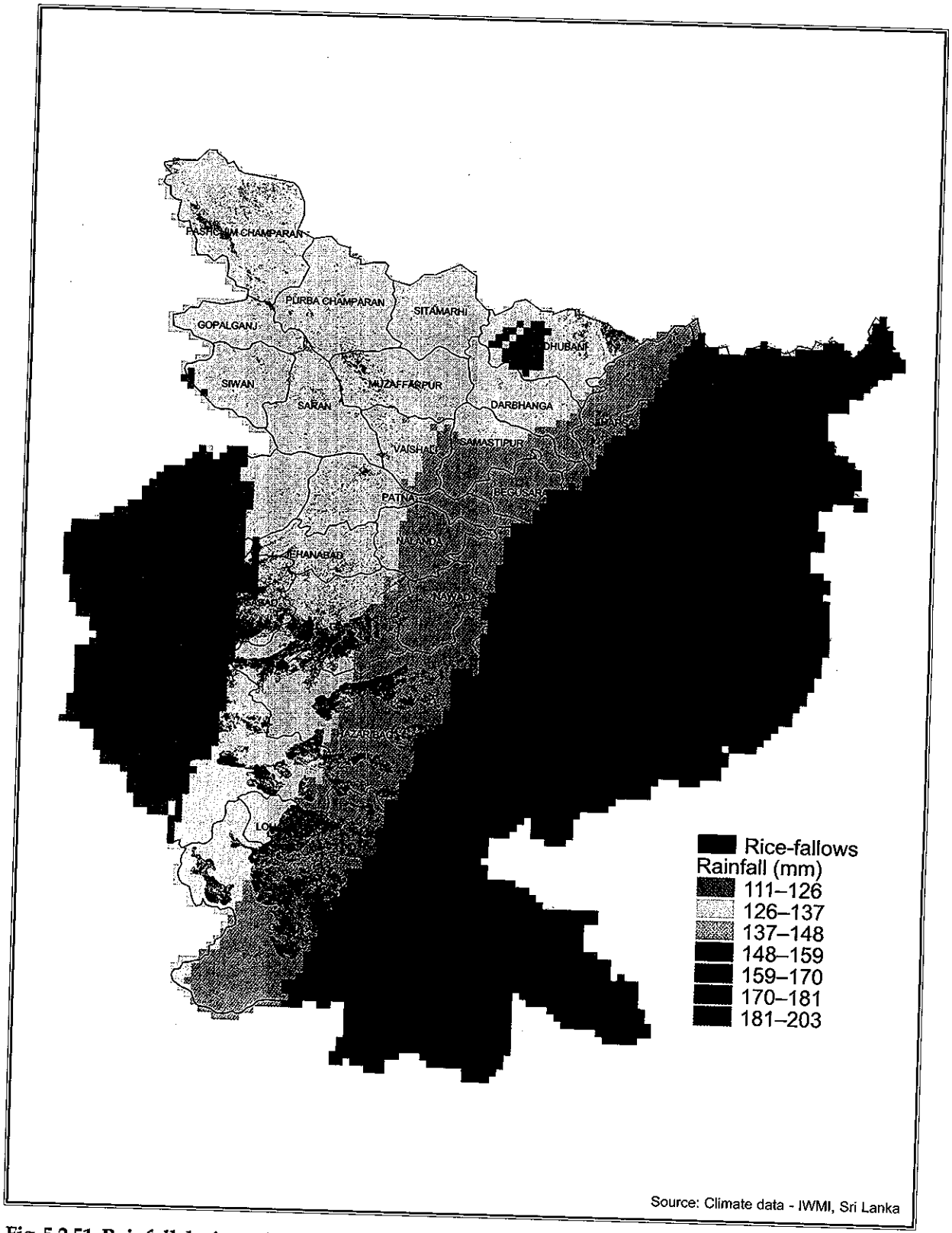


Fig. 5.2.51. Rainfall during rabi (October–March) in Bihar, India

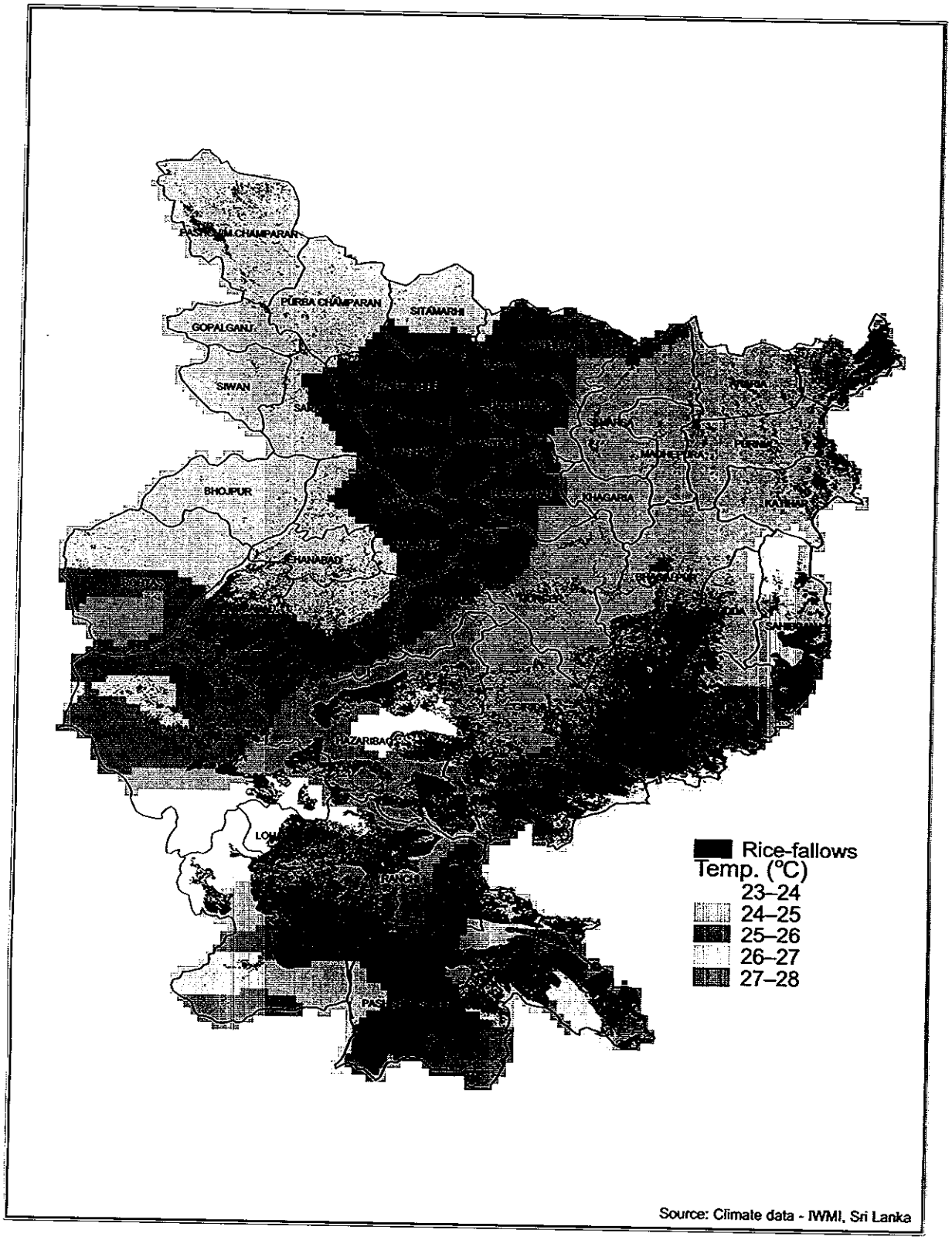


Fig. 5.2.52. Annual mean maximum temperature in Bihar, India

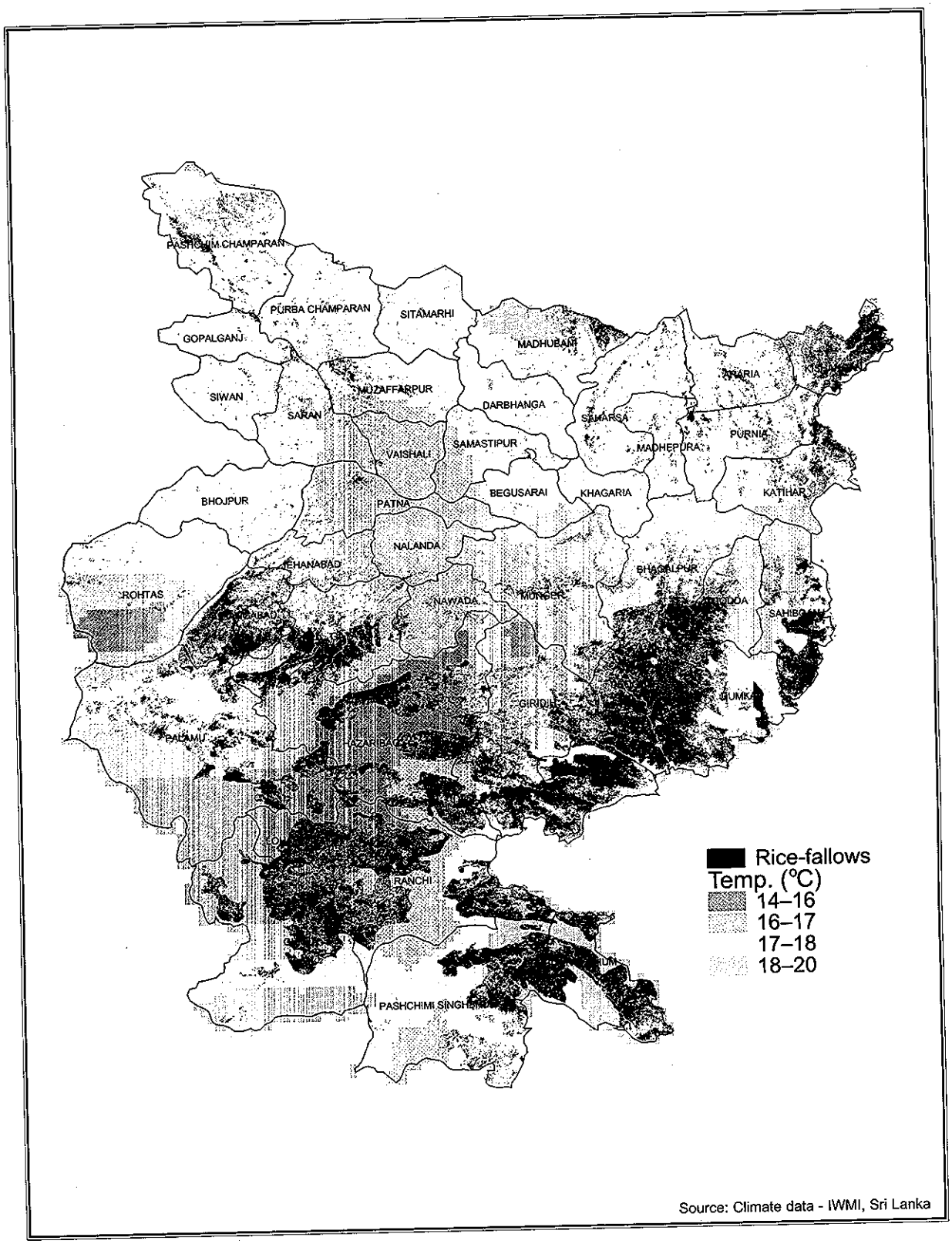


Fig. 5.2.53. Annual mean minimum temperature in Bihar, India

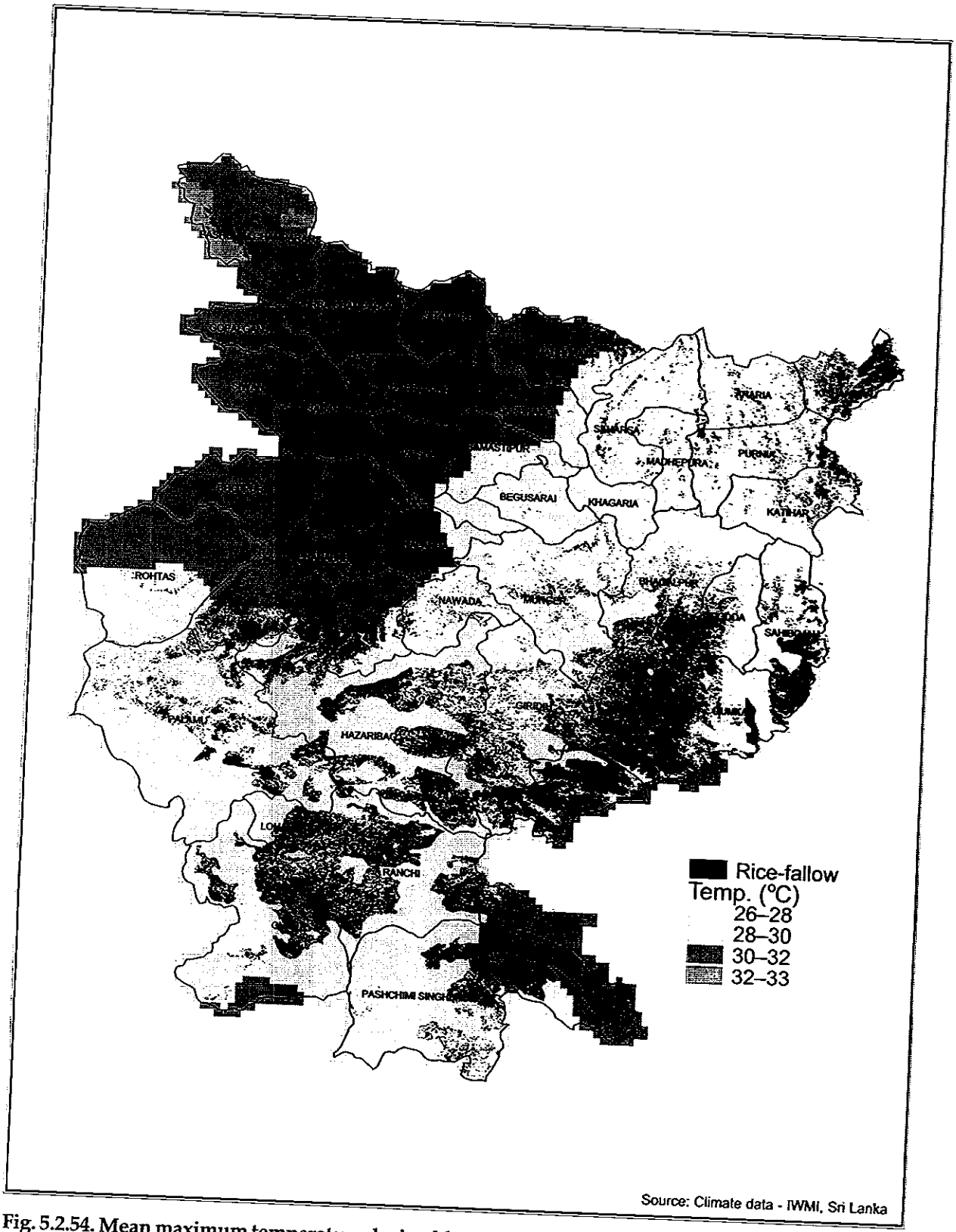
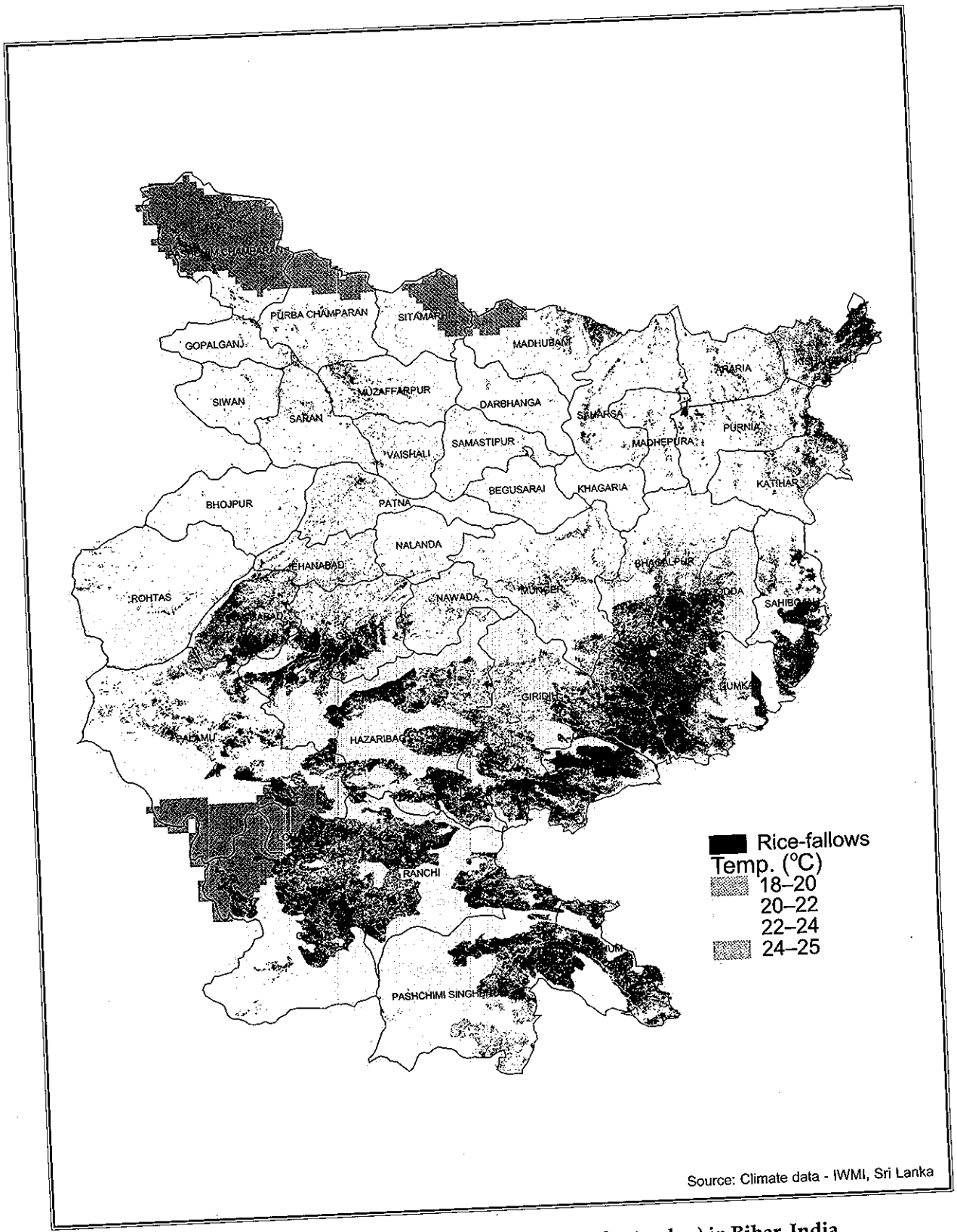


Fig. 5.2.54. Mean maximum temperature during kharif (June–September) in Bihar, India



Source: Climate data - IWMI, Sri Lanka

Fig. 5.2.55. Mean minimum temperature during kharif (June–September) in Bihar, India

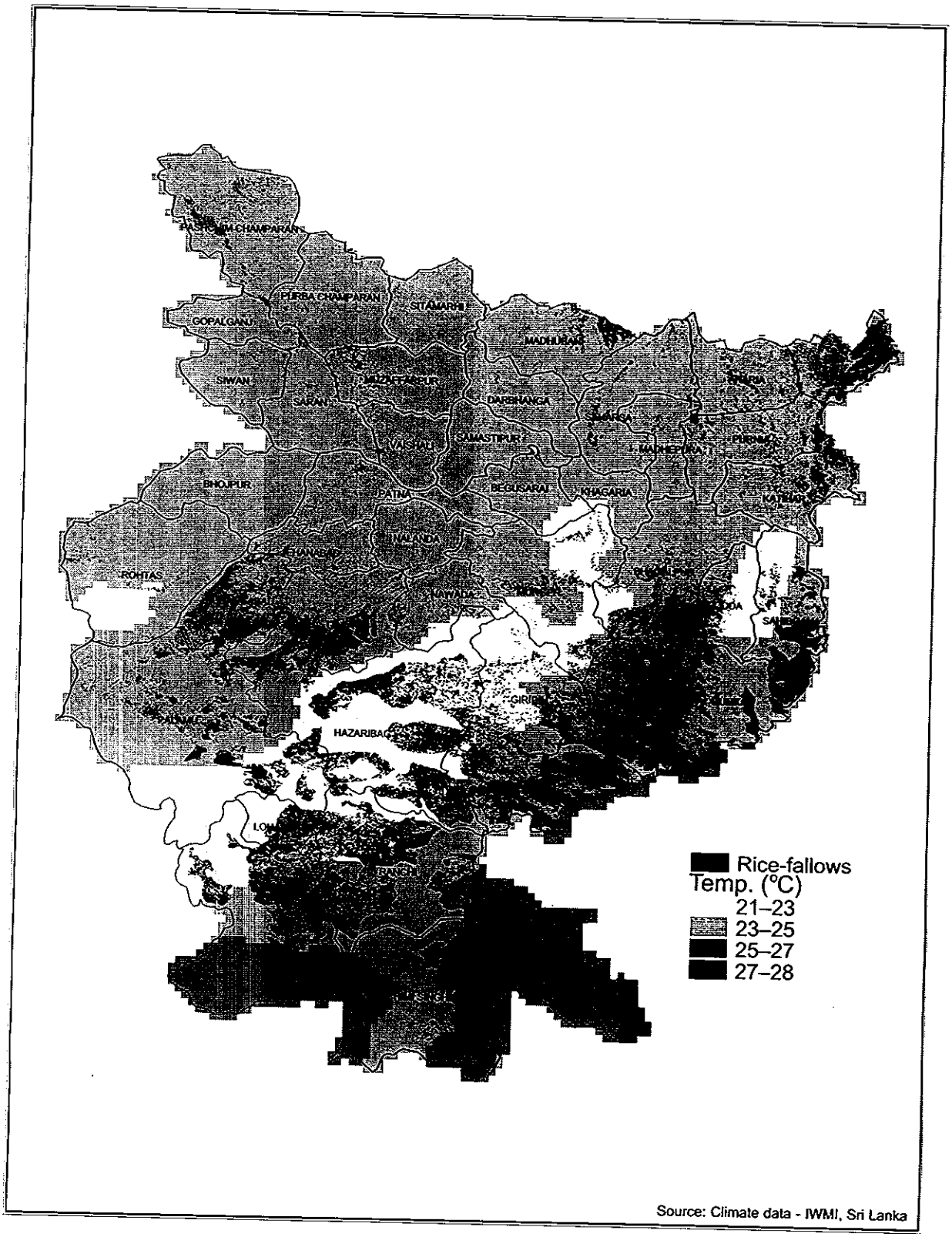


Fig. 5.2.56. Mean maximum temperature during rabi (October-March) in Bihar, India

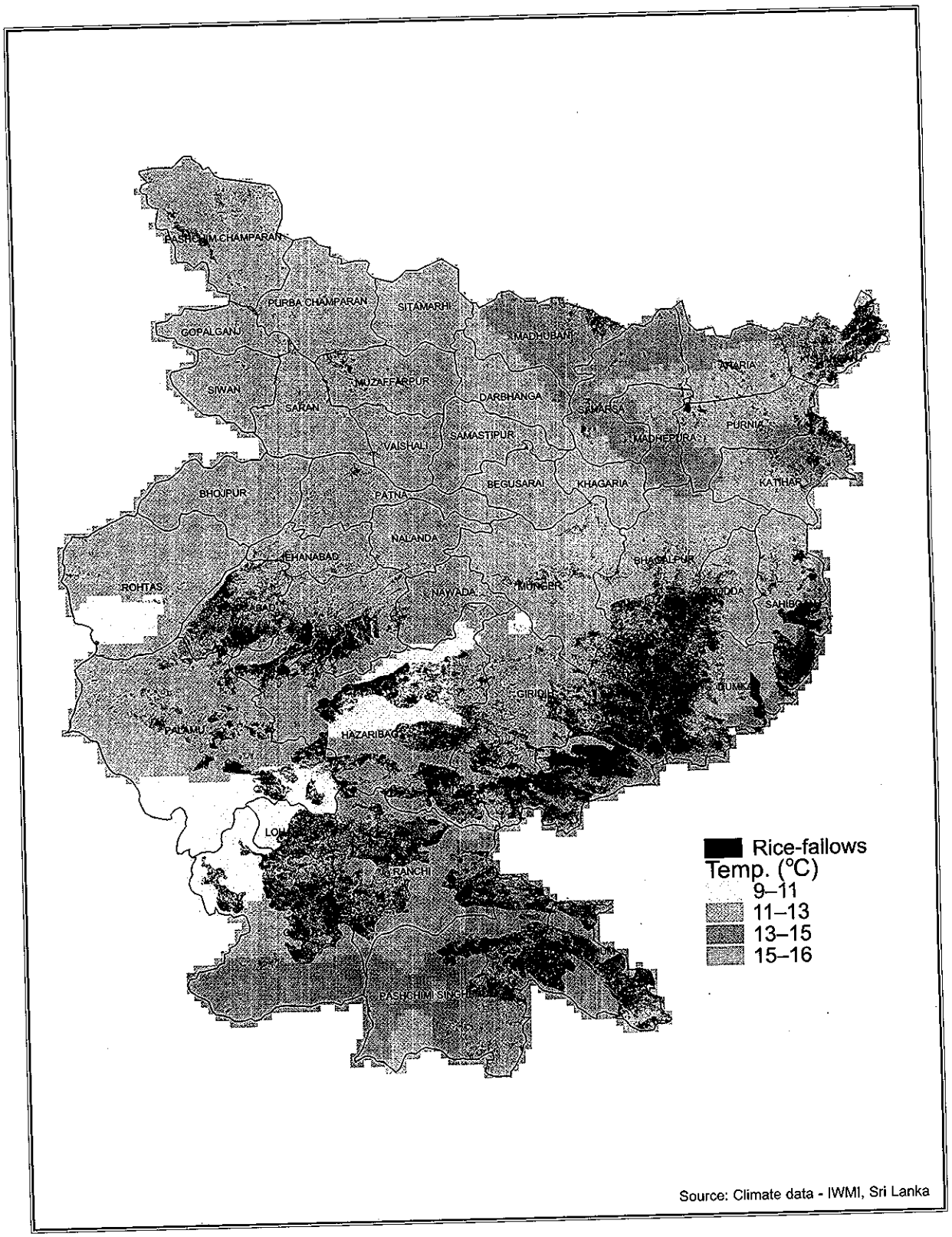


Fig. 5.2.57. Mean minimum temperature during rabi (October–March) in Bihar, India

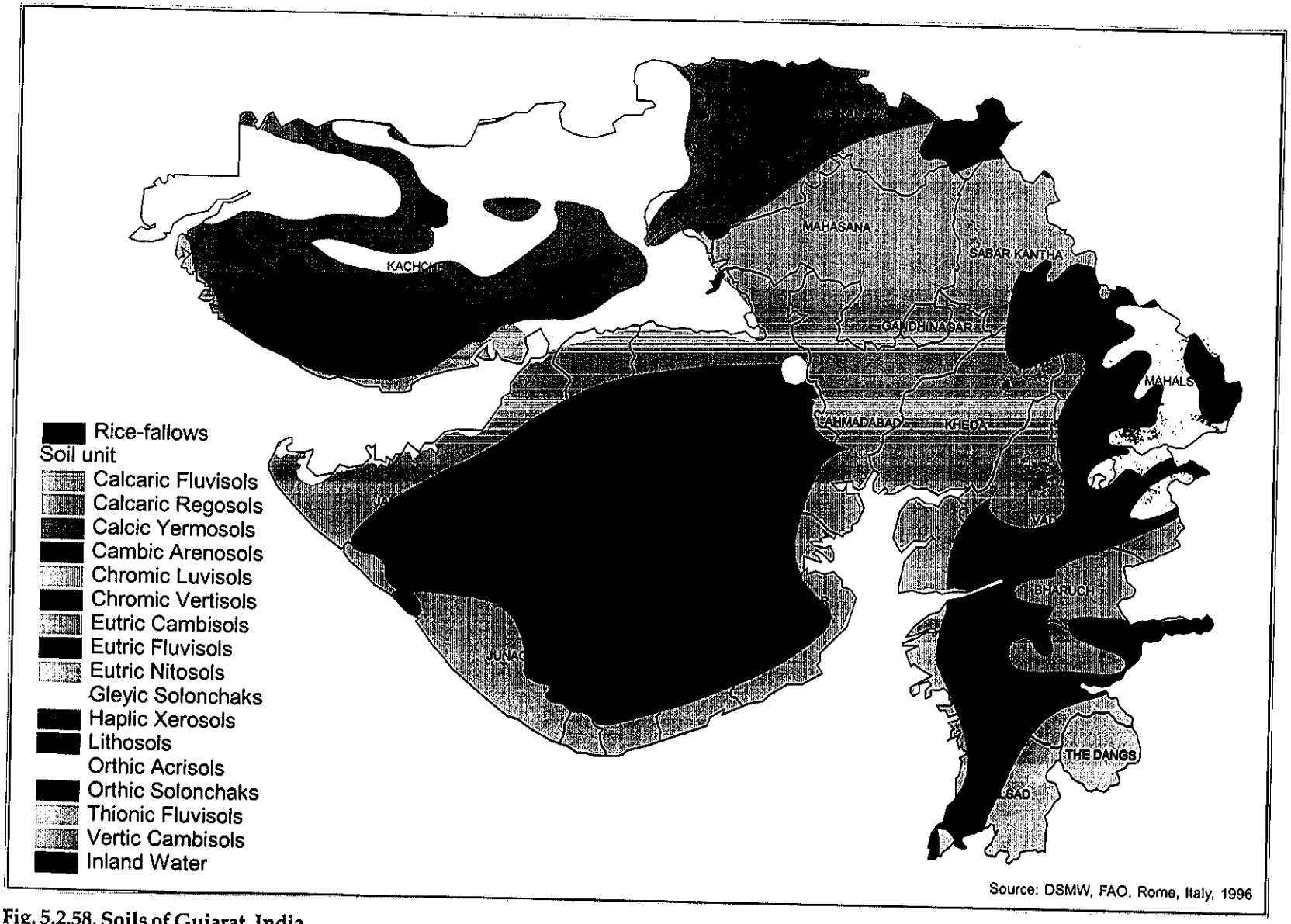


Fig. 5.2.58. Soils of Gujarat, India

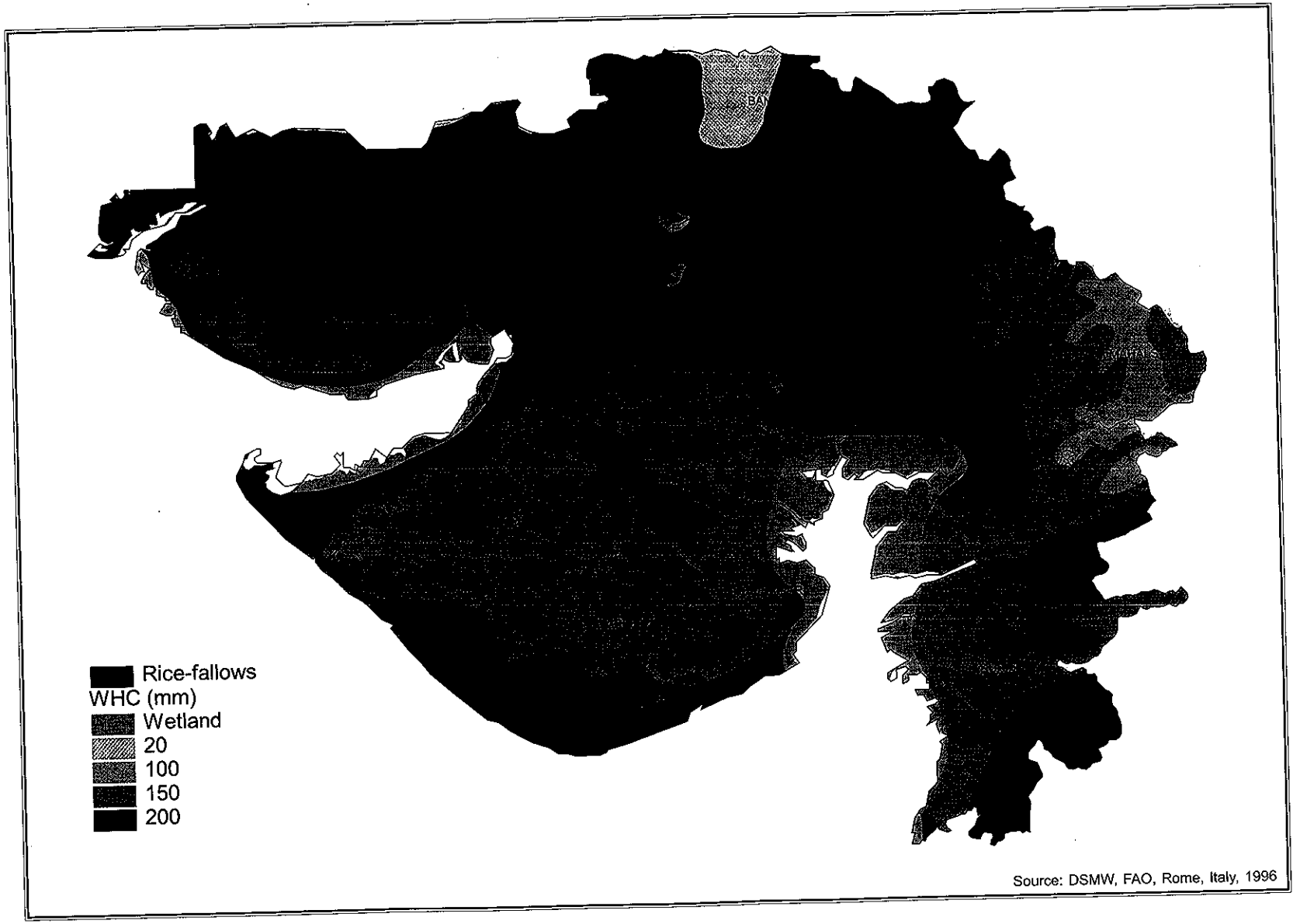


Fig. 5.2.59. Available soil water-holding capacity (WHC) in Gujarat, India

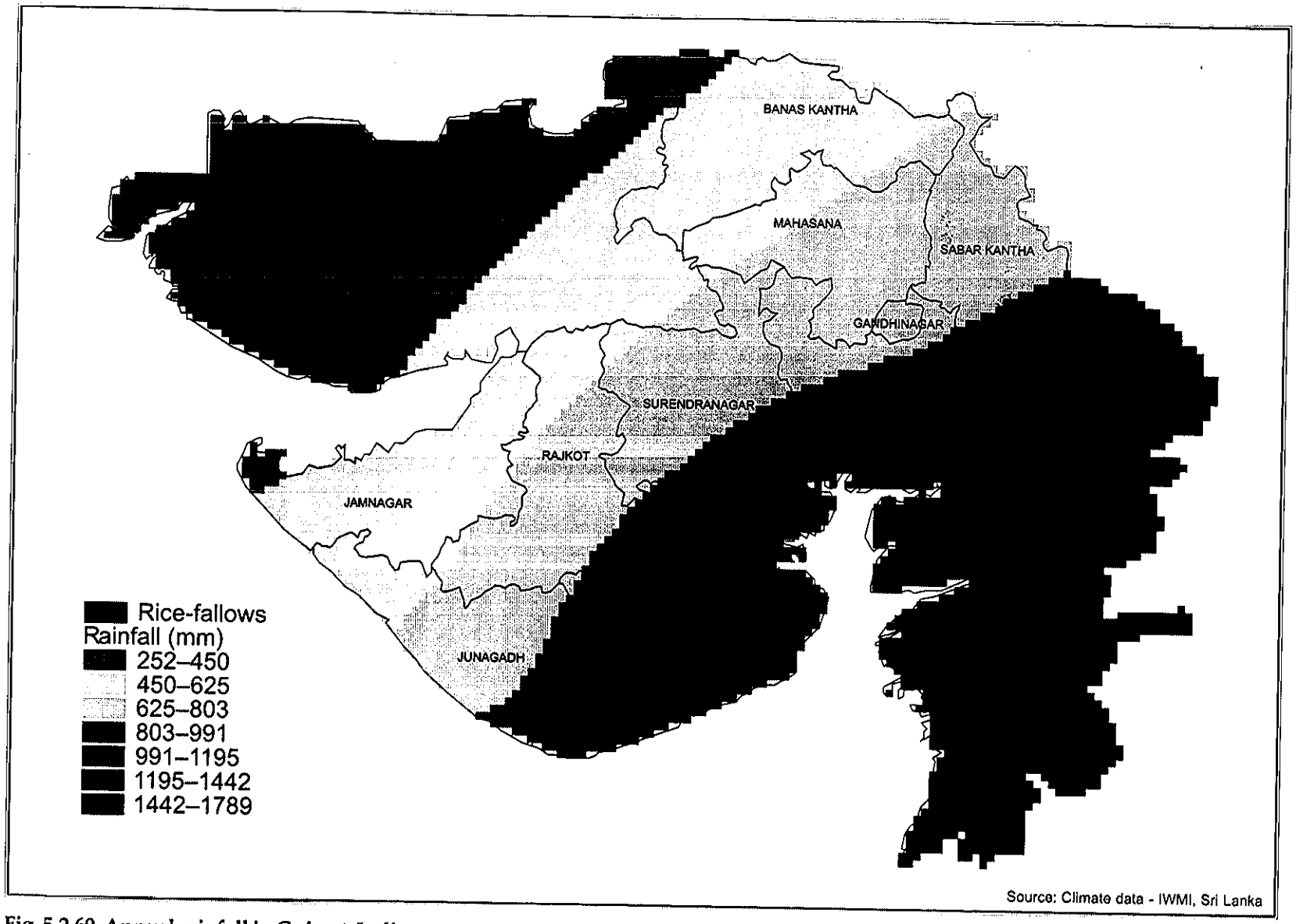


Fig. 5.2.60. Annual rainfall in Gujarat, India

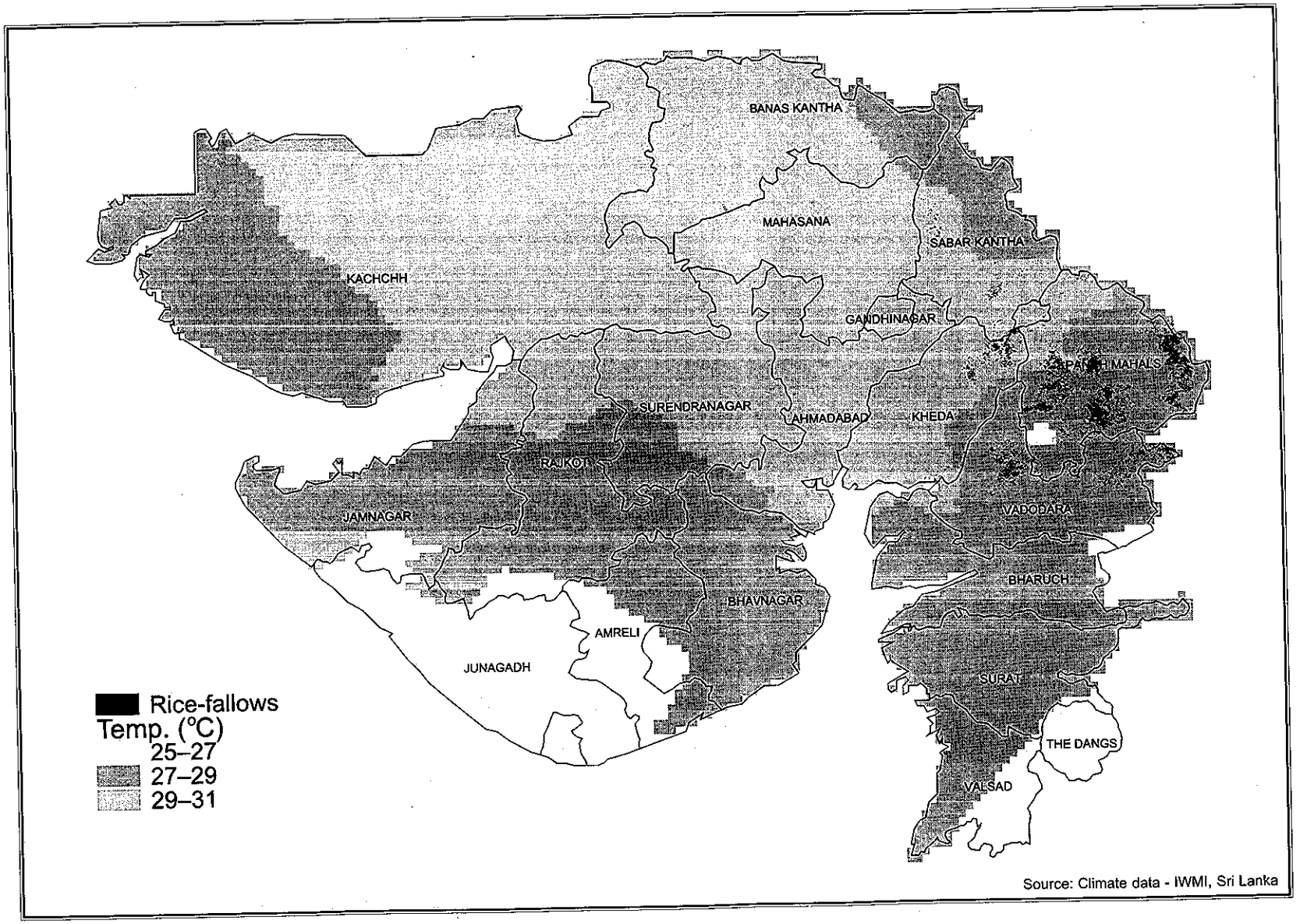


Fig. 5.2.61. Annual mean maximum temperature in Gujarat, India

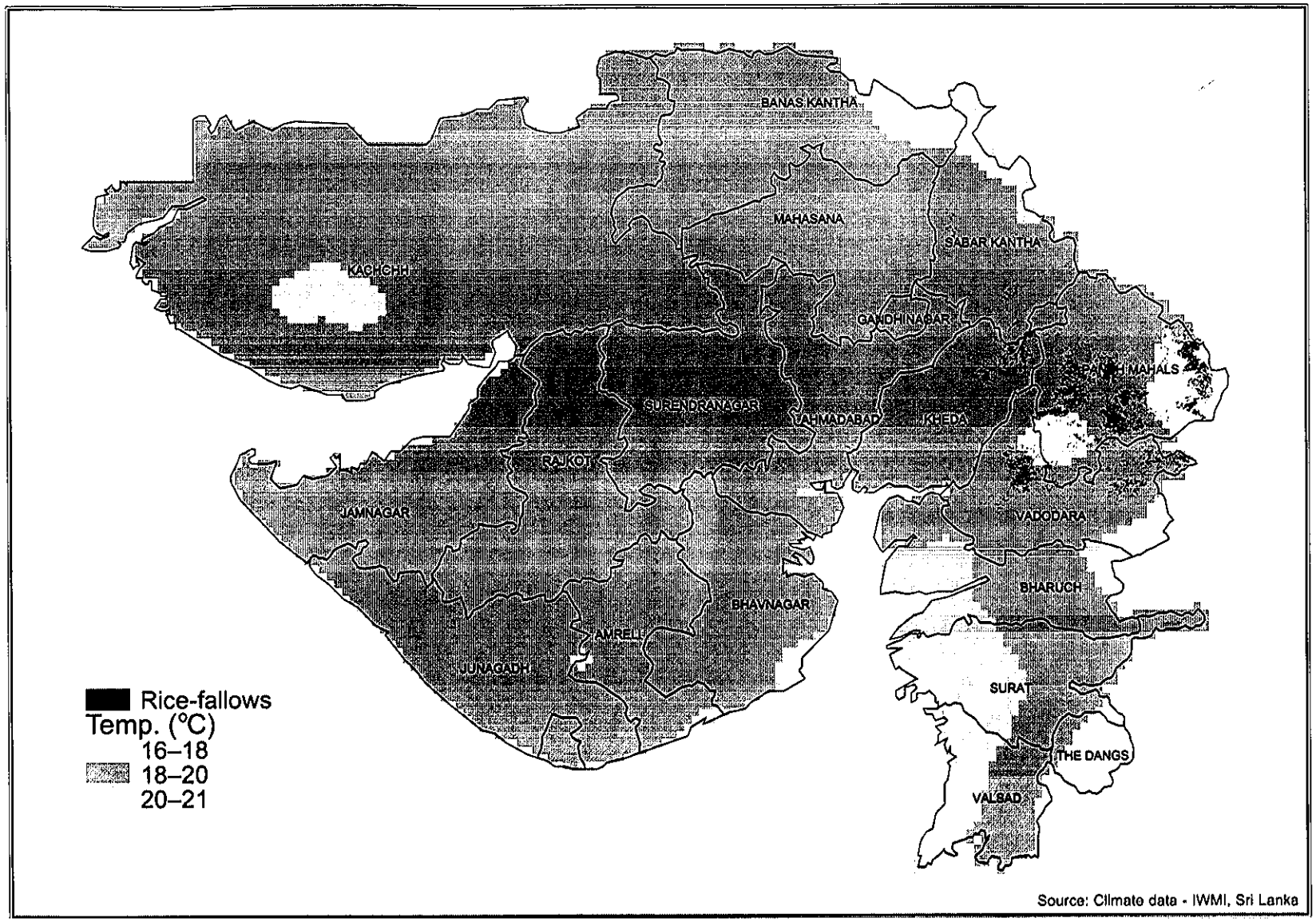


Fig. 5.2.62. Annual mean minimum temperature in Gujarat, India

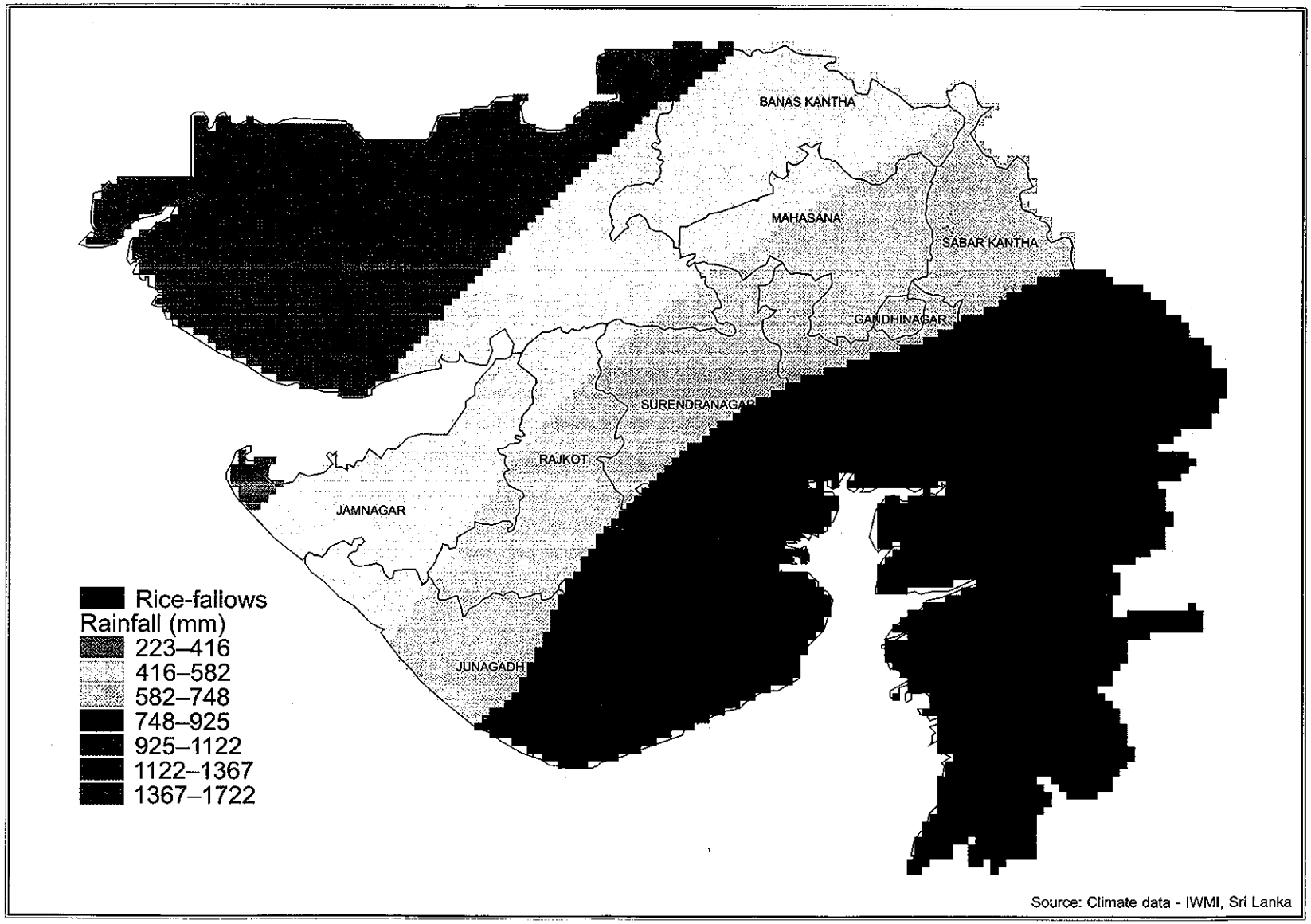


Fig. 5.2.63. Rainfall during kharif (June–September) in Gujarat, India

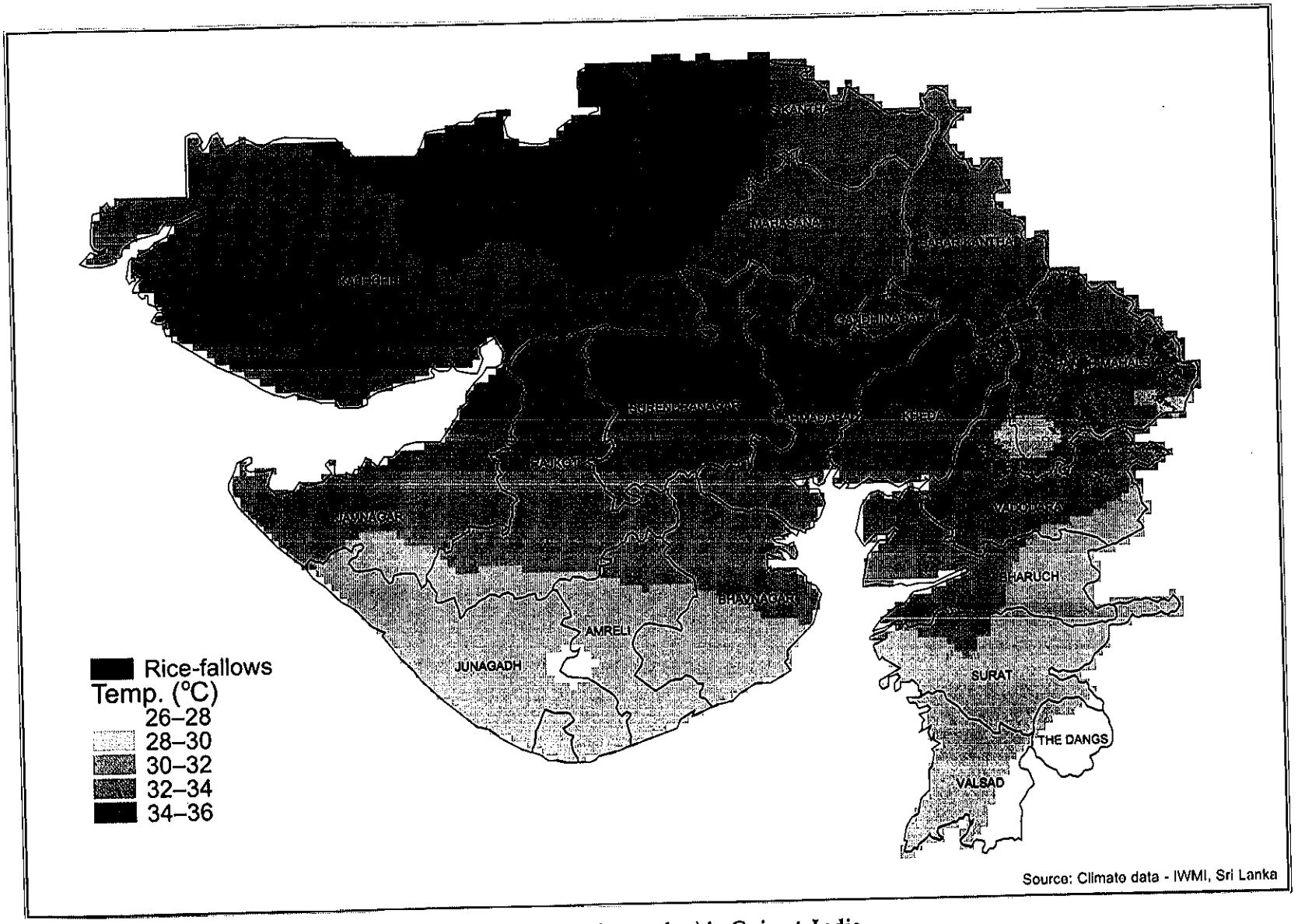


Fig. 5.2.64. Mean maximum temperature during kharif (June–September) in Gujarat, India

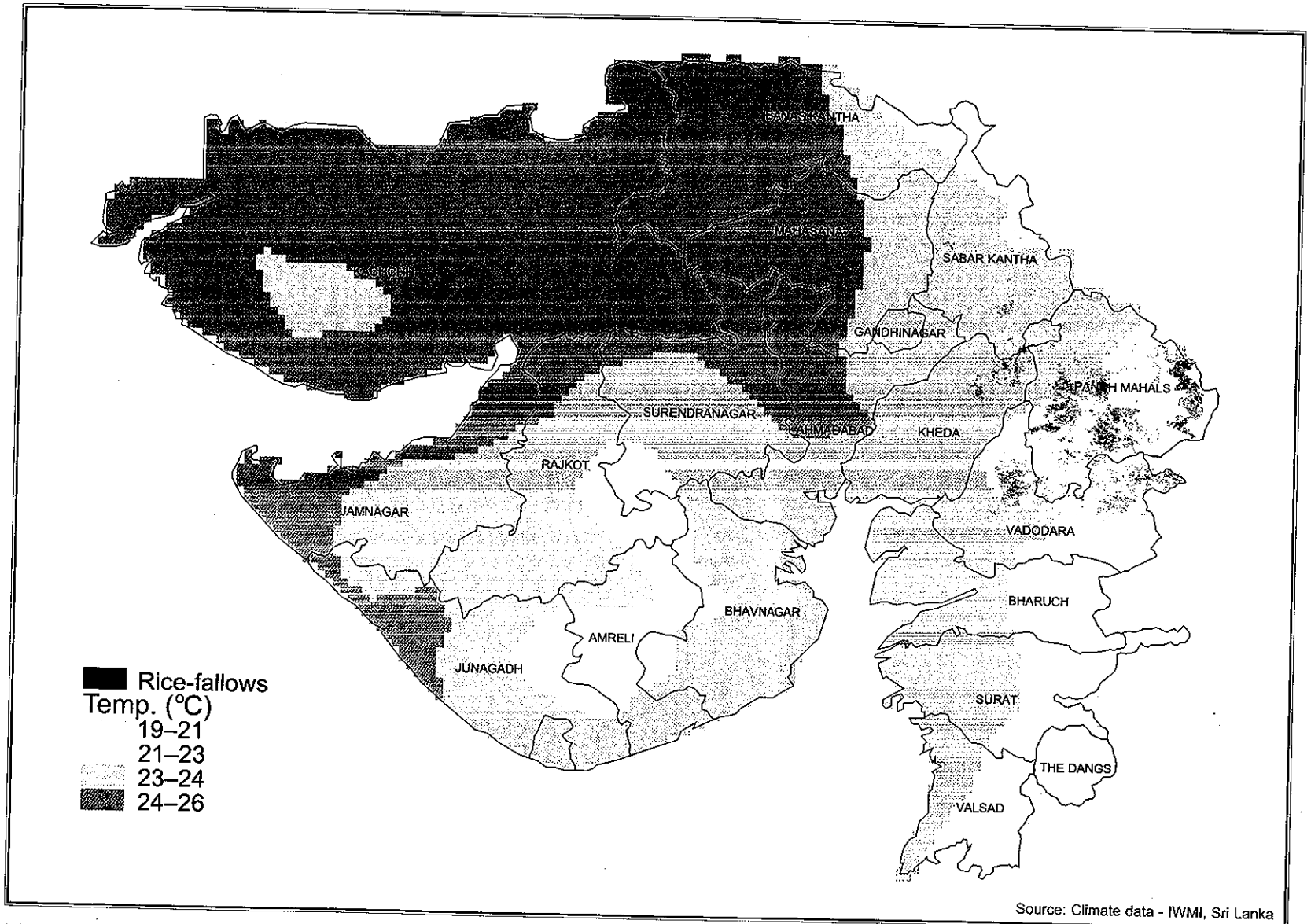


Fig. 5.2.65. Mean minimum temperature during kharif (June–September) in Gujarat, India

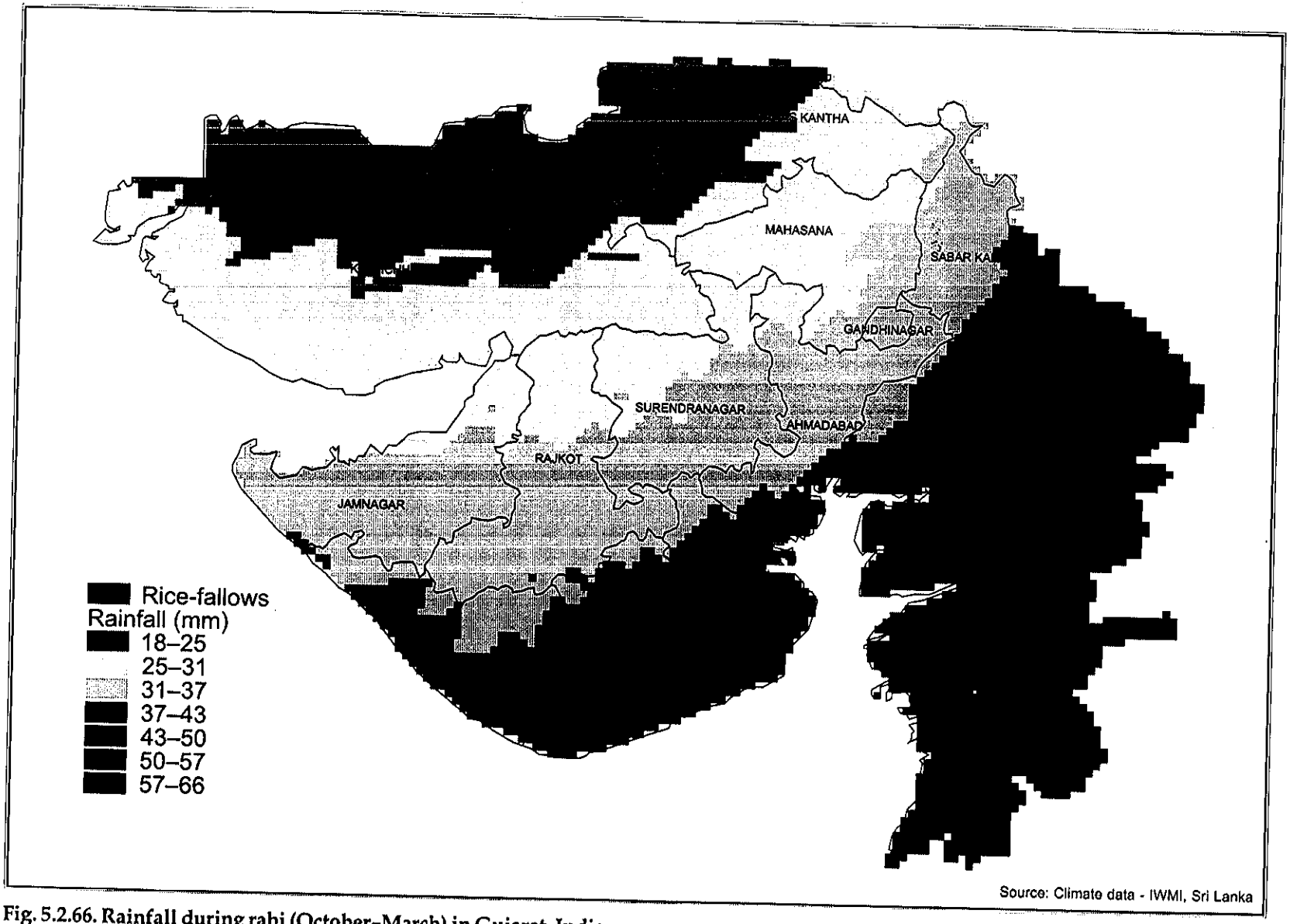


Fig. 5.2.66. Rainfall during rabi (October–March) in Gujarat, India

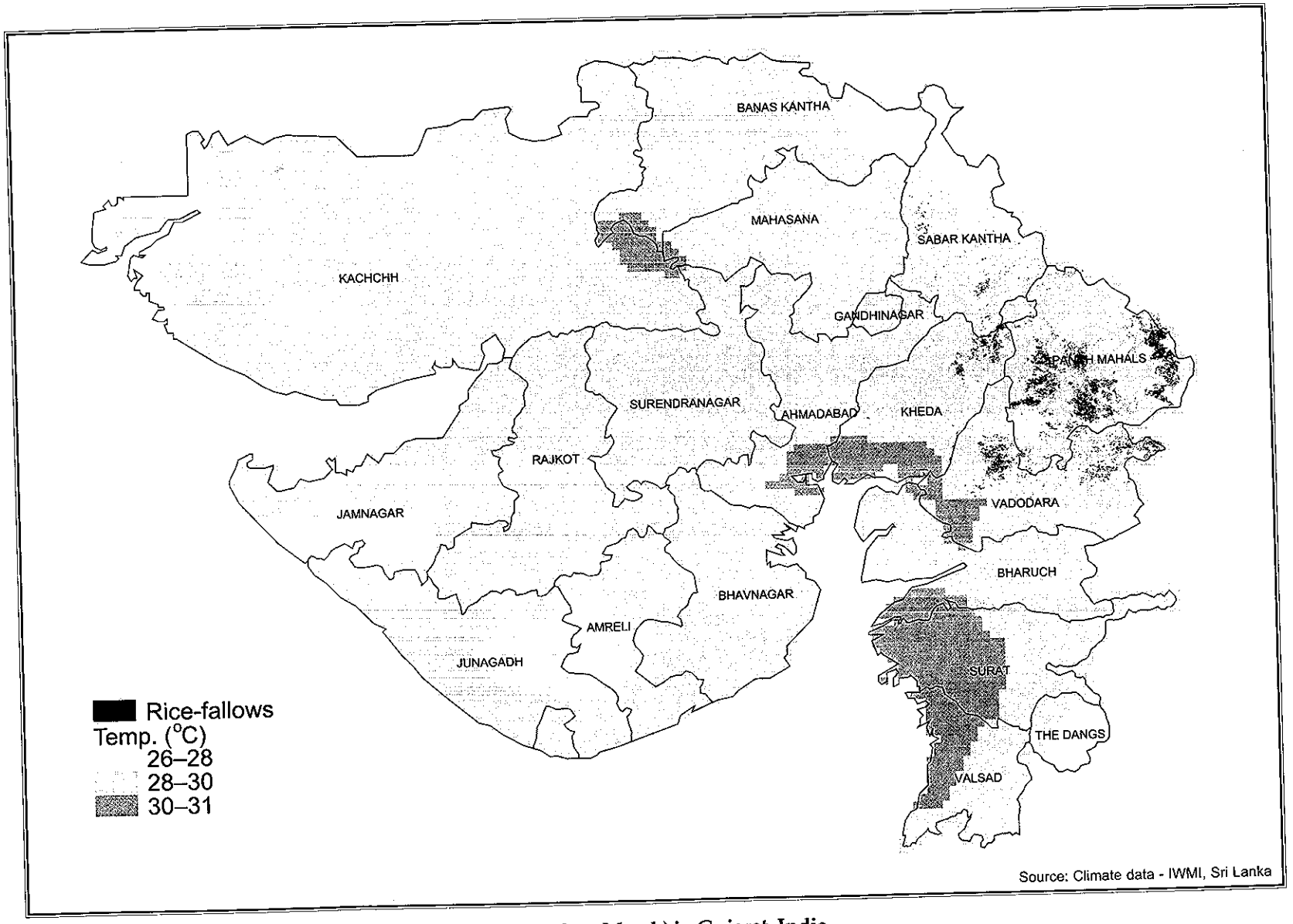


Fig. 5.2.67. Mean maximum temperature during rabi (October–March) in Gujarat, India

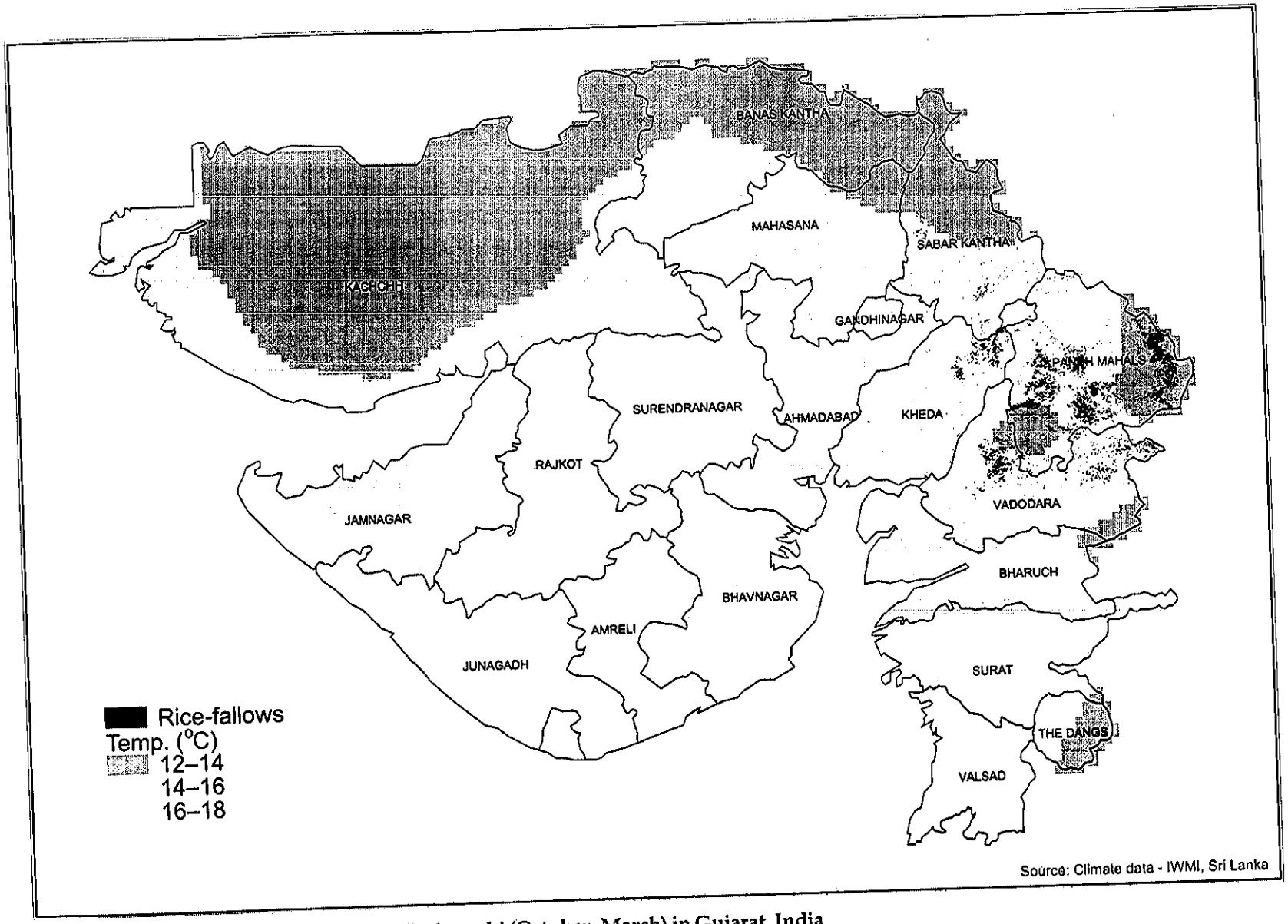


Fig. 5.2.68. Mean minimum temperature during rabi (October–March) in Gujarat, India

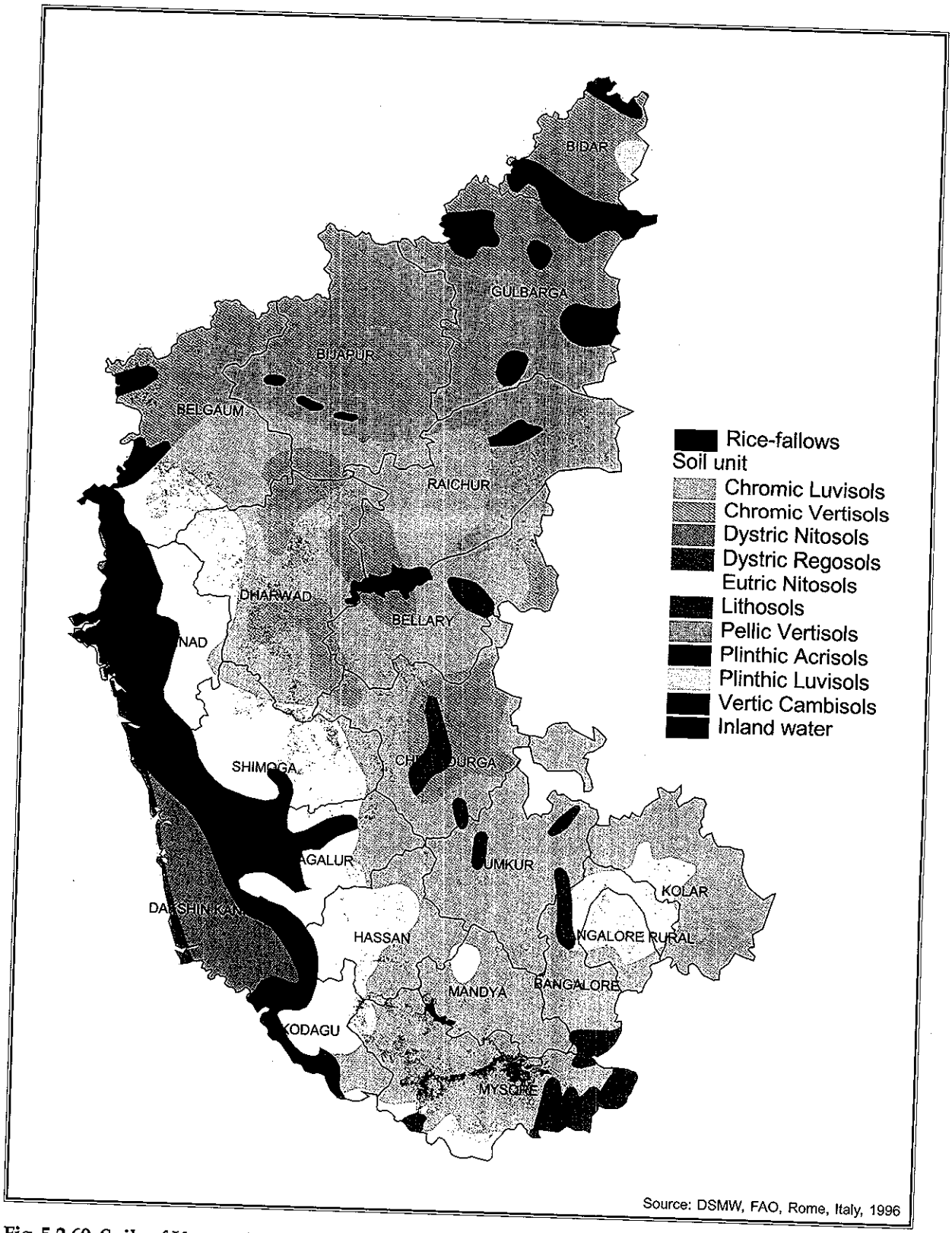


Fig. 5.2.69. Soils of Karnataka, India

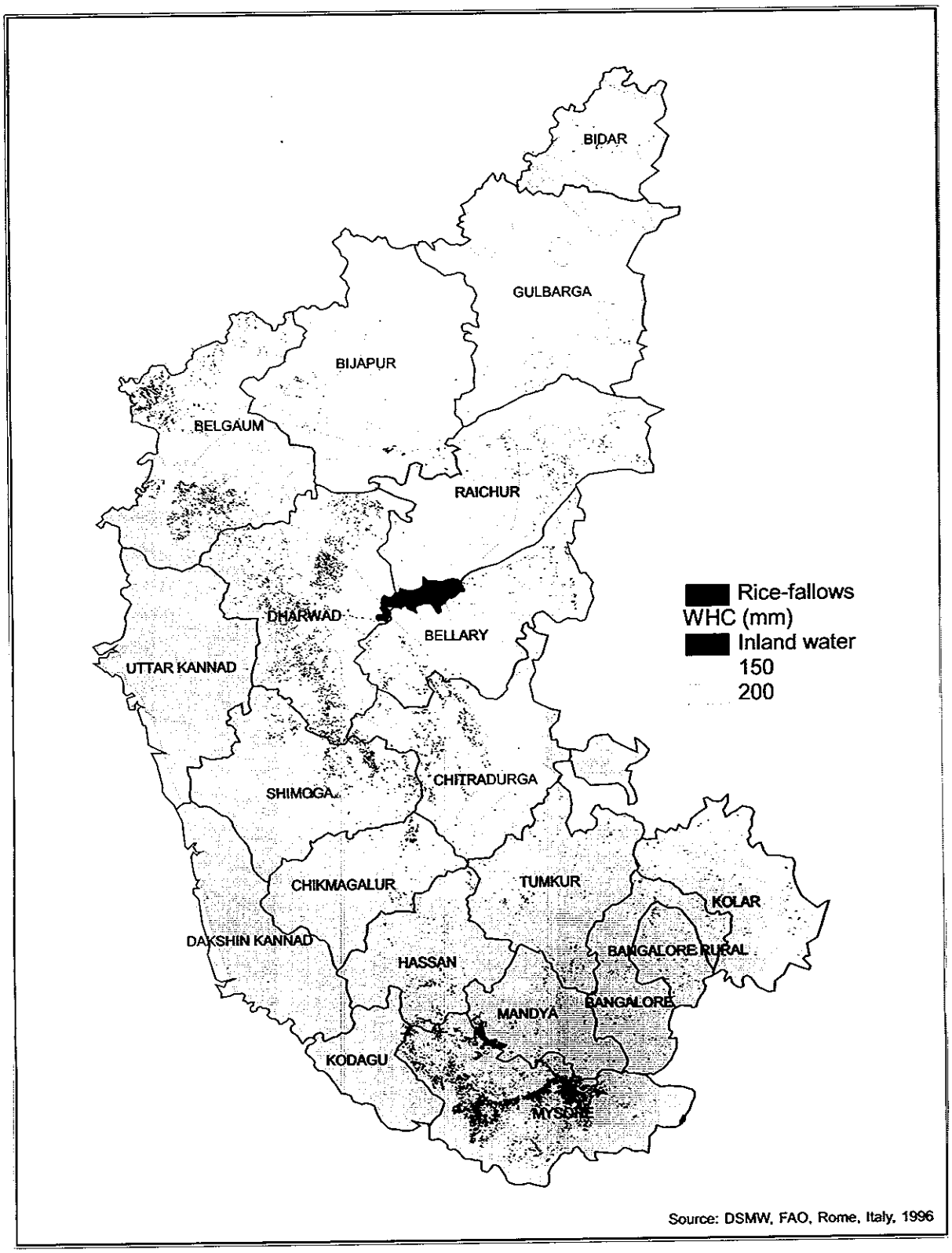


Fig. 5.2.70. Available soil water-holding capacity (WHC) in Karnataka, India

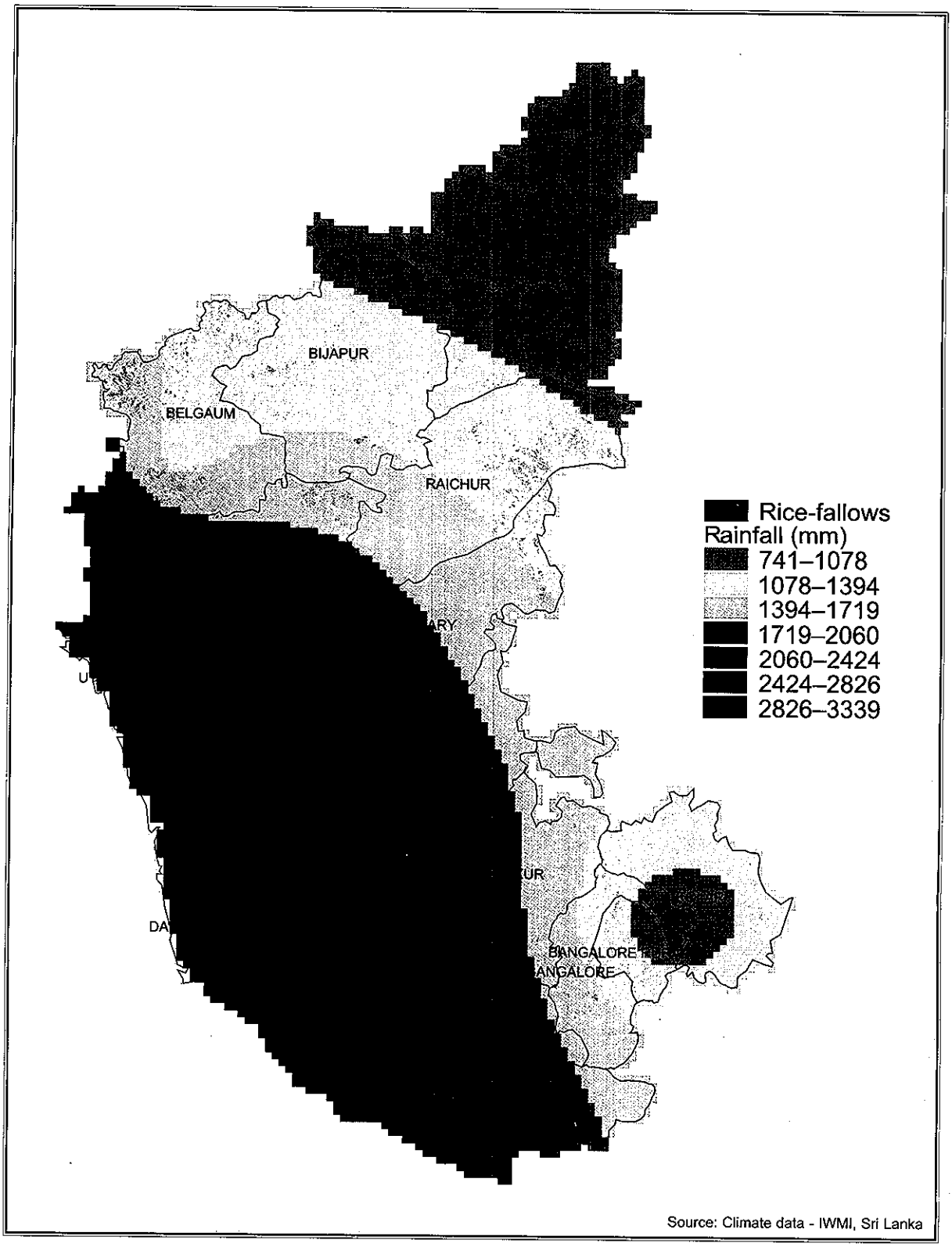


Fig. 5.2.71. Annual rainfall in Karnataka, India

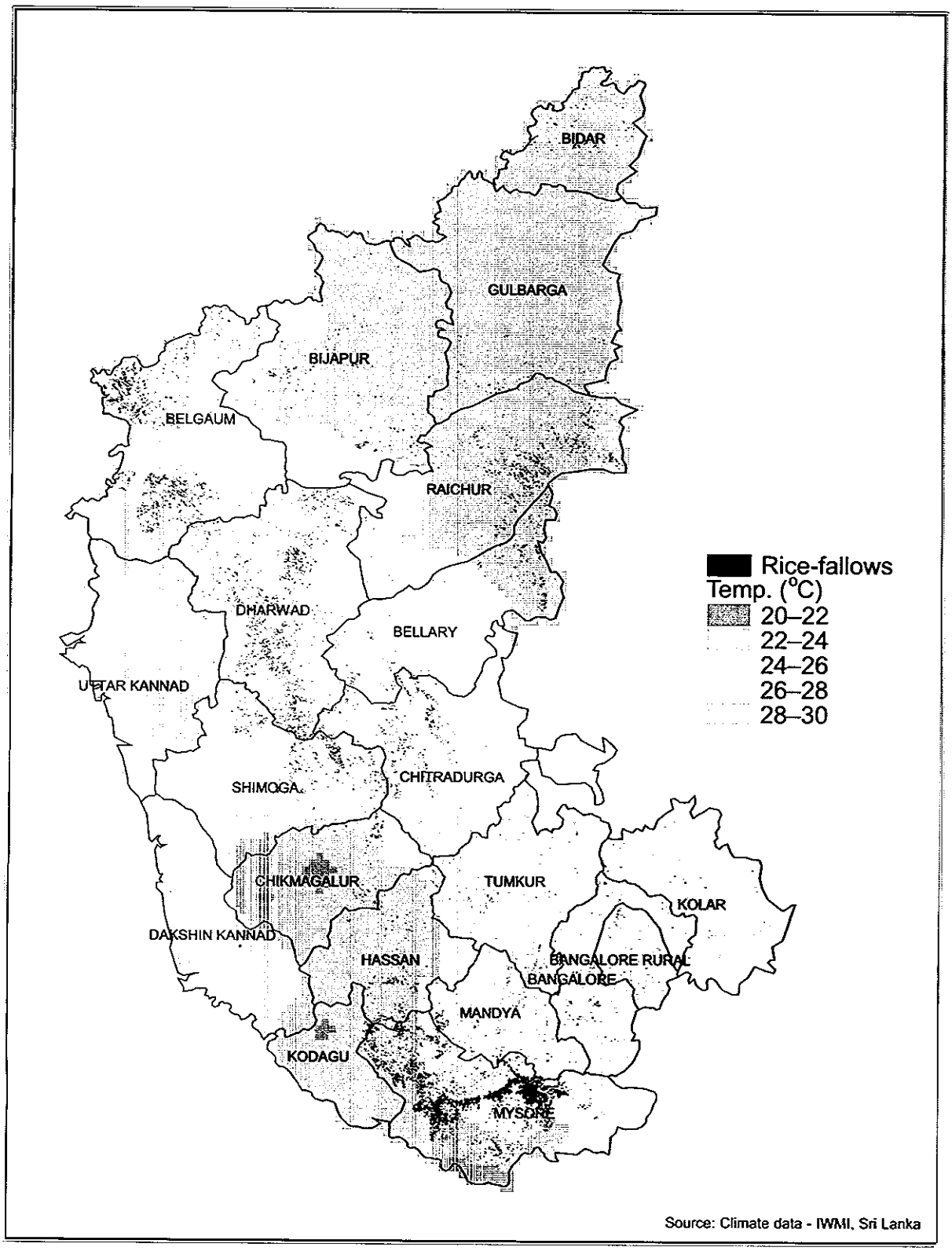


Fig. 5.2.72. Annual mean maximum temperature in Karnataka, India

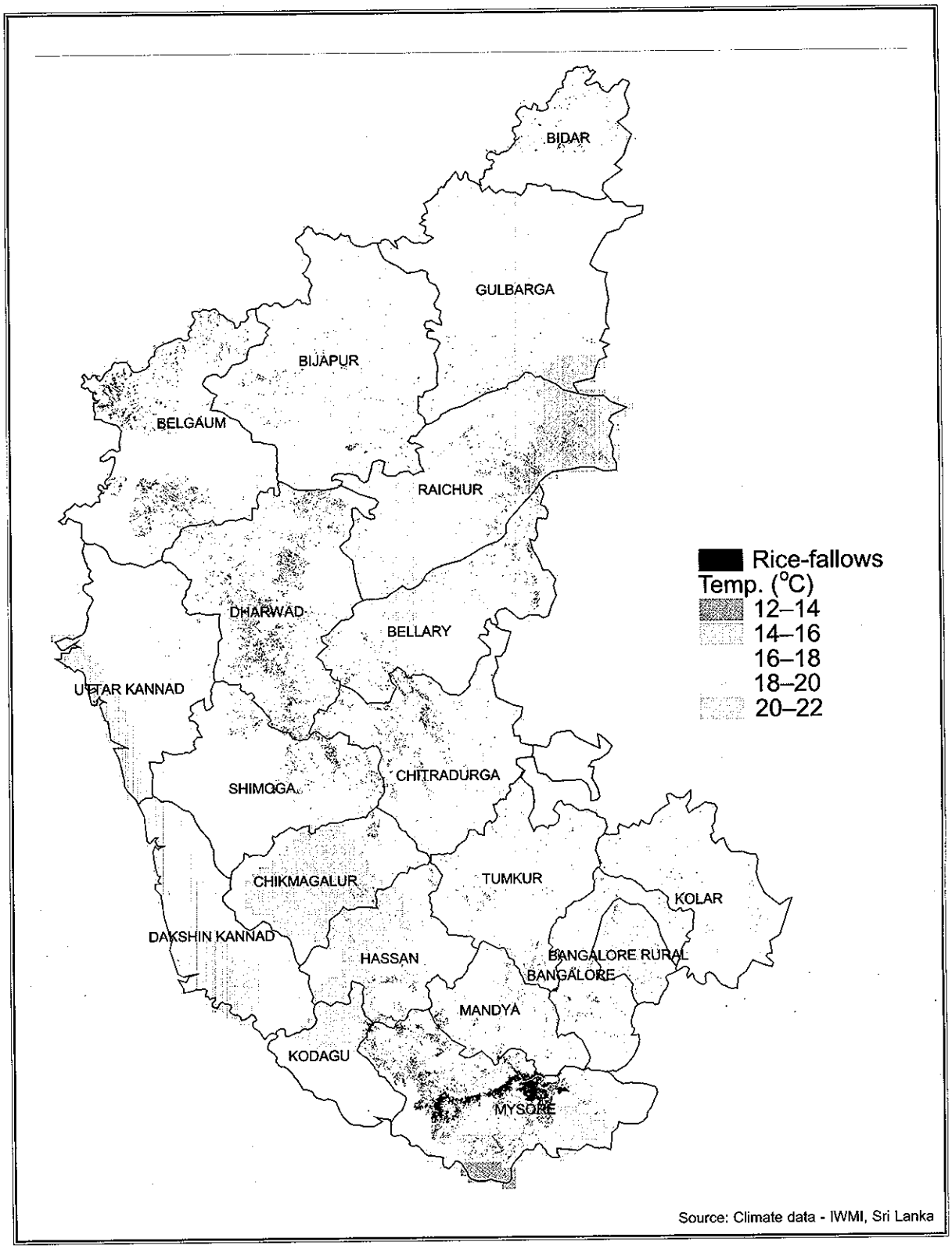


Fig. 5.2.73. Annual mean minimum temperature in Karnataka, India

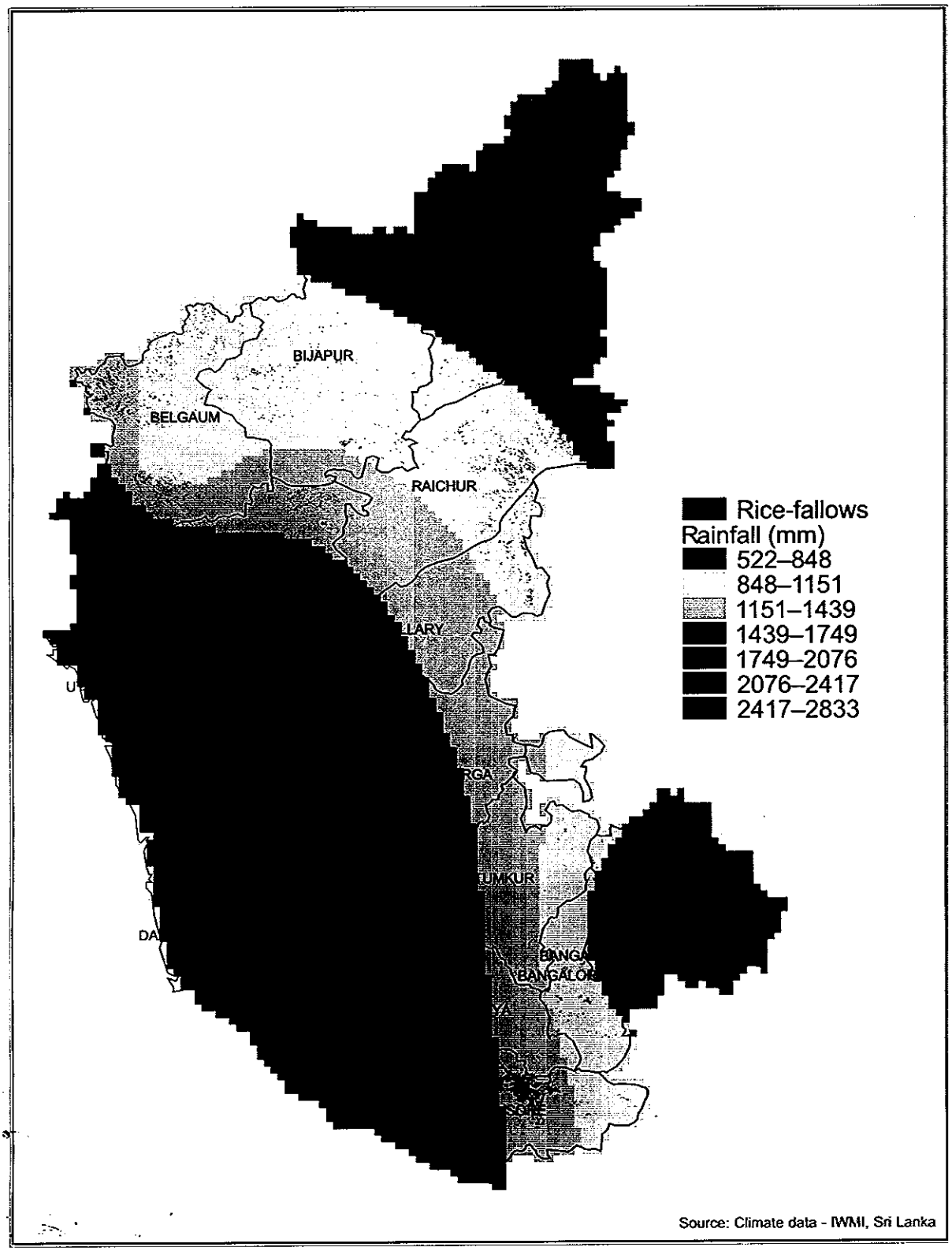


Fig. 5.2.74. Rainfall during kharif (June–September) in Karnataka, India

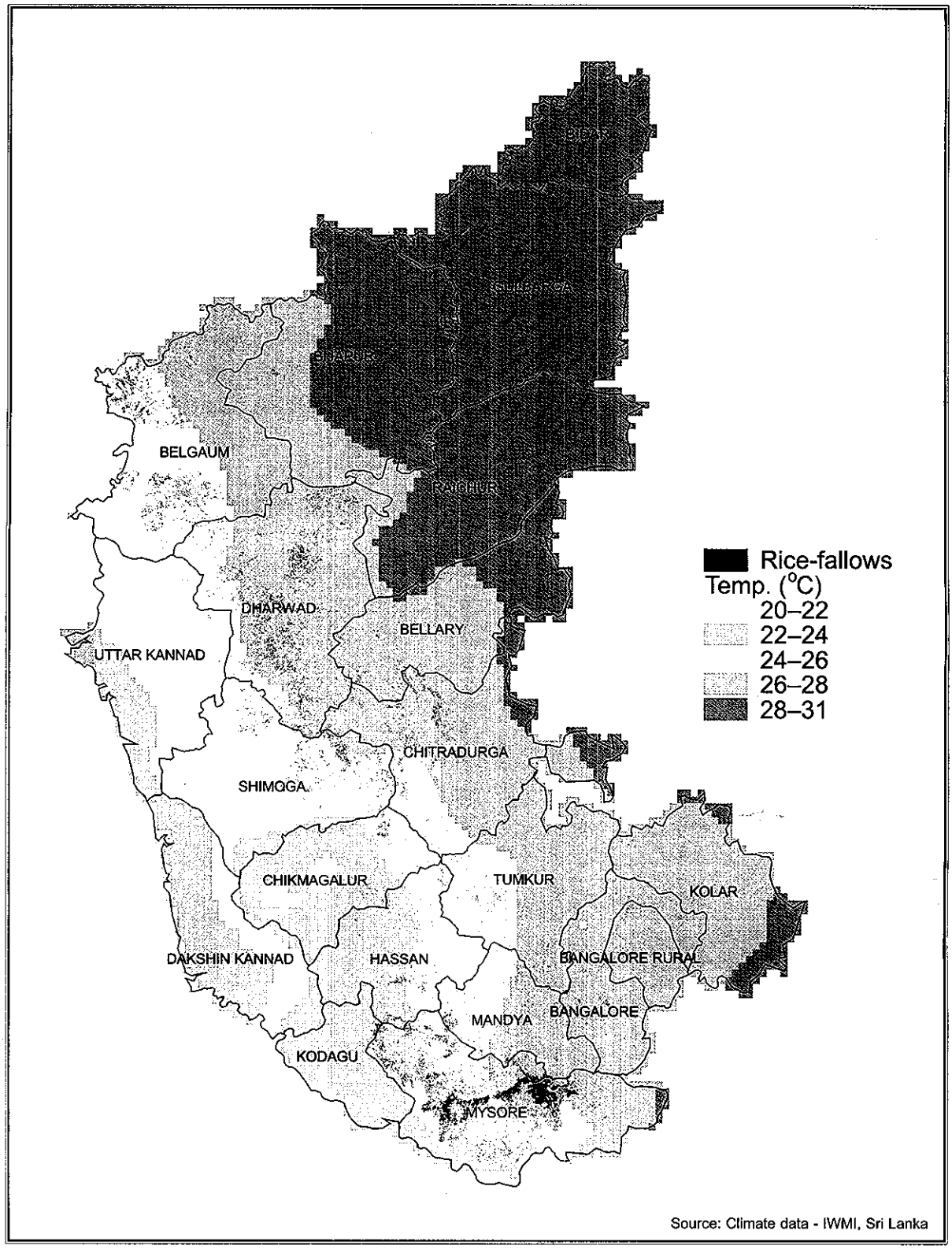


Fig. 5.2.75. Mean maximum temperature during kharif (June–September) in Karnataka, India

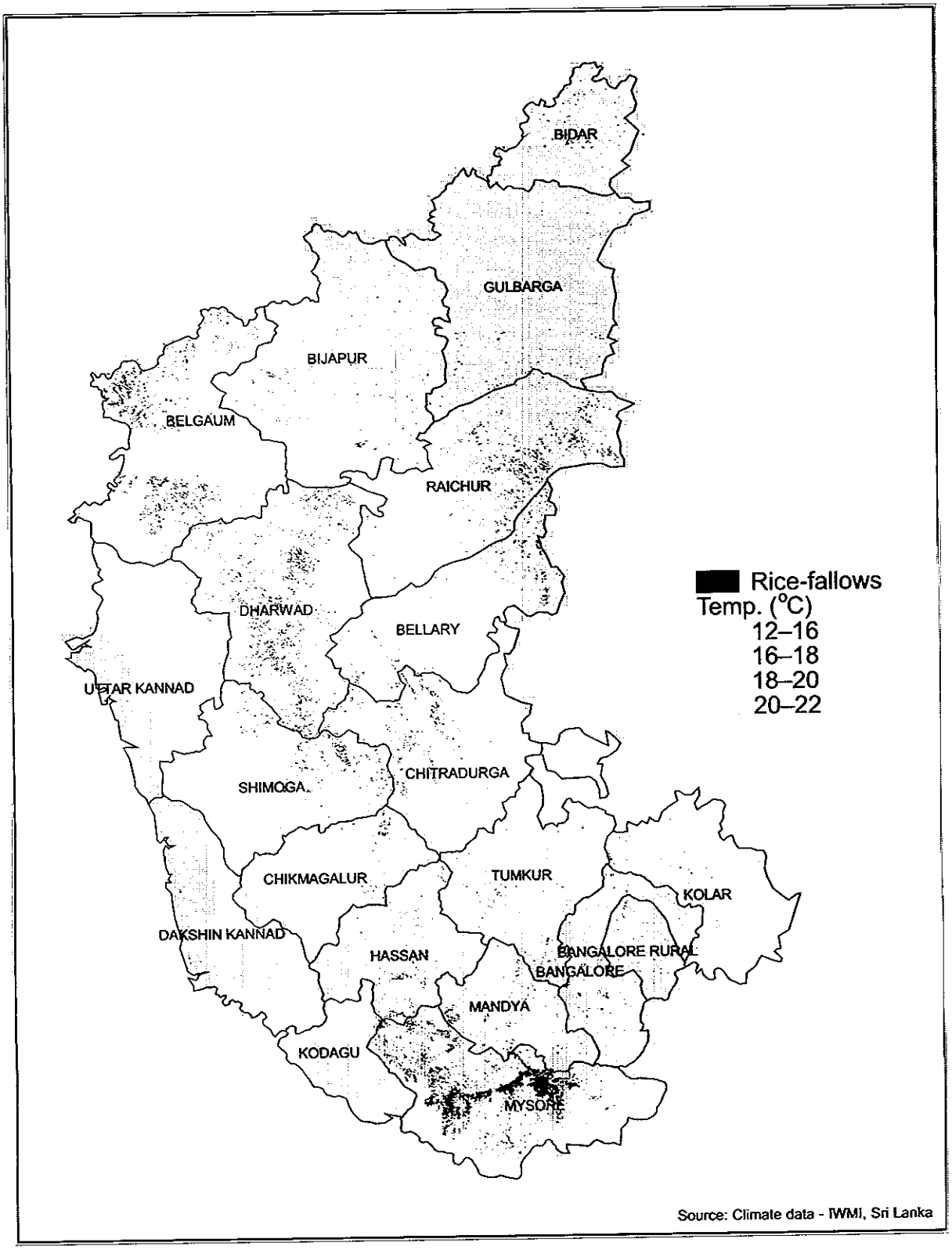


Fig. 5.2.76. Mean minimum temperature during kharif (June–September) in Karnataka, India

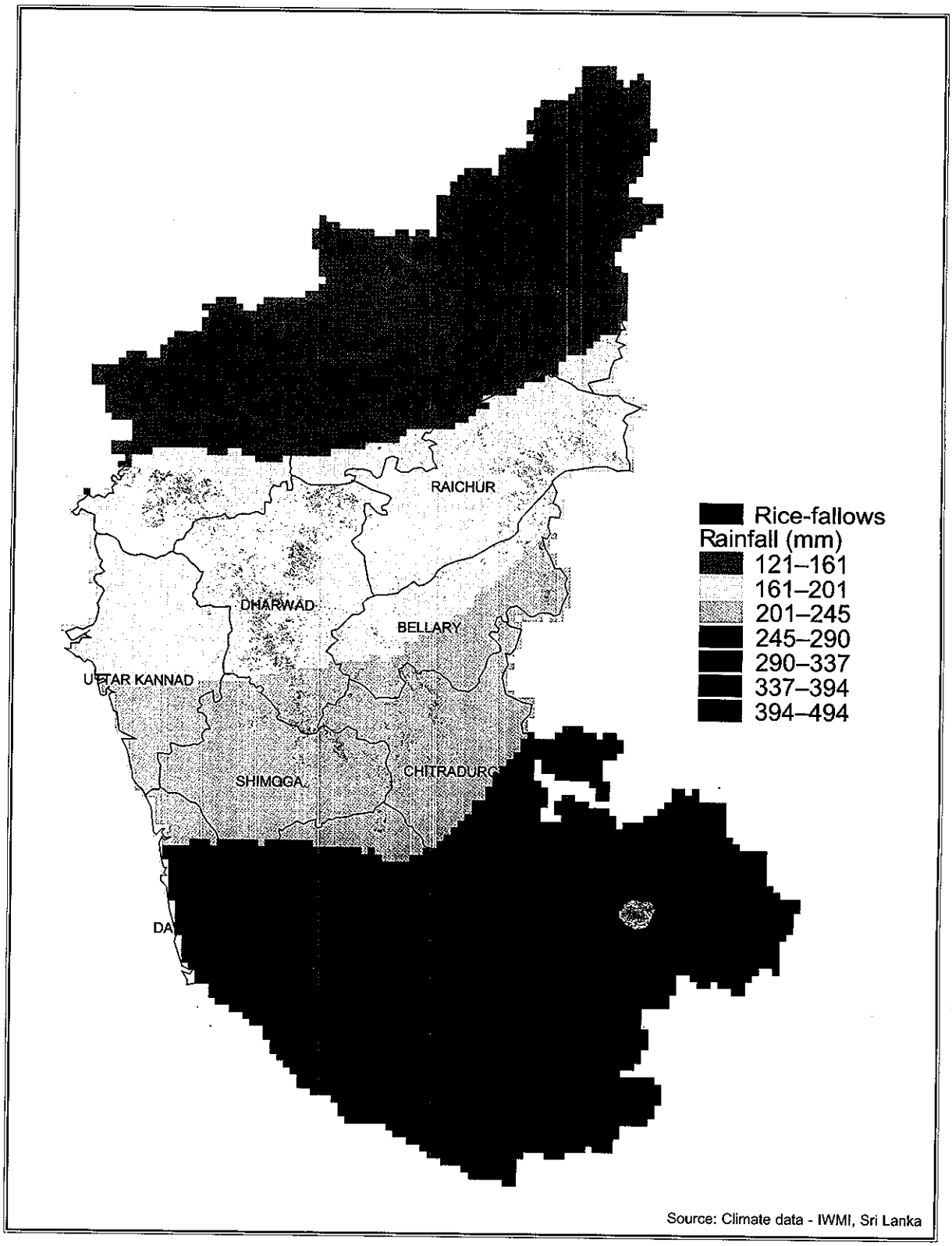


Fig. 5.2.77. Rainfall during rabi (October–March) in Karnataka, India

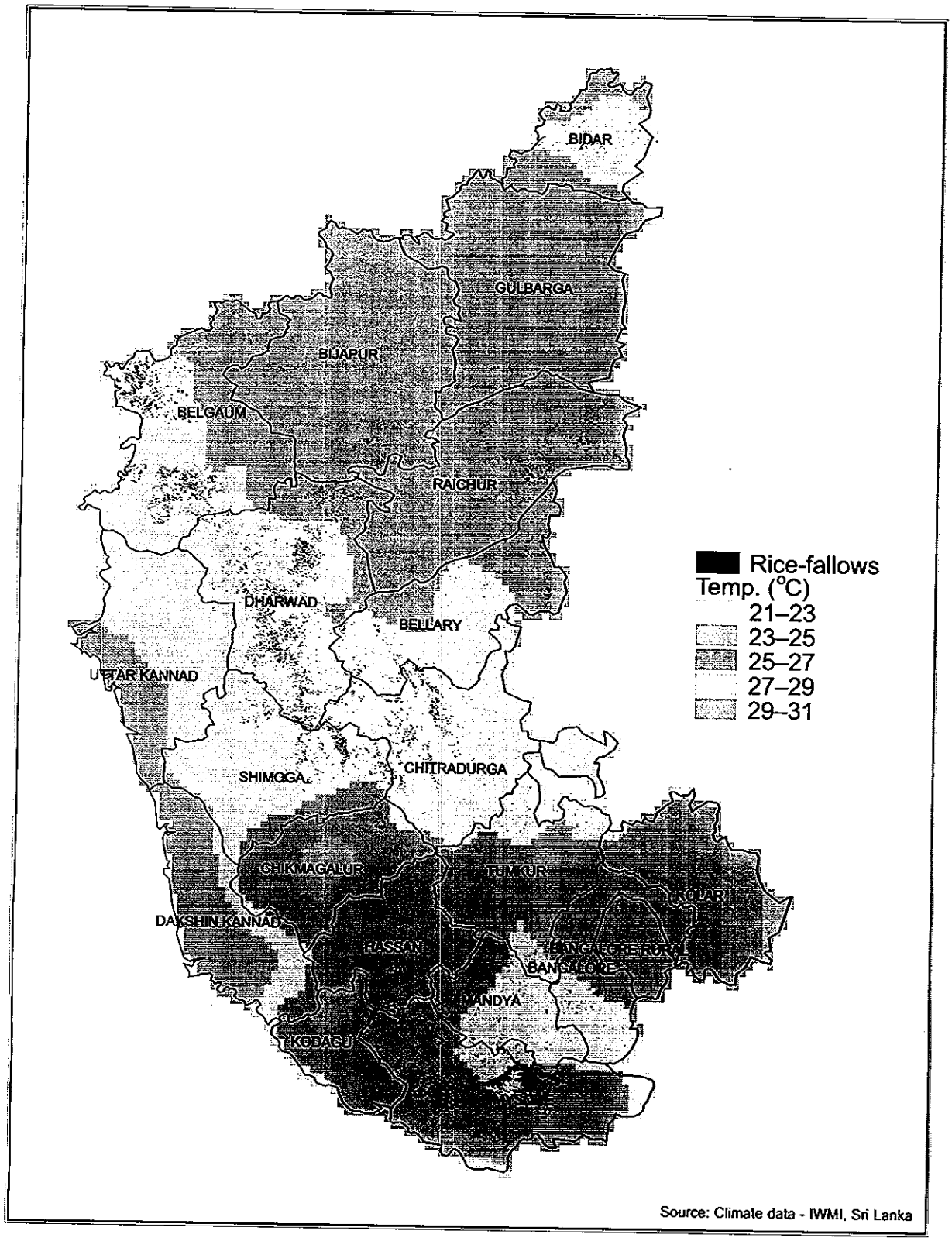


Fig. 5.2.78. Mean maximum temperature during rabi (October–March) in Karnataka, India

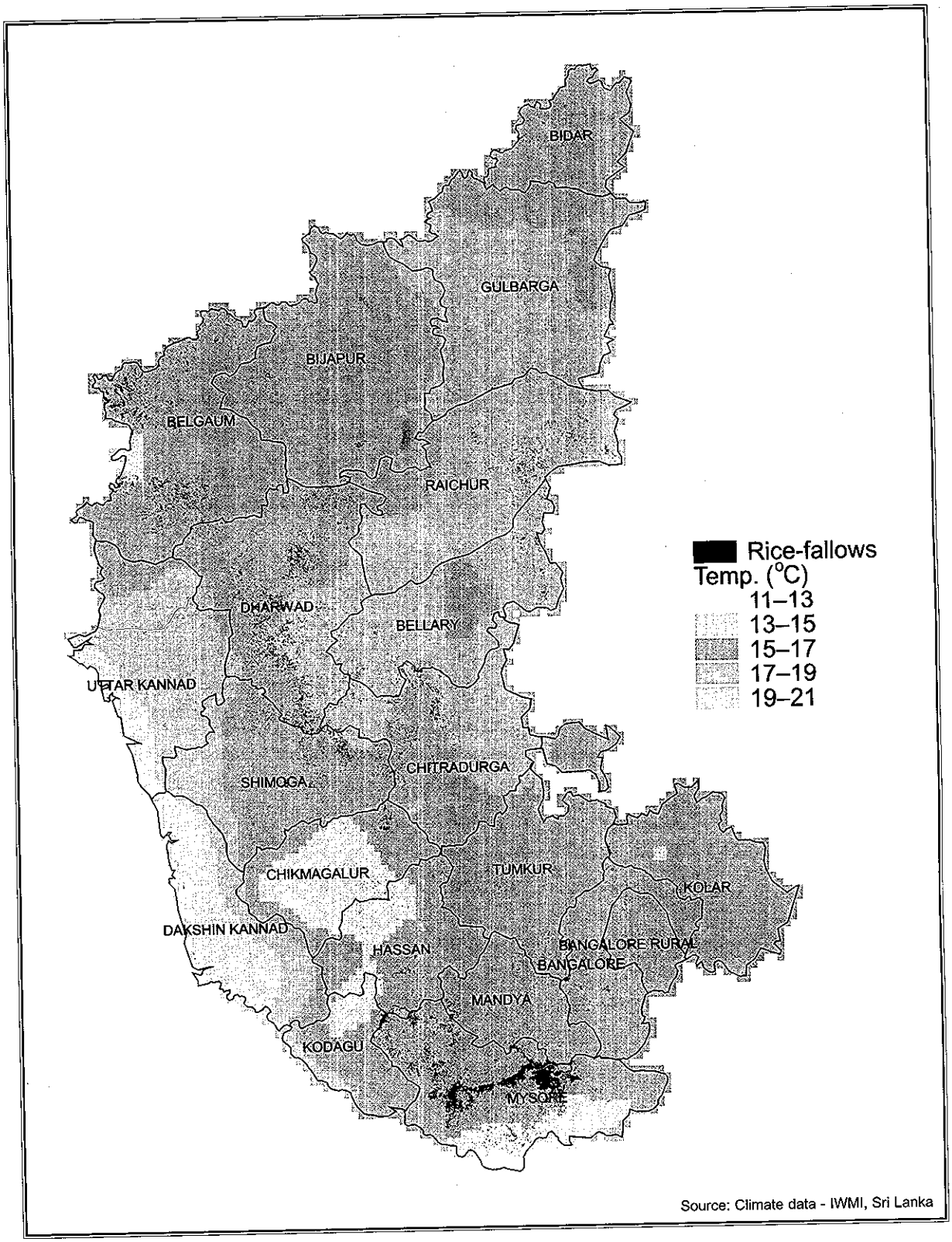
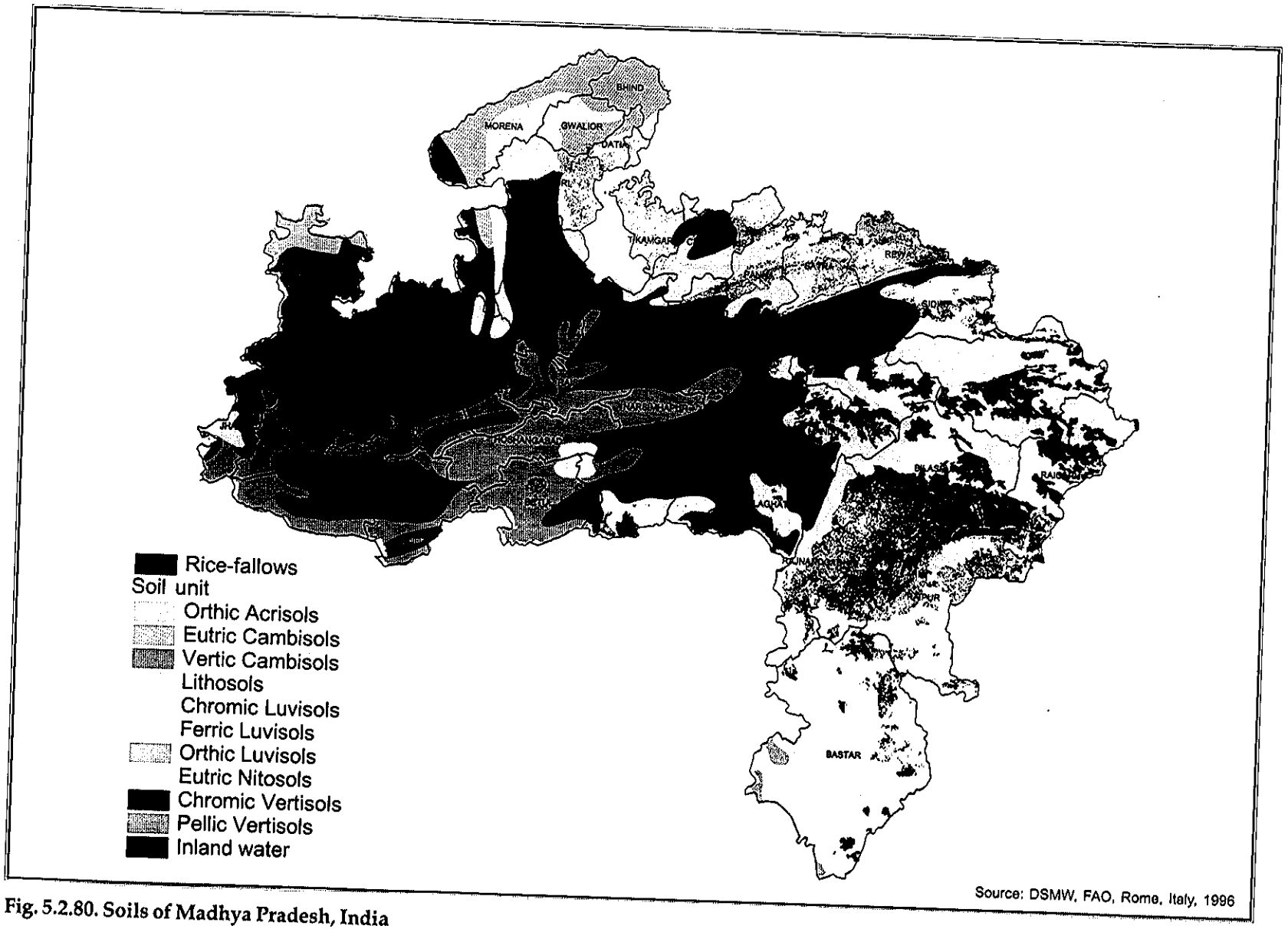


Fig. 5.2.79. Mean minimum temperature during rabi (October–March) in Karnataka, India



Source: DSMW, FAO, Rome, Italy, 1996

Fig. 5.2.80. Soils of Madhya Pradesh, India

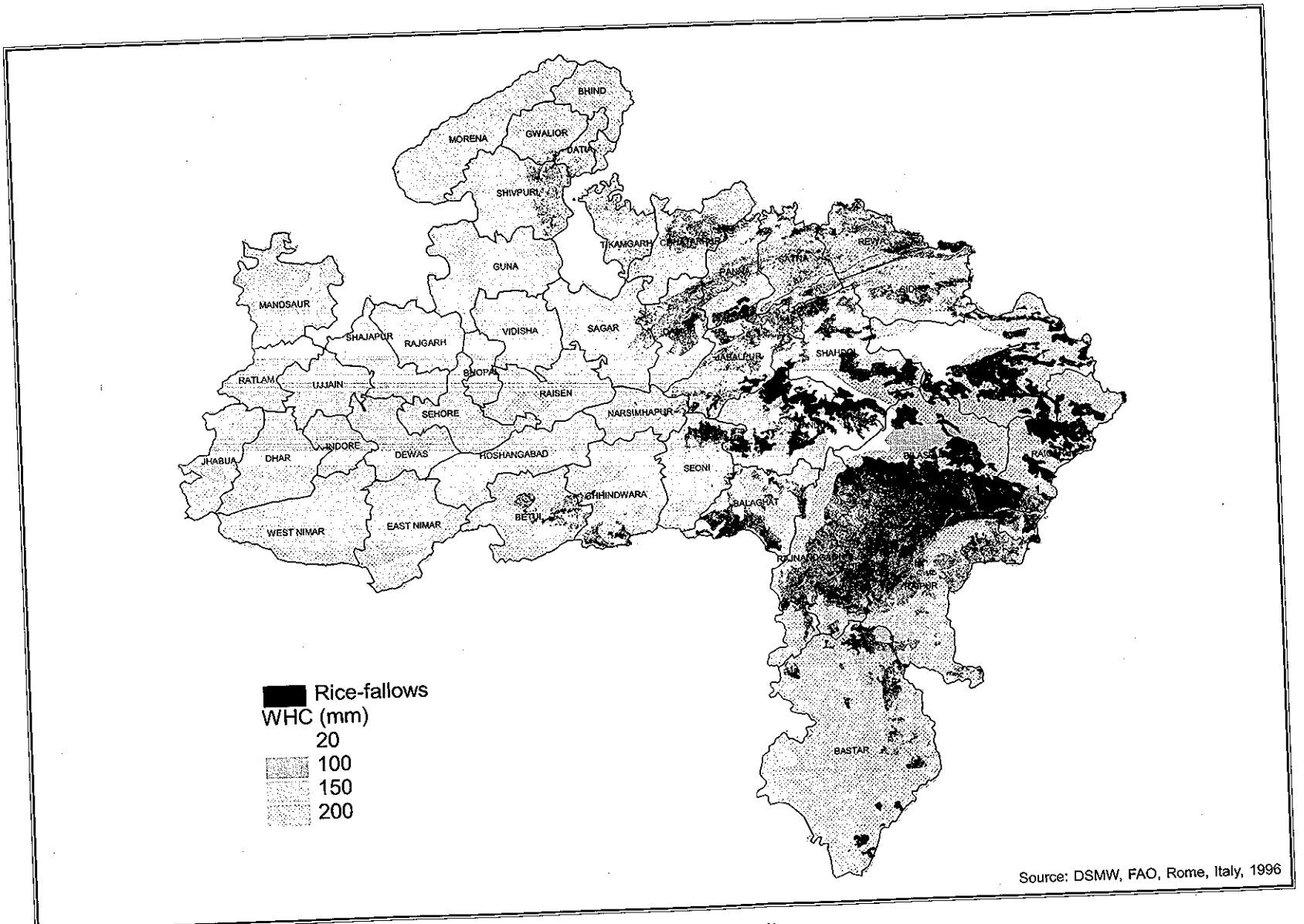


Fig. 5.2.81. Available soil water-holding capacity (WHC) in Madhya Pradesh, India

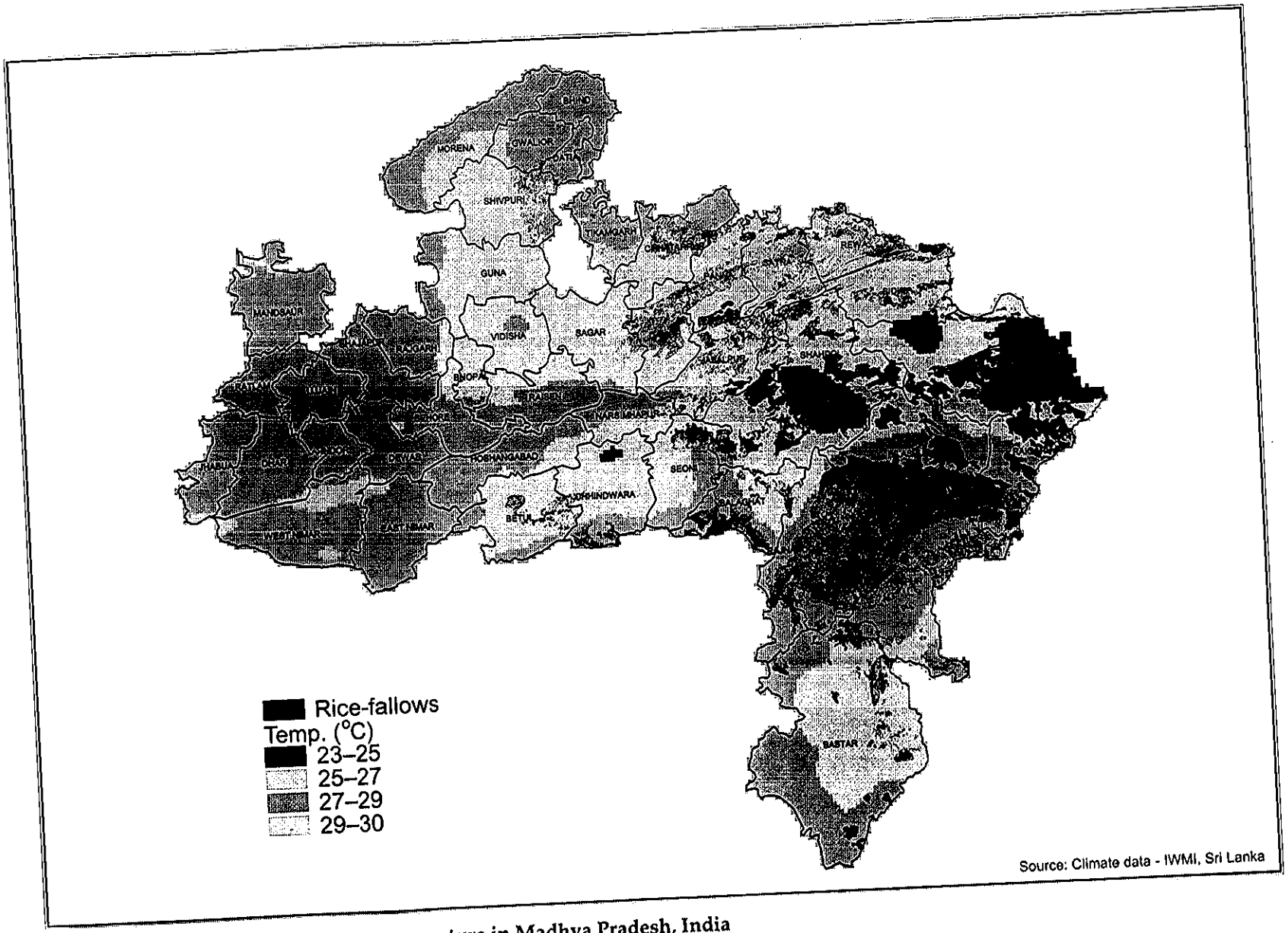
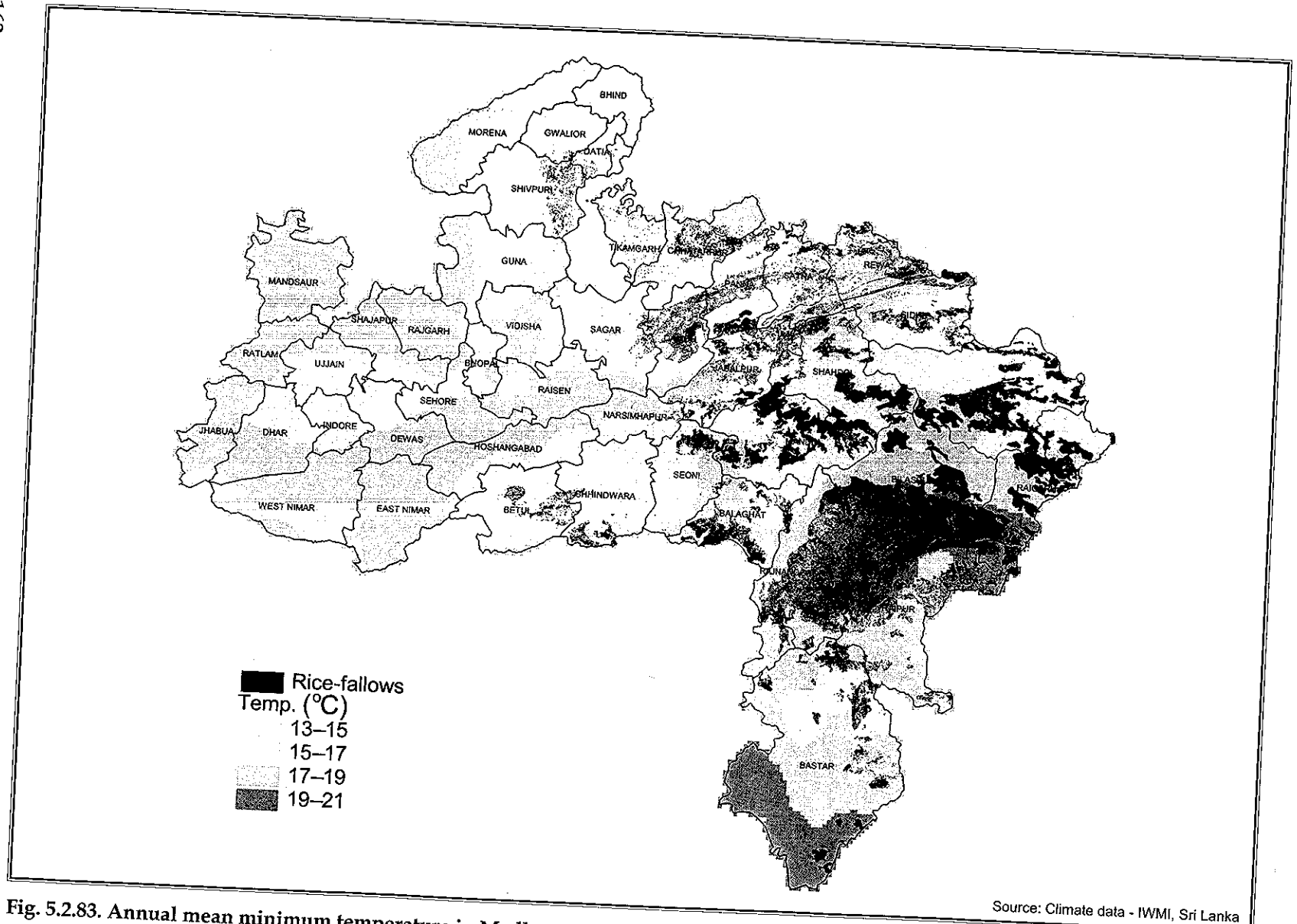


Fig. 5.2.82. Annual mean maximum temperature in Madhya Pradesh, India



Source: Climate data - IWMI, Sri Lanka

Fig. 5.2.83. Annual mean minimum temperature in Madhya Pradesh, India

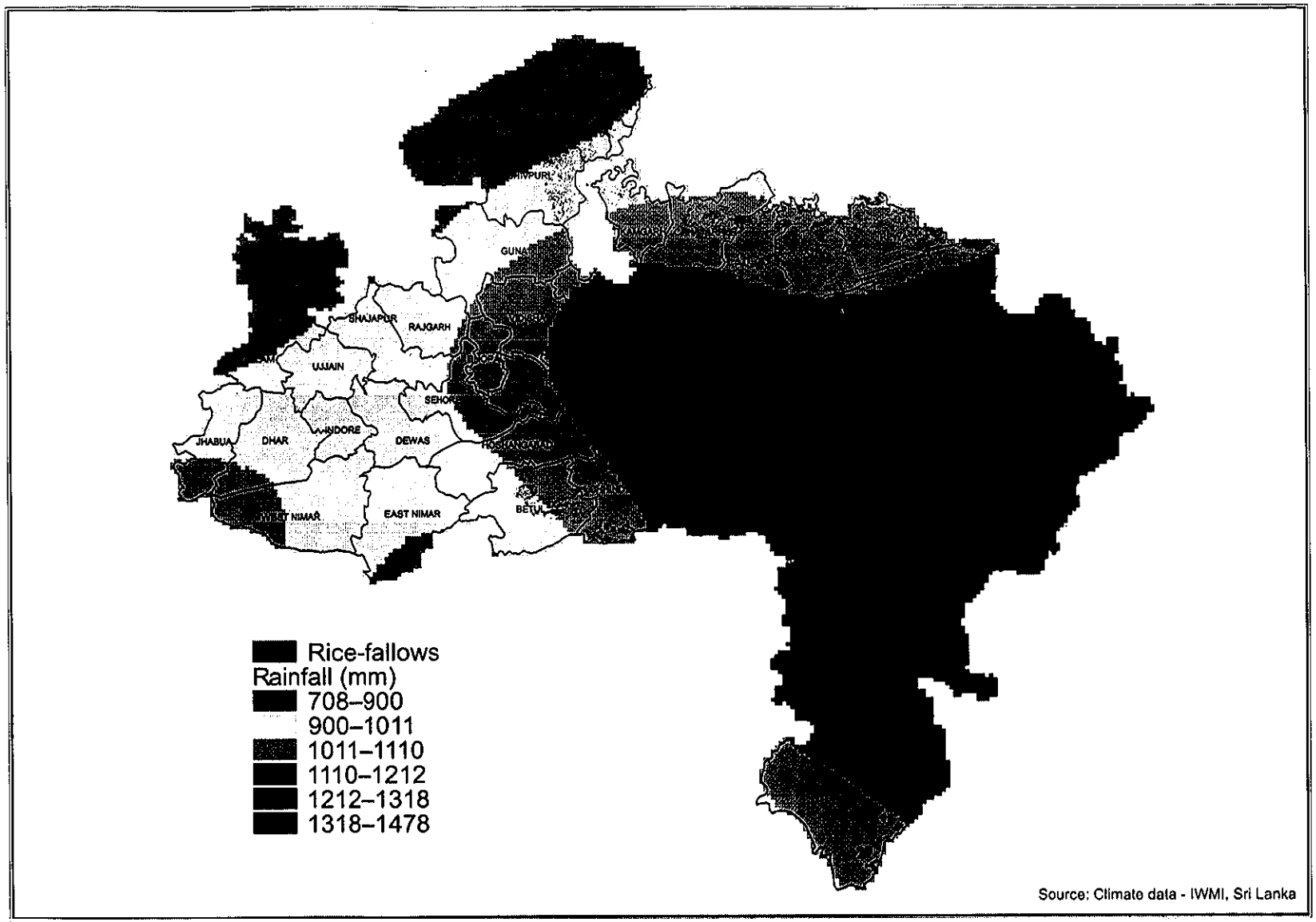


Fig. 5.2.84. Annual rainfall in Madhya Pradesh, India

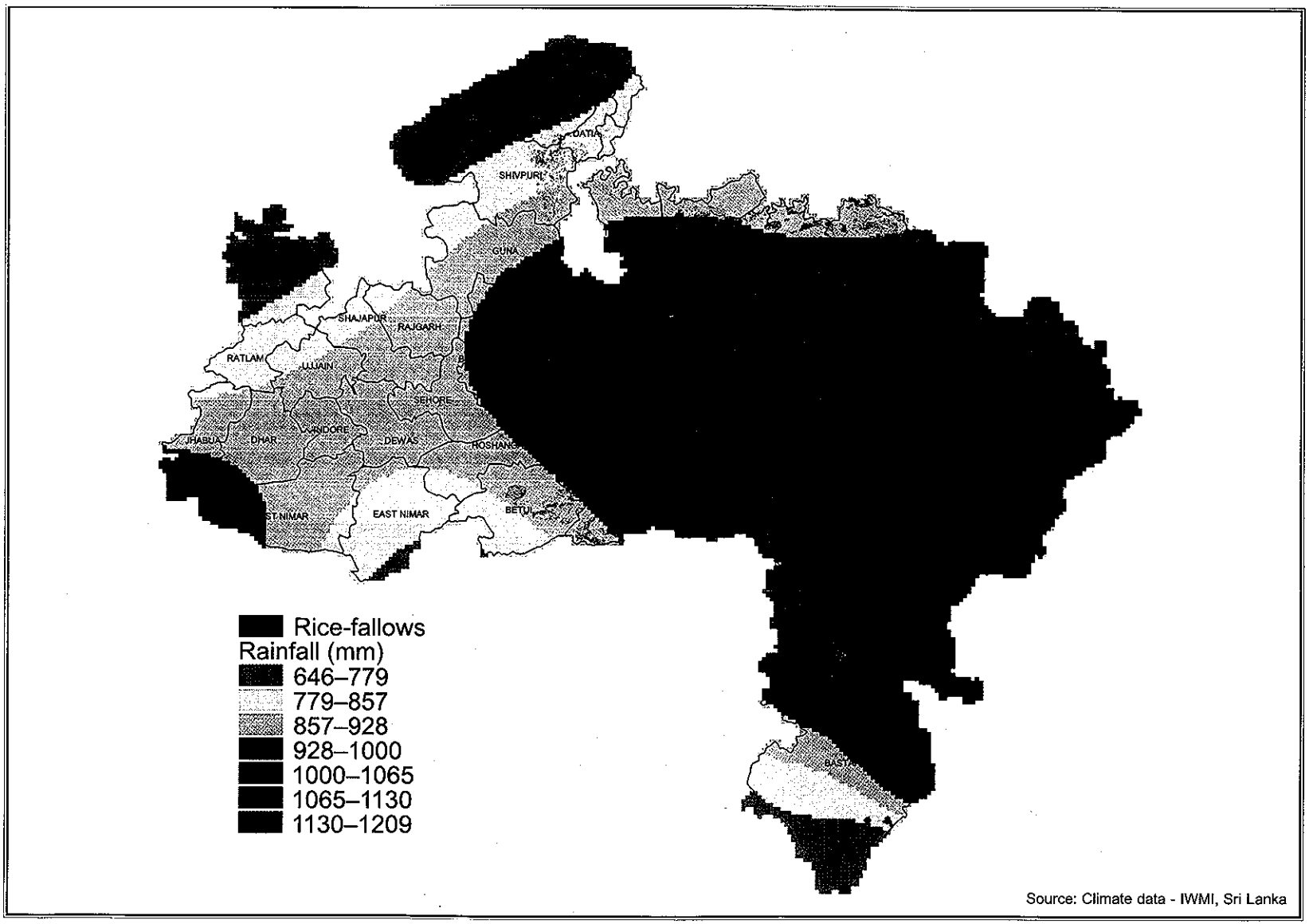


Fig. 5.2.85. Rainfall during kharif (June–September) in Madhya Pradesh, India

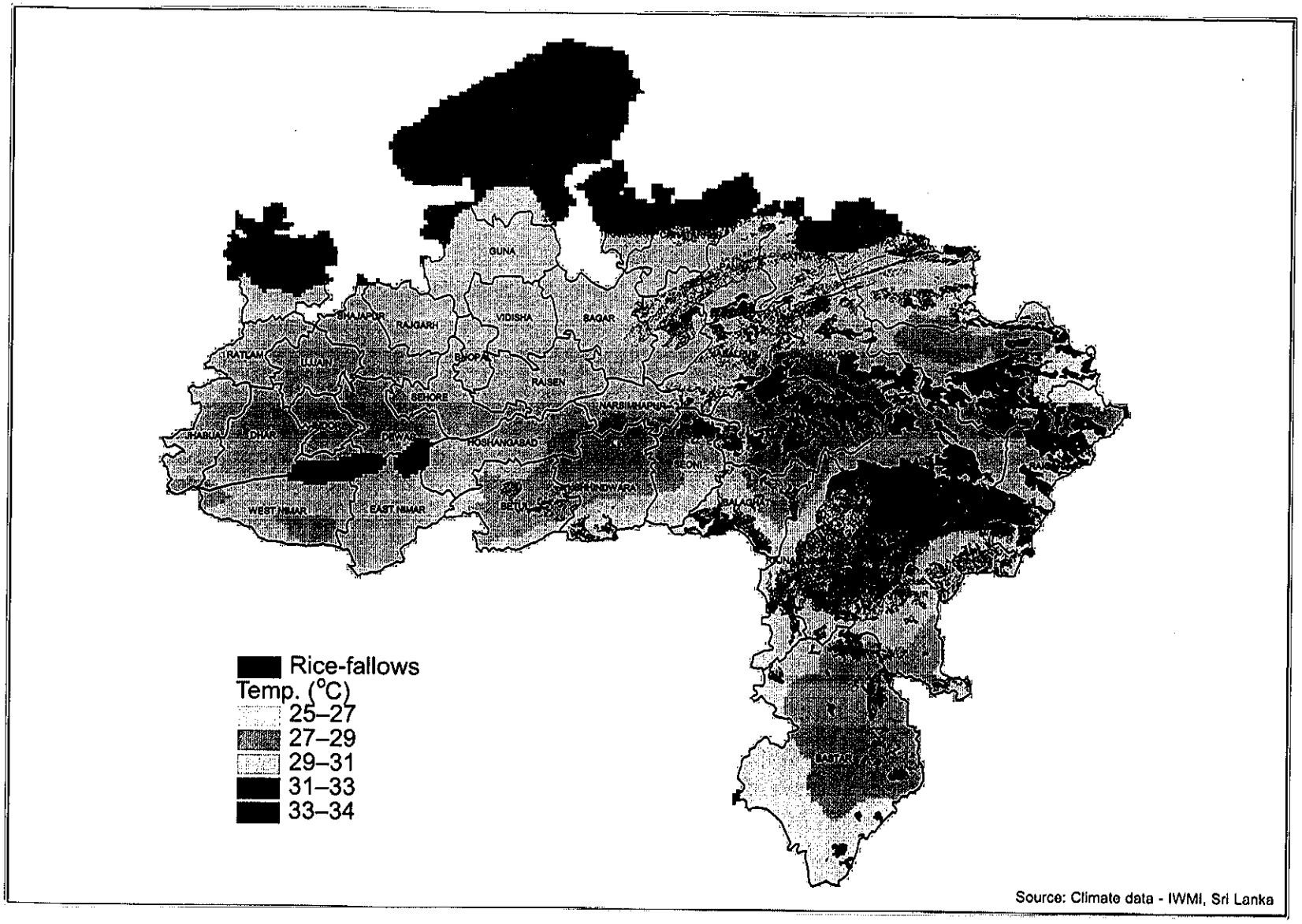


Fig. 5.2.86. Mean maximum temperature during kharif (June–September) in Madhya Pradesh, India

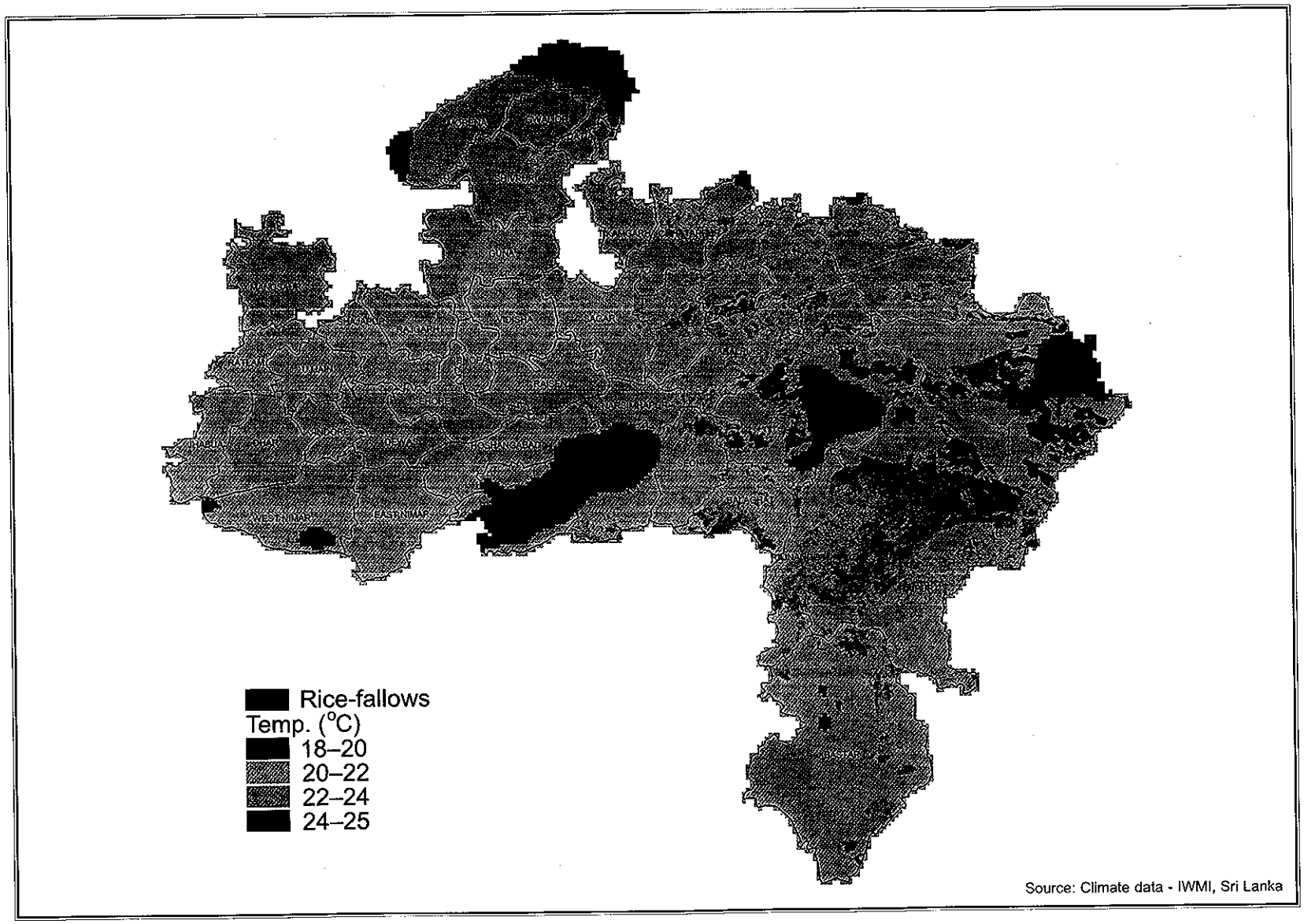


Fig. 5.2.87. Mean minimum temperature during kharif (June–September) in Madhya Pradesh, India

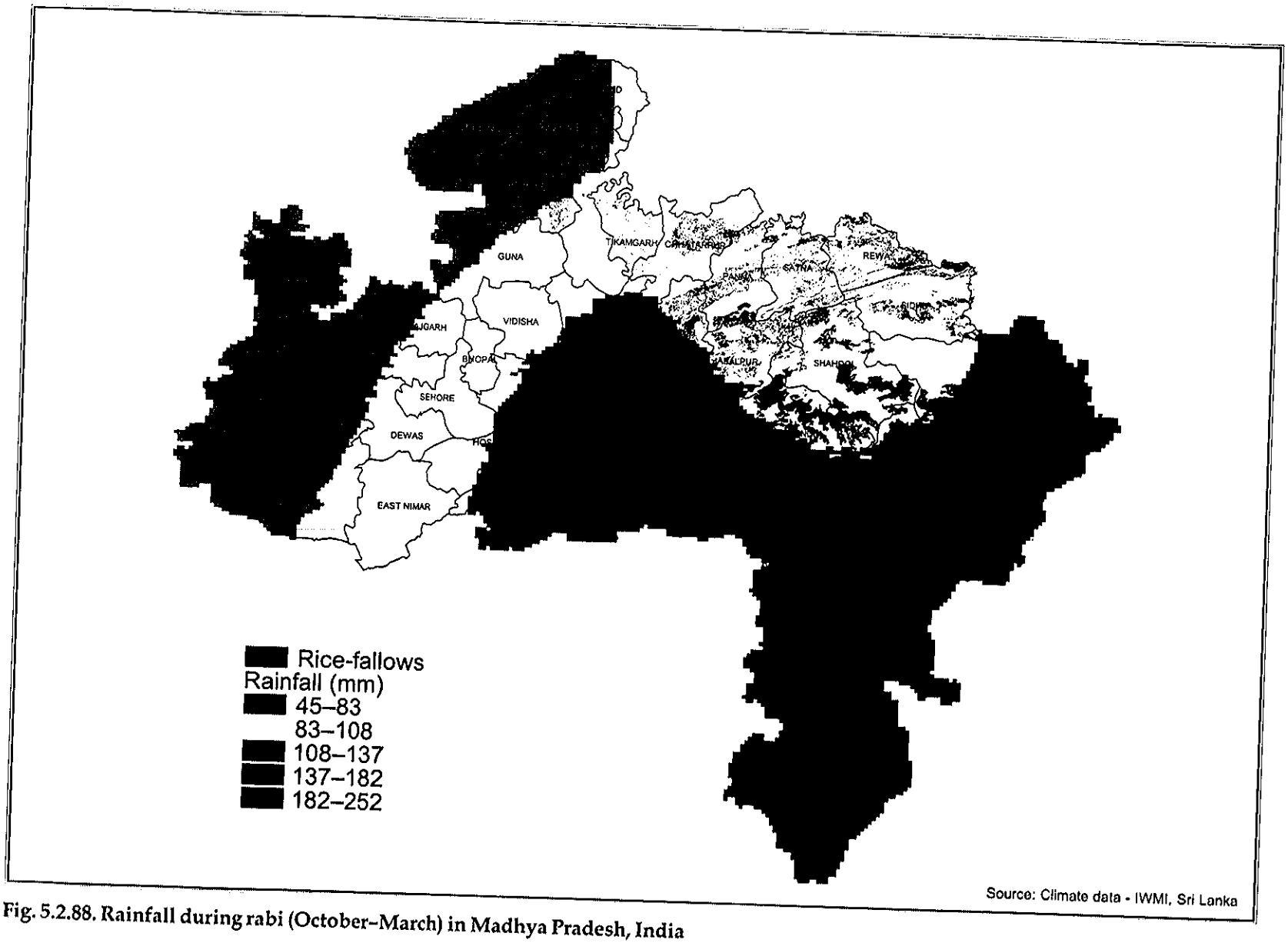


Fig. 5.2.88. Rainfall during rabi (October–March) in Madhya Pradesh, India

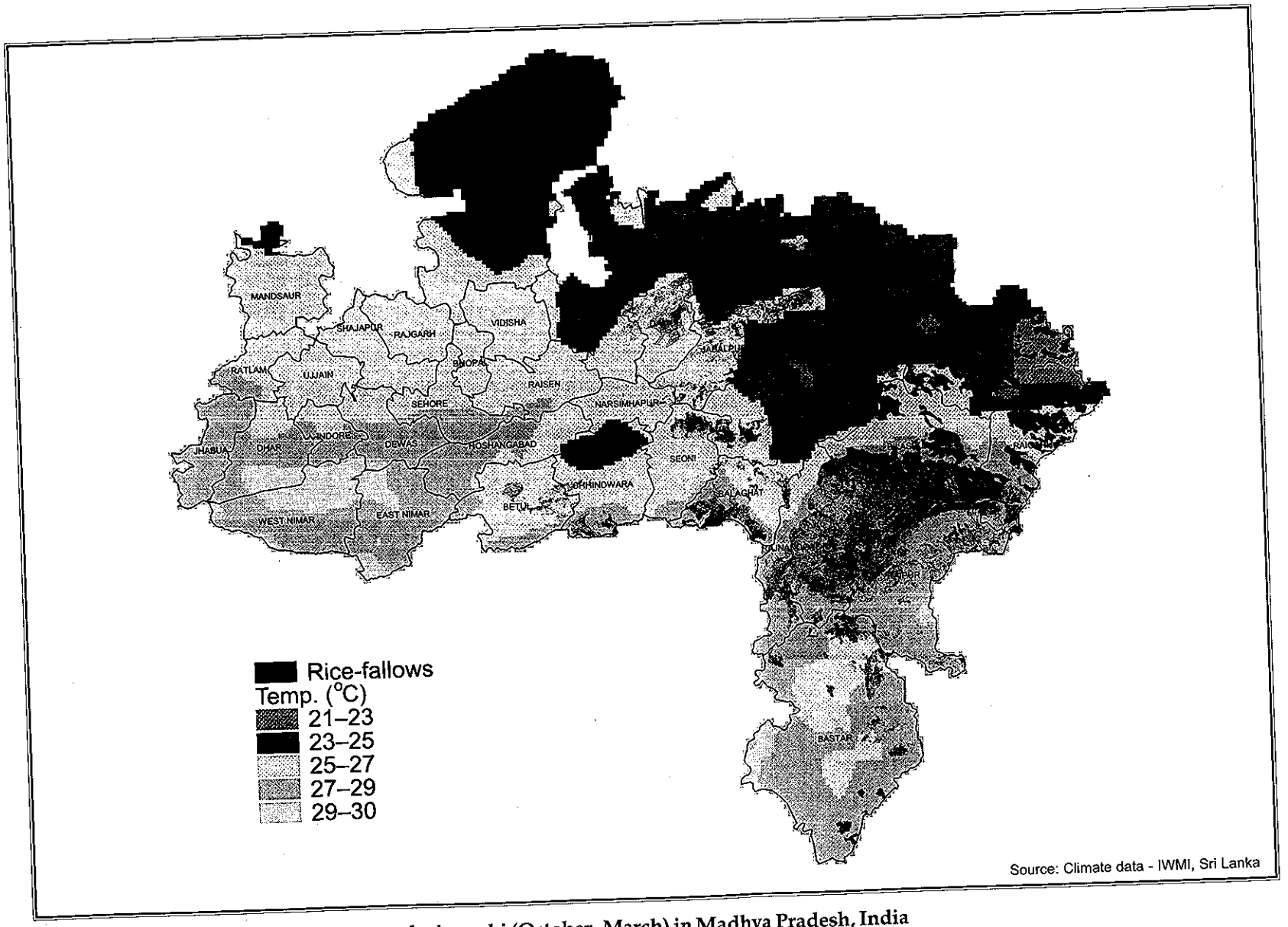


Fig. 5.2.89. Mean maximum temperature during rabi (October–March) in Madhya Pradesh, India

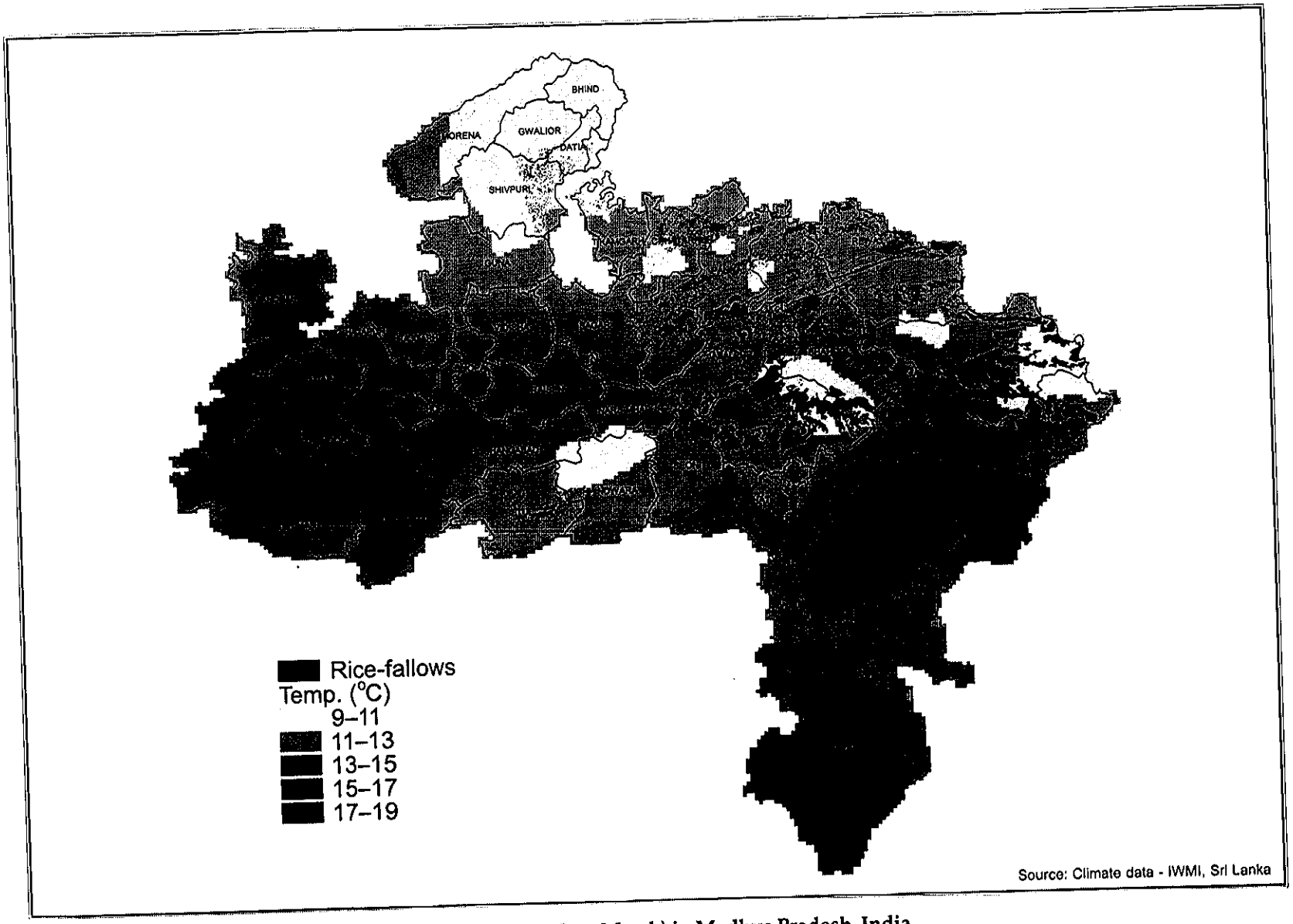


Fig. 5.2.90. Mean minimum temperature during rabi (October–March) in Madhya Pradesh, India

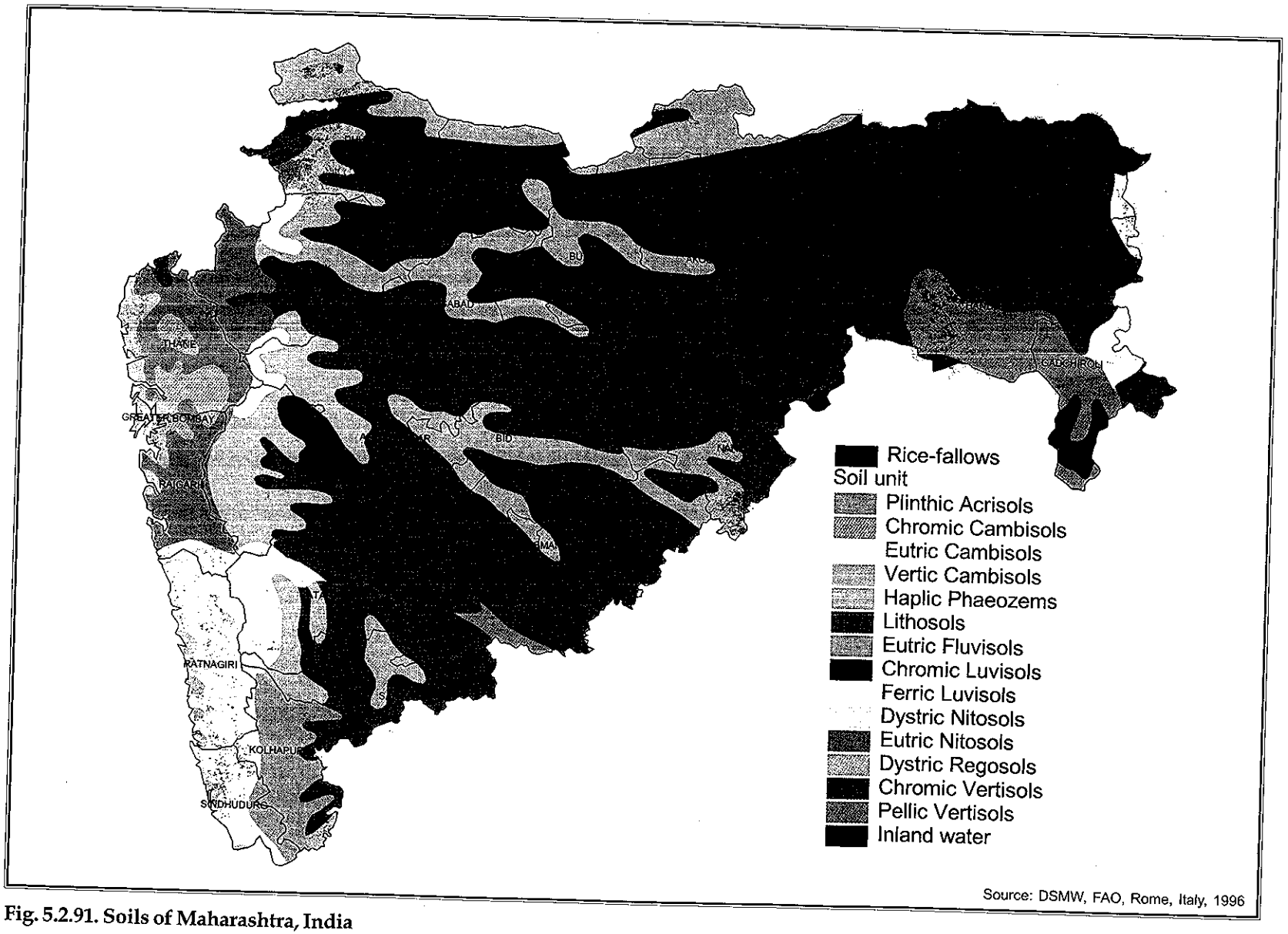


Fig. 5.2.91. Soils of Maharashtra, India

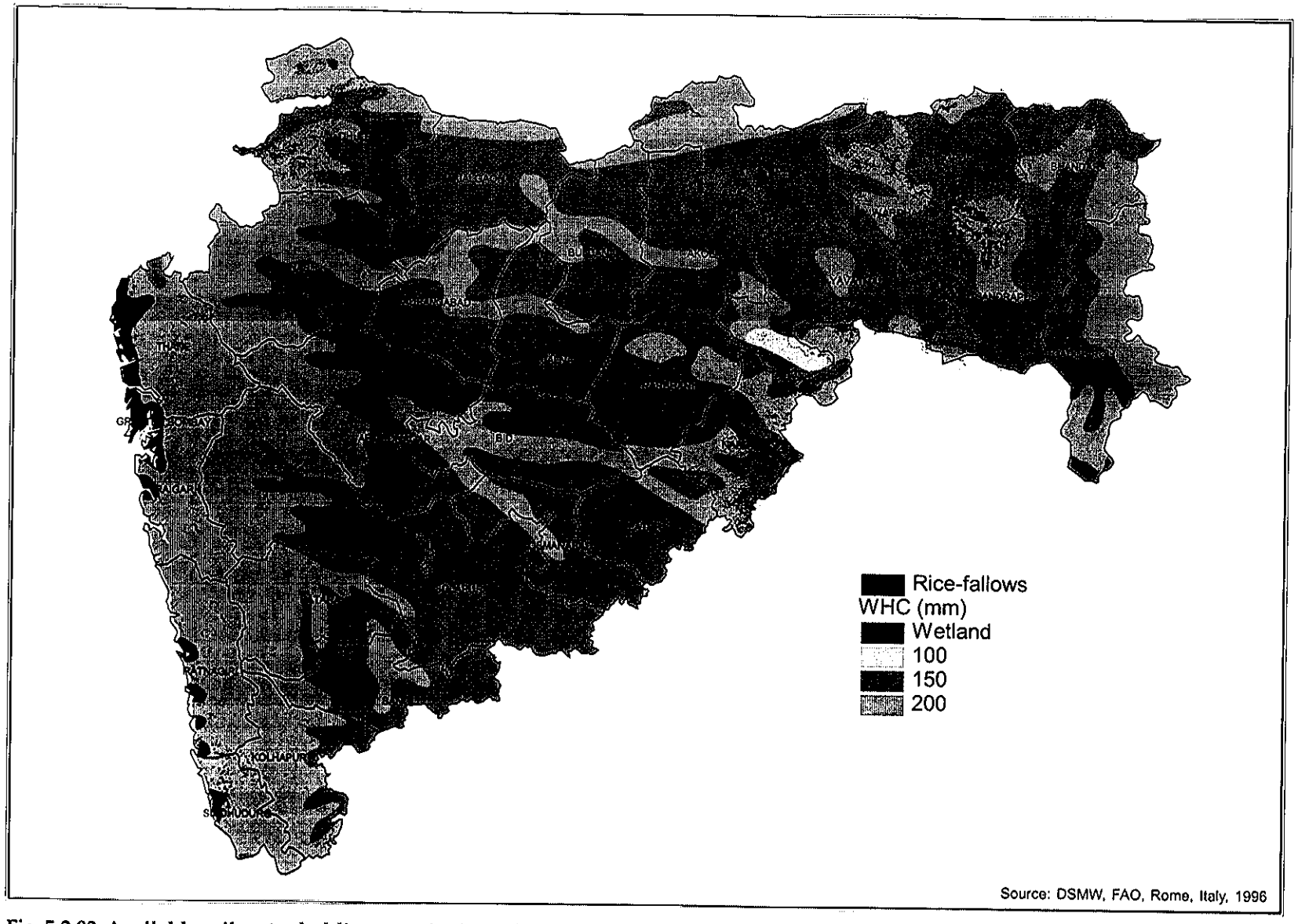


Fig. 5.2.92. Available soil water-holding capacity (WHC) in Maharashtra, India

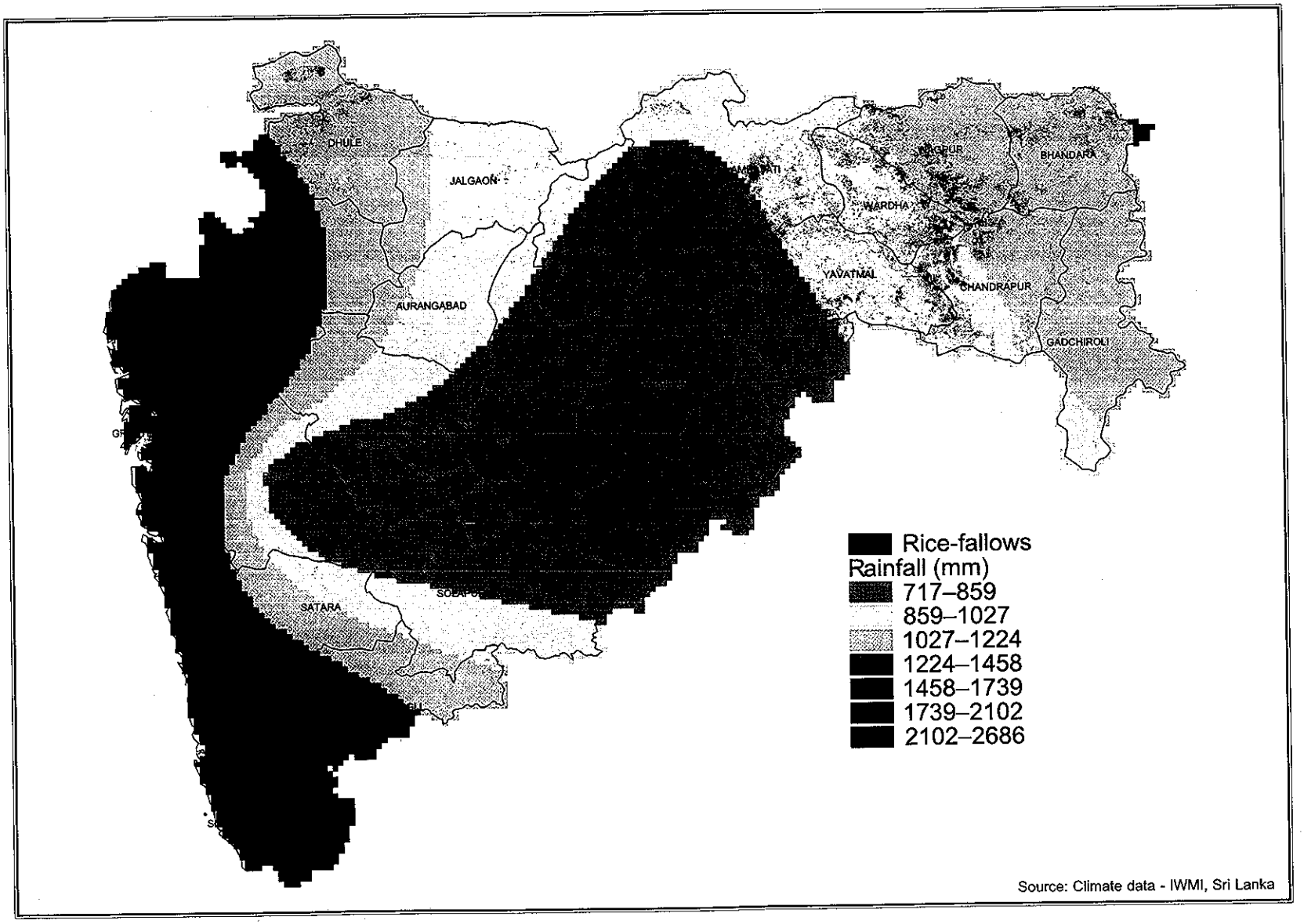


Fig. 5.2.93. Annual rainfall in Maharashtra, India

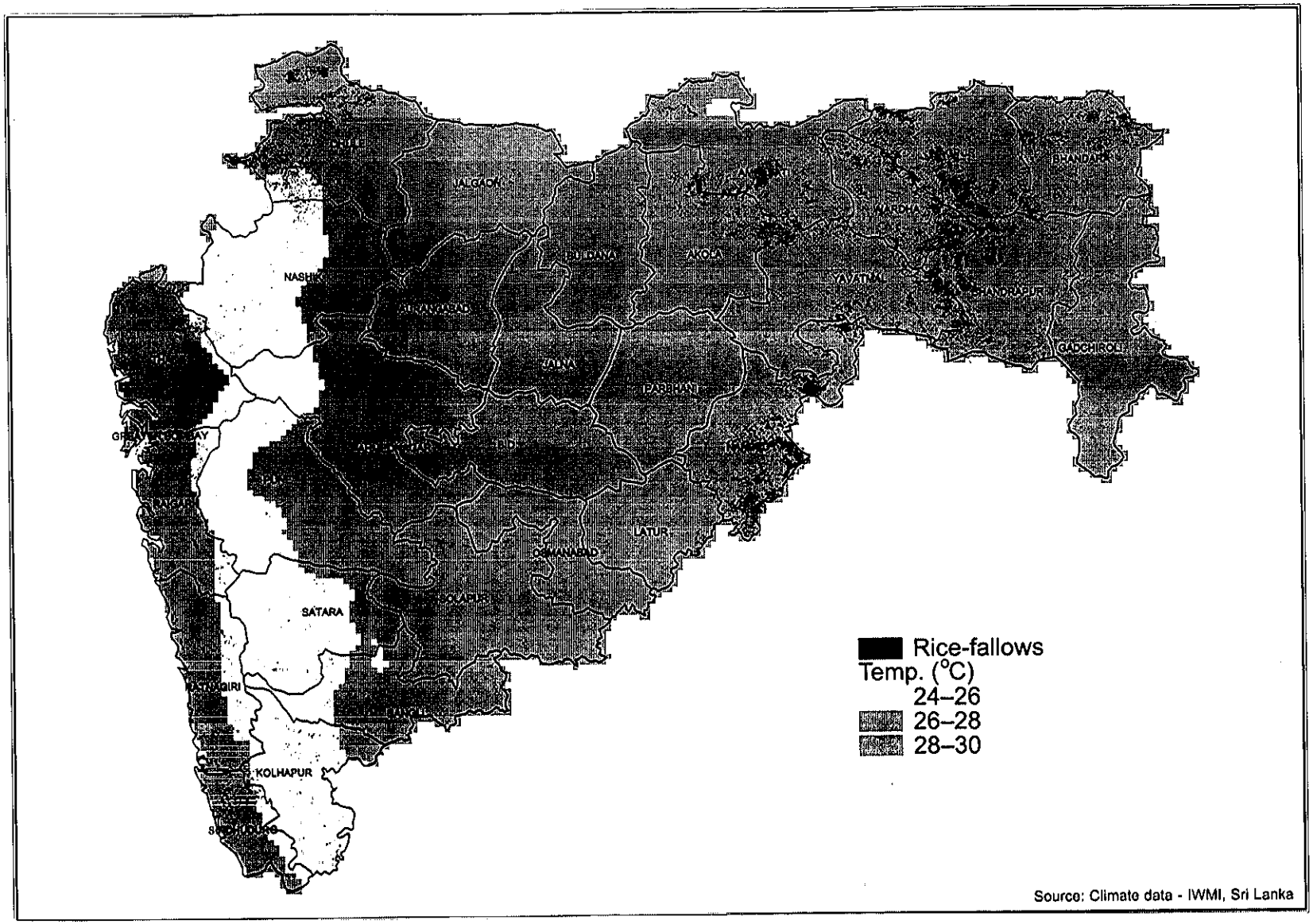


Fig. 5.2.94. Annual mean maximum temperature in Maharashtra, India

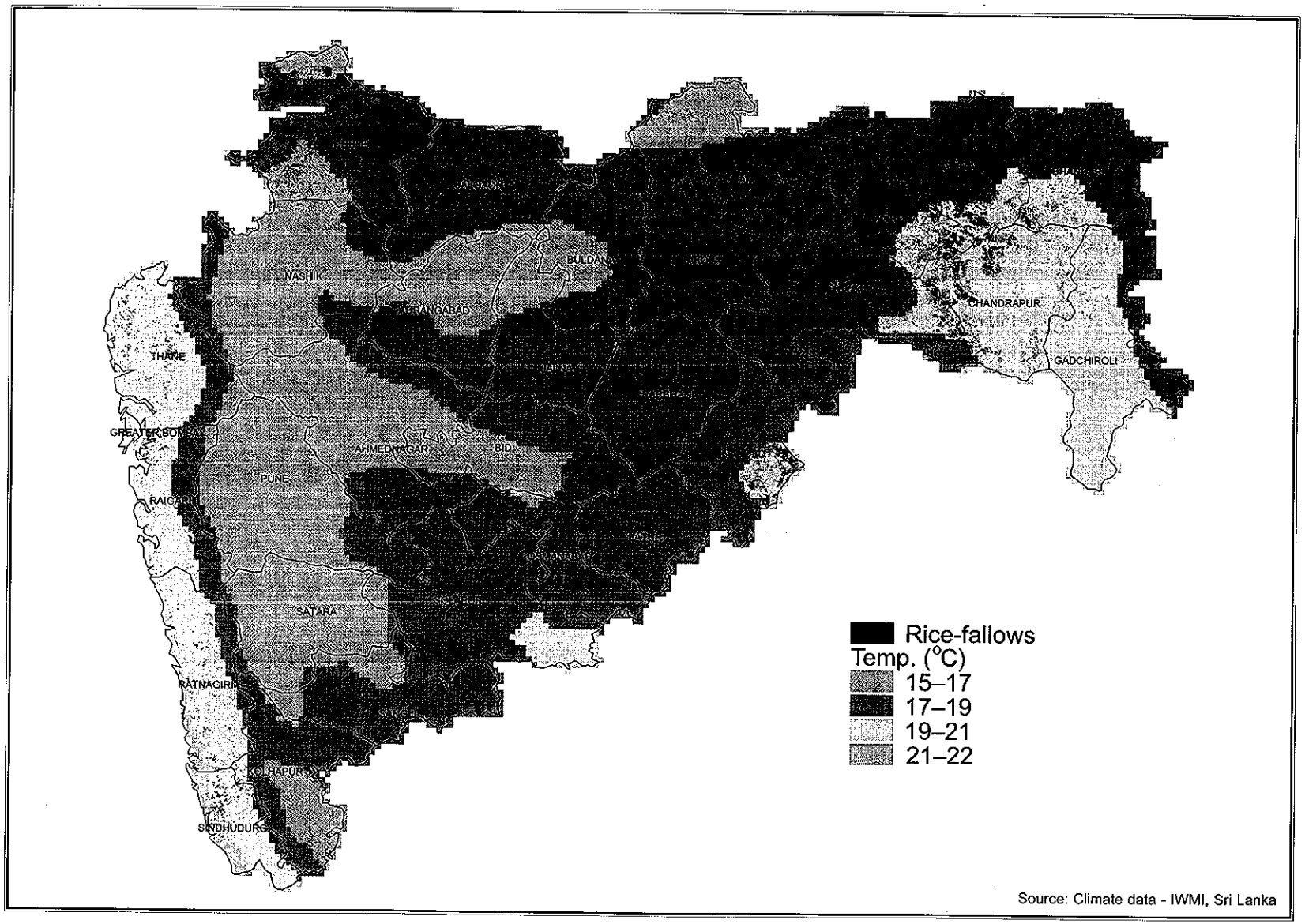
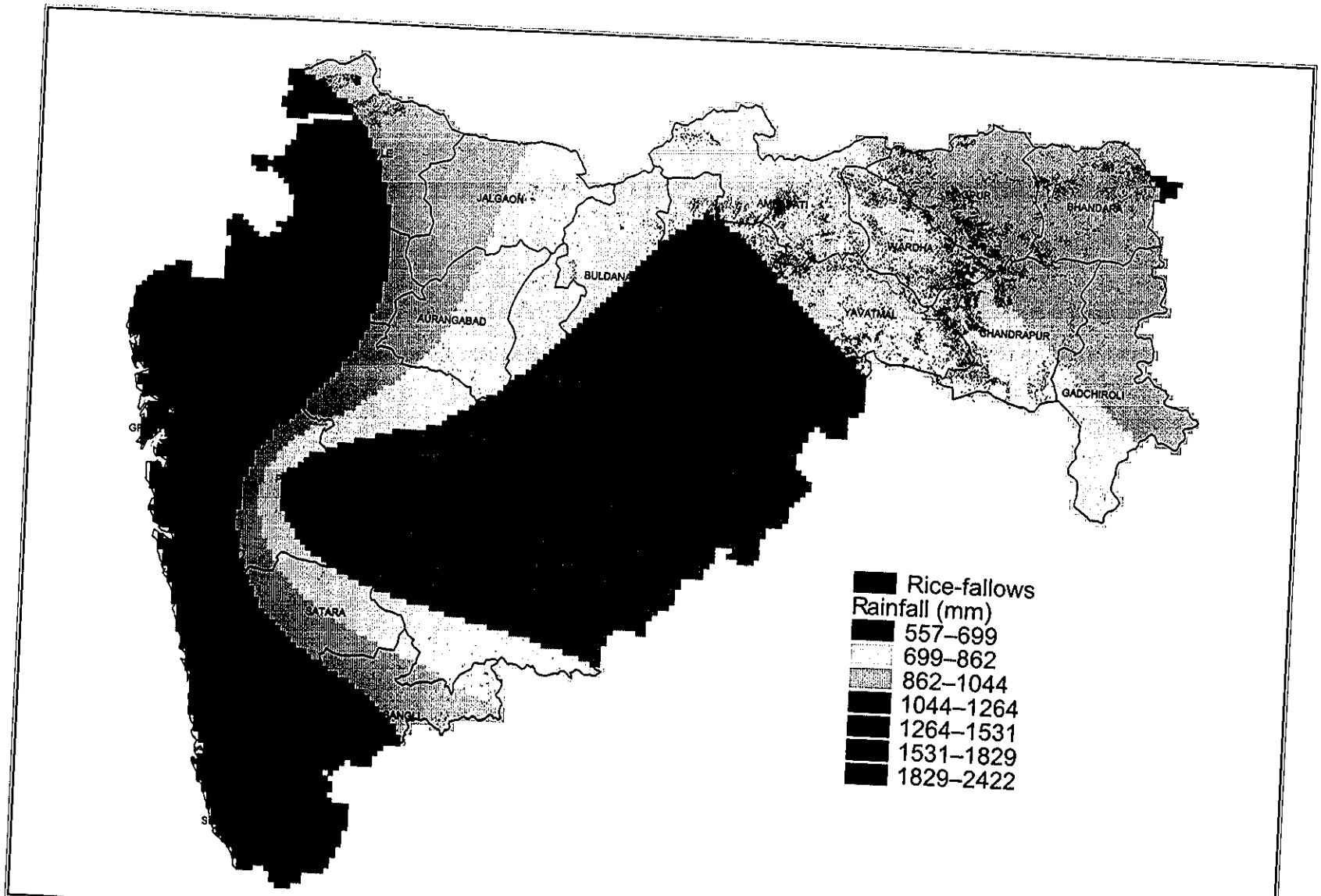


Fig. 5.2.95. Annual mean minimum temperature in Maharashtra, India



Source: Climate data - IWMI, Sri Lanka

Fig. 5.2.96. Rainfall during kharif (June-September) in Maharashtra, India

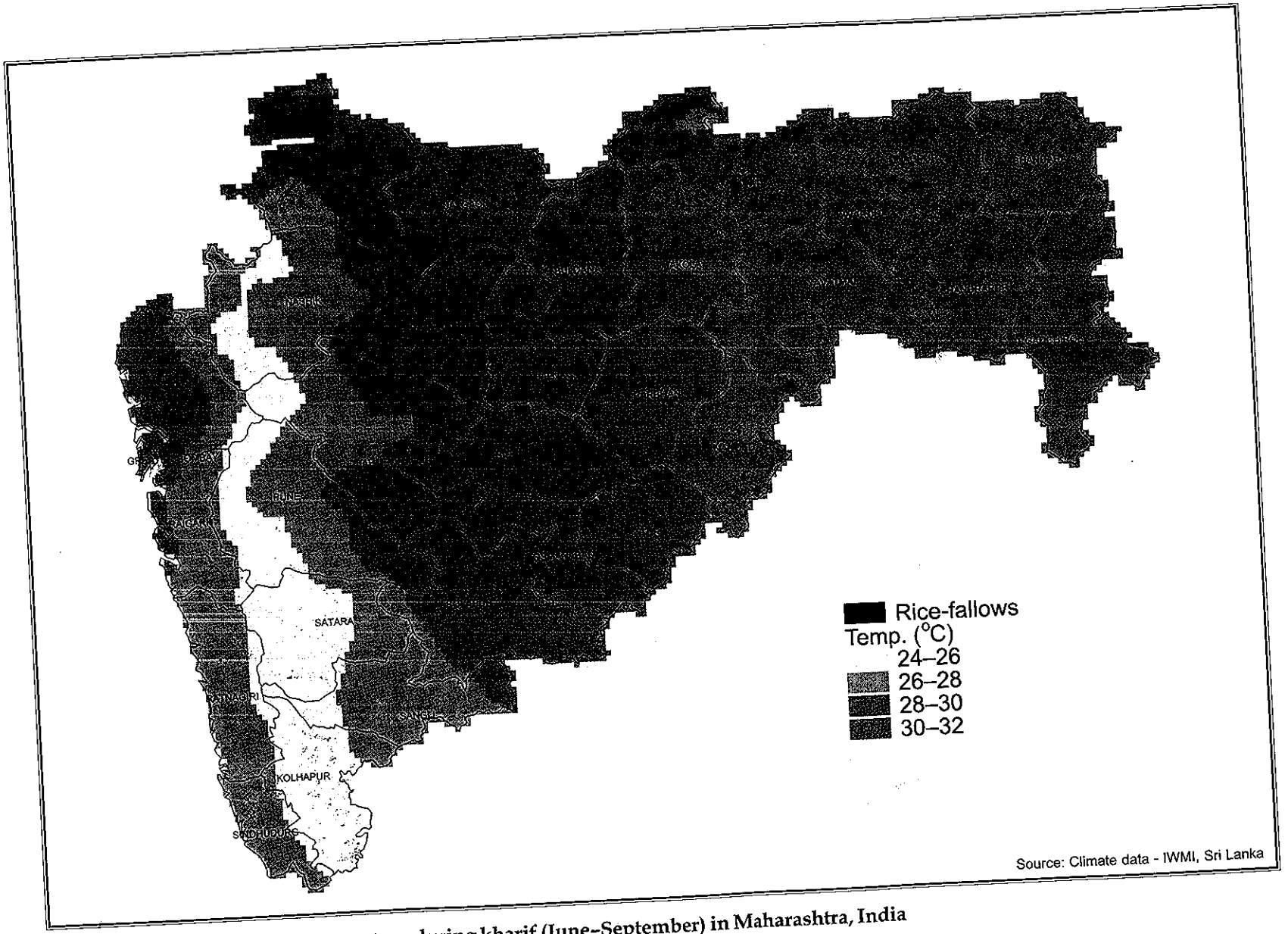


Fig. 5.2.97. Mean maximum temperature during kharif (June–September) in Maharashtra, India

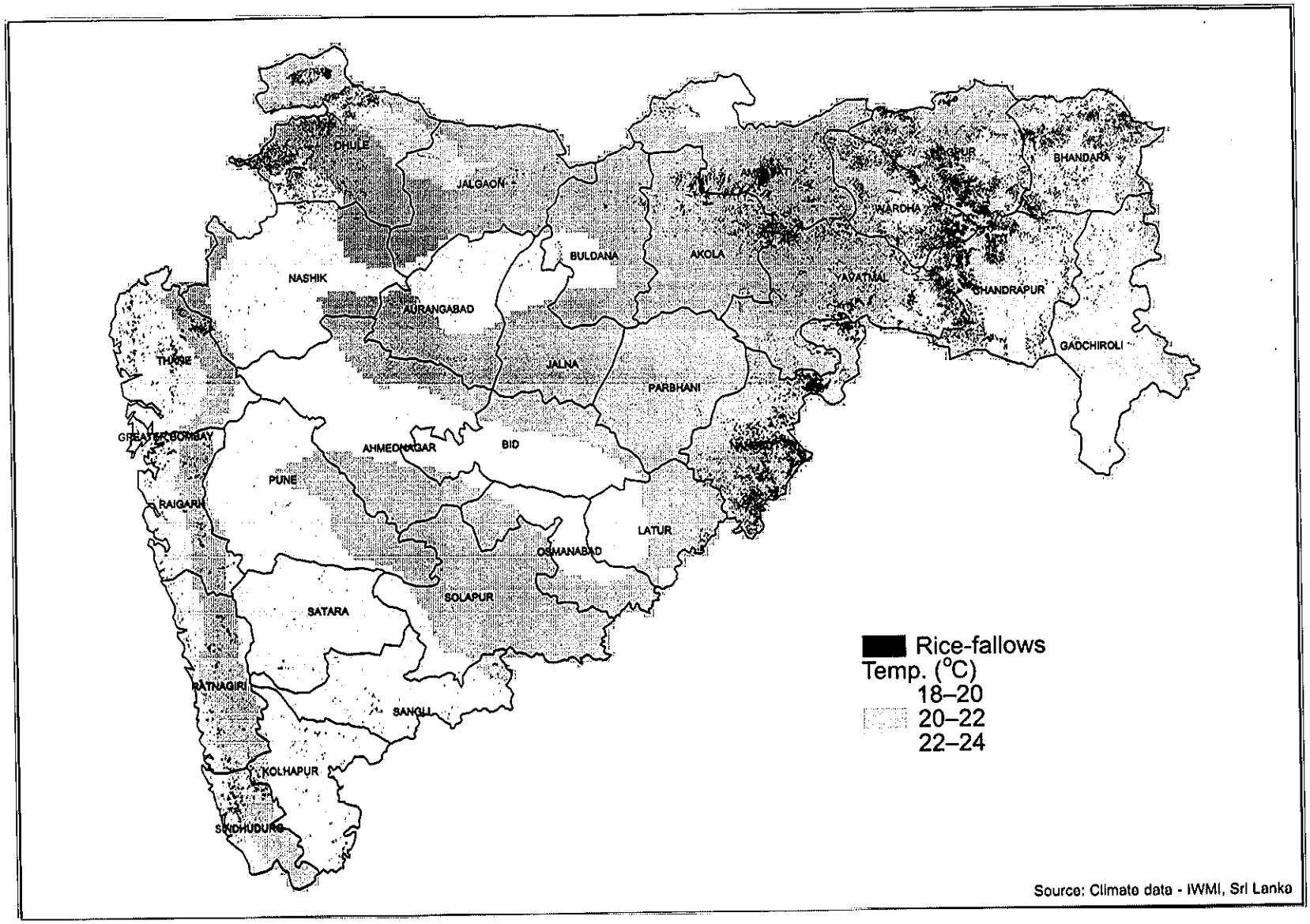


Fig. 5.2.98. Mean minimum temperature during kharif (June–September) in Maharashtra, India

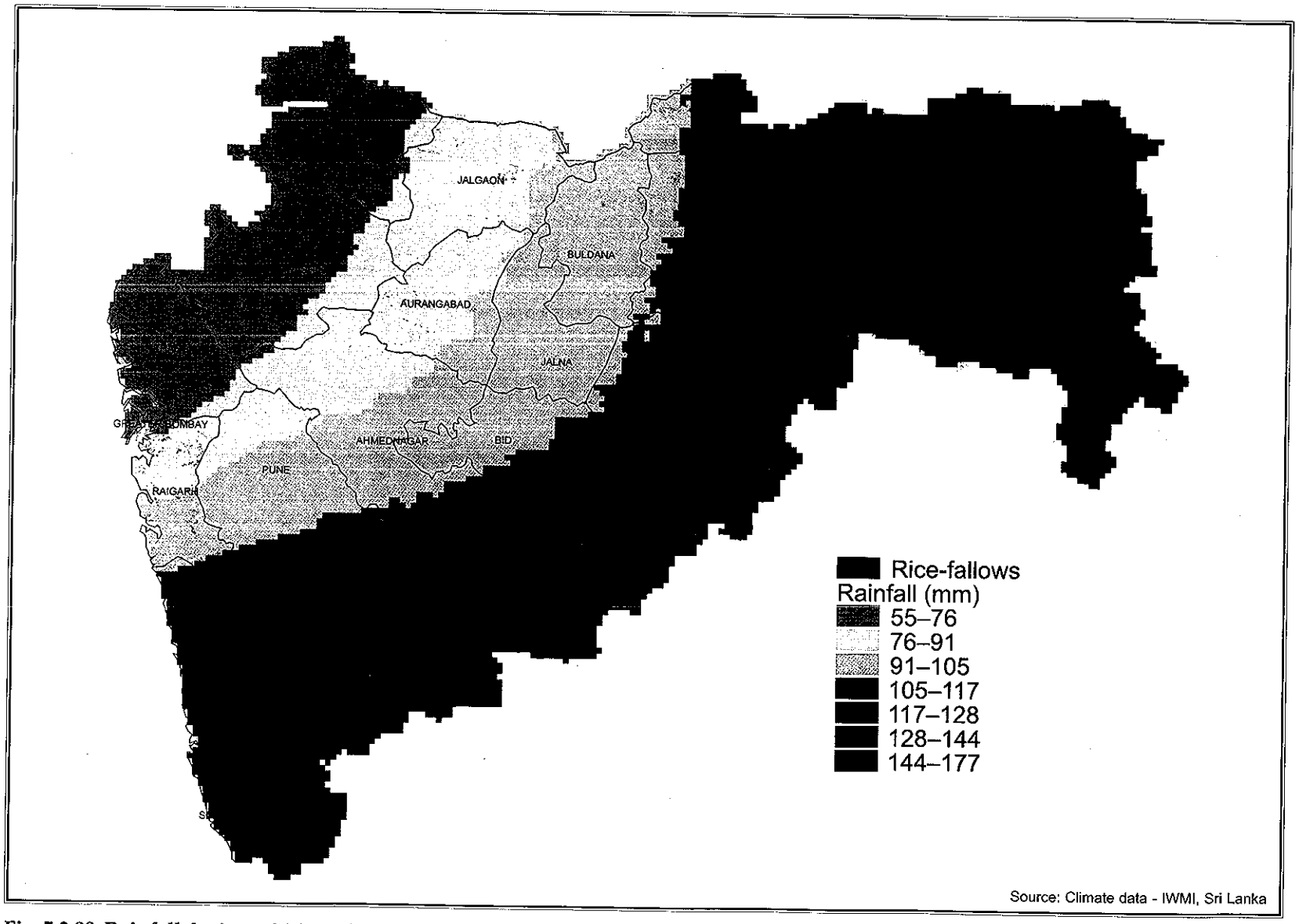


Fig. 5.2.99. Rainfall during rabi (October–March) in Maharashtra, India

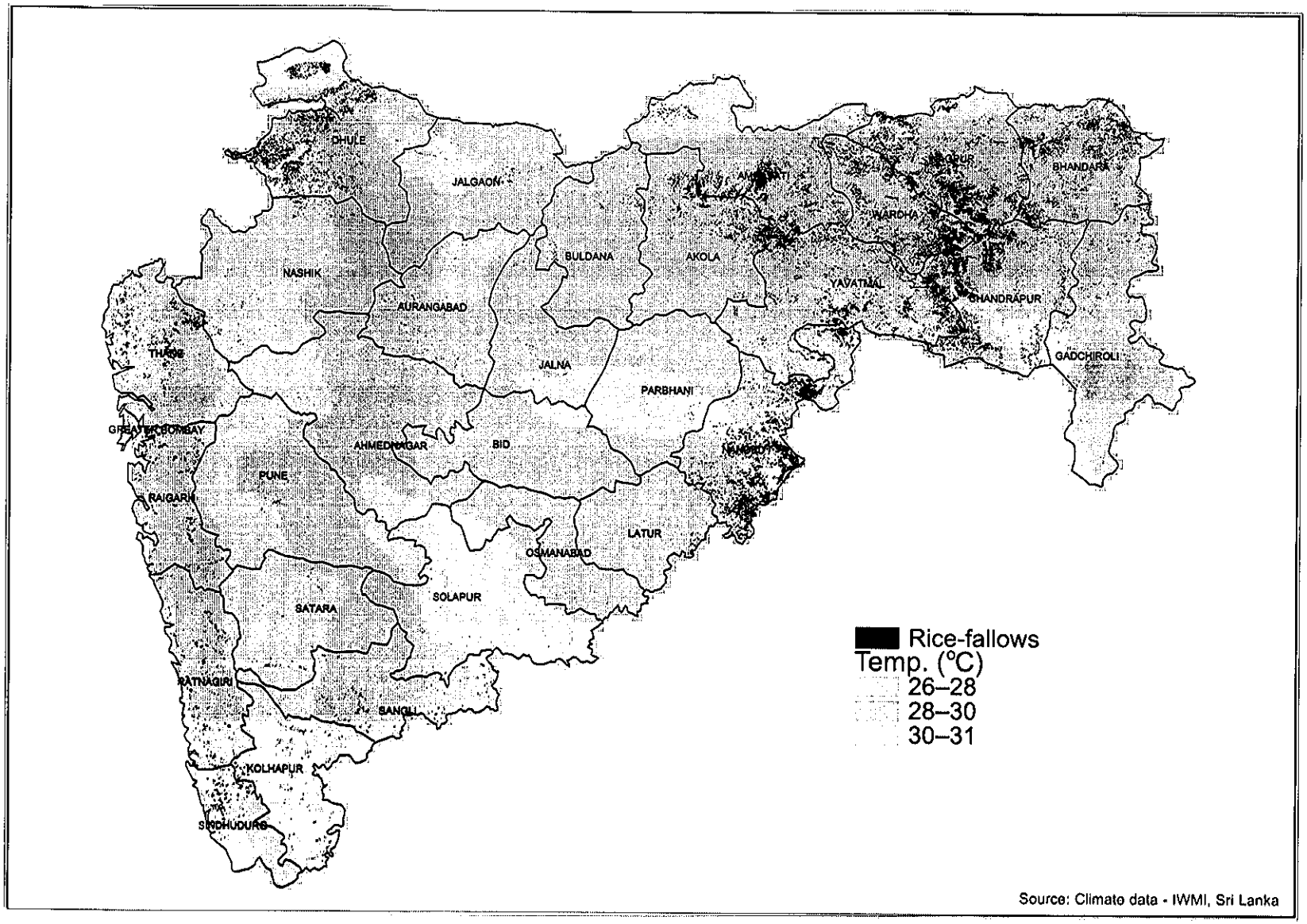


Fig. 5.2.100. Mean maximum temperature during rabi (October–March) in Maharashtra, India

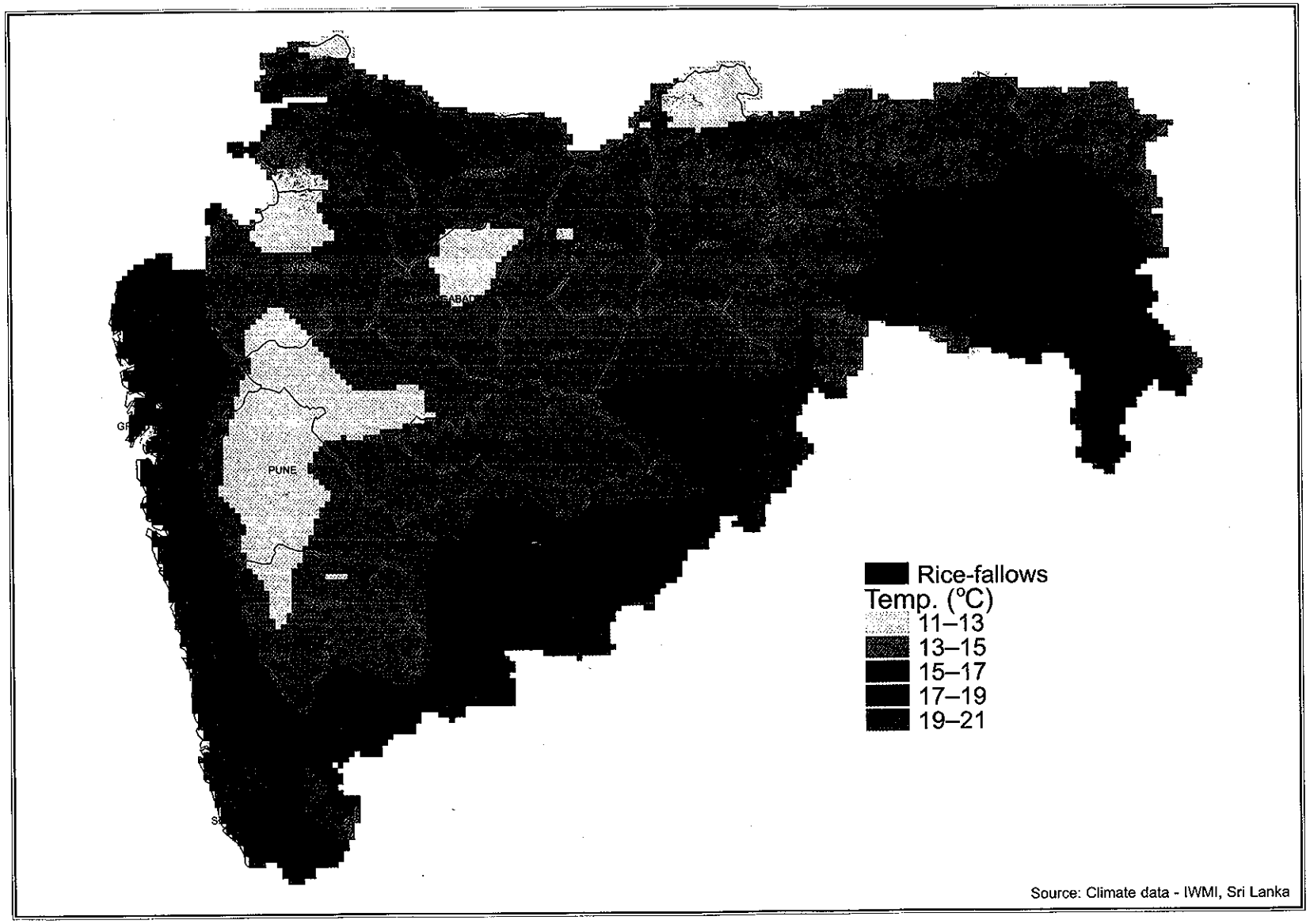


Fig. 5.2.101. Mean minimum temperature during rabi (October–March) in Maharashtra, India

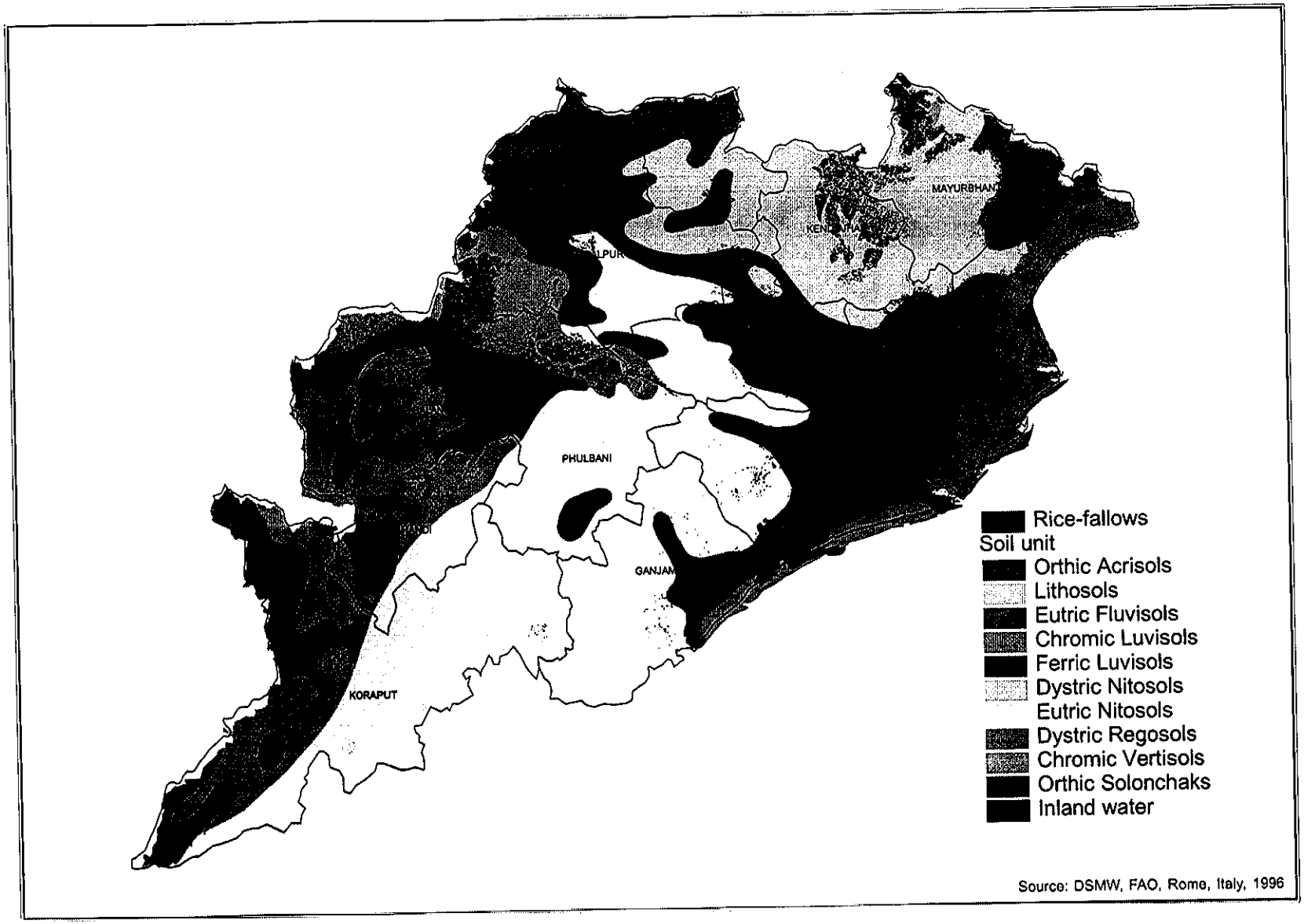


Fig. 5.2.102. Soils of Orissa, India

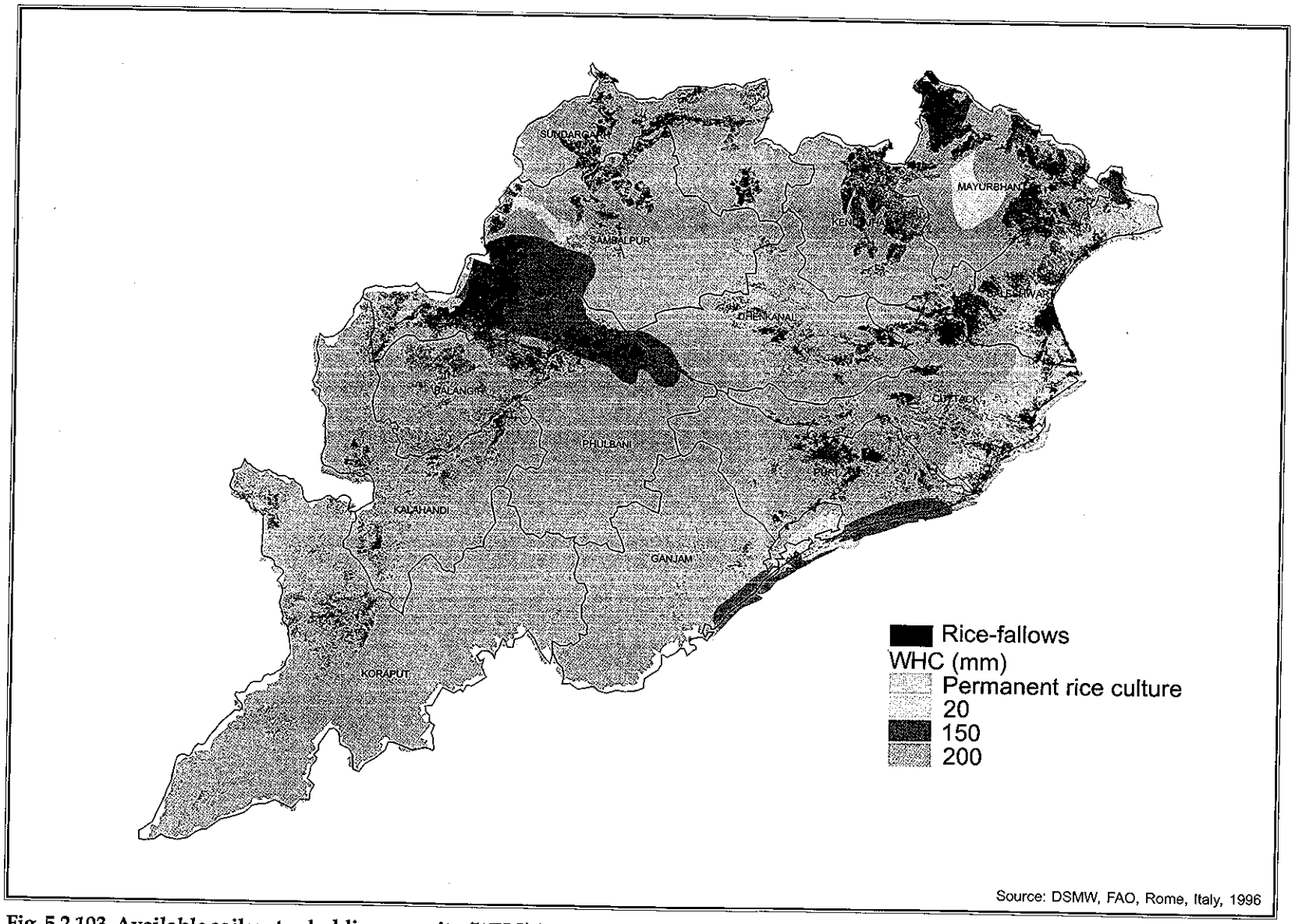


Fig. 5.2.103. Available soil water-holding capacity (WHC) in Orissa, India

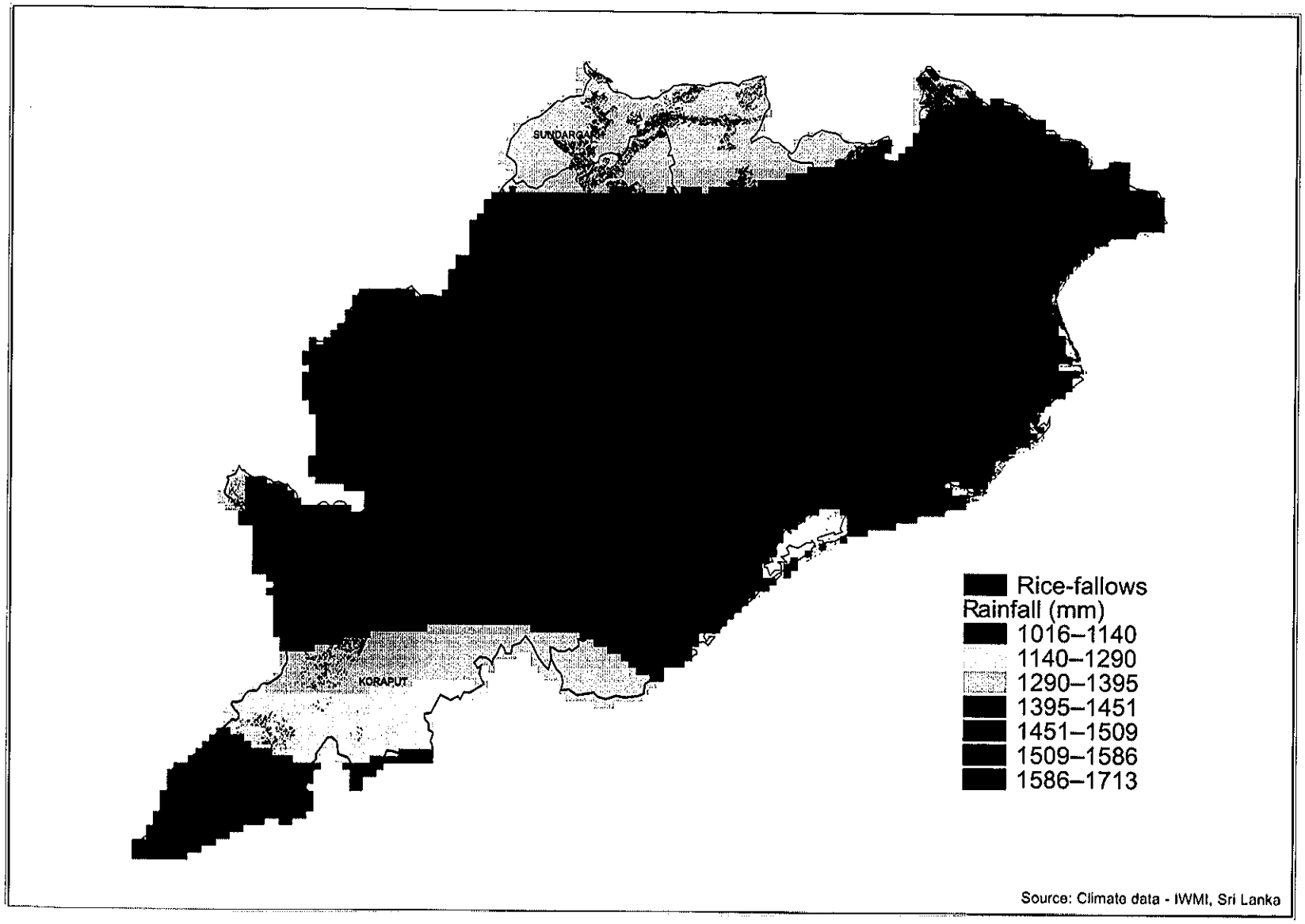


Fig. 5.2.104. Annual rainfall in Orissa, India

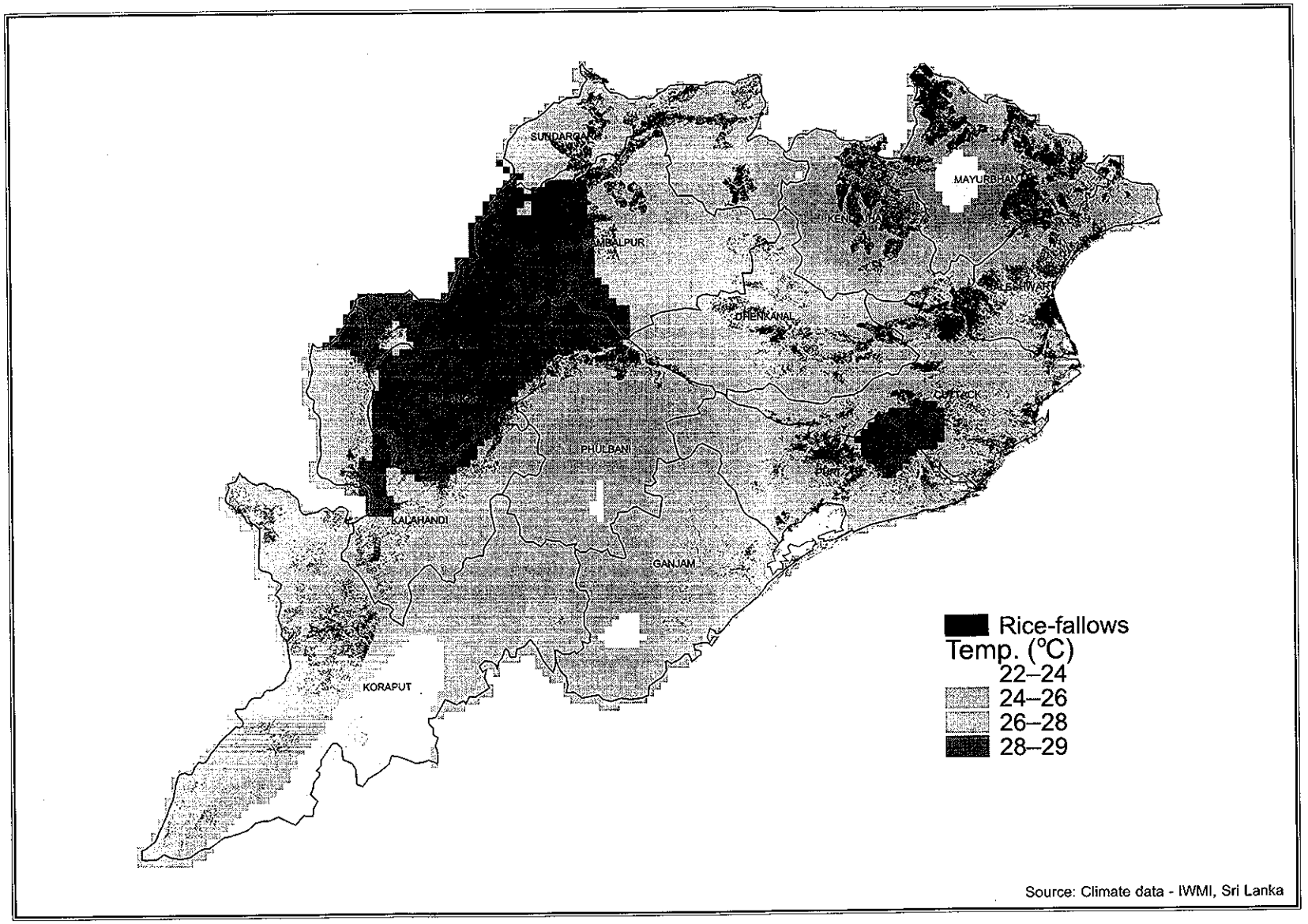


Fig. 5.2.105. Annual mean maximum temperature in Orissa, India

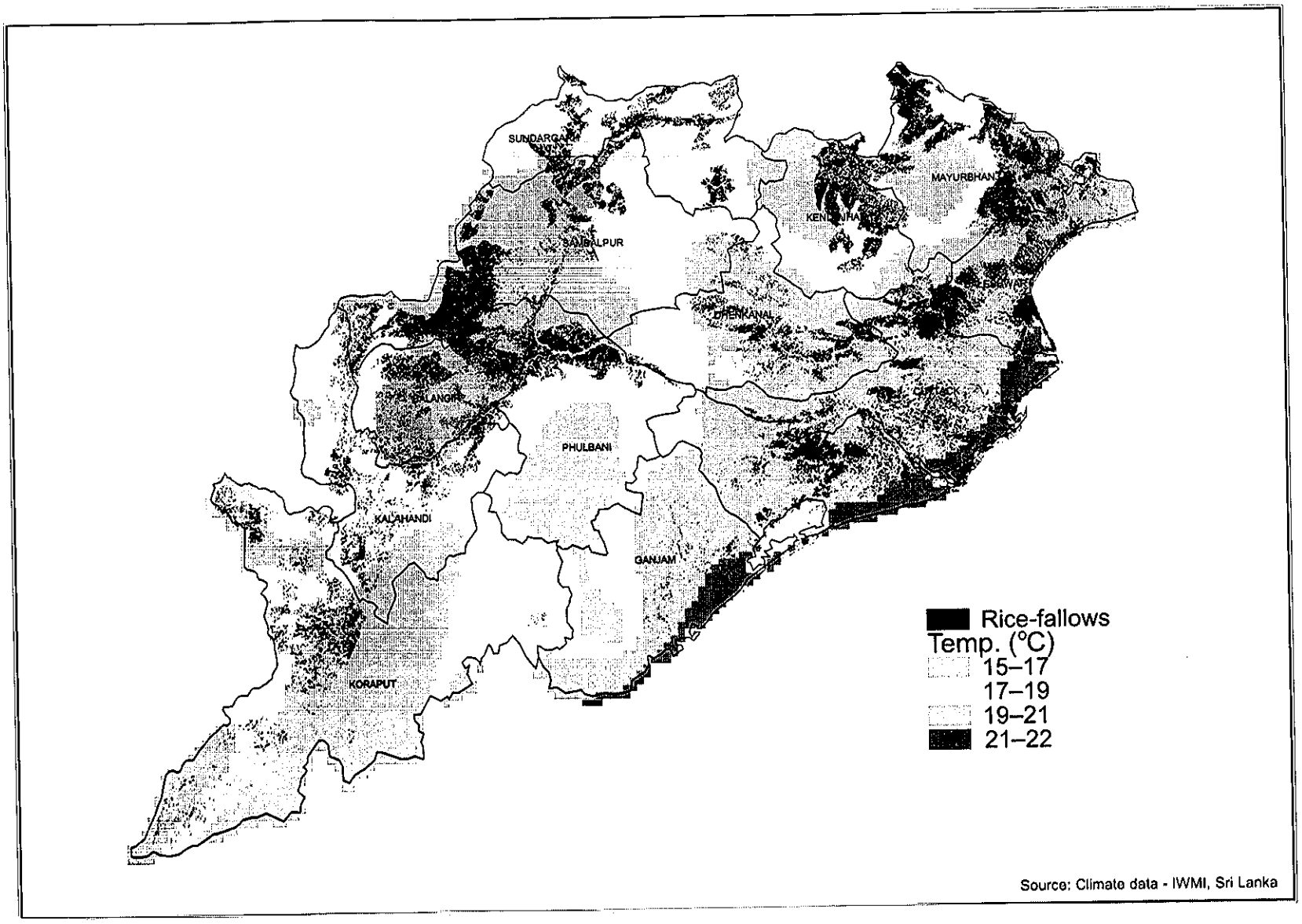


Fig. 5.2.106. Annual mean minimum temperature in Orissa, India

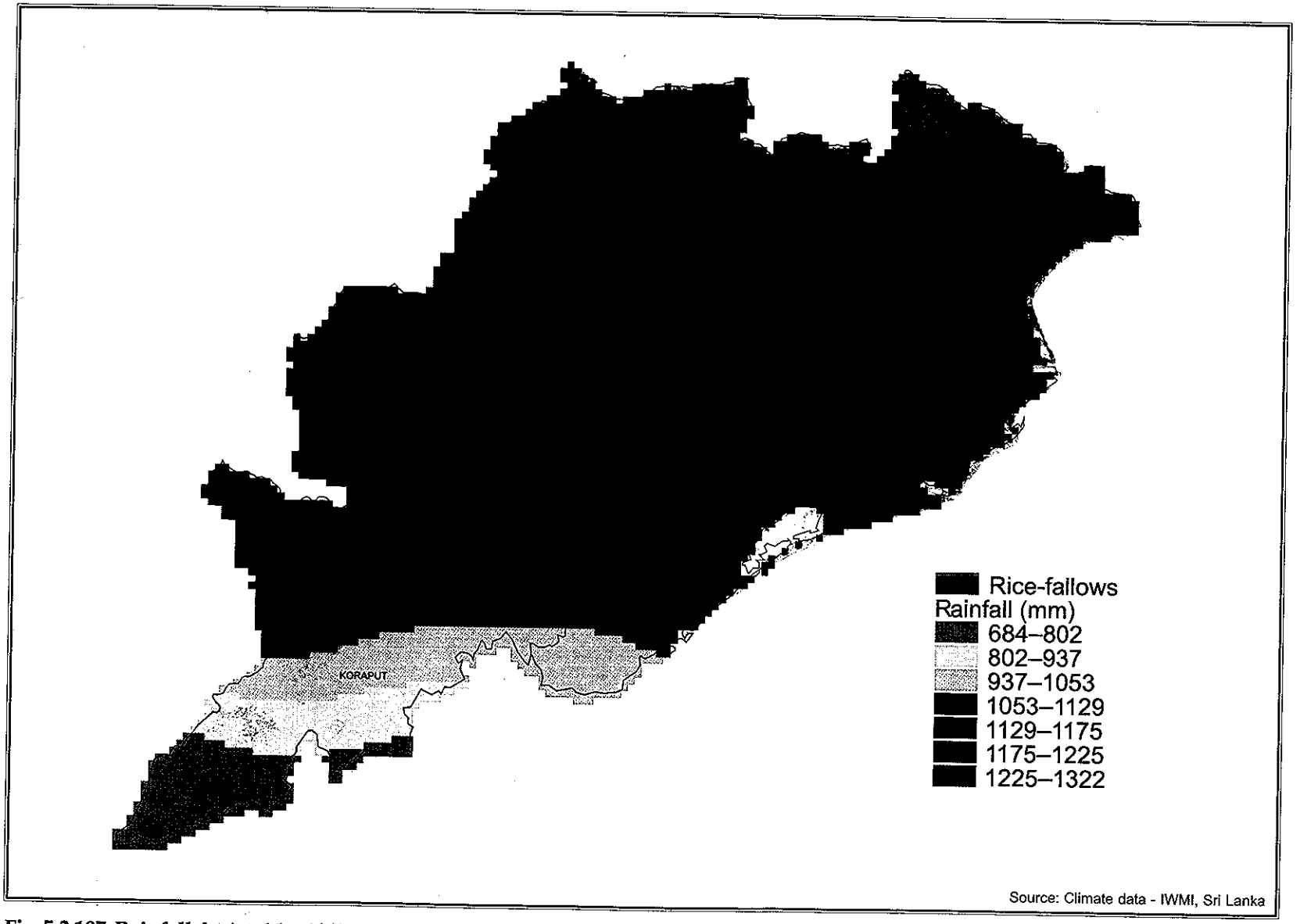


Fig. 5.2.107. Rainfall during kharif (June–September) in Orissa, India

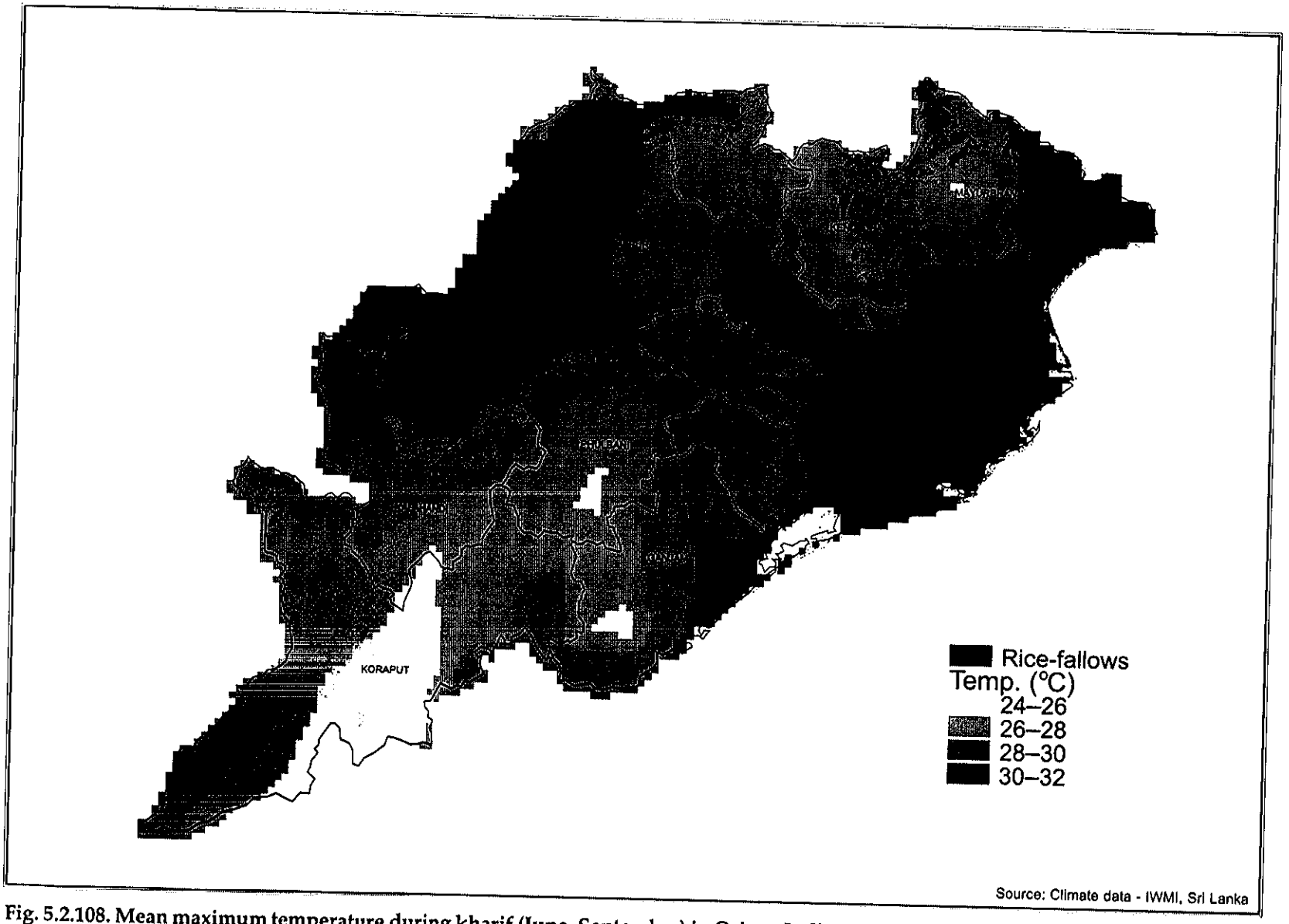


Fig. 5.2.108. Mean maximum temperature during kharif (June-September) in Orissa, India

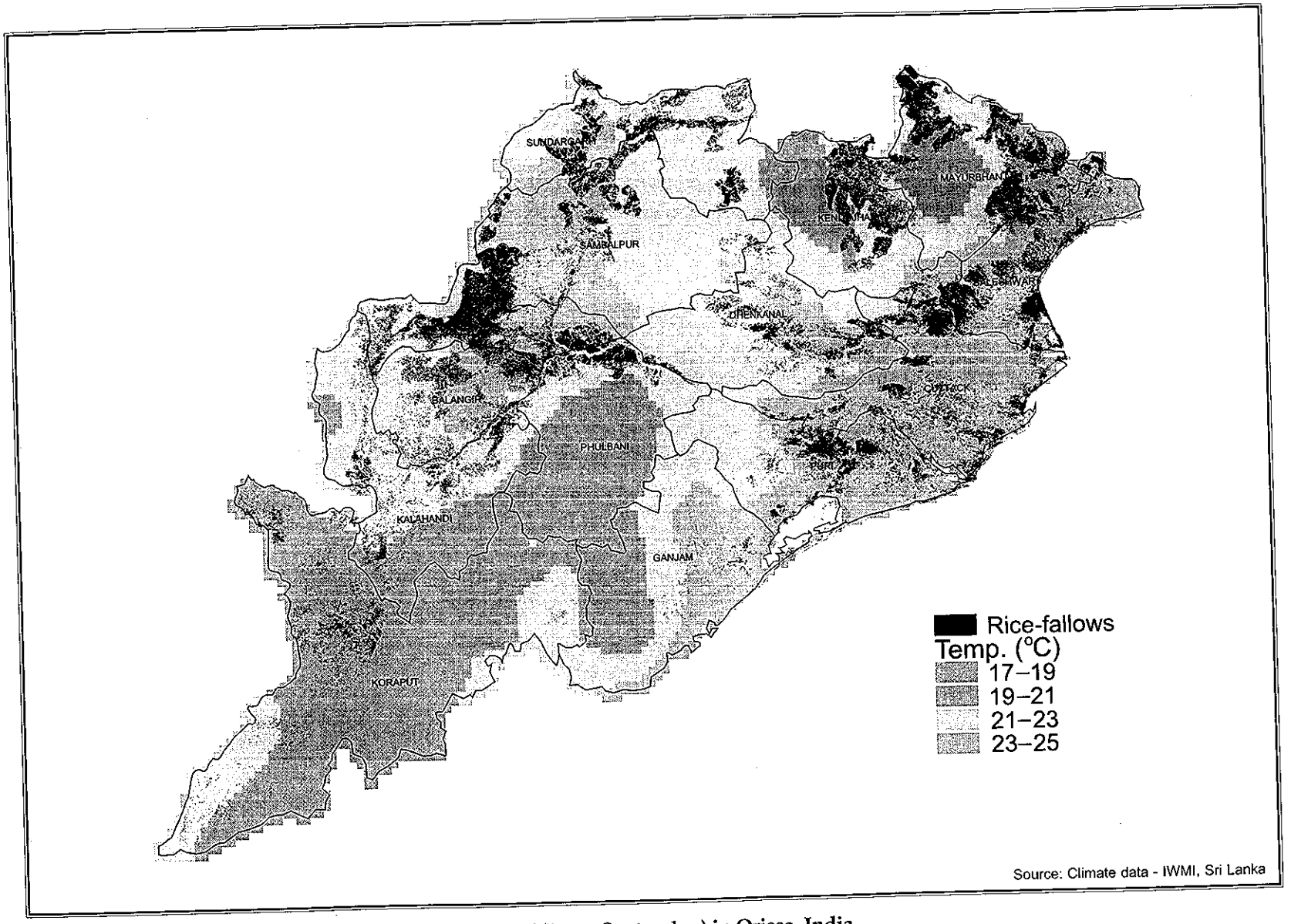


Fig. 5.2.109. Mean minimum temperature during kharif (June–September) in Orissa, India

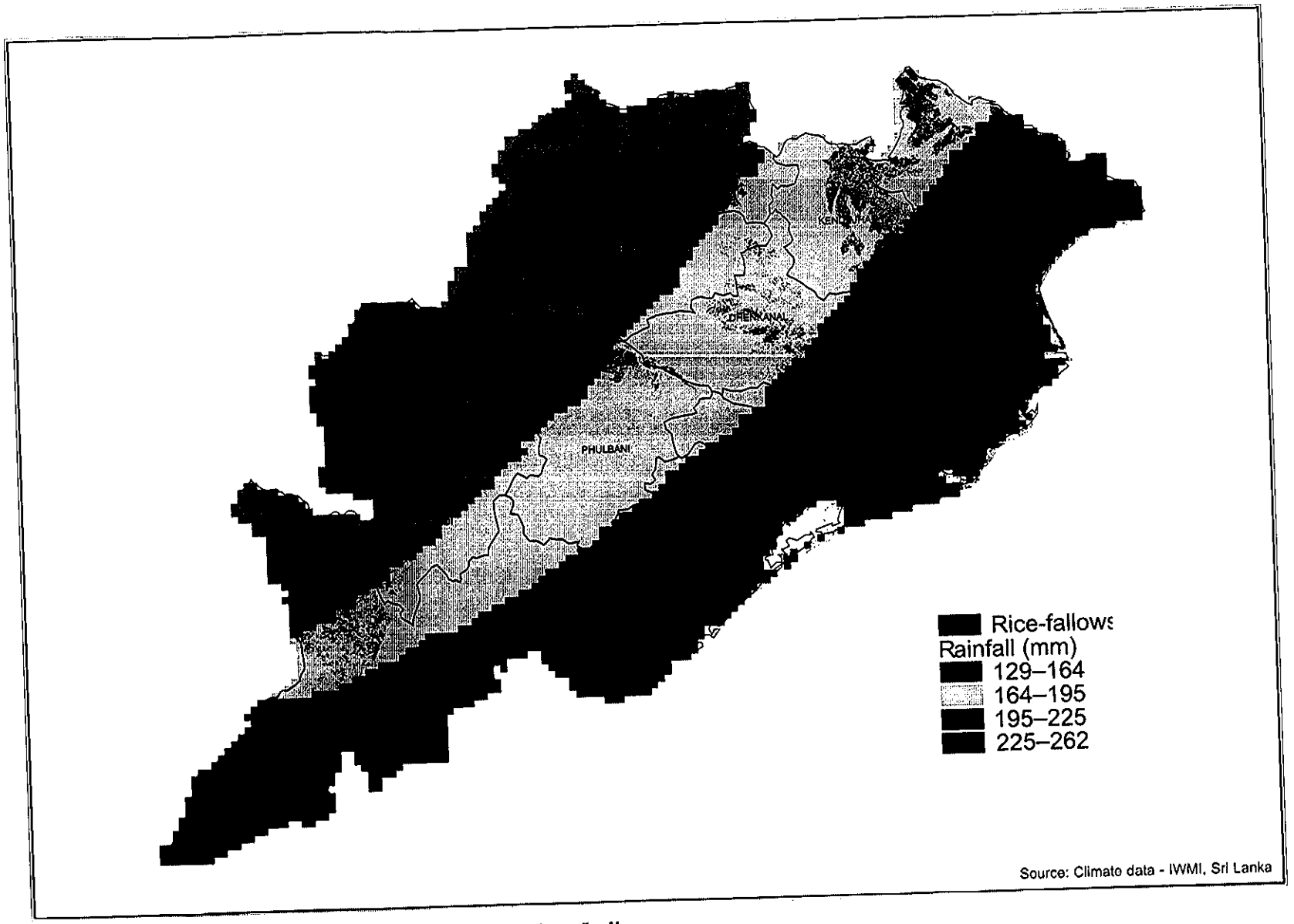


Fig. 5.2.110. Rainfall during rabi (October-March) in Orissa, India

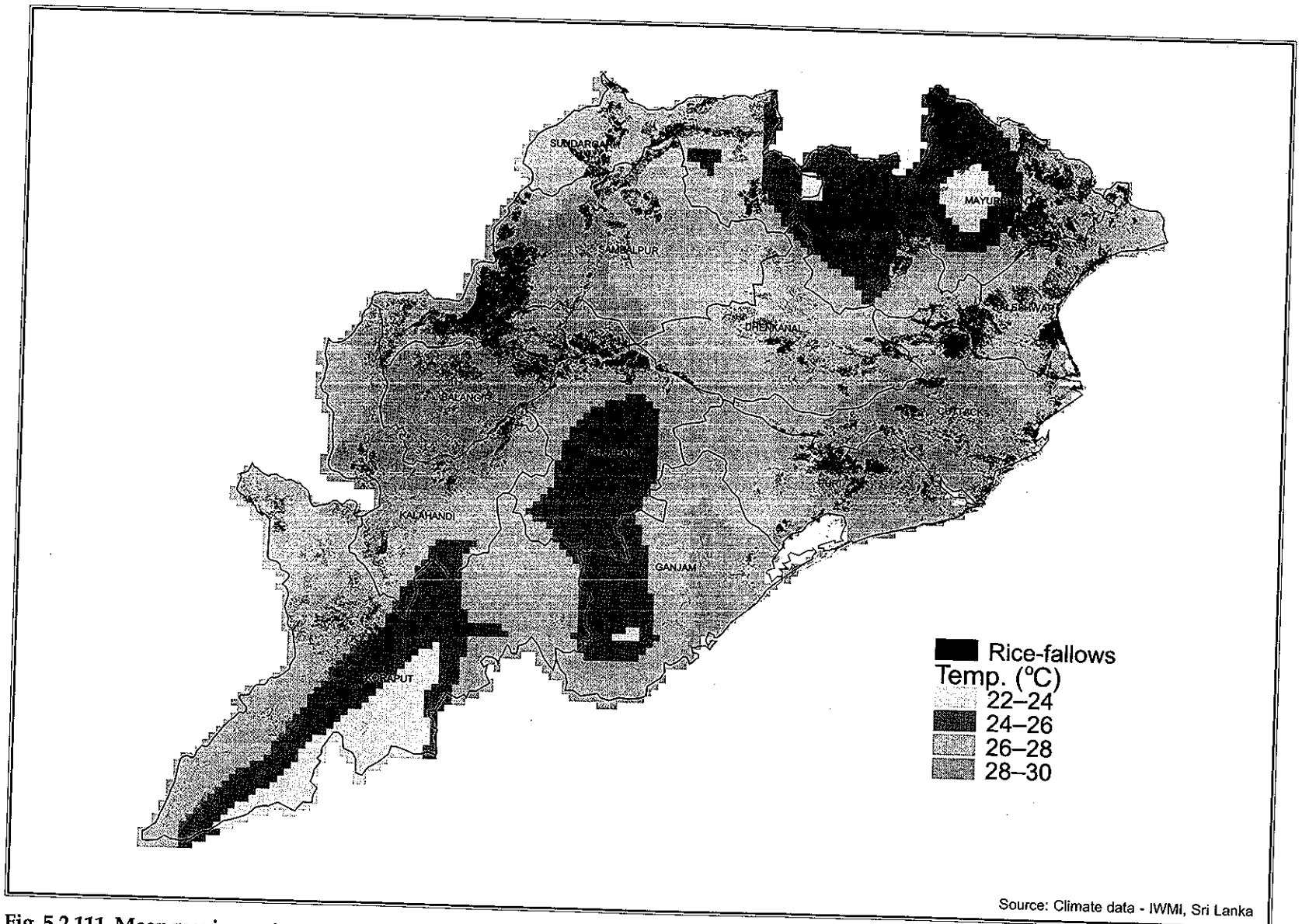


Fig. 5.2.111. Mean maximum temperature during rabi (October–March) in Orissa, India

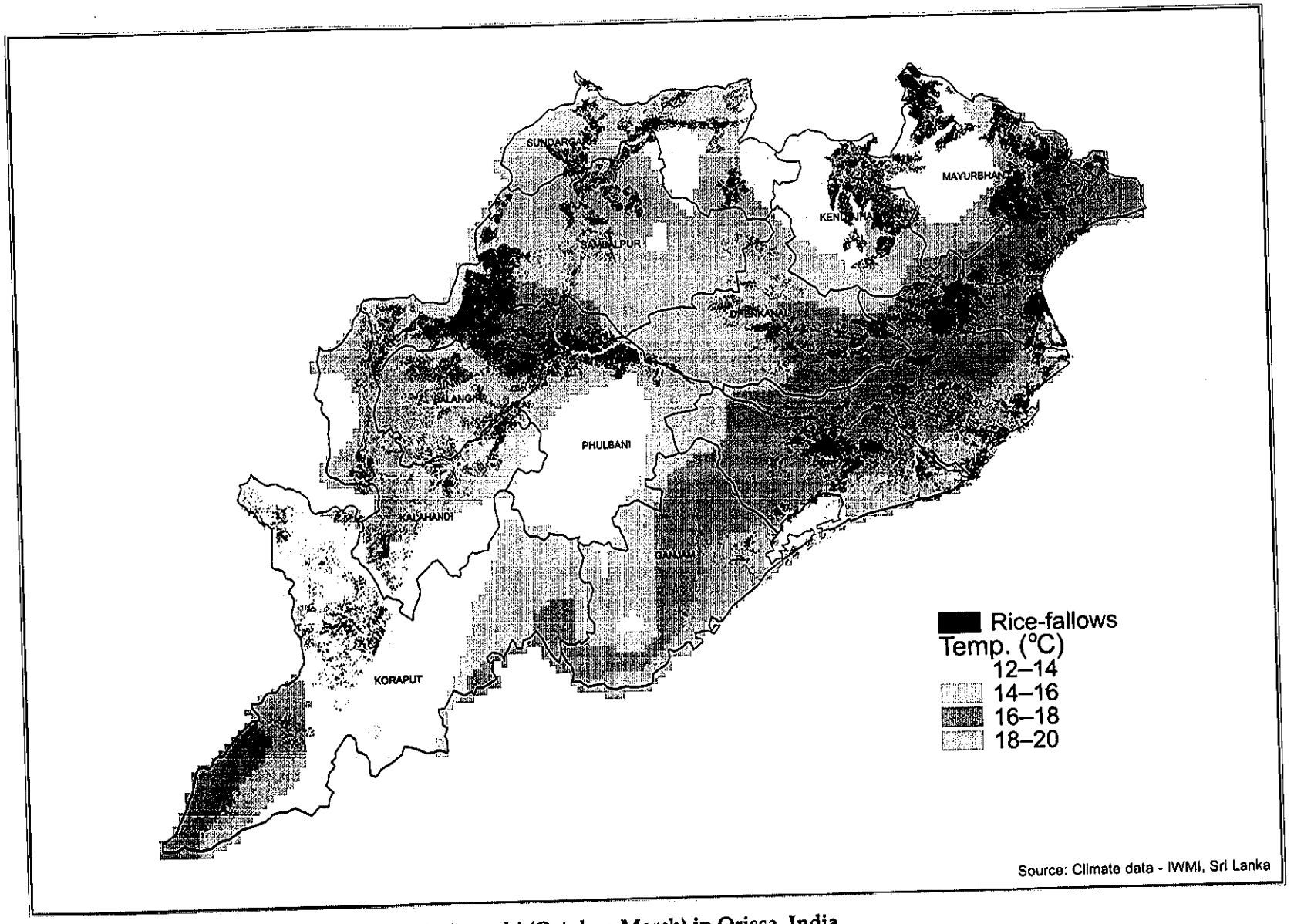


Fig. 5.2.112. Mean minimum temperature during rabi (October–March) in Orissa, India

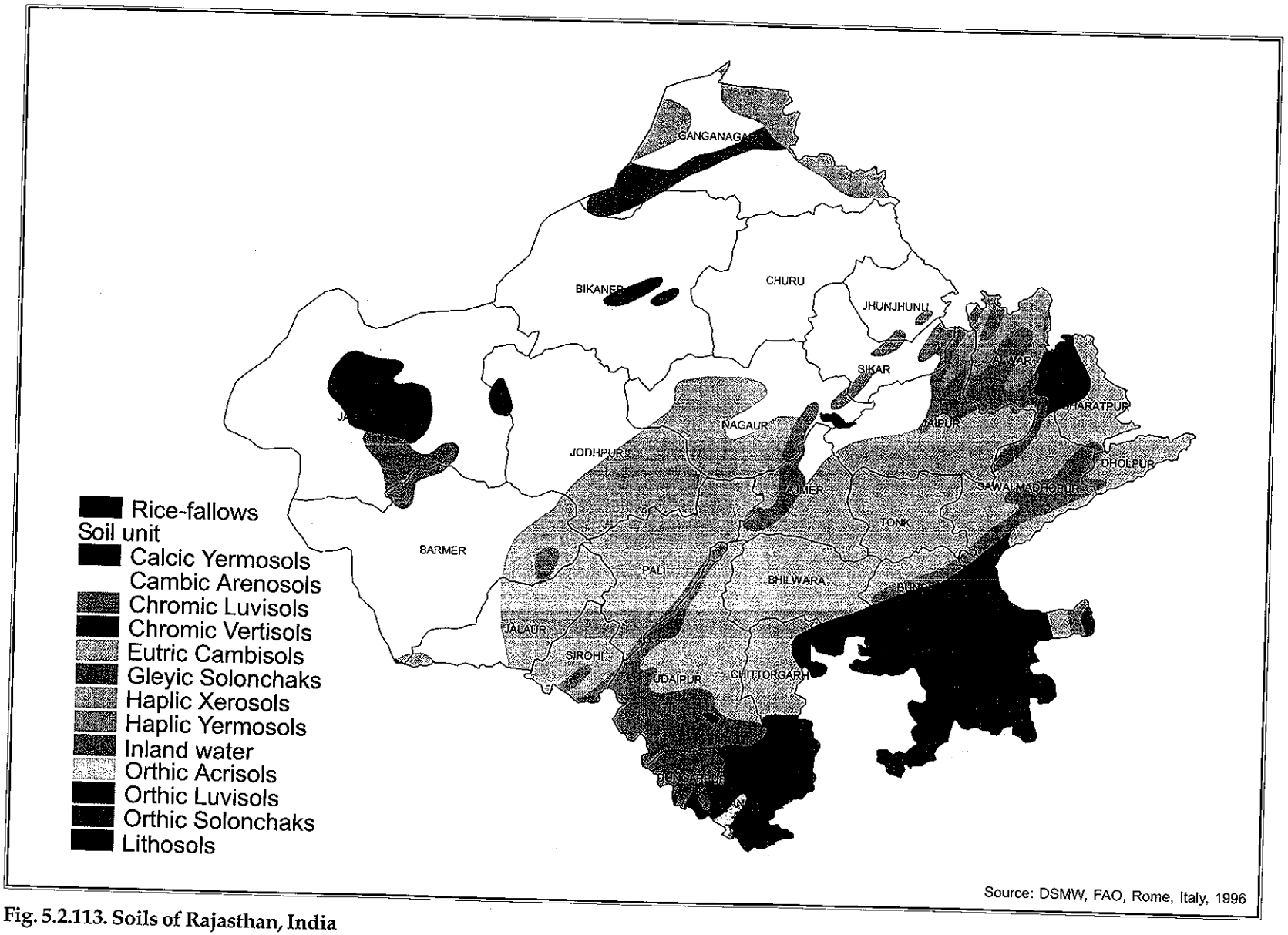
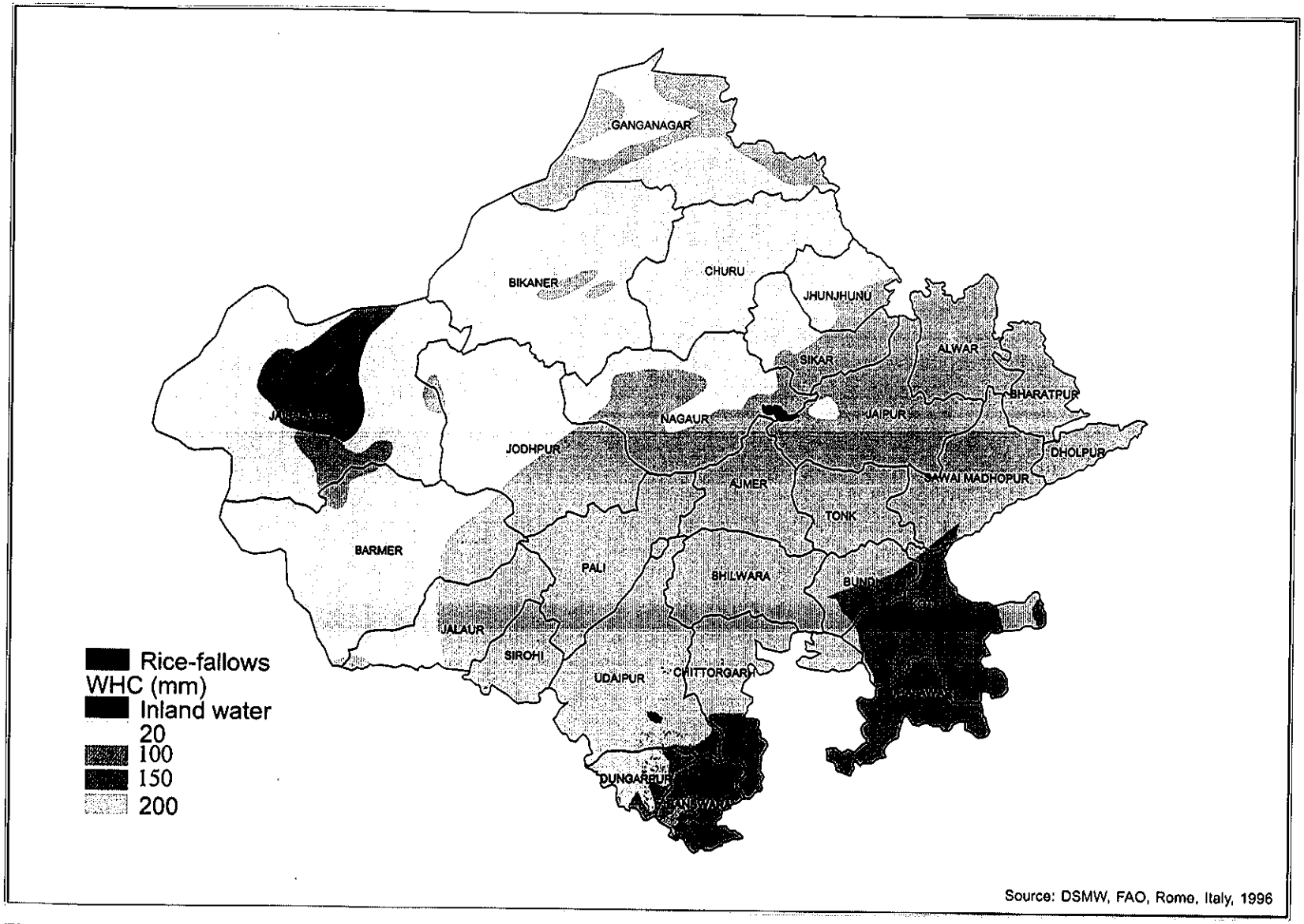


Fig. 5.2.113. Soils of Rajasthan, India



Source: DSMW, FAO, Rome, Italy, 1996

Fig. 5.2.114. Available soil water-holding capacity (WHC) in Rajasthan, India

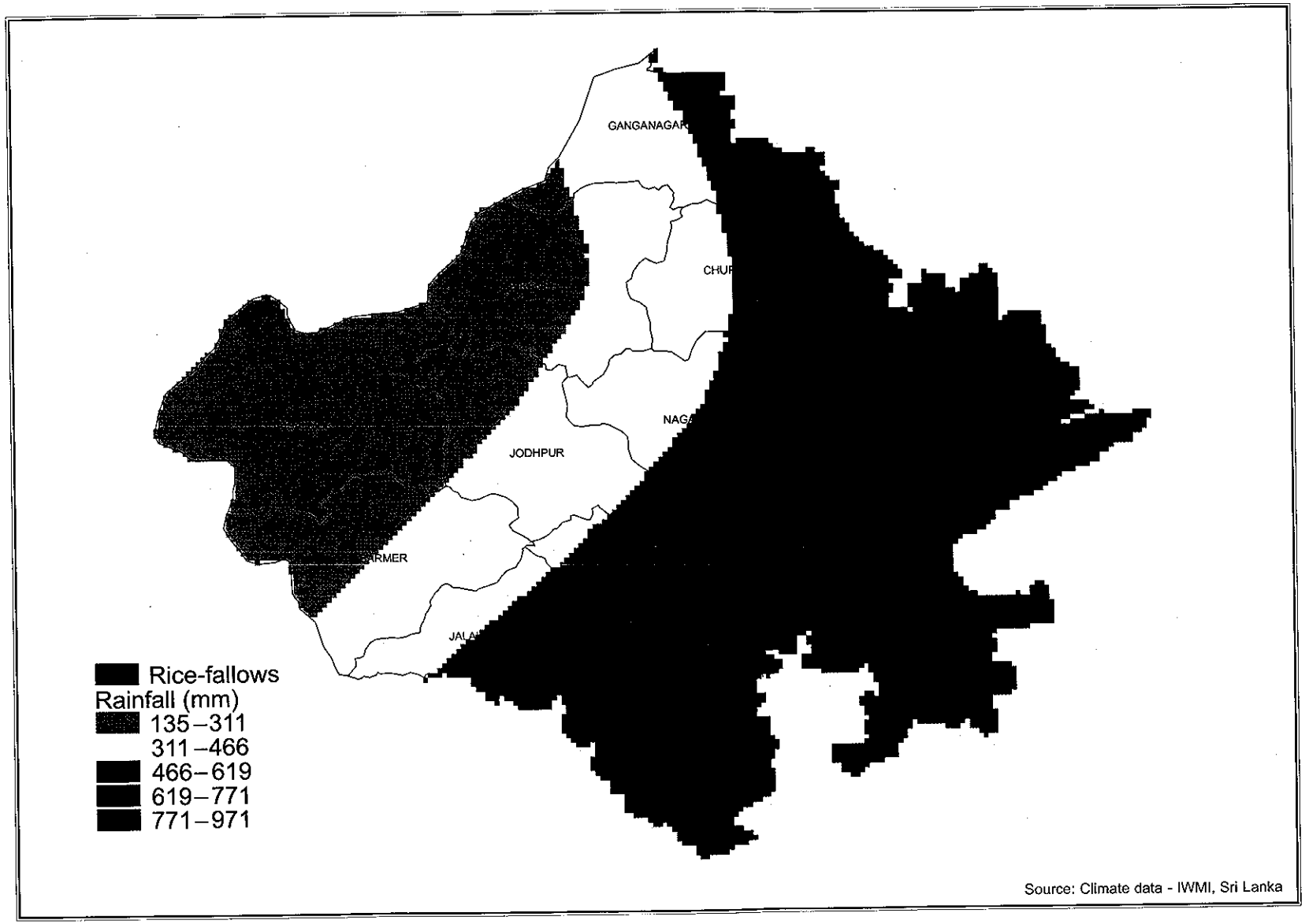


Fig. 5.2.115. Annual rainfall in Rajasthan, India

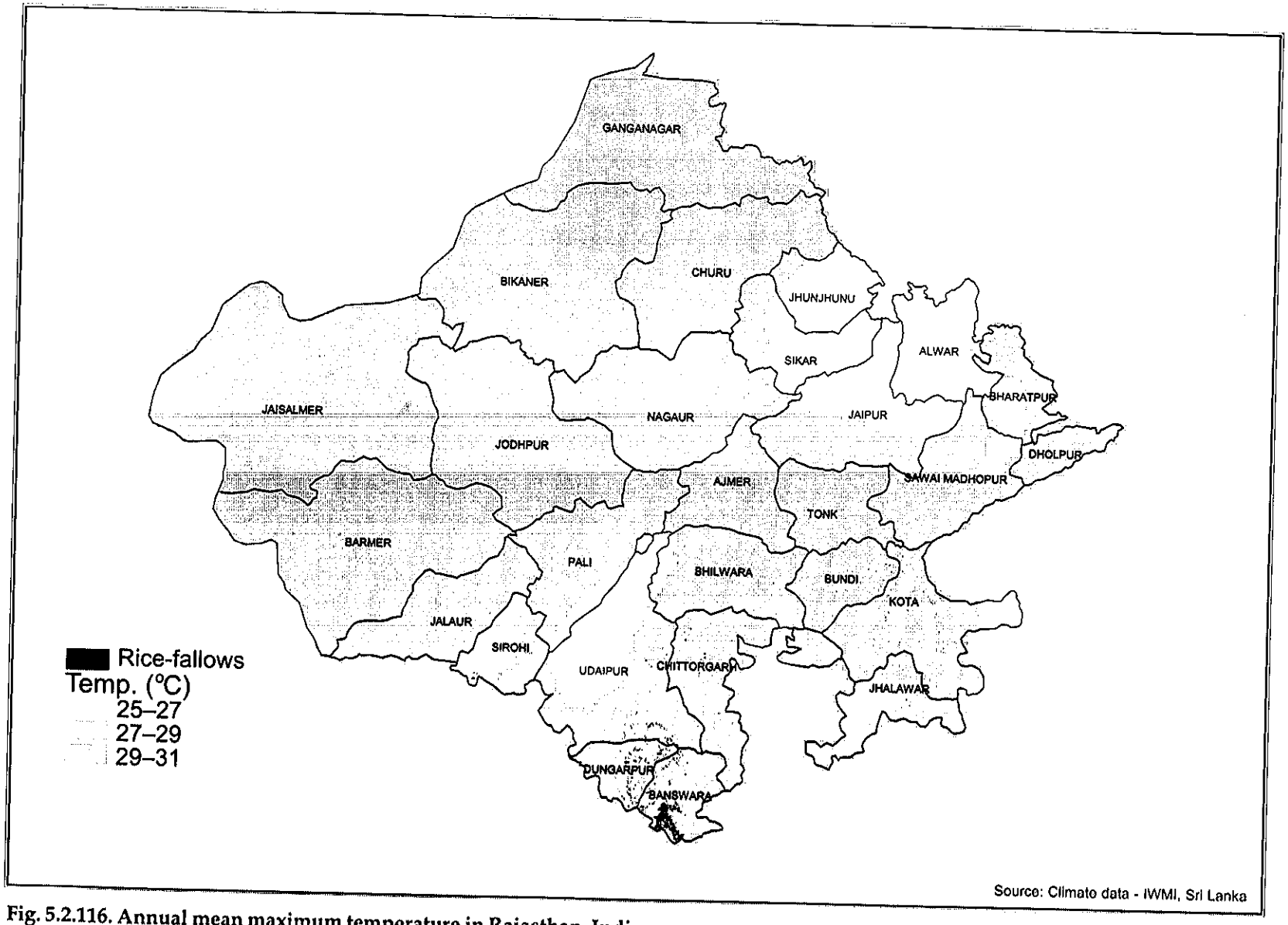


Fig. 5.2.116. Annual mean maximum temperature in Rajasthan, India

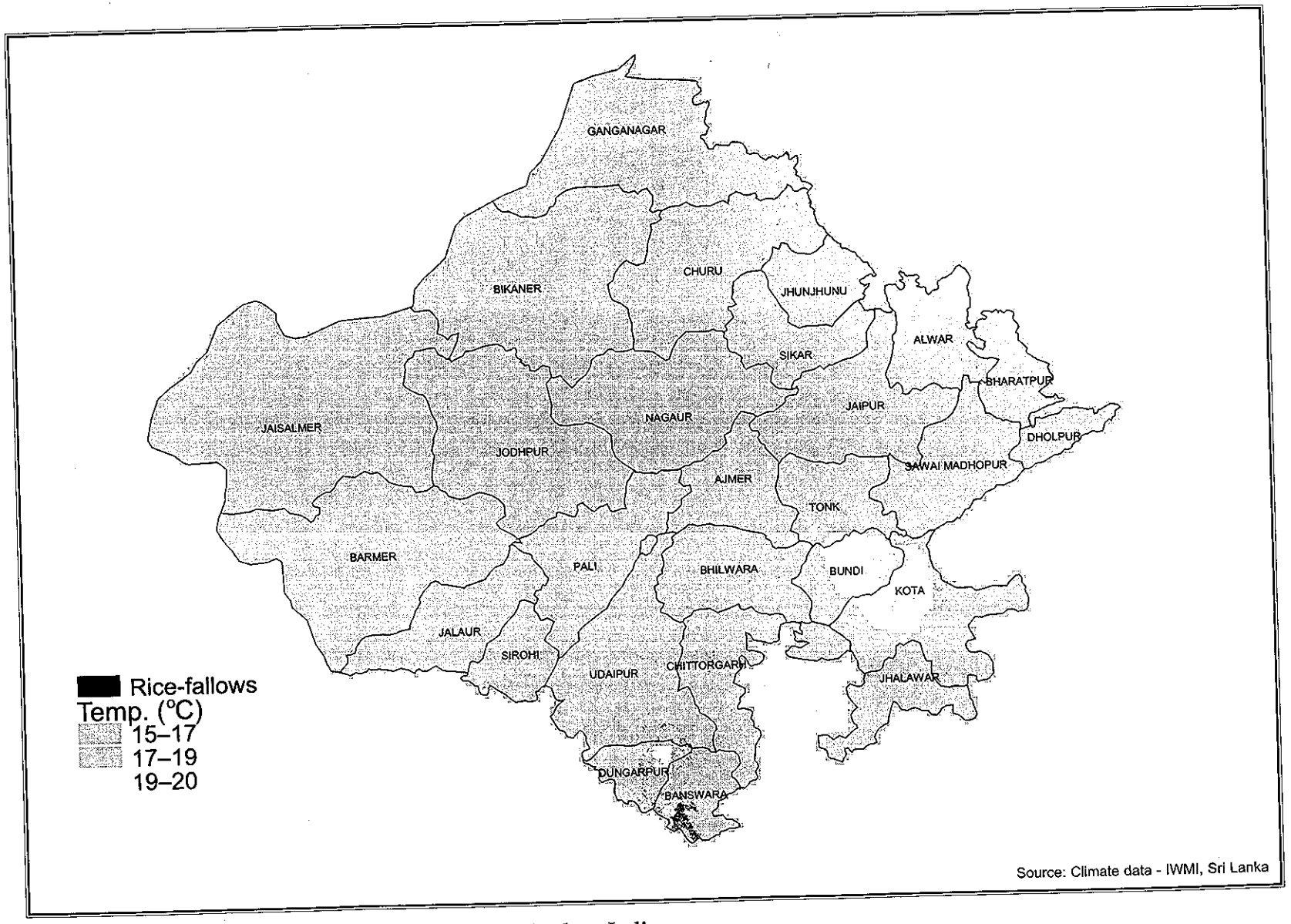


Fig. 5.2.117. Annual mean minimum temperature in Rajasthan, India

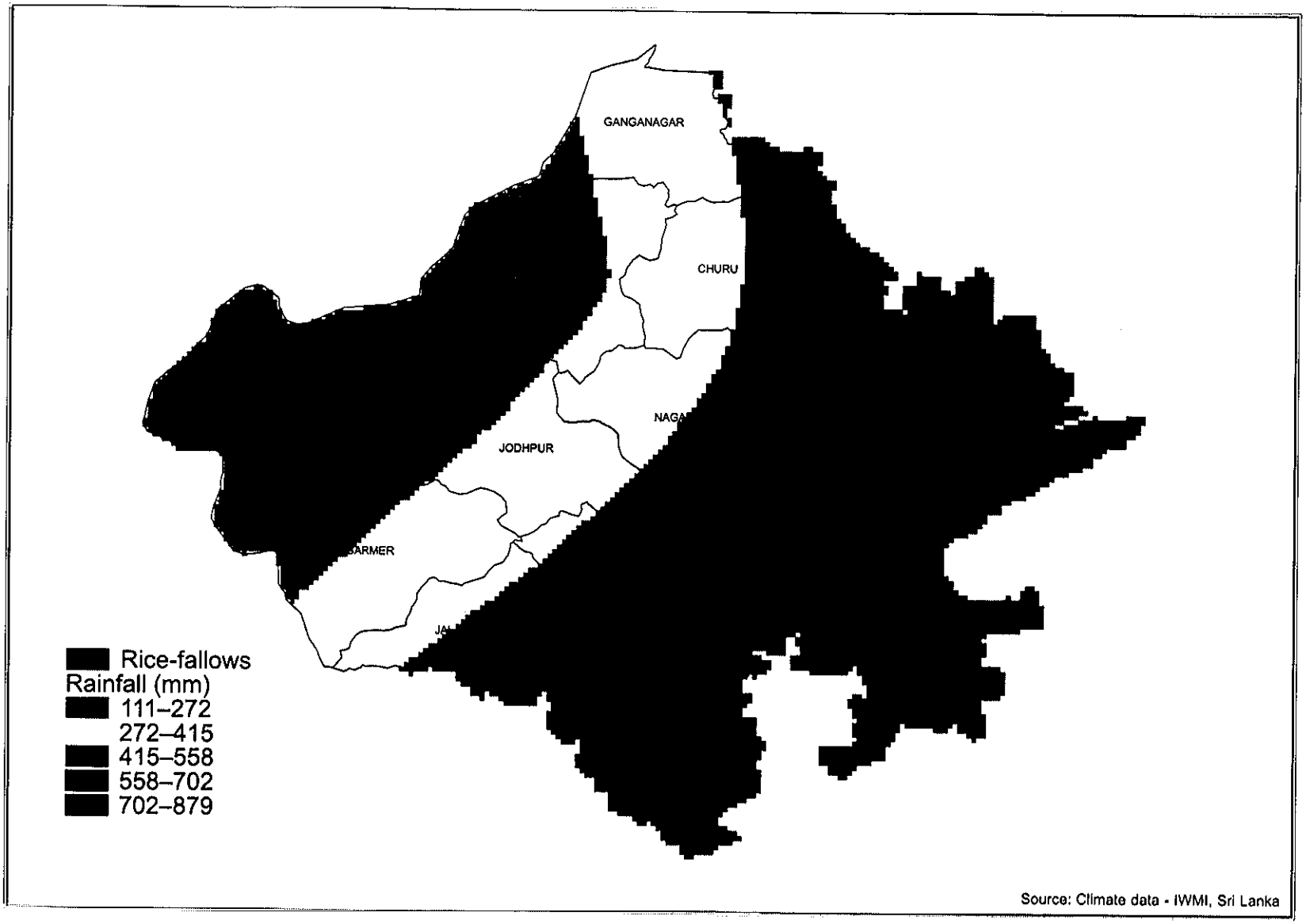


Fig. 5.2.118. Rainfall during kharif (June–September) in Rajasthan, India

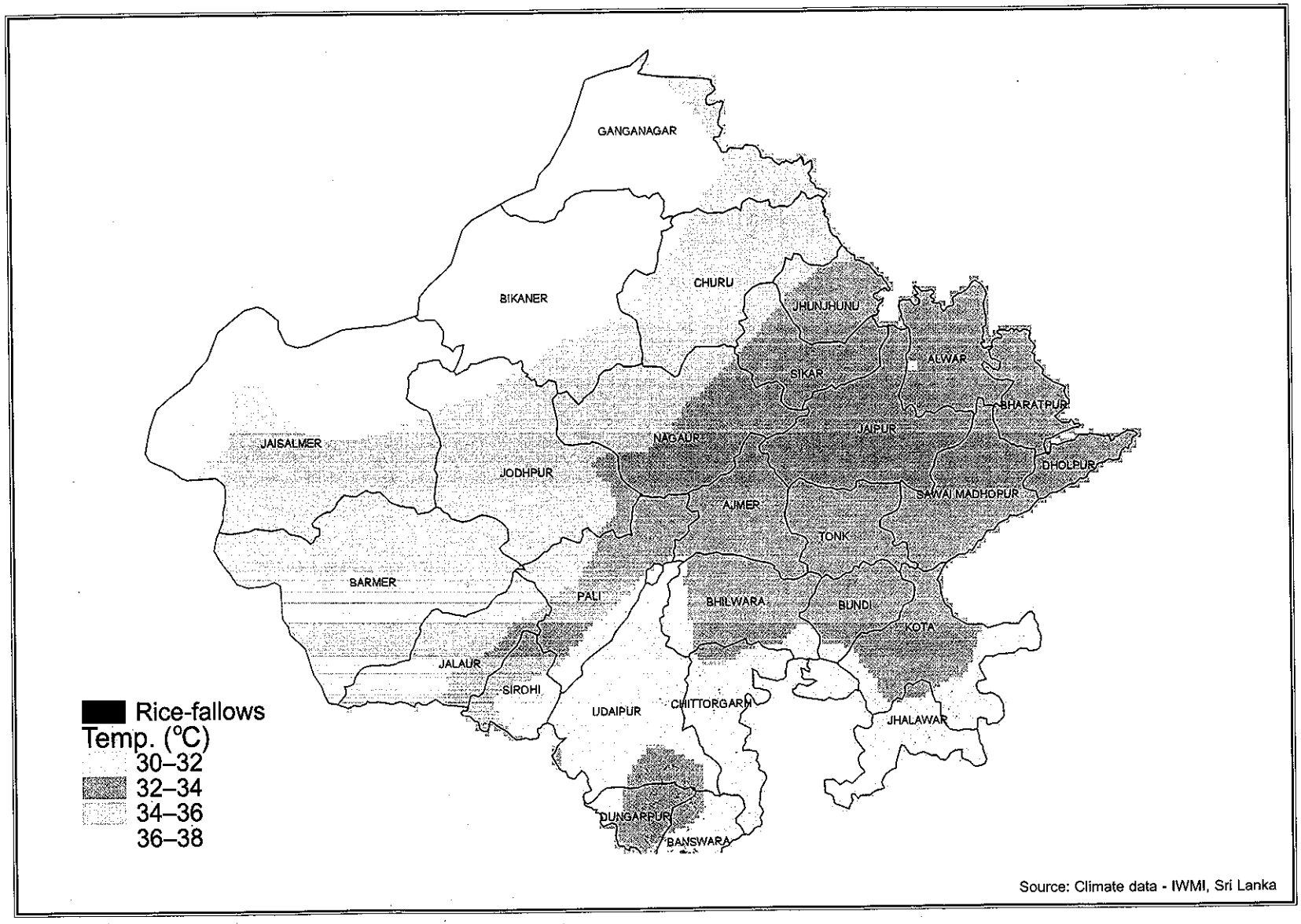
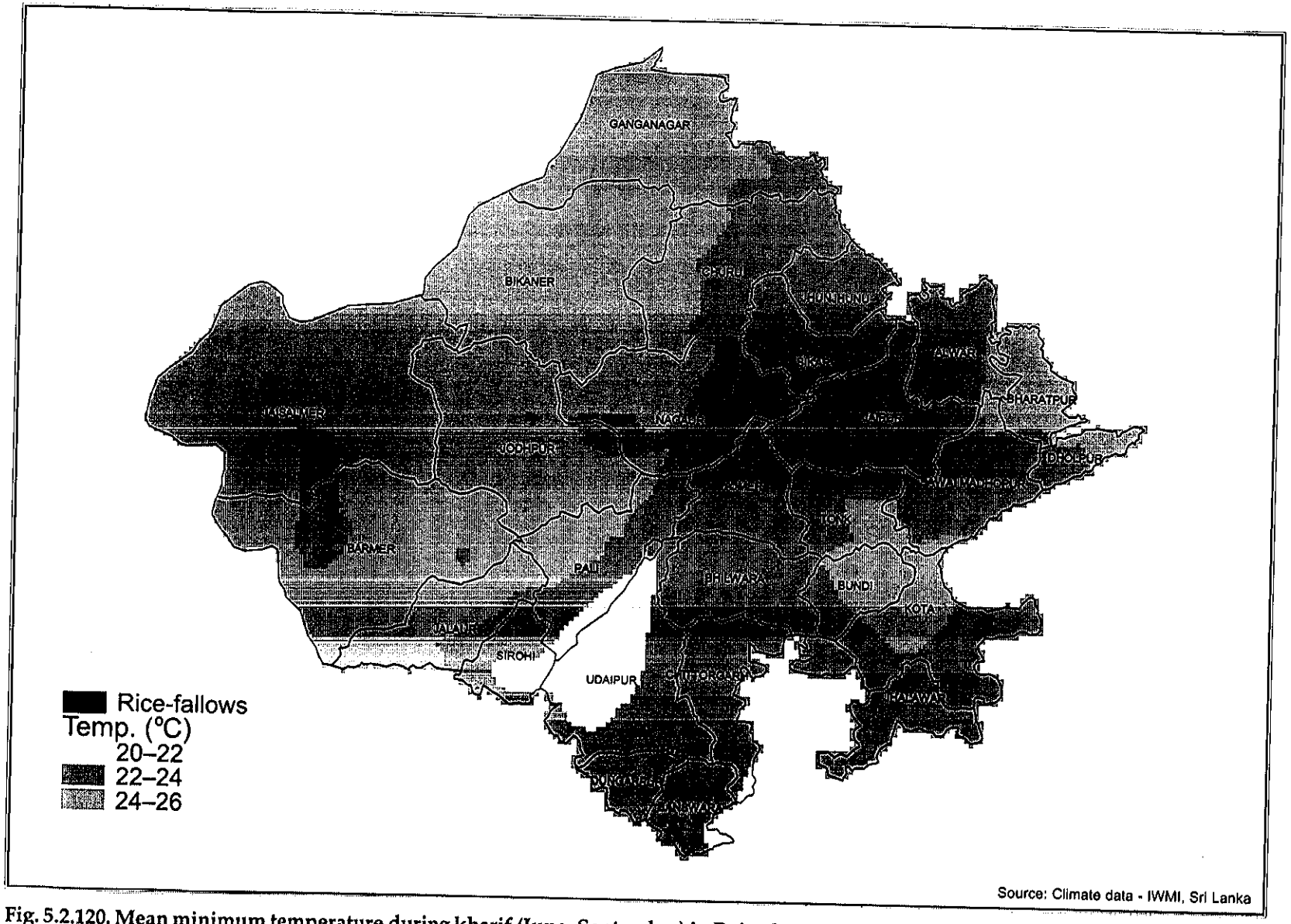


Fig. 5.2.119. Mean maximum temperature during kharif (June–September) in Rajasthan, India



Source: Climate data - IWMI, Sri Lanka

Fig. 5.2.120. Mean minimum temperature during kharif (June–September) in Rajasthan, India

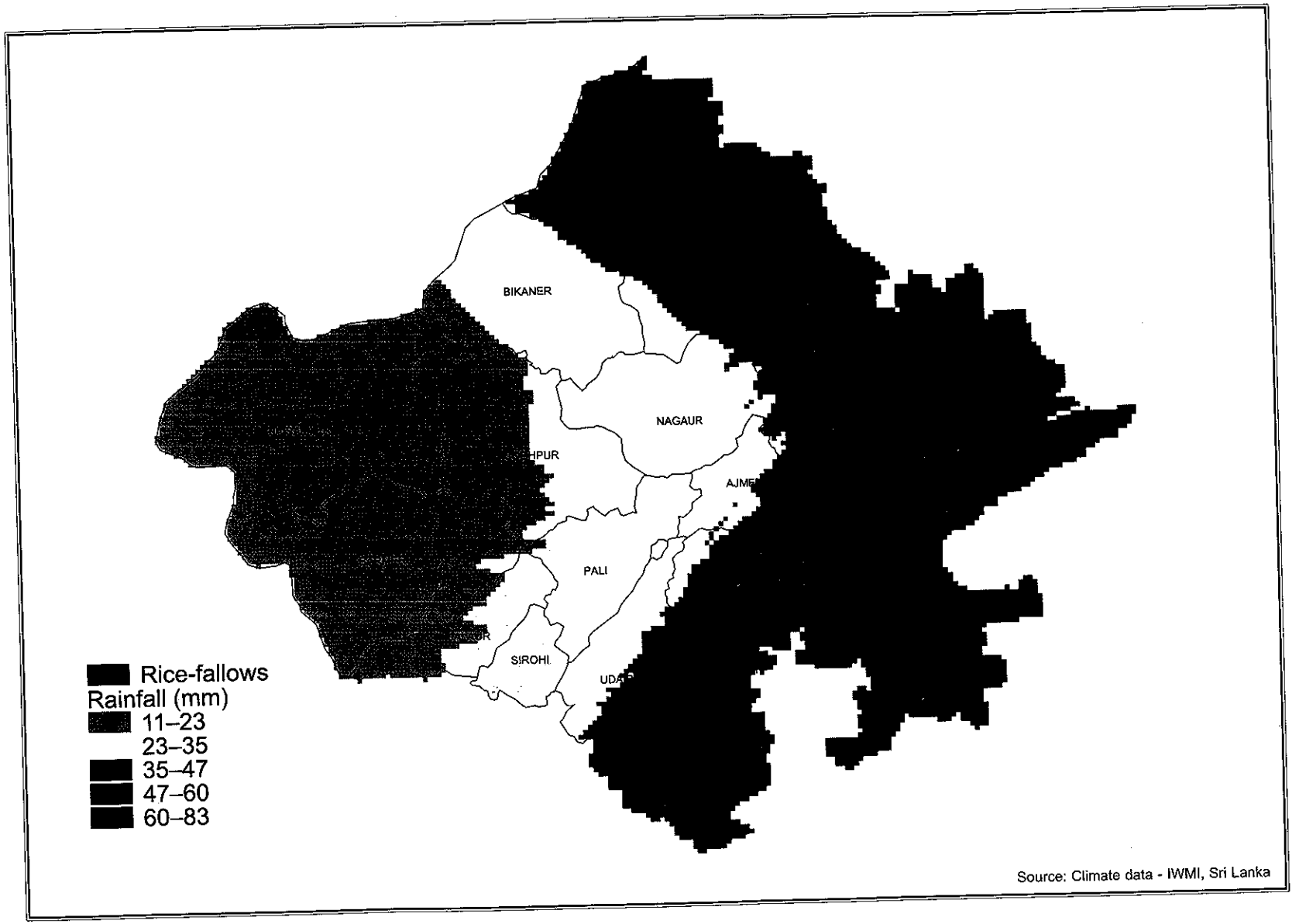


Fig. 5.2.121. Rainfall during rabi (October-March) in Rajasthan, India

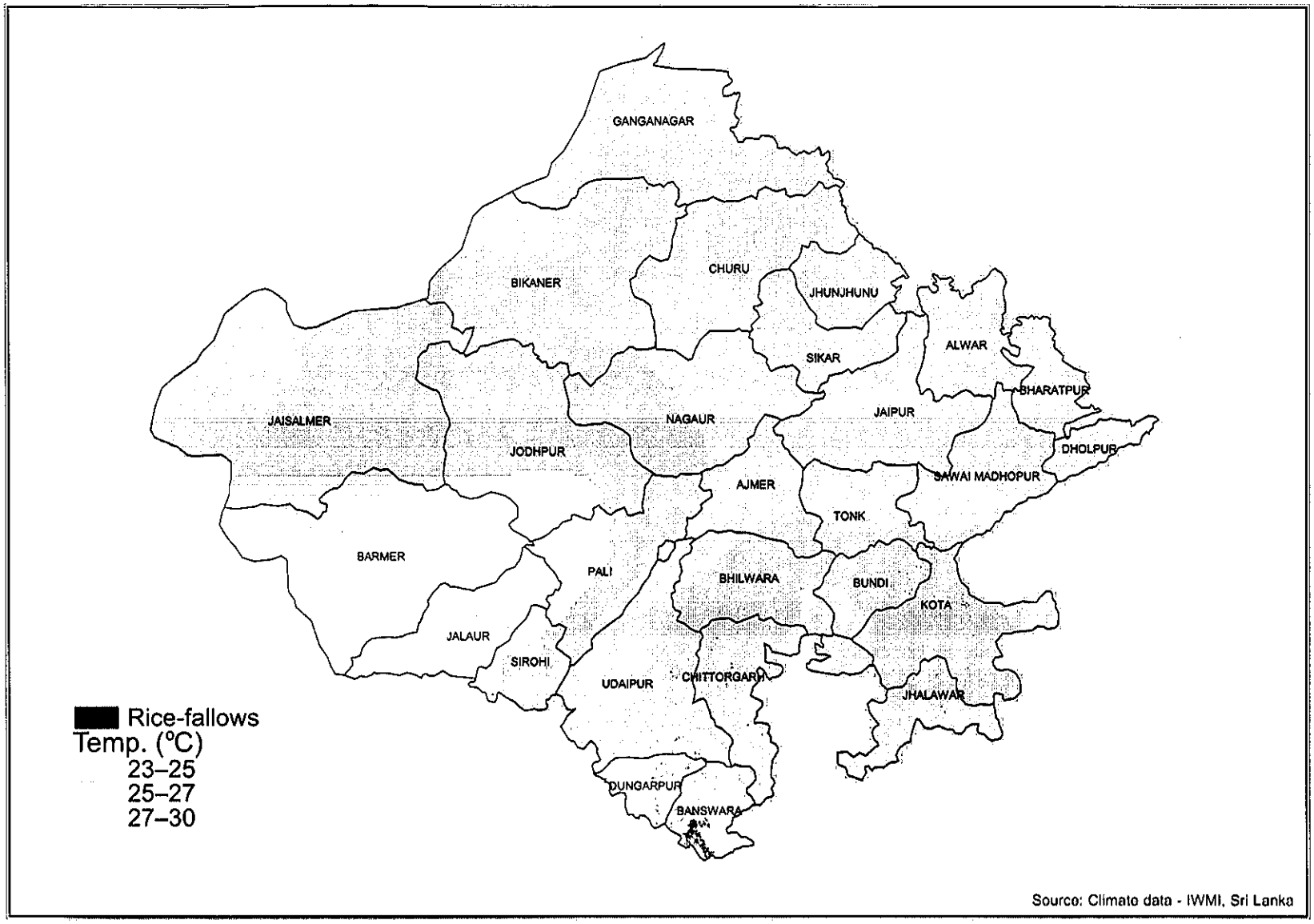


Fig. 5.2.122. Mean maximum temperature during rabi (October–March) in Rajasthan, India

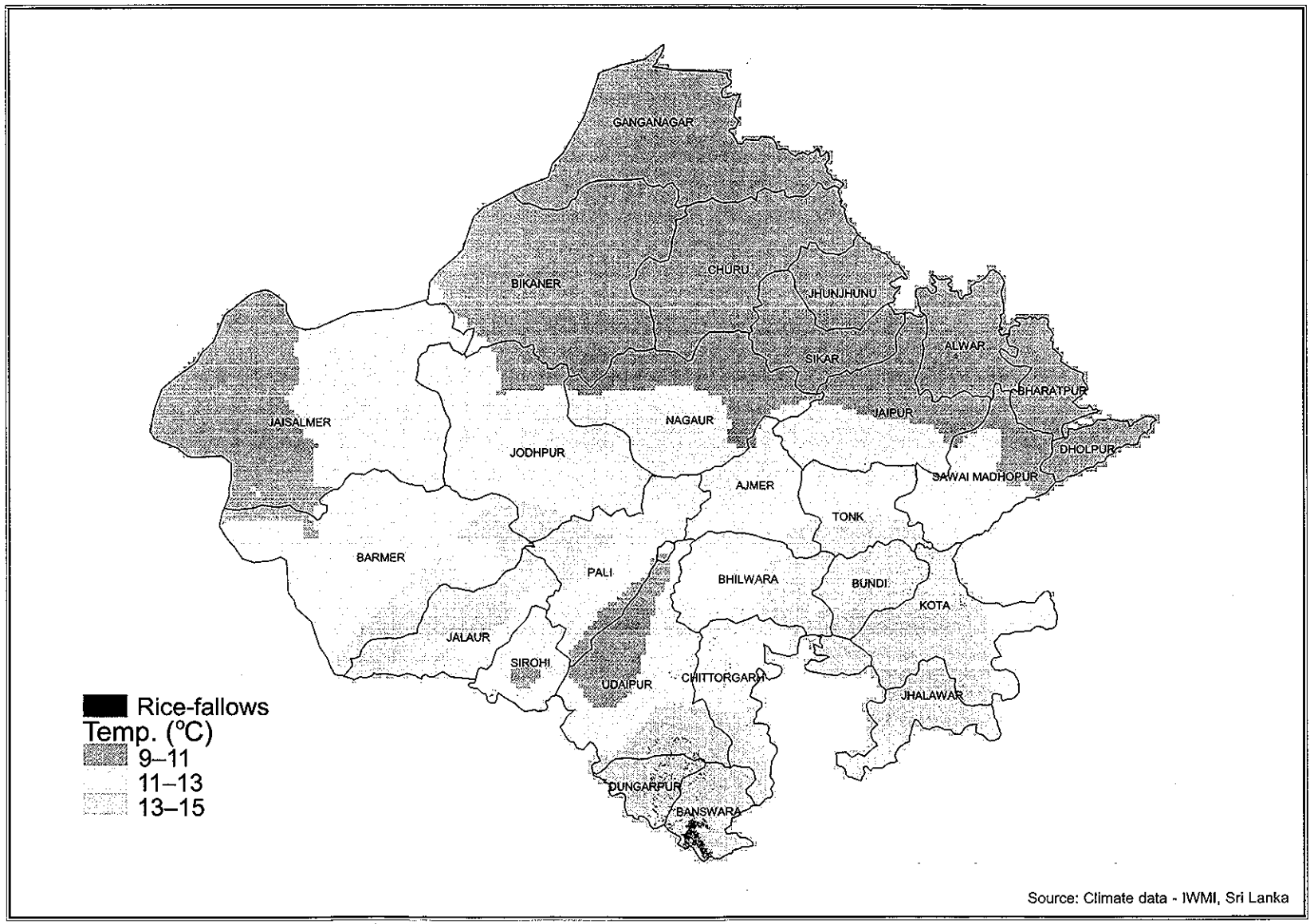


Fig. 5.2.123. Mean minimum temperature during rabi (October–March) in Rajasthan, India

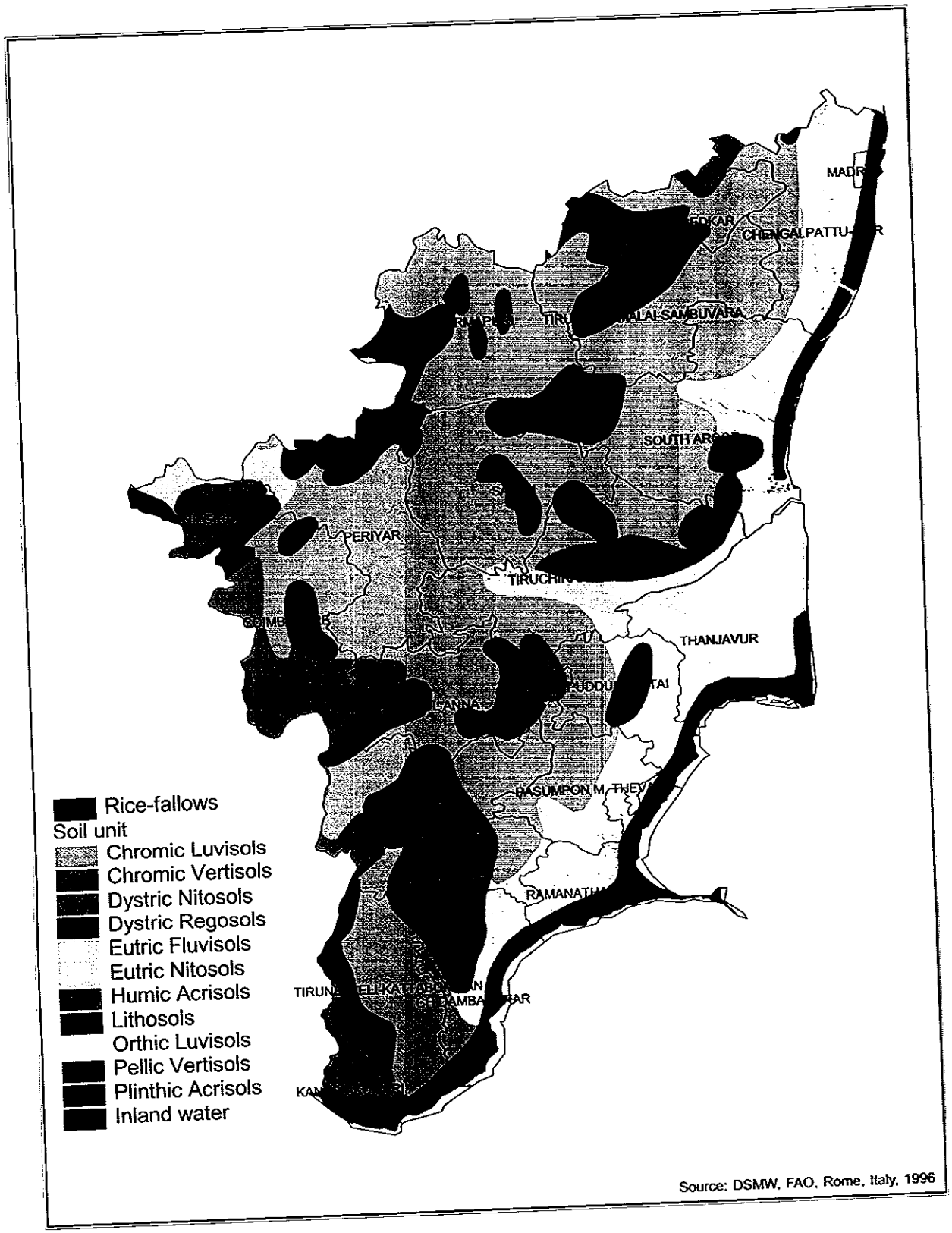


Fig. 5.2.124. Soils of Tamil Nadu, India

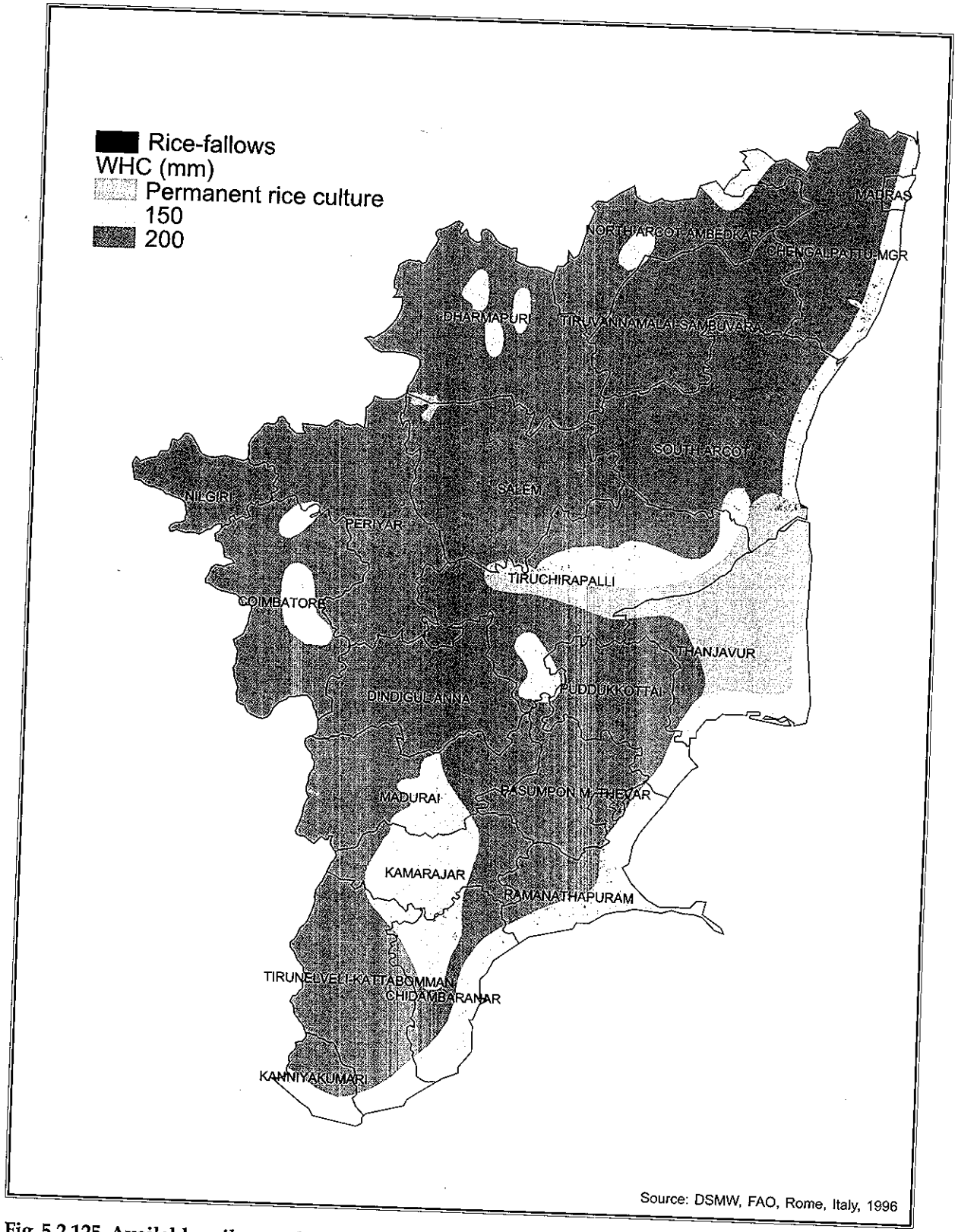


Fig. 5.2.125. Available soil water-holding capacity (WHC) in Tamil Nadu, India

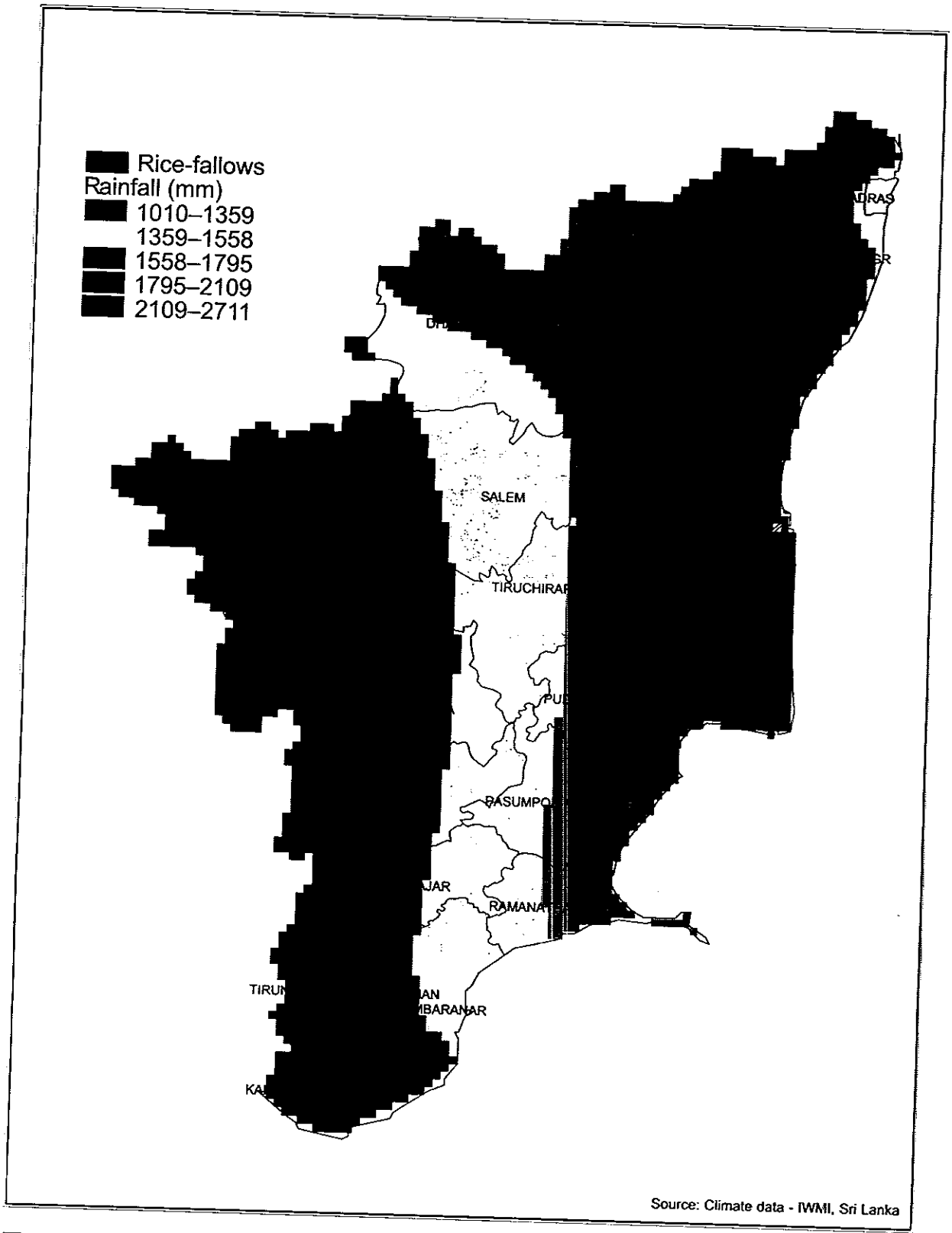


FIg. 5.2.126. Annual rainfall in Tamil Nadu, India

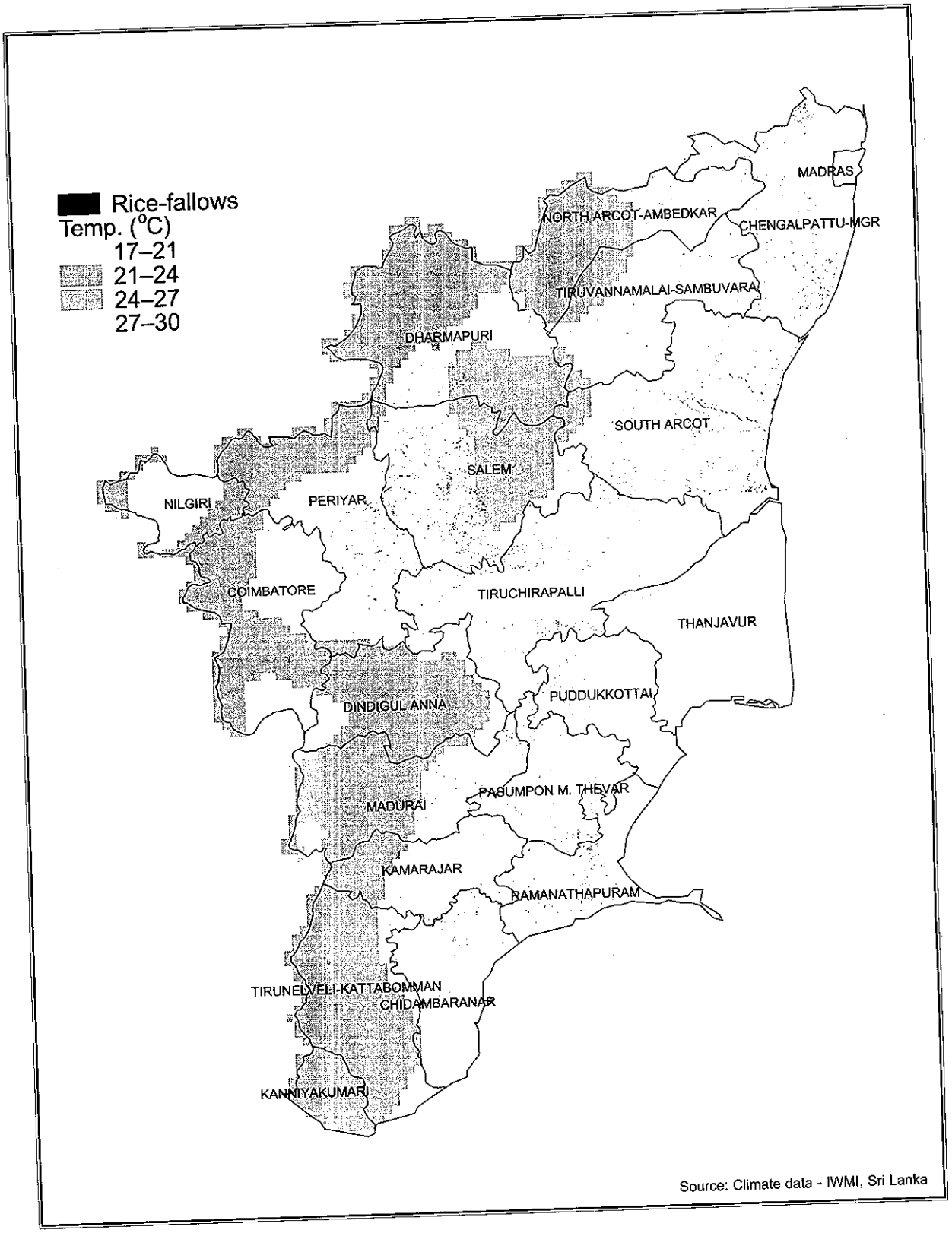


Fig. 5.2.127. Annual mean maximum temperature in Tamil Nadu, India

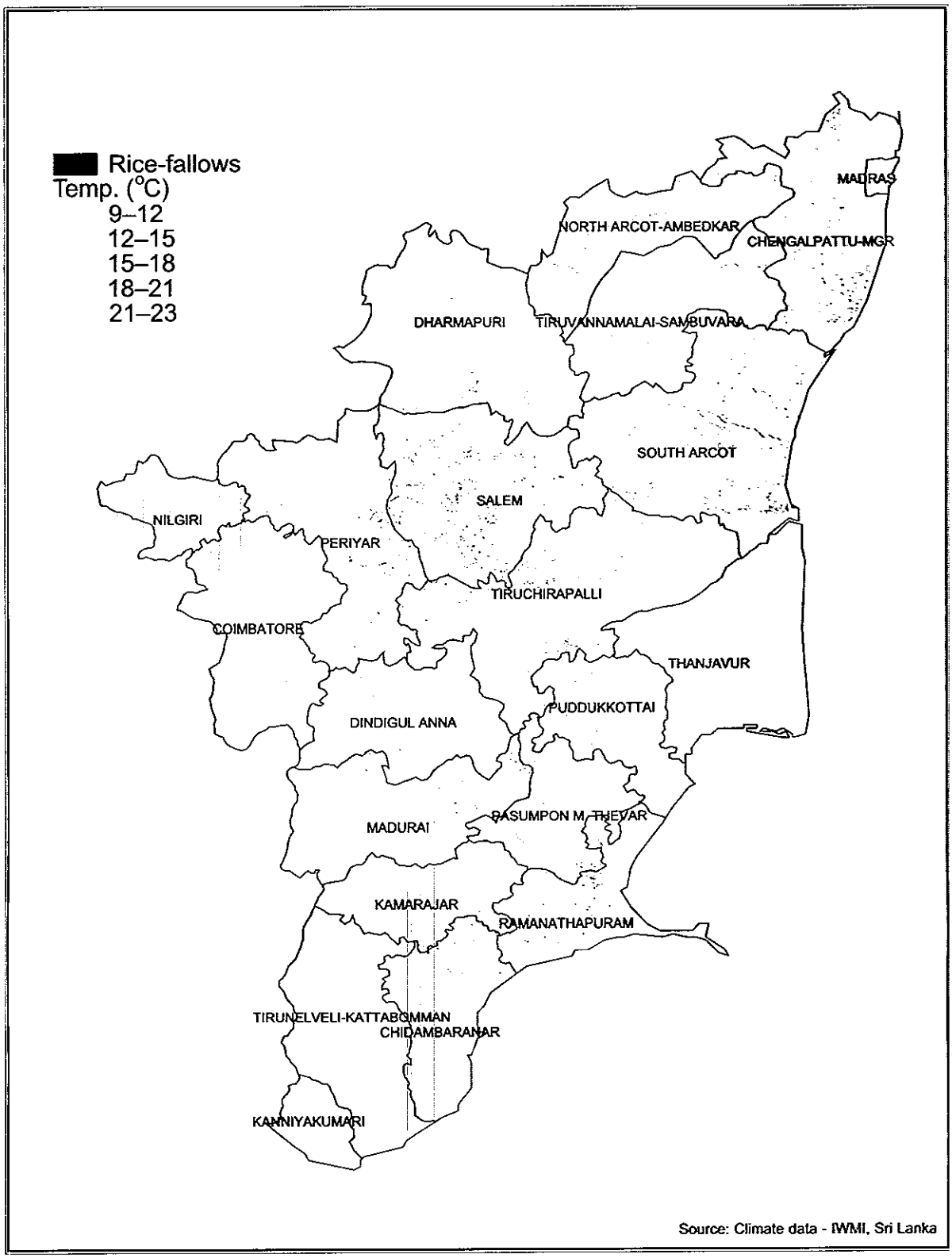


Fig. 5.2.128. Annual mean minimum temperature in Tamil Nadu, India

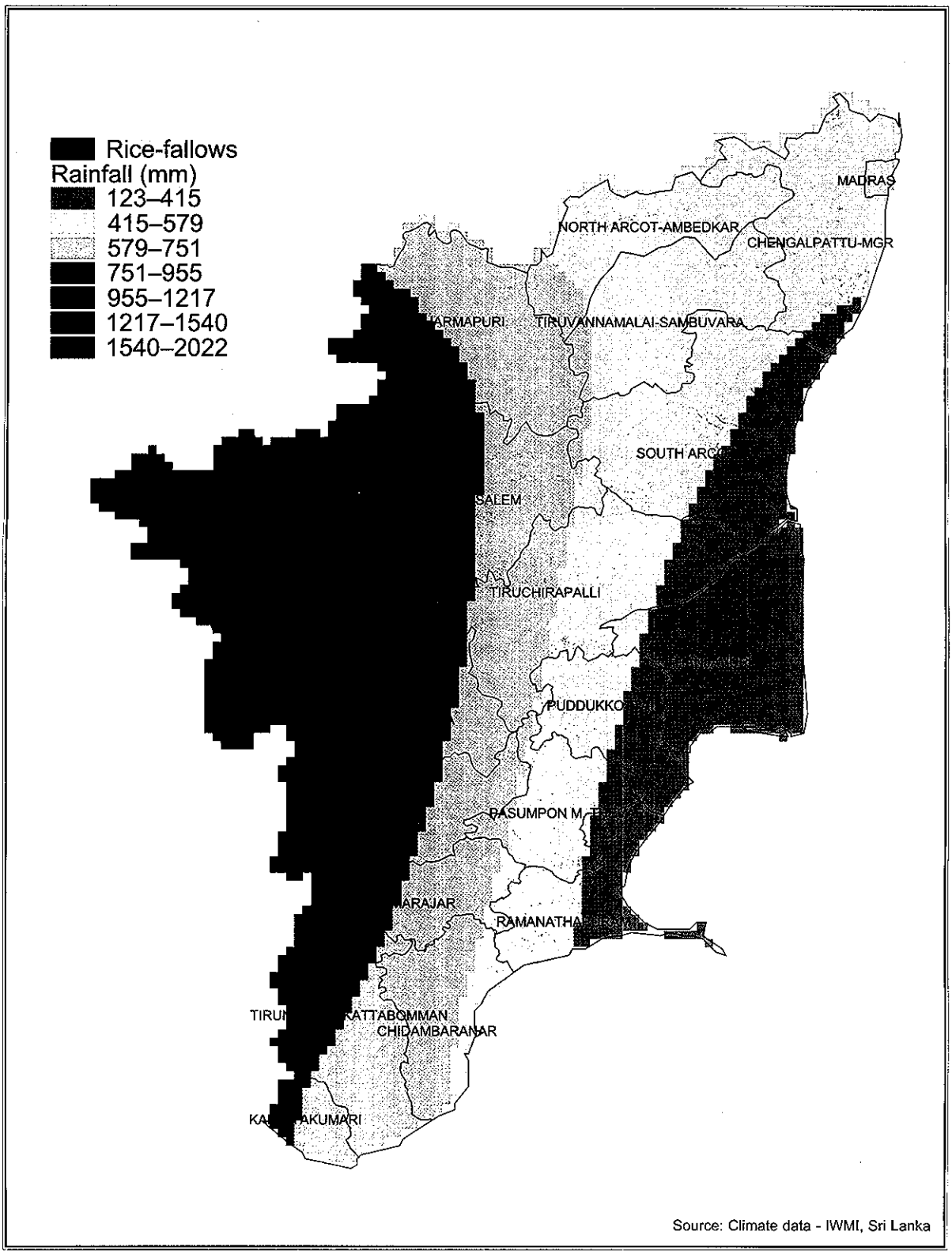


Fig. 5.2.129. Rainfall during kharif (June–September) in Tamil Nadu, India

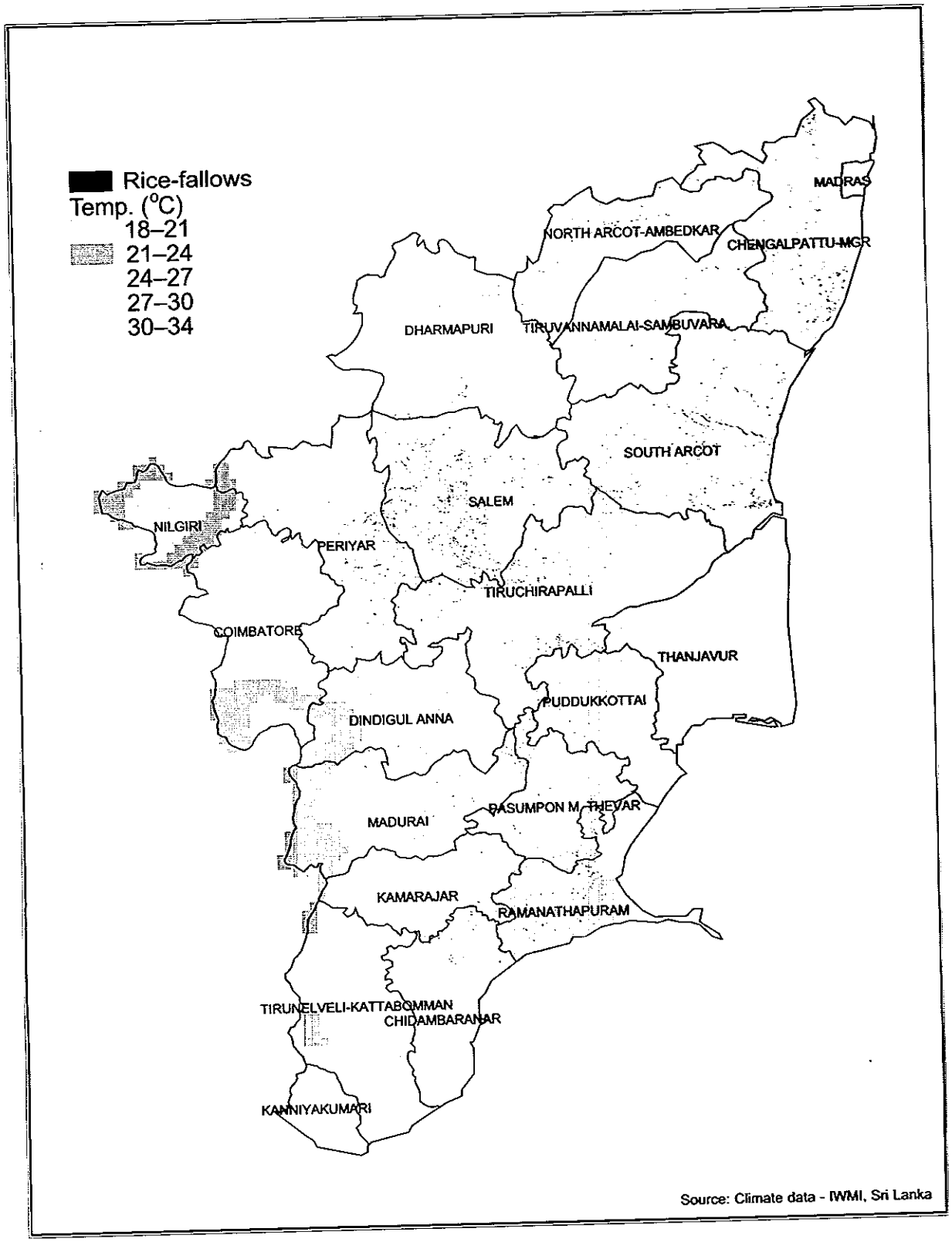


Fig. 5.2.130. Mean maximum temperature during kharif (June–September) in Tamil Nadu, India

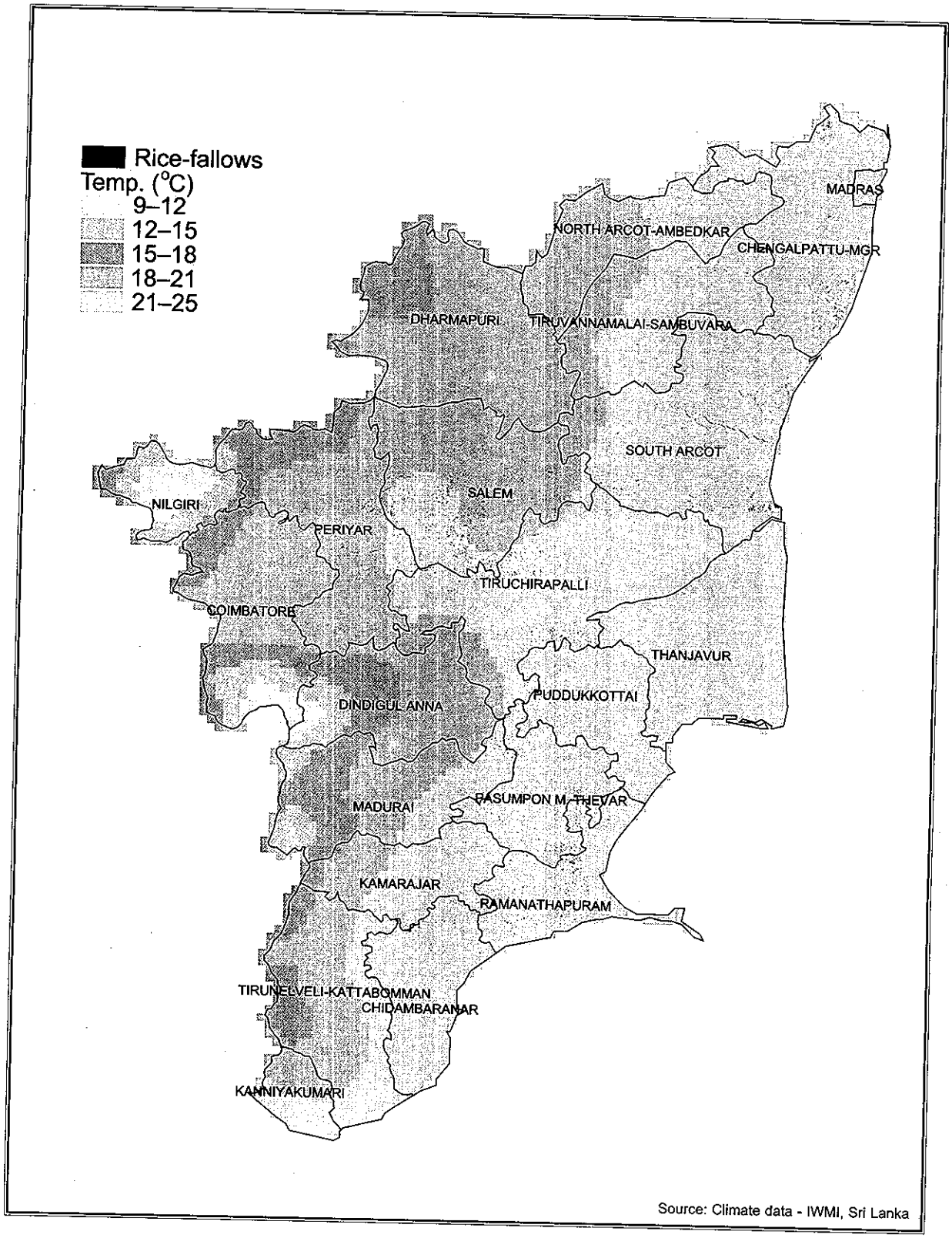


Fig. 5.2.131. Mean minimum temperature during kharif (June–September) in Tamil Nadu, India

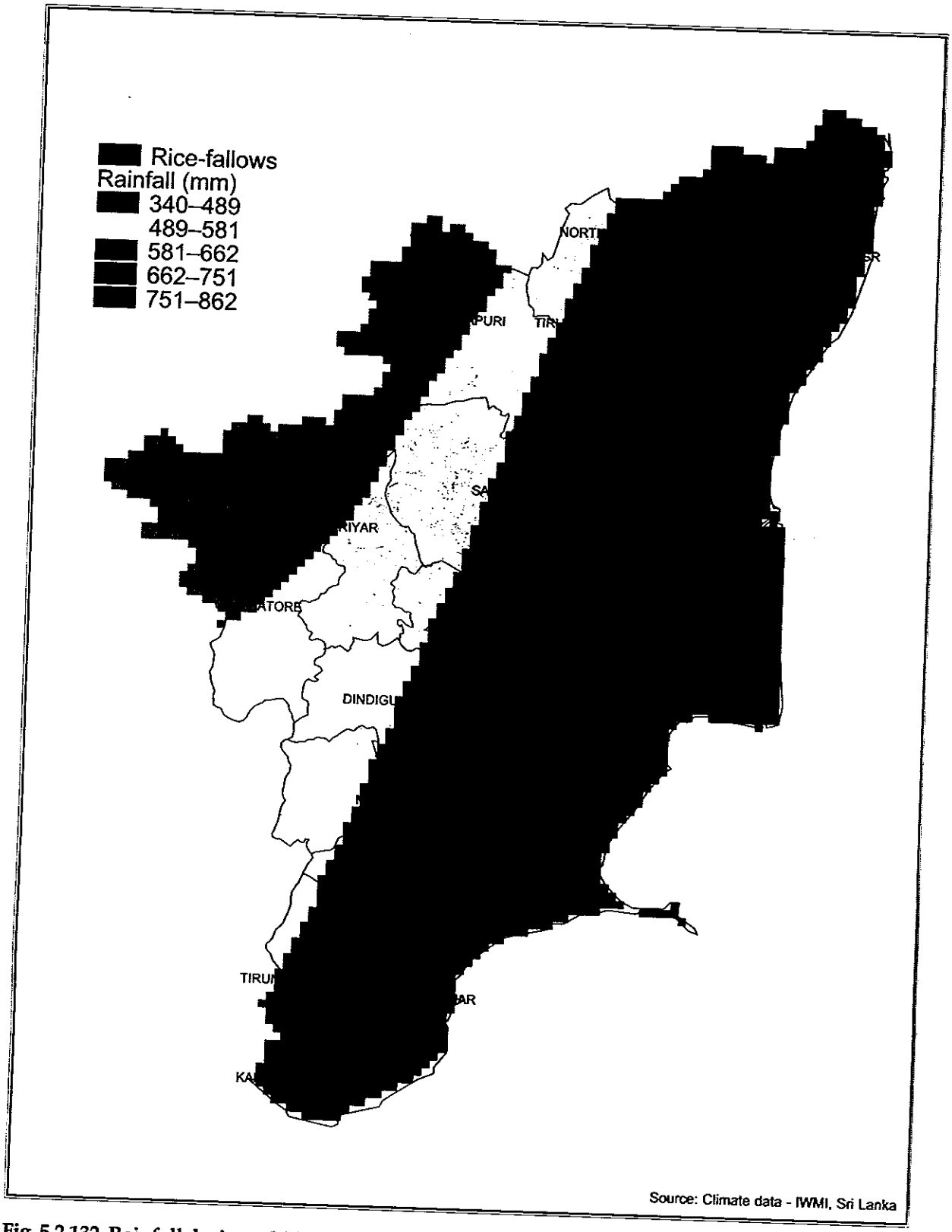


Fig. 5.2.132. Rainfall during rabi (October–March) in Tamil Nadu, India

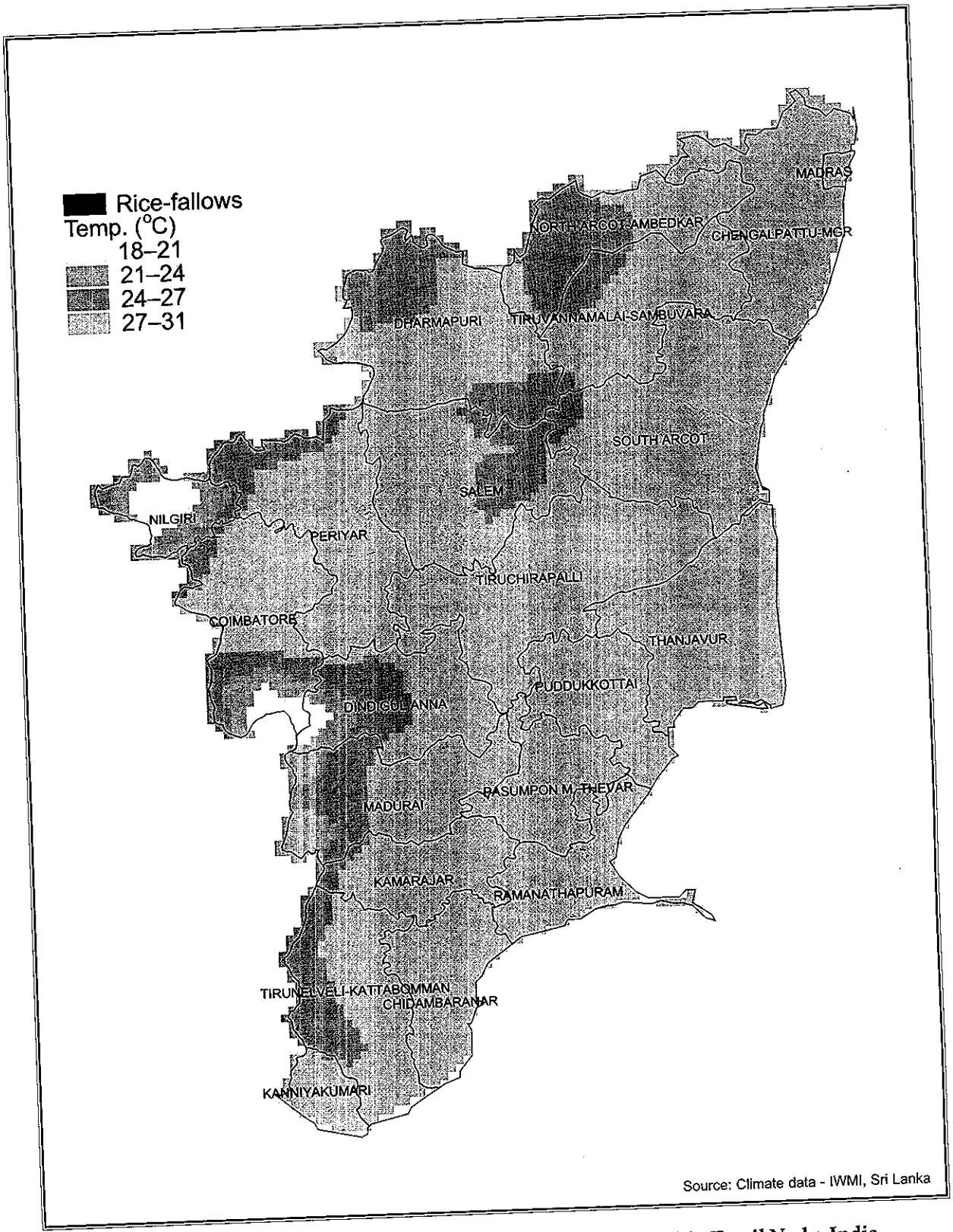


Fig. 5.2.133. Mean maximum temperature during rabi (October–March) in Tamil Nadu, India

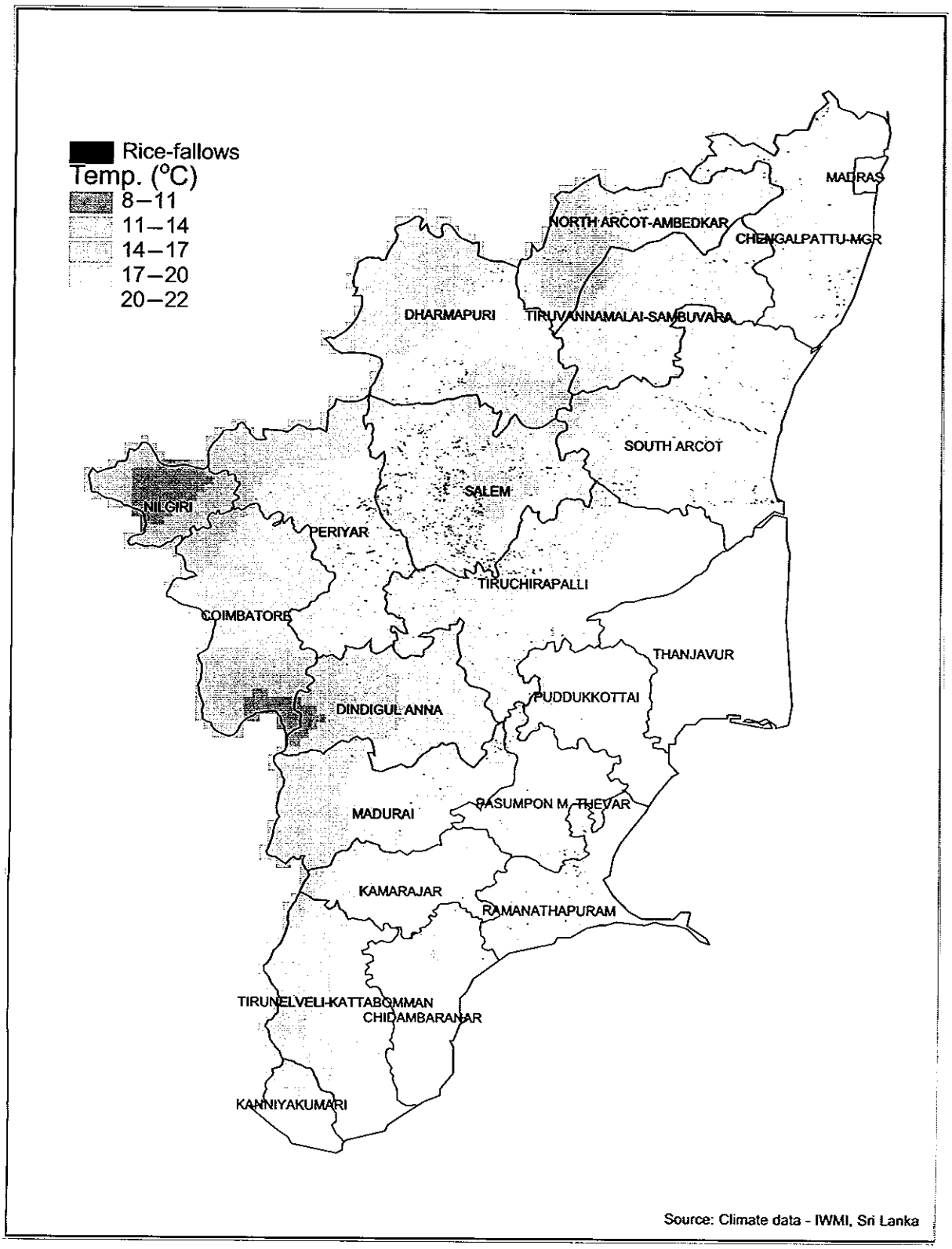


Fig. 5.2.134. Mean minimum temperature during rabi (October–March) in Tamil Nadu, India

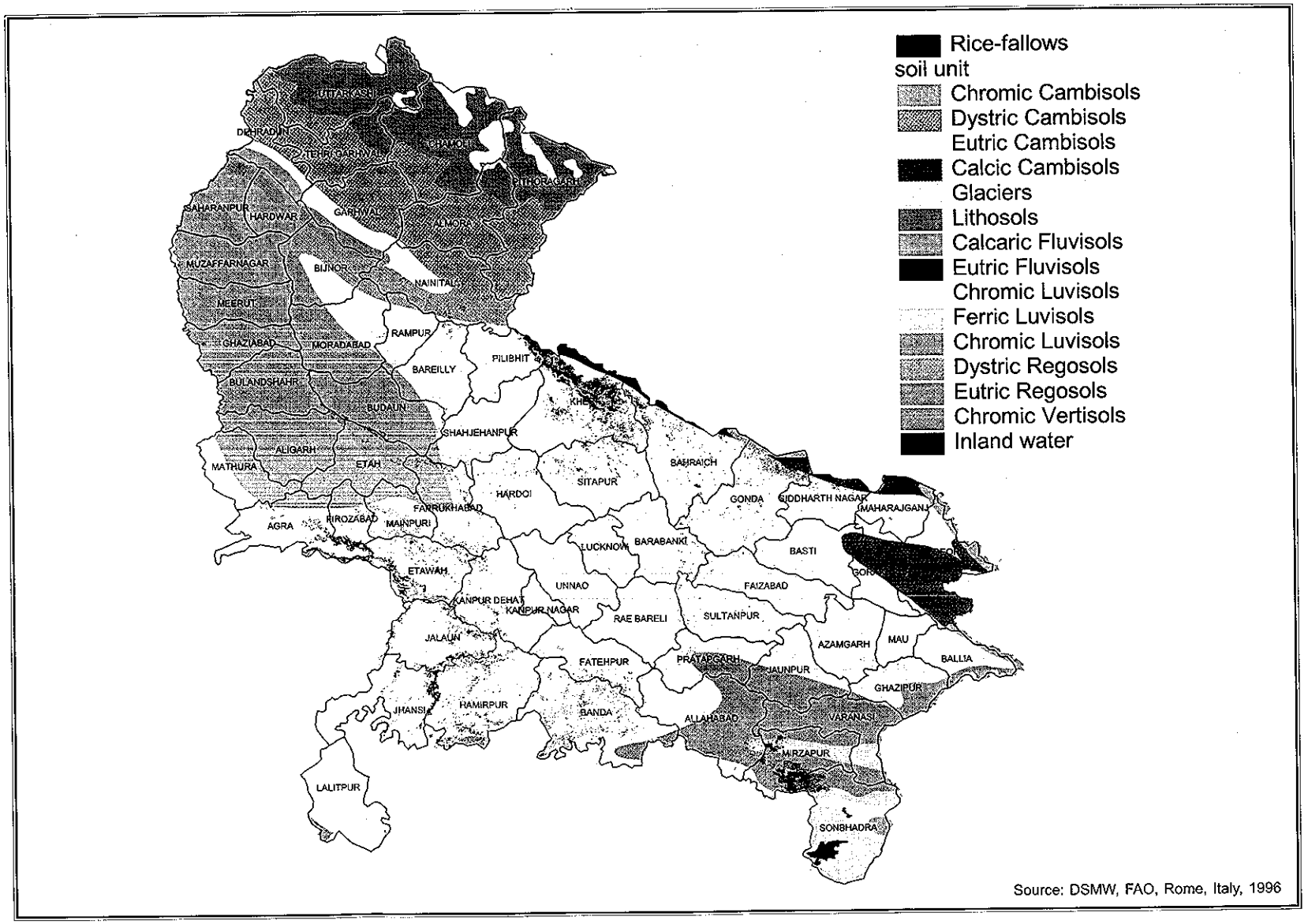


Fig. 5.2.135. Soils of Uttar Pradesh, India

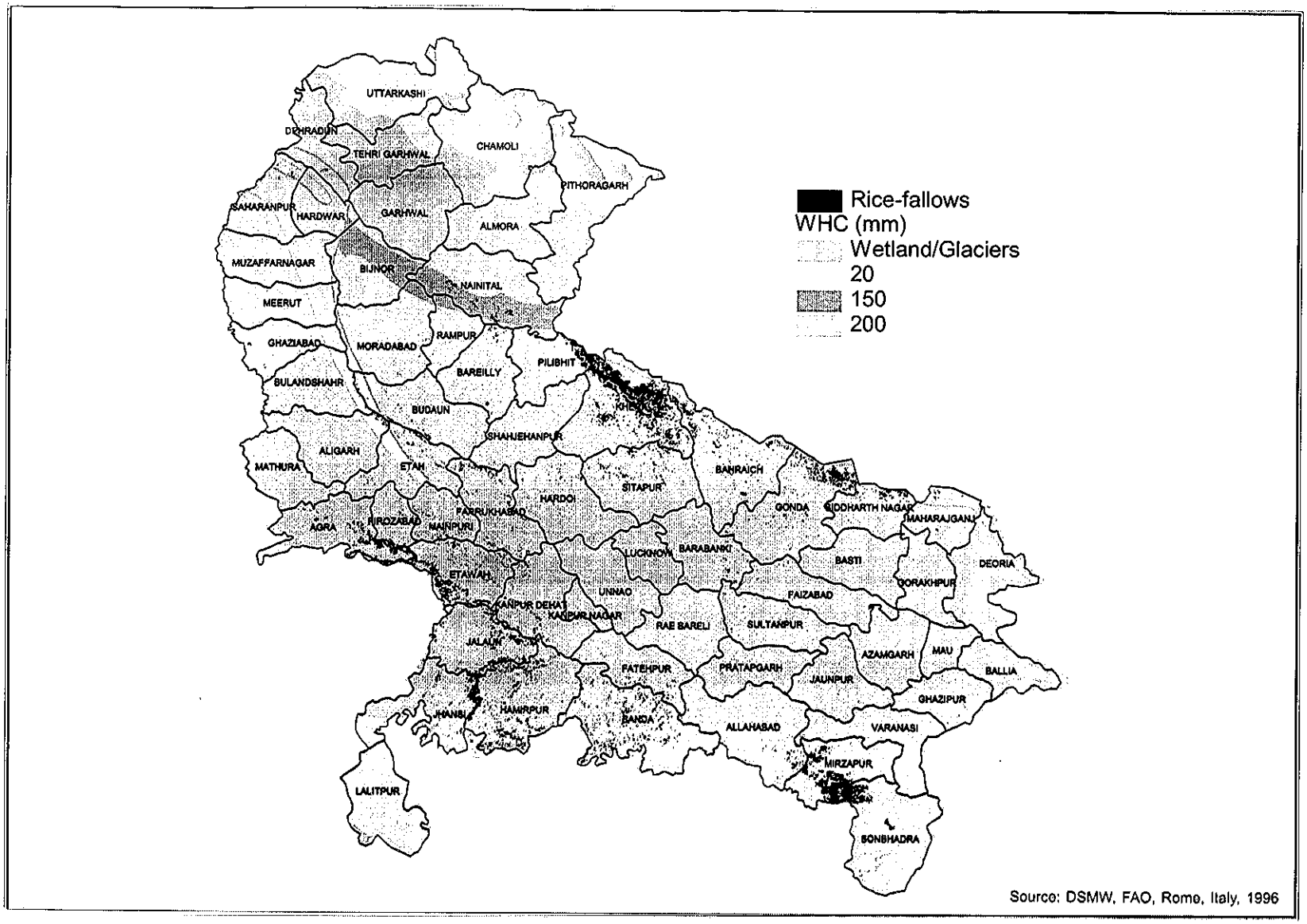


Fig. 5.2.136. Available soil water-holding capacity (WHC) in Uttar Pradesh, India

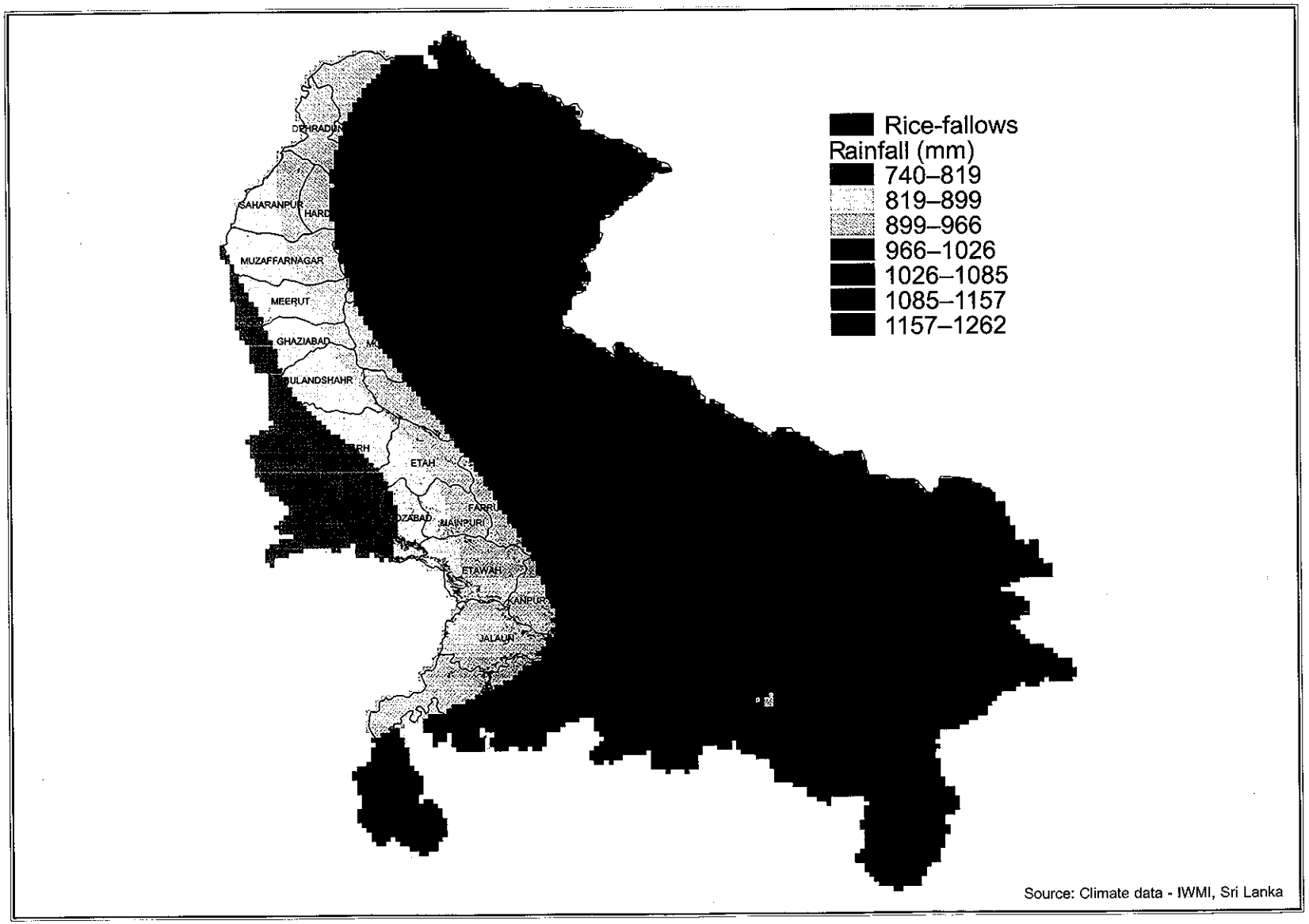


Fig. 5.2.137. Annual rainfall in Uttar Pradesh, India

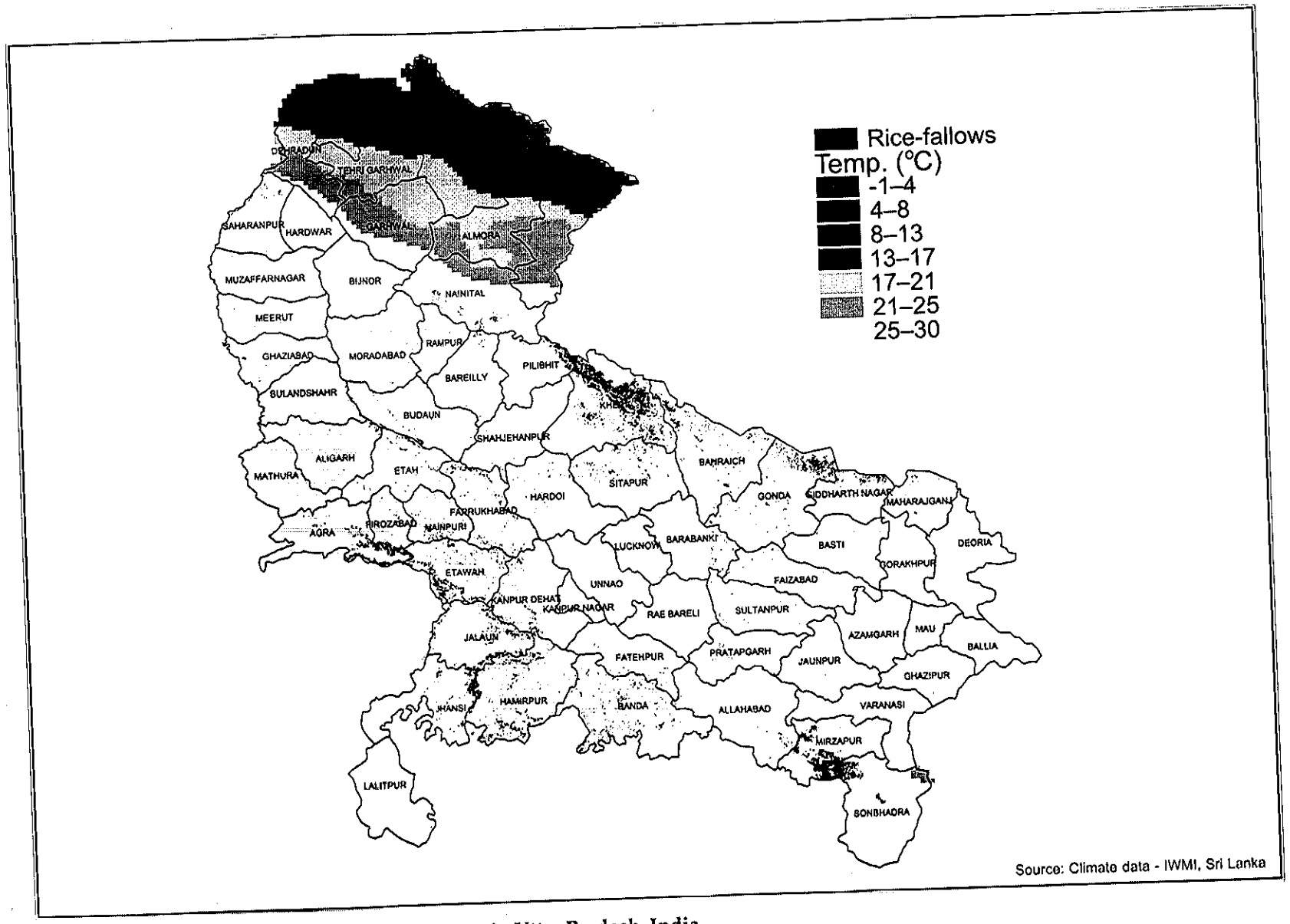
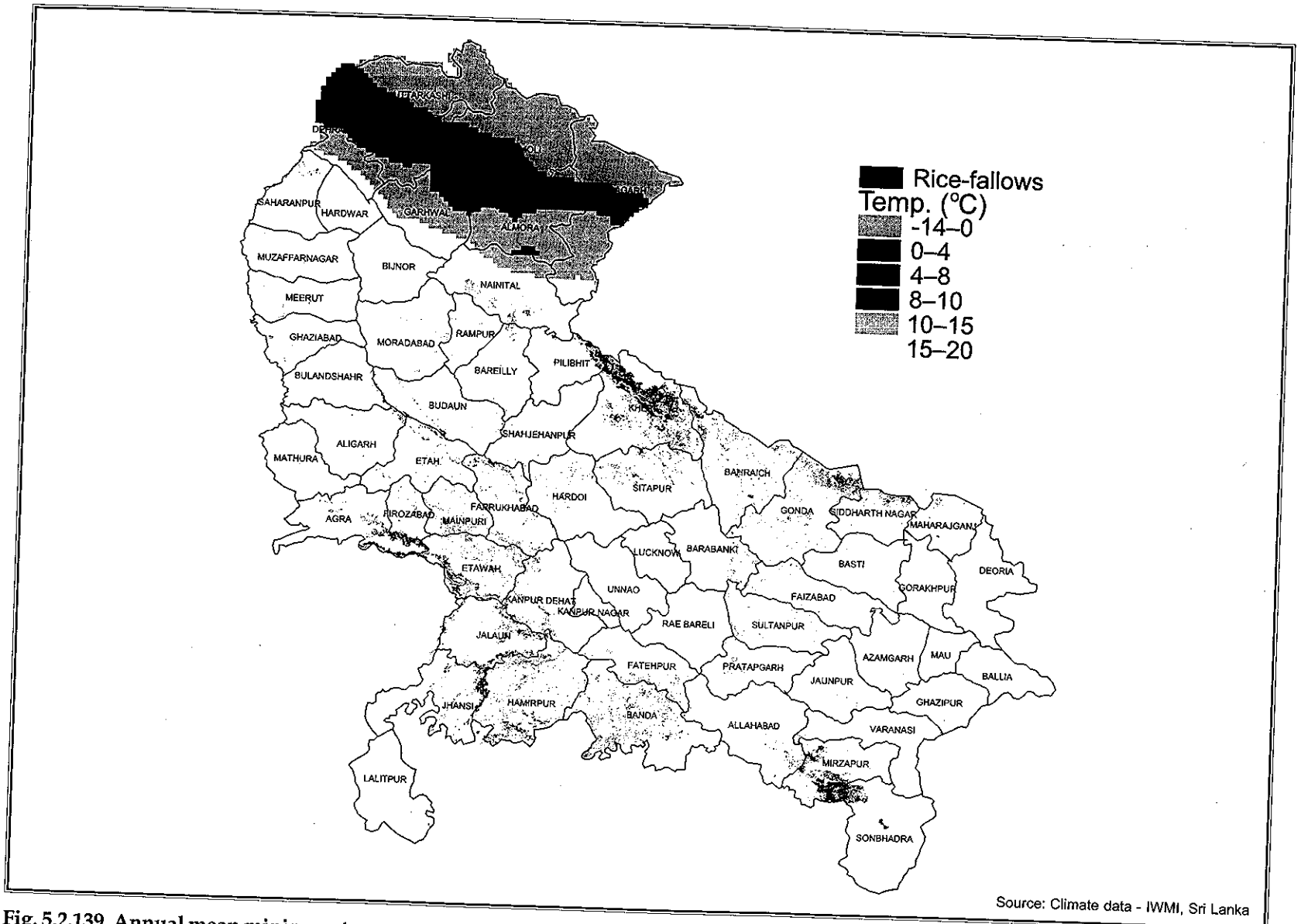


Fig. 5.2.138. Annual mean maximum temperature in Uttar Pradesh, India



Source: Climate data - IWMI, Sri Lanka

Fig. 5.2.139. Annual mean minimum temperature in Uttar Pradesh, India

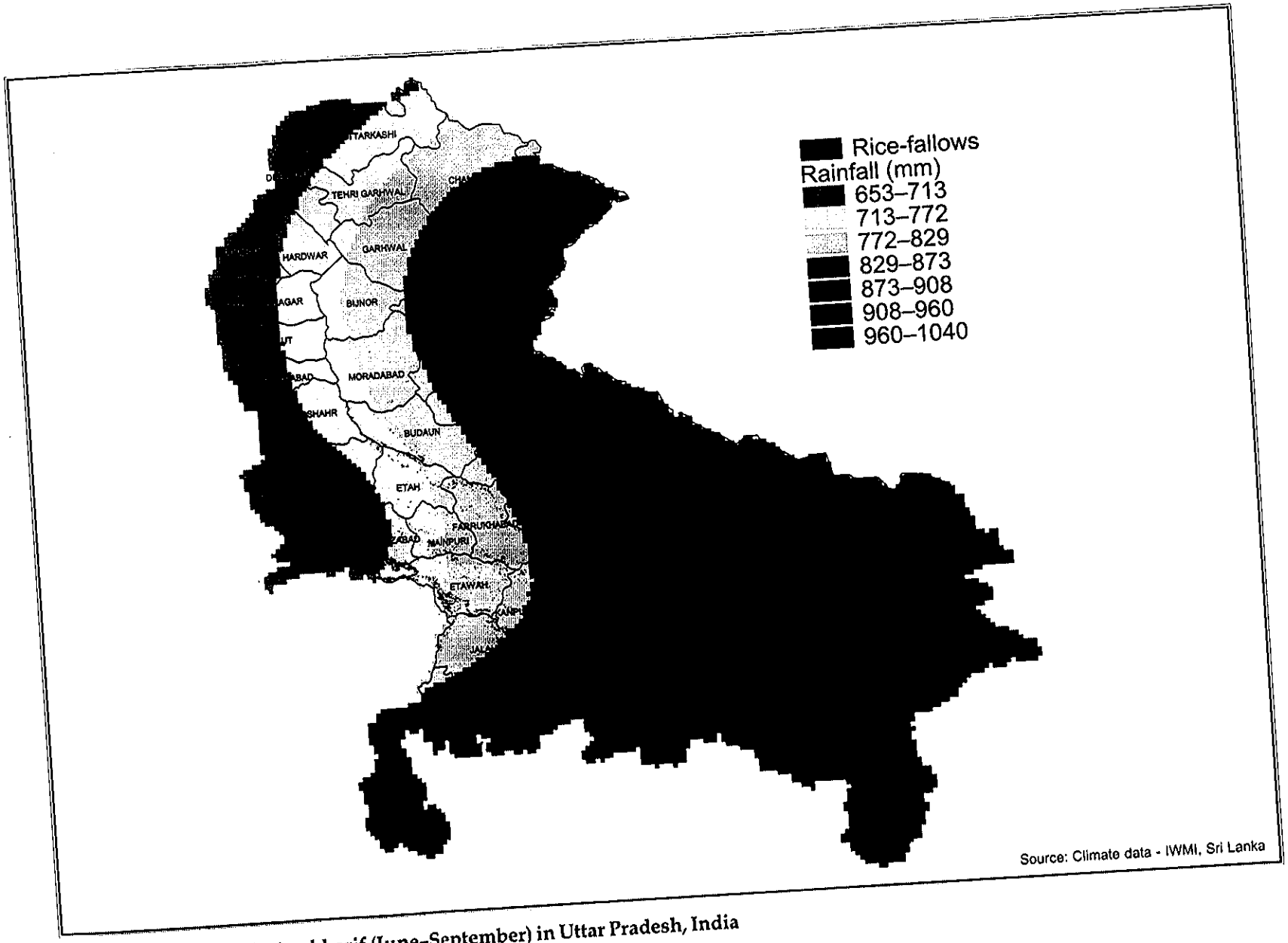
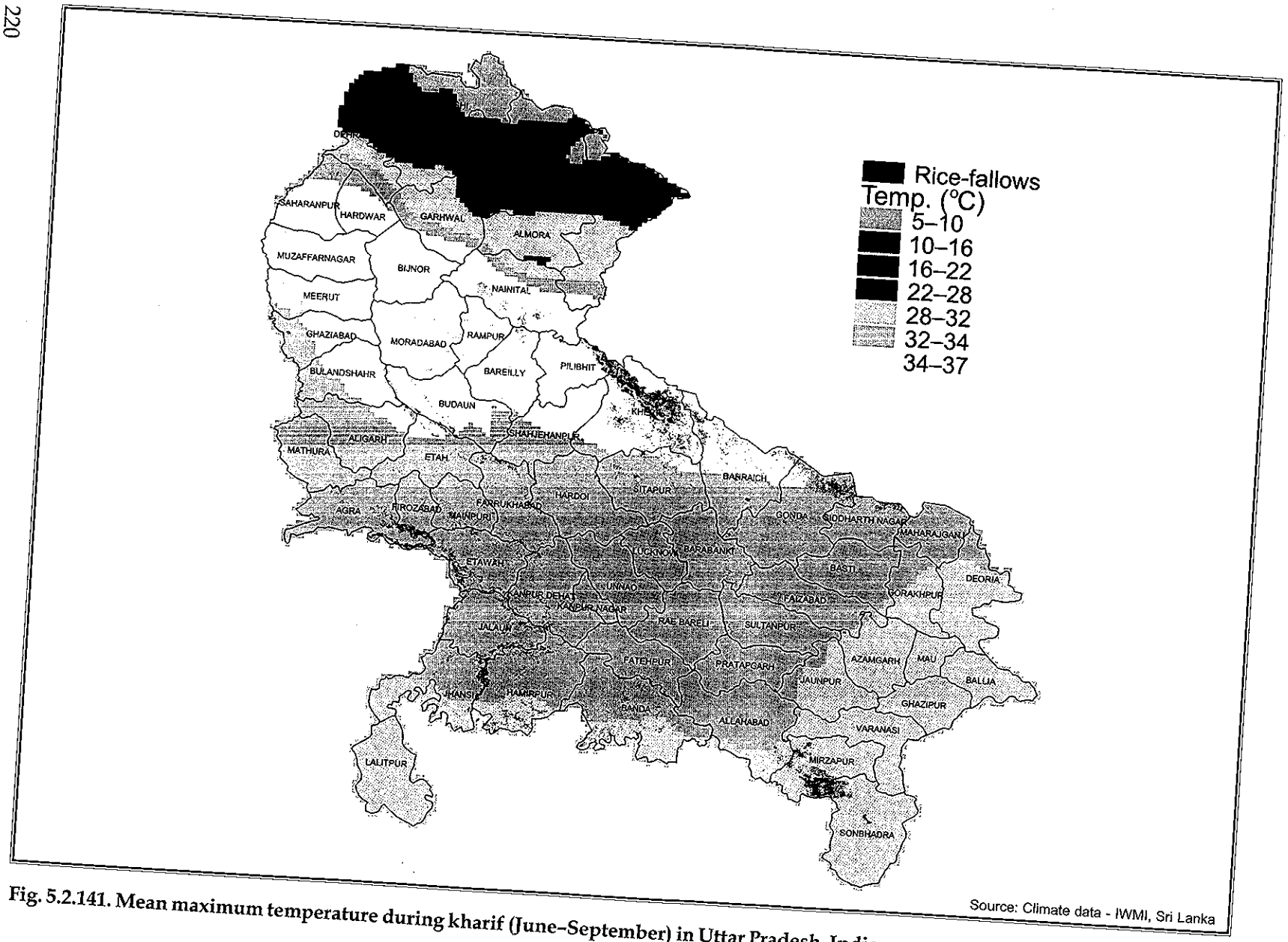


Fig. 5.2.140. Rainfall during kharif (June–September) in Uttar Pradesh, India



Source: Climate data - IWMI, Sri Lanka

Fig. 5.2.141. Mean maximum temperature during kharif (June–September) in Uttar Pradesh, India

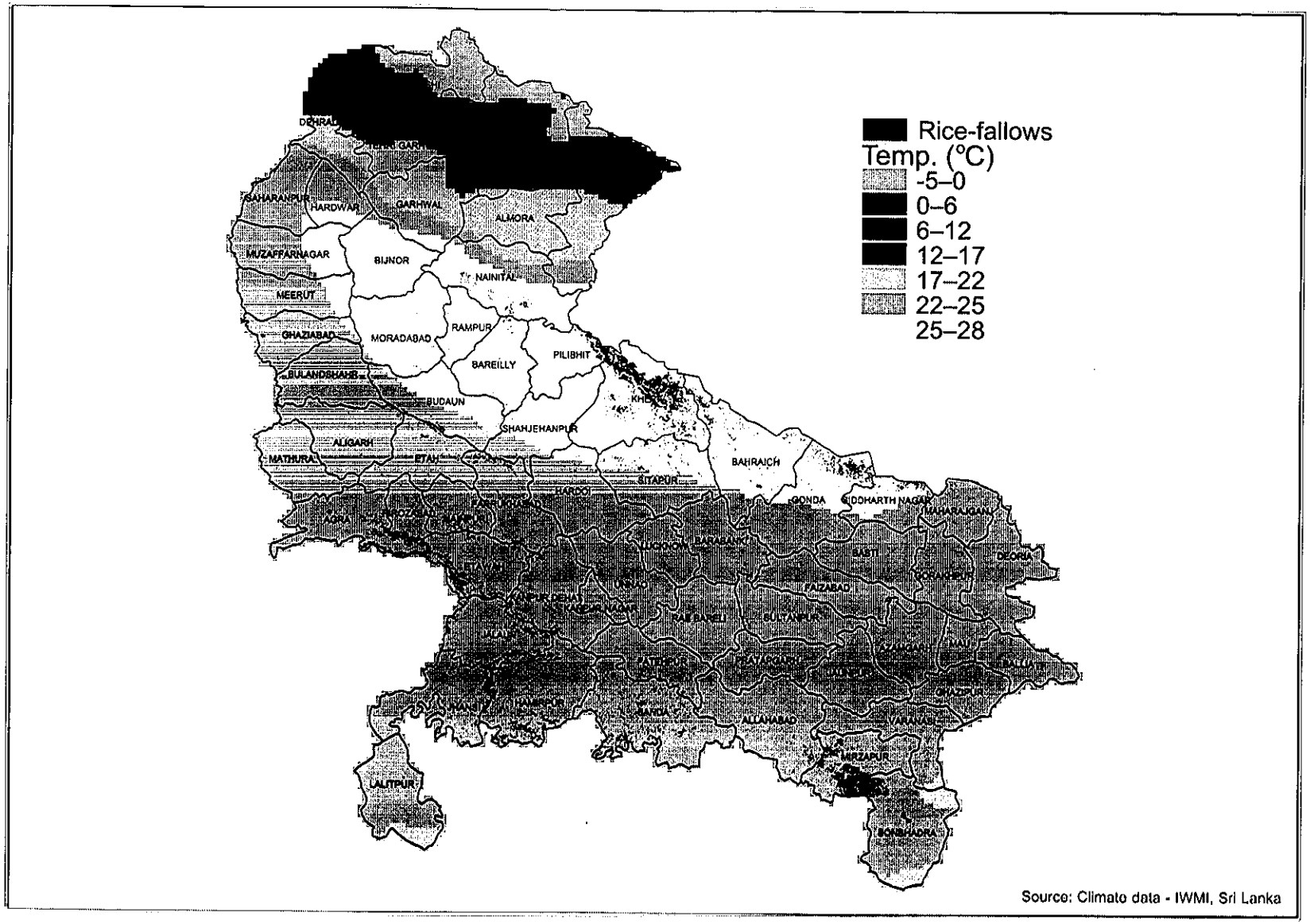


Fig. 5.2.142. Mean minimum temperature during kharif (June-September) in Uttar Pradesh, India

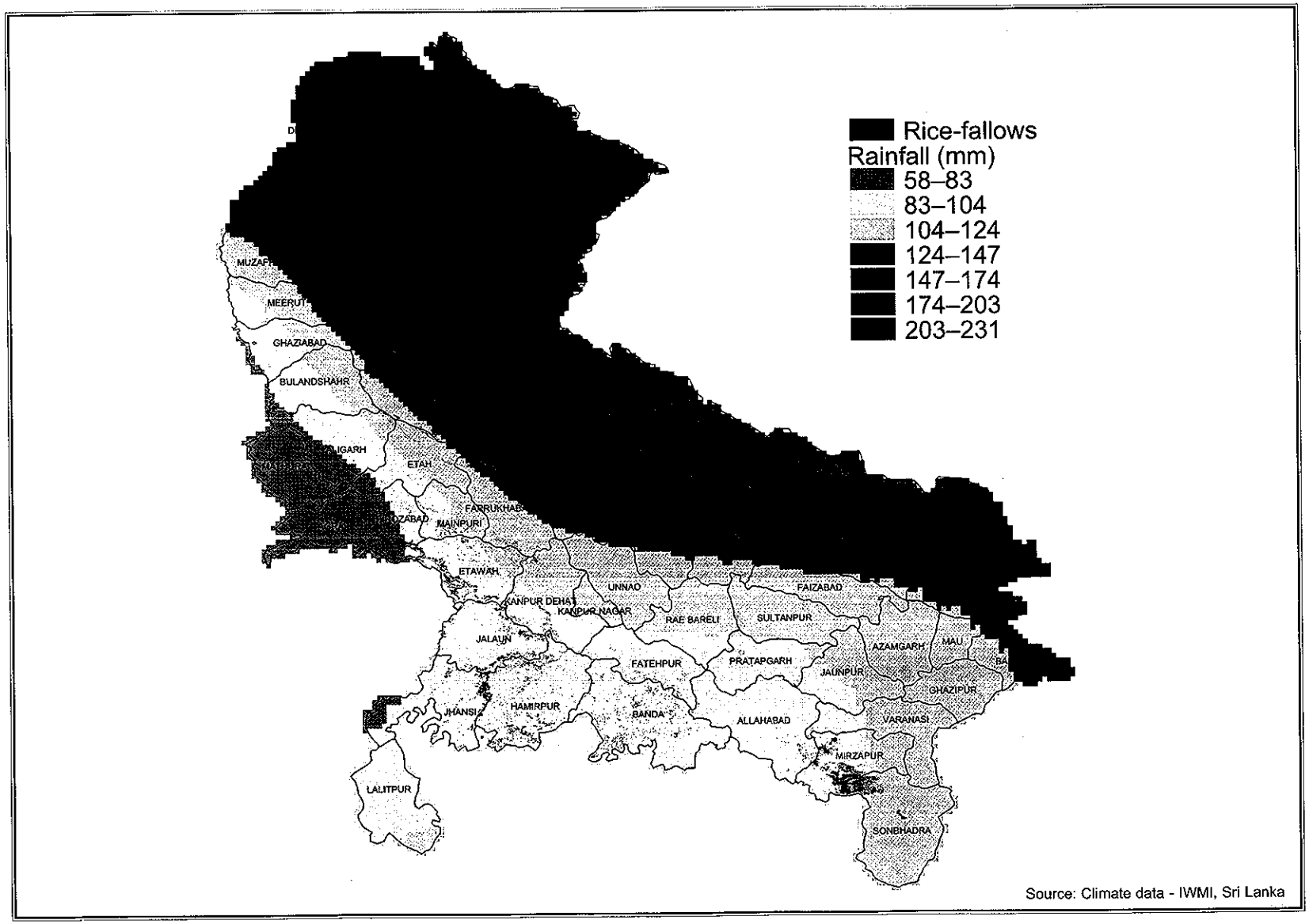


Fig. 5.2.143. Rainfall during rabi (October–March) in Uttar Pradesh, India

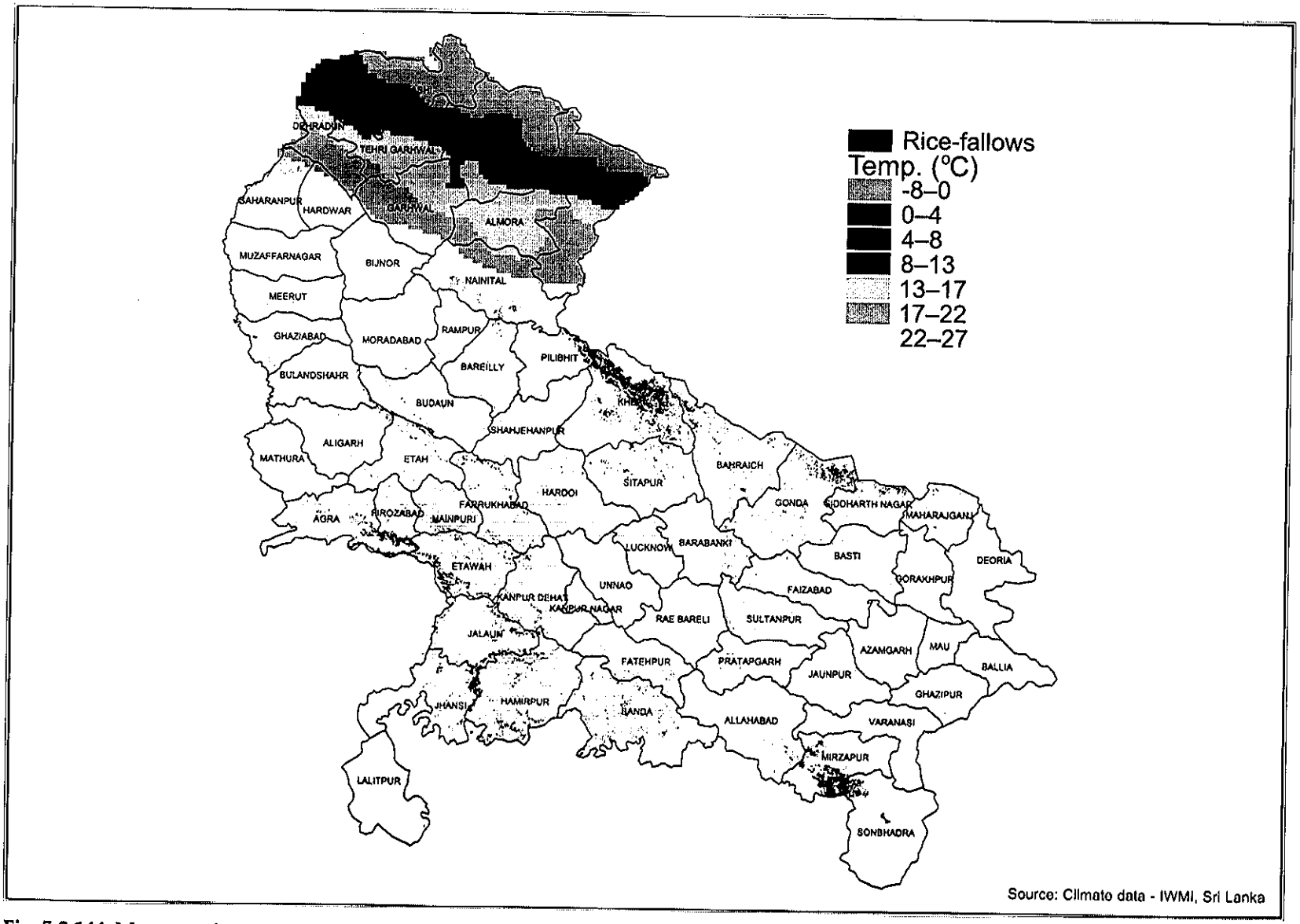


Fig. 5.2.144. Mean maximum temperature during rabi (October–March) in Uttar Pradesh, India

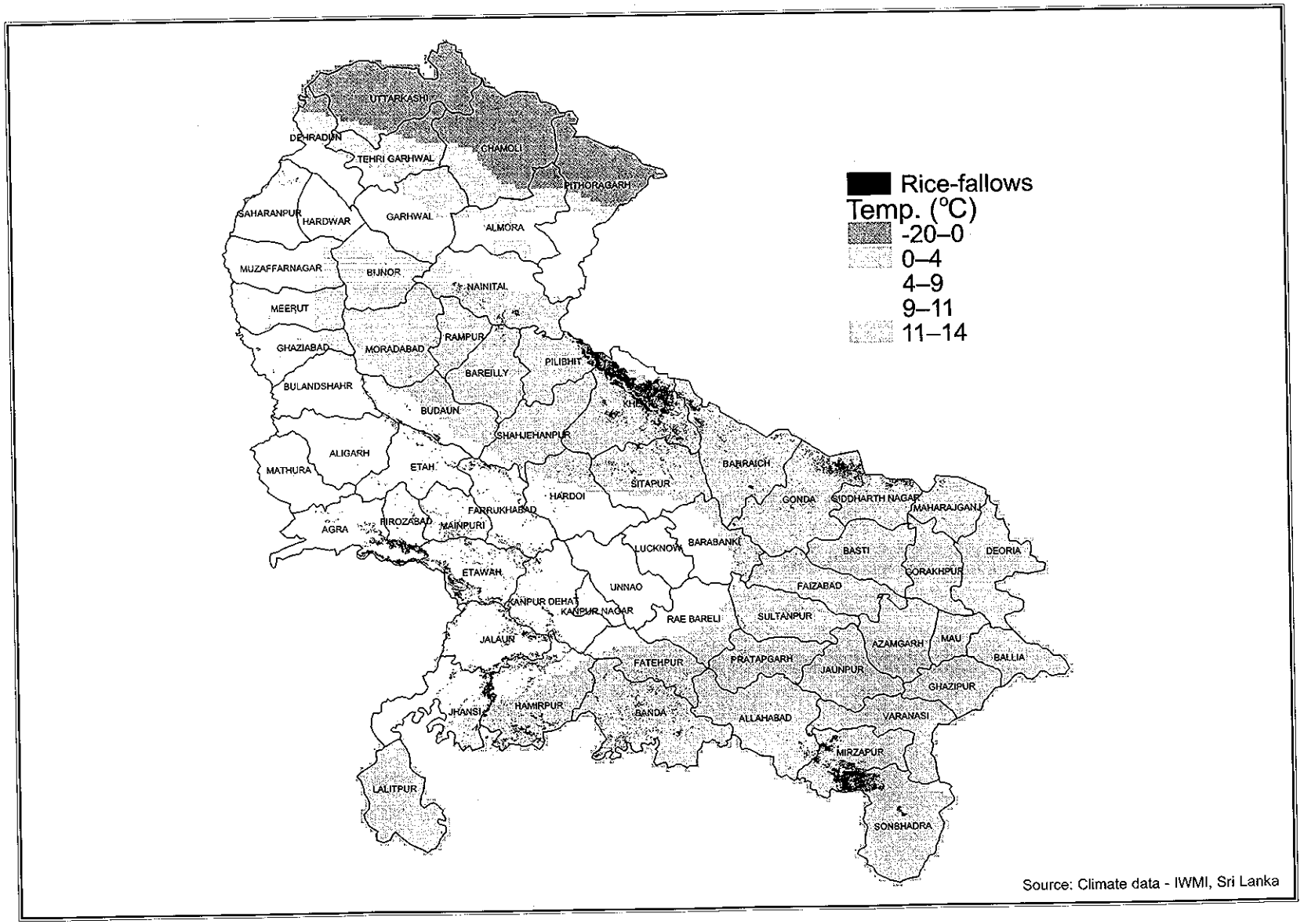


Fig. 5.2.145. Mean minimum temperature during rabi (October–March) in Uttar Pradesh, India

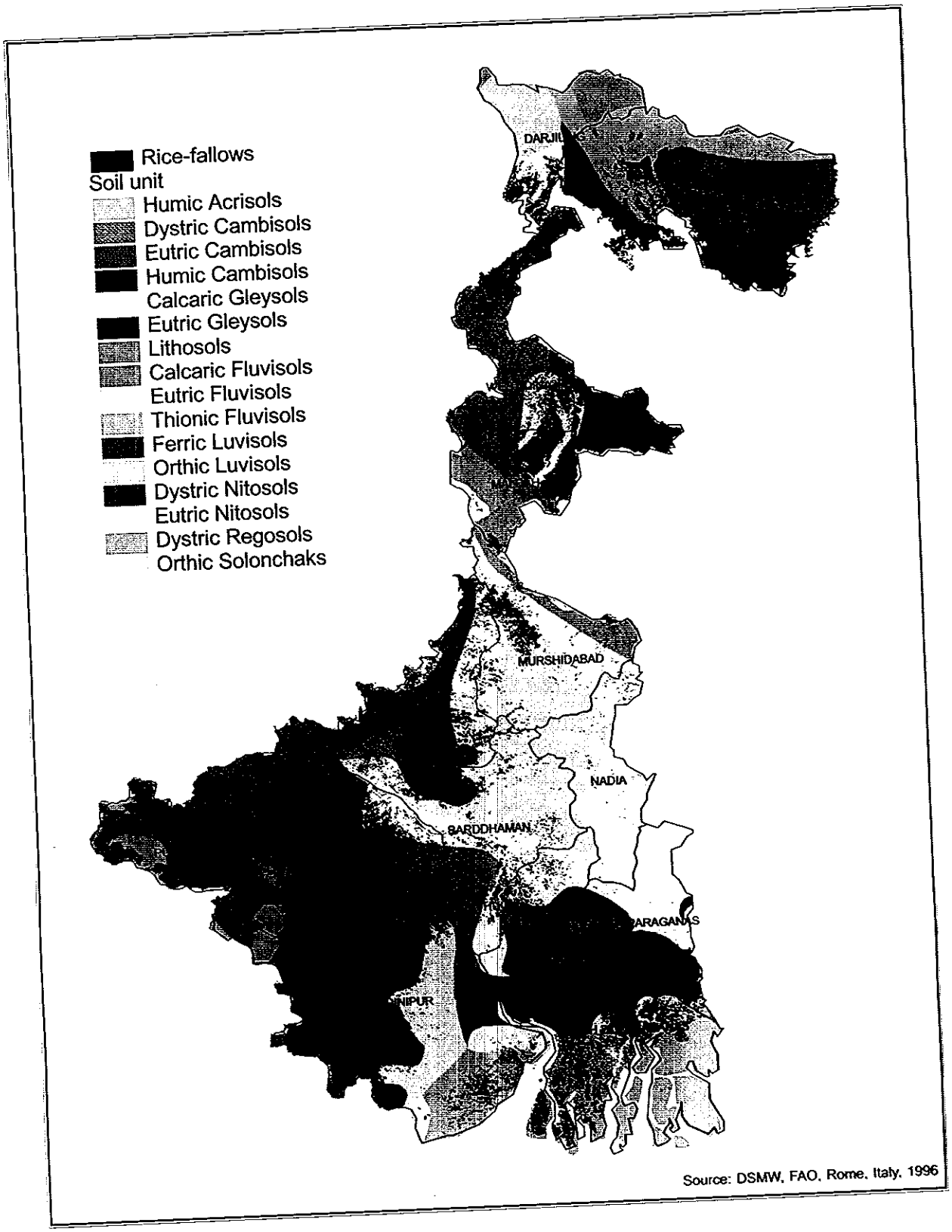
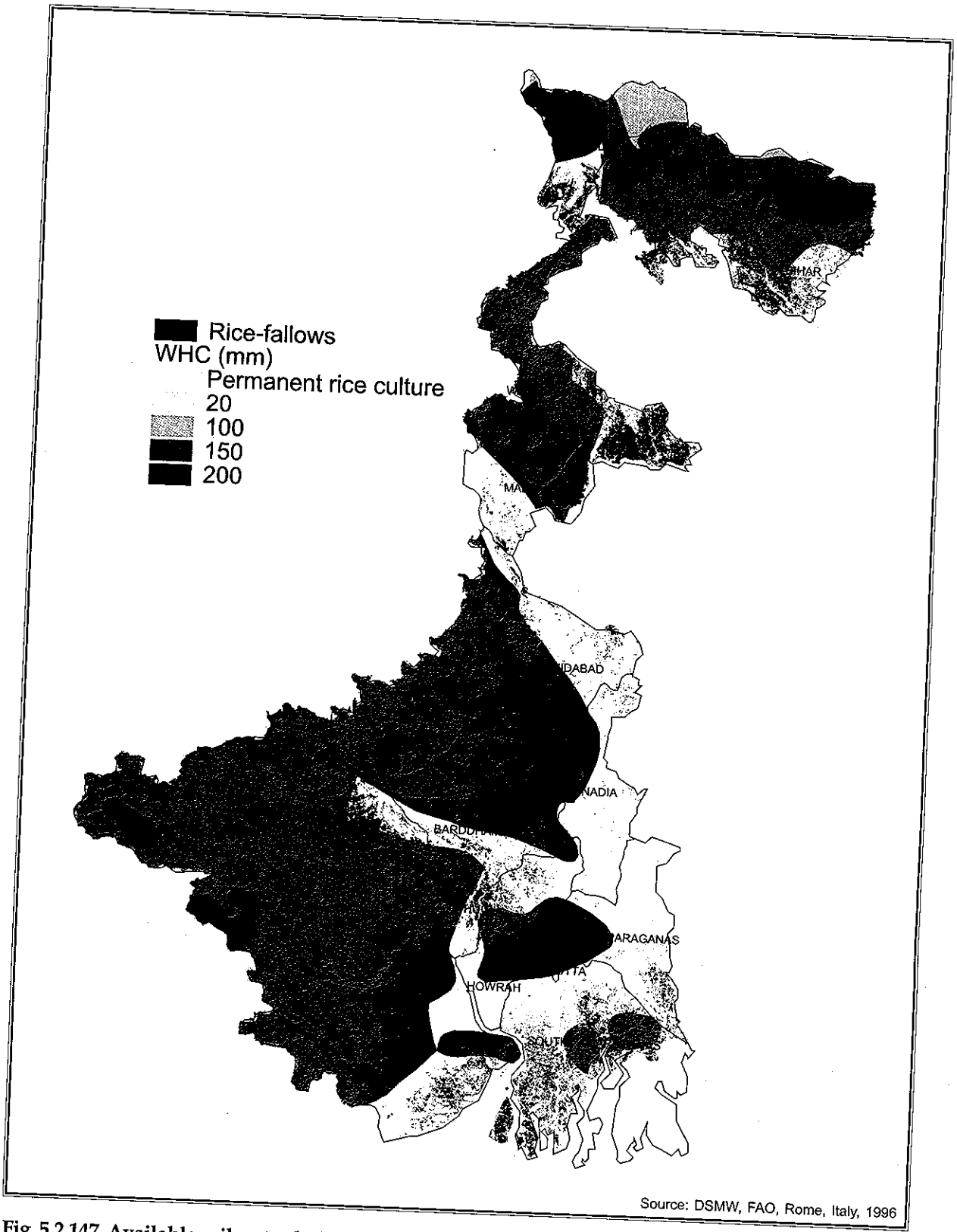


Fig. 5.2.146. Soils of West Bengal, India



Source: DSMW, FAO, Rome, Italy, 1996

Fig. 5.2.147. Available soil water-holding capacity (WHC) in West Bengal, India

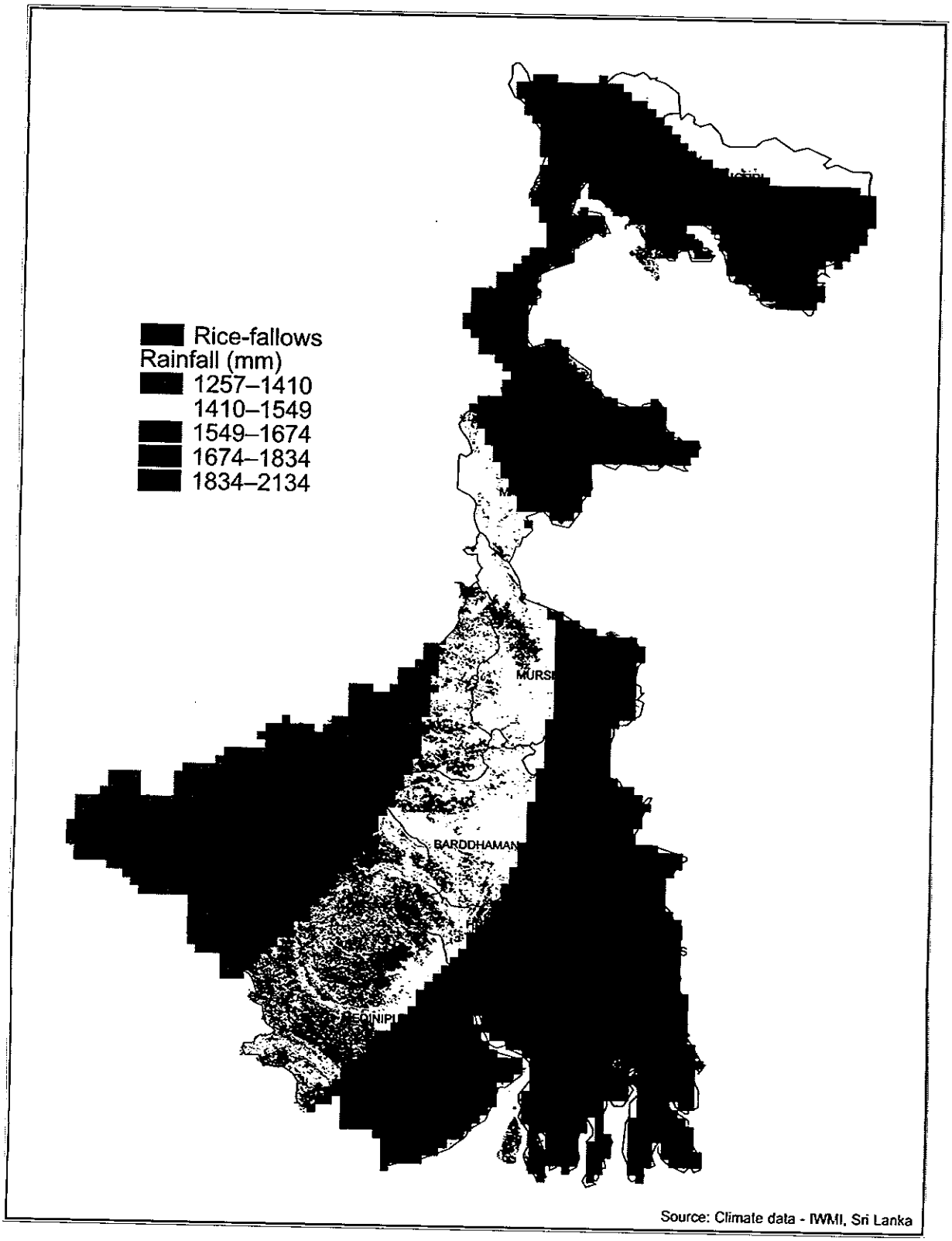


Fig. 5.2.148. Annual rainfall in West Bengal, India

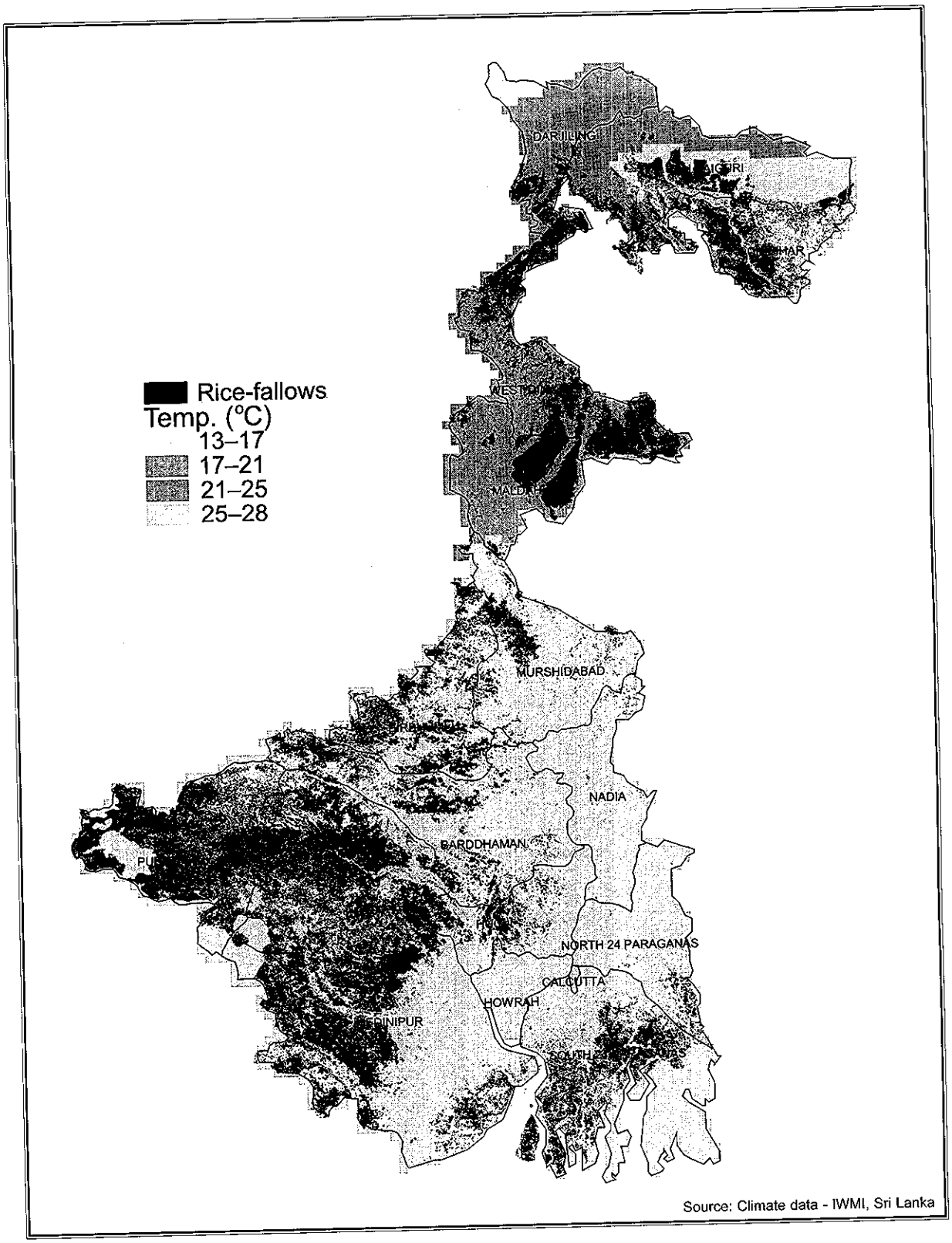


Fig. 5.2.149. Annual mean maximum temperature in West Bengal, India

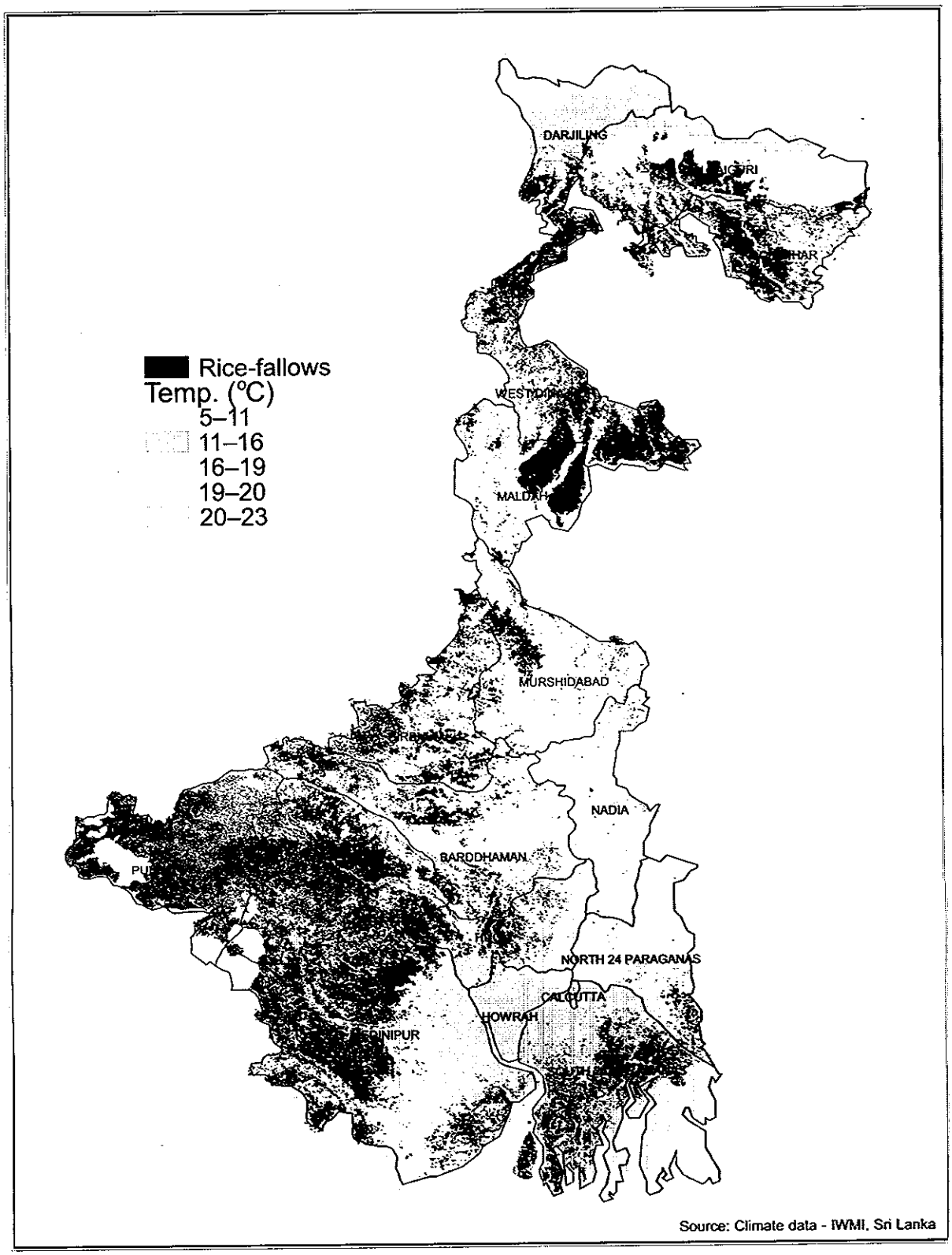


Fig. 5.2.150. Annual mean minimum temperature in West Bengal, India

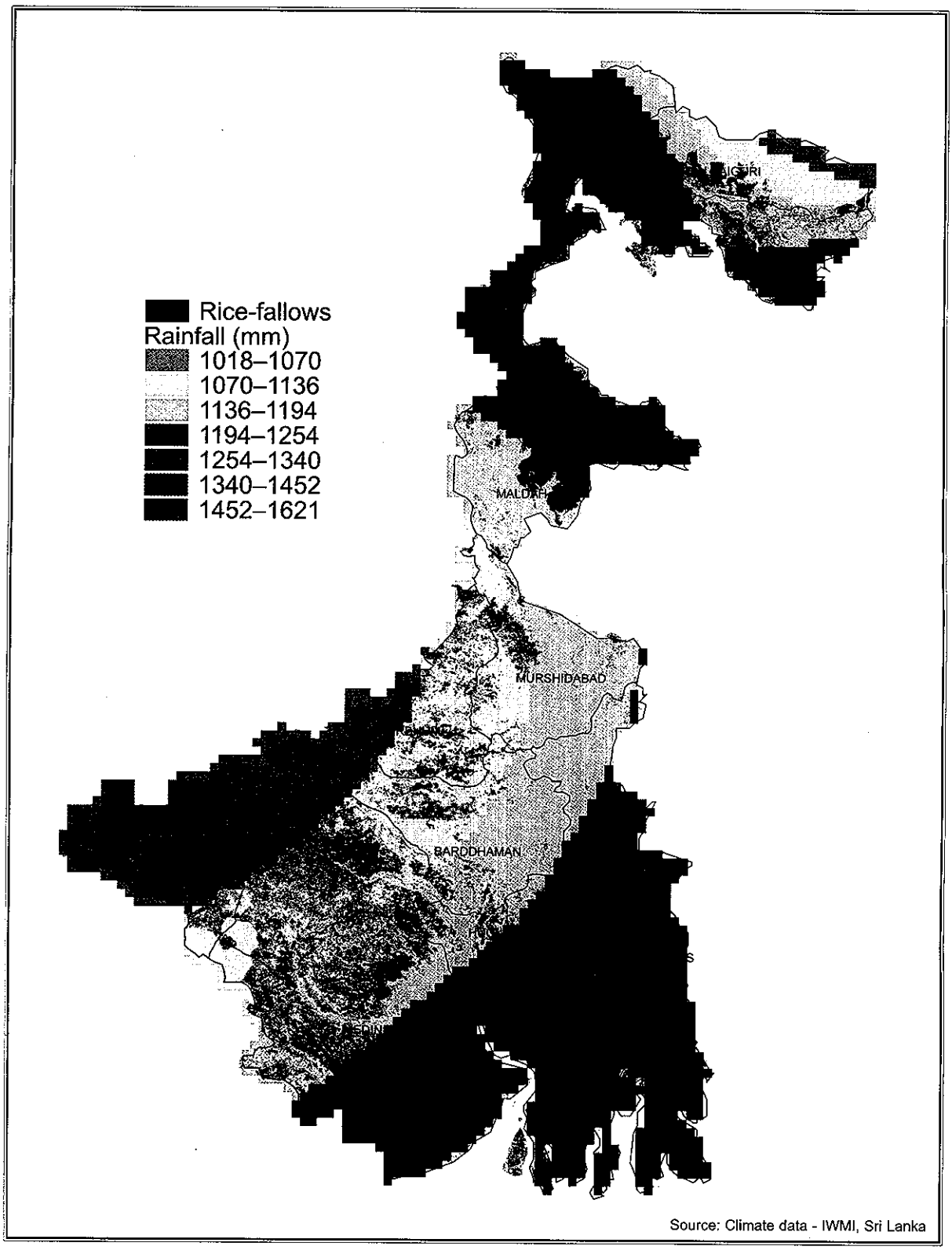


Fig. 5.2.151. Rainfall during kharif (June–September) in West Bengal, India

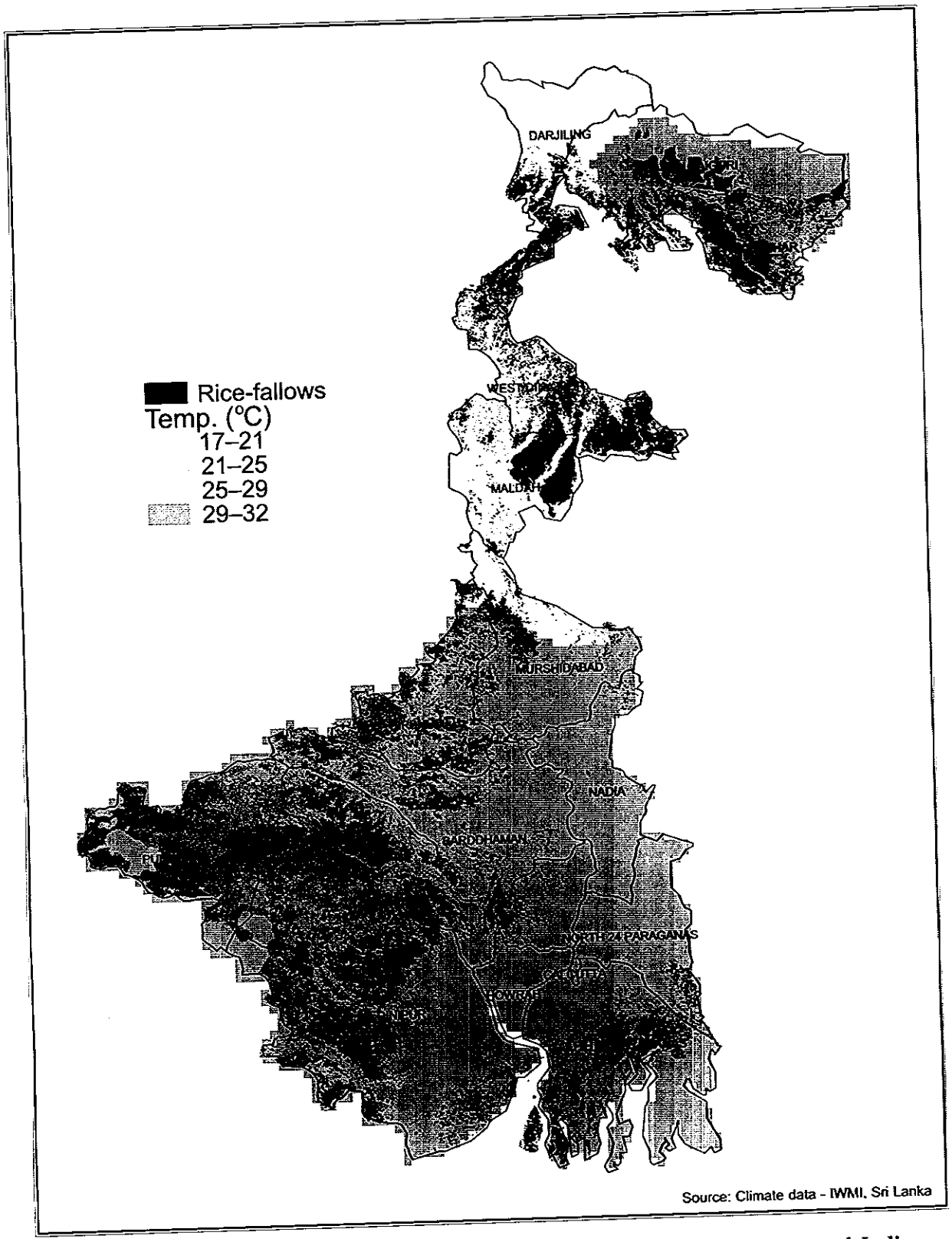


Fig. 5.2.152. Mean maximum temperature during kharif (June–September) in West Bengal, India

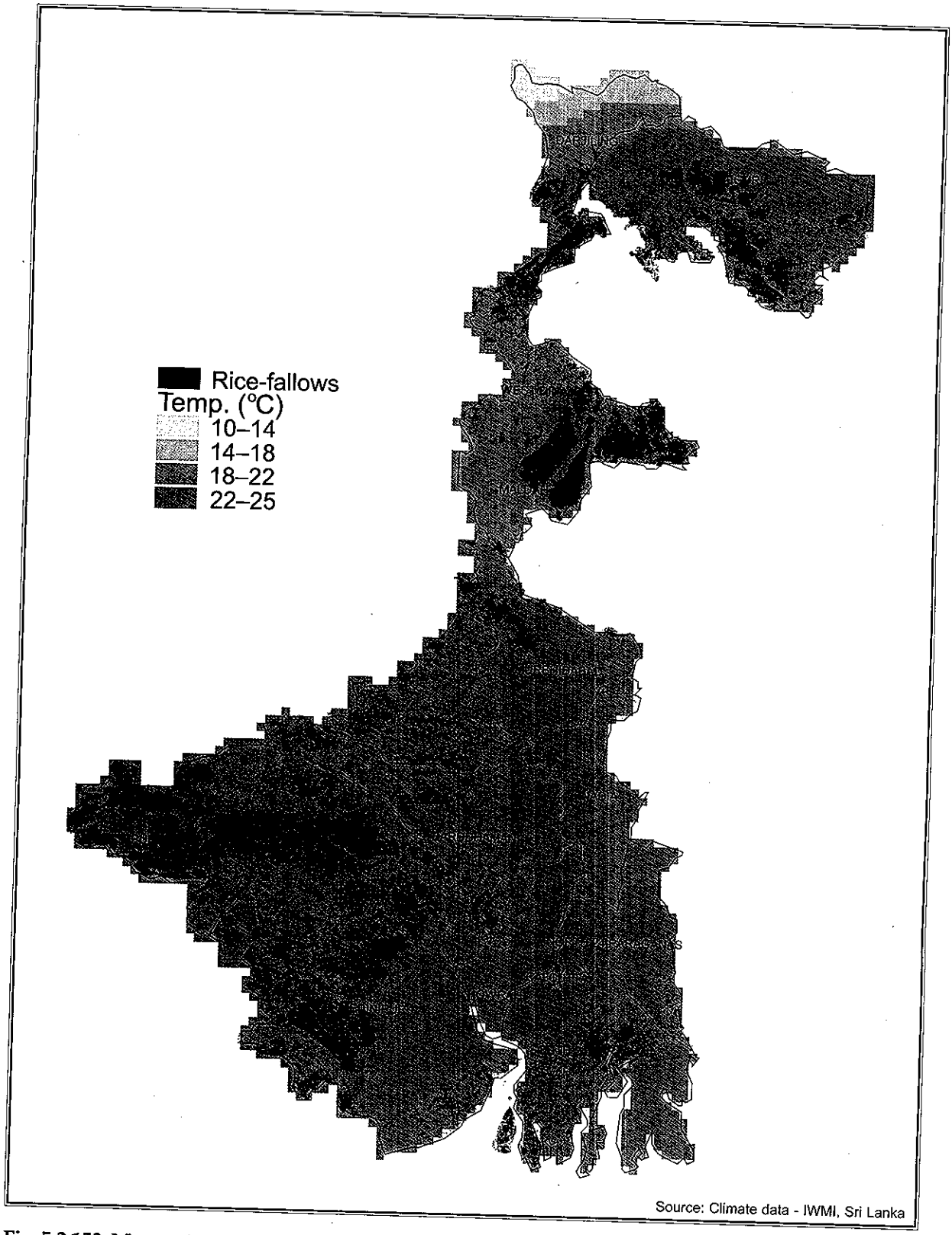


Fig. 5.2.153. Mean minimum temperature during kharif (June–September) in West Bengal, India

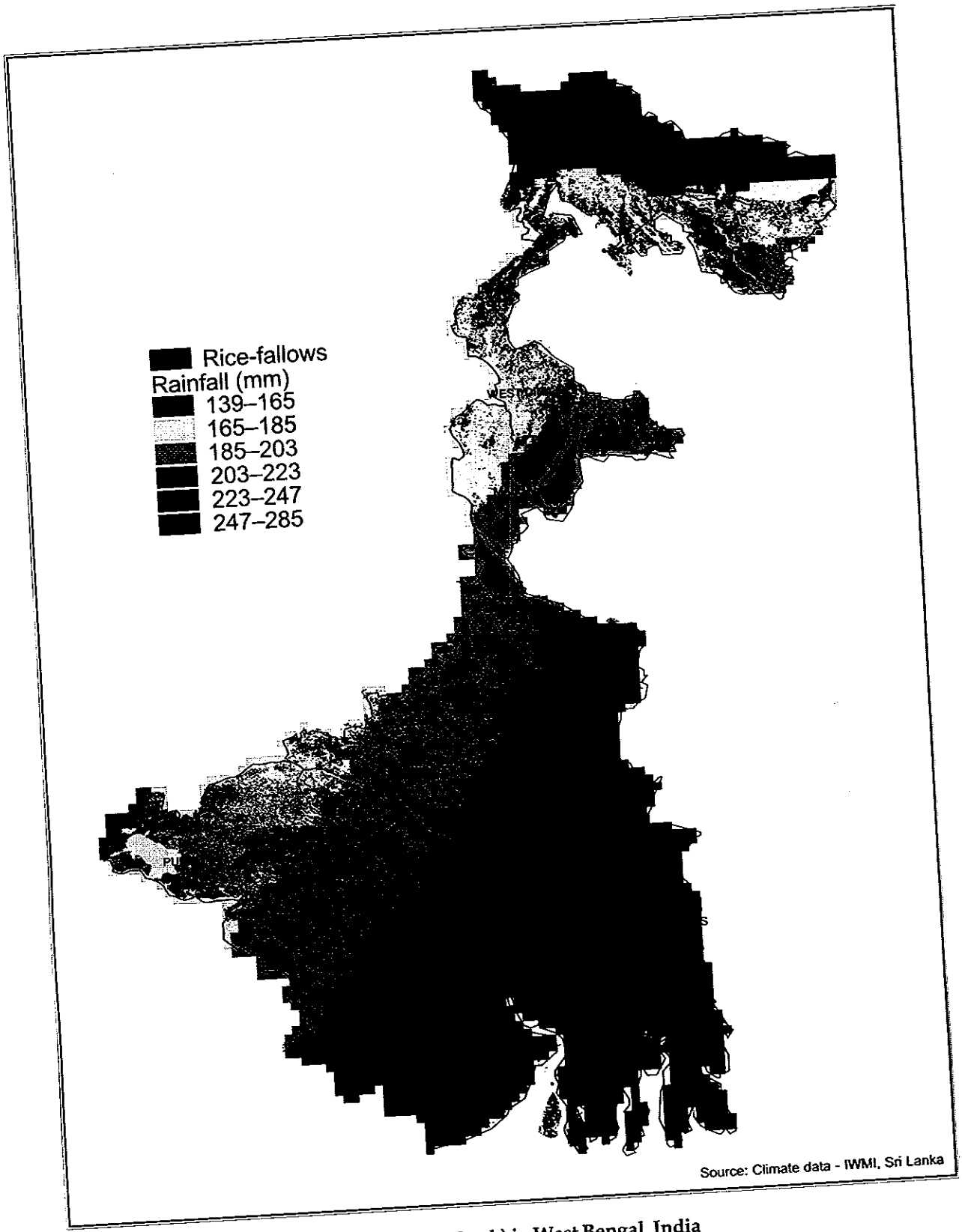
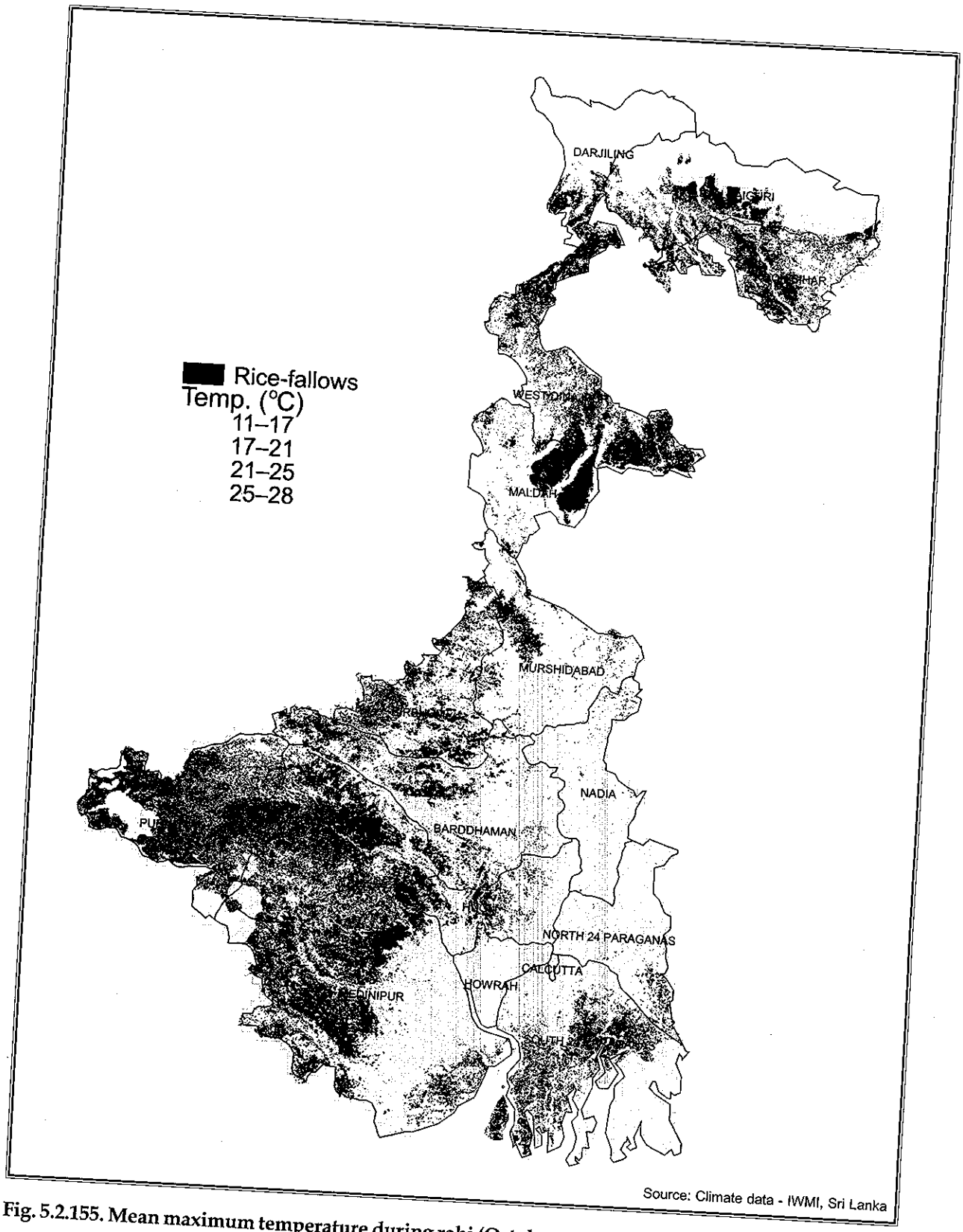


Fig. 5.2.154. Rainfall during rabi (October–March) in West Bengal, India



Source: Climate data - IWMI, Sri Lanka

Fig. 5.2.155. Mean maximum temperature during rabi (October–March) in West Bengal, India

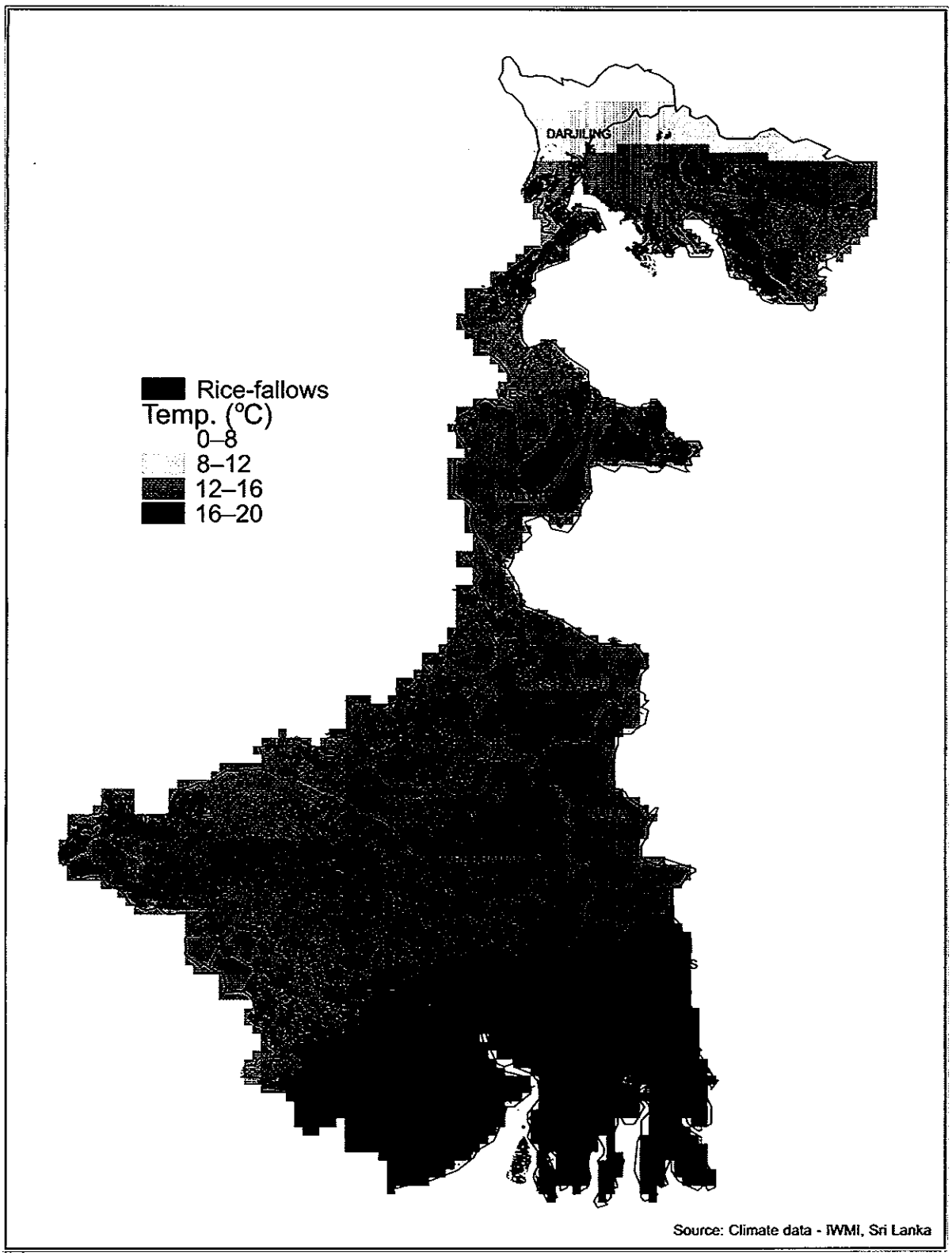


Fig. 5.2.156. Mean minimum temperature during rabi (October–March) in West Bengal, India

5.3. Nepal

Introduction

Rice-grain legumes cropping systems are long-standing traditional cropping patterns in Nepal, which are being increasingly replaced by the rice-wheat cropping system over the past 35 to 40 years. Legumes growing area has remained stagnant or has even decreased in many cases, and also legumes are being driven to more marginal areas because most of their traditional production niches are either occupied by rice during the kharif season or wheat during the rabi season. The growing area of chickpea and khesari has decreased by 36% and 40%, respectively, in the last 15 years. Nevertheless, this was compensated by an increase of 75% in lentil growing area (Table 5.3.1). This has led to increase in total grain legume area by 27%, an increase in grain legume production by 60% and an increase in per capita availability by 30% over the last 10 years (Pandey et al. 2000). However, the per capita legume consumption is only 9 kg per annum, which is one fourth of the recommended levels of FAO (FAO 1981).

Table 5.3.1. Area and production of rabi legumes in Nepal in 1985 and 1999.

Legume	Year	Area (ha)	Production (t)	Yield (t ha^{-1})	% change in area
Chickpea	1985	25,000	18,000	0.72	
	1999	16,046	12,798	0.79	–36
Lentil	1985	100,000	60,000	0.60	
	1999	174,594	132,290	0.76	+75
Khesari	1985	50,000	25,000	0.50	
	1999	30,000	20,000	0.67	–40

Source: Pandey et al. (2000).

Rice is grown in nearly 1.5 million ha in the Terai region of Nepal. A substantial amount of this land remains fallow during the rabi season, which could be effectively utilized for the cultivation of rabi season legumes, if suitable technological (both management and genetic) tools are available. Information on the spatial distribution and quantification of these rice-fallows have not been systematically documented so far. The present study is the first such study where satellite imagery and GIS tools are used to quantify the rice-fallows and document their spatial distribution in Nepal. Using GIS, we have overlaid the spatial distribution of rice-fallows on data of soils (FAO) and climate (IWMI). This is to understand and assess the potential adaptability of various short-season legumes to these rice-fallows and also to analyze the biotic and abiotic limiting factors for raising short-season legumes during the rabi season after the harvest of kharif rice crop.

Total Rice Area

According to crop statistics for Nepal, the rice cropped area was 1.486 million ha in 1997/98 and 1.514 million ha in 1998/99 (FAO 2000). The classified and unclassified (raw) images of satellite images of Nepal where rice area was demarcated during 1999 kharif season are presented in Figure 5.3.1. Based on the satellite image analysis, the rice area estimated for 1999 is 1.449 million ha, which is close to the crop statistics data based on 1997/98 or 1998/99.

Rice-fallow Estimations and Spatial Distribution

Based on the satellite image analysis, the total rice-fallows estimated in Nepal is 392,000 ha, and this amounts to 26% of the rice area. Unclassified and classified satellite images of Nepal taken during rabi season indicating the spatial distribution of rice-fallows are shown in Figure 5.3.2. In districts such as Jhapa, nearly 90% of the rice-growing area is left fallow during rabi season after rice harvest. A major portion of these fallows are located in the central and eastern portions of Terai (Jhapa, Morang, Saptari, Siraha, Dhanusha, and Kapilvastu districts).

Edaphic and Climatic Features of Rice-fallows

The Terai region represents 14% of the total land area of Nepal, but contains about 46% of the gross cultivated area (Pandey et al. 2000). The rice-based cropping is mostly concentrated in the Terai that consists of Eutric Fluvisols and Dystric Regosols soils, which are mostly rich alluvial deposits, predominantly of medium- to fine-textured sediments (Fig. 5.3.3), with an available water-holding capacity of 200 mm (Fig. 5.3.4). A major portion of these rice-fallows have Eutric Fluvisols (Fig. 5.3.3), while relatively small areas of rice-fallows in the districts Nawalparasi, Chitwan, Dang, Banke, Kailali, and Kanchanpur have Dystric Cambisols and Dystric Regosols. The soil organic matter levels in most of the rice-growing areas of Terai are low (<1%), which is a constraint to the rice-based system's productivity (Pandey et al. 2000). Also, most of the soils in Nepal (including Terai region) are deficient in N and P. Micronutrients such as Zn, B, and Mo are deficient in most of the Terai soils including rice-fallows (Pandey et al. 2000).

Annual rainfall where most of the rice-fallows are located (i.e., in the eastern region in Saptari, Morang, and Jhapa) is between 2000 mm and 2500 mm (Fig. 5.3.5). Rice-fallows that are located in the districts Dhanusha and Kapilvastu, fall in the annual rainfall zone of 1000–1500 mm (Fig. 5.3.5). About 80% of the total annual rainfall occurs in the kharif season (i.e., June to September), which is the main rice-growing period (Fig. 5.3.6). Mean rabi rainfall for rice-fallows located in the districts of Dhanusha, Siraha, Saptari, Sunsari, Morang, and Jhapa varied between 74 mm and 237 mm (Fig. 5.3.7). In the Terai where rice-fallows are mainly

located, the annual maximum temperatures range from 25°C to 33°C (Fig. 5.3.8) whereas the minimum temperatures vary from 15°C to 23°C (Fig. 5.3.9). The range of maximum and minimum temperatures during kharif is 25–37°C and 20–28°C, respectively (Figs. 5.3.10 and 5.3.11). Maximum and minimum temperatures during rabi season in the Terai are 20–28°C and 8–14°C, respectively (Figs. 5.3.12 and 5.3.13). Generally, the trend in seasonal variations of temperature is similar throughout the country, although topography significantly influences at the micro-level. Temperatures rise steadily from minimum values in winter, during January–February, to maximum values during April–May, and then fall slightly during the monsoon period due to presence of heavy clouds and rain. Temperatures then drop sharply to minimum values in winter. The maximum temperatures rise very sharply in spring (March to May), while the rise of minimum temperature is gradual.

Based on the WATBAL soil water balance model, the average monthly available soil water in the 1 m soil profile is estimated as 200 mm from July to September (Fig. 5.3.14). Also, the WATBAL model indicates that actual evapotranspiration/potential evapotranspiration (AE/PE) ratios (range 0.5–1.0) are reasonably favorable from June to December for most of the Terai where these rice-fallows are located (Fig. 5.3.15). Only during January to March, the crop is likely to face some degree of moisture deficit. But if the legume variety can mature by the end of February, the effect of moisture deficit on grain yield and productivity may be limited, and thus may not substantially reduce the grain yield (Figs. 5.3.14 and 5.3.15). However, the western Terai, comprising Banke, Dang, Kapilvastu, Rupandehi, Nawalparasi, and Chitwan is likely to face severe water deficit stress in January and February, and thus crops would ideally require one or two supplementary irrigations, if available, at least in February and March, or would be dependent on winter rains (Figs. 5.3.14 and 5.3.15).

If rice is sown in the beginning of June and harvested by the end of September, there will be adequate soil water available (about 200 mm at the time of sowing a legume) to support legume crops such as chickpea and lentil from October or November. If the anticipated winter rainfall is considered, which is about 50 mm per month on average over years, soil water levels will be more than adequate (total amount about 300 mm with the assumption that the rabi growing period is from October/November to February) to raise a good chickpea, lentil, or khesari crop in these rice-fallows. Since the evapotranspiration demand during the rabi season growing environment in the Terai of Nepal is only 2 mm day^{-1}, available soil water in these rice-fallows of Terai should be adequate, particularly in the eastern Terai to raise a good crop of chickpea or any other rabi season short-duration legume such as lentil, faba bean, or pea, if it can mature by early March. Planting of rice in June is certainly a possibility for the districts Sunsar, Morang, and Jhapa where the soil is nearly saturated by rainfall by the beginning of June (Fig. 5.3.14).

Legumes Suitable for Rice-fallows

The cool season legumes, lentil, chickpea, khesari, faba bean, and pea, are traditionally grown in the Terai region of Nepal and are suitable for the rice-fallows. Lentil is grown extensively in the central Terai region, where substantial rice-fallows exist in the districts of Parsa, Bara, Rautahat, and Sarlahi (Fig. 5.3.3). Though chickpea cultivation has moved from eastern to western Terai, substantial cultivation of chickpea is carried out in the central Terai districts of Kapilvastu and Rupandehi where rice-fallows exist (Pandey et al. 2000). Also, the eastern Terai districts of Mahottari and Dhanusha have substantial rice-fallows where chickpea is widely grown (Pandey et al. 2000). Thus, extension of chickpea and lentil into these rice-fallows where they are naturally adapted to this region appears to be the best option.

The available cultivars of chickpea and lentil require about 150 days to mature (Table 5.3.2), and thus are likely to face severe moisture deficits if the growing season extends into March and beyond. Hence, varieties/genetic stocks that can mature within 120 days would be ideal for these rice-fallows, so that they are suitable for late October or early November planting, but mature by the end of February or early March, without being subjected to moisture deficits. Also, deep rooted legumes such as chickpea and khesari are better suited for the entire Terai region including the western Terai, where moisture deficits are expected to be more severe during active reproductive growth. However, shallow rooted legumes such as lentil, pea, and faba bean are perhaps better suited to the rice-fallows located in the eastern Terai.

Table. 5.3.2. Chickpea and lentil varieties available for cultivation in the Terai region of Nepal.

Crop/Variety	Year of release	Origin	Days to maturity	Yield potential ($t\ ha^{-1}$)
Lentil				
Sindur	1979	Nepal	148	1.5
Simirik	1979	India (T 36)	143	1.5
Sishir	1979	India (P 43)	150	2.0
Simal	1989	India (LG 7)	143	2.1
Sikhar	1989	Pakistan (ILL 4404)	143	2.5
Chickpea				
Dhanush	1980	Nepal	144	1.8
Trishul	1980	Nepal	144	1.7
Radha	1987	India (JG 74)	142	1.6
Sita	1987	India (ICCC 4)	140	1.5
Kosheli	1990	India (ICC 31)	154	1.6
Kalika	1990	India (ICCL 82198)	152	1.4

Source: Pandey et al. (2000).

Constraints to Legumes Production

Abiotic constraints

Various climatic and soil factors limit the productivity of winter legumes, if introduced into rice-fallows. Among these, early and terminal drought, excess moisture, adverse temperatures, high humidity, and poor soil fertility are important in the rice-fallows of Nepal. Some of these constraints are common to rice-fallows irrespective of the region, whereas some of them are unique to the country or more specific to the location.

Crop establishment problems. Some of the challenges generally associated with rice-fallows in establishing a good plant stand in South Asia are also applicable for Nepal (see Section 4 for further discussion). In the western Terai, water deficits during germination and seedling establishment stage may reduce the plant stand, thus eventually limiting the yield potential, whereas in the eastern Terai, higher levels of soil moisture in the seed zone may create waterlogged conditions, and thereby also reduce plant stand. Legumes such as chickpea are highly sensitive to waterlogging during germination and seedling establishment stage (Saxena 1962). Crops such as lentil, pea, faba bean, and khesari are relatively more tolerant to waterlogging conditions compared to chickpea (Pandey et al. 2000). Lentil and khesari are traditionally grown as relay crops with summer season rice in the Terai region of Nepal. The seed is broadcast on saturated soils by the end of October to mid-November, about 10 to 20 days before rice harvest (Pandey et al. 2000). Perhaps seed dibbling can facilitate relay planting, and thus ensure a better plant stand for these two legumes, which should be explored further in future research.

Because of the hardpan in the sub-surface (about 30 cm deep), root penetration into deeper soil layers may be constrained for most crops, particularly for lentil, faba bean, and pea (Cook et al. 1995). This would render these crops highly susceptible to the water deficits as they would be unable to utilize the sub-soil water resources for growth, particularly in the reproductive phase during February to March.

Constraints linked to germination and plant stand establishment can be alleviated by selecting genetic stocks that have better adaptability to water deficit or excess during germination and plant establishment. Seed priming has been shown to substantially improve the plant stand for chickpea in rice-fallows in the Barind region of Bangladesh (Harris et al. 1999, Musa et al. 1999). However, little is known about the advantages of seed priming in plant stand establishment of legumes in rice-fallows of Nepal. Thus seed priming should be explored and evaluated as a management option for improving plant stand of legumes in the rice-fallows of Nepal. Also by adopting appropriate tillage and planting practices, plant stand can be substantially improved in these rice-fallows (see Section 4 for further discussion).

Root penetration through the hard pan should be facilitated by using appropriate tillage methods as this would facilitate optimum utilization of water stored in the soil profile, thus minimizing crop exposure to severe water deficits during the reproductive phase of growth.

Soil acidity. Soil acidity poses a serious constraint to legume introduction into rice-fallows as many soils of rice-fallows have pH values below 5.0. Also, legumes are relatively more sensitive to soil acidity compared to cereals and other non-legume crops (Choudhary and Pandey 1986, Chong et al. 1987). The symbiotic N fixation system of legumes is highly sensitive to low pH, thus posing the problem of N deficiency to legumes. Soil acidity problems, which are due to leaching of bases because of higher rainfall as well as acidic parent materials, are more severe in the rice-fallows of the eastern region compared to western Terai (Pandey et al. 2000). Lentil, pea, and faba bean may be more tolerant to acid conditions than legumes such as chickpea, which is more adapted to higher pH soils because of the ability of its roots to secrete organic acids (Chong et al. 1987, Ae et al. 1990).

Nutrient limitations. Low soil pH in rice-fallows is likely to create P deficiency conditions for legumes. Phosphorus deficiency has been reported to be widespread in Nepal where some rice-fallows are located (Joshy and Deo 1976). Severe B deficiency has been reported in the districts Chitwan and Nawalparasi, where significant areas of rice-fallows exist (Srivastava et al. 1997, 1999). Nevertheless, B deficiency appears to be widespread across the Terai region; but often the symptoms overlap with those of BGM (Pandey et al. 2000). Application of B fertilizer as boric acid (0.5 kg ha^{-1}) will correct the problem of B deficiency in rice-fallows (Srivastava et al. 1997, 1999). In addition to B deficiency, Mo deficiency has also been reported in chickpea (Srivastava et al. 1997) and Zn deficiency in lentil (Srivastava et al. 1999). Thus appropriate trace element fertilization is required if these and perhaps other legumes are to be successfully cultivated in rice-fallows.

Terminal drought. Terminal drought will be a certainty if legumes are introduced into rice-fallows of the entire Terai region. However, water deficits are less severe in the eastern Terai compared to the western Terai. Perhaps deep rooted crops such as chickpea and khesari will be more suitable in the western Terai as they have much better adaptation to drought compared to shallow rooted legumes such as lentil, faba bean, and pea, which are more suitable for the rice-fallows located in the eastern Terai region.

Current cropping practices use long-duration rice cultivars that mature in mid-November. Winter legumes (lentil, chickpea, khesari, faba bean, and pea) when planted in the end of November are likely to face terminal drought if the growing season extends into March. Hence, rice should be planted early enough (i.e., in June instead of July) and should mature

by the end of October; thus the rabi legume can be planted in November, so that it matures by early March. In this case, the rabi legume is less likely to be subjected to terminal drought stress. This strategy should be explored further by designing experiments evaluating various components (e.g., planting rice in early June, so that harvesting of rice is completed by the end of October; search for short-duration rice cultivars that mature by the end of October when planted in July; and develop short-duration legume varieties that mature within 120 days, so that they can be planted in November and mature by the end of February).

Cold stress. Research should be directed at identifying genetic stocks of chickpea and lentil that can set pods at low temperatures (i.e., at <5°C) (i.e., starting from January), so that most of the pod filling can occur during February or early March when temperatures begin to rise (Saxena et al. 1997). Thus the crop can mature by the end of February or in early March. This can protect the crop from exposure to severe moisture deficits during the active reproductive phase of growth that could drastically affect the yield. Some progress has already been made at ICRISAT in identification of genetic stocks such as ICCV 88501, 88502, and 88503 that could set pods at cool temperatures (i.e., at <5°C), where most of the existing cultivars fail (ICRISAT 1994). These traits need to be incorporated into the adapted genetic backgrounds of chickpea. Thus relevant varieties can be developed from these genetic stocks that are more suitable for rice-fallows of this region.

Biotic constraints

Diseases. Details of various diseases that affect the legumes potentially suitable for this region are presented in Table 5.3.3. Vascular wilt, collar rot, rust, and BGM are some of the most serious diseases that can cause substantial yield losses in lentil. The most important diseases of chickpea in the Terai region of Nepal are BGM, fusarium wilt, and collar rot. BGM is the most important disease of chickpea particularly in the eastern Terai where substantial portions of rice-fallows are located. This is one of the reasons for shifting of chickpea from its traditional production niche of eastern Terai to western Terai where the disease incidence is less. Recently, genetic stocks such as ICCX 840508-32 and ICCL 87305 were identified as resistant to BGM (NARC 1997). These should be recommended in rice-fallows where BGM can be a problem (such as the eastern districts of Terai). Integrated agronomic packages to manage BGM in Nepal, using a less susceptible variety, seed treatment with fungicide, need-based foliar sprays of fungicide, and prevention of dense canopies, have recently been found effective in Nepal (Pande and Narayana Rao 2000). Powdery mildew has been reported on khesari, but its effect seems to be relatively low on khesari production.

Table 5.3.3. Diseases of chickpea, lentil, faba bean, and pea and their distribution and status in the Terai region of Nepal.

Crop/Disease	Causal organism	Distribution	Status
Lentil			
Vascular wilt	*Fusarium oxysporum* f. sp *lentis*	Most of Terai	Major
Collar rot	*Sclerotium rolfsii*	Most of Terai	Major
Black root rot	*Fusarium solani*	Most of Terai	Minor
Rust	*Uromyces viciae-fabae*	Most of Terai	Major
Gray mold	*Botrytis cinerea*	Most of Terai	Major
Alternaria blight	*Alternaria alternata*	Most of Terai	Minor
Wet root rot	*Rhizoctonia solani*	Most of Terai	Minor
Chickpea			
Botrytis gray mold	*Botrytis cinerea*	Prevalent in central and eastern Terai	Major
Fusarium wilt	*Fusarium oxysporum* f. sp *ciceris*	Prevalent in central and eastern Terai	Major
Alternaria blight	*Alternaria alternata*	Sporadic across most of Terai	Minor
Sclerotinia stem rot	*Sclerotinia sclerotiorum*	Sporadic across most of Terai	Minor
Black root rot	*Fusarium solani*	Major in moist soil conditions such as eastern Terai	Major
Collar rot	*Sclerotium rolfsii*	Major in moist soil conditions such as eastern Terai	Major
Dry root rot	*Macrophomina phaseolina* (sclerotial state: *Rhizoctonia bataticola*)	Sporadic across most of Terai	Minor
Chickpea stunt	Bean (pea) leaf roll virus	Sporadic across most of Terai	Minor
Faba bean			
Rust	*Uromyces viciae-fabae*	Most of Terai	Major
Chocolate spot	*Botrytis fabae*	Most of Terai	Major
Root rot and wilt	*Fusarium* spp and *Rhizoctonia solani*	Most of Terai	Minor
Pea			
Pea seedborne mosaic	Pea seedborne mosaic virus	Most of Terai	Major
Powdery mildew	*Erysiphe pisi*	Most of Terai	Major

Source: Pandey et al. (2000).

Insect pests. There are many insect pests that infest legumes in Nepal, but only a few of them are a threat to chickpea and lentil (Table 5.3.4). The pod borer (*Helicoverpa armigera*) is a serious pest that can cause more than 60% yield damage in chickpea on farmers' fields (Thakur 1997). For faba bean and khesari, aphid infestation is common and causes some yield loss. Integrated pest management strategies are available that could be applied to combat the major insect pests of legumes in Nepal (Ranga Rao and Shanower 1999).

Table 5.3.4. Insect pests of lentil, chickpea, faba bean, pea and khesari and their status in the Terai region of Nepal.

Crop	Insect pests	Status
Lentil	*Agrotis ipsilon*	Major
	Acyrthosiphon pisum	Major
	Helicoverpa armigera	Major
	Callosobruchus chinensis	Major
	Callosobruchus maculatus	Major
	Phyllotreta sinuate	Minor
	Athalia sp	Minor
	Adonia variegata	Minor
Chickpea	*Agrotis ipsilon*	Major
	Plucia orichalcea	Minor
	Helicoverpa armigera	Major
	Callosobruchus chinensis	Major
	Callosobruchus maculatus	Major
Faba bean	*Aphis fabae*	Major
	Aphis craccivora	Minor
	Nezara antennata	Minor
	Helicoverpa armigera	Minor
Pea	*Acyrthosiphon pisum*	Major
	Helicoverpa armigera	Major
	Bruchus pisorum	Major
	Macrosiphum pisum	Minor
	Taeniothrips flavidulus	Minor
	Empoasca sp	Minor
	Phytomyza atricornis	Minor
	Lampides boeticus	Minor
Khesari	*Aphis craccivora*	Minor

Source: Pandey et al. (2000).

Socioeconomic constraints

Socioeconomic constraints largely emerge from the interaction of agroclimatic factors, farming systems, and characteristics of the legume crops. Neupane (1995) listed several socioeconomic constraints to legume cultivation. Grain legumes are not a staple food and hence farmers give less priority to legumes over other staple food crops such as rice or wheat. Legume varieties locally available are perceived as not responsive to improved management and having a high yield risk due to susceptibility to biotic and abiotic stresses. Market price of legumes fluctuates and availability of improved seed, production inputs, and extension services for legumes are not readily available to farmers. Farmers therefore usually grow grain legumes on poor soil as subsistence crops. Grain legumes have low profitability compared to other crops such as wheat, maize (*Zea mays* L.), barley (*Hordeum vulgare* L.), jute, potato (*Solanum tuberosum* L.), and sugarcane. Non-availability of stable, high-yielding, and disease resistant varieties, and lack of awareness of improved crop management technologies, and improved postharvest technologies to increase crop productivity also hinder cultivation of leguminous crops. There is little government policy emphasis (such as incentive pricing, marketing, and availability of seed) towards grain legumes cultivation.

Pakhribas Agricultural Center conducted a study in Change, Taplejung, Mechi Zone on the "Implications of rice-fallow in agricultural research" with the objectives to determine the proportion of farm holdings kept fallow, identify which farmers keep fallow lands, and assess why it is kept fallow (PAC 1993). Rice-fallow systems were found across 27% of all holdings within the Village Development Committee and extent of fallow varied by altitude and farmer category. Thirty-one percent fallow was at low altitude while 19% was at mid-altitude and 16% at high altitude. Food surplus farmers kept 30% of their total holding fallow after rice. Corresponding figures for the food balance group and food deficit group were 19% and 29%, respectively. As a proportion of holdings of Khet land among the three different farmer categories rice-fallow accounts for 35%, 23%, and 39% for food surplus, food balance, and food deficit groups, respectively. The main reasons given for keeping land fallow after rice were existence of marshy land, uncontrolled animal grazing, and lack of irrigation.

Bharati (1982) mentioned several problems in the marketing, storage, and processing of grain legumes in Nepal. There is no large-scale marketing arrangement either in the public or private sector, except for lentil. The government has not fixed the floor price for any grain legume. Hence, the traditional marketing system through which the product reaches the consumer from the farmer through many middlemen in the village and at

other levels still prevails. Lack of infrastructure such as transportation facilities is also a bottleneck in developing an effective market system. Mainly, the small-holder farmers store their grain under sub-optimal conditions. This results in loss of quality and quantity of grains due to reduced seed viability and damage and loss from insects and rodents. The absence of large-scale storage facilities also causes large-scale seasonal fluctuations in price of grain legumes. Processing of grain legumes is limited to lentil and pigeonpea and this involves cleaning, dehulling, and splitting. There is a strong demand for dehulled mung bean and black gram in the market but there are few mills to process these grain legumes. Though the study of Bharati (1982) is about 20 years old, the situation as described for markets and pricing mechanism still remains essentially the same.

Economic Feasibility of Growing Legumes in Rice-fallows

Cultivation of a crop may be technically feasible but it may not be profitable. If the crop is not profitable, then farmers will not grow the crop. Although Nepalese farmers can grow chickpea, lentil, khesari, and pea, their motivation to do so will depend on the likely costs and benefits involved. Results of an economic feasibility analysis, calculated from estimates of current prices, are provided in Tables 5.3.5 to 5.3.9. Cultivation of chickpea would provide Rs. 12,890 per hectare with an estimated BCR of 3.71 (Table 5.3.5). Cultivation of lentil in one hectare of land will provide a BCR of 2.87 and a net return of Rs. 13,650 (Table 5.3.6). Pea will provide a net return of Rs. 9,590 with an estimated BCR of 2.97 (Table 5.3.7). On the other hand, khesari will provide Rs. 6,240 as net return with a BCR of 3.01 (Table 5.3.8). Analysis of relative profitability showed that chickpea will provide highest return followed by pea, lentil, and khesari.

In a labor surplus economy like Nepal, scope for employment generation is always an opportunity for the farm households and national economy. It is estimated that cultivation of chickpea, lentil, or pea will create an employment opportunity of 28 person-days per hectare while khesari will provide 20 person-days work. On an average, cultivation of legumes in one hectare of fallow land will generate 26 person-days working opportunity and about Rs. 1,300 remuneration as labor wage. If all the rice-fallow areas (about 0.4 million ha) can be brought under legume cultivation then additional employment creation in the Nepalese economy will be 10.2 million person-days (Table 5.3.9).

Table 5.3.5. Cost and returns (per hectare) from cultivation of chickpea in rice-fallows in Nepal.

Description	Unit	Unit price (Rs)	Quantity	Amount (Rs.)
Inputs				1400.00
Labor	day	50.00	9	450.00
Land preparation and sowing	day	50.00	9	450.00
Weeding and cultural operations	day	50.00	10	500.00
Harvesting and threshing	day			600.00
Bullock labor	pair-day	50.00	9	450.00
Land preparation and sowing	pair-day	50.00	3	150.00
Threshing	pair-day			0.00
Machine cost	hour			0.00
Tractor/Power tiller for land preparation	hour			0.00
Threshing	hour	30.00	50	1500.00
Seed	kg			1100.00
Fertilizer	kg	7.50	100	750.00
Single superphosphate	kg	70.00	5	350.00
Boric acid	kg	80.00	2	160.00
Pesticides	number of sprays			4760.00
Total cost				
Outputs				
Grain yield	kg	20.00	800	16000.00
Fodder yield (byproduct)	kg	1.00	1500	1500.00
Green vegetable consumption	kg			150.00
Returns				
Gross return				17650.00
Net return				12890.00
Benefit-cost ratio (BCR)				3.71

Table 5.3.6. Costs and returns (per hectare) from cultivation of lentil in rice-fallows in Nepal.

Description	Unit	Unit price (Rs.)	Quantity	Amount (Rs.)
Inputs				1400.00
Labor	day	50.00	9	450.00
Land preparation and sowing	day	50.00	9	450.00
Weeding and cultural operations	day	50.00	10	500.00
Harvesting and threshing	day			600.00
Bullock labor	pair-day	50.00	9	450.00
Land preparation and sowing	pair-day	50.00	3	150.00
Threshing	pair-day			0.00
Machine cost	hour			0.00
Tractor/Power tiller for land preparation	hour			0.00
Threshing	hour	50.00	30	1500.00
Seed	kg			1100.00
Fertilizer	kg	7.50	100	750.00
Single superphosphate	kg	70.00	5	350.00
Boric acid	kg	80.00	2	160.00
Pesticides	number of sprays			4760.00
Total costs				
Outputs				
Grain yield	kg	25.00	500	12500.00
Fodder yield (byproduct)	kg	1.00	1000	1000.00
Green vegetable consumption	kg			150.00
Returns				
Gross return				13650.00
Net return				8890.00
Benefit-cost ratio (BCR)				2.87

Table 5.3.7. Cost per hectare and returns from cultivation of pea in rice-fallows in Nepal.

Description	Unit	Unit price (Rs.)	Quantity	Amount (Rs.)
Inputs				
Labor	day			1400.00
Land preparation and sowing	day	50.00	9	450.00
Weeding and cultural operations	day	50.00	9	450.00
Harvesting and threshing	day	50.00	10	500.00
Bullock labor	pair-day			600.00
Land preparation and sowing	pair-day	50.00	9	450.00
Threshing	pair-day	50.00	3	150.00
Machine cost	hour			0.00
Tractor/Power tiller for land preparation	hour			0.00
Threshing	hour			0.00
Seed	kg	40.00	40	1600.00
Fertilizer	kg			1100.00
Single superphosphate	kg	7.50	100	750.00
Boric acid	kg	70.00	5	350.00
Pesticides	number of sprays	80.00	2	160.00
Total cost				4860.00
Outputs				
Grain yield	kg	16.00	800	12800.00
Fodder yield (byproduct)	kg	1.00	1500	1500.00
Green vegetable consumption	kg			150.00
Returns				
Gross return				14450.00
Net return				9590.00
Benefit-cost ratio (BCR)				2.97

Table 5.3.8. Cost per hectare and returns from cultivation of khesari in rice-fallows in Nepal.

Description	Unit	Unit price (Rs.)	Quantity	Amount (Rs.)
Inputs				
Labor	day			1000.00
Land preparation and sowing	day	50.00	1	50.00
Weeding and cultural operations	day	50.00	9	450.00
Harvesting and threshing	day	50.00	10	500.00
Bullock labor	pair-day			150.00
Land preparation and sowing	pair-day	50.00	0	0.00
Threshing	pair-day	50.00	3	150.00
Machine cost	hour			0.00
Tractor/Power tiller for land preparation	hour			0.00
Threshing	hour			0.00
Seed	kg	20.00	35	700.00
Fertilizer	kg			1100.00
Single superphosphate	kg	7.50	100	750.00
Boric acid	kg	70.00	5	350.00
Pesticides	number of sprays	80.00	2	160.00
Total cost				3110.00
Outputs				
Grain yield	kg	12.00	600	7200.00
Fodder yield (byproduct)	kg	1.00	2000	2000.00
Green vegetable consumption	kg			150.00
Returns				
Gross return				9350.00
Net return				6240.00
Benefit-cost ratio (BCR)				3.01

Table 5.3.9. Labor requirement for growing chickpea, lentil, pea, and khesari in rice-fallows in Nepal.

Crop	Labor requirement (person-days ha^{-1})
Chickpea	28
Lentil	28
Field Pea	28
Khesari	20
Mean (legumes)	26
Total rice-fallow area (ha)	392,000
Potential employment creation (person-days)	10,192,000

Concluding Remarks

Currently grain legumes occupy 311,661 ha (Pandey et al. 2000), and utilization of the available rice-fallows for short-season legumes could result in nearly doubling of area under legumes (adding up to about 392,000 ha). This is a production niche in which cereals are not likely to be able to compete with legumes, and so should be fully exploited for improving the production of legumes in this country. Also, introducing short-season legumes (that mature within 120 days) into the rice-fallows of Terai region in Nepal could contribute to sustainability of these monocrop rice-based production systems. This is in addition to generating employment opportunity of 10.2 million person-days if the rice-fallows are utilized for legumes production. Crop rotation may not be feasible in this system as rice is the most important component of this production system and cannot be replaced in rotation. Thus, any scope of bringing a legume or any other crop into this production system depends on using the rabi season production environment. Although there are many constraints to growing grain legumes after rice in Nepal (Pandey et al. 2000), it is possible to alleviate these so as to achieve profitable and stable yields (Johansen et al. 2000b).

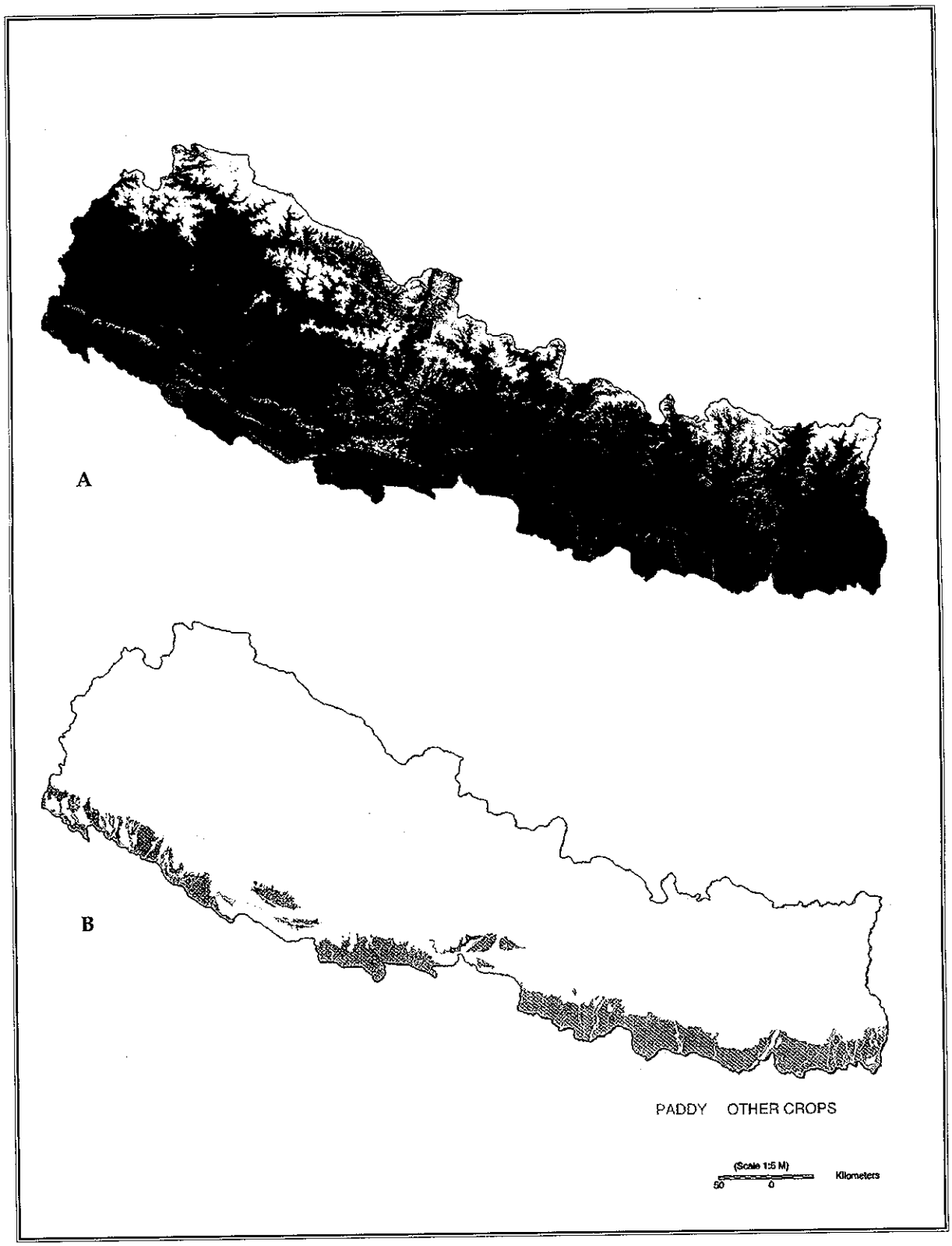


Fig. 5.3.1. Unclassified (A) and classified (B) satellite images of Nepal in kharif 1999

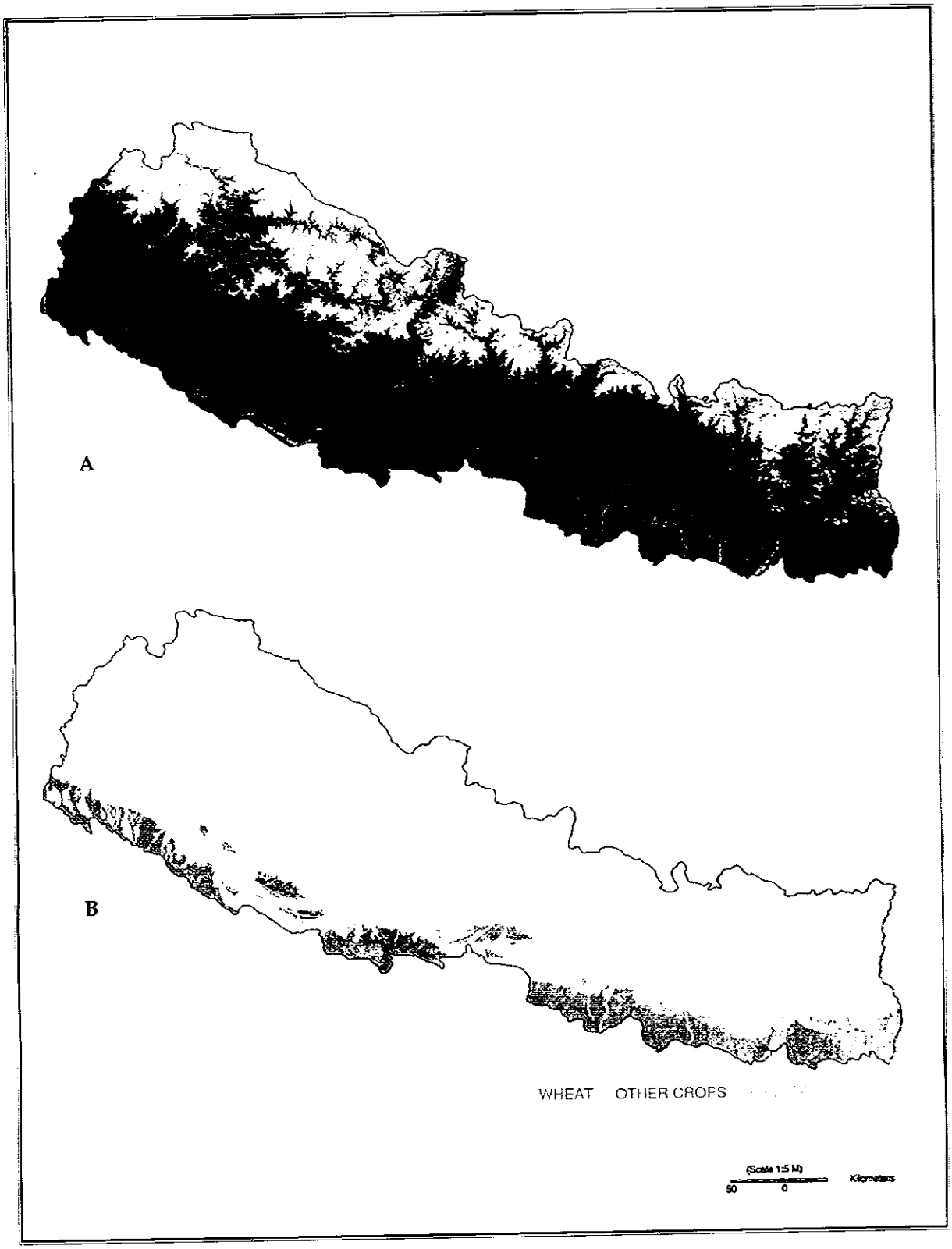
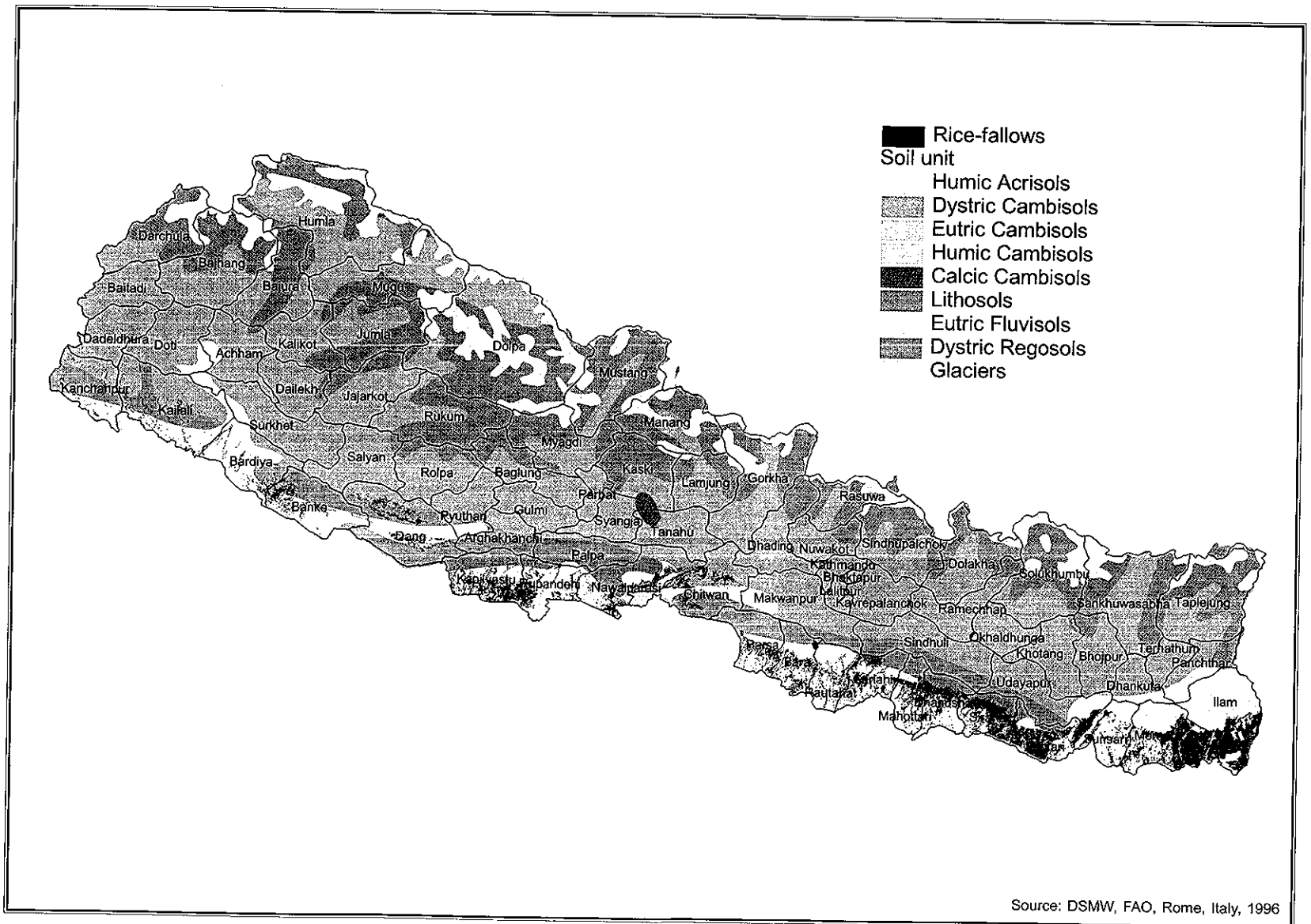


Fig. 5.3.2. Unclassified (A) and classified (B) satellite images of Nepal in rabi 1999/2000



Source: DSMW, FAO, Rome, Italy, 1996

Fig. 5.3.3. Soils of Nepal

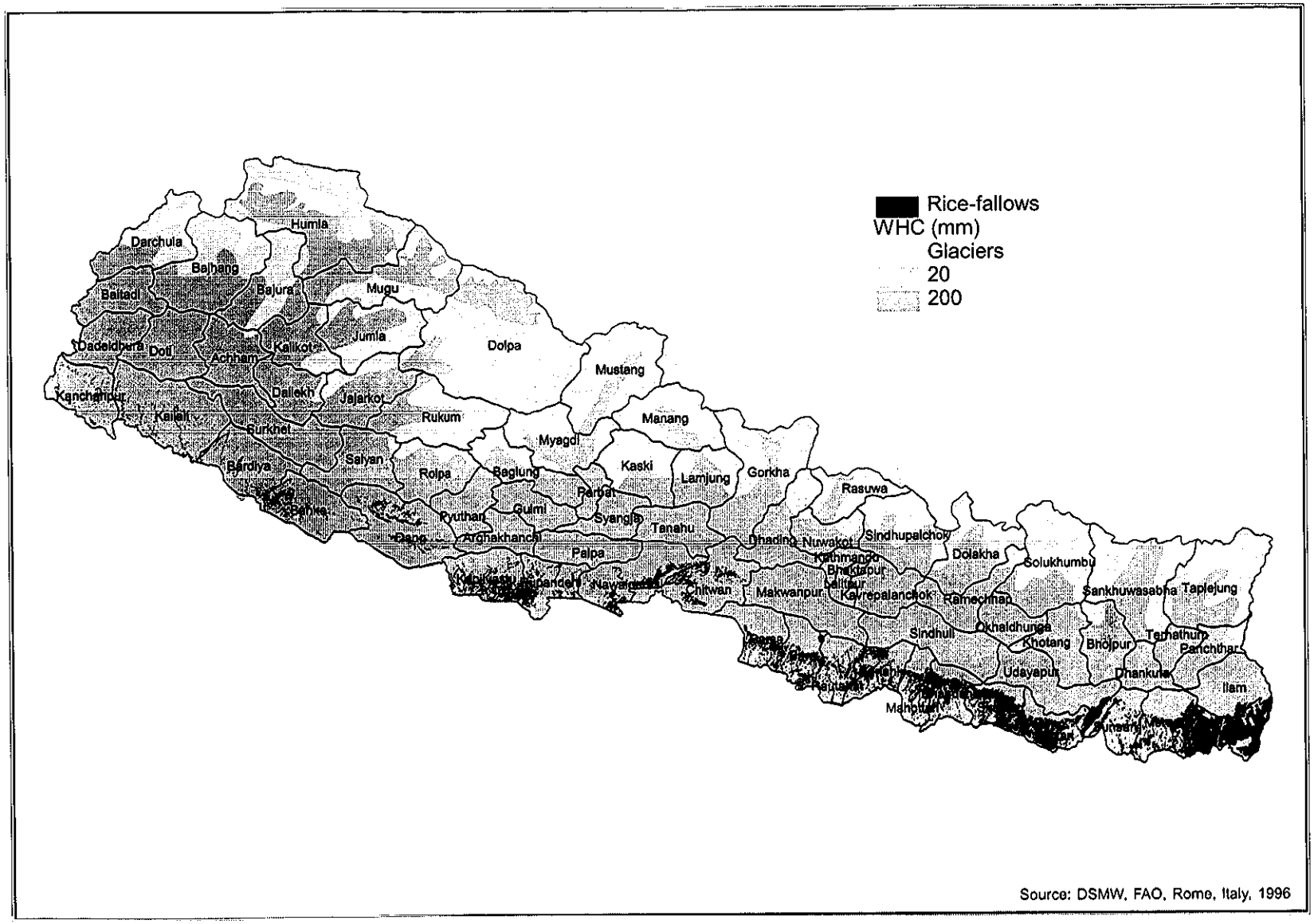


Fig. 5.3.4. Available soil water-holding capacity (WHC) in Nepal

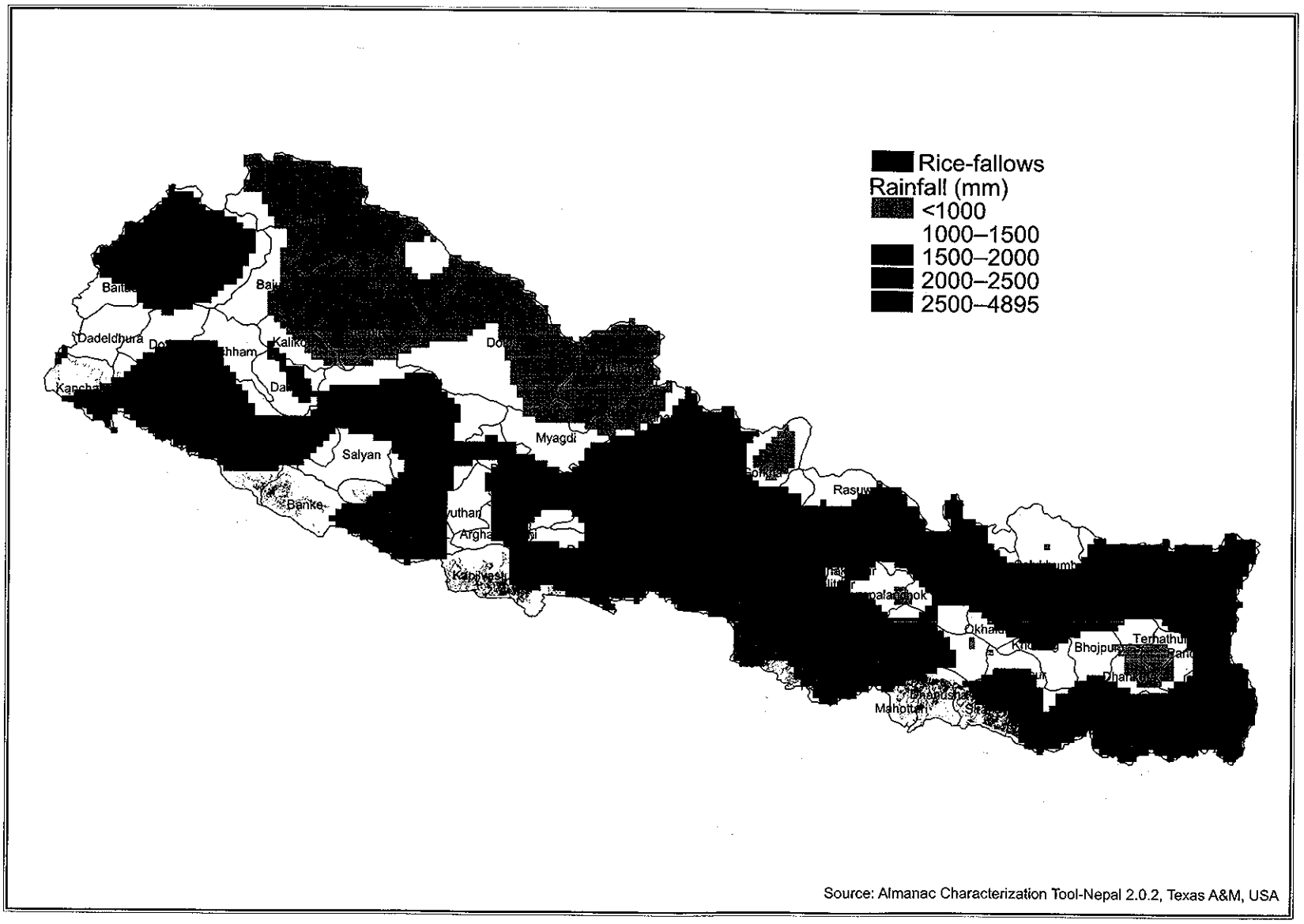


Fig. 5.3.5. Annual rainfall in Nepal

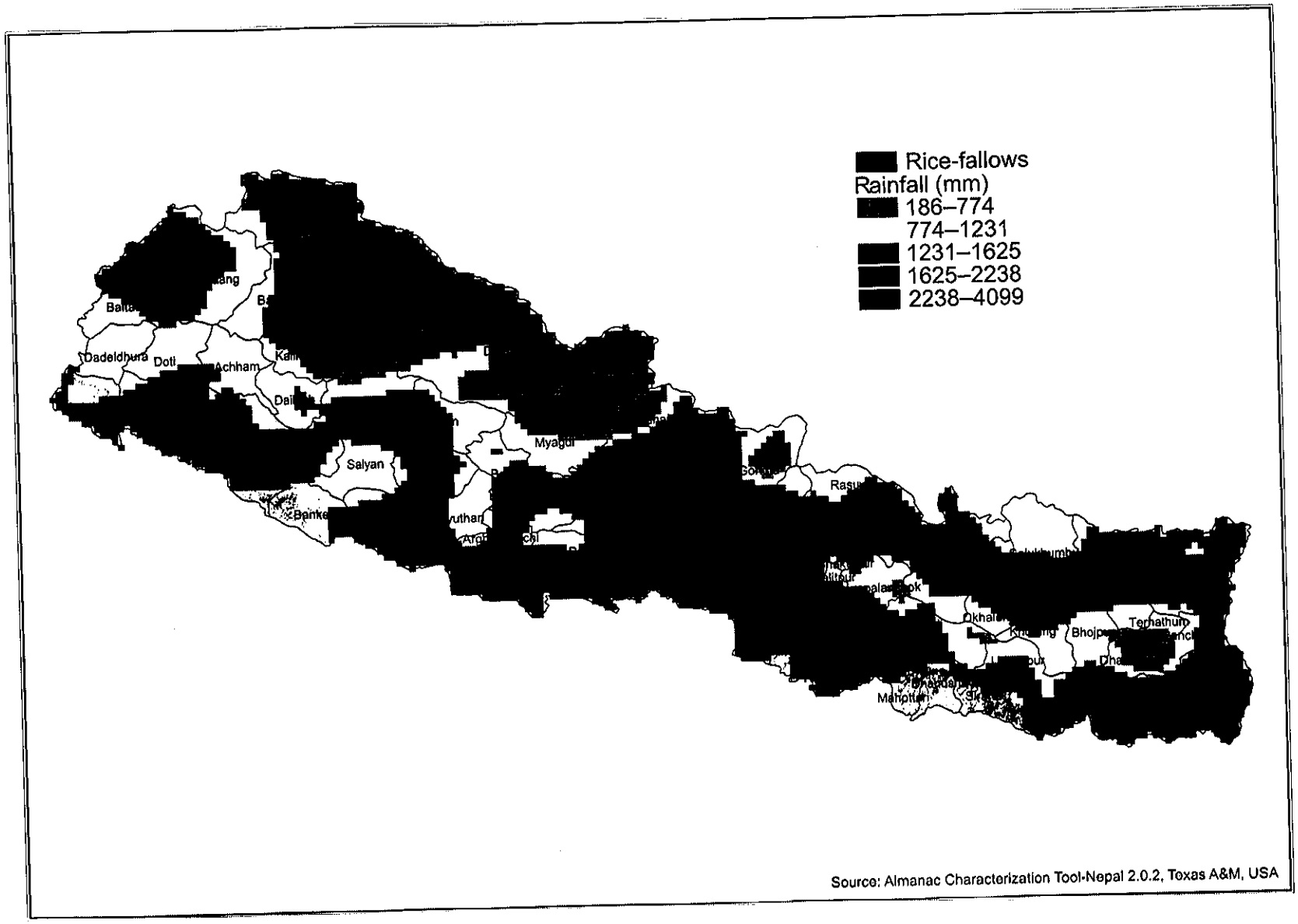
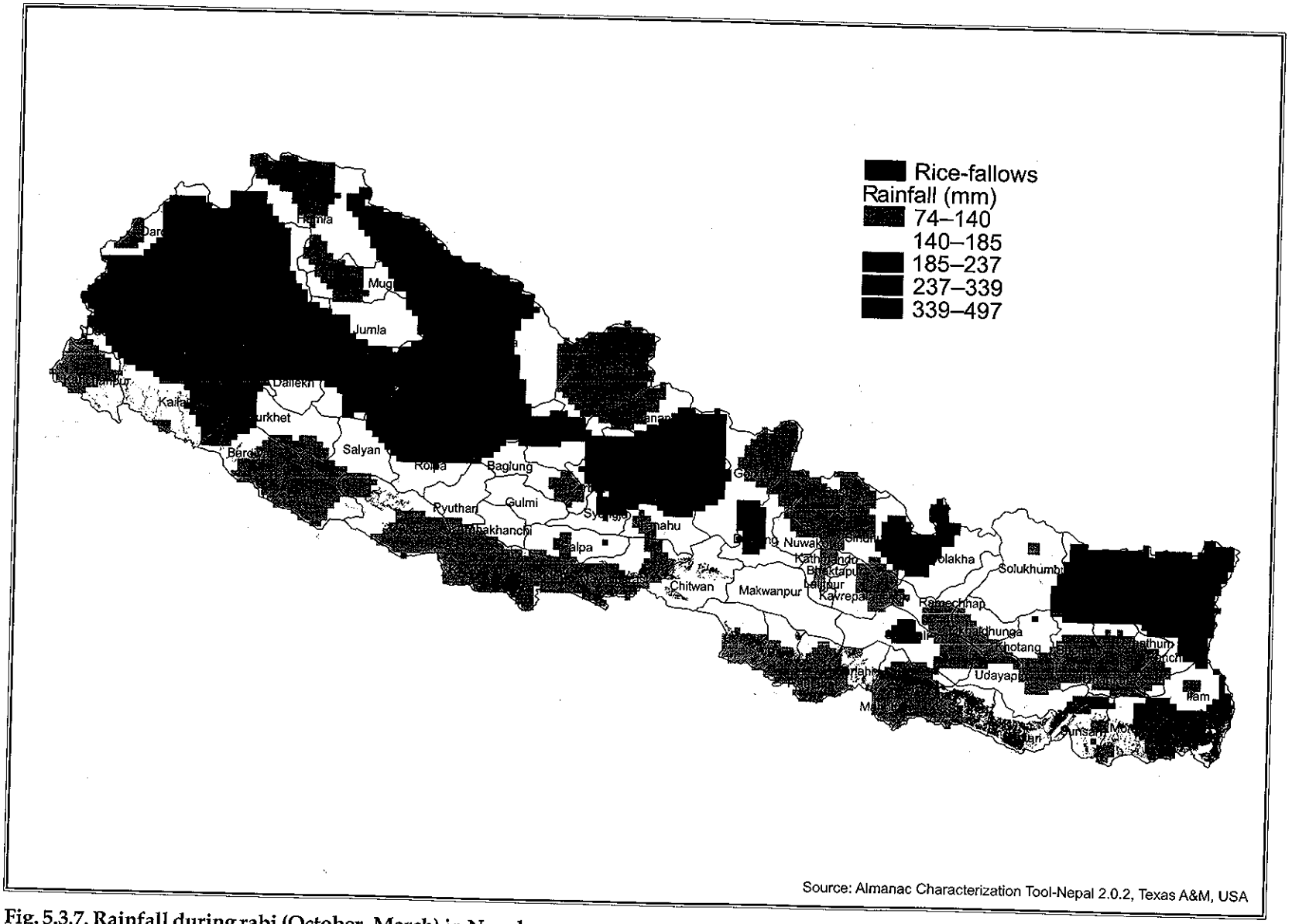


Fig. 5.3.6. Rainfall during kharif (June–Spetember) in Nepal



Source: Almanac Characterization Tool-Nepal 2.0.2, Texas A&M, USA

Fig. 5.3.7. Rainfall during rabi (October–March) in Nepal

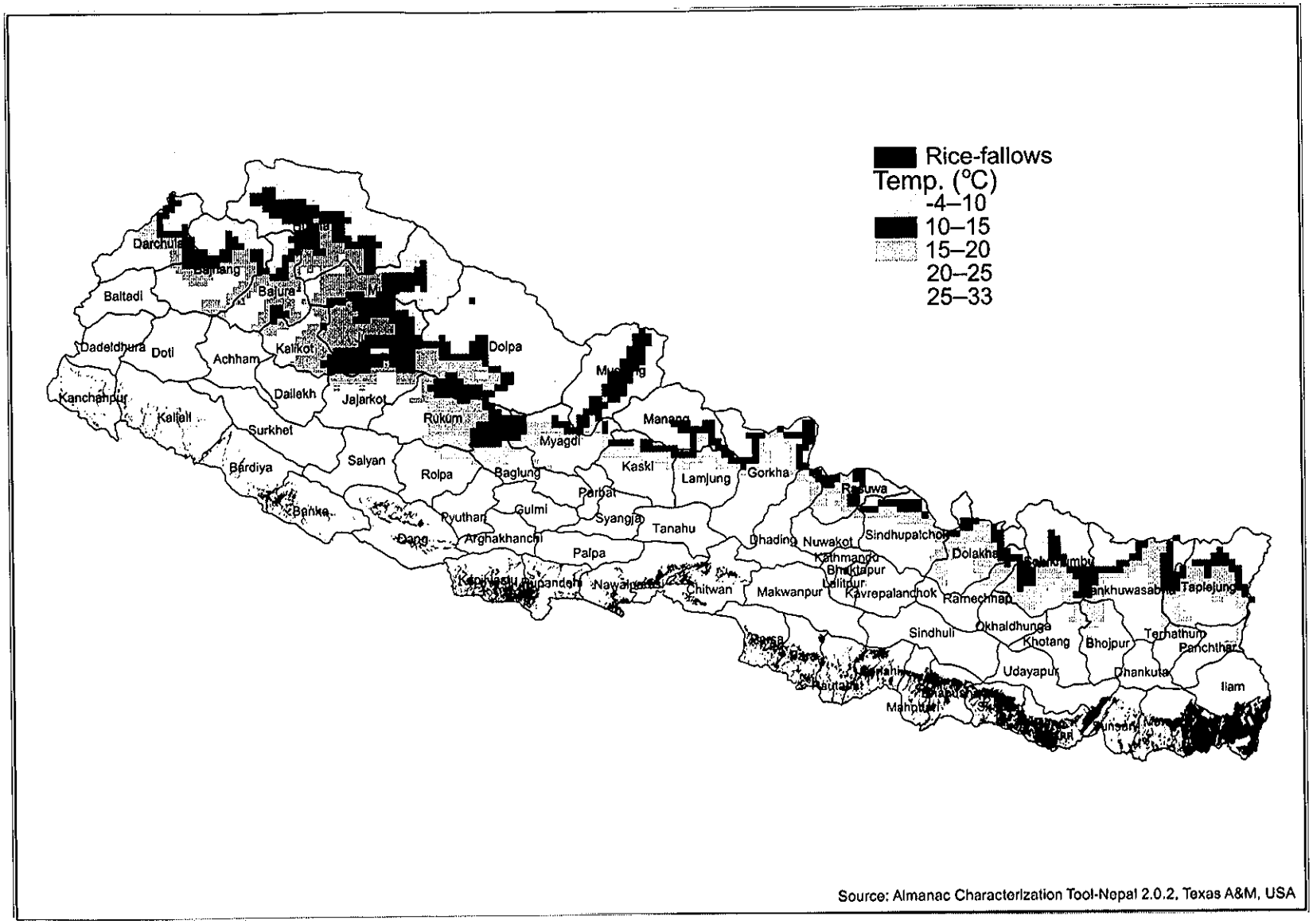
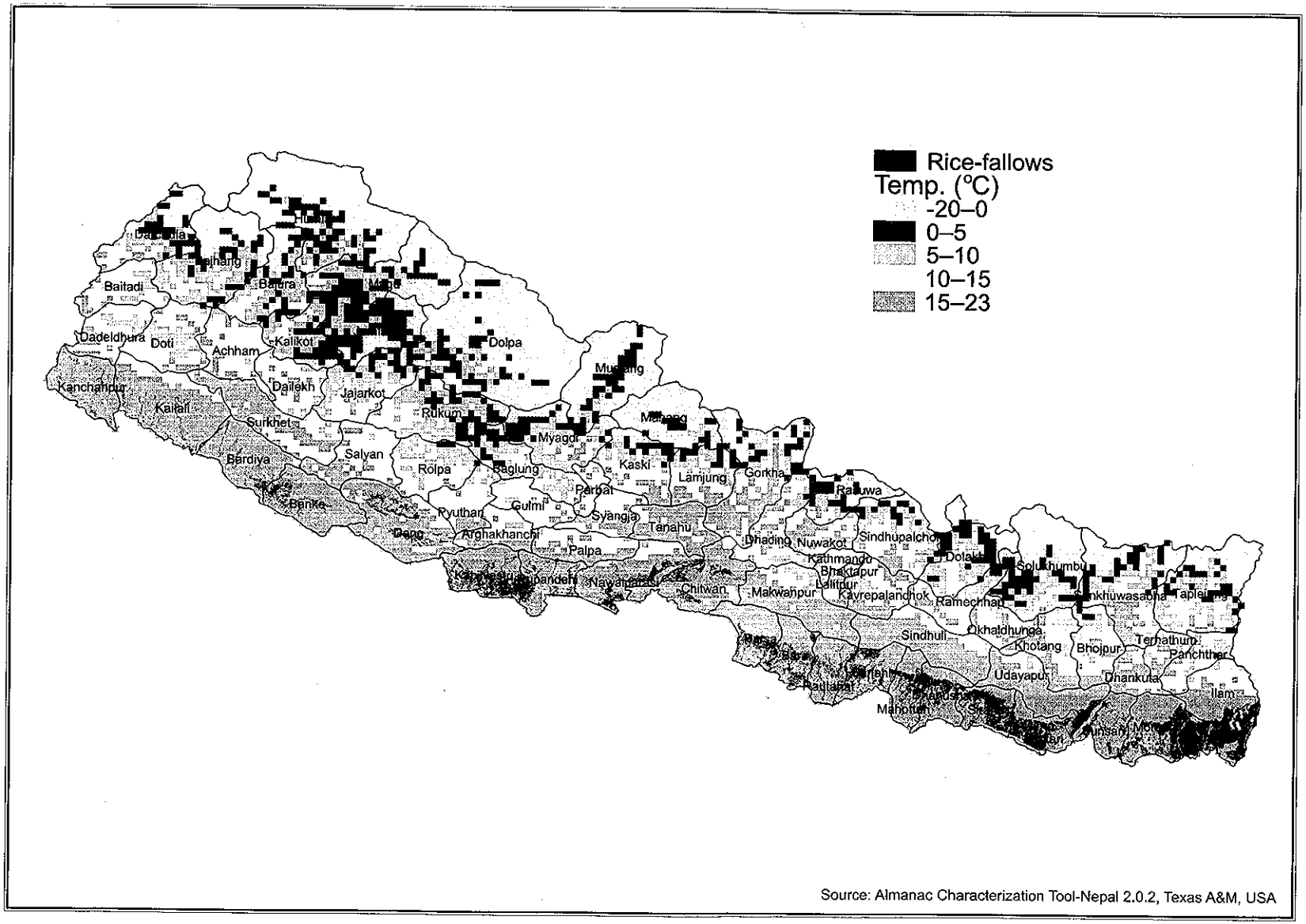
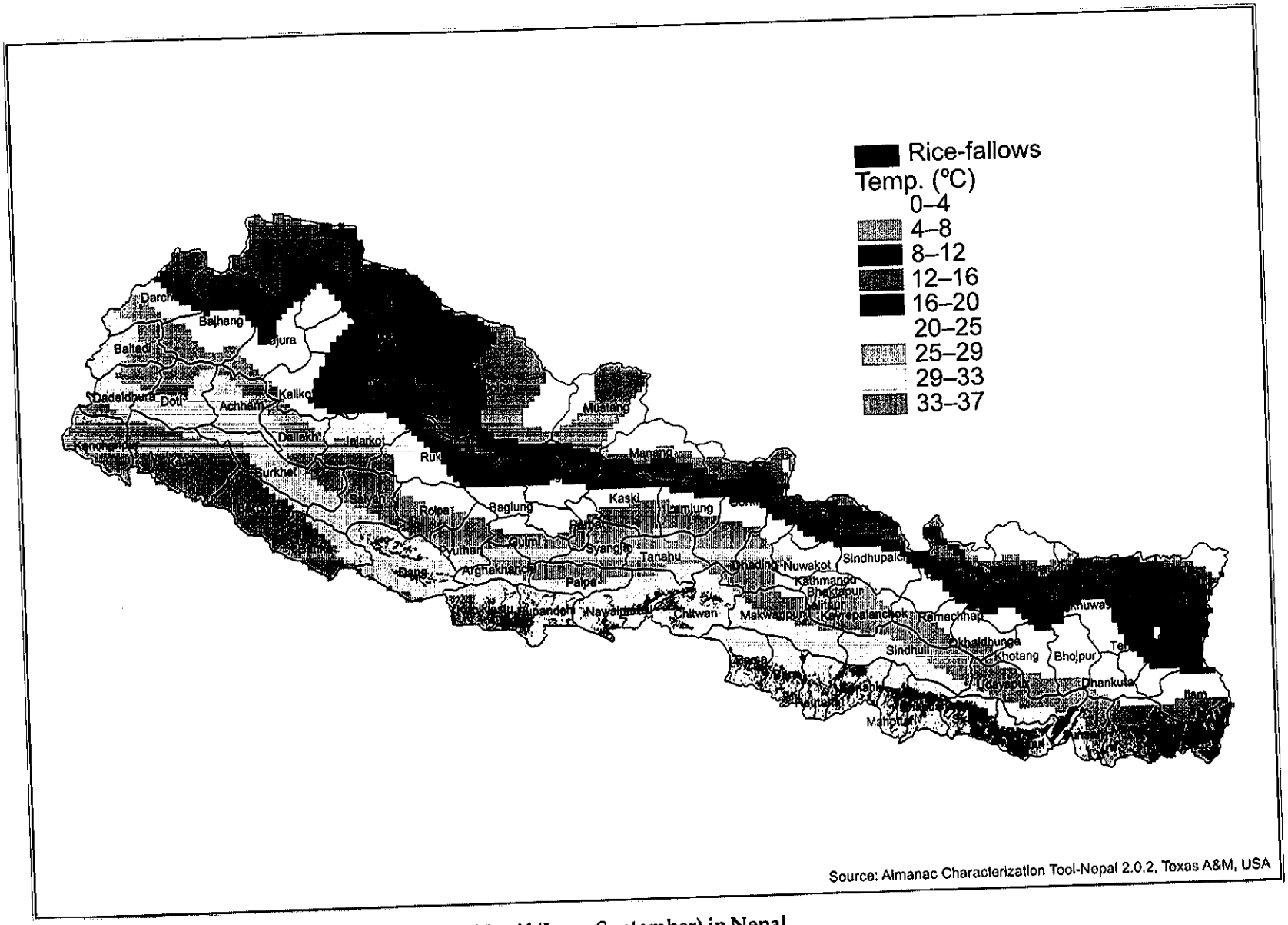


Fig. 5.3.8. Annual mean maximum temperature in Nepal



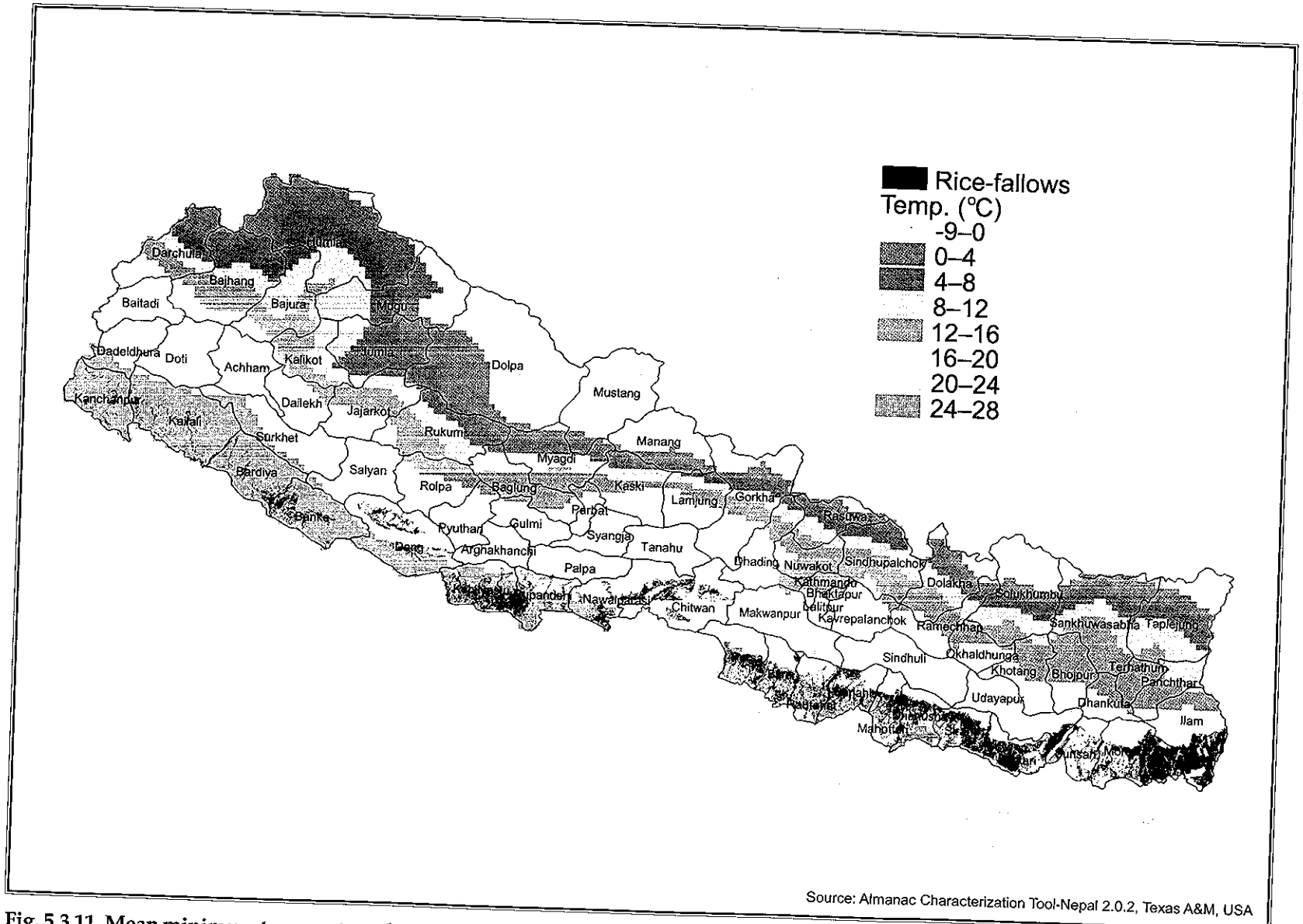
Source: Almanac Characterization Tool-Nepal 2.0.2, Texas A&M, USA

Fig. 5.3.9. Annual mean minimum temperature in Nepal



Source: Almanac Characterization Tool-Nepal 2.0.2, Texas A&M, USA

Fig. 5.3.10. Mean maximum temperature during kharif (June–September) in Nepal



Source: Almanac Characterization Tool-Nepal 2.0.2, Texas A&M, USA

Fig. 5.3.11. Mean minimum temperature during kharif (June–September) in Nepal

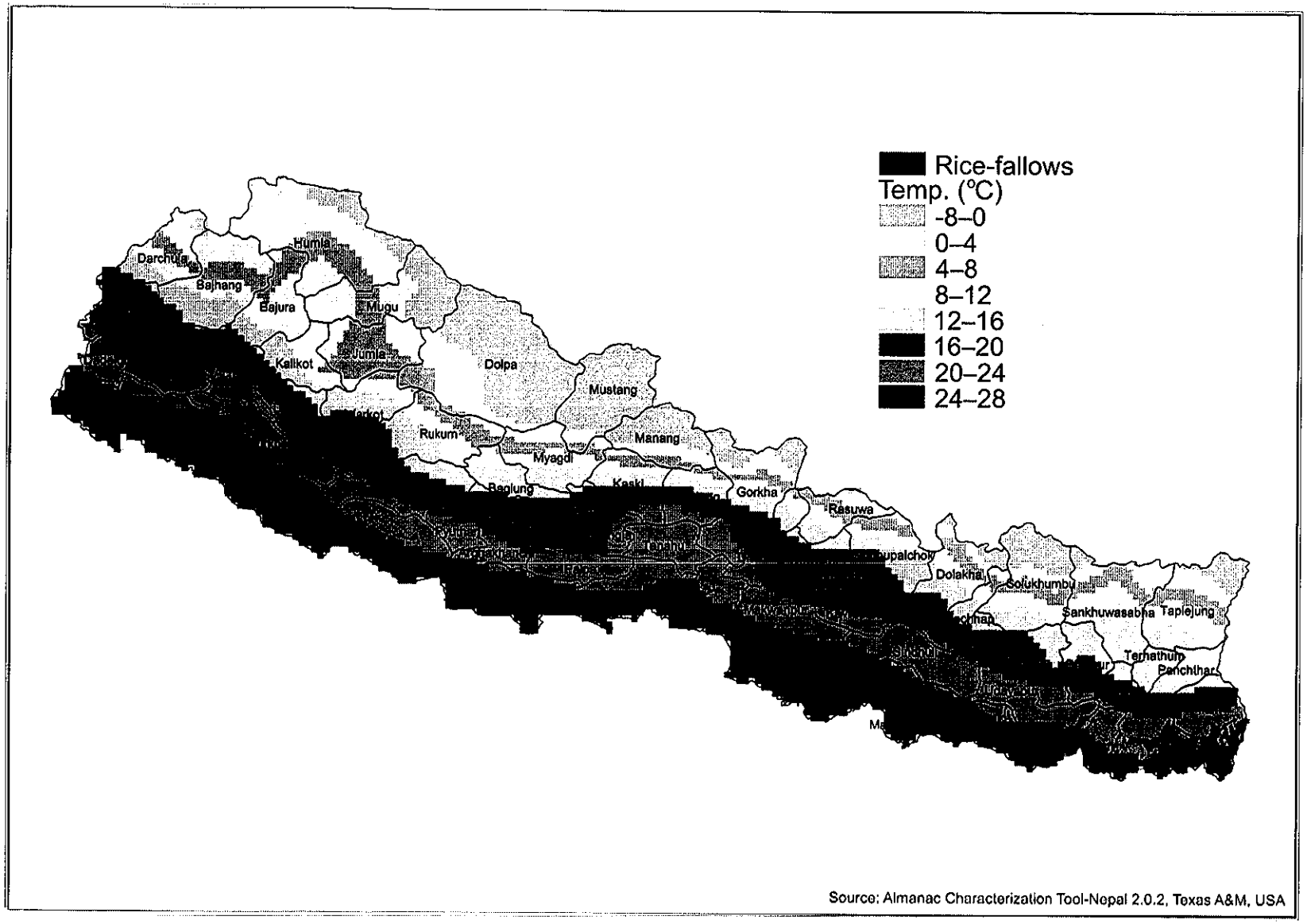


Fig. 5.3.12. Mean maximum temperature during rabi (October–March) in Nepal

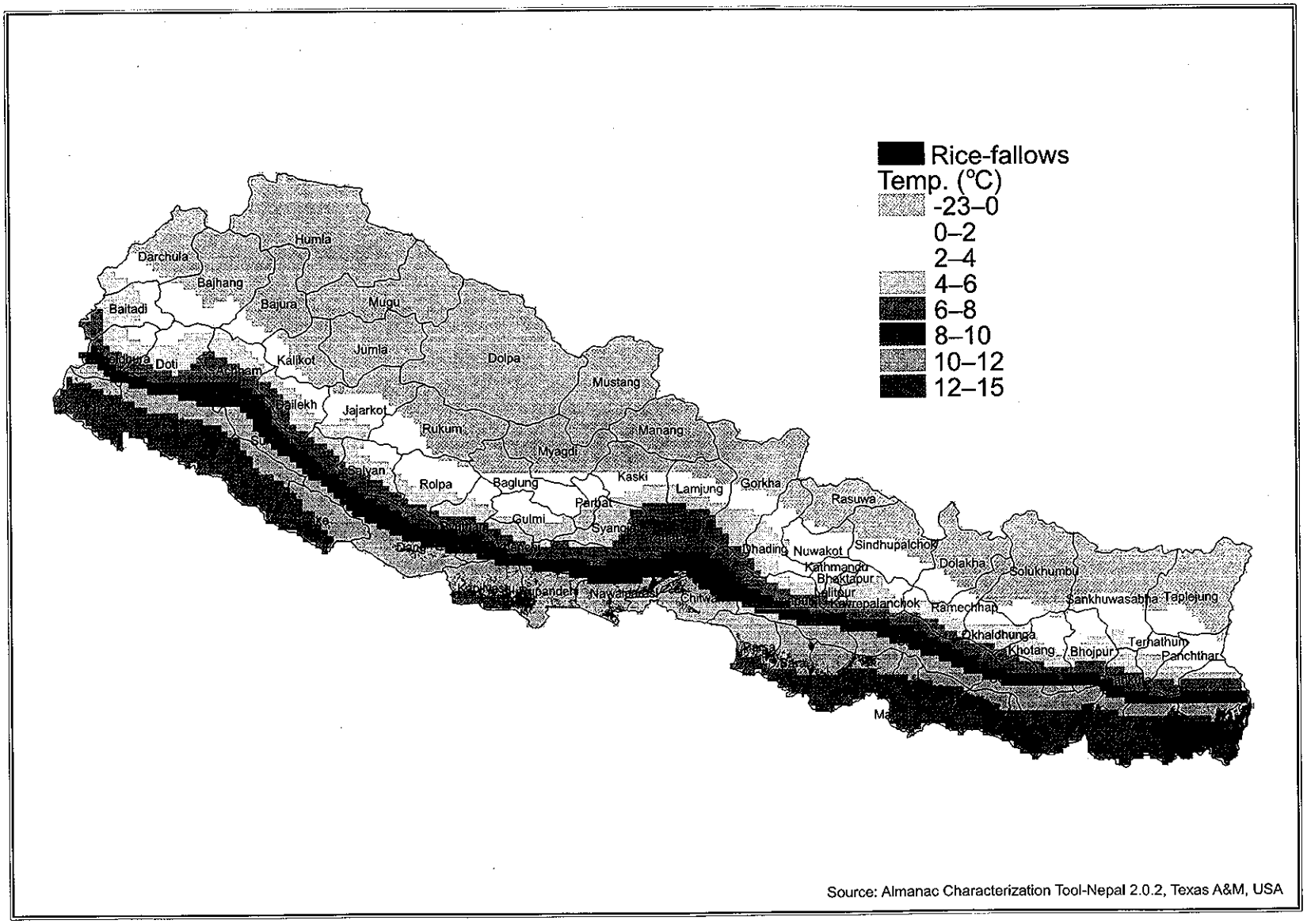


Fig. 5.3.13. Mean minimum temperature during rabi (October–March) in Nepal

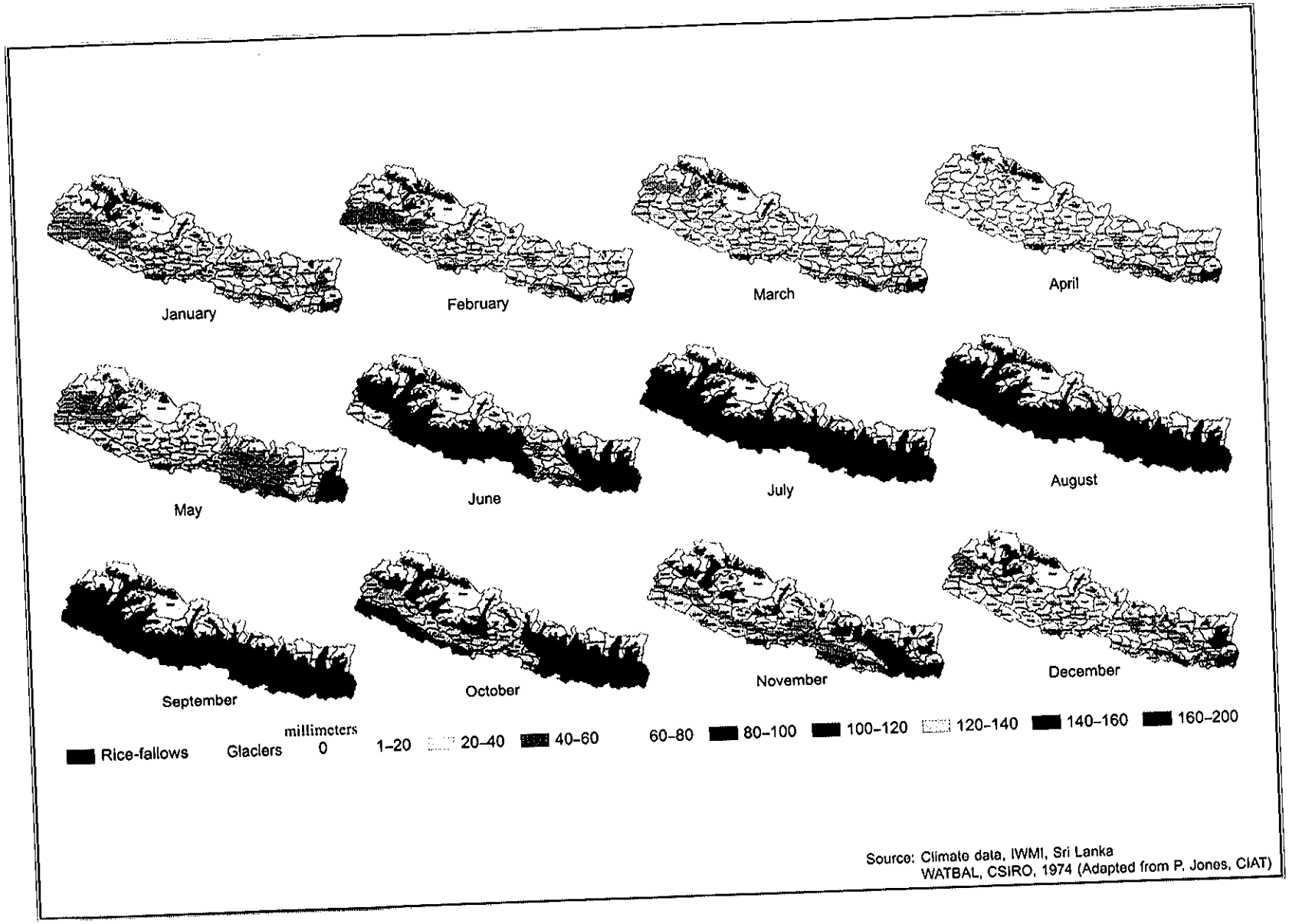


Fig. 5.3.14. Monthly available soil water in Nepal

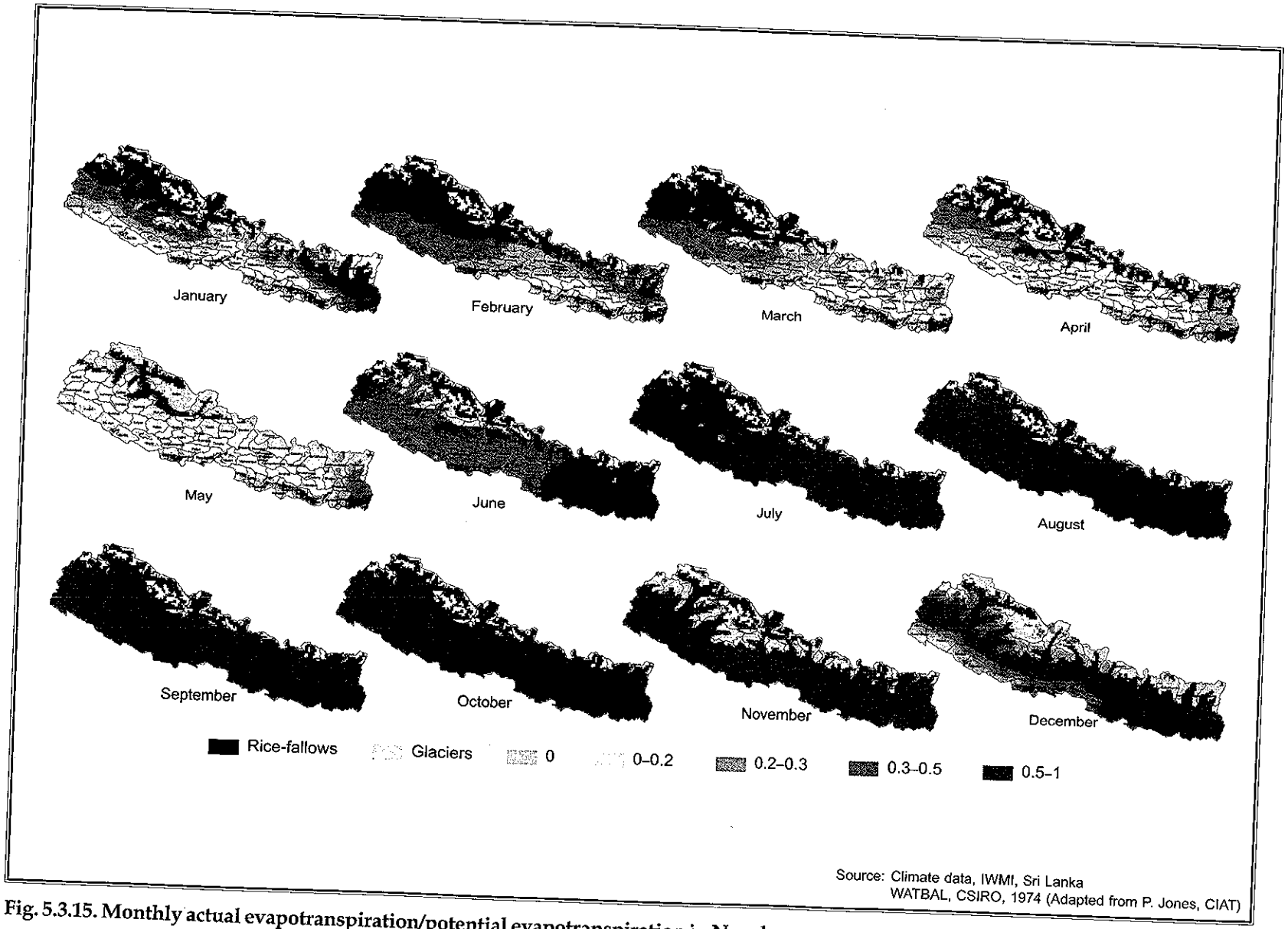


Fig. 5.3.15. Monthly actual evapotranspiration/potential evapotranspiration in Nepal

5.4. Pakistan

Introduction

Out of 80 million ha of cultivated land, nearly 80% is under irrigation in Pakistan (Government of Pakistan 1997–98). Rice occupies about 2.45 million ha, of which a major portion is under rice-wheat cropping system. Legumes are traditionally part of the cropping systems but have been increasingly replaced by either rice during kharif season or wheat during rabi season (Byerlee et al. 1986). Thus legumes area is either decreasing or is being relegated to more marginal lands where abiotic and biotic stresses are major constraints for expressing their yield potential (Zahid et al. 1998, Haqqani et al. 2000). A once common practice of rotating cereals with legumes has vanished because of crop intensification through cereal production (such as rice-wheat systems) (Byerlee et al. 1986, Zia et al. 1992, Zahid et al. 1998). The declining productivity in the rice-wheat production system is one of the major concerns to the food security of this region (Byerlee et al. 1986, Zia et al. 1992, Mann and Garrity 1994).

Legumes currently occupy an area of approximately 1.5 million ha (1.8% of the total cultivated land) and contribute about 4% of the total grain production in Pakistan (Haqqani et al. 2000). Wheat has replaced lentil and chickpea in many parts of Punjab and Sind provinces, and similarly black gram and mung bean are being replaced by rice (Zahid et al. 1998). For example, most of the lentil area in Sialkot was replaced by wheat with the availability of irrigation (Haqqani et al. 2000). Most of the chickpea in Punjab was replaced by wheat because of the epidemics of ascochyta blight, a devastating foliar disease caused by *Ascochyta rabiei* (Zahid et al. 1998). Because of the decrease in area of major grain legumes, Pakistan had imported nearly 261,800 t pulses in 1995/96 and will have to import more to meet the increasing demand of the growing population (Kelley and Parthasarathy Rao 1996). Also, monoculture systems (i.e., only rice-based) or entirely cereal based (i.e., rice-wheat rotations) are currently perceived as non-sustainable from a long-term perspective (Curl 1963, Arnon 1972, Mannering and Griffin 1981), compared to cereal crops grown in rotation with legumes (Odell et al. 1984, Dick et al. 1986a, 1986b, Johnston 1986, Bhatti 1987, Hargrove and Frye 1987, Havlin et al. 1990). Addressing various options including the use of rice-fallows for expanding legumes area will have to be explored in order to devise ways to improve legumes production in Pakistan. In this chapter, we quantify the rice-fallows in Pakistan and document their spatial distribution using satellite imagery. Using GIS, we overlaid the spatial distribution of rice-fallows on the climatic and edaphic database in order to understand and assess their suitability for introducing short-season legumes during the rabi season after the harvest of kharif rice.

Rice Area Estimations

Based on crop production statistics for 1994–95, rice area for Pakistan is 2.12 million ha (PARI 1995–96). Based on satellite image analysis for 2000, the rice-growing area was estimated as 2.45 million ha, which is within the expected range. The unclassified and classified satellite images of Pakistan during kharif depicting (i.e., delineating) the rice-growing areas are shown in Figure 5.4.1.

Rice-fallow Estimations

Satellite image analysis during the rabi season has estimated that nearly 140,000 ha of rice-fallows are available in Pakistan, and this amounts to 6% of its rice-growing area. Thus, most of the rice-growing area in Pakistan appears to be used for wheat during the rabi season. The unclassified and classified satellite images taken during rabi season depicting these rice-fallows are shown in Figure 5.4.2. There was little rice-fallow area identified in the province of Punjab as almost all of the rice-growing area appears to be under the rice-wheat production system. Most of the rice-fallows are located in Sind province and a small area of rice-fallows are located in Baluchistan (Fig. 5.4.2).

Edaphic and Climatic Features of Rice-fallows

Agricultural soils of Pakistan are mainly alluvial and vary from clayey to sandy soils. Clay loams and sandy loams are very common (Khan et al. 1991, Zahid et al. 1998). Using GIS, the spatial distribution of rice-fallows was overlaid on the soils database (FAO) and climatic data (IWMI) (Fig. 5.4.3). Two soil types, Haplic Yermosols and Calcaric Yermosols, represent most of the rice-fallows in Sind and Baluchistan provinces (Fig. 5.4.3). Available soil water-holding capacity of these rice-fallows is about 200 mm (Fig. 5.4.4). Annual rainfall varies from 87 mm to 300 mm in these areas (Fig. 5.4.5). Rainfall during kharif season (i.e., from June to September) ranges from 66 mm to 236 mm, which is not adequate for raising a rice crop (Fig. 5.4.6); thus rice in this region needs to be irrigated. Monthly available soil water and month-wise actual evapotranspiration/potential evapotranspiration (AE/PE) for these rice-fallows are presented in Figures 5.4.7 and 5.4.8 respectively. Using the WATBAL soil water balance model and the climatic data from IWMI, monthly available soil water was calculated. Using GIS, monthly available soil water data was overlaid on the spatial distribution of rice-fallows (Figs. 5.4.7 and 5.4.8). Since the model considers only the water input from rainfall, and most of the rice production is under irrigation in Pakistan, the available soil water for the rice crop or for the rice-fallows following rice crop will not represent the actual available water in the soil profile. So, we will have to assume that the soil

profile is fully charged during the rice-growing season through irrigation, and thus 200 mm should be available for the following rabi season crop, with the assumption that rice fields are fully charged with irrigation water before the harvest of kharif rice crop. Total rainfall during rabi (October to March) ranges from 10 mm to 56 mm (Fig. 5.4.9). Annual maximum and minimum temperatures in rice-fallows range from 30°C to 36°C and 17°C to 22°C, respectively (Figs. 5.4.10 and 5.4.11). During the kharif season, maximum temperatures in these rice-fallows range from 32°C to 43°C and minimum temperatures range from 20°C to 30°C (Figs. 5.4.12 and 5.4.13). Maximum temperatures during rabi season range from 25°C to 31°C, while minimum temperatures vary from 10°C to 15°C (Figs. 5.4.14 and 5.4.15).

Legumes Suitable for Rice-fallows

Since winter minimum temperatures vary from 10°C to 15°C in the rice-fallows, only cool season legumes can be grown. Among cool season legumes, khesari, lentil, and chickpea are the most suitable and also have good adaptation to this region.

Khesari

Khesari is mostly grown in Sind province as it has a good adaptation to paddy fields after the harvest of rice. Khesari cultivation is concentrated mainly in the districts of Thatta, Larkana, Jacobabad, and Shikarpur, where rice-fallows are located (Haqqani et al. 2000). The soils of these districts are loamy and clayey floodplain soils (Khan et al. 1991). The climate is very hot to arid in these areas. The mean annual rainfall is 125 mm. The average maximum temperature at sowing time is 25–31°C, falling to 20–24°C in December and January and rising again to 36–37°C at harvest time in early April. Minimum temperatures vary between 15°C and 17°C at sowing time and reach around 27°C in March at harvest (Khan et al. 1991). Khesari is also considered as an important fodder legume and is commonly rotated with rice (Thakur and Rai 1985). Since khesari is hardy and tolerant to drought, waterlogging, and salinity (Lal and Sarup 1989, Johansen et al. 1994, Haqqani and Arshad 1995), and has low production costs, its extension into rice-fallows should be the logical choice. Also, khesari seeds can be broadcast at least 10 days before rice harvest in the standing waters of rice fields; thus relay cropping could result in optimum utilization of stored soil moisture (at the time of rice harvest) for the production of this grain legume. Since most of these rice-fallows are located in Sind and Baluchistan, salinity and alkalinity could be serious limitations for production in these rice-fallows. Khesari, which has good adaptation to this stress and also to the temperature regime, would be the natural choice for this production niche. This cropping system will not only result in increased legume production but

also contribute substantially to the soil N reserves as khesari is an excellent N–fixing legume (Thakur and Rai 1985), and thus can contribute to the sustainability of the predominantly monocrop (i.e., rice) system.

Lentil

Lentil is grown in most parts of the country (Haqqani et al. 2000). Some of the varieties released in Pakistan are presented in Table 5.4.1. A major portion of lentil is grown in Rawalpindi, Bajaur, Jhelum, Gujrat, Gujranwala, and Sialkot districts where soils are silt loam, silty clay loam, and clay loams. Lentil occupies a considerable area along the Indus river in Sind province where soils are loamy and clayey floodplain soils. In this region the average maximum temperature at seeding time is 29–33°C, falling to 20–22°C in December and January, and rising again to 36–37°C at harvest. The area is very hot and arid. The annual rainfall ranges from 100 mm to 150 mm (Khan et al. 1991). There is much concern about the situation of lentil production in Pakistan as lentil area has considerably decreased. This has been primarily due to its replacement by wheat as irrigation water became available to the farmers in Sialkot, the former major lentil-growing district in Punjab province. Lentil can be relay sown. Thus the available stored soil moisture after the harvest of rice can be effectively and efficiently utilized for the production of this legume. However, lentil is prone to weed infestation and so effective chemical control is needed to augment the productivity of this legume. Non-availability of varieties having resistance to rust (*Uromyces viciae-fabae*) is one of the limiting factors for extending lentil cultivation into rice-fallows of Sind.

Table. 5.4.1. Chickpea and lentil cultivars released in Pakistan.

Crop/Cultivar	Year of release	Crop/Cultivar	Year of release
Chickpea		**Lentil**	
CM-72	1982	Mansehra-89	1989
C-44	1982	Masoor 85	1989
AUG 480	1982	Masoor 93	1989
DG-92	1989		
Noor 91	1992		
Punjab 91	1992		
Paidar 91	1992		
NIFA 88	1992		

Chickpea

Over 80% of the chickpea production is concentrated in the Thal region of the Punjab province (Habib et al. 1991). The varieties of chickpea released in Pakistan are given in Table 5.4.1. In Sind, chickpea production is concentrated mostly in Shikarpur, Jacobabad, Sukkur, Larkana, and Nawabshah districts, where some of these rice-fallows are located. Thus chickpea can also be a potential legume for rice-fallows. However, unlike khesari and lentil, chickpea cannot be sown as a relay crop with rice as this crop is highly susceptible to waterlogging (Saxena 1962). Since rainfall during the rabi season is not sufficient, and with the hot and dry air temperatures during February to March, chickpea faces severe water deficits during the growing season and also terminal drought if introduced into rice-fallows of this region. Since this area is relatively hot and arid, supplemental irrigation may be necessary for reliable chickpea cultivation in rice-fallows.

Constraints to Legumes Production

Abiotic constraints

Some of the abiotic constraints associated with rice-fallows which are discussed in Section 4 also apply to Pakistan. For the Sind region of Pakistan where most of these rice-fallows are located, soil alkalinity and salinity, particularly for the rabi season could be a limiting factor for utilizing rice-fallows for legumes production. Salinity may not be a production constraint during the kharif season for rice, as rice cultivation requires standing water and the salts in the surface soil are leached into the deeper layers of the soil. However, during rabi season, salts will move upwards because of the capillary action; the salts can accumulate in the root zone of legumes if introduced into these rice-fallows. Of the legumes that are suitable for these rice-fallows in Pakistan (i.e., chickpea, lentil, and khesari), only khesari has a reasonable degree of tolerance to salinity (Johansen et al. 1994, Haqqani and Arshad 1995). Thus, if lentil and chickpea are to be considered for these rice-fallows, perhaps, a moderate level of tolerance (i.e., at least tolerance up to 6 or 8 dS m^{-1}) is necessary. Thus, identification of genetic stocks or varieties that have tolerance to salinity should be a priority if lentil or chickpea are to be introduced into these rice-fallows. The other major limiting factors are soil physical constraints that are normally associated with rice-fallows in general and do not permit a good plant stand establishment, as mentioned earlier (see Section 4). Also, terminal drought is another limiting factor that is common to crops grown on stored soil moisture in rice-fallows, particularly under the warm conditions of Sind province.

Biotic constraints

Diseases. Among diseases, wilt is a serious disease of chickpea (fusarium wilt) and lentil (vascular wilt) in rice-fallows of Sind. Fusarium wilt is mostly prevalent in Sind, and has been reported for the districts of Shikarpur, Jacobabad, Nawabshah, Larkhana, and Sukkur (Sattar et al. 1953). Nearly 75% yield loss in chickpea due to fusarium wilt was reported (Akhtar 1956). The disease is caused by *Fusarium oxysporum* f. sp *ciceris* in chickpea and *Fusarium oxysporum* f. sp *lentis* in lentil and generally occurs at the seedling and flowering stages. Dry root rot (*Rhizoctonia bataticola*) is an important disease of chickpea and is also prevalent in Sind region (Khan 1979, Nene 1979). Other diseases of chickpea that are of minor importance are rust (*Uromyces ciceris-arietini*), powdery mildew (*Leveillula taurica*), and alternaria blight (*Alternaria* sp) (Kamal and Mughal 1968). Ascochyta blight is a major disease of lentil and chickpea in Punjab province, but is not a problem in Sind where most of the rice-fallows are located; thus it will not be a major production constraint (Nene 1982). Botrytis gray mold (*Botrytis cinerea*), sclerotinia stem rot (*Sclerotinia sclerotiorum*), and collar rot (*Sclerotium rolfsii*) are minor diseases of lentil in Sind (Qureshi et al. 1985).

Insect pests. Pod borer (*Helicoverpa armigera*) is the predominant insect pest of both lentil and chickpea in Shikarpur, Jacobabad, Larkana, Nawabshah, and Sukkur districts of Sind (Haqqani et al. 2000). It also has considerable economic importance in the Pothohar region and Thal desert of Punjab province. Semilooper (*Autographa nigrisigna*) is another pest of chickpea but it is of less economic importance.

Socioeconomic constraints

Government agricultural policies in Pakistan are primarily aimed at improving cereal production. Legumes receive relatively low attention from policy makers, and thus do not get adequate support for research, extension, and other crucial activities for production (Haqqani et al. 2000). Socioeconomic constraints faced by the Pakistani farmers in legumes cultivation are mentioned below.

Lack of improved khesari cultivars. Khesari is the most suitable among cool season legumes for the rice-fallows in Sind either as a relay crop or when sown after rice harvest, because of its adaptability to salinity and waterlogging, and also due to the hardy nature of the crop (Johansen et al. 1994, Haqqani and Arshad 1995). Also, khesari does not have many pest and disease problems that are mostly associated with lentil and chickpea. But improved khesari cultivars are not available in Pakistan. The existing khesari cultivars contain β-N-oxalyl, β-diaminopropionic acid (ODAP), a toxin that can cause lathyrism

if consumed in large quantity. Since low toxin improved khesari varieties are not available to the farmers, they do not want to increase production of the crop because of fear of lathyrism. Development of low toxin khesari cultivars is essential for promotion of this crop in rice-fallows.

Lack of seed availability. Improved varieties of chickpea, lentil, mung bean, and black gram have been released by pulse breeders for commercial cultivation in Pakistan, but seed supply organizations do not allocate adequate land area and resources to multiply quality seed of these minor crops. Virtually no seed production and dissemination system for pulses exists in the country (Haqqani et al. 2000). Lack of availability of improved seed is a major problem for the farmers (Bashir and Malik 1995).

Lack of credit facilities. Most of the farmers do not have enough cash on hand to buy quality seeds or inputs, even if they intend to. Credit facilities are not available for legume crops in the same way that they are for other crops such as rice and wheat (Bashir and Malik 1995, Haqqani et al. 2000). Lack of credit facilities to purchase inputs such as improved seed, fertilizer, and chemicals for plant protection is a major constraint for pulse production in Pakistan (Bashir and Malik 1995).

Absence of support price and marketing. Major cereals and cash crops receive priority for price support. Except for chickpea, support prices for food legumes are non-existent (Bashir and Malik 1995, Haqqani et al. 2000). Bashir and Malik (1995) reported that constant support of the government for increased production of major crops such as wheat, rice, cotton (*Gossypium* sp), and tobacco has been pushing pulses to more marginal areas, resulting in their low productivity. Markets for pulses are also thin compared to rice and wheat, which causes price fluctuations. Large fluctuations in market price of grain legumes also discourage farmers from growing them. Poor farmers cannot store their produce; they have to sell immediately after the harvest when prices are lowest in order to meet their necessities. From a low price at harvest time, the price increases sharply when the pulses produce reaches markets, creating a difference of 250 to 300% between the producers' and consumers' price. In this way, the resource-poor farmer is deprived of a rightful profit. Low market price for the grower and traders' monopoly impose special impediments on food legume production (Haqqani et al. 2000).

Mechanization. Appropriate agricultural equipment for legume cultivation in rice-fallows such as seed drills, and equipment to break the hard-pans that are usually associated with puddling and land preparation for rabi cultivation are generally not available. Availability of seed drills, harvesters, and threshers suitable for food legumes will be necessary to promote legumes in fallows after rice. Labor for growing food legumes on a large scale without mechanization is not available (Haqqani et al. 2000).

This situation poses difficulties for planting and pre- and postharvest mechanization and is also a serious handicap to increasing area and production of pulses.

Economic Feasibility of Growing Legumes in Rice-fallows

Using current price levels, we have estimated potential costs and benefits from growing chickpea, lentil, and khesari crops in rice-fallows of Pakistan (Tables 5.4.2 to 5.4.5). Cultivation of chickpea would provide Rs. 13,195 ha^{-1} as net return with an estimated BCR of 3.96 (Table 5.4.2). Cultivation of lentil would provide a BCR of 3.33 and net return of Rs. 9,545 (Table 5.4.3). Khesari will provide Rs. 7,335 as net return with a BCR of 4.64 (Table 5.4.4).

Cultivation of chickpea or lentil will create an employment opportunity of 28 person-days ha^{-1} while khesari will provide 20 person-days. On an average, cultivation of legumes in one hectare of fallow land will generate 26 person-days working opportunity and about Rs. 1,100 remuneration as labor wage. If all the rice-fallow areas (0.14 million ha) can be brought under legume cultivation then additional employment creation in Pakistan economy will be 3.64 million person-days (Table 5.4.5).

Table 5.4.2. Cost per hectare and returns from cultivation of chickpea in rice-fallows in Pakistan.

Description	Unit	Unit price (Rs.)	Quantity	Amount (Rs.)
Inputs				
Labor	day			1445.00
Land preparation and sowing	day	55.00	9	495.00
Weeding and cultural operations	day	50.00	9	450.00
Harvesting and threshing	day	50.00	10	500.00
Bullock labor	pair-day			600.00
Land preparation	pair-day	50.00	9	450.00
Threshing	pair-day	50.00	3	150.00
Seed	kg	30.00	50	1500.00
Fertilizer				
Diammonium phosphate	kg	7.50	100	750.00
Pesticides	number of sprays	80.00	2	160.00
Total cost				4455.00
Outputs				
Grain yield	kg	20.00	800	16000.00
Fodder yield (byproduct)	kg	1.00	1500	1500.00
Green vegetable consumption	kg			150.00
Returns				
Gross return				17650.00
Net return				13195.00
Benefit-cost ratio (BCR)				3.96

Table 5.4.3. Cost per hectare and returns from cultivation of lentil in rice-fallows in Pakistan.

Description	Unit	Unit price (Rs.)	Quantity	Amount (Rs.)
Inputs				
Labor				
Land preparation and sowing	day			1445.00
Weeding and cultural operations	day	55.00	9	495.00
Harvesting and threshing	day	50.00	9	450.00
Bullock labor	day	50.00	10	500.00
Land preparation	pair-day			600.00
Threshing	pair-day	50.00	9	450.00
Seed	pair-day	50.00	3	150.00
Fertilizer	kg	50.00	30	1500.00
Single superphosphate	kg	4.00	100	400.00
Pesticides	number of sprays	80.00	2	160.00
Total cost				4105.00
Outputs				
Grain yield	kg	25.00	500	12500.00
Fodder yield (byproduct)	kg	1.00	1000	1000.00
Green vegetable consumption	kg			150.00
Returns				
Gross return				13650.00
Net return				9545.00
Benefit-cost ratio (BCR)				3.33

Table 5.4.4. Cost per hectare and returns from cultivation of khesari in rice-fallows in Pakistan.

Description	Unit	Unit Price (Rs.)	Quantity	Amount (Rs.)
Inputs				
Labor				
Land preparation and sowing	day			1005.00
Weeding and cultural operations	day	55.00	1	55.00
Harvesting and threshing	day	50.00	9	450.00
Bullock labor	day	50.00	10	500.00
Land preparation	pair-day			150.00
Threshing	pair-day	50.00	0	0.00
Seed	pair-day	50.00	3	150.00
Pesticides	kg	20.00	35	700.00
	number of sprays	80.00	2	160.00
Total cost				2015.00
Outputs				
Grain yield	kg	12.00	600	7200.00
Fodder yield (byproduct)	kg	1.00	2000	2000.00
Green vegetable consumption	kg			150.00
Returns				
Gross return				9350.00
Net return				7335.00
Benefit-cost ratio (BCR)				4.64

Table 5.4.5. Potential employment generation through introduction of rice-fallows in Pakistan.

Crop	Labor requirement (person-days ha^{-1})
Chickpea	28
Lentil	28
Khesari	20
Mean (legumes)	26
Total rice-fallow area (ha)	140,000
Potential employment creation (person-days)	3,640,000

Concluding Remarks

Khesari is grown in nearly 100,000 ha in Pakistan (Haqqani et al. 2000). Given the pressing need to improve the grain legume production in the country, utilizing the available rice-fallows for grain legume production during rabi season can significantly improve the grain legume area and production. For instance, utilizing the available 143,000 ha of rice-fallows for khesari production can nearly triple the area and production of this legume. However, cultivation of khesari in Sind is not preferred because of the fear of lathyrism, present in khesari (Haqqani et al. 2000). Nevertheless, breeding for low-toxin genetic stocks of khesari is possible (Rahman et al. 2000), and should be provided the required funding support from the government. Though rice-fallows do not represent a large production niche in Pakistan, unlike the other South Asian countries of India, Nepal, and Bangladesh, these can have a significant impact on grain legume production if utilized appropriately. Also, utilization of rice-fallows for the production of short-season legumes could result in the generation of 3.6 million person-days employment. It is hoped that future research efforts and policy initiatives will address this issue of utilizing this production niche for legumes production in Pakistan.

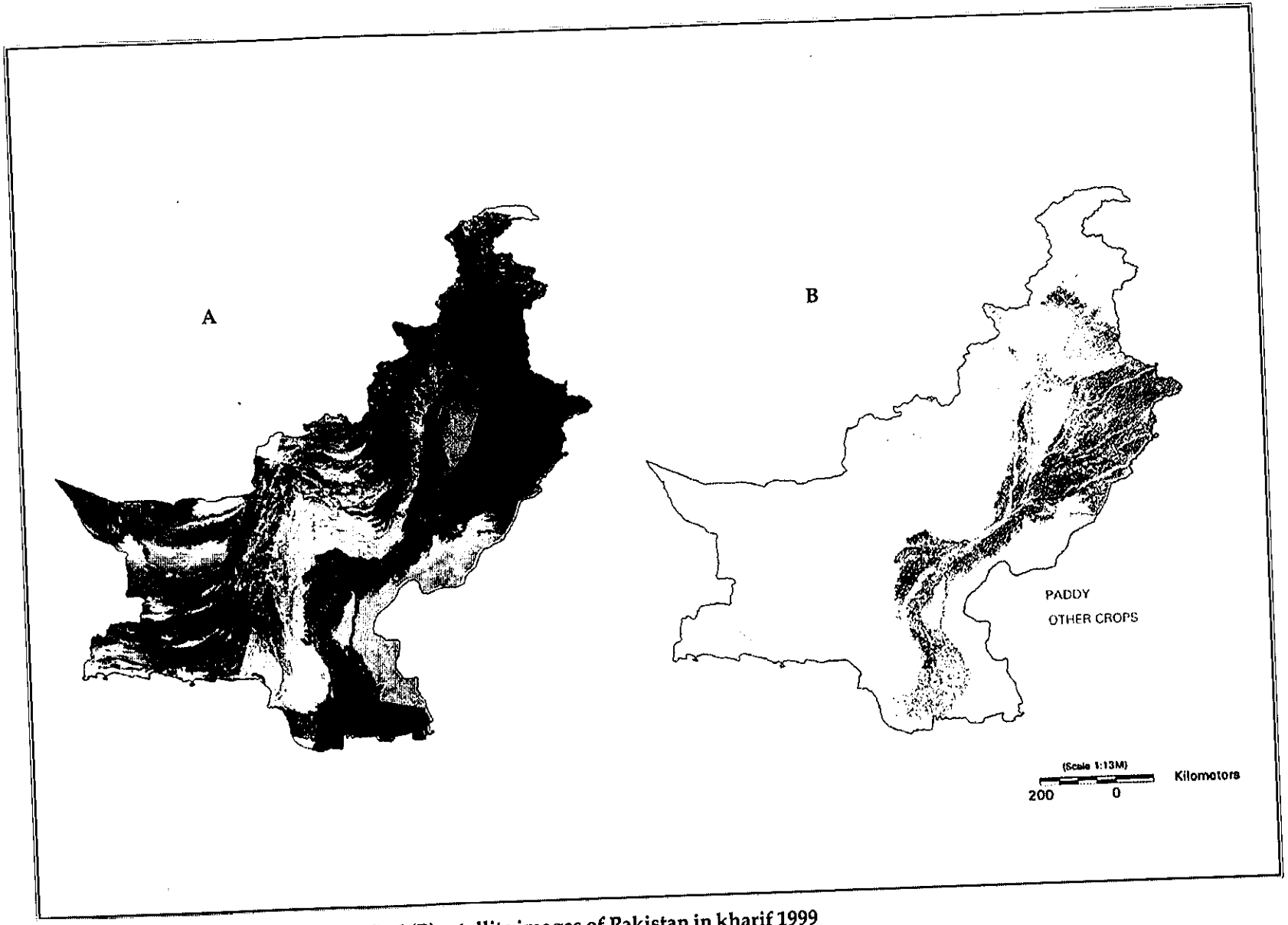


Fig. 5.4.1. Unclassified (A) and classified (B) satellite images of Pakistan in kharif 1999

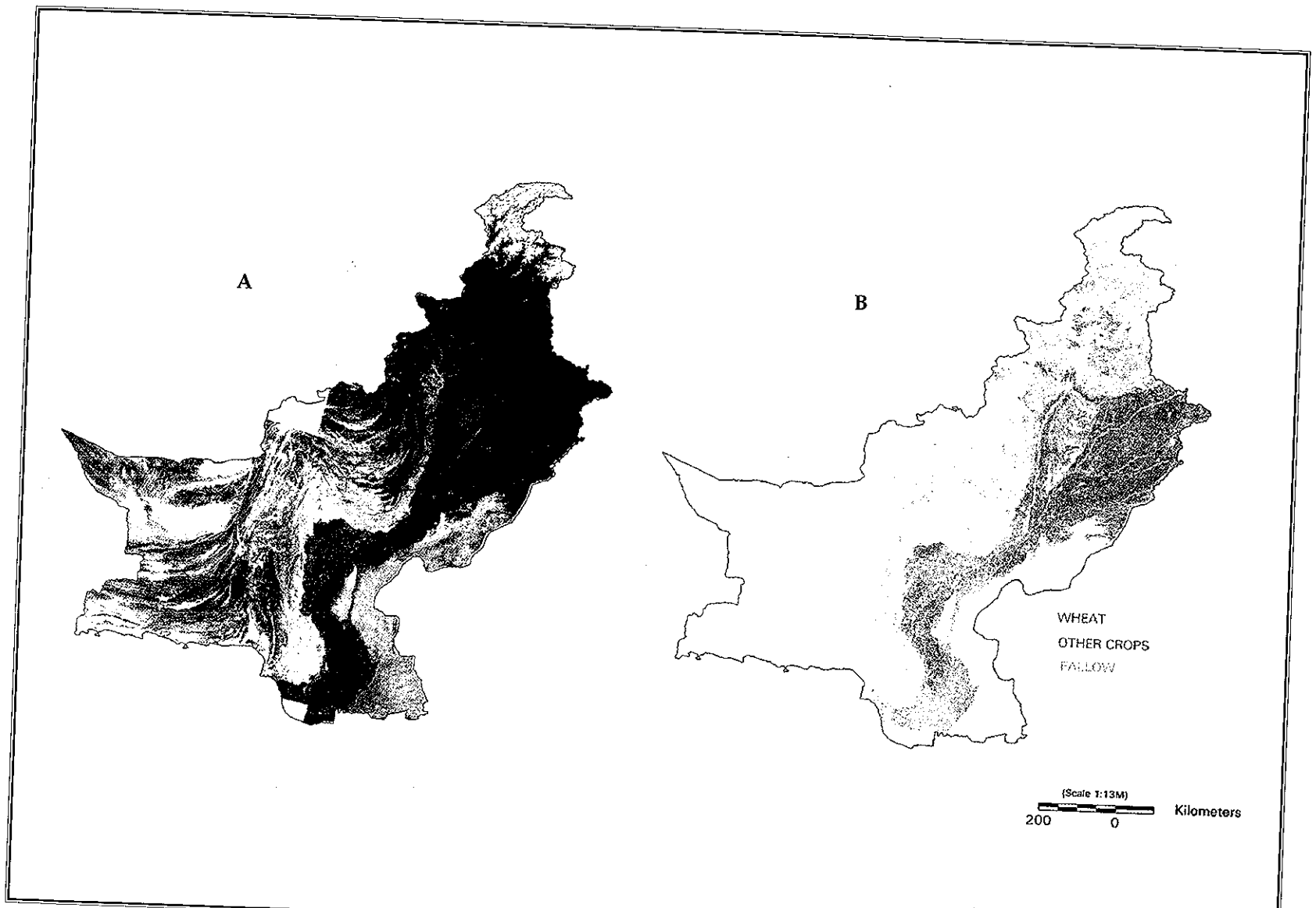


Fig. 5.4.2. Unclassified (A) and classified (B) satellite images of Pakistan in rabi 1999/2000

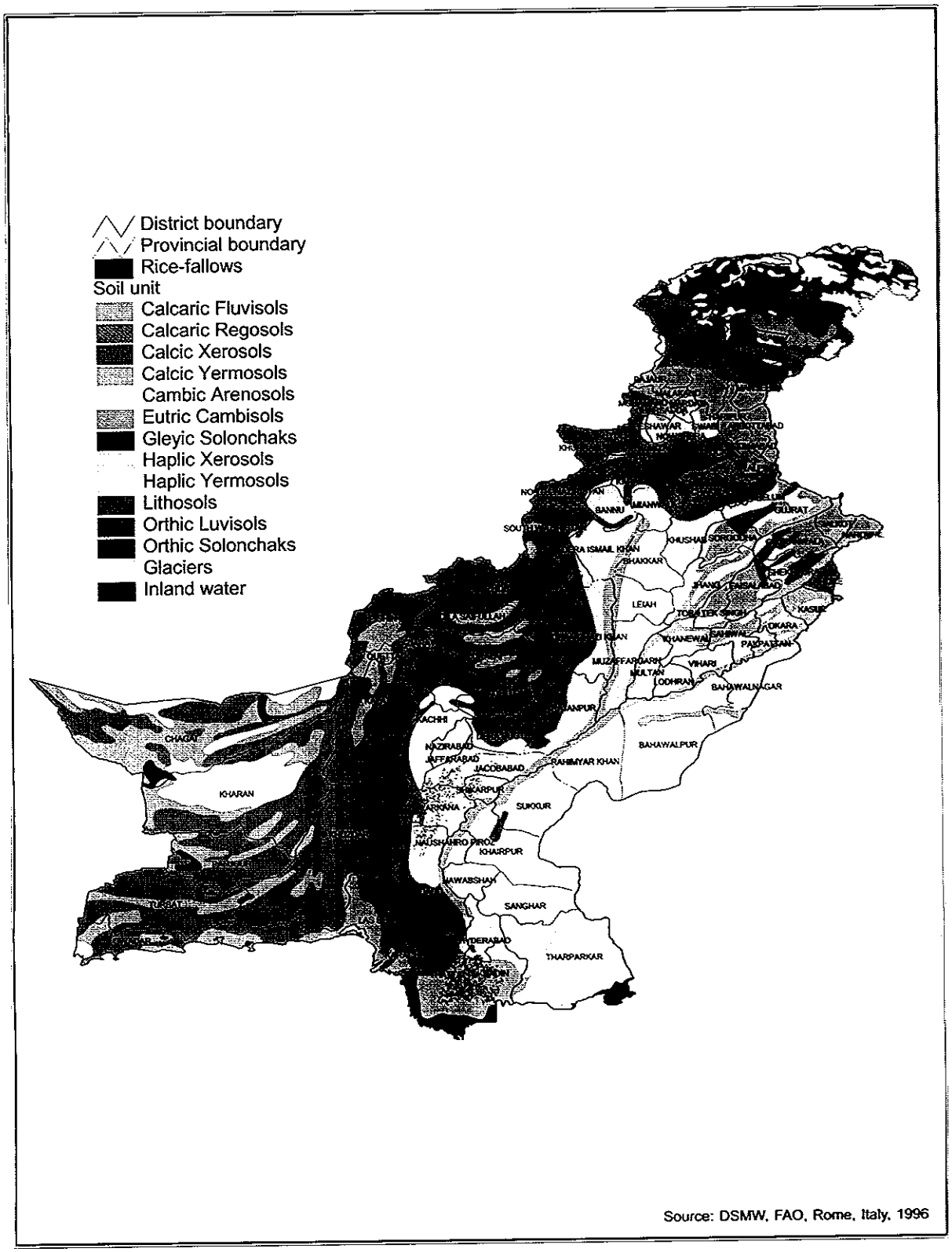
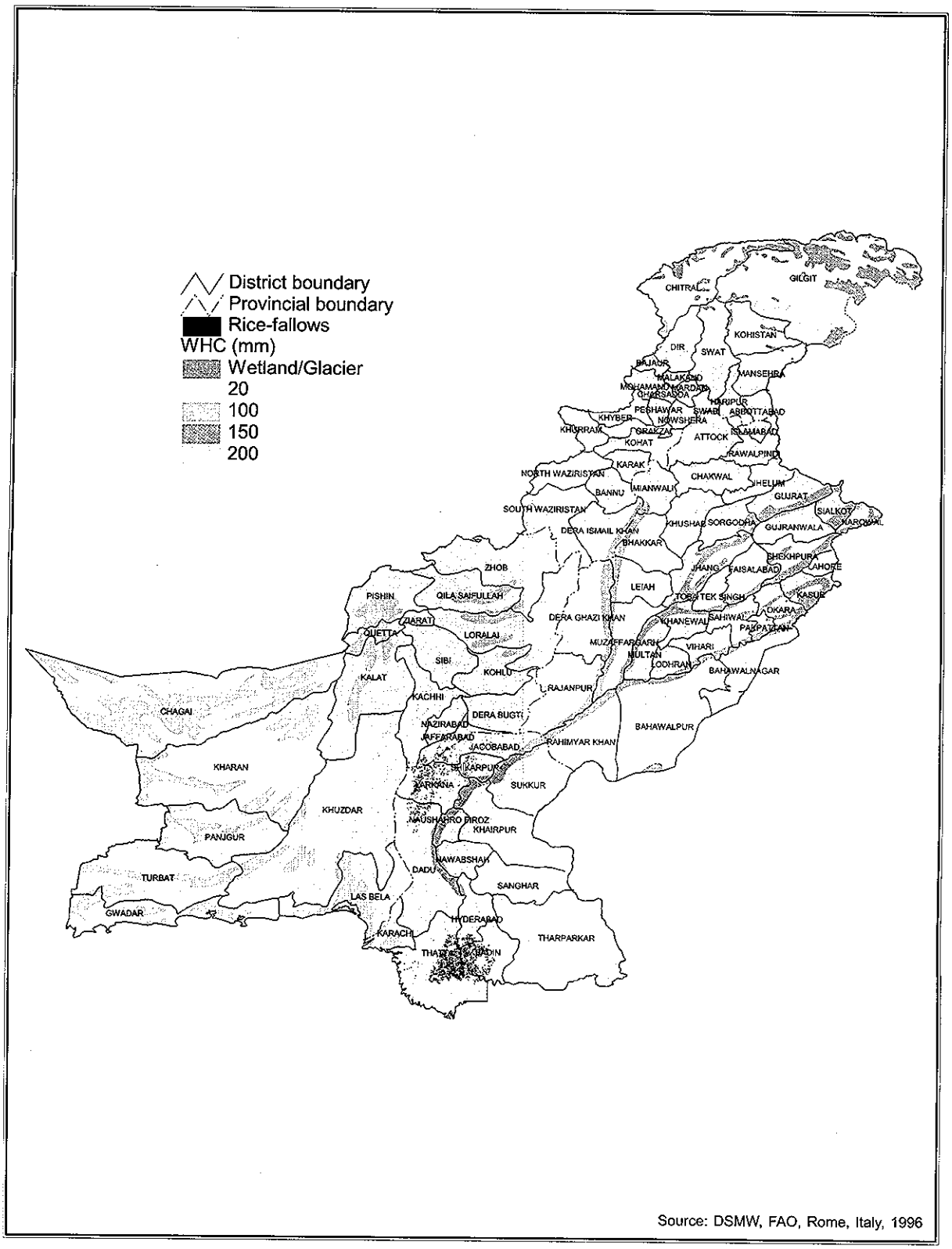


Fig. 5.4.3. Soils of Pakistan



Source: DSMW, FAO, Rome, Italy, 1996

Fig. 5.4.4. Available soil water-holding capacity (WHC) in Pakistan

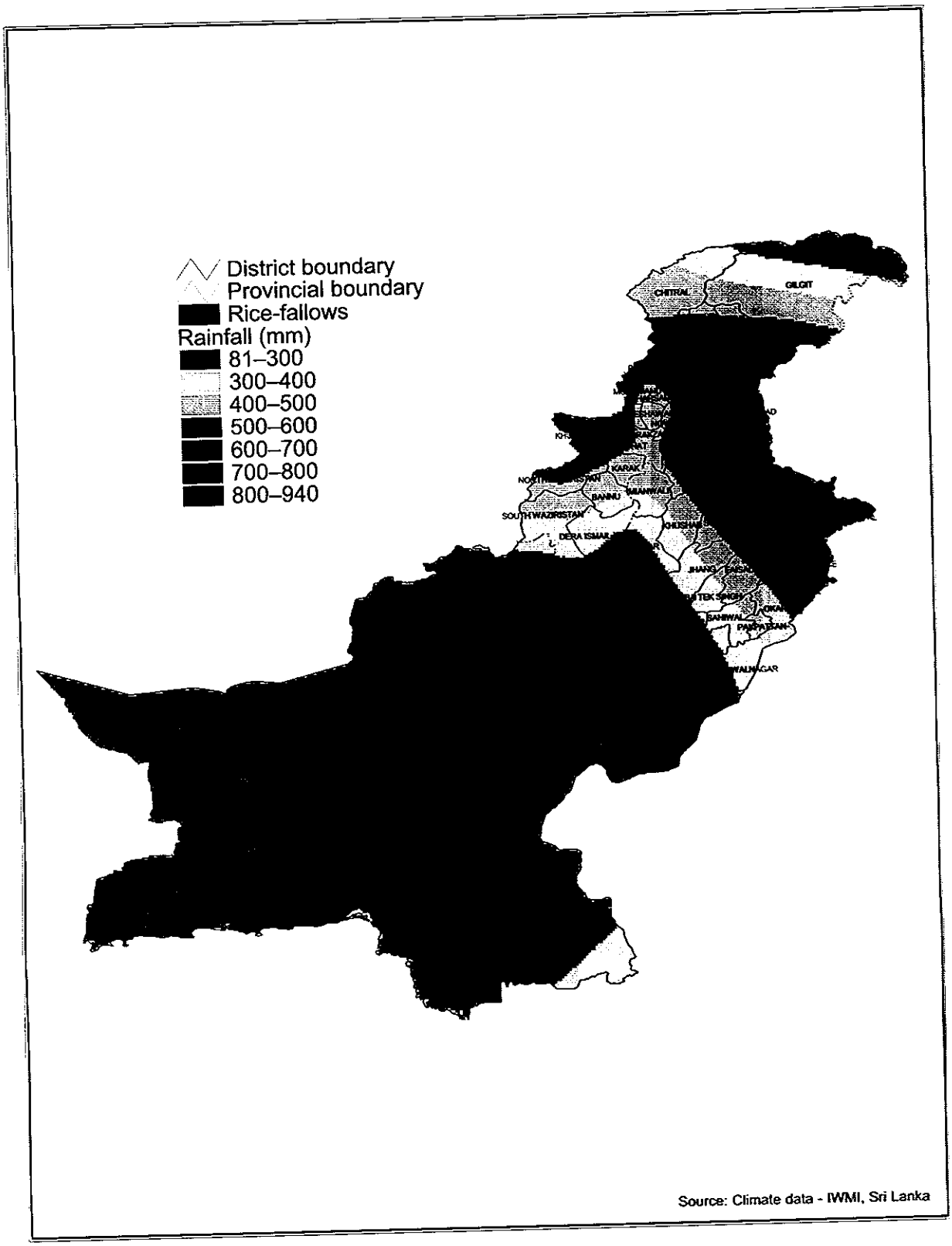


Fig. 5.4.5. Annual rainfall in Pakistan

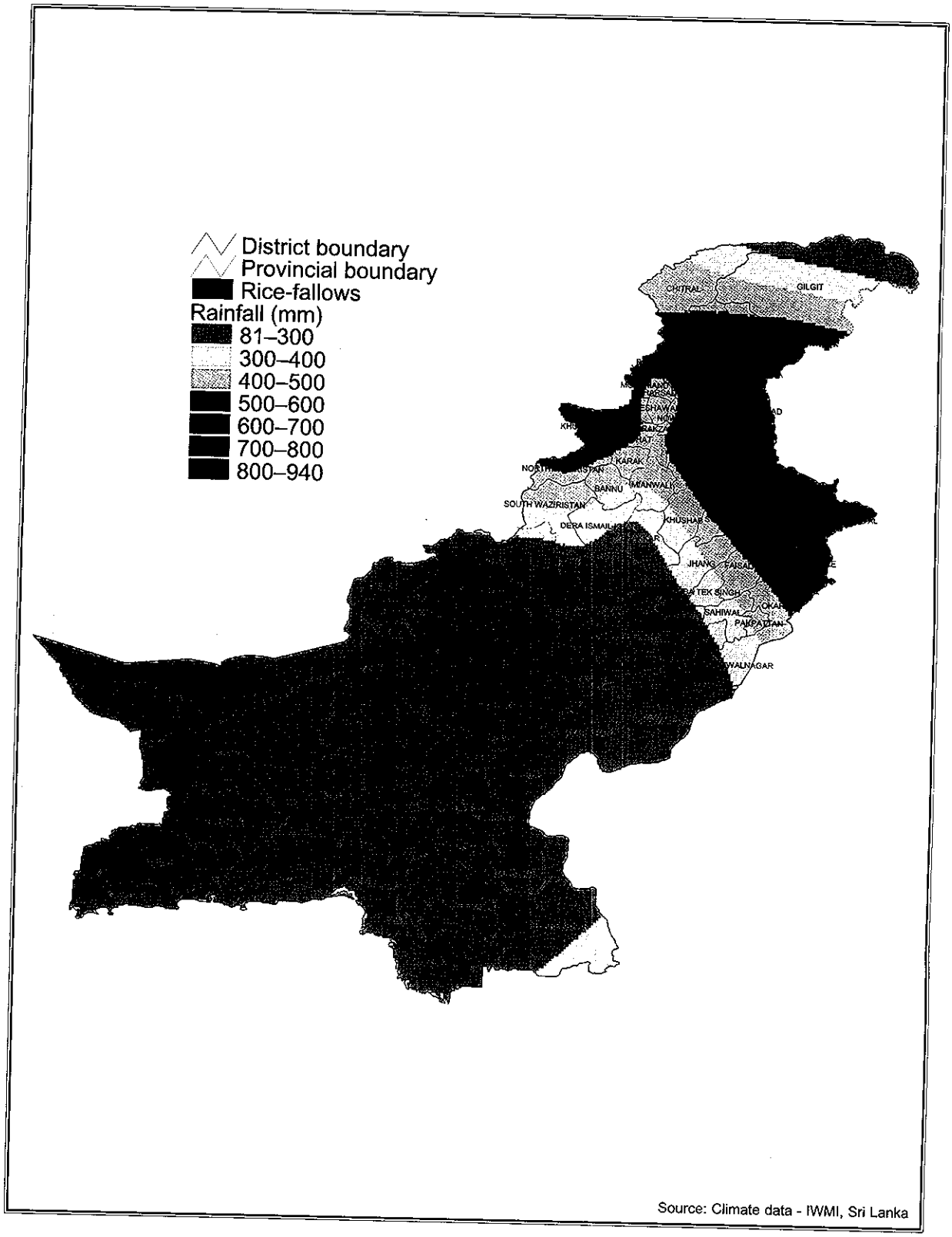


Fig. 5.4.6. Rainfall during kharif (June–September) in Pakistan

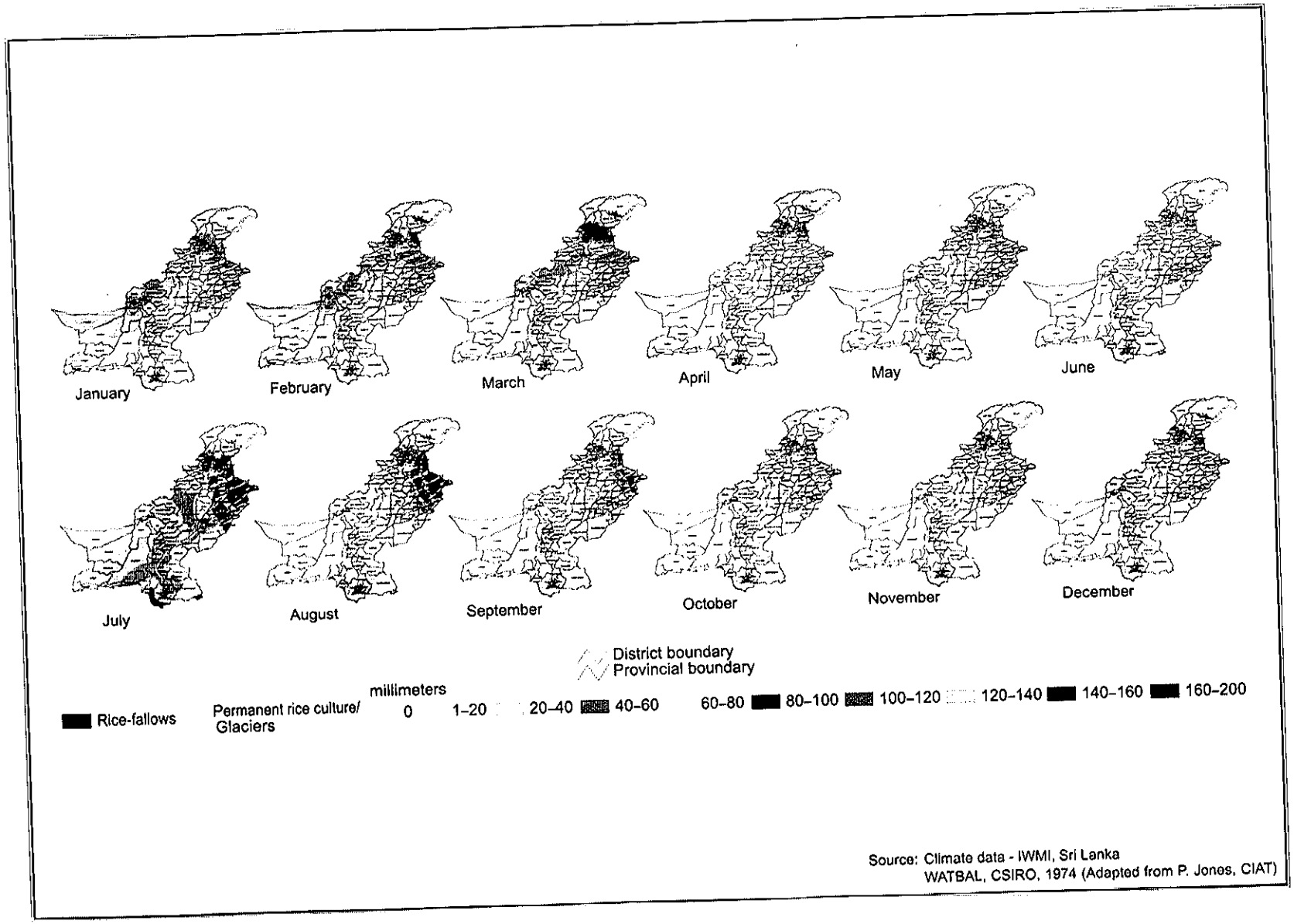


Fig. 5.4.7. Monthly available soil water in Pakistan

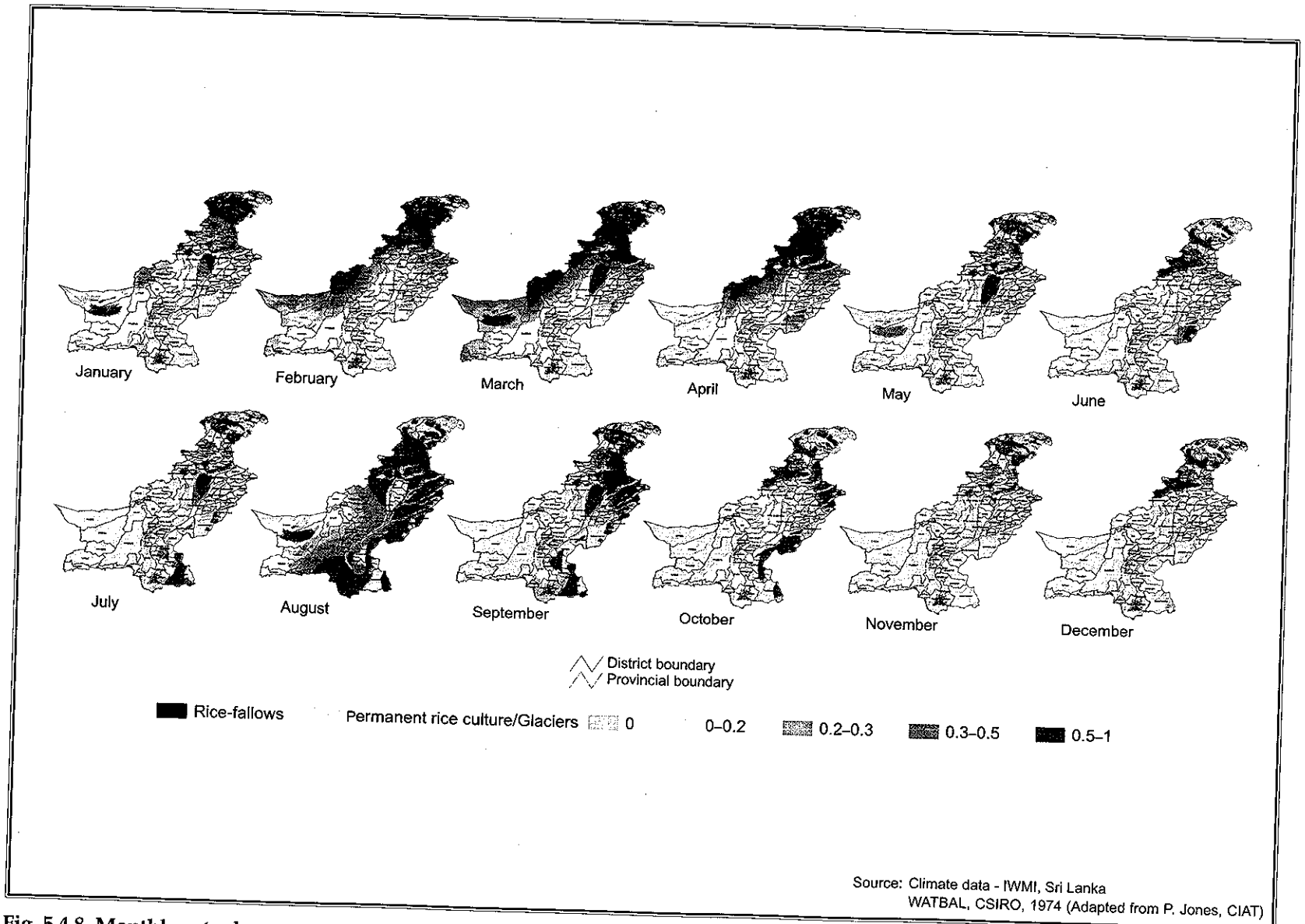


Fig. 5.4.8. Monthly actual evapotranspiration/potential evapotranspiration in Pakistan

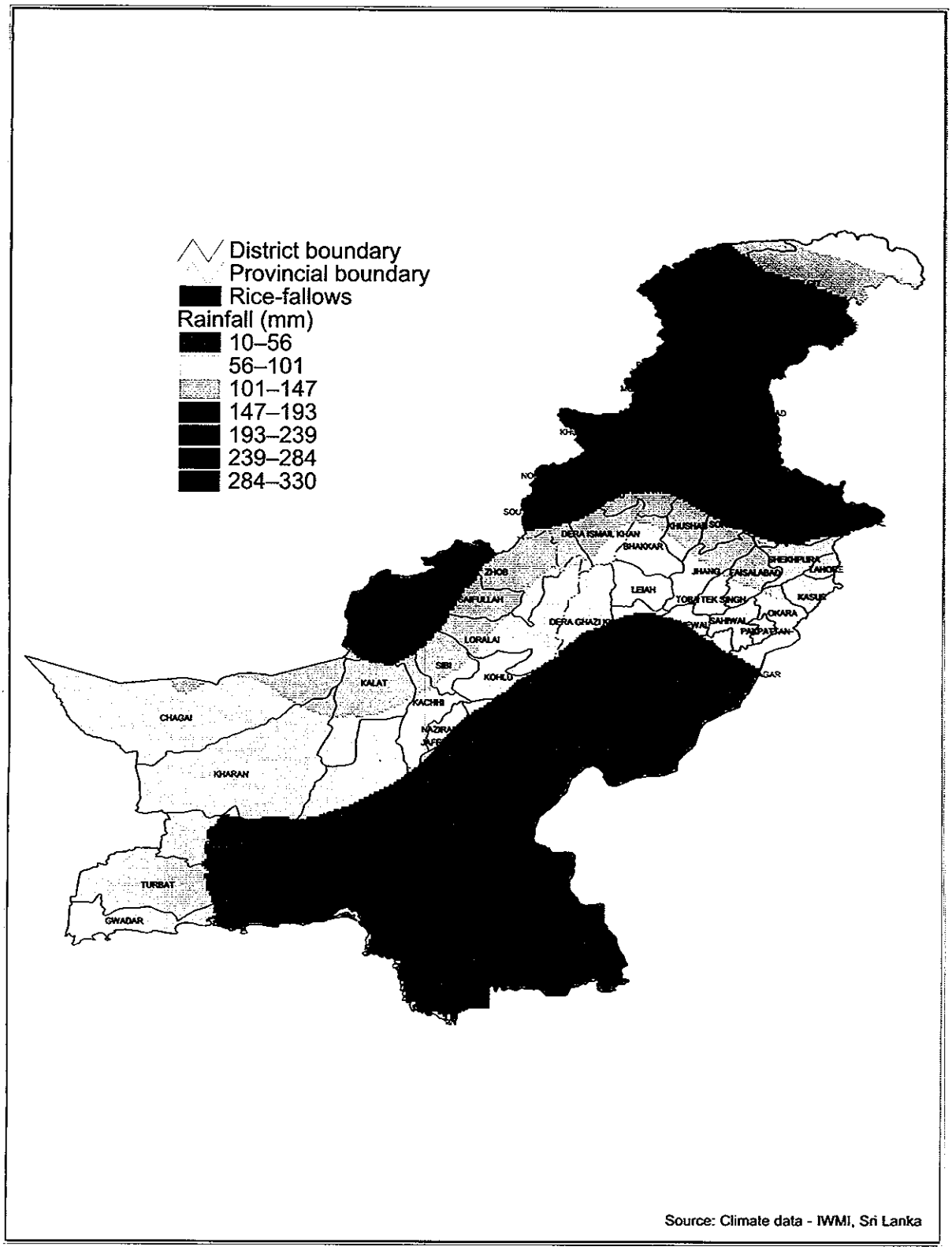
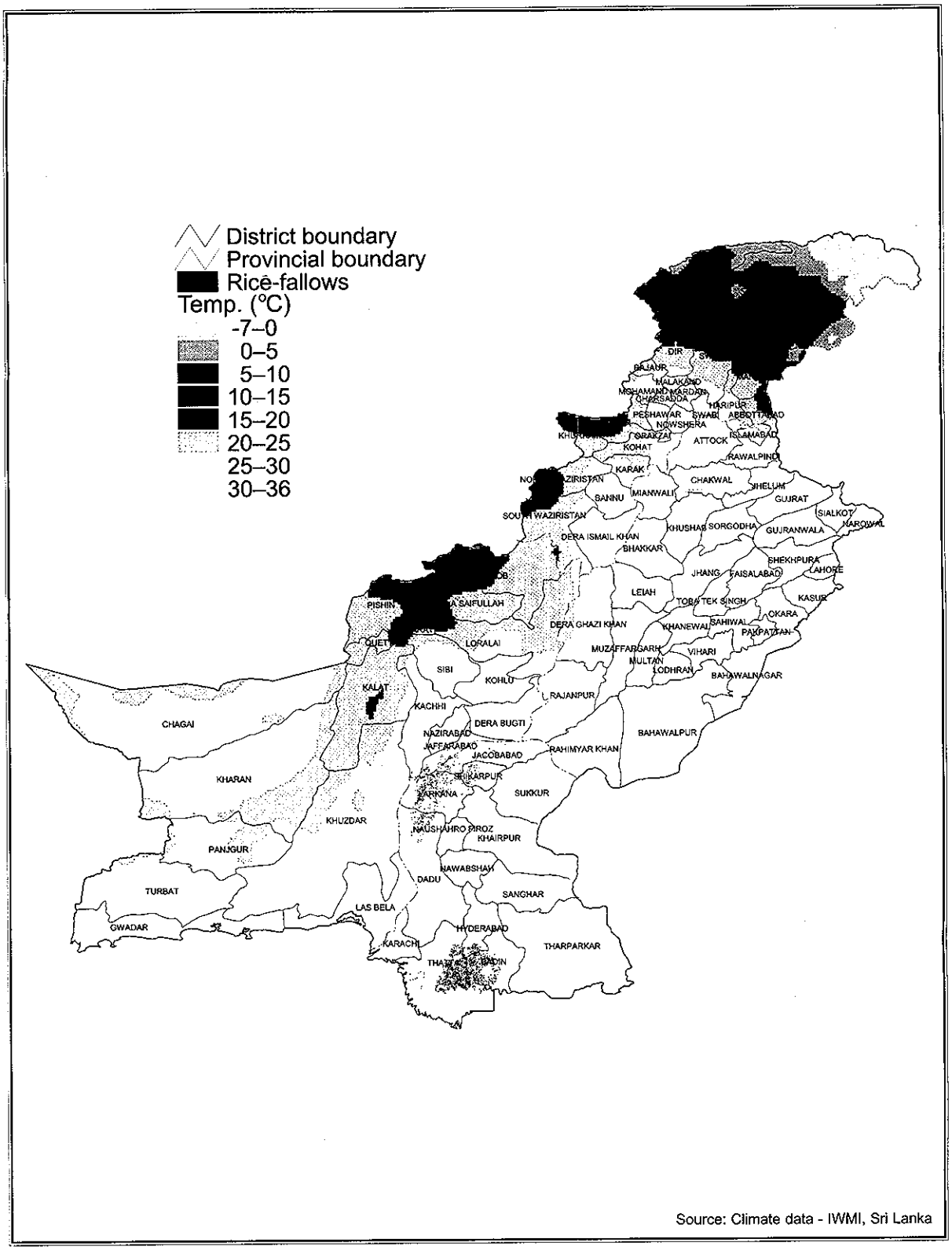


Fig. 5.4.9. Rainfall during rabi (October–March) in Pakistan



Source: Climate data - IWMI, Sri Lanka

Fig. 5.4.10. Annual mean maximum temperature in Pakistan

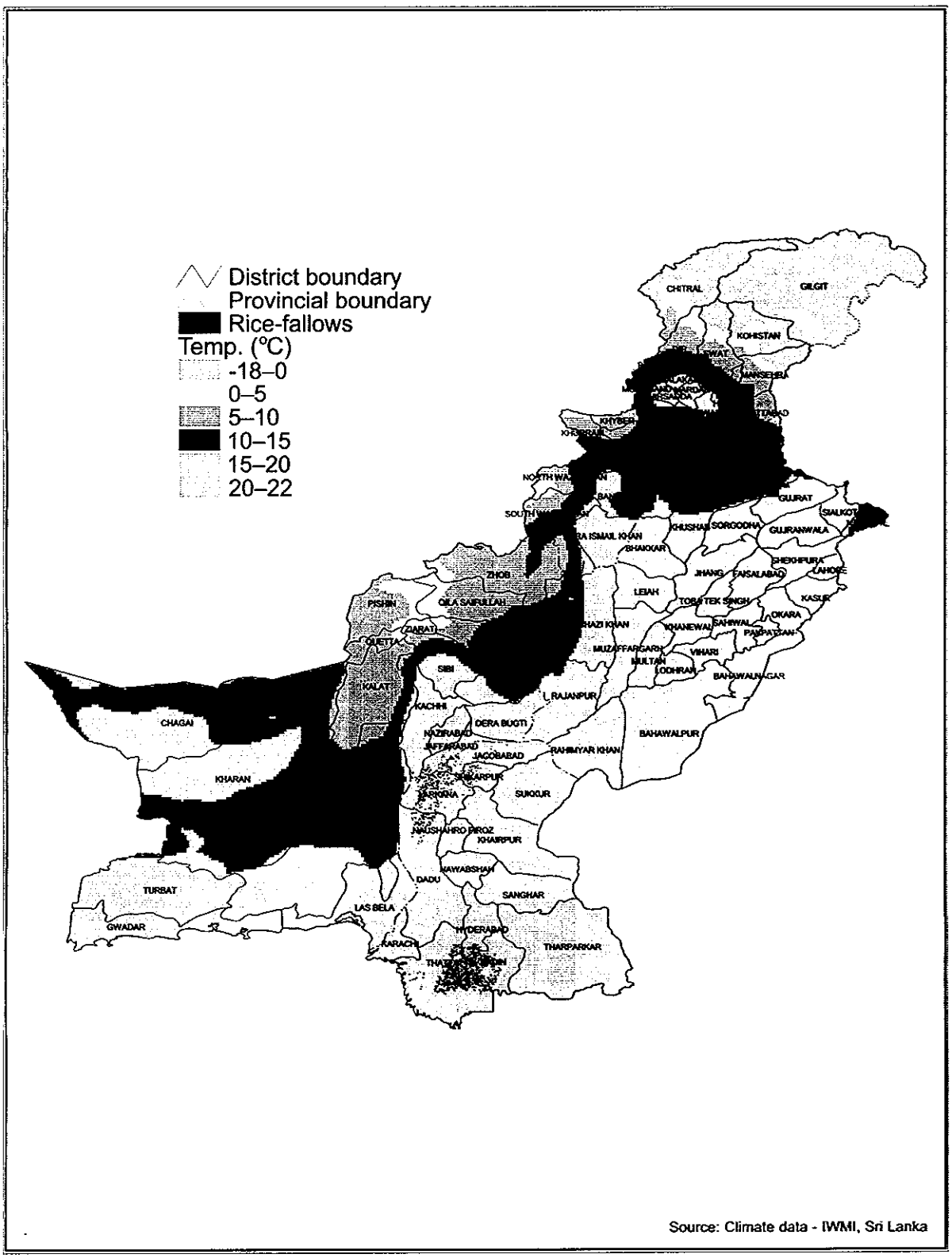
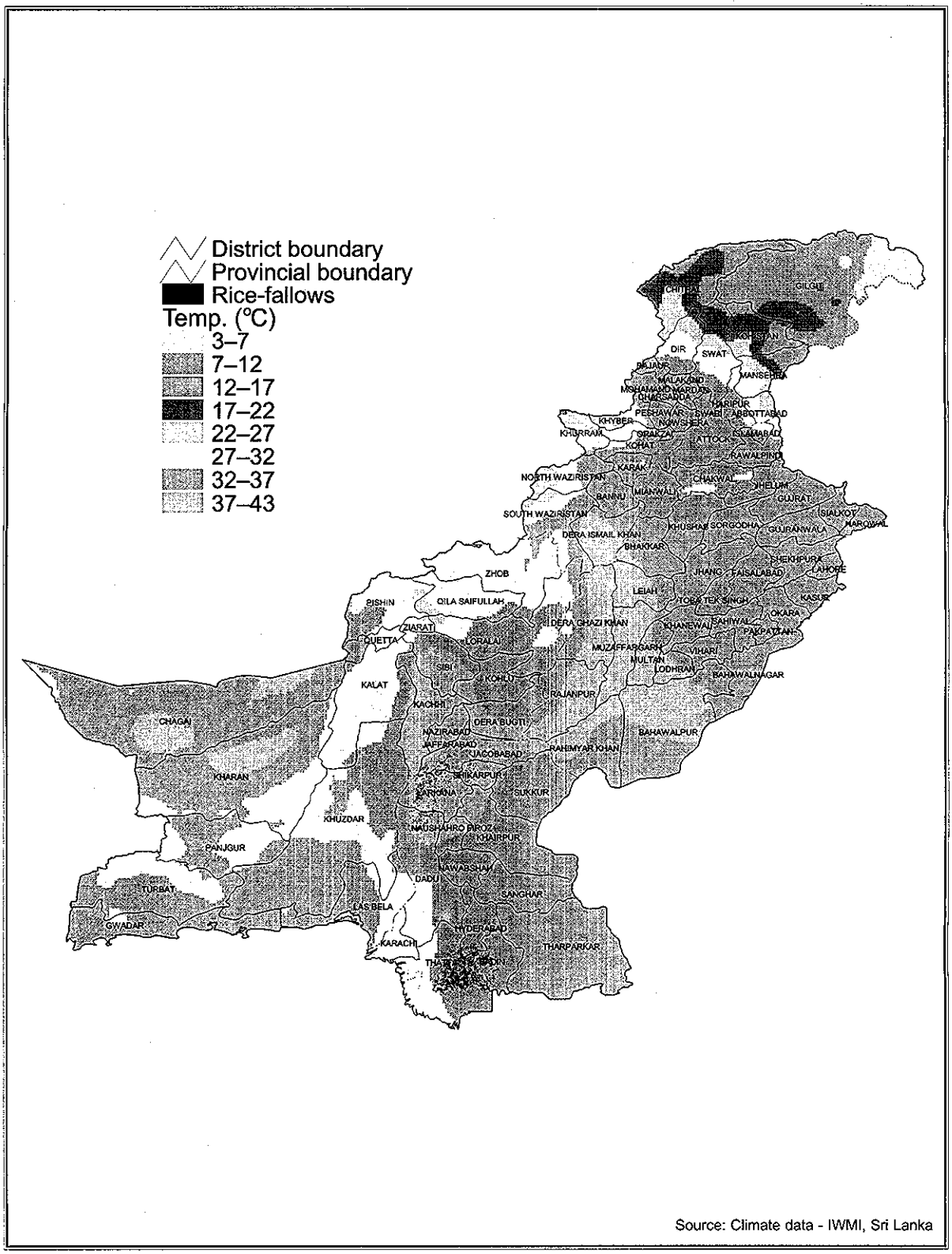


Fig. 5.4.11. Annual mean minimum temperature in Pakistan



Source: Climate data - IWMI, Sri Lanka

Fig. 5.4.12. Mean maximum temperature during kharif (June–September) in Pakistan

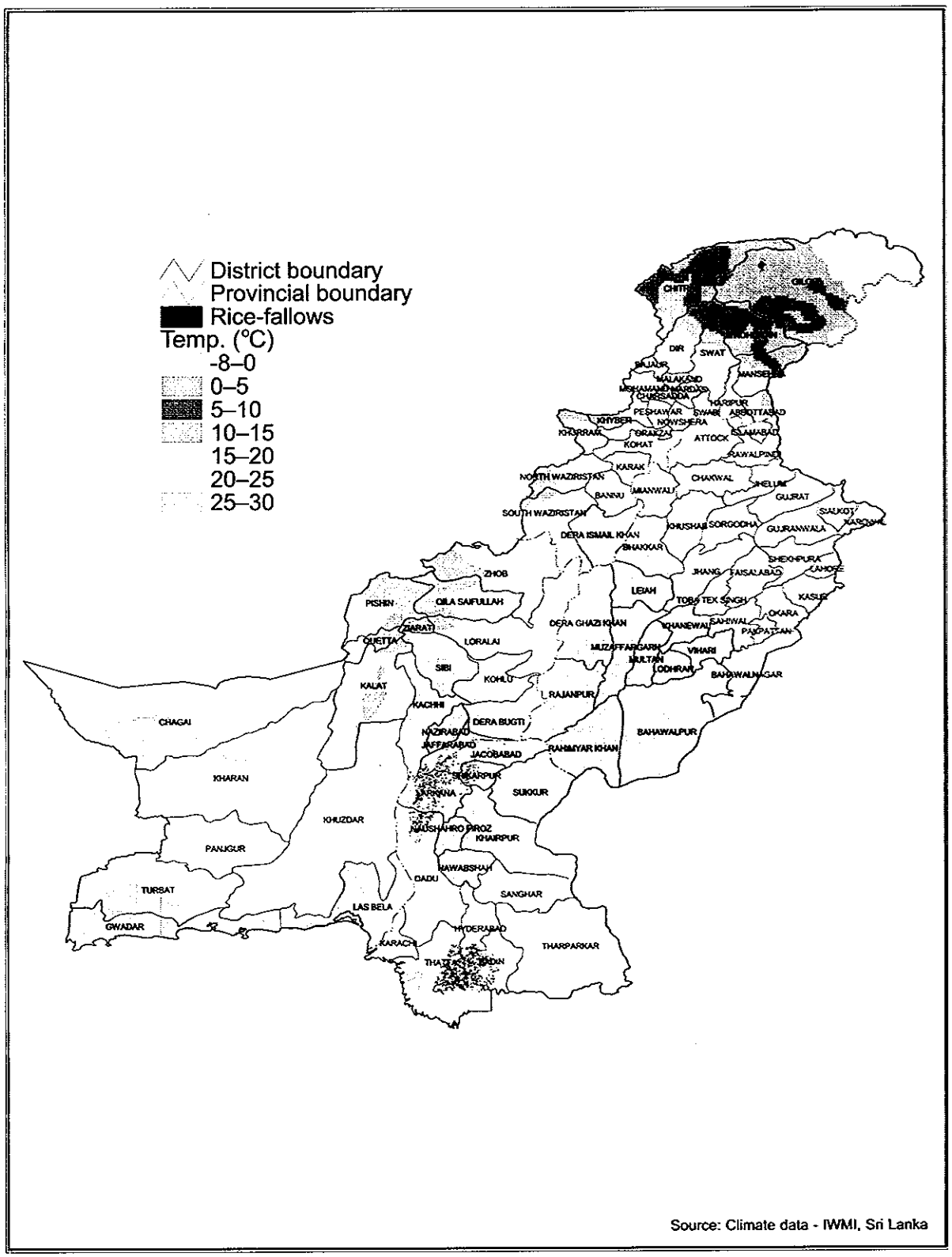
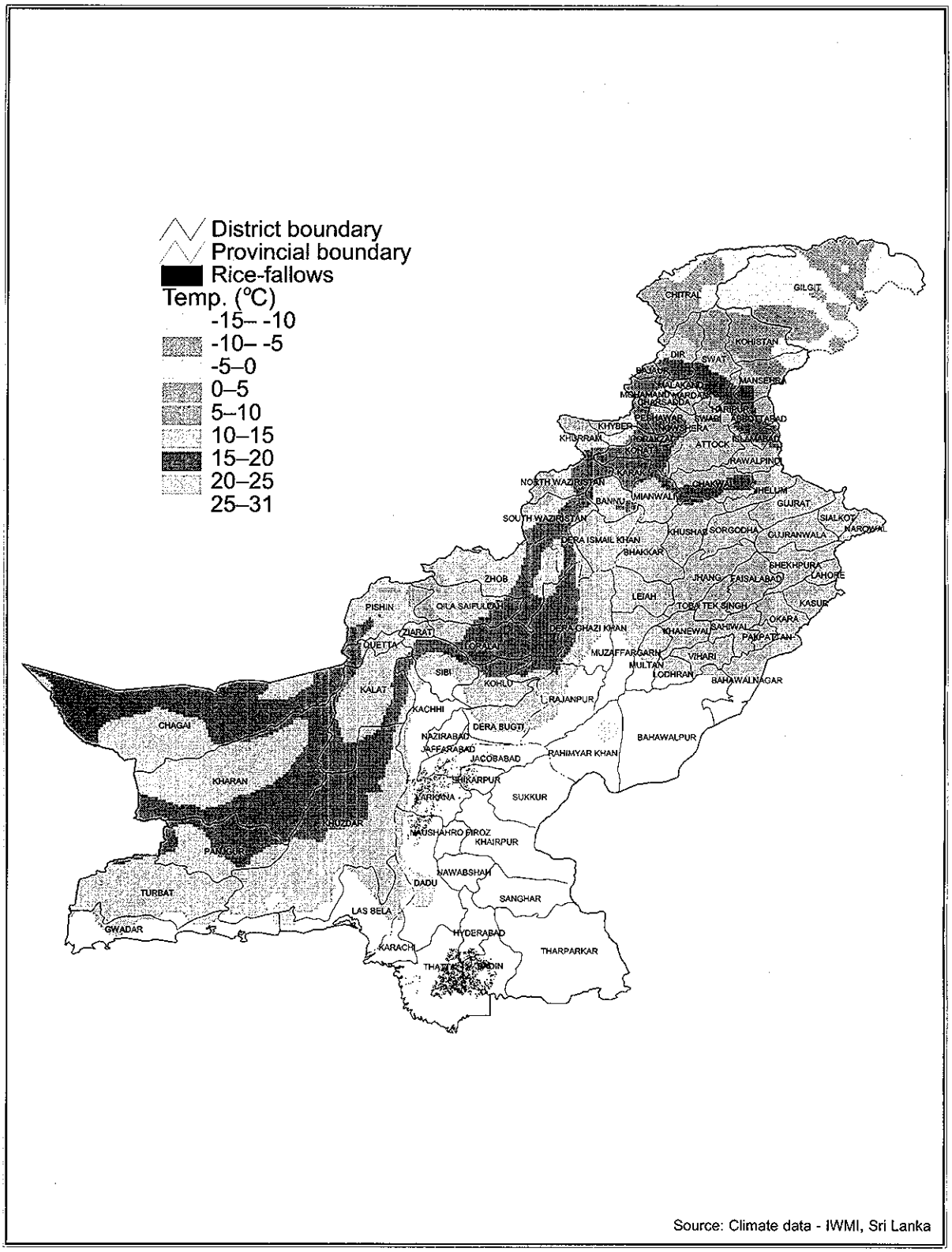


Fig. 5.4.13. Mean minimum temperature during kharif (June–September) in Pakistan



Source: Climate data - IWMI, Sri Lanka

Fig. 5.4.14. Mean maximum temperature during rabi (October–March) in Pakistan

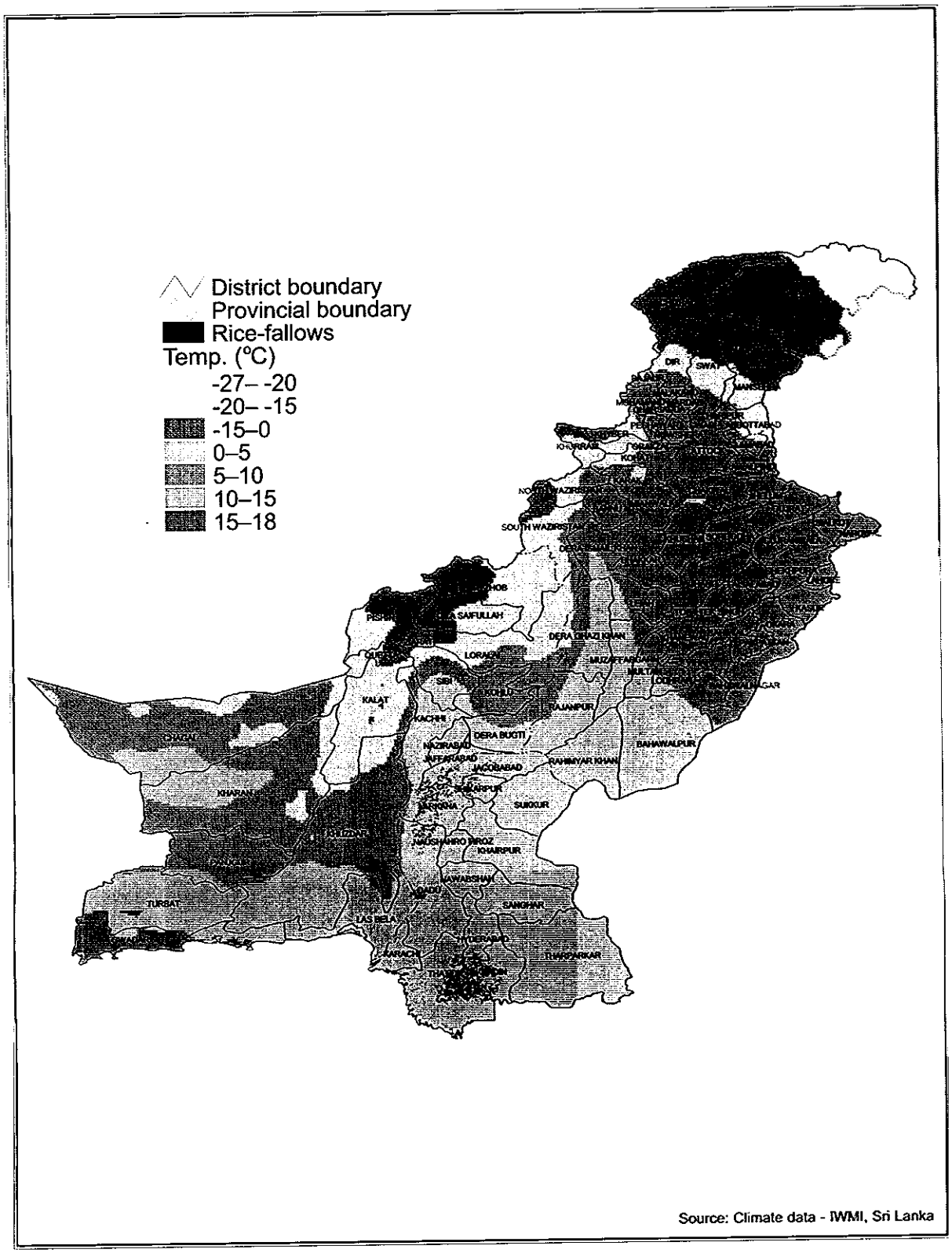


Fig. 5.4.15. Mean minimum temperature during rabi (October–March) in Pakistan

Future Outlook and Recommendations

6. Future Outlook and Recommendations

This study has shown that about 14.3 million ha remain fallow, after cultivation of rainy season rice, during the rabi season in the four South Asian countries of Bangladesh, India, Nepal, and Pakistan. This represents nearly 30% of the total area of 50 million ha rainfed rice cultivated and thus appears as an enormous resource that can be better utilized with application of appropriate, existing technology. This analysis has delineated which legumes are adapted to the specific rice-fallow areas identified. It has also pinpointed the major constraints to be addressed if reliable, remunerative grain legume yields are to be obtained in these areas; and ways of alleviating many of these constraints are indeed available. Therefore, components are now in place to initiate a systematic and concerted effort to better utilize rice-fallows, in terms of cultivation of legumes or other crops after rice. There is an increasing need to do this so as to better satisfy increasing demand for grain legumes in the region through local production rather than imports, tackle rural poverty endemic in rainfed rice-growing areas of South Asia and address sustainability issues of cereal-dominated cropping systems.

Despite the imposing list of agronomic constraints to legume cultivation after rice, there is a wide range of technologies currently available that can effectively address the major limitations. These have recently been elaborated for legumes in general for the Indo-Gangetic Plain region as a whole (Johansen et al. 2000b). However, following are some specific considerations for legumes cultivated after rice, in the major fallow areas identified in this study.

Sowing time is a critical consideration for growing rabi legumes, and particularly after rice as it is determined by harvest time of rice. Usually, legumes face a problem of delayed sowing caused by late harvest of rice (e.g., in late November or December). Shorter duration rice varieties of high yield potential are available, that would allow timely sowing of subsequent legume crops (Mazid et al. 1997). Further, agronomic practices allowing earlier planting of rice, such as dry seeding and early transplanting are feasible (Mazid et al. 1997). These options need promotion in terms of advantages offered in escape of terminal drought stress to rice and possibilities for double cropping by allowing timely sowing of the rabi crop. Legume crops that can be relay sown into rice, such as khesari or lentil, can to some extent avoid problems of late sowing but relay sowing is not currently an option for important potential rice-fallow crops like chickpea. Further studies are needed as to whether relay sowing of chickpea, whereby seedlings could establish in saturated soil, could be achieved through use of seed types better adapted

to germinating and establishing seedlings in saturated conditions or through seed pelleting. There are recently released grain legume varieties that are better adapted to late-sown conditions, and short-duration varieties better able to escape terminal drought and heat stress if sown late (Ali et al. 2000).

Once rice is harvested, soil tillage presents problems with respect to establishing a following legume crop. This is especially so if the soil and atmospheric conditions induce rapid soil drying, in turn causing sub-optimal moisture conditions in the seedbed for germination and emergence. A first consideration is to adapt the tillage method, turnaround time, and sowing method specifically for the prevailing conditions. Seed priming (soaking the seed overnight in water, surface drying, and sowing the next day) can markedly improve crop establishment, growth vigor, and ultimately grain yield in difficult seedbed conditions as found in rice-fallows (Harris et al. 1999, Musa et al. 1999). Manual dibbling of seed into deeper, moist soil layers without tillage is also an option for quick-drying soils (Cook et al. 1995). There is scope for mechanization of tillage and seed drilling operations in such difficult soil conditions (Carangal et al. 1987) but in most of the identified rice-fallow areas in this study, this appears only to be a long-term future option due to the prevailing resource-poor conditions of the majority of farmers.

Other problems relating to poor seedling establishment and sub-optimal plant population of legumes sown after rice can be addressed by established seed treatment techniques. These include *Rhizobium* inoculation to ensure abundant nodulation and hence self sufficiency in N nutrition, lime pelleting for acid soil conditions, inclusion of any necessary trace elements with the pellet, and seed treatment with fungicides to combat seedling diseases.

To cope with the major biotic stresses likely to constrain legumes growing after rice, various integrated pest and disease management strategies are available. Examples include integrated management of BGM (Pande et al. 1998, Pande and Narayana Rao 2000) and *Helicoverpa* pod borer management (Ranga Rao and Shanower 1999). Appropriate methods of postharvest handling for pulses are also available, but generally not known to resource-poor cultivators of rainfed rice.

It is likely that considerable areas of these rice-fallow lands have groundwater reserves that could be tapped for irrigation, thereby obviating the main reason for keeping land fallow during the rabi season. However, sustainability considerations of developing tube well irrigation schemes need to be contemplated in the light of previous such experience.

Ability of the groundwater to recharge after extraction of irrigation water needs to be considered to assess long-term viability of irrigation potential. Further, in Bangladesh and West Bengal (India) problems of arsenic contamination of groundwater have arisen, probably because of changes in the water table, and soil oxidation-reduction states, induced by pumping from tube wells. There are also problems of effective maintenance of tube well operation in resource-poor environments. It is recommended that a thorough feasibility and environmental analysis precede any further tube well development in the rice-fallow areas identified. It is therefore proposed that highest potential for utilization of the identified rice-fallows is under rainfed conditions, especially in view of the inputs required and the likelihood of technology acceptance by local farmers. If rabi crops with deep rooting potential, like chickpea, can be adequately established after rice harvest, there seems to be adequate stored soil moisture to permit shorter duration varieties to achieve acceptable grain yields (Yusuf Ali 2000).

It is noted that most of the rice-fallow areas identified coincide with areas of endemic rural poverty, and herein lies the challenge of exploiting rice-fallows. Despite agronomic and economic potential for legume cultivation in existing rice-fallows, special efforts will be required to encourage the essentially subsistence monocrop rice farmers to proceed in this direction. A first step would be to identify target areas for promotion of technologies for rice-fallow cultivation. In Bangladesh, rice-fallow areas in the Barind region are already being targeted for legume introduction, using seed priming as a vehicle for introducing the required cultivation technology to farmers (Musa et al. 1999). Additionally in Bangladesh, there are large rice-fallow areas in the extreme north and in coastal regions that could be similarly targeted for legumes cultivation. In India, major rice-fallow areas that could be targeted lie in southern Bihar (now Jharkand State), eastern Madhya Pradesh (now Chhatisgarh State), western West Bengal, and in Orissa, all regions of high poverty incidence. In Nepal, the eastern Terai has been identified as a major rice-fallow area. However, in Pakistan the rice-fallow area is relatively small. It is proposed that particular locations in these rice-fallow areas be identified for implementation of focused programs to promote legume cultivation after rice.

Having identified target sites it would then be necessary to conduct on-farm demonstrations of the technologies required to achieve remunerative yields, with affordable necessary minimum inputs. This would best be done through farmer-managed trials, soliciting farmer participation in the total exercise from the outset. It would also be necessary to induce government policy support in the form of increased availability of necessary inputs, credit facilities suitable for resource-poor farming communities,

improved infrastructure and marketing arrangements, and initial price and procurement support for resultant legume grain. The expansion of black gram in the rice-fallows of coastal Andhra Pradesh (India) provides an example of how successful demonstration of improved technology can rapidly induce rice farmers to adopt legume cultivation after rice on a large scale, to their considerable profit (Satyanarayana et al. 1994). We propose that this example can be repeated with other grain legumes in other rice-fallow areas by well-focused demonstration of existing appropriate technologies.

This study provides an example of how sophisticated technology, in this case satellite imagery and GIS, can be mobilized to address seemingly intractable problems of rural poverty, by pointing to viable development opportunities. As a result of the analysis, it can be more clearly seen how not-so-new agronomic knowledge, but knowledge nevertheless out of reach of resource-poor farmers, can be directed to tackle rural poverty issues. In this case the approach is to induce crop diversification, which can in turn encourage development of supporting agro-industry, such as pulses processing and dairying. Remote sensing and GIS can continue to be used in this process, to monitor resultant changes in the cropping system and adoption of new technologies so as to guide fine tuning of the process.

It is concluded that attempts to increase legume cultivation in the rice-fallows of South Asia are both necessary and viable, and of increasing urgency due to an ever-increasing human population and continued environmental degradation. These attempts are necessary to address the high level of rural poverty in major rice-fallow regions, reverse declining trends in per capita availability of grain legumes, and increase ultimate sustainability of the rice-based cropping systems themselves. Many studies referred to herein and reported elsewhere suggest that widespread cultivation of legumes or other short-duration crops under rainfed conditions in existing rice-fallow lands is viable. What is now required is a focused effort and policy support for technology implementation, jointly with the resource-poor rural communities of the region.

7. Literature Cited

Abedin, M.Z., and **Hossain, M.A.** 1991. Prospects of increasing pulses production through improved cropping systems. Pages 65–73 *in* Advances in pulses research in Bangladesh: proceedings of the Second National Workshop on Pulses, 6–8 Jun 1989, Joydebpur, Bangladesh. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Ae, N., Arihara, J., Okada, J., Yoshihara, T., and **Johansen, C.** 1990. Phosphorus uptake by pigeonpea and its role in cropping systems of the Indian subcontinent. Science 248:477–480.

Ahlawat, I.P.S., Singh, A., and **Saraf, C.S.** 1982. Yield of lentil cultivars as affected by date and rate of seeding under late sown condition. Indian Journal of Agronomy 27:259–262.

Ahlawat, I.P.S., Singh, A., and **Saraf, C.S.** 1983. Higher seed rate increased yield of late sown lentil. Indian Farming 33:28–29.

Akhtar, M. 1956. Further studies on the wilt diseases of gram in Punjab. M.Sc. thesis, University of Punjab, Lahore, Pakistan.

Ali, M., Joshi, P.K., Pande, S., Asokan, M., Virmani, S.M., Kumar, R., and **Kandpal, B.K.** 2000. Legumes in the Indo-Gangetic Plain of India. Pages 35–70 *in* Legumes in rice and wheat cropping systems of the Indo-Gangetic Plain – Constraints and opportunities (Johansen, C., Duxbury, J.M., Virmani, S.M., Gowda, C.L.L., Pande, S., and Joshi, P.K., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and Ithaca, New York, USA: Cornell University.

Allen, D.J. 1983. The pathology of tropical food legumes: disease resistance in crop improvement. New York, USA: John Wiley & Sons. 413 pp.

Arnon, I. 1972. Crop production in dry areas. Vol. 1. Background and principles. London, UK: Leonard Hill.

Bakr, M.A., and **Ahmed, F.** 1993. Integrated management of stemphylium blight of lentil. Presented at the 6th International Congress of Plant Pathology, Montreal, Canada.

BARC (Bangladesh Agricultural Research Council). 1981. Annual report 1980/81. Dhaka, Bangladesh: BARC.

BARC (Bangladesh Agricultural Research Council). 1982. Annual report 1981/82. Dhaka, Bangladesh: BARC.

BARC (Bangladesh Agricultural Research Council). 1983. Annual report 1982/83. Dhaka, Bangladesh: BARC.

BARC (Bangladesh Agricultural Research Council). 1984. Annual report 1983/84. Dhaka, Bangladesh:BARC

BARC (Bangladesh Agricultural Research Council). 1985. A review of results of the National Coordinated Cropping Systems Research Project in Bangladesh. Dhaka, Bangladesh: BARC.

BARC (Bangladesh Agricultural Research Council). 1995. Strategic plan for national agricultural research system to the year 2010 and beyond. Dhaka, Bangladesh: BARC.

BARI (Bangladesh Agricultural Research Institute). 1987. Annual report of Pulses Improvement Program, 1986/87. Pulses Research Center. Ishurdi, Pabna, Bangladesh: BARI. pp 143–144.

BARI (Bangladesh Agricultural Research Institute). 1989–90. Annual report 1989–90. Joydebpur, Gazipur, Bangladesh: BARI.

BARI (Bangladesh Agricultural Research Institute). 1993. Annual report of Pulses Breeding, 1992/93. Pulses Research Center. Ishurdi, Pabna, Bangladesh: BARI.

BARI (Bangladesh Agricultural Research Institute). 1997–98. Annual report 1997–98. Joydebpur, Gazipur, Bangladesh: BARI.

Bashir, M., and **Malik, V.** 1995. Production of pulse crops in Pakistan. Pages 169–190 *in* Production of pulse crops in Asia and the Pacific region (Sinha, S.K., and Paroda, R.S., eds.). RAPA Publication no. 1995/8. Bangkok, Thailand: Regional Office for Asia and the Pacific (RAPA), Food and Agriculture Organization of the United Nations.

BBS (Bangladesh Bureau of Statistics). 1997. Statistical year book of Bangladesh for 1993. Statistics Division, Ministry of Planning, Government of Bangladesh. Dhaka, Bangladesh: BBS.

Bharati, M.P. 1982. Country report on the status of grain legumes production in Nepal. Pages 449–472 *in* Grain legumes production in Asia. Tokyo, Japan: Asian Productivity Organization.

Bhatti, I.M. 1987. Rice-wheat cropping systems report, Sind, Pakistan. Pages 185–195 *in* Proceedings of the 18th Asian Rice Farming Systems Working Group Meeting. Los Baños, Philippines: International Rice Research Institute.

Bolaria, T.S. 1982. Grain legumes production in India. Pages 297–356 *in* Grain legumes production in Asia. Tokyo, Japan: Asian Productivity Organization.

BRRI (Bangladesh Rice Research Institute). 1992. A review of BRRI cropping systems research 1974–1988 (compiled by Nizam Uddin Ahmed). Rice Farming Systems Division. Joydebpur, Gazipur, Bangladesh: BRRI.

Byerlee, D., Hobbs, P.R., Majid, A., Akhtar, V, and **Hashmi, N.I.** 1986. Increasing wheat productivity in the context of Pakistan's irrigated systems. A view from the farmers' field. PARC/CIMMYT Paper no. 86-7. Islamabad, Pakistan: PARC/CIMMYT Coordinated Wheat Programme.

Byerlee, D., and **White, R.** 1997. Agricultural systems intensification and diversification through food legumes: technological and policy options. Presented at the III International Food Legumes Research Conference, 22–26 Sep 1997, Adelaide, Australia.

Carangal, V.R., Rao, M.V., and **Siwi, B.H.** 1987. Limits imposed by management in irrigated farming systems. Pages 64–71 *in* Food legumes improvement for Asian farming systems: proceedings of an International Workshop held in Khon Kaen, Thailand, 1–5 September 1986 (Wallis, E.S., and Byth, D.E., eds.). ACIAR Proceedings no. 18. Canberra, Australia: Australian Centre for International Agricultural Research.

Cass, A., Gusli, S., and **Macleod, D.A.** 1994. Sustainability of soil structure quality in rice paddy-soyabean cropping systems in South Sulawesi, Indonesia. Soil and Tillage Research 31:339–352.

Chakraborty, M., Panigrahy, S., and **Sharma, S.A.** 1997. Discrimination of rice crop grown under different cultural practices using temporal ERS-1 SAR data. ISPRS Photogrammetry and Remote Sensing 52:183–191.

Chong, K., Wynne, V., Elkan, G.H., and **Schneewies, T.G.** 1987. Effects of soil acidity and aluminium content on *Rhizobium* inoculation, growth and nitrogen fixation of groundnut and other legumes. Tropical Agriculture 64:97–104.

Choudhary, M.A., and **Pandey, R.K.** 1986. Extending limits to legume crop establishment in rainfed lowland rice. Pages 235–239 *in* Food legumes improvement for Asian farming systems: proceedings of an International Workshop held in Khon Kaen, Thailand, 1–5 September 1986 (Wallis, E.S., and Byth, D.E., eds.). ACIAR Proceedings no. 18. Canberra, Australia: Australian Centre for International Agricultural Research.

Colwell, R.N. 1983. Matter-energy interaction in the optical region. Pages 62–110 *in* The manual of remote sensing. Second edition, Vol. 1. New York, USA: American Society of Photogrammetry.

Cook, S.M.F., Gupta, S.C., Woodhead, T., and **Larson, W.E.** 1995. Soil physical constraints to establishment of mungbeans (*Vigna radiata* L. Wilczek) in paddy rice (*Oryza sativa* L.) soils. Soil and Tillage Research 33:47–64.

Curl, E.A. 1963. Control of plant diseases by crop rotation. Botanical Review 29:413–479.

Dick, W.A., Van Doren, D.M. Jr., Triplett, G.B. Jr., and **Henry, J.** 1986a. Influence of long-term tillage and rotation combinations on crop yields and selected soil parameters. I. Results obtained for a Mollic Ochraquellf. Soil Research Bulletin 1181. Wooster, Ohio, USA: Ohio Agriculture Research and Development Center, Ohio State University.

Dick, W.A., Van Doren, D.M. Jr., Triplett, G.B. Jr., and **Henry, J.** 1986b. Influence of long-term tillage and rotation combinations on crop yields and selected soil parameters. II. Results obtained for a Typic Fragiudalf. Soil Research Bulletin 1181. Wooster, Ohio, USA: Ohio Agriculture Research and Development Center, Ohio State University.

Elias, S.M. 1991. Socio-economic constraints limiting pulses production. Pages 169–175 *in* Advances in pulses research in Bangladesh: proceedings of the Second National Workshop on Pulses, 6–8 Jun 1989, Joydebpur, Bangladesh. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

ERDAS (Earth Resources Data Analysis Systems). 1999. Imagine Version 8.4. Atlanta, Georgia: ERDAS Inc.

FAO (Food and Agriculture Organization of the United Nations). 1981. FAO production yearbook 1980. Rome, Italy: FAO.

FAO (Food and Agriculture Organization of the United Nations). 1996. Digital Soil Map of the World and Derived Soil Properties. CDROM Series. Rome, Italy: FAO.

FAO (Food and Agriculture Organization of the United Nations). 2000. FAO production yearbook 1999. Rome, Italy: FAO.

FAO (Food and Agriculture Organization of the United Nations). 2001. Website: http://www.fao.org

Gadkari, P.D., and **Laxman Singh.** 1979. Pulse crops of Madhya Pradesh. Jabalpur, India: Directorate of Extension Services, Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV).

Goodman, R.M., and **Nene, Y.L.** 1976. Virus diseases of soybean. Pages 91–96 *in* Expanding the use of soybeans. Proceedings of Conference for Asia and Oceania, Chiang Mai, Thailand. INTSOY Series No. 10. Urbana, Illinois, USA: University of Illinois.

Government of Pakistan. 1997–98. Agricultural Statistics of Pakistan. Ministry of Food, Agriculture and Livestock. Islamabad, Pakistan: Government of Pakistan.

Greenland, D.J. 1985. Physical aspects of soil management for rice-based cropping systems. *In* Soil physics and rice. Proceedings of a Workshop on Physical Aspects of Soil Management in Rice-based Cropping Systems, 10–14 December 1984. Los Baños, Philippines: International Rice Research Institute.

Guyot, G. 1990. Optical properties of vegetation canopies. Pages 19–44 *in* Applications of remote sensing in agriculture (Steven, M.D., and Clark, J.A., eds.). Cambridge, UK: University Press.

Habib, R.K., Iqbal, S.M., Haqqani, A.M., Khan, S.A., and **Malik, B.A.** 1991. Thal – the home of chickpea in Pakistan. International Chickpea Newsletter 24:7–10.

Hadas, A. 1985. Water transfer to germinating seeds as affected by soil hydraulic properties and seed-water contact impedance. Pages 501–511 *in* Heat and mass transfer in the biosphere. I. Transfer processes in the plant environment (DeVries, D.A., and Afgan, N.H., eds.). New York, USA: John Wiley & Sons.

Hadas, A., and **Russo, D.** 1974. Water uptake by seeds as affected by water stress, capillary conductivity and seed-soil water contact. 1. Experimental Study. Agronomy Journal 66:643–647.

Haqqani, A.M., and **Arshad, M.** 1995. Crop status and genetic diversity of grasspea in Pakistan. Pages 59–65 *in* Lathyrus genetic resources in Asia: proceedings of a Regional Workshop, Raipur, India, 27–29 December 1995 (Arora, R.K., Mathur, P.N., Riley, K.W., and Adam, Y., eds.). New Delhi, India: International Plant Genetic Resources Institute (IPGRI) Office for South Asia.

Haqqani, A.M., Zahid, M.A., and **Malik, M.R.** 2000. Legumes in Pakistan. Pages 98–128 *in* Legumes in rice and wheat cropping systems of the Indo-Gangetic Plain – Constraints and opportunities (Johansen, C., Duxbury, J.M., Virmani, S.M., Gowda, C.L.L., Pande, S., and Joshi, P.K., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and Ithaca, New York, USA: Cornell University.

Hargrove, W.L., and **Frye, W.W.** 1987. The need for legume cover crops in conservation tillage production. Pages 1–4 *in* The role of legumes in conservation tillage systems (Power, J.F., ed.). Ankeny, Iowa, USA: Soil Conservation Society of America.

Harris, D., Joshi, A., Khan, P.A., Gothkar, P., and **Sodhi, P.S.** 1999. On-farm seed priming in semi-arid agriculture: development and evaluation in maize, rice and chickpea in India using participatory methods. Experimental Agriculture 35:15–29.

Havlin, J.L., Kissel, D.E., Maddux, L.D., Classen, M.M., and **Long, J.H.** 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. Soil Science Society of America Journal 54:448–452.

Hobbs, P., and **Morris, M.** 1996. Meeting South Asia's future food requirements from rice-wheat cropping systems: priority issues facing researches in the post-green revolution era. Natural Resource Group Paper 96-01. Mexico: Centro Internacional de Mejoramiento de Maíz y Trigo.

Hoffer, R.M. 1978. Biological and physical considerations in applying computer aided analysis techniques to remote sensor data. Pages 227–289 *in* Remote sensing – The quantitative approach (Swain, P.H., and Davis, S.M., eds.). New York, USA: McGraw Hill International Book Company.

Hossain, I.M. 1993. Socio-economic assessment of technology on pulses production and constraints to its higher production at farm level. Presented at the seminar of Agricultural Economics Division, BARI, 23 August 1993, Joydebpur, Bangladesh.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1994. Cold-tolerant chickpea varieties ICCV 88503, ICCV 88506, ICCV 88510. ICRISAT Plant Material Description no. 53. Patancheru 502 324, Andhra Pradesh, India: ICRISAT. 4 pp.

Johansen, C., Ali, M., Gowda, C.L.L., Ramakrishna, A., Nigam, S.N., and **Chauhan Y.S.** 2000a. Regional opportunities for warm season grain legumes in the Indo-Gangetic Plain. Pages 185–199 *in* Legumes in rice and wheat cropping systems of the Indo-Gangetic Plain – Constraints and opportunities (Johansen, C., Duxbury, J.M., Virmani, S.M., Gowda, C.L.L., Pande, S., and Joshi, P.K., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and Ithaca, New York, USA: Cornell University.

Johansen, C., Baldev, B., Brouwer, J.B., Erskine, W., Jermyn, W.A., Lijuan, L., Malik, B.A., Miah, A.A., and **Silim, J.N.** 1994. Biotic and abiotic stresses constraining productivity of cool season food legumes in Asia, Africa and Oceania. Pages 175–193 *in* Expanding the production and use of cool season food legumes (Muehlbauer, F.J., and Kaiser, W.J., eds.). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Johansen, C., Duxbury, J.M., Virmani, S.M., Gowda, C.L.L., Pande, S., and **Joshi, P.K.** (eds.) 2000b. Legumes in rice and wheat cropping systems of the Indo-Gangetic Plain – Constraints and opportunities. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and Ithaca, New York, USA: Cornell University. 230 pp.

Johnston, A.E. 1986. Soil organic matter effects on soil and crops. Soil Use Management 20:97–105.

Joshi, P.K. 1998. Performance of grain legumes in the Indo-Gangetic Plain. Pages 3–31 *in* Residual effects of legumes in rice and wheat cropping systems of the Indo-Gangetic Plain (Kumar Rao, J.V.D.K., Johansen, C., and Rego, T.J., eds.). Patancheru 502 324,

Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and New Delhi 110 001, India: Oxford & IBH Publishing Co. Pvt. Ltd.

Joshi, P.K., Asokan, M., Datta, K.K., and **Kumar, P.** 2000. Legumes in the Indo-Gangetic Plain of India. Pages 176–184 *in* Legumes in rice and wheat cropping systems of the Indo-Gangetic Plain – Constraints and opportunities (Johansen, C., Duxbury, J.M., Virmani, S.M., Gowda, C.L.L., Pande, S., and Joshi, P.K., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and Ithaca, New York, USA: Cornell University.

Joshi, P.K., Kelley, T.G., Whitaker, M.L., Parthasarathy Rao, P., and **Lalitha, S.** 1994. Food and agriculture and environment in India: Historical trends and projections. Presented at Food, Agriculture and Environment: Vision 2020, International Food Policy Research Institute, Washington, D.C., USA.

Joshi, P.K., and **Pande, S.** 1996. Constraints to and prospects for adoption of extra-short-duration pigeonpea in northern India: Some socioeconomic aspects. Pages 106–115 *in* Prospects for growing extra-short-duration pigeonpea in rotation with winter crops: proceedings of the IARI/ICRISAT Workshop and Monitoring Tour, 16–18 Oct 1995, New Delhi, India. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Joshy, D., and **Deo, G.P.** 1976. Fertilizer recommendations for major crops in Nepal. Khumaltar, Lalitpur, Nepal: Soil Science Division, Nepal Agricultural Research Council.

Joy, P.P., Rajaram, K.P., and **James, K.I.** 1986. Rice-legume cropping system. International Rice Research Newsletter 11:37–38.

Kamal, M.L., and **Mughal, S.M.** 1968. Studies on plant diseases of south-west Pakistan. Tandojam, Pakistan: Agricultural Research Institute, Department of Agriculture, Government of West Pakistan.

Karim, M.A., and **Rahman, M.M.** 1991. Status of insect and vertebrate pest management research on pulses. Pages 135–138 *in* Advances in Pulses Research in Bangladesh: Proceedings of the Second National Workshop on Pulses, 6–8 Jun 1989, Joydebpur, Bangladesh. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Karim, M.R., Islam, Q.M.S., and **Haque, A.K.M.H.** 1998. Chickpea in the high Barind of Bangladesh. Pages 126–135 *in* Assessing joint research impacts: Proceedings of an international workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, 2–4 Dec 1996, ICRISAT, Patancheru, India (Bantilan, M.C.S., and Joshi, P.K., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Kasturirangan, K., Aravamudam, R., Deekshatulu, B.L., George Joseph, and **Chandrasekhar, M.G.** 1996. Indian Remote Sensing Satellite (IRS) – 1C – The beginning of a new era. Current Science 70:495–500.

Keig, G., and **McAlpine, J.R.** 1974. Watbal: A computer system for the estimation and analysis of soil moisture regimes from simple climatic data. Technical Memorandum 74/4. Australia: Division of Land Resources, Commonwealth Scientific and Industrial Research Organization.

Kelley, T.G., and **Parthasarathy Rao, P.** 1996. Current status of chickpea in WANA and South Asia: Analysis of trends in production, consumption and trade. Pages 239–254 *in* Adaptation of chickpea in the West Asia and North Africa region (Saxena, N.P., Saxena, M.C., Johansen, C., Virmani, S.M., and Harris, H., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and PO Box 5466, Aleppo, Syria: International Center for Agricultural Research in the Dry Areas.

Kennedy, G., Ram, P.R., Naidu, M.R., and **Nivasulu, R.S.** 1990. Economic analysis of major pulses in Guntur District, Andhra Pradesh. Agricultural Situation in India 45:173–181.

Khan, I.U., 1979. Chickpea pathology in Pakistan. Page 257 *in* Proceedings of the International Workshop on Chickpea Improvement, 28 Feb–2 March 1979, ICRISAT, Hyderabad, India. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Khan, M.A., Haqqani, A.M., and **Zubair, M.** 1991. Pakistan. Pages 53–57 *in* Agroclimatology of Asian grain legumes (chickpea, pigeonpea, and groundnut) (Virmani, S.M., Faris, D.G., and Johansen, C., eds.). Research Bulletin no. 14. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Krishna Rao, M.V., Hebbar, K.R., and **Venkataratnam, L.** 1997. Evaluation of IRS-1C data for discrimination and acreage estimation of crops grown under multiple crop situation. Remote Sensing for Natural Resources. Presented at the National Symposium on Remote Sensing for natural resources with special emphasis on water management, held at Pune during 4–6 Dec 1996.

Kumar, J., Rahman, M., Musa, A.M., and **Islam, S.** 1994. Potential for expansion of chickpea in the Barind region of Bangladesh. International Chickpea and Pigeonpea Newsletter 1:11–13.

Kumar, P., Joshi, P.K., Johansen, C., and **Asokan, M.** 2000. Total factor productivity of rice-wheat cropping systems in India – The role of legumes. Pages 166–175 *in* Legumes in rice and wheat cropping systems of the Indo-Gangetic Plain – Constraints and opportunities (Johansen, C., Duxbury, J.M., Virmani, S.M., Gowda, C.L.L., Pande, S., and Joshi, P.K,. eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and Ithaca, New York, USA: Cornell University.

Kumar Rao, J.V.D.K., Dart, P.J., and **Usha Kiran, M.** 1982. Cowpea group *Rhizobium* in soils of the semi-arid tropics. Pages 291–295 *in* Biological nitrogen fixation technology for tropical agriculture: papers presented at a Workshop, 9–13 Mar 1981, Cali, Colombia (Graham, P.H., and Harris, S.C., eds.). Cali, Colombia: Centro Internacional de Agricultura Tropical.

Kumar Rao, J.V.D.K., Johansen, C., and **Rego, T.J.** (eds.) 1998. Residual effects of legumes in rice and wheat cropping systems of the Indo-Gangetic Plain. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and New Delhi 110 001, India: Oxford & IBH Publishing Co. Pvt. Ltd. 250 pp.

Lal, M.S., and **Sarup, I.** 1989. Socio-economic issues in relation to production and consumption of *Lathyrus sativus* in India. Pages 55–60 *in* Grasspea, threat and promise (Spencer, P.S., ed.). New York, USA: Third World Medical Research Foundation.

Lal, S. 1984. Constraints and opportunities in pulse production in eastern Uttar Pradesh. Pages 89–106 *in* Pulse production constraints and opportunities (Srivastava, H.C., Bhaskaran, S., Menon, K.K.G., Ramanujam, S., and Rao, M.V., eds.). New Delhi, India: Oxford & IBH Publishing Co. Pvt. Ltd.

Liu, Quif-Fong. 1984. Faba bean (*Vicia faba*) cultivation. Kunming, Yunnan, China: Peoples Publishing House. 186 pp.

Makkouk, K.M., Bos, L., Horn, N.M., and **Srinivasa Rao, B.** 1993. Screening for virus resistance in cool season food legumes. Pages 179–192 *in* Breeding for stress tolerance in cool season food legumes (Singh, K.B., and Saxena, M.C., eds.). Chichester, UK: John Wiley & Sons.

Mann, R.A., and **Garrity, D.P.** 1994. Green manures in rice-wheat cropping systems in Asia. Pages 27–42 *in* Green manure production systems for Asian ricelands (Ladha, J.K., and Garrity, D.P., eds.). Los Baños, Philippines: International Rice Research Institute.

Mannering, J.V., and **Griffin, D.R.** 1981. Value of crop rotations under various tillage systems. Purdue University Cooperative and Extension Service Publication (Tillage) AY-230. Purdue, USA: Purdue University.

Mazid, M.A., Mannan, M.A., Mollah, M.I.U., Ahmed, H.U., Haron, M., and **Ali, A.** 1997. Technology packages for rice-based cropping system for increased productivity of Rajshahi region. Pages 92–104 *in* Proceedings of the Farmer Extension Workshops. In collaboration with DAE, BRRI and BARI during October 1996 to August 1997. Dhaka, Bangladesh: Thana Cereal Technology Project and Identification Project (GOB/UNDP/FAP/Project BGD/89/045).

Mehta, S.L., and **Santha, I.M.** 1996. Plant biotechnology for development of non-toxic strains of *Lathyrus sativus*. Pages 129–138 *in Lathyrus* genetic resources in Asia. Proceedings of a Regional Workshop, 27–29 December 1995, Raipur, India. New Delhi, India: International Plant Genetic Resources Institute (IPGRI) Office for South Asia.

Miah, A.A., Maniruzzaman, A.F.M., and **Rahman, M.M.** 1991. Problems and prospects of pulses production. Pages 87–94 *in* Advances in pulses research in Bangladesh: proceedings of the Second National Workshop on Pulses, 6–8 Jun 1989, Joydebpur, Bangladesh. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Miah, M.M.U. 1995. Boron deficiency in cereals and vegetables in soils of Bangladesh. Pages 97 *in* Proceedings of the International Conference of Commission IV, International Society of Soil Science, 1–3 December 1992, Dhaka, Bangladesh (Hussain, M.S., Imamul

Huq, S.M., Anwar Iqbal, M., and Khan, T.H., eds.). Dhaka, Bangladesh: Bangladesh Agricultural Research Council.

Mohammad, A., Barnett, F.L., Vanderlip, R.L., and **Khaleeq, B.** 1989. Emergence and stand establishment of pearl millet as affected by mesocotyl elongation and other seedling traits. Field Crops Research 20:41–49.

Muehlbauer, F.J., Johansen, C., Singh, L., and **Kelley, T.G.** 1998. Crop improvement: Emerging trends in pulses. Pages 147–166 *in* Crop productivity and sustainability – Shaping the future. Proceedings of the 2nd International Crop Science Congress (Chopra, V.L., Singh, R.B., and Verma, Anupam, eds.). New Delhi, India: Oxford & IBH Publishing Co. Pvt. Ltd.

Musa, A.M., Johansen, C., Kumar, J., and **Harris, D.** 1999. Response of chickpea to seed priming in the High Barind Tract of Bangladesh. International Chickpea and Pigeonpea Newsletter 6:20–23.

NARC (Nepal Agricultural Research Council). 1997. Annual report. Nepal: NARC.

Nasr, H.M., and **Selles, F.** 1995. Seedling emergence as influenced by aggregate size, bulk density, and penetration resistance of the seedbed. Soil and Tillage Research 34:61–76.

Navalgund, R.R., Parihar, J.S., Venkataratnam, L., Krishna Rao, M.V., Panigrahy, S., Chakraborthy, M., Hebbar, K.R., Oza, M.P., Sharma, S.A., Bhagia, N., and **Dadhwal, V.K.** 1996. Early results from crop studies using IRS-1C data. Current Science 70:568–574.

Nene, Y.L. 1979. Diseases of chickpea. Pages 171–178 *in* Proceedings of the International Workshop on Chickpea Improvement, 28 Feb–2 Mar 1979, ICRISAT, Hyderabad, India. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Nene, Y.L. 1982. A review of aschochyta blight of chickpea. Tropical Pest Management 28:61–70.

Neupane, R.K. 1995. Status of food legumes research and production in Nepal. Pages 147–162 *in* Production of pulse crops in Asia and the Pacific region (Sinha, S.K., and

Paroda, R.S., eds.). RAPA Publication No. 1995/8. Bangkok, Thailand: Regional Office for Asia and the Pacific (RAPA), Food and Agriculture Organization of the United Nations.

Nigam, R.K. 1980. Knowledge level of farmers on improved pulse production. Indian Journal of Pulses Research 3:100–101.

Odell, R.T., Melsted, S.W., and **Walker, W.M.** 1984. Changes in organic carbon and nitrogen of morrow plot soils under different treatments, 1904–1973. Soil Science 137:160–171.

PAC (Pakhribas Agricultural Center). 1993. Annual report 1991–92. Dhankuta, Nepal: PAC.

Pande, S., Johansen, C., and **Narayana Rao, J.** 1998. Management of botrytis gray mold of chickpea – a review. Pages 23–40 *in* Recent advances in research and management of botrytis gray mold of chickpea: summary proceedings of the Fourth Working Group Meeting to Discuss Collaborative Research on Botrytis Gray Mold of Chickpea, 23–26 Feb 1998, BARI, Gazipur, Joydebpur, Bangladesh (Pande, S., Bakr, M.A., and Johansen, C., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Pande, S., and **Joshi, P.K.** 1995. Constraints and prospects of legumes in the rice-wheat based cropping system in Terai region of Nepal, Trip report 7, Dec 31, 1995. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Pande, S., and **Narayana Rao, J.** 2000. Integrated management of chickpea in the rice-based cropping systems of Nepal, 1999–2000 postrainy season. ICRISAT, Natural Resource Management Program, Progress Report. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 33 pp. (Limited circulation.)

Pande, S., Sharma, S.B., and **Ramakrishna, A.** 2000. Biotic stresses affecting legumes production in the Indo-Gangetic Plain. Pages 129–155 *in* Legumes in rice and wheat cropping systems of the Indo-Gangetic Plain – Constraints and opportunities (Johansen, C., Duxbury, J.M., Virmani, S.M., Gowda, C.L.L., Pande, S., and Joshi, P.K., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and Ithaca, New York, USA: Cornell University.

Pandey, S.P., Yadav, C.R., Shah, K., Pande, S., and **Joshi, P.K.** 2000. Legumes in Nepal. Pages 71–97 *in* Legumes in rice and wheat cropping systems of the Indo-Gangetic Plain – Constraints and opportunities (Johansen, C., Duxbury, J.M., Virmani, S.M., Gowda, C.L.L., Pande, S., and Joshi, P.K., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and Ithaca, New York, USA: Cornell University.

PARI (Pakistan Agricultural Research Institute). 1995–96. Annual report. Pakistan: PARI.

Parihar, J.S., Panigrahy, S., Patel, N.K., Dadhwal, V.K., Medhavy, T.T., Ghose, B.K., Ravi, N., Pani, K.C., Panigrahy, B.K., Sridhar, V.N., Mohanty, R.R., Nanda, S.K., Tripathy, D.P., Mishra, P.K., Bhatt, H.P., Oza, S.R., Sudhakar, S., Sudha, K.S., Kumar, P., and **Das, N.K.** 1990. Rice acreage estimation in Orissa using remotely sensed data. Status report on RSAM Project: Crop acreage and production estimation. SAC Status report: RSAM/SAC/CAPE/SR/25/90.

Parihar, S.S., Ghildyal, B.P., Painuli, D.K., and **Sur, H.S.** 1985. Physical properties of mineral soils affecting rice-based cropping systems. Pages 57–70 *in* Soil physics and rice. Los Baños, Philippines: International Rice Research Institute.

Paroda, R.S., Woodhead, T., and **Singh, R.B.** (eds.) 1994. Sustainability of rice-wheat production systems in Asia. RAPA Publication: 1994/11. Bangkok, Thailand: Regional Office for Asia and the Pacific (RAPA), Food and Agriculture Organization of the United Nations. 209 pp.

Qureshi, S.H., Bashir, M., and **Alam, S.S.** 1985. Diseases of rabi pulses and their control. Pakistan Journal of Agricultural Research 6:17–19.

Radha, Y.R., Seetharaman, G., Ram, S., and **Subbiah, G.** 1989. Efficiency of input use – a comparative study in rice-rice and rice-pulse farming systems. Economic Affairs 34:219–224.

Rahman, M.M. 1989. Evaluation of different indices for developing an insecticide application schedule against *Euchrysops cnejus* Fab. infesting mung bean. Page 84 *in* Abstracts, 14th Bangladesh Science Conference, Section 1.

Rahman, M.M., Bakr, M.A., Mia, M.F., Idris, K.M., Gowda, C.L.L., Kumar, J., Deb, U.K., Malek, M.A., and **Sobhan, A.** 2000. Legumes in Bangladesh. Pages 5–34 *in* Legumes in rice and wheat cropping systems of the Indo-Gangetic Plain – Constraints and opportunities (Johansen, C., Duxbury, J.M., Virmani, S.M., Gowda, C.L.L., Pande, S., and Joshi, P.K., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and Ithaca, New York, USA: Cornell University.

Rahman, M.M., and **Mallick, R.N.** 1988. Factors which limit cool season food legume productivity in Bangladesh. Pages 229–234 *in* World crops: Cool season food legumes (Summerfield, R.J., ed.). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Rahman, M.S., and **Kar, N.K.** 1988. Screening of crop species tolerant to drought in early kharif. Pages 107–111 *in* Annual research report, Barind Farming Systems Research (FSR) Site, Kazihatta, Rajshahi, 1987/88. Joydebpur, Gazipur, Bangladesh: Bangladesh Agricultural Research Institute.

Raisuddin, M., and **Nur-E-Elahi.** 1984. Technologies for low rainfall in Barind Tract. Pages 107–118 *in* Proceedings of the 1st BRRI-extension Multilocation Working Group Meeting on Rice-based Cropping System. Gazipur, Joydebpur, Bangladesh: Bangladesh Rice Research Institute.

Ramakrishna, A., Anders, M.M., and **Flower, D.J.** 1992. Rice-based cropping systems – ICRISAT experience. Pages 55–58 *in* Monitoring AGLN crops in rice-based cropping system: summary proceedings of the Myanmar-AGLN/ICRISAT Workshop and Monitoring Tour, 17–25 Jan 1992, Yangon and Yezin, Myanmar. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Ranga Rao, G.V., and **Shanower, T.G.** 1999. Identification and management of pigeonpea and chickpea insect pests in Asia. Information Bulletin no. 57. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 96 pp.

Ranga Rao, G.V., Wightman, J.A., Arjuna Rao, P., Mahesh Babu, P., Sitharama Rao, G., and **Rameswara Rao, V.** 1996. Integrated pest management of groundnut insect-pests. Pages 147–161 *in* Plant protection and environment (Reddy, D.V.R., Sharma, H.C., Gour, T.B., and Diwakar, B.J., eds.). Rajendranagar, Hyderabad, India: Plant Protection Association of India.

Raychaudhuri, S.P., Agarwal, R.R., Datta Biswas, N.R., Gupta, S.P., and **Thomas, P.K.** 1963. Soils of India. New Delhi, India: Indian Council of Agricultural Research.

Razzaque, M.A., and **Sattar, M.A.** 1998. Overview and prospects for enhancing residual benefits of legumes in rice and wheat cropping systems in Bangladesh. Pages 153–175 *in* Residual effects of legumes in rice and wheat cropping systems of the Indo-Gangetic Plain (Kumar Rao, J.V.D.K., Johansen, C., and Rego, T.J., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and New Delhi 110 001, India: Oxford & IBH Publishing Co. Pvt. Ltd.

Reddy, P.S. (ed.) 1988. Groundnut. New Delhi, India: Indian Council of Agricultural Research. 583 pp.

Reddy, P.S., Basu, M.S., Khaleque, M.A., Hoque, M.S., Naazar Ali, Shah Nawaz Malik, Hla Than, Tin Soe, Regunathan, B., Mishra, B., Murthy, T.G.K., and **Nigam, S.N.** 1992. Status of groundnut research and production in South Asia. Pages 133-147 *in* Groundnut – a global perspective: proceedings of an international workshop, 25–29 Nov 1991, ICRISAT Center, India (Nigam, S.N., ed.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Reddy, S.J. 1979. User's manual for the water balance models. RP 02046. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 28 pp. (Limited distribution.)

Richard, G., and **Guerif, J.** 1988. Influence of aeration conditions in the seedbed on sugar beet seed germination: Experimental study and model. Pages 103–108 *in* Proceedings of 11th ISTRO Internatioanl Conference, Edinburgh, Vol. 1.

Rupela, O.P., and **Saxena, M.C.** 1987. Nodulation and nitrogen fixation in chickpea. Pages 191–206 *in* The chickpea (Saxena, M.C., and Singh, K.B., eds.). Wallingford, Oxon, UK: CAB International.

SAC. 1999. National wheat production forecast (1998-99) using multi date WiFS and meteorological data. RSAM/SAC/FASAL-TD/SN/01/99.

Sarkar, A.K., Lal, S., Singh, R.P., and **Singh, S.** 1998. Soils of Bihar plateau – Their characteristics and management. Technical Bulletin No. 3/98, Department of Soil Science & Agricultural Chemistry. Ranchi, India: Birsa Agricultural University.

Sattar, A., Arif, A.G., and **Din, M.N.** 1953. Effect of soil temperature and moisture on the incidence of gram blight. Pakistan Journal of Scientific Research 5:16–21.

Satyanarayana, A., Murthy, S.S., Johansen, C., Laxman Singh, Chauhan, Y.S., and **Kumar Rao, J.V.D.K.** 1988. Introducing pigeonpea into rice-fallows of coastal Andhra Pradesh. International Pigeonpea Newsletter 7:11–12.

Satyanarayana, A., Sudhakar Babu, K., Seenaiah, P., and **Prasada Rao, M.P.** 1994. Extending pulses area production in rice fallows. Presented at the International Symposium on Pulses Research, New Delhi, India.

Saxena, M.C., Murinda, M.V., Turk, M., and **Trabulsi, N.** 1983. Productivity and water use of lentil as affected by date of sowing. LENS Newsletter 10:28–29.

Saxena, N.P. 1962. Effect of waterlogging on wheat and gram. M.Sc. thesis, Indian Agricultural Research Institute, New Delhi, India.

Saxena, N.P., Saxena, M.C., and **Johansen, C.** 1997. Chickpea ideotypes for low and high input coordinates. Pages 217–231 *in* Recent advances in pulses research (Asthana, A.N., and Ali, Masood, eds.). Kanpur, India: Indian Society of Pulses Research and Development, Indian Institute of Pulses Research.

Setty, R.A., and **Channabasavanna, A.S.** 1993. Rice based cropping system and its economics. Journal of Farming Systems 9:115–118.

Shinde, R.P., Mahadkar, U.V., Chavan, S.A., and **Khanvilkar, S.A.** 1992. Effects of rabi legumes on yield, nitrogen economy of succeeding rice and economics of cropping systems. Journal of Maharashtra Agricultural University 17:40–42.

Singh, D.P. 1995. Pulses in India. Pages 101–112 *in* Production of pulse crops in Asia and the Pacific region (Sinha, S.K., and Paroda, R.S., eds.). Bangkok, Thailand: Regional Office for Asia and the Pacific (RAPA), Food and Agriculture Organization of the United Nations.

Singh, K.M., and **Singh, R.K.P.** 1995. An economic analysis of lentil cultivation in north-east alluvial plains of Bihar. Economic Affairs 40:157–163.

Singh, O.P., and **Singh, K.J.** 1993. Changing scenario of soybean insect pests. Pages 48–55 *in* Pests and pest management in India – The changing scenario (Sharma, H.C.,

and Veerabhadra Rao, M., eds.). Rajendranagar, Hyderabad, India: Plant Protection Association of India.

So, H.B., and **Woodhead, T.** 1987. Alleviation of soil physical limits to productivity of legumes in Asia. Pages 112–120 *in* Food legume improvement for Asian farming systems: proceedings of an International Workshop held in Khon Kaen, Thailand, 1–5 September 1986 (Wallis, E.S., and Byth, D.E., eds.). ACIAR Proceedings no. 18. Canberra, Australia: Australian Centre for International Agricultural Research.

Srivastava, S.P., Johansen, C., Joshi, M., and **Rego, T.J.** 1999. Boron deficiency of lentil in Nepal. LENS Newsletter 26:22–24.

Srivastava, S.P., Yadav, C.R., Rego, T.J., Johansen, C., and **Saxena, N.P.** 1997. Diagnosis and alleviation of boron deficiency causing flower and pod abortion in chickpea (*Cicer arietinum* L.) in Nepal. Pages 95–99 *in* Boron in soils and plants (Bell, R.W., and Rerkasem, B., eds.). Developments in Plant and Soil Sciences. Vol. 76. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Subbarao, G.V., Johansen, C., Slinkard, A.E., Rao, R.C.N., Saxena, N.P., and **Chauhan, Y.S.** 1995. Strategies for improving drought resistance in grain legumes. CRC Critical Reviews in Plant Sciences 14:469–523.

Taylor, H.M., and **Gardner, H.R.** 1963. Penetration of cotton seedling roots as influenced by bulk density, moisture content and strength of soil. Soil Science 96:153–156.

Taylor, H.M., and **Ratliff, L.F.** 1969. Root elongation rates of cotton and groundnut as a function of soil strength and soil water content. Soil Science 108:113–119.

Taylor, H.M., Robertson, G.M., and **Parker, J.J.** 1966. Soil strength, root penetration relations for medium- to coarse-textured soil material. Soil Science 102:18–22.

Thakur, H.C., and **Rai, B.** 1985. Cultivation of khesari in paddy fallows. Indian Farming 9:9–11.

Thakur, P. 1997. *Helicoverpa* management through IPM approach on chickpea. Presented at the Winter Crops Workshop, 8–10 Sep 1997, Khumaltar, Lalitpur, Nepal.

Venkataratnam, L. 1999. Use of remote sensing in distribution of environment and crop distribution. Pages 97–104 *in* GIS analysis of cropping systems: proceedings of an International Workshop on Harmonization of Databases for GIS Analysis of Cropping Systems in the Asia Region, 18–19 Aug 1997, ICRISAT-Patancheru, India (Pande, S., Johansen, C., Lauren, J., and Bantilan, F.T., Jr., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and Ithaca, New York, USA: Cornell University.

Vepraskas, M.J. 1988. Bulk density values diagnostic of restricted root growth in coarse-textured soils. Soil Science Society of American Journal 52:1117–1121.

Vepraskas, M.J. 1994. Plant response mechanisms to soil compaction. Pages 263–287 *in* Plant environment interactions (Wilkinson, R.E., ed.). New York, USA: Marcel Dekker Inc.

Yadav, D.S., Panwar, K.S., and **Singh, V.K.** 1997. Management of pulse crops in sequential cropping. Pages 475–487 *in* Recent advances in pulses research (Asthana, A.N., and Ali, Masood, eds.). Kanpur, India: Indian Society of Pulses Research and Development, Indian Institute of Pulses Research.

Yusuf Ali, M. 2000. Influence of phosphorus fertilizer and soil moisture regime on root system development, growth dynamics and yield of chickpea. Ph.D. thesis, Bangladeshi Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur, Bangladesh. 221 pp.

Zahid, M.A., Mann, R.A., and **Shah, Z.** 1998. Overview and prospects for enhancing residual benefits of legumes in rice and wheat cropping systems in Pakistan. Pages 190–206 *in* Residual effects of legumes in rice and wheat cropping systems of the Indo-Gangetic Plain (Kumar Rao, J.V.D.K., Johansen, C., and Rego, T.J., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and New Delhi 110 001, India: Oxford & IBH Publishing Co. Pvt. Ltd.

Zia, M.S., Rahmatullah, G.M.A., and **Aslam, M.** 1992. Fertilizer management in rice-wheat system. Progressive Farming 12:14–18.

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