Effects of Environmental Change on the Water Balance in Sri Lanka

Yuji MIYASHITA

1 9 9 7

Effects of Environmental Change on the Water Balance in Sri Lanka

Yuji MIYASHITA

A dissertation submitted to the Doctoral Program
in Geoscience, the University of Tsukuba
in partial fulfillment of the requirements for the
degree of Doctor of Philosophy (Science)

January, 1997

Acknowledgements

The author would like to thank Professor Dr. Kazuo Kotoda, Institute of Geoscience, University of Tsukuba, for his guidance and encouragement. The author is grateful to Associate Professor Dr. Tadashi Tanaka, Associate Professor Dr. Norio Tase, Associate Professor Dr. Jun Shimada, Institute of Geoscience, University of Tsukuba, for their suggestions.

The author is grateful to Professor Dr. Isamu Kayane, Aichi University, for his suggestions and discussions. The author is also grateful to Dr. Michiaki Sugita, Dr. Yuichi Suzuki, Institute of Geoscience, University of Tsukuba, Associate Professor Dr. Akihiko Kondoh, Chiba University, Dr. Maki Tsujimura, Aichi University of Education, Dr. Kunihide Miyaoka, Institute of Geoscience, University of Tsukuba.

In addition, thanks are also extended to Vice Chancellor, Dr. Madduma Bandara, C.M. and Mr. Vythiringam Nandakumar, Department of Geography, University of Peradeniya, Sri Lanka, for making available the facilities for data collection and field survey.

The author's special thanks should also go to Professor Dr. Kiyotaka Nakagawa, Division of Science, Joetsu University of Education, Professor Dr. Hisashi Edagawa, Department of Geography, Nara University and Professor Dr. Masatoshi Aoki, Tokyo University of Agriculture and Technology, for offering their collecting data on the longterm hydrometeorological data. In addition, special thanks also to Prof. Dr. Tetsuzo Yasunari and Dr. Tomohiko Tomita, Institute of Geoscience, University of Tsukuba, for their suggestions and offering their collected data of SST.

The author would like to thank Dr. Xianfang Song, Post Doctoral Fellowship of Science and Technology Agency, Mr. M.L.Ameer, University of Peradeniya, Sri Lanka, for their assistance in the field survey and data collection.

Abstract

In Sri Lanka, climatological and hydrological conditions have been observed over one hundred years and over forty years, respectively. The climatological phenomena have been observed at the fourteen meteorological offices since the late nineteenth century. The monthly precipitation has been measured also at many tea estates in and around the central highland. On the other hand, the monthly discharge height had measured at 148 stations in the 29 rivers.

From the comparisons of the water balance variations among the watersheds, the effects of environmental changes on the water balance were discussed. The environmental changes of Sri Lanka are characterized by the temporal and spatial variations of air temperature and precipitation as climatological elements and by the temporal and spatial variations of vegetation and land use elements.

The climatological changes in Sri Lanka are summarized as follows. The air temperature of almost all area of the island shows an increasing trend, and the lapse rate of Sri Lanka decreases about 0.038 °C/100m in the last 100 years. The decrease in the lapse rate of Sri Lanka means that the air temperature at the central highland area increases more than lowland area. The trend of precipitation decreases at almost all area excluding southwestern coastal area. In particular, the trend of precipitation at the central highland area and eastern coastal area in the semiarid region show a clear decrease in the southwest monsoon season and in the northeast monsoon season, respectively.

The result of the comparisons between the water balances classified the watersheds into the three groups that the trends of runoff ratio are increasing, decreasing and invariance. In particular, the watersheds classified into the group with the increasing trend of runoff ratio distributed mainly in the southwest inland area. Those watersheds show the converse trends as the decreasing trend of areal precipitation and the increasing trend of discharge.

The water balances of the watersheds classified into the group with invariable trend of runoff ratio show the variations caused by the areal precipitation changes. These watersheds of this group have two types of the response to the precipitation changes. The

variations of water balance of the watersheds belong to the former type show the decrease of evapotranspiration when the areal precipitation decreases. Many watersheds of this type distributed in the semiarid region. On the other hand, the watersheds of the other type indicate the decrease of discharge with the decrease of areal precipitation, and many watersheds distributed in the central highland area. The decreases of precipitation in the semiarid and humid regions occurred in the difference seasons. The precipitation in the semiarid region was decreased in the dry season. On the contrary, the precipitation in the humid region was decreased in the wet season. It is considered that the precipitation controls the amount of evapotranspiration in the dry season of semiarid region, because of the potential evapotranspiration in this period would exceed the precipitation. Therefore, the decrease of precipitation will affect directly the evapotranspiration. The result of water balance analysis demonstrates this effect in the semiarid regions. The water balance variations of the watersheds located in the semiarid region show the similar trends between the areal precipitation and evapotranspiration of watershed. On the other hand, it is considered that the decrease of precipitation in the wet season of humid region will give little effect on the amount of evapotranspiration and will decrease the discharge, because of the precipitation would exceed enough for the potential evapotranspiration. From the water balance variations of the watersheds located in the humid region, the effect on the discharge is confirmed.

In the watersheds that show the increasing and decreasing trends of runoff ratio, other factors will exceed the effect of climatological changes, and seems to affect the water balance in the local scale. The results of overlay analyses between the location of the watersheds with a rapid discharge change and the proportion of the land use by districts show that the areas of those watersheds indicate high proportions of distribution of the land use classified as "sparsely used cropland" and tea cultivation. This "sparsely used cropland" consists of shifting cultivation, abandoned tea, land under development and so on. It seems that these land use changes affect an amount of evapotranspiration, infiltration and storage capacity. The watersheds with increasing trend of discharge show the correlation between the regression coefficient of discharge trend and the changes of the tea cultivation area. Those results suggest the change of land use from tea cultivation makes increase of discharge amount.

Biographical Sketch

Yuji MIYASHITA was born on April 2, 1969 in Nagano prefecture, central highland of Japan. He graduated from the College of Natural Sciences, University of Tsukuba, Ibaraki, Japan in 1992 with a B.S. with the topic on the isotope hydrology in the highland. In March of 1994, he received a Master of Environ. Sciences from the Master program in Environmental Sciences at University of Tsukuba. The title of his master's thesis was "Hydrochemical evolution of groundwater in the tropical monsoon" in which the evolution of groundwater quality was investigated through field survey in Sri Lanka. Since 1994 he has studied the subject of the water balance and environmental change, and he wrote this doctor's thesis using the longterm hydrometeorological data in Sri Lanka.

Contents

List of Tables

List of Figures

Chapter I

Introduction

1.1 Previous study

One of issues that we are now confronted with is global climate change caused by the greenhouse gases. The global warming is defined as a climate change, on a global scale, caused by an enhanced greenhouse effect. The greenhouse gases include water vapour, carbon dioxide, tropospheric ozone, nitrous oxide and methane, which are transparent to short wave radiation but opaque to long wave radiation. In the greenhouse gases, the water vapour is the most importance gas. The atmospheric gases that contribute to the enhanced greenhouse effect include carbon dioxide, methane, nitrous oxide, ozone, halocarbons, and precursors of any of these gases. The concentration of atmospheric carbon dioxide variations has been measured since 1957 at Mauna Loa observatory, Hawaii. The annual average CO_2 concentration was increased 3.4% between 1956 and 1971 (Keeling *et al.*, 1976). He indicated the effects of increasing amounts of industrial CO_2 in the air on a global scale. Now the atmospheric CO_2 is observed continuously about fifty points in all the world (Nozaki, 1993).

The global warming shows the increase of global averaged surface temperature. However, the surface temperature also shows the decrease locally at the Northern Atlantic, for instance, between an average temperature of 30 years from 1931 and an average from 1961 (Hulme *et al.*, 1992). The change of precipitation also attests an involved regional difference. Therefore, the water balance of watershed influenced by the climate change on the regional scale has regional variation and various problems.

The Intergovernmental Panel on Climate Change (IPCC) was jointly established by two organizations of World Meteorological Organization (WMO) and Unite Nations Environment Programme (UNEP) in 1988. The Panel formed three Working Groups as follows:

Working Group I ; to assess the available scientific information on climate change,

Working Group II ; to assess the environmental and socio-economic impacts of climate change, and

Working Group III ; to formulate response strategies.

The Panel also established a Special Committee on the Participation of Developing Countries to promote the participation of those countries in its activities. The IPCC First Assessment Report was completed in August 1990 and the report consists of the IPCC Scientific Assessment (IPCC, 1990a), the IPCC Impacts Assessments (IPCC, 1990b), the IPCC Response Strategies, the Policymakers' Summary of the IPCC Special Committee and the IPCC Overview.

According to the IPCC Scientific Assessment Report, the main equilibrium changes in climate due to a doubling of carbon dioxide deduced from some models are followings. The number of asterisks indicates the degree of confidence determined subjectively from the amount of agreement between models, our understanding of the model results, and our confidence in the representation of the relevant process in the model. Five asterisks indicate virtual certainties, one asterisk indicates low confidence.

Temperature

***** the lower atmosphere and Earth's surface warm;

***** the stratosphere cools;

*** near the Earth's surface, the global average warming lies between +1.5°C and +4.5°C, with a "best guess" of 2.5°C (The IPCC (1992) Supplement favoured a lightly lower figure than 2.5°C);

*** the surface warming at high latitudes is greater than the global average in winter but smaller than in summer (in time- dependent simulations with a deep ocean, there is little warming over the high-latitude southern ocean);

*** the surface warming and its seasonal variation are least in tropics.

Precipitation

**** the global average increases (as does that of evaporation), the larger the warming, the larger the increase;

*** increases at high latitudes throughout the year;

*** increases globally by 3% to 15% (as does evaporation);

** increases at mid-latitudes in winter;

** the zonal mean value increases in the tropics although there are areas of decreases; shifts in the main tropical rain bands differ from model to model, so there is little consistency between models in simulated regional changes;

** changes little in subtropical areas.

Soil moisture

*** increases in high latitudes in winter;

** decreases over northern mid-latitude continents in summer.

Snow and sea ice

**** the area of sea ice and seasonal snow-cover diminish.

The report added that the results from models become less reliable at smaller scales, so predictions for smaller than continental regions should be treated with great caution.

The hydrological response on the climate change was reviewed by the Working Group II of the IPCC. This report classified the past researches into four groups that studied to clear the hydrological phenomena caused by the artificial climate change in the future:

1) The analytical method of long-term variance on the discharge and climate elements(e.g. Revelle and Waggoner, 1983; Schwarz, 1977; Glantz; 1988, Demaree and Nicolis, 1990; Karl and Riebsame, 1989).
2) The method to estimate the future amount of all evaporation based on the long-term water balance(e.g. Glantz and Wigley, 1987; Griffiths, 1989).
3) The method using the atmospheric General Circulation Model (GCM) (e.g. US EPA, 1984; Sanderson and Wong, 1987; Singh, 1987).
4) The method to estimate the change of hydrological condition of watershed using the deterministic water balance model with climatological data including the result of GCM(e.g. Nemec and Schaake, 1982; Gleick, 1986, 1987; Mather and Feddema, 1986; Cohen, 1986; Flaschka *et al.*, 1987; Bultot *et al.*, 1988)

This report indicates that we need careful treatment of the results of methods 1 and 2 by reason that the method was extrapolated from the past correlation to the future. In the case of using atmospheric GCM methods, the results of hydrological simulation based on several GCMs had no conformable regions. The report adduced low resolution and simplistic hydrological process on the models for this reasons. This report also indicates that the method using the deterministic water balance model can simulate the change of discharge, when the regional climate change was estimated. These are useful for water resources management. This report shows one of conclusions that even though it will be comparatively little climate change, it will cause the serious problems for water resources at many regions. And this report shows that the study of hydrometeorological change caused by an enhanced greenhouse effect will be needed more regions, because we have little information on these.

In the tropics, besides climate changes like global warming, the large-scale change of vegetation caused by deforestation of tropical rain forest changes a regional hydrological cycle and environments. The studies of the hydrology and effects of conversion on the moist tropical forests were reviewed by Bruijnzeel (1990). The more specific reviews can be summarized as follows:

1) The hydrological cycle in moist tropical forests

2) Nutrient budgets

3) Hydrological impact of forestation or deforestation

4) Hydrochemical and soil chemical responses to forestation or deforestation

The method to estimate the evapotranspiration as a part of hydrological cycle was reviewed by Shuttleworth (1979) and Stewart (1984). A general distinction can be made between water balance methods and micrometeorological techniques. The majority of published estimates for evapotranspiration in moist tropical forests has been made by water balance method. On the other hand, this water balance method indicated some problems that the catchment study is unable to provide short-term estimates of evapotranspiration such as for periods less than a week or information on the relative importance of the various components of evapotranspiration. And, areal precipitation estimated from relatively little observation points are unreliable for larger tropical watersheds, especially forested ones.

Bruijnzeel (1990) summarised about 20 locations data with respect to the effect of land cover transformation on water yield in the humid tropics. There are including a few examples located on the seasonal subtropical forests. He indicated that the technique so-called "paired catchment method" is effective way to clear the hydrological impact of the deforestation. This method is to compare the hydrological variations on the two or more catchments of similar size, geology, slopes, exposure, vegetation and others. These watersheds situated close to one another. The vegetation of a "control basin" was left unchanged, and the vegetation or land use of "experimental basin" was changed.

In his summarises, the paired catchment method was adopted at eleven locations, the site or catchment water balance method was at eight locations and another one location had Penman-Monteith method. He indicates that the relatively small catchments show the clear relationship between the increase of water yield and a replacement of tall vegetation by a shorter one and vice versa. However, the effects of conversion may be more difficult to discern in the case of larger watersheds with a variety land use and vegetation in various stages of regeneration.

Many water balance studies on moist tropical forested catchments were reviewed by Kuraji, K.(1996), where he classed the study of water balance five categories as follows :

1) Study to elucidate the individual water balance from observations of the water balance elements such as precipitation of watershed, discharge and variation of storage (e.g. Doley, 1981; Oyebande, 1988; Bruijnzeel, 1988, 1989, 1990)
2) Study to calculate the amount of evapotranspiration from observations of precipitation, amount of crown interception, variation of soil moisture and others at the flatland without discharge.
3) Study to determine the point evapotranspiration from micro-meteorological model with long-term micro-meteorological elements and crown interception observation data, parameterized by the short-term direct measurement of variation of soil moisture and turbulent flux(e.g. Calder, *et al.*, 1986; Shuttleworth, 1988)

4) Study to discuss the large-areal water balance from land surface evapotranspiration presumed potential evapotranspiration (Climatological water balance method) (e.g. Yoshino, 1984).

5) Study to presume the amount of discharge and variation of storage in the large area from atmospheric water balance based on the four Dimensional Data Assimilation (4DDA) (Atmospheric water balance method) (e.g. Matsuyama, 1992; Matsuyama *et al.*, 1994)

Kuraji (1996) reviewed studies of 33 watersheds, 17 countries about category 1, and considered the relationship between annual evapotranspiration and regional group, elevation of watershed and vegetation. As a result of his review, it was clear that an effect of dry season gives more important factor on evapotranspiration of watershed than elevation of catchment. This review showed from comparison with water balance of deforested watersheds that the deforestation of tropical forest decreased the evapotranspiration. That amount of decrease was equivalent to the evapotranspiration that a few month dry season repress.

He also indicates the one of problems of these studies that the hydrological measurements was observed only one hydrological year in a number of studies. In the 33 watersheds of his review, the watershed with longest observation was Watawala watershed in Sri Lanka with 21 hydrological years observation (Madduma Bandara and Kuruppuarachchi, 1988), and averaged period of observation was 9.5 years. In the tropics, especially Sri Lanka has data of long-term hydroclimatological observation. The climatological and hydrological observation have been carried out since the mid-nineteenth century and 1920, respectively. In particular, the precipitation was observed at many tea estates in the central highland. Nakagawa *et al.* (1995) collected and published the database of those long-term hydroclimatological observations in Sri Lanka.

Johnson and Scrivenor (1981) generalised the regional geography of Sri Lanka. They cleared that the differences of the agricultural types depend on the climatological and hydrological environments. They minutely analyzed the economical geography on the tea production that is one of the major production in Sri Lanka.

One of the primary surveys on the natural geography in Sri Lanka had been carried out by Farmar (1952,1954). He described the agriculture, land and water use and cleared those problems in the seasonal dry area in the Sri Lanka. Domrös (1978,1979,1981,1984) also determined the agricultural land use in the whole island in particular the relationship with monsoon.

Kayane and Nakagawa (1983) studied the water balance of Sri Lanka. They illustrated the evapotranspiration of Sri Lanka by the analyses of water balance of 70 watersheds in Sri Lanka, and made a comparative study of evapotranspiration with potential evapotranspiration calculated by Penman method. Nakagawa *et al.* (1983) also compared the heat balance between seasonal dry area and wet area in Sri Lanka from micrometeorological observations.

Kayane *et al.* (1983) continuously observed longer than one year the water quality of grand water and tank water and those water levels in the small drainage basin with 16 small village tanks in a shallow valley system located in the seasonal dry area in Sri Lanka. They determined the seasonal variations of the electrical conductivity with groundwater level variations. As the results of those observations, they indicated the effects of infiltration water with salinization or dilution on the groundwater quality.

One of the study of the seasonal change of groundwater and its hydrochemical evolution was carried out by Miyashita (1994). He analyzed the groundwater and rainfall water quality from the wet to dry season. In this study he discussed the seasonal recharge systems that rainfall water will infiltrate only wet season from the comparisons of water quality variations between the stable isotopes and dissolved matters of groundwater. Song (1996) compared the water cycle and groundwater quality among six small catchment areas in the individual climatological zones. He cleared the spatial and temporal variations of groundwater quality, and discussed the effects on the water quality.

Madduma Bandara and Kuruppuarachchi (1988) determined the discharge variations from the Peradeniya watershed located in the upper Mahaweli Ganga river, Sri Lanka. The Peradeniya watershed that the area is 1108km^2 indicated increasing trend of discharge for the wet months of July, August and September since the 1940's. However, the discharge for the dry months of January, February and March decreased slightly. They also indicated that the trend of annual precipitation at Nuwara Eliya, central highland of Sri Lanka decreased in the last one hundred years. They calculated the land use change on the upper Mahaweli Ganga river catchment area between 1956 and 1981. In this period, tea cultivation and forest area decreased from 61% to 39% and from 17% to 15%, respectively. On the other hand, the homesteads and croplands increased from 7% to 17% and from 7% to 15%, respectively. As the results of those, they determined the effect of deforestation in the large watershed.

The climate change around Sri Lanka was reported by Kayane *et al.* (1995). They indicated that the precipitation in the southwest monsoon season decreased in the central highland of Sri Lanka since 1870's. In particular, the trends of precipitation were in inverse between the southwest coastal sites and central highland site. They discussed the effects of the global warming to the hydrological phenomena, that the increase of sea surface temperature over the Indian Ocean will intensify the Indian monsoon circulation, and the intensified monsoon increases the coastal windward rainfall in Sri Lanka and decreases the mountainous and leeward rainfall.

The Natural Resources, Energy and Science Authority of Sri Lanka (1991) reported the land use change in the whole island between 1956 and 1984. The land use of forest and tea cultivation were decrease about 26% and 14% , respectively. Perera *et al.* (1992) also determined the land use change at central south Sri Lanka using satellite images from 1977 until 1987. The land use of the area that is 1278km^2, the elevation changes from 80 to 1500m changed about 16% decrease in evergreen forests and 39% increase in scrublands.

1.2 Objectives of this study

The present study will deal with the determination of long-term water balance of Sri Lanka and the effect of environmental changes on the water balance. The more specific objectives of this study can be summarized as follows :

1) To describe the spatial and temporal variation of individual elements of water balance

2) To make clear the regional characteristics of water balance

3) To investigate the relationship between water balance and the environmental change such as climate change and land use change.

Chapter 2

Descriptions of study area

Sri Lanka (Democratic Socialist Republic of Sri Lanka) is located in the southeast of the subcontinent of India between the latitude of 5°55' N - 9°51' N, the longitude of 79°42' E - 81°53' E (Fig.1). This country has a maximum length of 432 km in the direction of north-south, a maximum width of 224 km of east-west, an area of 65,525km^2 and the length of the shoreline of about 1,600km. Sri Lanka also had a population of 16.99 million in 1990. The population was about 6.6 times from 1891. The average population density was 0.023 people per square kilometer in 1981.

2.1. Topography

Sri Lanka has the central highland situated in the south-center where many mountains over 2,000m such as Mt. Pidurutalagala (7°00'N/80°46.3'E) of 2,524m above the sea level, the highest peak in Sri Lanka, are located. The north and periphery of the central highland are low and flat plain (Fig.2). Sri Lanka could be divided into five topographical regions as follows (Fig.3):

1. The central highland

This region could be subdivided into following three units.

1.1. The central massif proper.

This unit consists of all the mountains of higher then 2,000m and some plateaus such as the Horton plain national park and the Uva basin famed as the Uva tea.

1.2. The Dumbara massif

This unit located at the northeastern central massif proper.

1.3. The Bulutota massif

This unit situated at the southwestern central massif proper.

2. The south-west country

This region has a characteristic topography of elongated parallel ridges cut by the rivers beginning of the central massif. The pattern of stream networks shows the trellis patterns and so the system of drainage is called rectangular.

3. The east and south-east country

This is a undulating plains dotted with isolated hills.

4. The northern lowland

This region has a similar characteristic topography to the East and South-east country.

5. The Coastal fringe

This region consists of a series of lagoons, marshes, sandbars, spits, peninsulas, dunes, and others.

2.2. Geology

The island of Sri Lanka, like the Indian peninsula and Antarctica, formed part of Gondwana land in the distant geological past. Sri Lanka was never fully submerged by the sea. The only major submergence was in Tertiary times when Miocene sediments were laid down in the northwestern belt of the island, including the Jaffna peninsula. As a result, about nine tenths of the area of the island is not covered by any sedimentary rocks. Figure 4 shows the geological map of Sri Lanka. The Precambrian rocks consist predominantly of a sedimentary succession of a variety of rocks now converted under intense metamorphic condition into a succession of well-banded gneisses, granulites, quartzites and crystalline limestone. The Miocene formations cover large areas in the northwest and in the Jaffna peninsula. They are important aquifers used extensively in the north for irrigation. The Pleistocene consists of two formations: an upper red earth formation and a lower gravel deposit. Those deposits lie in coastal area.

2.3. Climate

There is a marked contrast in climate due to the central highland being surrounded by an extensive lowland area. The regional differences in temperature are due to altitude, because there is no temperature variation due to latitude. Mean annual temperature in the lowlands is around 27°C, with a daily range of about 6°C, ground frost can sometimes appear in Nuwara Eliya in the central highlands, where the mean annual temperature is 16°C. In most part of the country, daily temperature ranges are more significant than the seasonal changes.

The average annual precipitation in Sri Lanka varies from 900mm to 6,000mm(Fig.5). The higher values are experienced on the western slopes of the central highland. The lower values are on the northwestern and southeastern lowlands. According to the spatial and regional distributions of precipitation, Sri Lanka has been divided mainly into three zones, the Wet Zone, the Dry Zone and the Intermediate Zone.

The climate of island is influenced by two wind regimes caused by the movement of intertropical convergence zone (ITCZ). The southwest monsoon season is from May to September and the northeast monsoon season from December to February. The monsoonal precipitation is mainly orographic. The precipitation during the two intermonsoonal periods, the First Intermonsoon season between March and April and the Second Intermonsoon season between October and November is mainly convectional.

Figures 6 and 7 show a seasonal variation of average temperature and precipitation between 1961 and 1990 at Colombo, Galle, Kandy, Nuwara Eliya, Puttalam, Trincomalee and Jaffna. Among these cities, Colombo, Galle, Kandy and Nuwara Eliya are under the Wet Zone. The other cities, Puttalam, Trincomalee and Jaffna are in the Dry Zone. The cities located in the Dry Zone show higher temperature than the other cities located in the Wet Zone in the southwest monsoon season. As shown in Fig.7, the Dry Zone has a little precipitation.

2.4. Vegetation and land use

Sri Lanka is endowed with lands that can be highly productive so long as they have adequate water. Over two-thirds of land area are flat or undulating with gentle slopes. About one-third of Sri Lanka is agricultural use. Forests and wildlife use is other one-third, and the rest is under transportation, human settlements, and a variety of other uses.

Most gently sloping lands are within the agriculturally rich areas of the Dry Zone, but agriculture is also important in the central highland. Plantation agriculture has flourished from the beginning of the colonial period.

The natural vegetation of Sri Lanka covers an area of 23,750 km^2 or 36.5 percent of the land area of this country. This includes natural plant communities, both high forest and open forest. The present land uses of major crops were paddy, tea, rubber and coconut. Those areas at 1982 were 4,995.2 km^2 of paddy, 2,071.4 km^2 of tea, 1,711.5 km^2 of rubber and 4,162.5 km^2 of coconut. Figure 8 shows distributions of paddy at 1986 and tea cultivation at 1983.

2.5. Surface water and water use

Sri Lanka has a radial network of rivers that begin in the central highlands. Some 103 river basins cover 59,217 km^2. Most identifiable stream basins are less than 100 km^2 and carry water only during the rainy season. Figures 9 and 10 and Table 1 show the stream networks, divide of watersheds and list of watersheds of Sri Lanka, respectively. The watersheds are numbered anti-clockwise in the map starting with the Kelani Ganga. The largest watershed of Sri Lanka is the Mahaweli Ganga, covered about 16% (10,327 km^2) of the island's land area. It also carries the largest volume of discharge amount. Eighty watersheds numbered from 19 to 98 in the map account for the surface water supply of the Dry Zone. Four watersheds ranking after the Mahaweli belong to the size category of over 2,500 km^2. Eight others follow in the category 1,250-2,500 km^2. The median size of the Sri Lankan watershed is 164 km^2.

Use and development of water resources have been an integral part of Sri Lanka's heritage. About 12,000 small tanks now irrigate some 2,690 km^2 mainly in the Dry Zone. Figure 11 shows a schematic diagram of inter-connected Tank irrigation system. In order to supplement the water for seasonal crop in lowland areas of Dry Zone, this tank system was developed by the ancients through their empirical observations of the landscape and topography.

Large-scale development of water resources for irrigation and hydropower progressed rapidly during the last fifty years. One of the large-scale new irrigation systems was started at Pollgola down stream from Peradeniya station from 1976 by the Mahaweli Development Project.

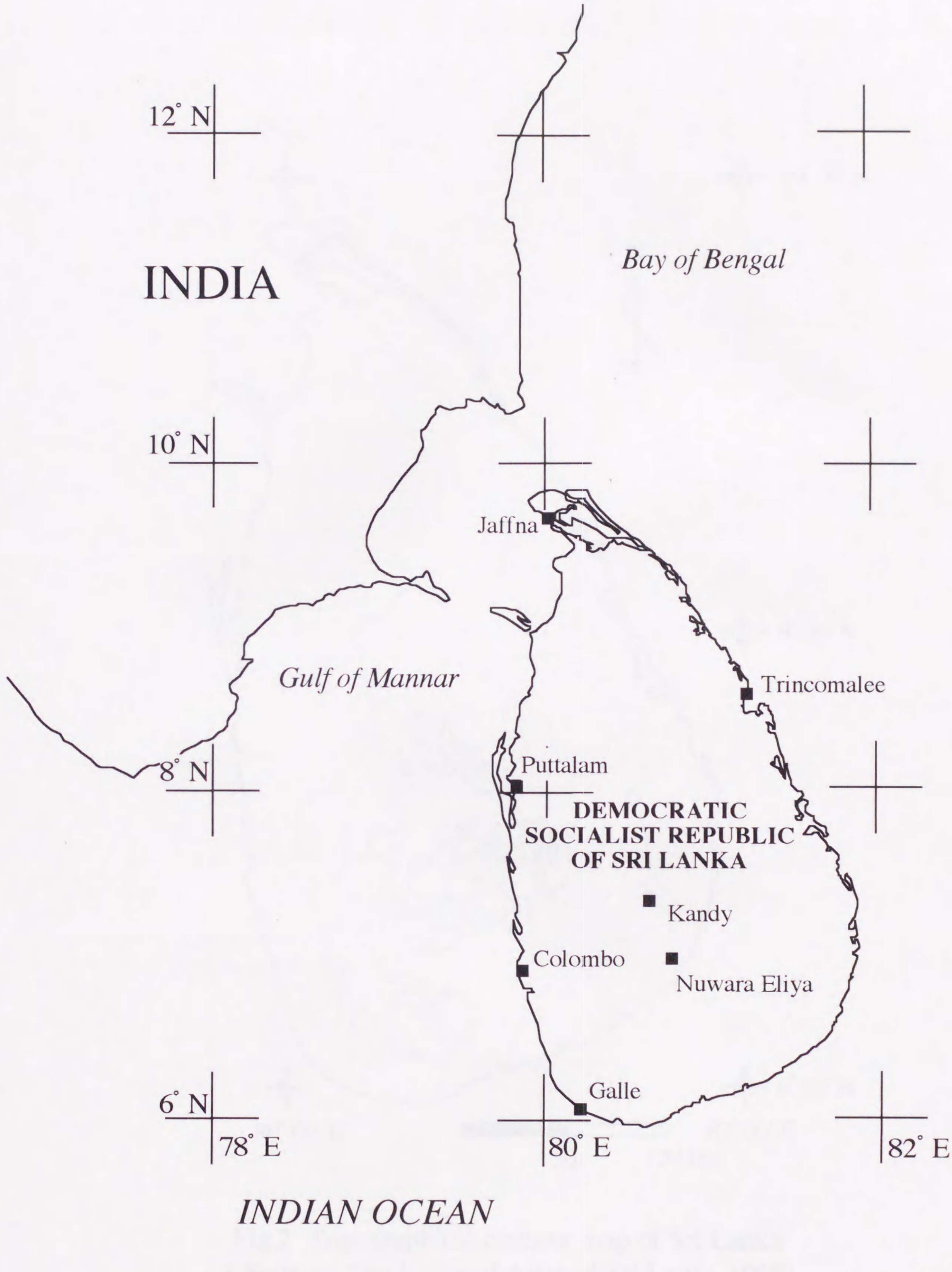


Fig. 1 Location of study area

Fig.2 Topographical contour map of Sri Lanka
(Source : The National Atlas of Sri Lanla. 1988)

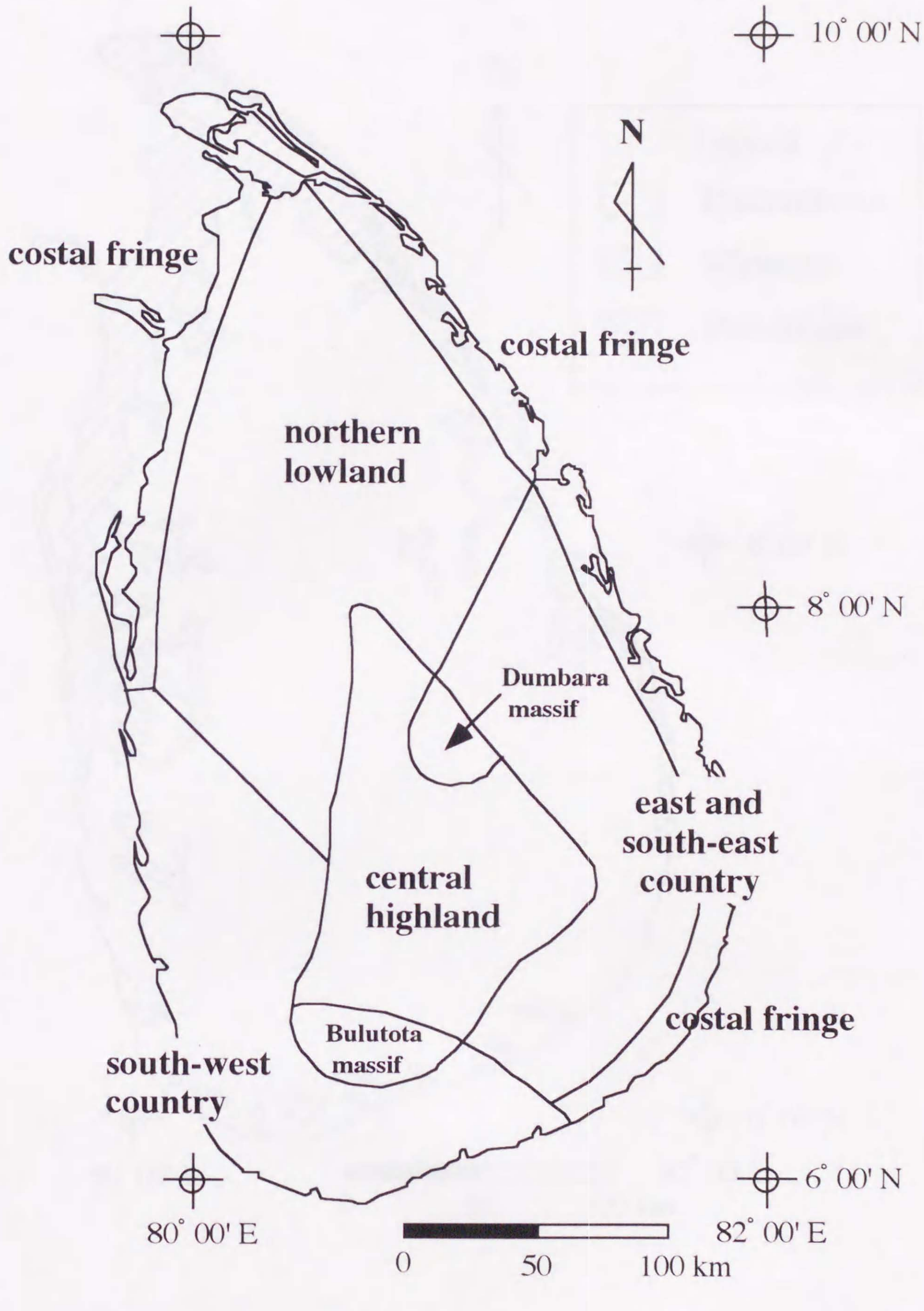


Fig.3 Distribution of topographical region of Sri Lanka
(Source : The National Atlas of Sri Lanka, 1988)

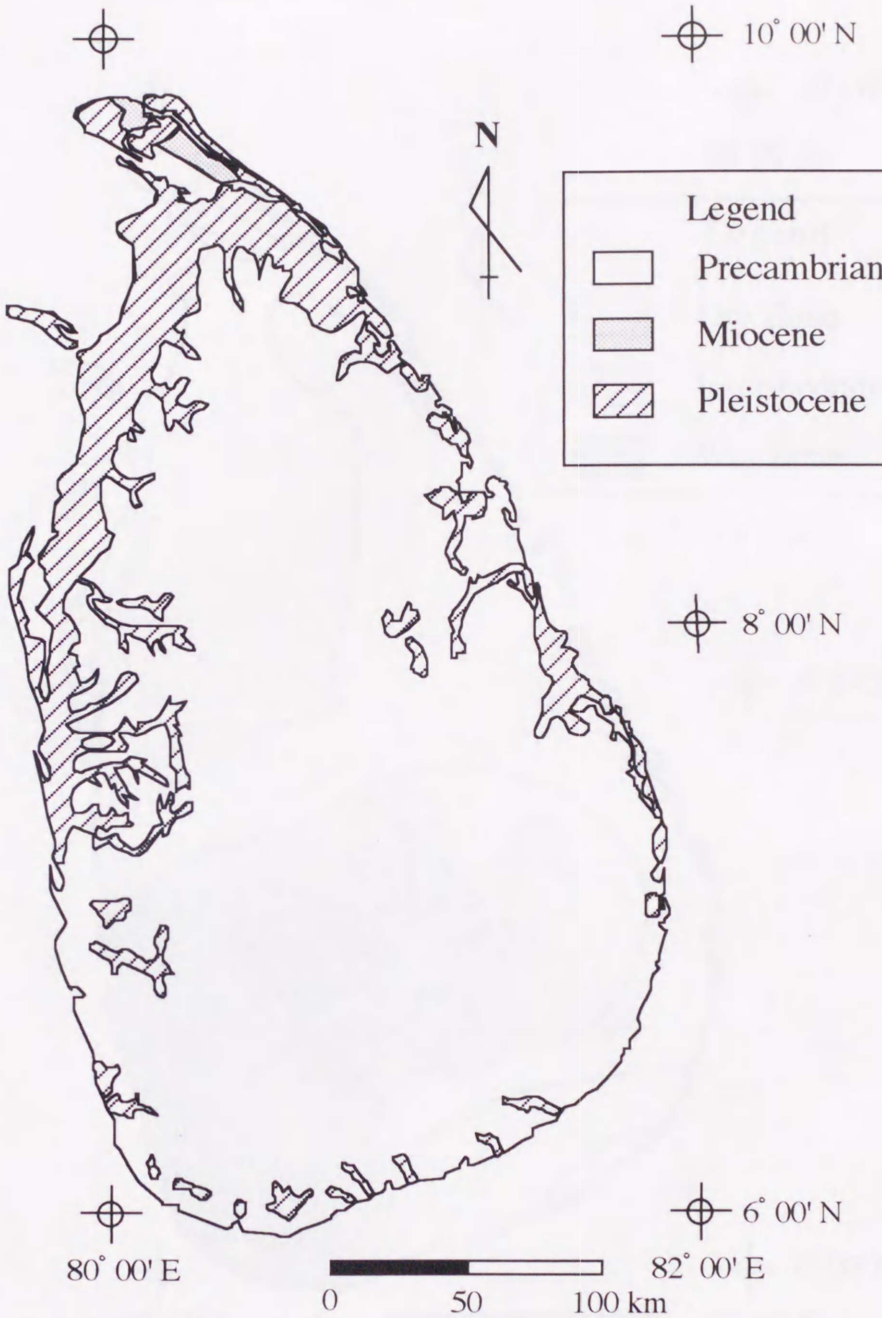


Fig.4 Geology of Sri Lanka
(Source : The National Atlas of Sri Lanka, 1988)

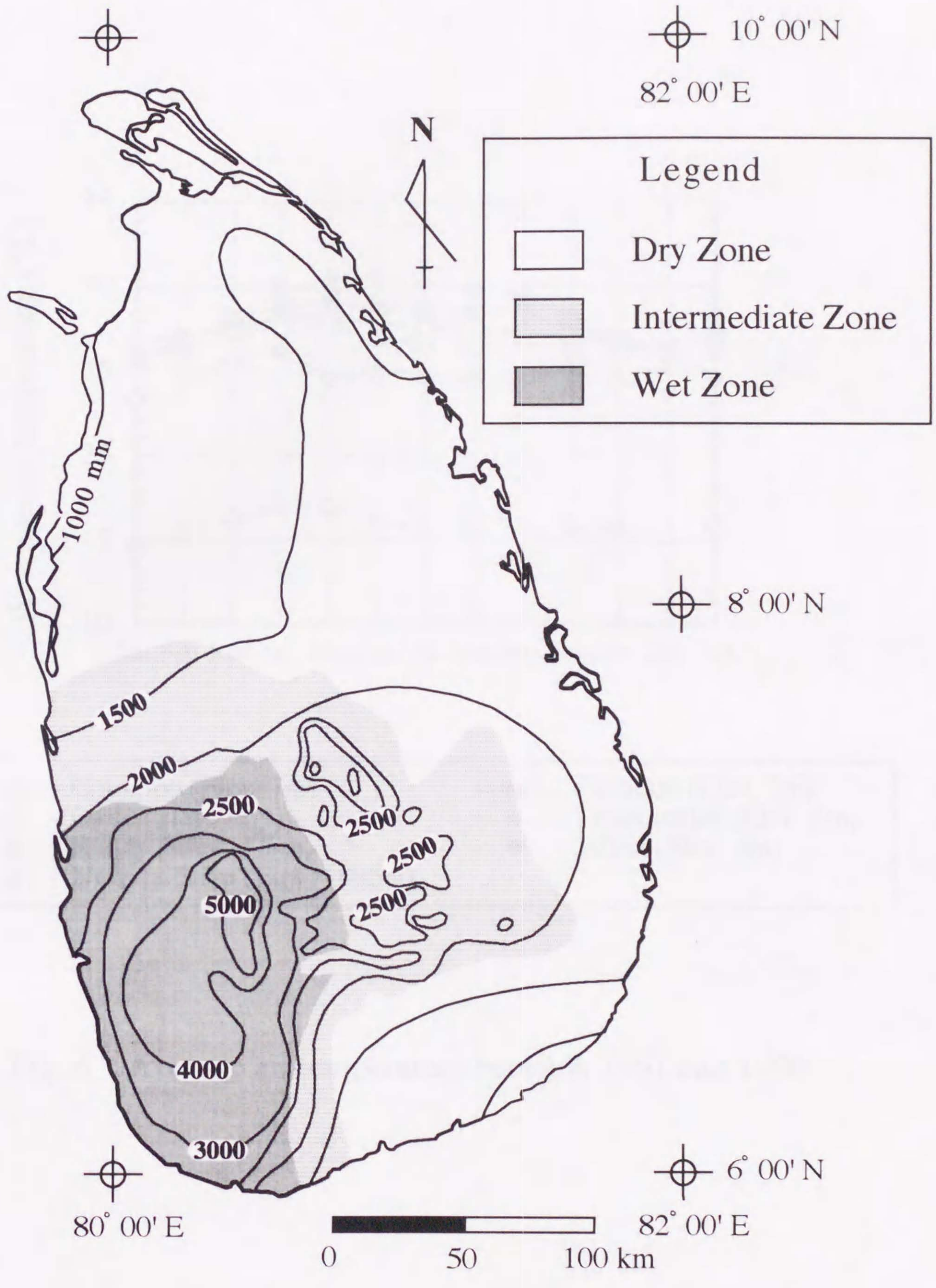


Fig. 5 Isohyet map of mean annual precipitation and climatological zone of Sri Lanka (Source : The National Atlas of Sri Lanka, 1988)

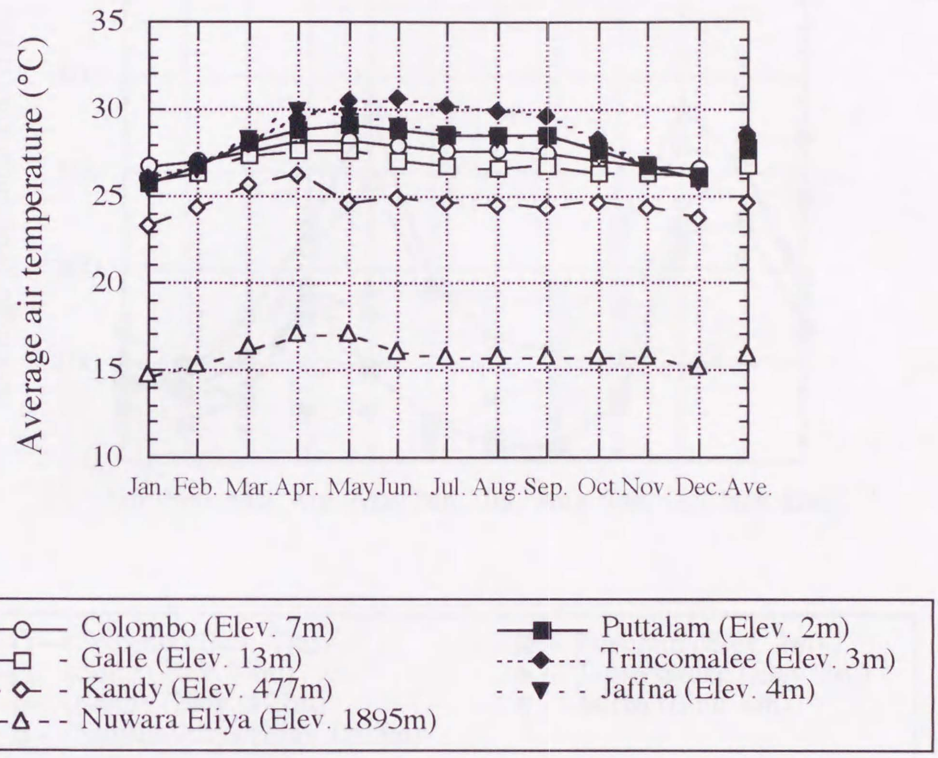


Fig. 6 Average air temperature between 1961 and 1990

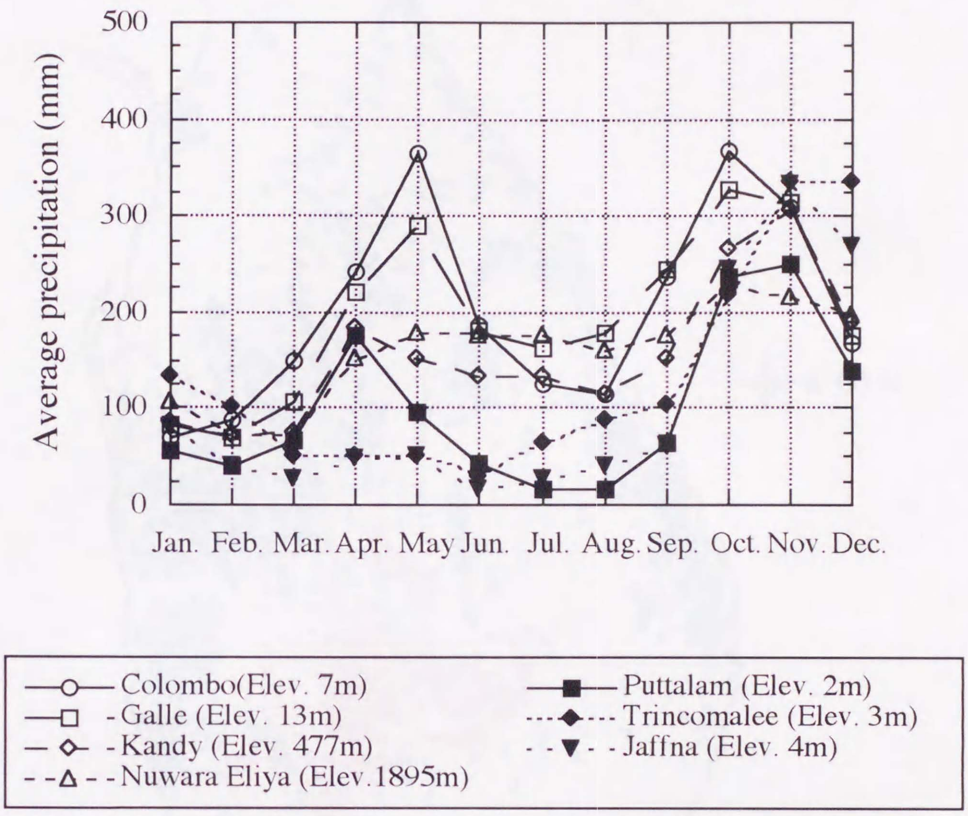


Fig. 7 Average precipitation between 1961 and 1990

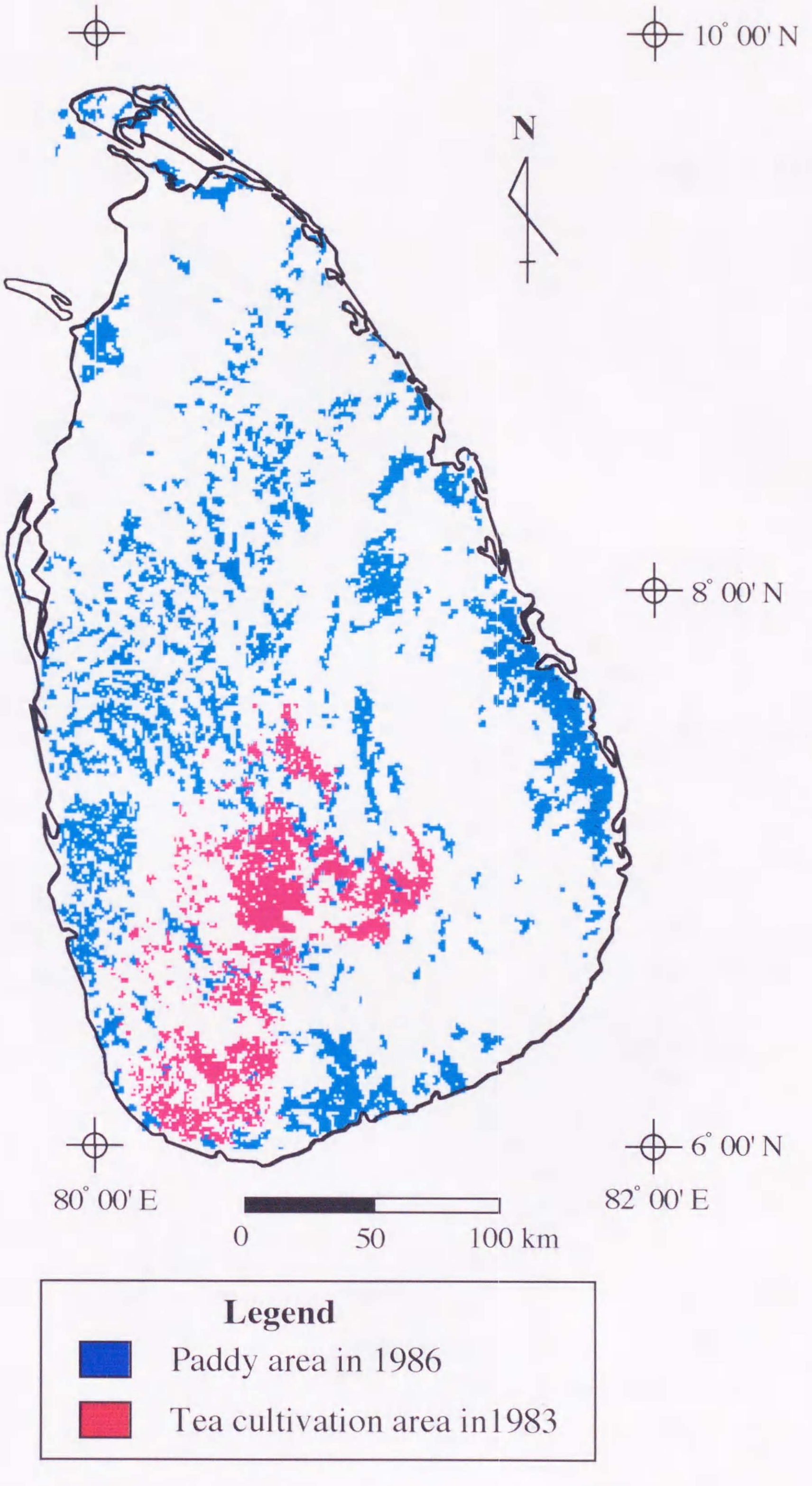


Fig. 8 Distribution map of paddy area in 1986
and tea cultivation area in 1983 of Sri Lanka

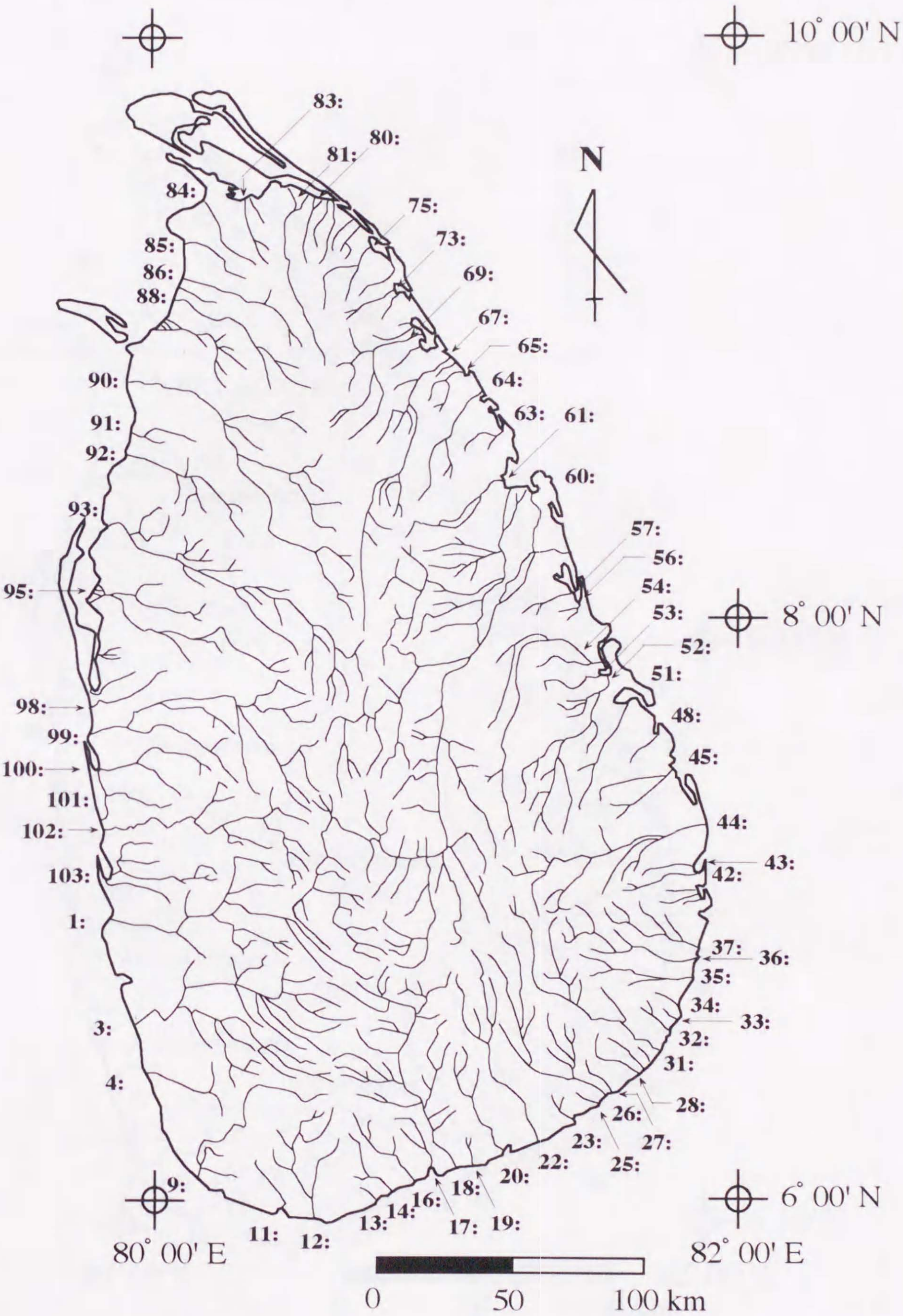


Fig.9 Stream networks of Sri Lanka

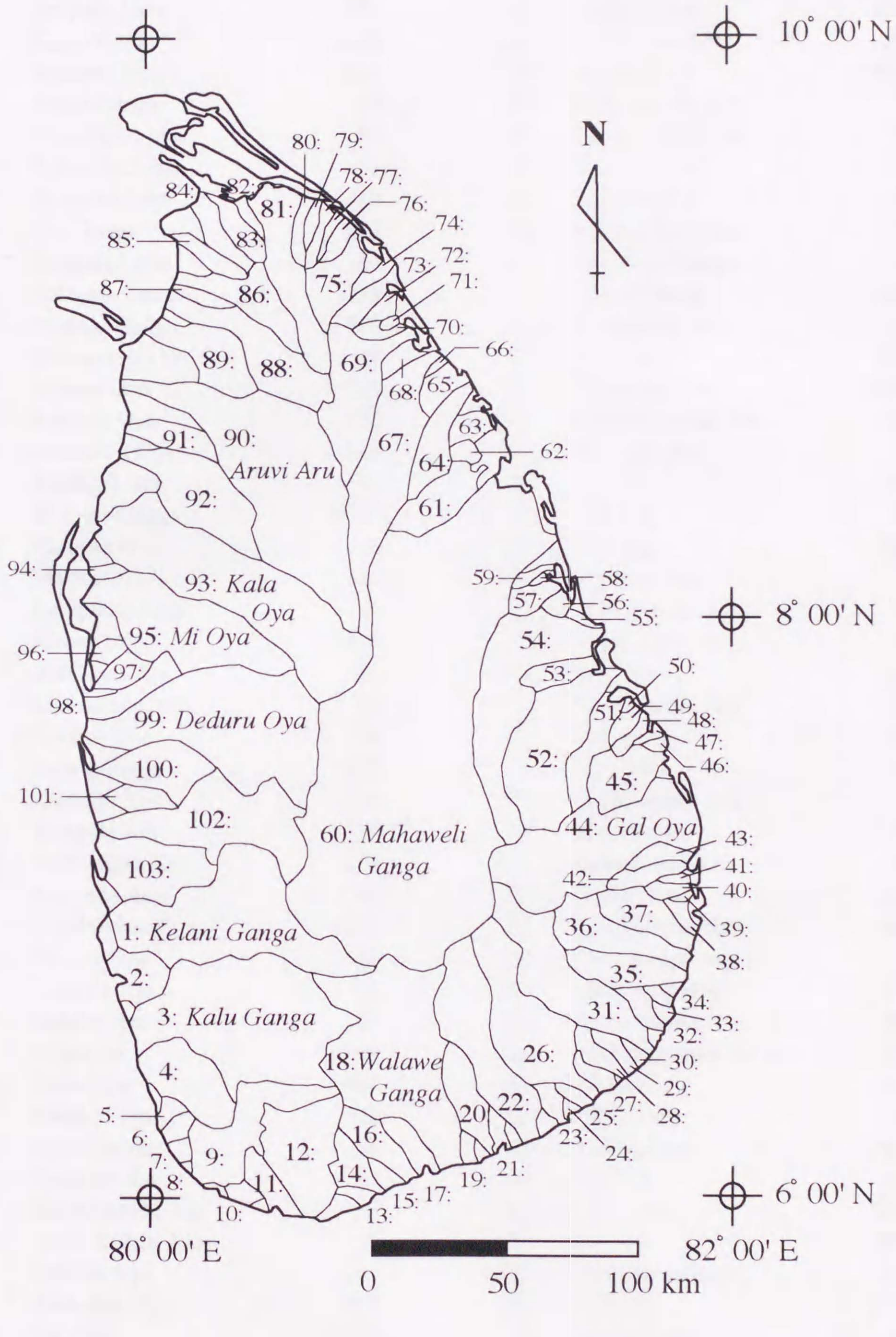


Fig.10 Distribution map of 103 watersheds of Sri Lanka

Table 1 List of watersheds of Sri Lanka

Basin No.	Name of basin	Catchment area (km^2)
1	Kelani Ganga	2278
2	Bolgoda Lake	374
3	Kalu Ganga	2688
4	Bentota Ganga	622
5	Madu Ganga	59
6	Madampe Lake	90
7	Telwatta Ganga	51
8	Ratgama Lake	10
9	Gin Ganga	922
10	Koggala Lake	64
11	Polwatta Ganga	233
12	Nilwala Ganga	960
13	Sinimodera Oya	38
14	Kirama Oya	223
15	Rekawa Oya	755
16	Urubokka Oya	348
17	Kachigal Ara	220
18	Walawe Ganga	2442
19	Karagan Oya	58
20	Malala Oya	399
21	Embilikala Oya	59
22	Kirindi Oya	1165
23	Bambawe Ara	79
24	Mahasilawa Oya	13
25	Butawa Oya	38
26	Menik Ganga	1272
27	Katupila Ara	86
28	Kurunde Ara	131
29	Namadagas Ara	108
30	Karambe Ara	46
31	Kumbukkan Oya	1218
32	Bagura Oya	92
33	Girikula Ara	15
34	Helawe Ara	51
35	Wila Oya	484
36	Heda Oya	604
37	Karanda Oya	422
38	Saymena Aar	51
39	Tandiadi Aar	22
40	Kangikadichi Aar	56
41	Rufus Kulam Aru	35
42	Pannela Oya	184
43	Ambalam Oya	115
44	Gal Oya	1792
45	Andella Oya	522
46	Thumpankeni Tank	9
47	Namadaka Aru	12
48	Mandipattu Aru	100
49	Pathanthe Aru	100
50	Vett Aru	26

Basin No.	Name of basin	Catchment area (km^2)
51	Magalavatavan Aru	346
52	Mundeni Aru	1280
53	Miyangolle Ela	225
54	Maduru Oya	1541
55	Pulliyanpota Aru	52
56	Kirimechchi Odai	77
57	Bodigoda Aru	164
58	Mandan Aru	13
59	Makarachchi Aru	37
60	Mahaweli Ganga	10327
61	Kantale basin	445
62	Palampotta Ara	69
63	Pan Oya	143
64	Pankulam Aru	382
65	Kunchikumban Aru	205
66	Pulakutti Aru	20
67	Yan Oya	1520
68	Mee Oya	90
69	Ma Oya	1024
70	Churiyan Aru	74
71	Chavar Aru	31
72	Paladi Aru	61
73	Nay Aru	187
74	Kodalikkallu Aru	74
75	Per Aru	374
76	Pali Aru	84
77	Maruthapilly Aru	41
78	Toravil Aru	90
79	Piramenthal Aru	82
80	Netheli Aru	120
81	Kanakarayan Aru	896
82	Kalavalappu Aru	56
83	Akkarayan Aru	192
84	Mandekal Aru	297
85	Pallavarayankaddu Aru	159
86	Pali aru	451
87	Chippi Aru	66
88	Parangi Aru	832
89	Nay Aru	560
90	Aruvi Aru	3246
91	Kal Aru	210
92	Modaragam Aru	932
93	Kala Oya	2772
94	Moongil Ara	44
95	Mi Oya	1516
96	Madurankuli Aru	62
97	Kalagamu Oya	151
98	Rathambala Oya	215
99	Deduru Oya	2616
100	Karambalan Oya	589
101	Ratmal Oya	215
102	Maha Oya	1510
103	Attanagalu Oya	727

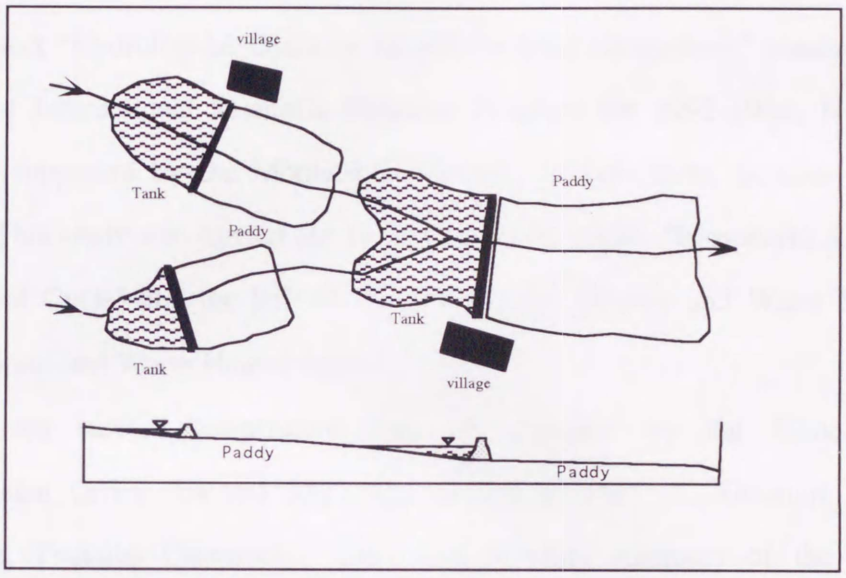


Fig. 11 Schematic diagram of inter-connected Tank irrigation system

Chapter 3

Data Sources

The data of hydroclimatological observation of Sri Lanka in this study were employed from the databook of "Longterm Hydrometeorological Data in Sri Lanka" edited by Nakagawa *et al.* (1995). The databook is the first part of a two-part data book, based on the project "Hydrological Cycle in Humid Tropical Ecosystems" conducted as Field Research of International Scientific Research Program for 1992-1994, No.04041023, financially supported by the Monbusho (Ministry of Education, Science, Sports and Culture). This study was carried out in relation to the IGBP, "Biospheric Aspects of the Hydrological Cycle" and the IHP-IV Project, "Water Balance and Water Resources in Humid Tropics and Warm Humid Areas."

The sea surface temperature data set compiled by the United Kingdom Meteorological Office (UKMO SST) was offered by Prof. T. Yasunari, Institute of Geoscience, Tsukuba University. This is a monthly summary of the sea surface temperature reported by ships for every 5° × 5° ocean square around the island of Sri Lanka.

The monthly surface air temperature and monthly precipitation data were collected from the original manuscripts of the Department of Meteorology in Colombo in principle. However, the data of main meteorological stations during the period form the beginning of observation to 1980 were already collected and published by Yoshino and Suppiah (1982). Precipitation data were also quoted from the Masterplan for Electricity Supply of Sri Lanka (1987), which is a study carried out on behalf of the German Agency for Technical Cooperation by a joint-venture consortium of Lahmeyer International-decon, Consulting Engineers from Frankfurt, FR Germany, in collaboration with the Ceylon Electricity Board, the Central Engineering Consultancy Bureau and other Sri Lankan Government Institutions. All the stations for surface air temperature and precipitation are not only listed in Tables 2 and 3, but are also plotted in Figs.12 and 13, respectively.

The monthly discharge data were extracted from the Hydrological Annual Report published by the Hydrology Division, Irrigation Department, Ministry of Lands, Irrigation & Mahaweli Development and the Masterplan for Electricity Supply of Sri Lanka (1987). The stations for discharge are listed in Table 4, and the locations are plotted in Fig.14. The station number in Table 4 based on the hydrometric station cording system established for the Masterplan data base. These consist simply of a normal four or five figures cord as follows:

No.b b s s   or   No.b b b s s   (3.1.)

where b b or b b b are river basin number from 01 to 103, s s is chronological sequence number in the watersheds. In Fig.14, each plot is marked only the chronological sequence number of the cording system.

For the land use analyses of this study, land use maps listed in the Table 5 were used.

Table 2 List of stations for air temperature

No.	Station mane	Lat.(N) °	'	"	Long.(E) °	'	"	Elev. (m)	Period
3	Jaffna	9	39		80	1		4	1869 - 1984
15	Mannar	8	59		79	55		4	1870 - 1990
23	Trincomalee	8	35		81	15		3	1869 - 1993
32	Anuradhapura	8	21		80	23		93	1870 - 1993
49	Puttalam	8	2		79	50		2	1869 - 1993
70	Batticaloa	7	43		81	42		3	1869 - 1993
86	Kurunegala	7	28		80	22		116	1885 - 1993
104	Kandy	7	20		80	38		477	1870 - 1992
167	Badulla	6	59		81	3		670	1869 - 1993
171	Nuwara Eliya	6	58		80	46		1895	1869 - 1993
186	Colombo	6	54	0	79	52	47	7	1869 - 1993
223	Ratnapura	6	41		80	24		34	1869 - 1993
272	Hambantota	6	7		81	8		16	1869 - 1993
275	Galle	6	2		80	13		13	1869 - 1993

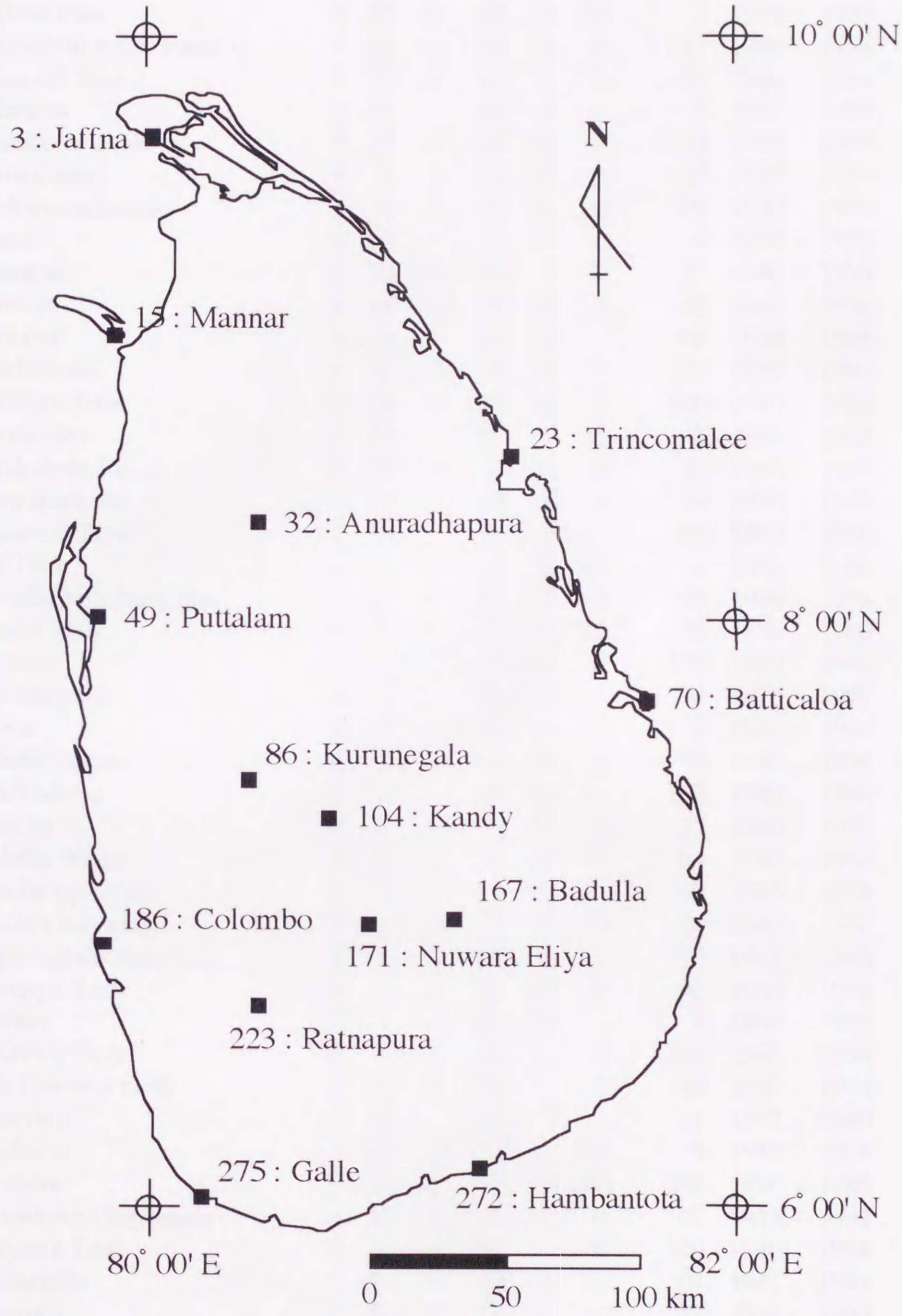


Fig.12 Location of air temperature observation

Table 3 List of stations for precipitation

No.	Station mane	Lat.(N) °	'	"	Long.(E) °	'	"	Elev. (m)	Period
2	Kankesanturai	9	48		80	4		15	1950 - 1990
3	Jaffna	9	39		80	1		4	1871 - 1990
4	Elephant Pass	9	30	10	80	24	25	3	1922 - 1980
7	Killinochchi-cattle Farm	9	24	0	80	28	0	11	1946 - 1994
8	Iranamadu Tank	9	21	0	80	24	0	30	1940 - 1994
9	Mullaitivu	9	16		80	51		2	1871 - 1990
11	Kannukkeni Tank	9	12	0	80	48	0	14	1940 - 1994
13	Vavunikulam	9	6	0	80	20	0	35	1957 - 1994
14	Kanakarayankulam	9	3	0	80	31	0	59	1940 - 1994
15	Mannar	8	59		79	55		4	1870 - 1990
18	Murunkan	8	50	0	80	3	0	17	1940 - 1994
19	Padawiya	8	49	0	80	45	0	55	1964 - 1994
20	Vavuniya	8	45		80	30		98	1958 - 1993
21	Cheddikulam	8	40	0	80	18	0	53	1951 - 1989
22	Kebethigollewa	8	38	0	80	40	0	100	1940 - 1985
23	Trincomalee	8	35		81	15		3	1869 - 1993
24	Marichchakuddi	8	34	0	79	56	0	11	1940 - 1990
25	Horowupathana	8	33	0	80	50	0	70	1940 - 1944
26	Madawachchiya	8	33		80	29		85	1890 - 1980
27	Allai Tank	8	24	10	81	18	40	6	1876 - 1980
29	Anuradhapura Expl. Stn.	8	22	0	80	25	0	90	1940 - 1994
30	Kantalai Tank	8	22	0	81	0	22	76	1876 - 1980
31	Mihintale	8	21	0	80	31	0	177	1940 - 1994
32	Anuradhapura	8	21		80	23		93	1870 - 1993
33	Kal Aar	8	18	0	81	16	0	12	1941 - 1994
34	Nochchiyagama	8	16	0	80	12	0	78	1948 - 1994
35	Nachchaduwa	8	15	0	80	28	0	102	1940 - 1994
38	Karaitivu	8	13	0	79	49	0	27	1940 - 1994
42	Kaudulla Wewa	8	8	0	80	56	0	84	1953 - 1994
43	Maha Illuppallama	8	7		80	28		138	1905 - 1993
45	Tabbowa Irrigation	8	4	0	79	57	0	24	1940 - 1994
46	Hingurakgoda Agr.	8	3	13	80	56	57	70	1944 - 1985
48	Minneriya Tank	8	3	0	80	57	0	92	1940 - 1994
49	Puttalam	8	2		79	50		2	1869 - 1993
52	Kalawewa Tank	8	0	0	80	32	0	122	1940 - 1994
55	Maha Uswewa Tank	7	57	0	80	4	0	60	1940 - 1994
57	Topawewa	7	56		81	0		61	1957 - 1980
59	Valachenai	7	55	0	81	32	0	5	1940 - 1994
60	Pelwehera	7	54	21	80	40	29	238	1930 - 1985
61	Anamaduwa Dispensary	7	53	0	80	0	0	60	1940 - 1994
62	Mediyawa Tank	7	53	0	80	17	0	109	1940 - 1994
63	Angamedilla	7	51	0	80	55	0	93	1941 - 1994
65	Bakamuna	7	46	0	81	11	0	62	1941 - 1994
66	Nikaweratiya	7	45	0	80	7	0	60	1941 - 1994
67	Ridibendi Ela	7	44	0	80	15	0	54	1940 - 1994
68	Polontalawa	7	43	0	80	0	0		1953 - 1994
70	Batticaloa	7	43		81	42		3	1869 - 1993
71	Millawana Estate	7	40	0	80	33	0	232	1940 - 1994
72	Nalanda Exper. Station	7	40	0	80	38	0	267	1940 - 1994
73	Wariyapola	7	38	5	80	15	7	85	1886 - 1980
75	Chilaw	7	35	0	79	47	20	3	1911 - 1980
76	Gammaduwa Estate	7	34	26	80	41	42	731	1944 - 1973
77	Illukkumbura	7	33	0	80	46	0	608	1940 - 1994
79	Pallegama	7	32	28	80	50	1	192	1944 - 1968

Table 3 (continued)

No.	Station mane	Lat.(N)			Long.(E)			Elev.	Period
		°	'	"	°	'	"	(m)	
80	Batalagoda Tank	7	32	0	80	27	0	139	1940 - 1994
81	Maha Oya	7	32	0	81	22	0	45	1940 - 1993
85	Wiharagama estate	7	29	48	80	38	31	1067	1950 - 1985
86	Kurunegala	7	28		80	22		116	1885 - 1993
87	Matale PWD	7	28		80	37		369	1871 - 1980
88	Wariyapola Estate	7	27	47	80	37	37	365	1944 - 1985
89	Horakelle	7	27	0	79	51	0	15	1869 - 1980
90	Nilloomally estate	7	26	38	80	43	15	1097	1923 - 1981
91	Elkaduwa	7	25	14	80	41	9	853	1944 - 1985
92	Woodslee	7	25	12	80	30	56		1951 - 1973
94	Kankaniyamulla	7	24	0	80	2	0	53	1940 - 1991
95	Gonawella	7	22	34	80	48	0	1280	1952 - 1974
96	Horaborawewa	7	22	1	81	0	14	91	1911 - 1982
97	Kobanella	7	21	15	80	50	21	1372	1944 - 1985
98	Galphela	7	21	13	80	42	14	701	1944 - 1985
99	Polgamahela	7	20	16	80	17	52	73	1949 - 1985
104	Kandy	7	20		80	38		477	1870 - 1992
105	Aluthnuwara	7	19	0	81	0	0	98	1940 - 1994
106	Morayaya	7	18	28	80	58	36	98	1944 - 1966
107	Iddemekelle Estate	7	18	15	80	56	16	661	1944 - 1984
108	Kempitikande	7	18	11	80	25	44		1944 - 1965
109	Eraminigolla	7	18	0	80	23	0	97	1940 - 1994
110	Rajawella Estate	7	17	43	80	43	50	457	1944 - 1983
111	Ambanpitiya	7	17	31	80	28	18	323	1871 - 1985
112	Ampara Tank	7	17	10	81	39	55	27	1876 - 1980
113	Peradeniya Gardens	7	16	15	80	35	28	469	1944 - 1985
115	Walpita	7	16	0	80	3	0	47	1941 - 1994
116	Mapakadawewa	7	16	0	81	2	0	107	1941 - 1994
117	Woodside estate	7	15	52	80	49	39	1067	1944 - 1985
118	Kadugannawa	7	15	26	80	20	58	518	1944 - 1981
124	Negombo	7	13	0	79	50	10	3	1871 - 1980
125	Kirimetiya Estate	7	13	0	80	41	0	1107	1940 - 1994
126	Minipe Irrig.	7	12	57	80	58	36	113	1944 - 1972
128	Haguranketha Group	7	10	41	80	46	28	1356	1952 - 1979
129	Kandaketiya	7	10	20	81	0	25	122	1947 - 1985
130	Pindeniya	7	10	7	80	17	26	76	1949 - 1974
131	Meeriyatenna	7	10	5	80	47	45	1357	1944 - 1979
132	Pathigama Estate	7	10	4	80	41	52	1067	1944 - 1985
133	Bibile Dispensary	7	10	0	81	14	0	249	1940 - 1994
135	Katunayake	7	10		79	53		9	1960 - 1993
136	Pasyala	7	9	0	80	8	0	48	1945 - 1994
137	New Forest	7	8	50	80	40	50	1067	1901 - 1993
138	Aranayake	7	8	45	80	27	37	300	1949 - 1984
139	Orwell Estate	7	8	39	80	34	49	511	1944 - 1972
140	Lugal Oya	7	8	29	81	6	55	1317	1944 - 1963
141	Undugoda	7	8	0	80	22	0	289	1950 - 1994
142	Sagamam Tank	7	7	35	81	48	40	12	1872 - 1980
143	Sogama Estate	7	7	33	80	37	12	1067	1886 - 1985
145	Meddegoda	7	7	14	80	30	19	847	1944 - 1971
146	Hope Estate	7	6	31	80	44	20	1356	1891 - 1985
147	Kellie Estate	7	6	11	80	26	0	954	1949 - 1985
148	Henarathgoda Bot Grnds	7	6	0	79	59	0	27	1940 - 1994
149	Udemedura	7	5	58	80	53	46		1944 - 1972
150	Helboda North	7	5	49	80	40	48	1494	1944 - 1985
151	Helbodde Estate	7	5	10	80	39	50	834	1885 - 1993

Table 3 (continued)

No.	Station mane	Lat.(N) °	'	"	Long.(E) °	'	"	Elev. (m)	Period
152	Maha Uva Estate	7	4	59	80	51	39	1128	1944 - 1985
153	Kurundu Oya	7	4	25	80	50	10	1570	1882 - 1993
154	Nawalapitiya	7	3	48	80	31	31	1158	1938 - 1985
155	Mahadowa Estate	7	3	37	80	38	34	1390	1944 - 1985
156	Welitalawa	7	3	14	80	22	57		1949 - 1985
157	Keenakelle	7	3	10	81	0	52	1177	1944 - 1985
158	Oonagalla Estate	7	2	15	80	35	49	1219	1944 - 1985
159	Legerwatta Estate	7	1	49	80	0	38	1219	1944 - 1985
160	Liddesdle Estate	7	1	47	80	51	12	509	1944 - 1985
161	Labookelle Estate	7	1	25	80	42	31	1524	1944 - 1985
162	Ingoya Estate	7	0	35	80	25	51	305	1949 - 1985
163	Blackwater	7	0	13	80	29	42	671	1944 - 1985
164	Kenilworth	6	59	37	80	28	30	762	1949 - 1985
165	Kirklees Estate	6	59	13	80	56	3	1433	1944 - 1985
166	Kandaploa	6	59	1	80	49	27	1570	1944 - 1970
167	Badulla	6	59		81	3		670	1869 - 1993
168	Wewesse Estate	6	58	8	81	6	18	914	1944 - 1985
169	Watagoda	6	58	0	80	39	5	1342	1910 - 1986
171	Nuwara Eliya	6	58		80	46		1895	1869 - 1993
172	Watawala	6	57	48	80	31	22	960	1910 - 1993
173	Arslena	6	57	25	80	29	21	457	1949 - 1983
174	Nanu Oya	6	56	35	80	44	25	1628	1944 - 1976
176	Limyagala Group	6	55	57	80	21	41	259	1949 - 1989
177	Udahenkande	6	55	48	80	19	55	1140	1953 - 1968
178	Hakgala Botanical Gd	6	55	30	80	9	0	1701	1883 - 1993
179	Lower Spring valley	6	55	21	81	5	51	1113	1944 - 1985
181	Mousagalla	6	55	11	81	7	50	1372	1944 - 1962
182	Awissawella	6	55	10	80	11	0	229	1871 - 1980
183	Norton Bridge	6	54	56	80	31	6	896	1944 - 1985
184	Abergeldie Group	6	54	30	80	35	20	1098	1884 - 1993
186	Colombo	6	54	0	79	52	47	7	1869 - 1993
188	Welimada Group	6	54	0	80	54	0	1155	1911 - 1980
189	Gourukella	6	54	0	81	5	0	1189	1877 - 1980
191	Hatton Police Station	6	53	45	80	35	44	1262	1944 - 1967
192	Maliboda	6	53	27	80	25	26	274	1949 - 1985
193	Ambewela	6	53		80	46		1828	1952 - 1992
194	Pottuvil	6	53		81	50			1983 - 1990
195	Strathden	6	52	51	81	1	17	853	1944 - 1973
196	Luccombe Estate	6	52	22	80	31	54	1097	1944 - 1976
197	Erabedda Patnas	6	52	4	80	54	38	1250	1944 - 1977
198	Hapugastenna Estate	6	52		80	32		595	1944 - 1993
199	Annfield Estate	6	52		80	38		1311	1888 - 1993
200	South Wanarajah	6	51	53	80	34	56	1140	1949 - 1982
201	Holmwood Estate	6	51	15	80	42	37	1585	1881 - 1993
202	Eheliyagoda	6	51	0	80	16	0	226	1917 - 1980
204	Sandringham Estate	6	50	10	80	45	0	1601	1881 - 1993
205	Maskeliya Hospital	6	50	0	80	34	20	1219	1882 - 1993
206	Norwood (New Valley)	6	50	0	80	36	10	1098	1879 - 1991
209	Ohiya Forest	6	49	12	80	50	22	1774	1944 - 1968
210	Ratmalana	6	49		79	53		5	1935 - 1993
211	Diyatalawa	6	49		80	58		1248	1901 - 1992
212	West Haputale Estate	6	48	4	80	49	33		1949 - 1983
213	Kumbukkan	6	48	0	81	17	0	160	1940 - 1963
214	Campion Estate	6	47		80	42		1820	1885 - 1993
215	Rayigama	6	46	0	80	11	0	112	1940 - 1994

Table 3 (continued)

No.	Station mane	Lat.(N) °	'	"	Long.(E) °	'	"	Elev. (m)	Period
216	Nagarat Estate	6	46	0	80	46	36	2073	1949 - 1984
217	Panawa Tank	6	45	0	81	46	0	14	1940 - 1990
218	Detanagalla	6	44		80	41		315	1912 - 1993
219	Bandaragama	6	43	0	80	0	0	8	1940 - 1994
220	Alupolla Group	6	43		80	35		763	1932 - 1993
221	Rassagala Estate	6	41	33	80	37	54	549	1949 - 1973
222	Keenagala Ella	6	41	28	80	43	25		1948 - 1959
223	Ratnapura	6	41		80	24		34	1869 - 1993
224	Lellopitiya Estste	6	40	30	80	29	40	206	1955 - 1993
225	Massena	6	40	23	80	37	23		1949 - 1954
226	Horagoda Estate	6	40	6	80	14	43	61	1955 - 1984
227	Kalutara P.W.D.	6	40	0	79	57	0	17	1940 - 1994
229	Balangoda Post Office	6	39	0	80	42	0	551	1940 - 1994
230	Ginnihiriya	6	38	4	80	49	51	2152	1944 - 1975
231	Pelmadulla	6	37	23	80	32	18	146	1949 - 1985
232	Mahawelatenna	6	35	31	80	44	44	549	1949 - 1985
233	Clyde Estate	6	35	0	80	2	0	29	1952 - 1994
234	Watapota	6	34	18	80	30	49	366	1955 - 1978
235	Gonapenigala Iranganie E.	6	34	0	80	20	0	234	1940 - 1994
238	Wellandura Estate	6	32	0	80	34	0	341	1955 - 1994
239	Hambegamuwa	6	32	0	80	57	0	131	1940 - 1994
240	Kokawita	6	29	32	80	22	38	456	1949 - 1969
241	Depedena Group	6	28	0	80	33	0	919	1942 - 1994
242	Vedagala	6	27	15	80	25	32		1949 - 1970
244	Kumbaduwa Estate	6	25	40	80	12	1		1949 - 1980
246	Lauderdale Group	6	25	8	80	36	23		1954 - 1985
247	Pelawatte	6	25	0	80	13	0	36	1959 - 1994
248	Yala	6	23	0	81	31	0	3	1923 - 1980
250	Panilkande Estate	6	21	33	80	37	38	579	1949 - 1985
251	Annigkande	6	20	50	80	36	10	533	1878 - 1980
253	Tawalama	6	20	28	80	21	22	30	1954 - 1985
254	Embilipitiya Irri. Tank	6	20	0	80	51		6	1940 - 1993
256	Hingalgoda Estate	6	19	17	80	18	55	61	1952 - 1971
257	Millewa Estate	6	17	35	80	27	41	76	1952 - 1985
258	Balapitiya	6	17	0	80	3	0	15	1943 - 1991
259	Tissamarama	6	16	20	81	12	10	24	1871 - 1980
260	Opata	6	16	5	80	24	29		1949 - 1963
261	Morawaka	6	15	25	80	29	25		1949 - 1961
262	Kirama	6	13	0	80	40	0	118	1940 - 1994
264	Mawarella Estate	6	12	0	80	35	0	343	1940 - 1994
266	Baddegama Estate	6	11	0	80	11	0	46	1940 - 1994
268	Mamadola	6	10	0	80	59	0	18	1940 - 1994
270	Maliduwa	6	7	56	80	24	52		1949 - 1963
272	Hambantota	6	7		81	8		16	1869 - 1993
273	Ellawella Tank	6	5	0	80	36	0	92	1940 - 1991
274	Labuduwa	6	4	0	80	19	0	122	1940 - 1994
275	Galle	6	2		80	13		13	1869 - 1993
276	Dandeniya Tank	5	59	30	80	39	20	49	1880 - 1980
277	Kekanadura	5	59	0	80	36	0	49	1871 - 1980

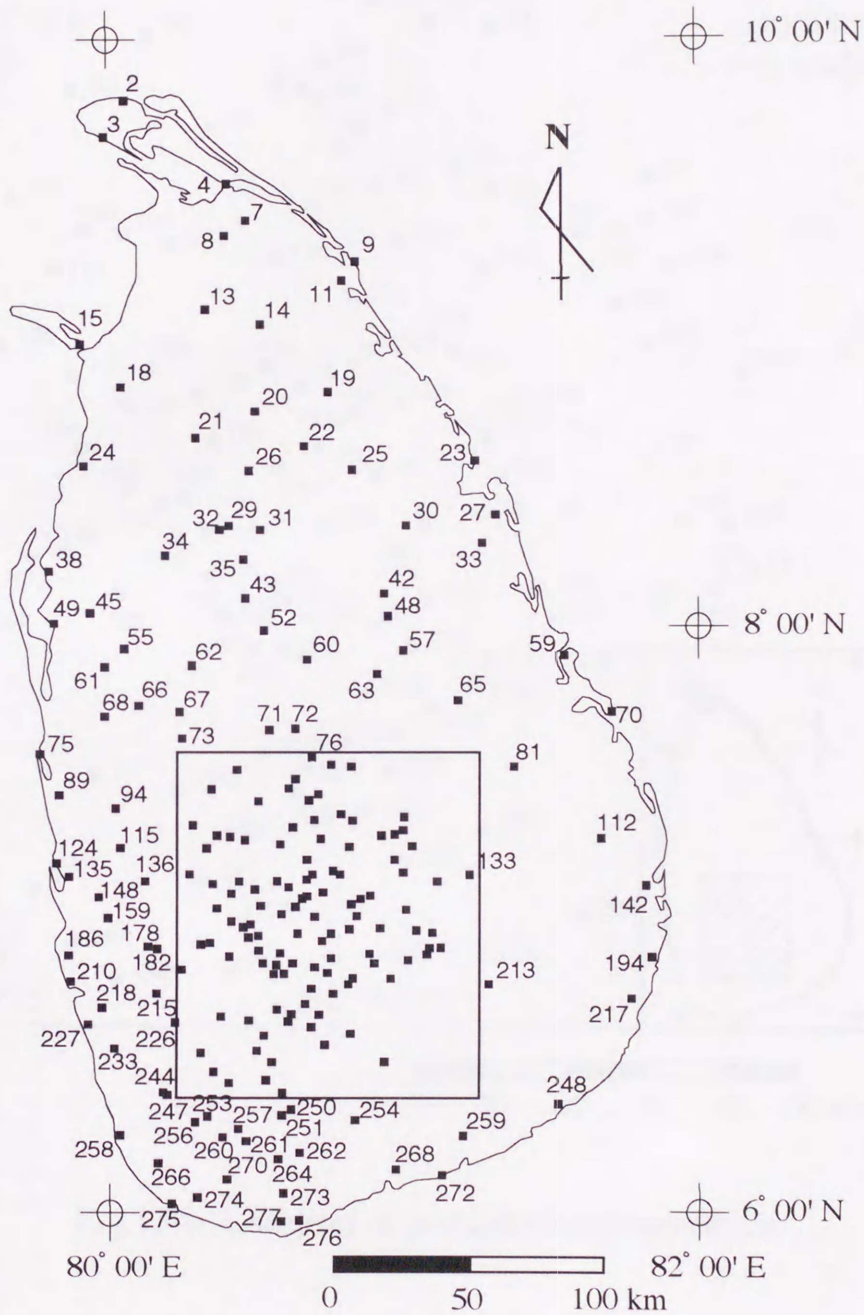


Fig.13-a Location of precipitation observation

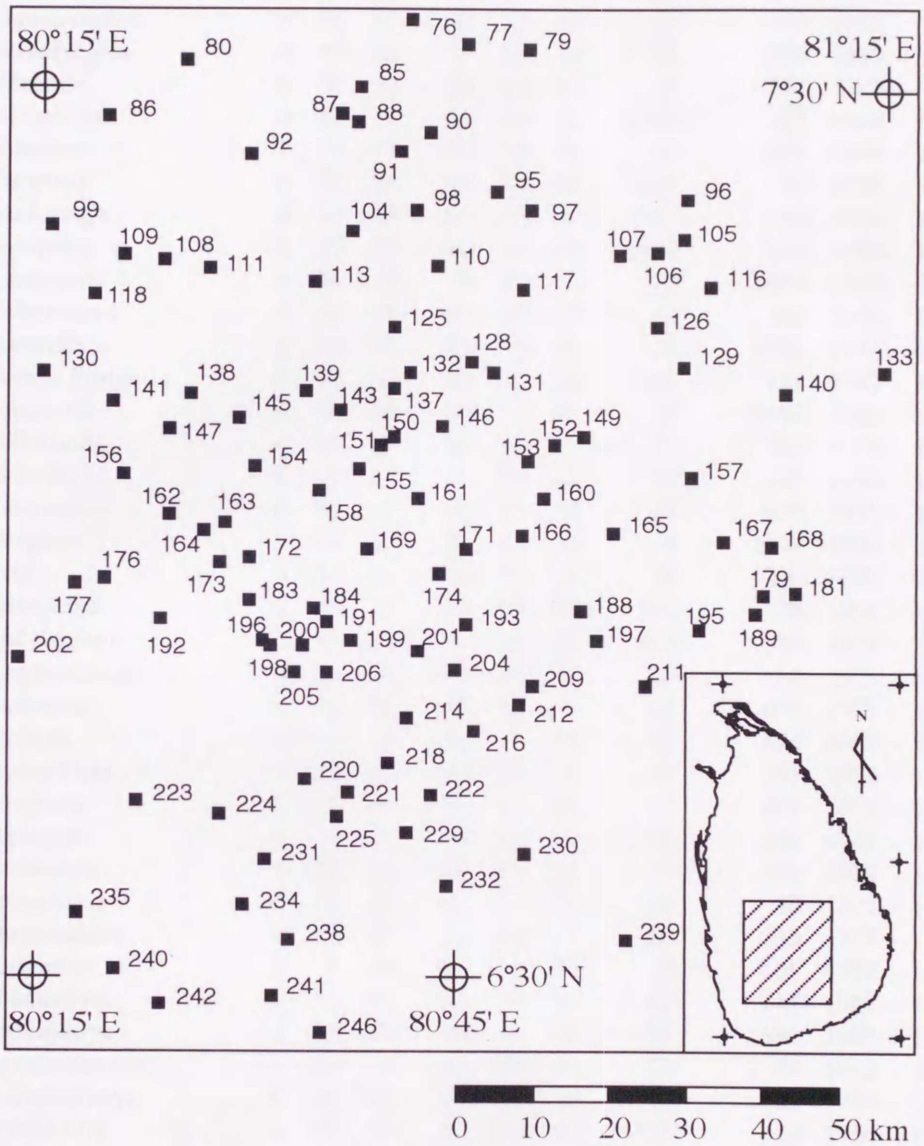


Fig.13-b Location of precipitation observation

Table 4 List of stations for discharge

No.	Station mane	Lat.(N) °	'	"	Long.(E) °	'	"	Elev. (m)	Discharge area (km²)	Period
0101	Nagalagam Street	6	57	30	79	52	30	0	2085	1924 - 1960
0102	Glencourse	6	58	30	80	10	51	18	1463	1948 - 1993
0103	Metiyadola	7	1	34	80	16	26	20	606	1948 - 1982
0104	Algoda bridge	6	56	55	80	15	40	26	345	1948 - 1993
0105	Deraniyagala	6	55	30	80	20	15	82	152	1948 - 1993
0106	Kitulgala	6	59	30	80	24	45	56	388	1948 - 1993
0107	Mossakelle	6	50	15	80	33	0	1158	122	1948 - 1969
0108	Imbulana	7	3	47	80	15	40	26	329	1948 - 1974
0109	Norwood	6	50	30	80	36	30	1100	95	1956 - 1993
0109A	Castlereigh	6	50	40	80	36	0	1027	114	1956 - 1958
0110	Laxapana	6	53	15	80	30	40	854	168	1954 - 1986
0111	Kaduwela	6	56	5	79	59	5	10	1884	1960 - 1967
0112	Holombuwa	7	11	35	80	15	45	53	155	1962 - 1993
0114	Hanwella	6	54	35	80	4	45	16	1782	1973 - 1993
0115	Norton Bridge	6	54	30	80	31	15	900	131	1983 - 1986
0301	Putupaula	6	36	40	80	3	55	2	2598	1943 - 1993
0302	Millakanda	6	37	25	80	10	25	17	769	1950 - 1993
0303	Malwala	6	41	15	80	25	24	18	329	1954 - 1979
0304	Nambapana	6	41	11	80	25	5	13	629	1956 - 1979
0305	Ellagawa	6	43	52	80	13	0	4	1393	1956 - 1993
0306	Dela	6	37	20	80	27	10	29	220	1956 - 1993
0307	Lellopitiya	6	40	5	80	29	30	104	76	1958 - 1966
0308	Kukulegama	6	33	20	80	20	30	200	334	1973 - 1993
0309	Maguru Ganga	6	28	0	80	15	40	28	136	1973 - 1979
0310	Ratnapura	6	40	30	80	24	0	14	604	1977 - 1993
0901	Agaliya	6	11	15	80	11	45	10	696	1927 - 1993
0902	Jesmin Dam	6	20	40	80	20	0	27	361	1973 - 1993
0903	Udugama	6	13	30	80	19	20	17	498	1973 - 1979
1201	Bopagoda	6	9	20	80	29	5	18	442	1940 - 1993
1202	Namimana	5	57	30	80	33	30	2	958	1972 - 1979
1203	Hulanduwa	6	11	40	80	27	5	24	70	1972 - 1979
1204	Bingamahara	6	12	40	80	28	40	26	333	1973 - 1989
1205	Kadduwa	6	2	10	80	30	50	6	601	1975 - 1993
1601	Julampitiya	6	11	40	80	44	40	62	141	1947 - 1961
1801	Embilipitiya	6	20	40	80	53	55	31	1580	1942 - 1968
1802	Liyanagahatota	6	14	0	80	56	30	17	2284	1942 - 1948
1803	Halmillaketiya	6	18	40	80	52	0	46	166	1954 - 1962
1804	Belihul Oya	6	43	0	80	46	0	594	49	1956 - 1960
1804A	Belihul Oya	6	44	30	80	45	0	820	42	1984 - 1986
1805	Uda Walawe	6	27	10	80	50	30	76	1155	1957 - 1961
1806	Samanalawewa	6	40	30	80	48	5	364	353	1958 - 1986
1807	Timbolketiya	6	24	25	80	47	55	64	269	1958 - 1967
1808	Weragala	6	39	0	80	54	0	117	261	1963 - 1971
1809	Mahagama	6	19	45	80	55	30	36	366	1951 - 1965
1810	Mawigala	6	35	35	80	48	50	427	23	1964 - 1979
1811	Waguregama	6	34	15	80	49	55	108	99	1963 - 1965
1812	Modarawana	6	19	10	80	49	0	70	109	1956 - 1958
2201	Lunuganwehera	6	21	10	81	13	10	35	913	1944 - 1979
2202	Poonagala	6	43	50	81	1	40	487	5.5	1955 - 1962
2203	Wellawaya	6	43	55	81	6	25	154	160	1956 - 1993
2204	Kuda Oya	6	31	30	81	7	25	81	291	1967 - 1990
2601	Kataragama	6	25	10	81	19	45	34	787	1944 - 1993

Table 4 (continued)

No.	Station mane	Lat.(N) °	'	"	Long.(E) °	'	"	Elev. (m)	Discharge area (km²)	Period
3101	Kumbukkana	6	48	25	81	17	35	137	259	1957 - 1961
3102	Nakkala	6	53	30	81	17	45	160	216	1973 - 1993
3103	Maligawila	6	41	35	81	22	40	81	375	1974 - 1989
3104	Maligawila	6	42	0	81	24	35	70	302	1974 - 1979
3501	Wedagama	6	45	40	81	44	35	9	404	1946 - 1957
3601	Siyambalanduwa	6	54	20	81	32	40	55	295	1945 - 1993
3602	Heda Oya Dam Site	6	52	10	81	36	55	38	409	1951 - 1957
3603	Lahugala	6	53	0	81	41	45	24	471	1958 - 1960
3701	Hulange	6	56	40	81	39	10	35	145	1953 - 1962
4201	Thottama	7	6	30	81	41	25	34	95	1945 - 1968
4401	Inginiyagala	7	12	30	81	32	0	42	995	1937 - 1949
4402	Pitakumbura	7	8	45	81	17	55	195	188	1984 - 1991
5101	Periya Aru	7	30	0	81	29	20	36	119	1942 - 1979
5201	Weragoda	7	33	35	81	19	50	48	225	1945 - 1991
5202	Nilobe	7	30	40	81	22	40	44	159	1944 - 1981
5203	Maha oya	7	32	0	81	21	30	39	300	1946 - 1961
5204	Rugam	7	38	10	81	27	0	23	1295	1953 - 1960
5205	Pollebedda	7	28	0	81	23	50	48	137	1980 - 1988
5401	Welikanda	7	56	10	81	15	0	29	1068	1946 - 1979
5402	Kandegama Dam Site	7	38	18	81	12	40	61	453	1951 - 1979
5403	Maduru Oya Bridge	7	23	0	81	11	30	118	158	1981 - 1986
6001	Manampitiya	7	54	40	81	5	10	32	7418	1941 - 1993
6002	Galoya Junction	8	8	25	80	51	10	84	199	1941 - 1959
6003	Angamedilla	7	51	0	80	54	10	67	1363	1952 - 1993
6004	Peradeniya	7	15	30	80	35	25	463	1167	1943 - 1993
6005	Gurudeniya	7	16	30	80	40	33	425	1418	1944 - 1978
6006	Nalanda	7	40	15	80	38	15	243	126	1943 - 1960
6007	Weragantota	7	19	0	80	59	10	76	4092	1945 - 1993
6008	Elahera	7	40	45	80	45	25	133	774	1946 - 1993
6009	Morape	7	3	40	80	37	20	640	555	1946 - 1981
6010	P.W.D. Bridge	8	13	25	80	53	20	88	45	1946 - 1976
6011	Gampola	7	9	50	80	34	20	493	951	1951 - 1978
6012	Kandakaduturai	8	4	0	81	9	10	23	7529	1952 - 1965
6013	Nadumodara	8	10	25	81	12	20	15	8618	1952 - 1961
6014	Ulhitiya	7	34	15	81	0	35	78	357	1953 - 1980
6015	Teldeniya	7	17	40	80	46	0	411	160	1954 - 1978
6016	Randenigala	7	12	10	80	56	10	141	2365	1954 - 1983
6017	Kandaketiya	7	10	30	81	0	20	126	387	1954 - 1979
6018	Gadugudawaa	7	16	15	81	3	5	106	91	1953 - 1958
6019	Meegahakiula	7	9	30	81	3	35	121	196	1955 - 1966
6020	Watawala	6	56	50	80	32	10	829	65	1957 - 1977
6021	Talawakelle	6	56	25	80	39	45	1200	297	1954 - 1993
6022	Bawagama	7	2	55	80	31	55	578	169	1957 - 1966
6023	Talawakanda	7	0	30	80	58	25	575	520	1957 - 1991
6024	Allai Kantalai	8	19	0	81	10	0	8	9606	1958 - 1986
6025	Mallanda	7	3	40	80	32	10	578	188	1958 - 1966
6026	Bowatenna	7	39	10	70	42	25	212	520	1958 - 1962
6027	Holbrook	6	52	50	80	41	40	1346	121	1959 - 1978
6028	Victoriya	7	14	25	80	47	0	366	1653	1958 - 1978
6029	Welimada	6	54	15	80	54	30	1070	179	1959 - 1978
6030	Wellewella	7	36	25	80	50	0	140	194	1960 - 1973
6032	Moragahamulla	7	16	57	80	48	26	427	73	1963 - 1979

Table 4 (continued)

No.	Station mane	Lat.(N) °	'	"	Long.(E) °	'	"	Elev. (m)	Discharge area (km^2)	Period
6033	Rantembe	7	11	52	80	57	14	114	3113	1979 - 1986
6034	Caledoniya	6	54	0	80	42	0	1280	183	1983 - 1993
6071	Elgin Falls	6	52	45	80	48	15	1827	23	1920 - 1960
6072	Uduwalwala	7	28	30	80	55	15	77	115	1954 - 1962
6077	Hembarawa	7	31	30	80	58	25	64	4530	1953 - 1978
6078	Hanguranketa	7	11	30	80	45	45	533	103	1954 - 1960
6079	Geli oya	7	12	45	80	36	15	467	1066	1955 - 1962
6081	Dastota	7	51	0	81	2	0	34	5501	1957 - 1959
6082	Pallewatta	7	21	30	80	57	45	86	116	1958 - 1960
6084	Teldeniya	7	5	30	81	2	50	271	280	1958 - 1960
6085	Watumulla	7	5	50	80	51	15	870	34	1958 - 1960
6087	Uraniya	7	13	0	81	7	3	182	34	1977 - 1979
6701	Huruluwewa	8	13	35	80	43	40	120	200	1942 - 1949
6702	Pangurugaswewa	8	44	55	80	52	45	21	1311	1946 - 1981
6703	Horowapotana	8	34	36	80	52	42	44	942	1951 - 1993
6704	Wahalkada	8	43	36	80	51	5	31	91	1951 - 1974
6705	Illukwewa	8	20	10	80	44	5	98	315	1972 - 1979
6901	Yakawewa	8	43	25	80	40	50	70	110	1979 - 1993
7501	Oddusu Dam	9	13	0	80	41	30	10	303	1976 - 1979
8101	Parasan Kulam	8	59	45	80	33	0	65	133	1980 - 1985
8801	Chinnaralayan kaddu	8	57	30	80	20	20	40	560	1980 - 1985
9001	Kappachchi	8	35	55	80	16	20	36	2117	1948 - 1989
9002	Tekkam	8	44	55	80	11	0	18	3071	1945 - 1959
9003	Rambawa	8	27	10	80	30	25	77	364	1955 - 1972
9301	Kadigala	8	7	20	80	15	40	57	1564	1945 - 1964
9302	Nochchiyagama	8	11	50	80	5	50	24	1948	1957 - 1984
9303	Galewela	7	48	30	80	36	25	171	41	1958 - 1993
9305	Dambulla	7	47	45	80	35	50	179	18	1971 - 1979
9306	Ibbnkatuwa	7	50	40	80	38	0	157	70	1971 - 1979
9307	Kumbukwewa	8	7	15	80	17	30	64	1160	1977 - 1983
9308	Kumbukwewa	8	7	0	80	17	40	65	117	1977 - 1983
9501	Mahauswewa	7	57	50	80	4	8	35	595	1954 - 1985
9502	Tabbowa	8	2	50	79	55	5	10	1078	1960 - 1979
9901	Hettipola	7	36	30	80	5	35	40	233	1944 - 1983
9902	Batalagoda	7	31	0	80	28	0	122	210	1945 - 1947
9903	Alawala Anicut	7	28	20	80	27	10	125	102	1945 - 1962
9904	Chilaw	7	36	0	79	48	58	0	2611	1949 - 1993
9907	Moragaswewa	7	41	45	79	59	50	15	2002	1978 - 1989
10201	Alawwa	7	17	30	80	14	25	49	804	1947 - 1993
10202	Badalgama	7	18	10	79	58	50	12	1360	1953 - 1993
10203	Giriulla	7	19	30	80	6	55	27	1191	1958 - 1993
10301	Attanagalla	7	6	45	80	8	10	24	114	1950 - 1993
10302	Karasnagala	7	6	45	80	10	15	28	53	1971 - 1986
10303	Alawala	7	6	55	80	10	40	30	13	1971 - 1984

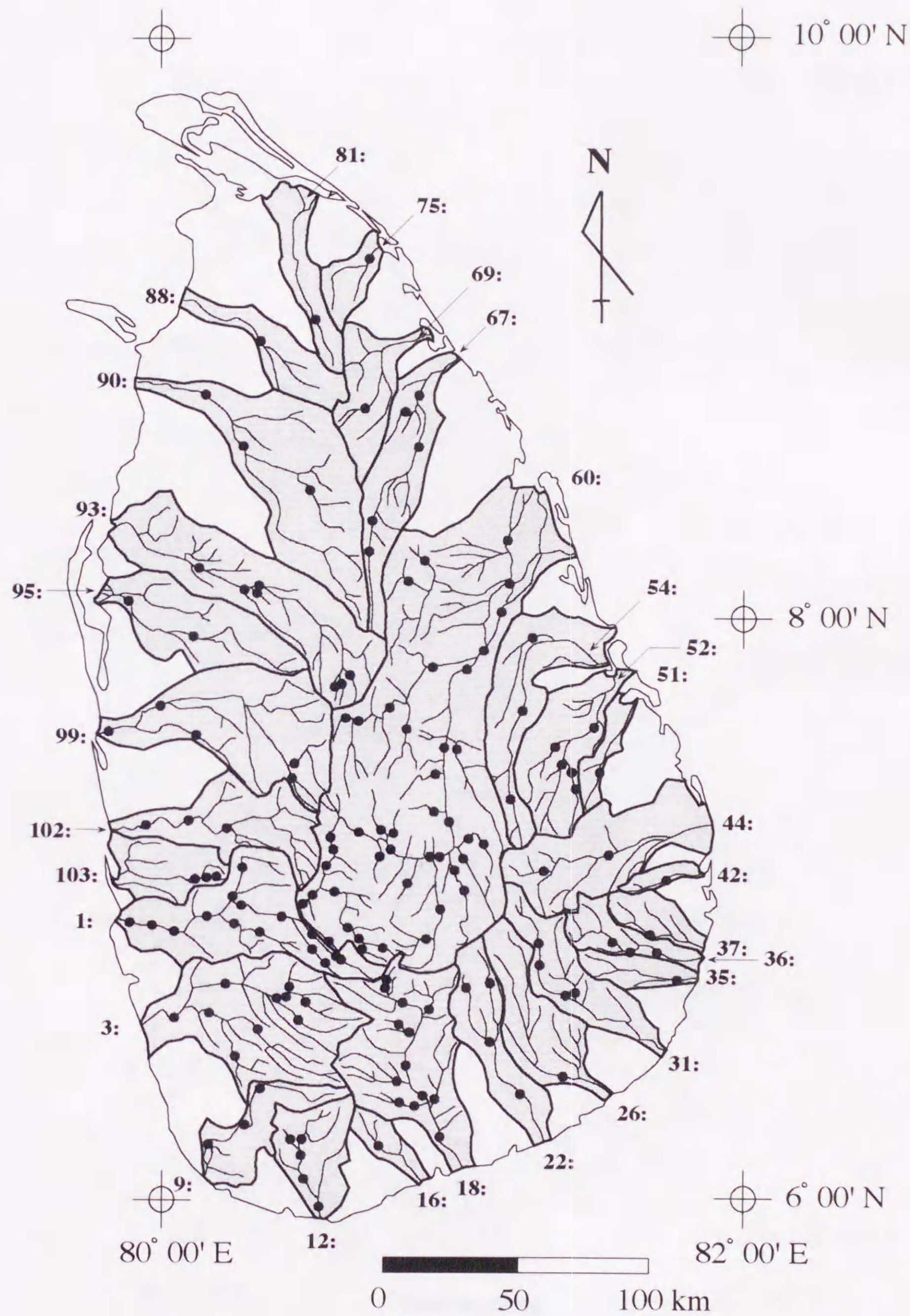


Fig.14-a Locaion of discharge observation and stream networks

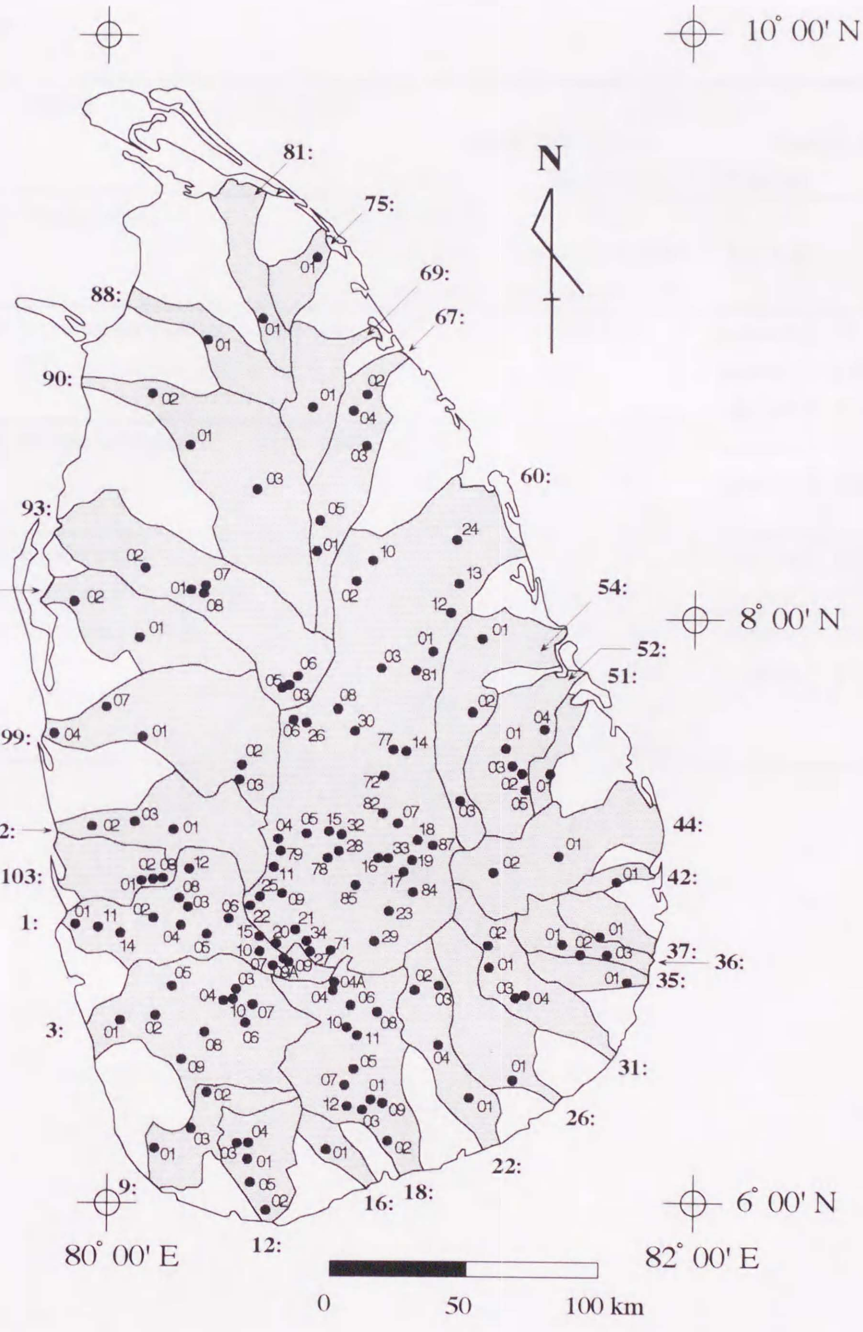


Fig.14-b Locaion and chronological sequence number of discharge observation

Table 5 List of maps

Map	Scale	Region	Published	Data Source			
				Aerial photographs		Satellite Images	
				Scale	Observation	Sattelite	Date
Tea Map	1/500000	Whole island	1988	1/40000	1956		
				1/20000	taken after 1979	Landsat	
				1/50000	taken after 1979		
Land use Map	1/100000	Kurunegala District	Feb. 1985	1/50000	Feb.1981	Landsat,2	1978-06-22
						Landsat,2	1980-02-07
						Landsat,3	1983-01-04
	1/100000	Puttalam District	Aug. 1985	1/50000	Feb.Mar.1981	Landsat,2	1980-02-07
				1/10000	Mar.1981	Landsat,3	1983-01-04
				1/40000	Feb.Mar.1956		
	1/100000	Kandy and Nuwara Eliya District	Mar. 1984	1/50000	Jan. Feb. May 1981	Landsat,2	1978-06-22
				1/23000	Feb. 1979	Landsat,2	1980-02-06
	1/100000	Ratnapura District	Dec. 1987	1/50000	Jan. Feb. 1981	Landsat,2	1980-02-06
				1/20000	Jan. May 1982	Landsat,2	1983-04-14
				1/20000	Feb. Mar 1983		
				1/20000	Jan. Oct.1984		

Chapter 4

Method

4.1 Analysis of spatial and temporal variations of temperature and precipitation

Temporal variation of temperature and precipitation

The temporal variations of air temperature and precipitation are determined by a trend analysis. The monthly and annual trends of air temperature and precipitation are calculated using the data observed over 100 years as shown in Tables 6 and 7. The temporal variations of SST around the island of Sri Lanka, the latitude of 0°-10°N, the longitude of 75°-85°E, are also determined by the trend analysis.

The trend of temperature and precipitation was calculated from the regression equation obtained from the results using a least square method. The regression equation can be expressed as

$$Y = a X + b \qquad (4.1.)$$

where a is regression coefficient and b is y-interception.

Spatial variation of temperature and precipitation

The spatial variations of the trend of air temperature and precipitation are illustrated by the isopleth of regression coefficients of the trend analysis.

4.2. Water balance

In general, when consider the water balance in Sri Lanka, the calculation period of the water balance is set as the hydrological year from October to September. On the other hand, most climatological observations were aggregated in the period set to the calendar year. The water balances calculated for the hydrological year and calendar year in the several watersheds show the almost same consequence (Fig.15). In this Fig.15, areal precipitations of watersheds were estimated by the arithmetic mean method. From those water balances calculated for the hydrological year and calendar year have little difference, this study adopted the calendar year for the calculation of water balance.

4.2.1. Areal precipitation

It is not accomplished to measure the true amount of areal precipitation of watershed, nevertheless the importance. The methods to estimate the amount of areal precipitation of a watershed are listed as follows.

Arithmetic mean method

This is an unweighted mean method to average all the observations of precipitation in the catchment area. When the rainfall amount at *n* points in the catchment are given by the P_1, P_2, ... , and P_n, the averaged areal precipitation ($\bar{P}$) is calculated by the following equation :

$$\bar{P}=\frac{1}{n}\times(P_1+P_2+\cdots+P_n) \qquad (4.2.)$$

Grid method

This is a method to average the precipitation of node calculated from isohyet or others.

In this study, the results of the annual water balance calculated by the arithmetic mean method and the grid method were compared. As the results of comparison for the major watersheds, the areal precipitation calculated by the arithmetic mean method showed a little overestimation as shown in Fig.16.

4.2.2. Annual water balance

In generally, water balance equation can be expressed as

$$P = Q + Et + \Delta S \qquad (4.3.)$$

where P is precipitation, Q is discharge, Et is evapotranspiration and ΔS is storage change. The storage change is negligible when water balance is considered over longer than one hydrological year.

In this study, the annual water balance of watershed is computed from monthly areal precipitation calculated by grid method using 1' × 1' grid and monthly discharge data as follows :

$$\sum_{n=1}^{12} P_n = \sum_{n=1}^{12} Q_n + \sum_{n=1}^{12} E_{t\ n} \qquad (4.4.)$$

where 1 to 12 indicate month as January to December, $\sum_{n=1}^{12} E_{t\ n}$ is annual water loss.

4.3. Land use for each catchment area

The data set for the major land uses such as paddy and tea cultivation were made by the numeric data of 500m × 500m square grid. The land use and elevation data sets were also made by numeric data of 500m × 500m square grid for the major watershed such as Malwala watershed (0303) of Kalu Ganga River, Peradeniya watershed (6004), Morepe watershed (6009), Watawala watershed (6020), Talawakelle watershed (6021), Holbrook watershed (6027) of Mahaweli Ganga River, Mahauswewa watershed (9501) and Tabbowa watershed (9502) of Mi Oya River.

Table 6 List of stations of air temperature observed over 100 years

Meteorological st.	Lat.(N) ° ' "	Long.(E) ° ' "	Elev. (m)	Period	Number of years	Regression line of annual air temperature (Y=aX+b) a (°C/year)	b (°C)	Coefficient (r^2)
Galle	6 2	80 13	13	1869 - 1992	123	0.0002	26.2	0.0005
Hambantota	6 7	81 8	16	1869 - 1992	123	0.0035 **	20.4	0.1247
Ratnapura	6 41	80 24	34	1869 - 1992	123	0.0055 **	16.5	0.1648
Colombo	6 54	79 52	7	1869 - 1992	124	0.0012	24.8	0.0181
Nuwara Eliya	6 58	80 46	1895	1869 - 1992	122	0.0101 **	-4.2	0.5498
Badulla	6 59	81 3	670	1869 - 1992	124	0.0053 **	13.0	0.2132
Kandy	7 20	80 38	477	1870 - 1992	123	-0.0007	26.0	0.0035
Kurunegala	7 28	80 22	116	1885 - 1992	123	0.0010 **	25.8	0.0144
Batticaloa	7 43	81 42	3	1869 - 1992	123	0.0010	25.8	0.0144
Puttalam	8 2	79 50	2	1869 - 1992	124	0.0091 **	9.7	0.4337
Anuradhapura	8 21	80 23	93	1870 - 1992	122	0.0051 **	17.5	0.1757
Trincomalee	8 35	81 15	3	1869 - 1992	121	0.0031 **	22.3	0.0607
Mannar	8 59	79 55	4	1870 - 1990	117	0.0008	26.5	0.0056
Jaffna	9 39	80 1	4	1869 - 1984	115	0.0027 **	22.4	0.0550

(Remarks * : significant at the 5 % of significance level)

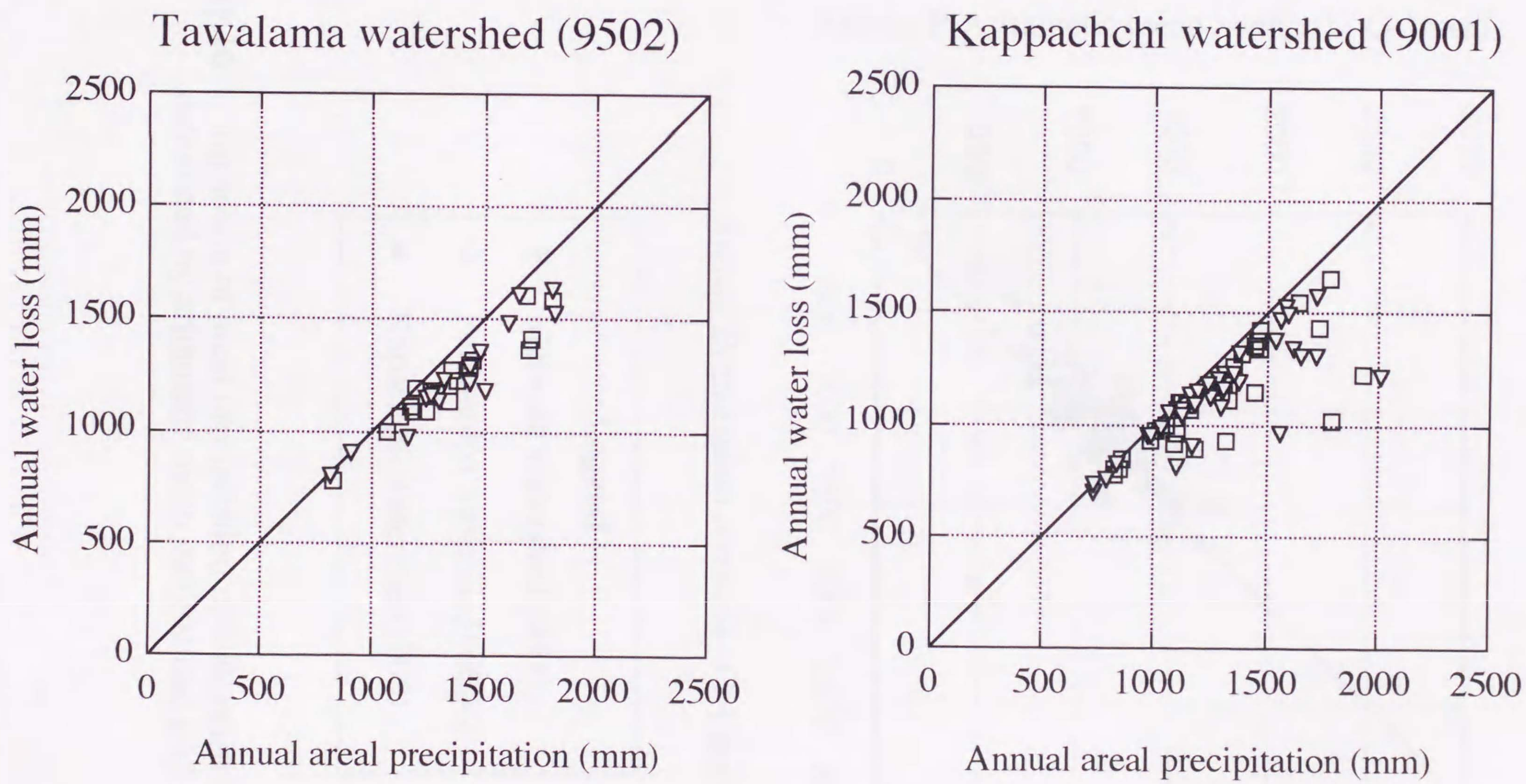
(Remarks ** : significant at the 1 % of significance level)

Table 7 List of stations of precipitation observed over 100 years

Meteorological st.	Lat.(N) ° ' "	Long.(E) ° ' "	Elev. (m)	Period	Number of years	Regression line of annual precipitation (Y=aX+b) a	b	Coefficient (r^2)
Kekanadura	5 59 0	80 36 0	49	1871 - 1980	110	0.580	708.8	0.0019
Dandeniya Tank	5 59 30	80 39 20	49	1880 - 1980	101	-0.956	3697.7	0.0035
Galle	6 2	80 13	13	1869 - 1992	125	0.820	795.4	0.0052
Hambantota	6 7	81 8	16	1869 - 1992	124	0.842	-603.4	0.0133
Tissamarama	6 16 20	81 12 10	24	1871 - 1980	110	0.384	306.3	0.0025
Anningkande	6 20 50	80 36 10	533	1878 - 1980	103	-0.019	3619.6	0.0000
Ratnapura	6 41	80 24	34	1869 - 1992	125	-1.119	5981.8	0.0071
Campion Estate	6 47	80 42	1820	1885 - 1993	98	-1.970	6261.9	0.0289
Sandringham	6 50 10	80 45 0	1601	1881 - 1993	106	0.994	228.8	0.0068
Holmwood Estate	6 51	80 42	1585	1881 - 1993	102	-6.507 **	15091.9	0.1594
Colombo	6 54	79 52	7	1869 - 1992	125	3.276 **	-4073.3	0.0579
Gourukella	6 54 0	81 5 0	1189	1877 - 1980	104	-0.102	2589.4	0.0000
Awissawella	6 55 10	80 11 0	229	1871 - 1980	110	0.959	2105.9	0.0033
Hakgala	6 55 30	80 9 0	1701	1883 - 1993	55	-4.672 **	11241.7	0.1924
Nuwara Eliya	6 58	80 46	1895	1869 - 1992	125	-5.133 **	12109.1	0.2121
Badulla	6 59	81 3	670	1869 - 1992	125	-2.223 *	6114.2	0.0420
Kurundu Oya	7 4 25	80 50 10	1570	1882 - 1993	100	3.078	-3178.6	0.0363
Sagamam Tank	7 7 35	81 48 40	12	1872 - 1980	109	1.874	-2030.7	0.0201
Negombo	7 13 0	79 50 10	3	1871 - 1980	110	3.029 *	-3940.4	0.0472
Ambanpitiya	7 14 15	80 19 35	201	1871 - 1980	105	-5.422 **	12363.3	0.1306
Ampara Tank	7 17 10	81 39 55	27	1876 - 1980	105	-5.422 **	12363.3	0.1306
Kandy	7 20	80 38	477	1870 - 1992	123	-2.793 **	7443.1	0.0788
Horakelle	7 27 0	79 51 0	15	1869 - 1980	112	0.746	279.9	0.0035
Kurunegala	7 28	80 22	116	1885 - 1992	109	0.006	2084.9	0.0000
Matale PWD	7 28	80 37	369	1871 - 1980	110	-3.026 *	7804.3	0.0370
Batticaloa	7 43	81 42	3	1869 - 1992	124	0.567	555.7	0.0030
Puttalam	8 2	79 50	2	1869 - 1992	125	0.285	605.0	0.0014
Anuradhapura	8 21	80 23	93	1870 - 1992	124	-0.933	3182.5	0.0123
Kantalai Tank	8 22 0	81 0 22	76	1876 - 1980	105	-3.980 *	9404.9	0.0909
Allai Tank	8 24 10	81 18 40	6	1876 - 1980	105	-9.410 **	19818.0	0.2581
Trincomalee	8 35	81 15	3	1869 - 1992	122	0.428	801.2	0.0018
Mannar	8 59	79 55	4	1870 - 1990	117	-0.038	1046.6	0.0000
Mullaitivu	9 16	80 51	2	1871 - 1980	118	0.223	947.3	0.0005
Jaffna	9 39	80 1	4	1869 - 1990	118	0.091	1082.7	0.0001

(Remarks * : significant at the 5 % of significance level)

(Remarks ** : significant at the 1 % of significance level)



Legend
□ Calender year
▽ Hydrological year

Fig.15 Comparison of water balance between hydrological year and calender year

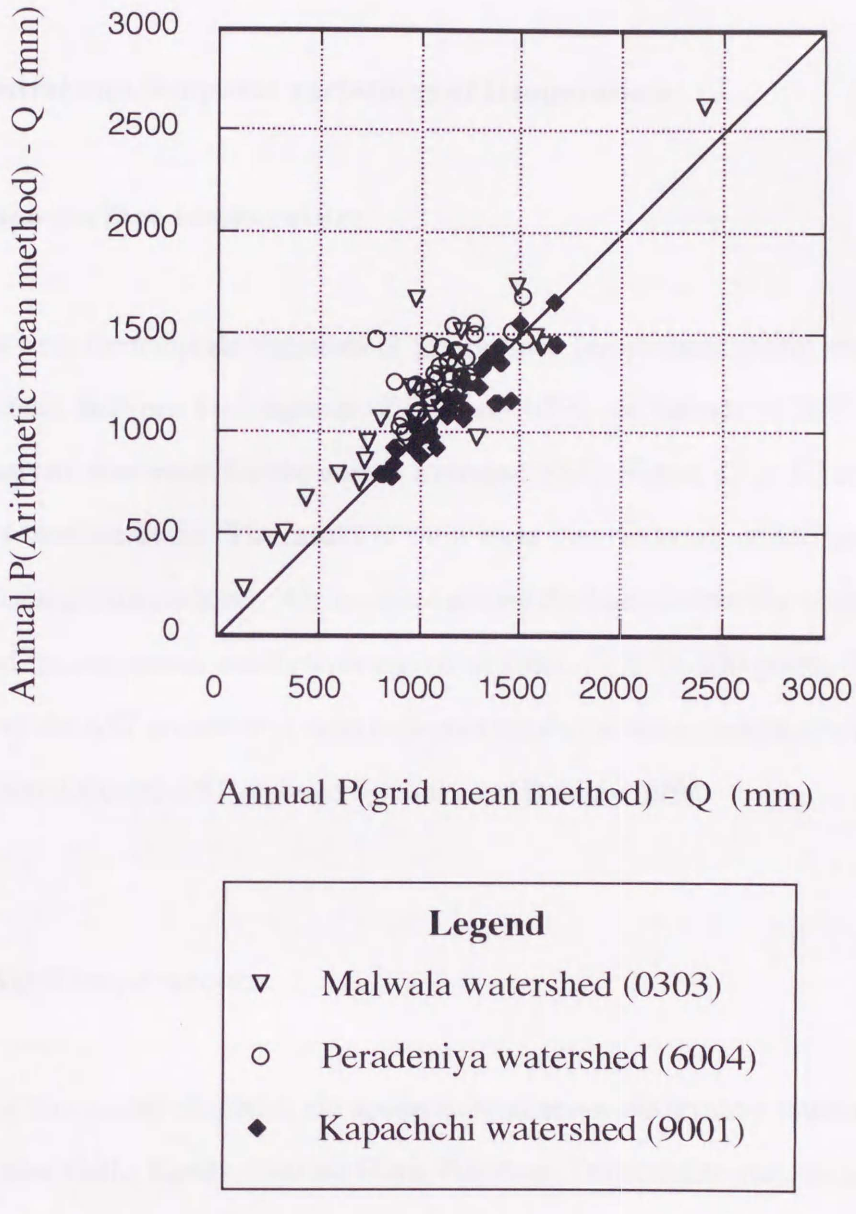


Fig.16 Comparison of areal precipitation of watershed between calculated by arithmetic mean method and grid method

Chapter 5

Results

5.1. Spatial and temporal variations of temperature

5.1.1. Sea surface temperature

To clear the temporal variations of Sea Surface Temperature (SST) around the island of Sri Lanka, between the longitude of 0°N and 10°N, the latitude of 75°E and 85°E, the trend analysis was made for the annual averaged SST. Figure 17 and Table 8 show the results of trend analyses. The results of t-test show that the trends of SST are significant at the 1 % of significance level. All sea areas around Sri Lanka show the increasing trend of SST, and the regression coefficients are about 0.86 - 0.95 °C/100 years. The trends and patterns of the SST around Sri Lanka indicated the almost same variation with the Northern Hemisphere COADS SST reported by Jones and Bradley, 1992.

5.1.2. Air Temperature

The time series of annual air temperature at seven observation stations in Sri Lanka of Colombo, Galle, Kandy, Nuwara Eliya, Puttalam, Trincomalee and Jaffna are shown in Fig.18. The seasonal variations of regression coefficients of monthly air temperature of same observation stations as Fig.18 are represented in Fig.19. Figure 18 shows that Sri Lanka had two warm periods in the last one hundred years. The first period was in the 1920's and the other period was in the 1980's. The long-term variations of annual air temperature shows the contrastive variation before the 1920's and after. The variations of former period show steep changes and regional difference, while the variations in the latter period show that the temperature had gentle increase. As shown in Fig.19, almost all stations excluding Kandy show increasing trend of annual temperature. In particular, about +1.0°C of increasing trend of air temperature are exhibited at Nuwara Eliya (+1.014°C/100 years) in the central highland area and Puttalam (+0.913°C/100 years) in the Dry Zone at the west seaside. The stations of Puttalam, Trincomalee and Jaffna located in the Dry Zone indicate a strong trend of increase of air temperature during the southwest monsoon season from June to September.

Figure 20-a to Fig. 20-l show the isopleths on the regression coefficients of monthly air temperature from January to December, and Fig.20-m shows the isopleth of annual air temperature trend. Those isopleths were figured by the regression coefficients calculated by the trend analyses of 14 stations listed in Table 6. The results of t-test show that the trends of air temperature at almost all stations excluding coastal stations with small trend of air temperature were significant at the 1 % of significance level. Figure 20-m shows that the trends on the coast excluding around Puttalam located in the Dry Zone on the west coast are less than +0.4 °C/100 years, smaller than inland area. The spatial variation is illustrated that the trend of air temperature increase toward central highland. From monthly maps of distribution of isopleth, it is clear that almost all areas of island show increasing trend during the period of the southwest monsoon season from May to September.

Figure 21 shows the secular change of lapse rate. This lapse rate was calculated on the every year since 1869 using a least square method from annual air temperature of 14 stations listed in Table 6. The maximum value of the lapse rate is 0.694°C/100m in 1875, and the minimum is 0.592°C/100m in 1990. The average of 124 years is 0.634°C/100m, and the lapse rate decreases 0.038°C/100m in 100 years. This means that the temperature difference between the different heights decreases. In the case of Sri Lanka, it is showed that the increase of air temperature at the central highland exceeded at lowland area.

The century-long variations of surface temperature at major stations in Sri Lanka and the SST on the west part of the island were reported and discussed by Kayane *et al.* (1995). As the results of analyses of air temperature in this chapter, it is clear that the stations located in the Dry Zone and the stations located in the Wet Zone of the west coastal area show the different trend of surface temperature. The stations located on the southwest coastal area in the Wet Zone such as Colombo and Galle indicate few increases of the trends. The same tendency was reported by Kayane *et al.* (1995). On the other hand, the trend of Puttalam station located on the west coastal area in the Dry Zone shows an intense increase in surface temperature. As a consequence of regional difference in the trends on the west coastal area, it was considered that areal difference of Sri Lanka, Dry Zone and Wet Zone, has different causes or response for the warming.

5.2. Spatial and temporal variations of precipitation

The time series of annual precipitation at seven observation stations in Sri Lanka of Colombo, Galle, Kandy, Nuwara Eliya, Puttalam, Trincomalee and Jaffna are shown in Fig.22. The seasonal variations of regression coefficient of monthly precipitation of same observation stations represented in Fig.22 are shown in Fig.23. In Fig.23, stations of a) to d) are located in the Wet Zone, and stations of e) to g) are located in the Dry Zone. The stations located in the Wet Zone indicate the decreasing trend of annual precipitation after the 1950's. Figure 23 shows that the stations are classified into three regions according to the pattern of seasonal variation of regression coefficient, those regions are stations Colombo and Galle located in the south west coast of Wet Zone, stations Kandy and Nuwara Eliya located in the central highland of Wet Zone and stations Puttalam, Trincomalee and Jaffna located in the northern lowland of Dry Zone. Figure 23 indicates that the regression coefficient in the Dry Zone show close to zero. However, the regression coefficient in the Wet Zone show the variety.

Figure 24-a to Fig.24-l show the isopleths of the regression coefficients of monthly precipitation from January to December, and Fig.24-m shows the isopleth of annual precipitation trend. Those isopleths were figured by the regression coefficients calculated by the trend analyses of 34 stations listed in Table 7. Some stations showing notable trend of precipitation such as Colombo and Nuwara Eliya are significant at the 1 % of significance level. As shown in Fig.24-m, the distribution of trend of the annual

precipitation show that the increasing areas of the trend distributed around Jaffna peninsula, north of island and west and southeast coast. However, the most decreasing areas distribute around Nuwara Eliya, the central highland region and near Trincomalee of east coast. From monthly maps of the isopleth, it is clear that large areas in and around central highland show decreasing trend in the southwest monsoon season from May to September. Those figures indicate that the area around near Trincomalee, upwind area of northeast monsoon, shows the decreasing trend from November to January.

Figure 25-a to Fig.25-l show the relationship between the elevation of observation stations and regression coefficients of each monthly precipitation trend from January to December, and Fig.25-m shows the same relation of annual precipitation trend. Those figures are plotted with the elevation of observation station as abscissa, and regression coefficients of precipitation as ordinate. Those figures also are plotted with the stations located in the Wet Zone as solid symbols and the stations located in the Dry Zone as open symbols. Figure 25 indicates that the relationship between elevations of observation stations and monthly precipitation trend in the Wet Zone shows negative correlation in the southwest monsoon season from May to September. Figures 25 indicate that the regression coefficients show close to zero, and the no relations with elevation exist in the northeast monsoon season from December to February. These results indicate that the decrease of precipitation in and around the central highland mainly occurs in the southwest monsoon season.

The temporal and spatial variations of monthly precipitation in Sri Lanka was also reported and discussed by Madduma Bandara and Kuruppuarachchi (1988) and Kayane *et al.*. (1995). In particular, Kayane *et al.* (1995) reported the spatial distribution of the trends of the southwest monsoon rainfall using the 16 observation points data. The author extends the number of stations for spatial analysis of the trend of monthly precipitation. As the results of the analysis using a twice number of observation points compareing with Kayane *et al.*. (1998), it is clear that the monthly precipitation in the east part of Dry Zone decrease intensely in the second intermonsoon season and the northeast monsoon season from October to January. Kayane *et al.* (1995) discussed only the intensification of southwest monsoon.

The numbers of meteorological observation point in the east part of Dry Zone are fewer than in the Wet Zone. In addition, most stations in this area concentrate near the coast. These uneven distributions of the data make difficult the discussion on the northeast monsoon. On the other hand, it is considered that the decrease of precipitation in this period affects the water balance and hydrological conditions more than other seasons because this period is the dry season with little precipitation.

5.3. Spatial and temporal variations of land use

The aerial photography of whole Sri Lanka has been taken several times from 1956. The newly published land use maps on the scale of 1/100,000 are prepared from aerial photographs from 1979 to 1983 and from satellite images by the Center for Remote Sensing, Survey Department, Sri Lanka. This land use map totalizes the area of land use by districts. As shown in Table 9, the land use was classified into seven categories.

Figure 26 shows the distribution of tea cultivation by districts. The districts with over 5% tea cultivation area were only 6 districts, Nuwara Eliya District as 36.7%, Matala District as 15.7%, Kandy District as 15.5%, Badulla District as 12.8%, Galle District as 9.7% and Ratnapura District as 6.5% among the 26 districts. These results indicate that the tea was cultivated intensively in the central highland.

Figure 27 shows the distribution of paddy area by districts. The paddy area was distributed with high percentage except mountainous central highland. In particularly, the paddy area was distributed over 15% at the lowland of Wet Zone. The highest distribution of paddy area was seen at Batticaloa District located in the east coast as 25.6%. The lowest distribution was at Moneragala District as 2.6% and the average among 26 districts was 12.6%.

Figure 28 shows the distribution of dense forest by districts. The dense forest of Sri Lanka was distributed with high percentage at the area with low population density of Dry Zone and mountainous central highland area. The highest distribution of dense forest was observed at Mullaitivu District as 51.0%. However the lowest distribution was seen at Jaffna as 0% and the average of 26 districts was 17.6%.

Figure 29 shows the distribution of sparsely used cropland by districts. The sparsely used cropland is a category of land use that consists of shifting cultivation, land under development and abandoned shifting cultivation, tea, rubber and coconut land. This land use was distributed with high percentage at the Dry Zone. In the Dry Zone, the paddy and sparsely used cropland was major agricultural land. On the other hand, the almost all districts located in the Wet Zone showed less than 10% of land use of sparsely used cropland excluding Ratnapura District. In Ratnapura Districtt, this land use was distributed in twice as mach as the average. The highest distribution of sparsely used cropland was at Moneragala District as 33.0%, the lowest distribution was at Kegalle District as 0% and the average of 26 districts was 15.7%.

The proportions of all categories of land use at 1979/83 on the selected eight watersheds are calculated using numerical data set. Figure 30 and Table 10 show the percentage of land uses for these eight watersheds.

Figure 31 indicates the distribution of land use in Peradeniya watershed (6004) in the Upper Mahaweli Ganga River catchment. Peradeniya watershed is located in the central highland of Wet Zone, the elevations of observation station and average of watershed are 463m and 1174m above the sea level. The area of watershed is 1167km², and occupies 11.3% of Mahaweli Ganga River catchment area. This Peradeniya watershed has four small watersheds. These are Holbrook watershed (6027), Talawakelle watershed (6021), Morape watershed (6009), Watawala watershed (6020) and Peradeniya watershed. The land uses for the Peradeniya watershed generally distributed toward upstream such as paddy, homesteads, tea, forest and grass land. The Peradeniya watershed had higher percentage of tea cultivation than other watersheds. The distribution of tea cultivation of Peradeniya watershed was 43% of whole watershed and Watawala watershed was 66%.

The land use pattern in Malwala watershed (0303) in the Upper Kalu Ganga River area are shown in Fig.32. Malwala watershed is located in the south-west of central highland of the Wet Zone, and the elevations of observation station and average of watershed are 18m and 464m above the sea level, respectively. The area of watershed is $329km^2$, and occupies 12.2% of Kalu Ganga River catchment area. The land use such as tea cultivation, forest and sparsely used cropland occupies about three-fourths in this watershed.

Figure 33 indicates the distribution of land use in the Mi Oya River catchment area as Tabbowa watershed (9502). Tabbowa watershed is located in the west northern lowland of the Dry Zone. This watershed includes the Mahauswewa watershed. Their areas of Tabbowa and Mahauswewa watersheds are $1,078km^2$ and $595km^2$, respectively. The elevations of observation stations at Tabbowa and Mahauswewa watersheds are 10m and 35m, respectively. The average elevations of Tabbowa and Mahauswewa watersheds are 85m and 105m, respectively. The conspicuous land use of those watersheds were tank, paddy, mangroves and sparsely used cropland.

The Natural Resources, Energy and Science Authority of Sri Lanka reported the land use change of the whole island between 1956 and 1984 at 1988. Table 11 summarizes the areal change of major land uses. The tea cultivation and forest areas decreased about 14% and 26% during this period. However, other crops increased about 40%.

The Center for Remote Sensing, Survey Department of Sri Lanka (1988) published the Tea Map indicating the distribution of tea cultivation in 1956 and 1979/83. Figure 34 shows the distribution of tea cultivation of Sri Lanka in 1956, and Fig.35 shows the distribution of tea cultivation in 1979/83. Figure 36 indicates the distribution of area where the land use changes to tea cultivation from others between 1956 and 1979/83. Figure 36 illustrates that the newly cultivated areas distribute in the almost area where the tea cultivated at 1956. In particularly, the areas of tea cultivation where the land use changes from other cultivations were distributed notably on Matara and Galle Districts of the southwest country.

The distribution of abandoned tea cultivation area between 1956 and 1979/83 is shown in Fig.37. This area distributed notably on the south of Kandy and west of Nuwara Eliya.

5.4. Spatial and temporal variations of water balance

The results of annual averaged water balance of 135 watersheds based on the data of more than one year is listed in Table 12. This results was obtained for only years that the water loss of the year is positive. The stations listed in Table 12 include the observation stations affected by human activities such as construction of reservoirs for hydropower and irrigation. The results of water balance of the selected 33 watersheds with no effect of human activities and observation period over 10 years data are shown in Table 13. These 33 watersheds can be classified into five climatic and topographic regions of southwest coast of Wet Zone, southwest inland of Wet Zone, central highland of Wet Zone, southeast of Dry Zone and northern lowland of Dry Zone.

Figure 38 shows the distribution of average annual areal precipitation of the 33 watersheds. When a watershed has other upstream watersheds, the elements of water balance was recalculated about the values of between area of those observation points. The maximum of average annual areal precipitation is 4794.2mm of Deraniyagala watershed (0105) and the minimum is 1326.3mm of Yakawewa watershed (6901). The average of 15 watersheds located in the Wet Zone is 3290.2mm and that of 18 watersheds located in the Dry Zone is 1623.4mm.

The distribution of average annual discharge of the 33 watersheds is shown in Fig.39. The maximum of average annual discharge is 4411.0mm of Deraniyagala watershed (0105) where Kelani Ganga River flows. This watershed also has maximum areal precipitation. However, the minimum of average annual discharge is 132.3mm of Tabbowa watershed (9502) of Mi Oya River. The average of 15 watersheds located in the Wet Zone is 2136.4mm and that of 18 watershed located in the Dry Zone is 479.0mm.

Figure 40 illustrates the distribution of the average annual runoff ratio of the 33 watersheds. The average of it of 15 watersheds located in the Wet Zone is 63% and that of 18 watersheds located in the Dry Zone is 28%.

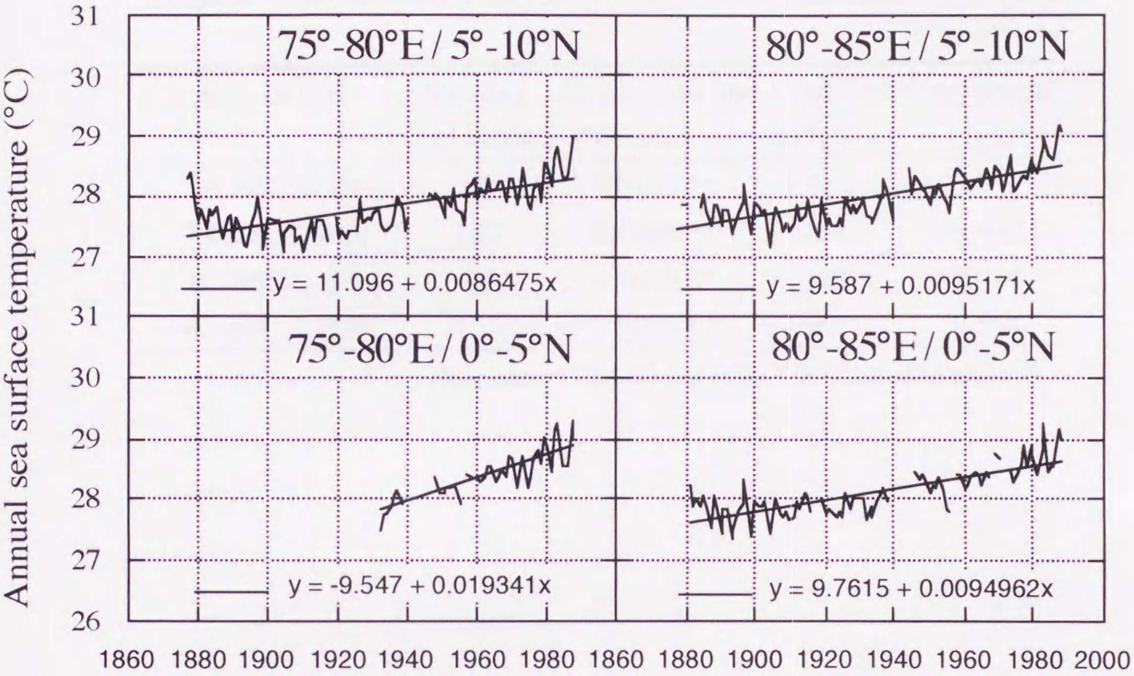
Figure 41 shows the distribution of the average annual water loss of the 33 watersheds. The estimated water loss with no effect of human activities and long-term observation data can be considered as actual evapotranspiration of a watershed. The maximum and minimum of average annual actual evapotranspiration of watershed are 2009.6mm and 482.5mm, respectively. The average of it of 15 watersheds located in the Wet Zone is 1153.9mm and that of 18 watersheds located in the Dry Zone is 1150.6mm. There is no difference in the averages of actual evapotranspiration between the Wet Zone and the Dry Zone. The total average of all 33 watersheds is 1152.1mm.

Figure 42 indicates the time series of water balance elements at five representative watersheds of Putupaula watershed of Kalu Ganga River (0301), Malwala watershed of Kalu Ganga River (0303), Peradeniya watershed of Mahaweli Ganga River (6004), Lunugamwehera watershed of Kirindi Oya River (2201) and Kappachchi watershed of Aruvi Aru River (9001) which represent each climatic and topographic region, respectively. Only the Malwala watershed (0303) located in the southwest inland of Wet Zone shows the converse trend between areal precipitation and discharge. However, other four watersheds in this figure indicate almost similar decreasing trend between areal precipitation and discharge.

Figure 43 indicates the distribution of trend of areal annual precipitation of the selected 33 watersheds. These trends are classified into three categories based on the values of regression coefficients such as increasing trend with the value of higher than +3mm/year, decreasing trend with the values of less than -3mm/year and invariable with the values between -3mm/year and +3mm/year. The results of trend analyses of annual areal precipitation, annual discharge, annual water loss and annual runoff ratio for the 33 watersheds are shown in Table 14. The results of t-test show that the trends of water balance in the Wet Zone are significant at the 1 % of significance level. On the other hand, many watersheds located in the Dry Zone show a large standard error. Figure 43 shows that 22 of 33 watersheds have the decreasing trend of areal precipitation.

The distribution of trend of discharge classified by into the same category as Fig.43 is illustrated in Fig.44. The seven of 33 watersheds have the decreasing trend of discharge, but 15 watersheds have the increasing trend of discharge. The increasing trend of discharge distributes notably in the southwest inland of the Wet Zone. This region shows the converse trend between areal precipitation and discharge, as shown in Fig.43. In the Wet Zone, only inland area shows the increasing trend of discharge. Therefore, it is presumed that some geographical factors such as deforestation may affect the tendency observed in this area.

Figure 45 indicates the distribution of trend of water loss of the catchments area classified into the same category as Fig.44. The 21 of 33 watersheds indicate the decreasing trend of water loss of catchment area.



(Sea surface temperature data set compiled by United Kingdom Meteorological Office (UKMO SST) was quoted from Nakagawa *et al.*(1995))

Fig.17 Time series of sea surface temperature around the island of Sri Lanka

Table 8 Regression analyses of annual sea surface temperature

Area of SST	Number of years	Regression line (Y=aX+b) a (°C/year)	b (°C)	Coefficient (r^2)
75-80E/0-5N	47	0.0193 **	-9.547	0.693
75-80E/5-10N	107	0.0086 **	11.096	0.462
80-85E/0-5N	95	0.0095 **	9.762	0.614
80-85E/5-10N	106	0.0095 **	9.587	0.554

(Remarks ** : significant at the 1 % of significance level)

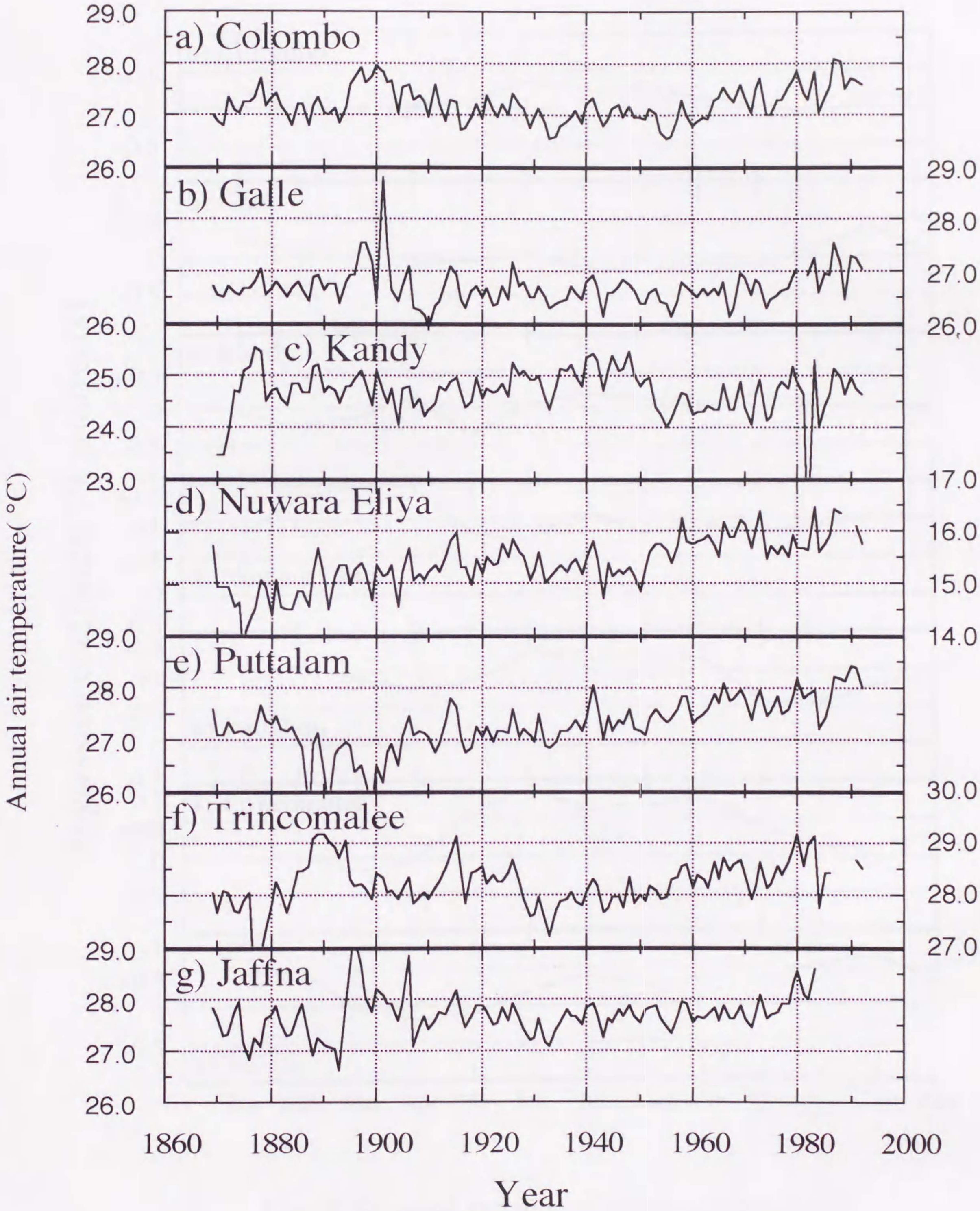


Fig.18 Time series of annual air temperature

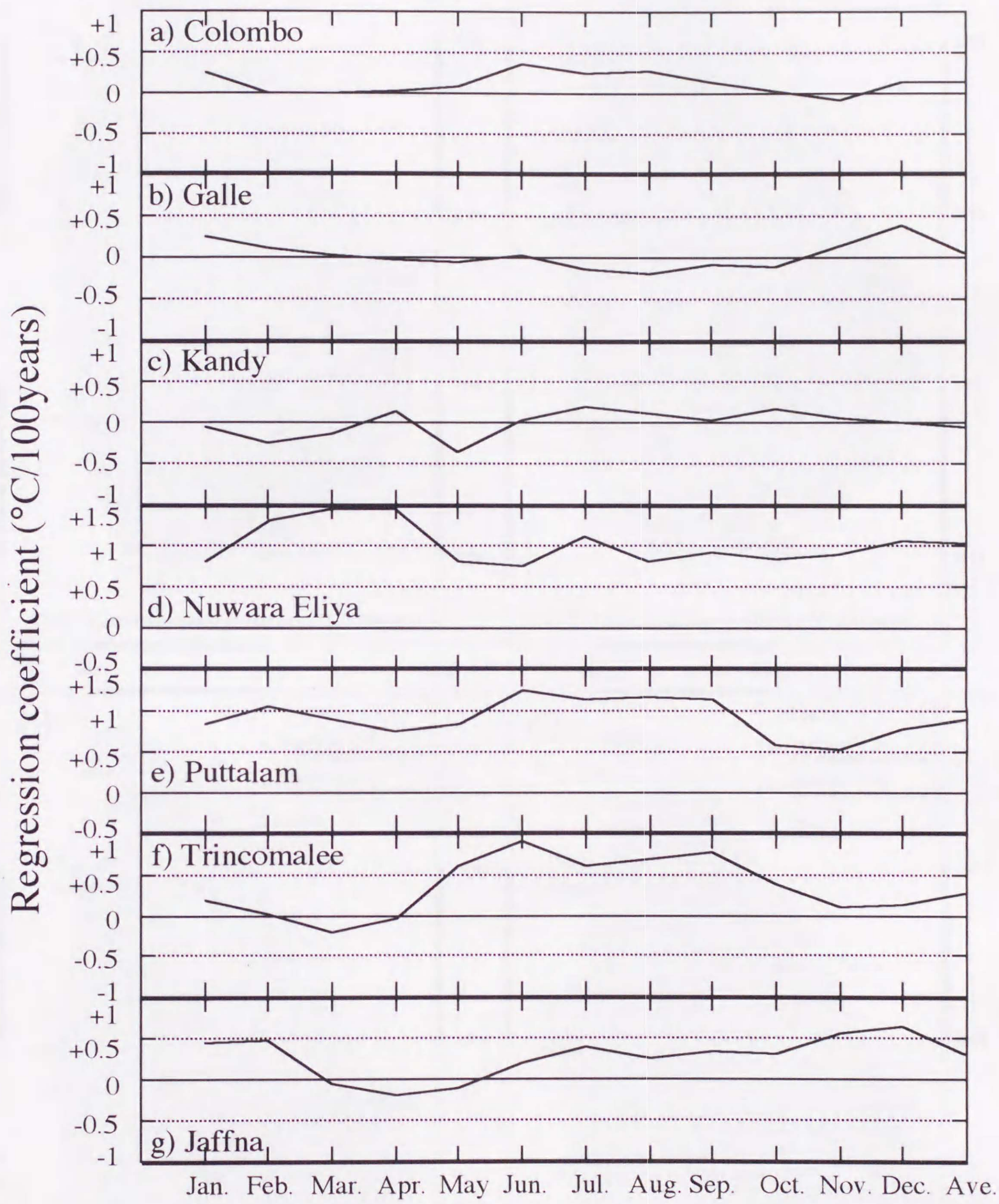


Fig.19 Seasonal variation of regression coefficient of monthly air temperature

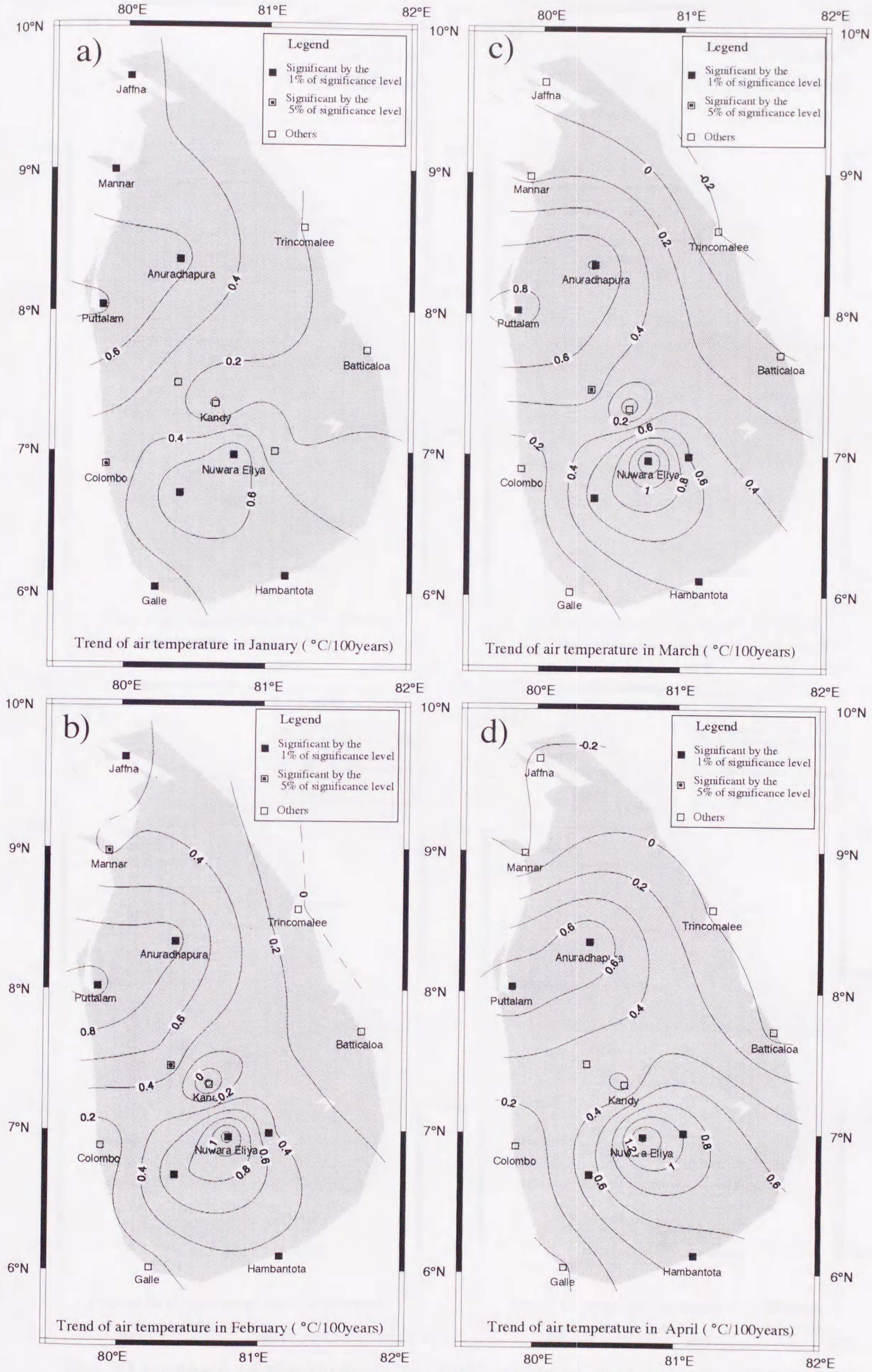


Fig.20 Isopleth of the regression coefficients of monthly air temperature (in January - in April)

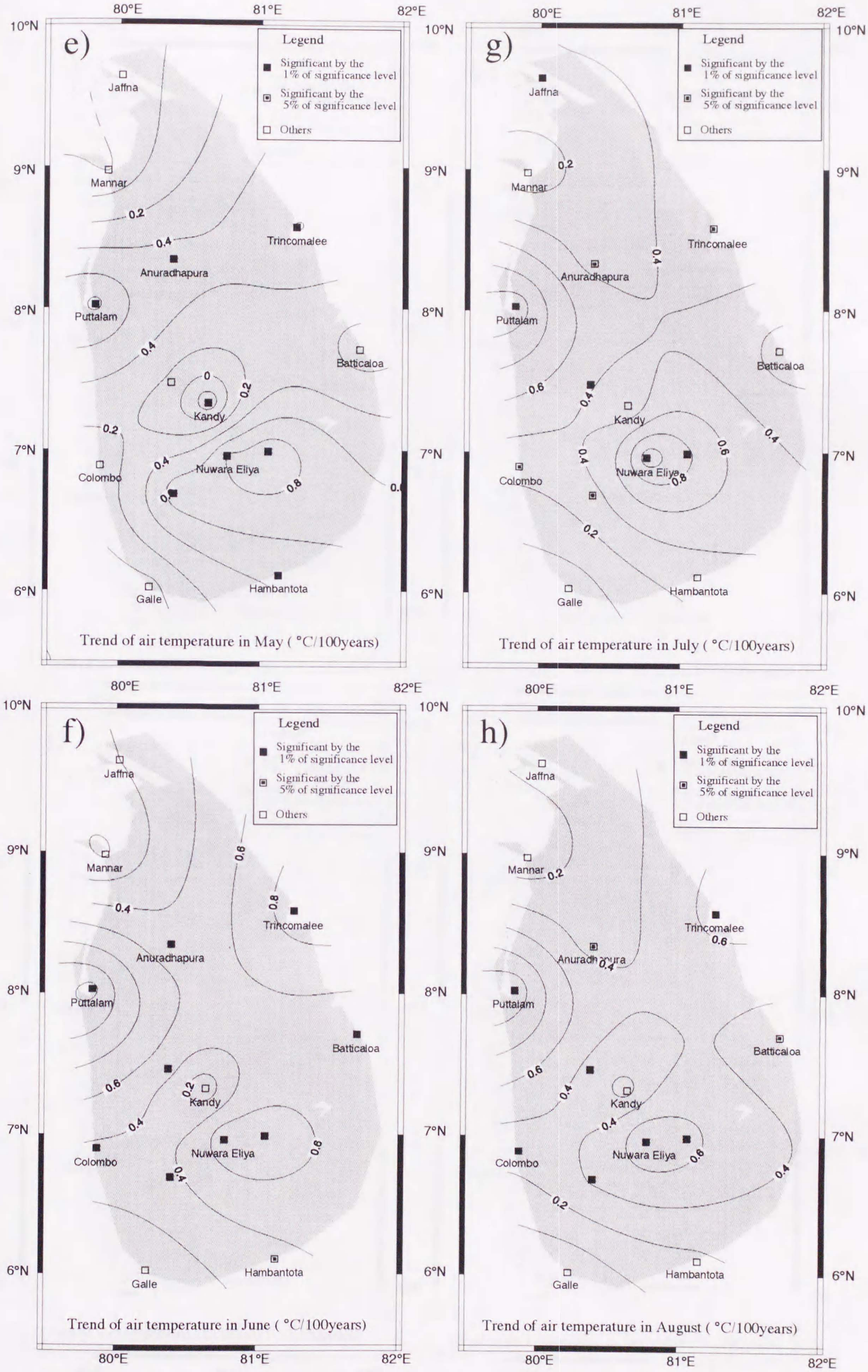


Fig.20 Isopleth of the regression coefficients of monthly air temperature (continue but in May - in August)

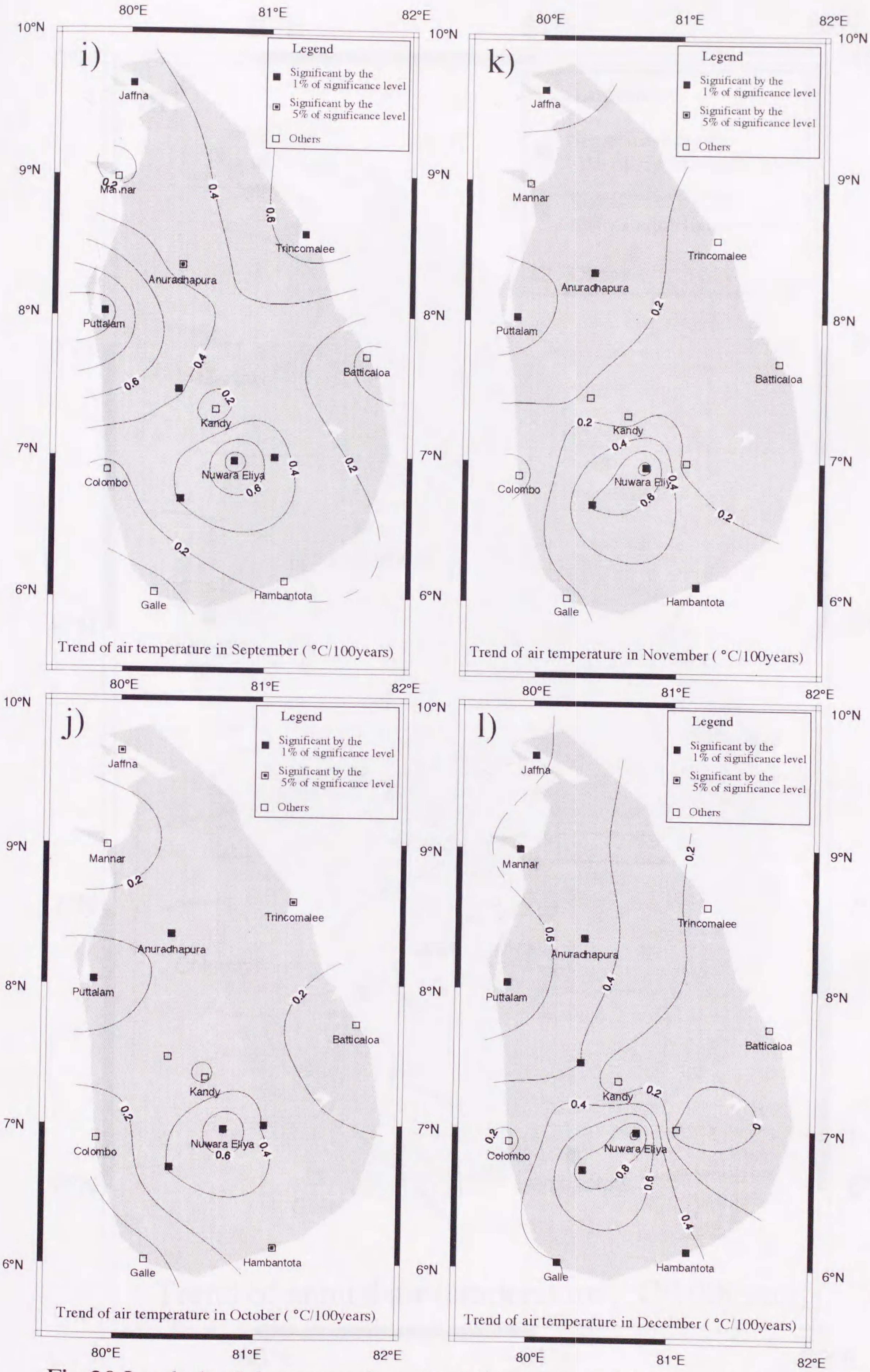


Fig.20 Isopleth of the regression coefficients of monthly air temperature (continue but in September - in December)

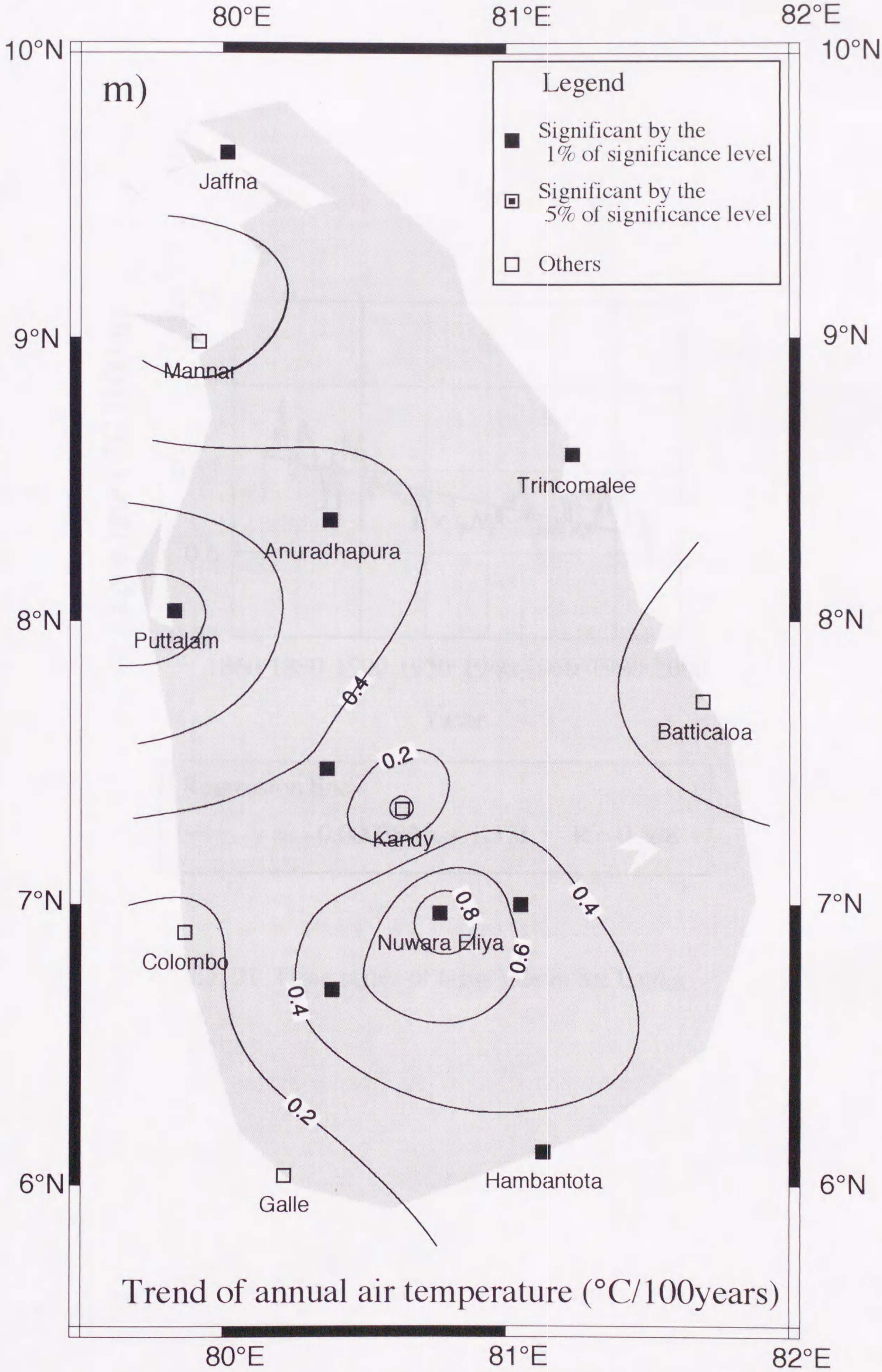


Fig.20 Isopleth of the regression coefficients of annual air temperature

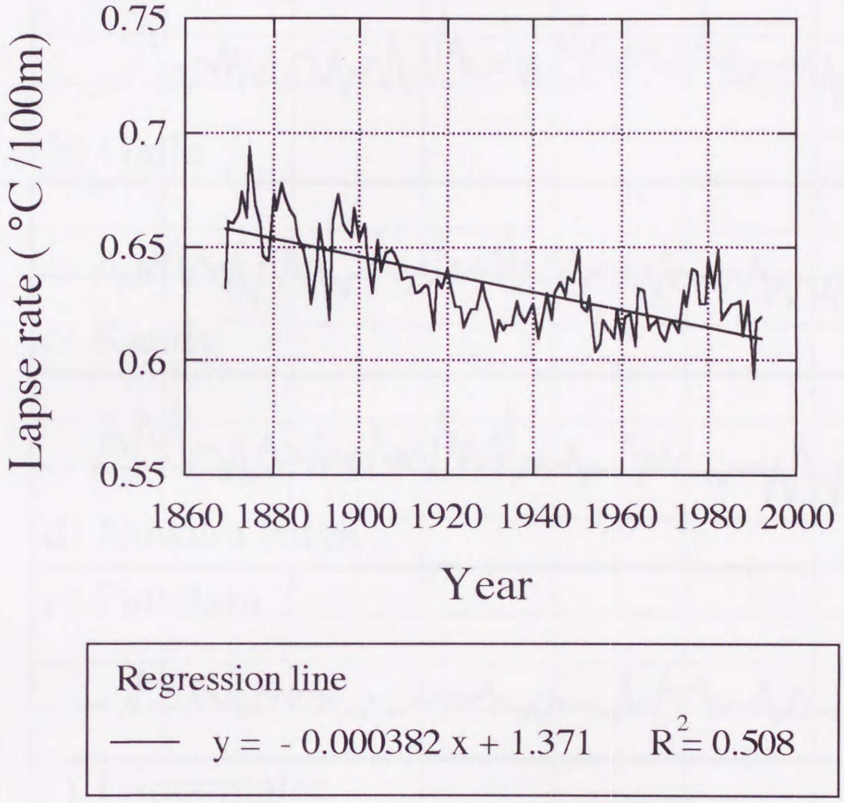


Fig. 21 Time series of lapse rate in Sri Lanka

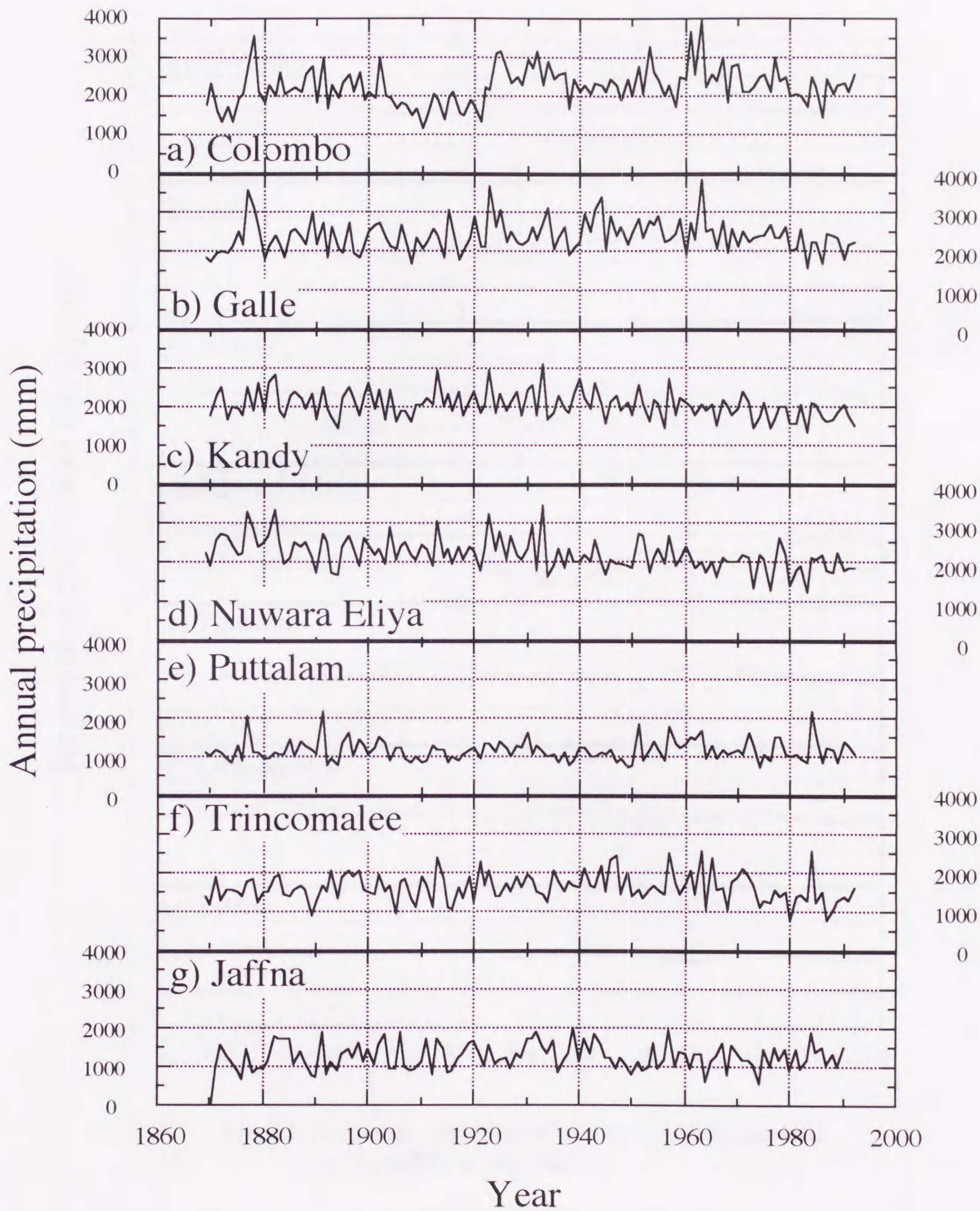


Fig.22 Time series of annual precipitation

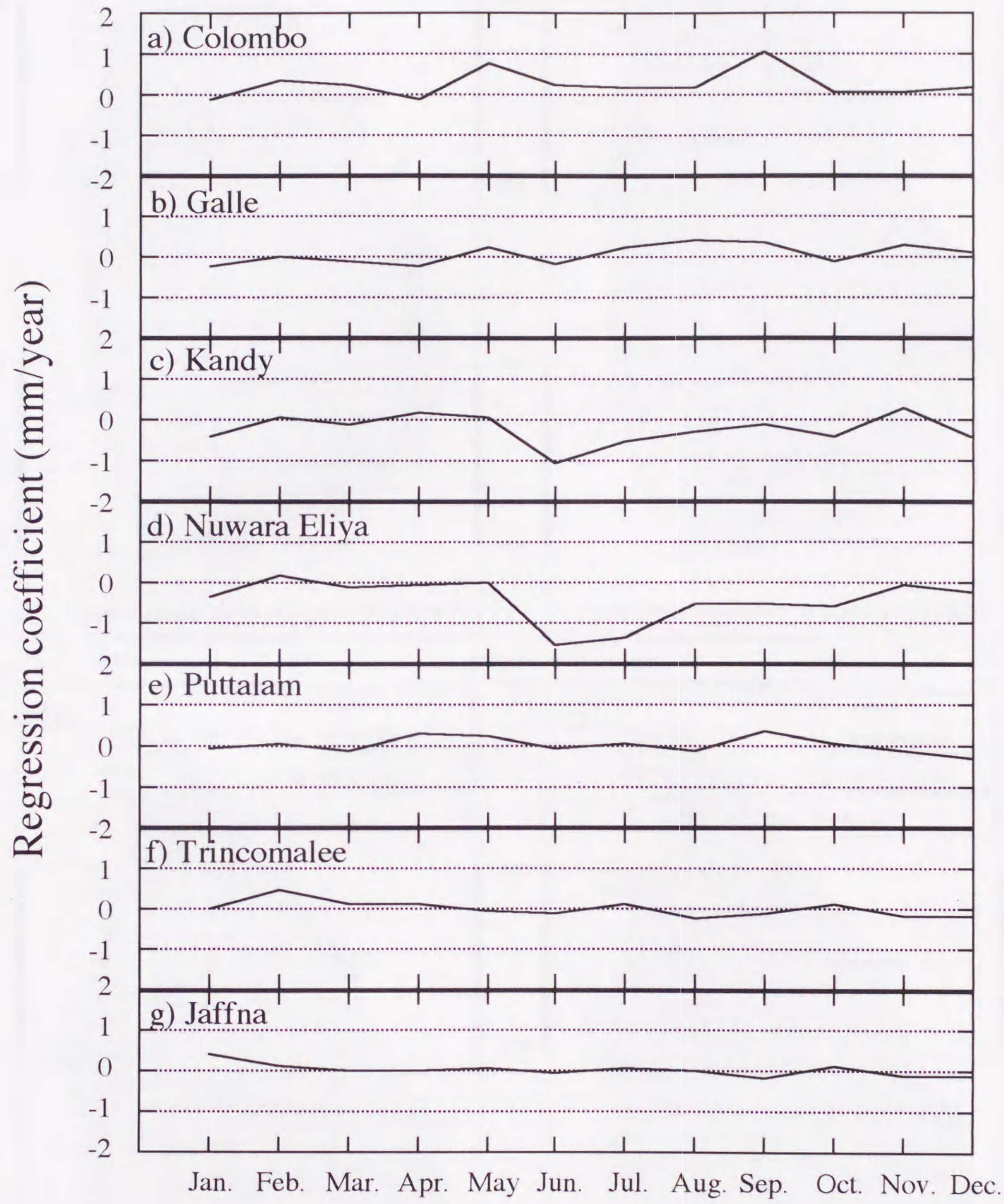


Fig.23 Seasonal variation of regression coefficitent of monthly precipitation

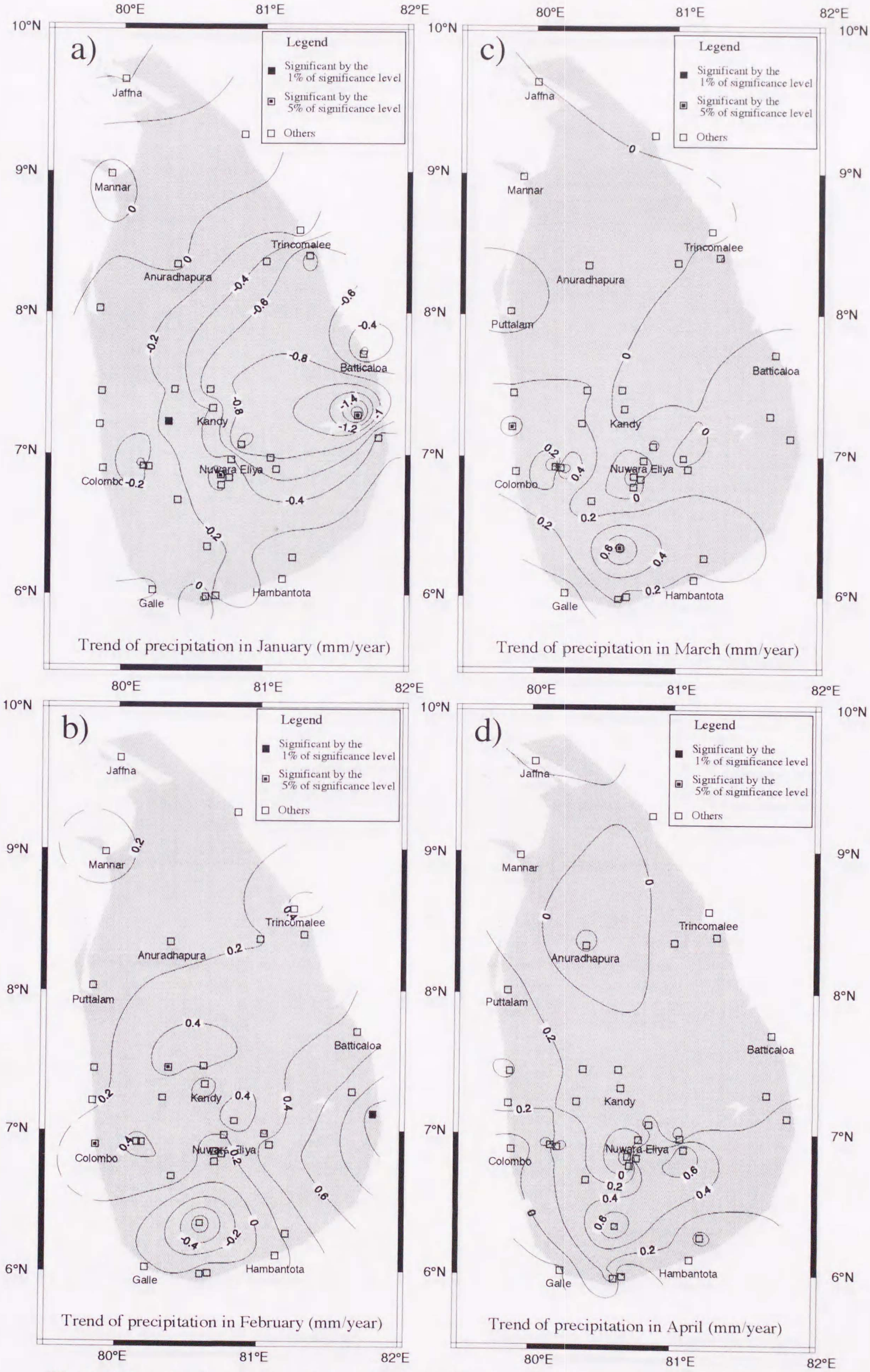


Fig.24 Isopleth of the regression coefficients of monthly precipitation (in January - in April)

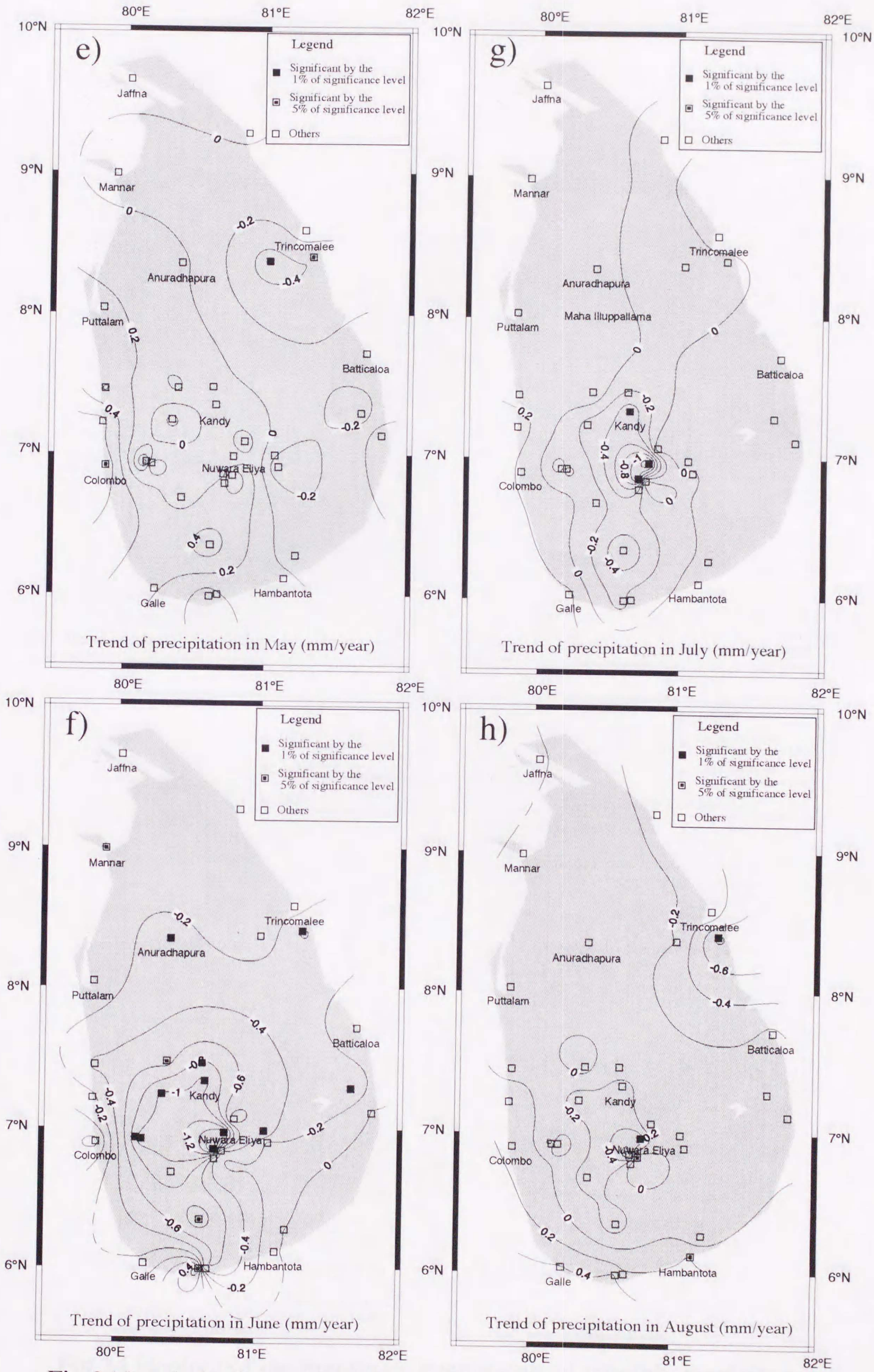


Fig.24 Isopleth of the regression coefficients of monthly precipitation (continue but in May - in August)

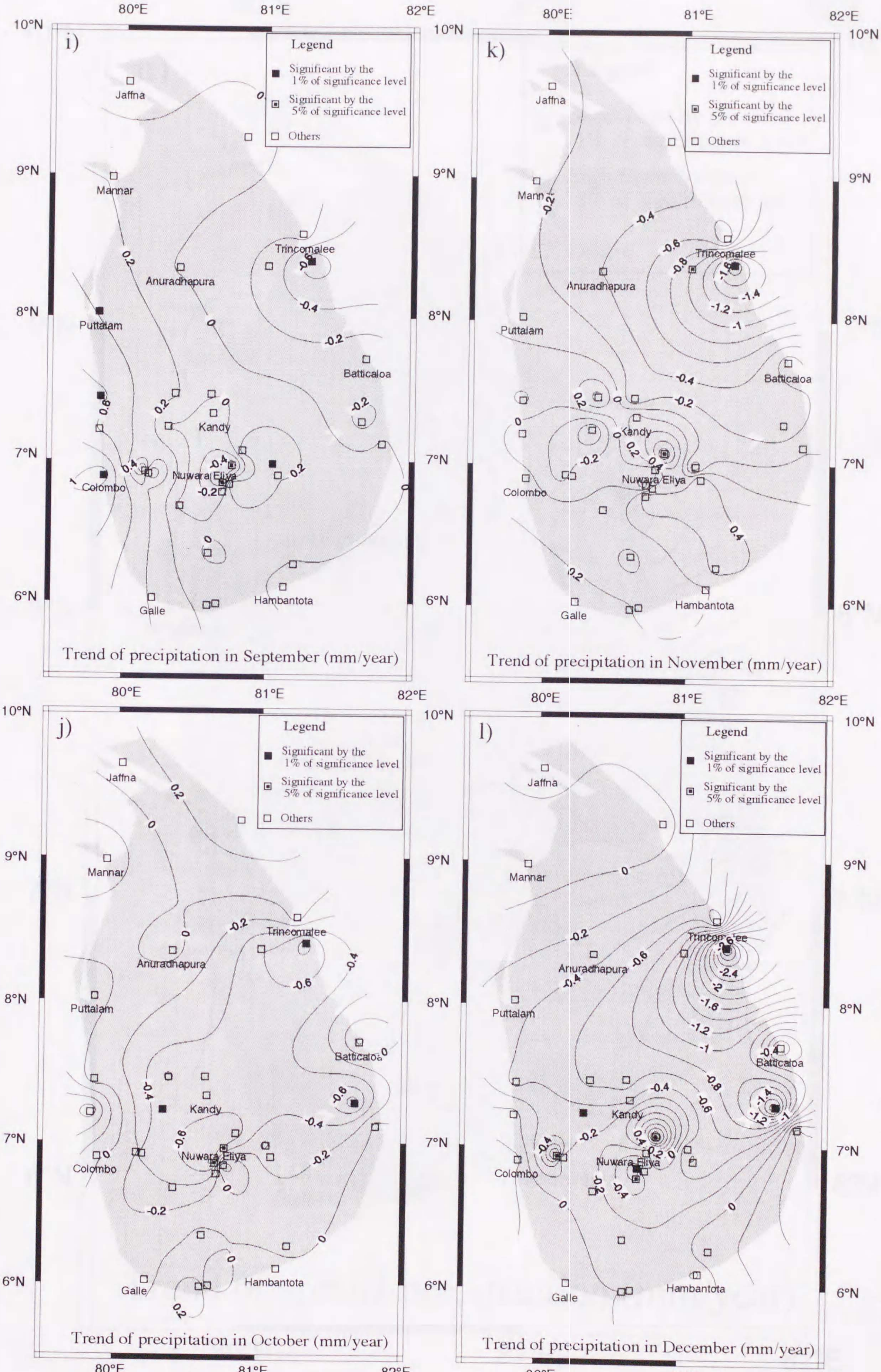


Fig.24 Isopleth of the regression coefficients of monthly precipitation (continue but in September - in December)

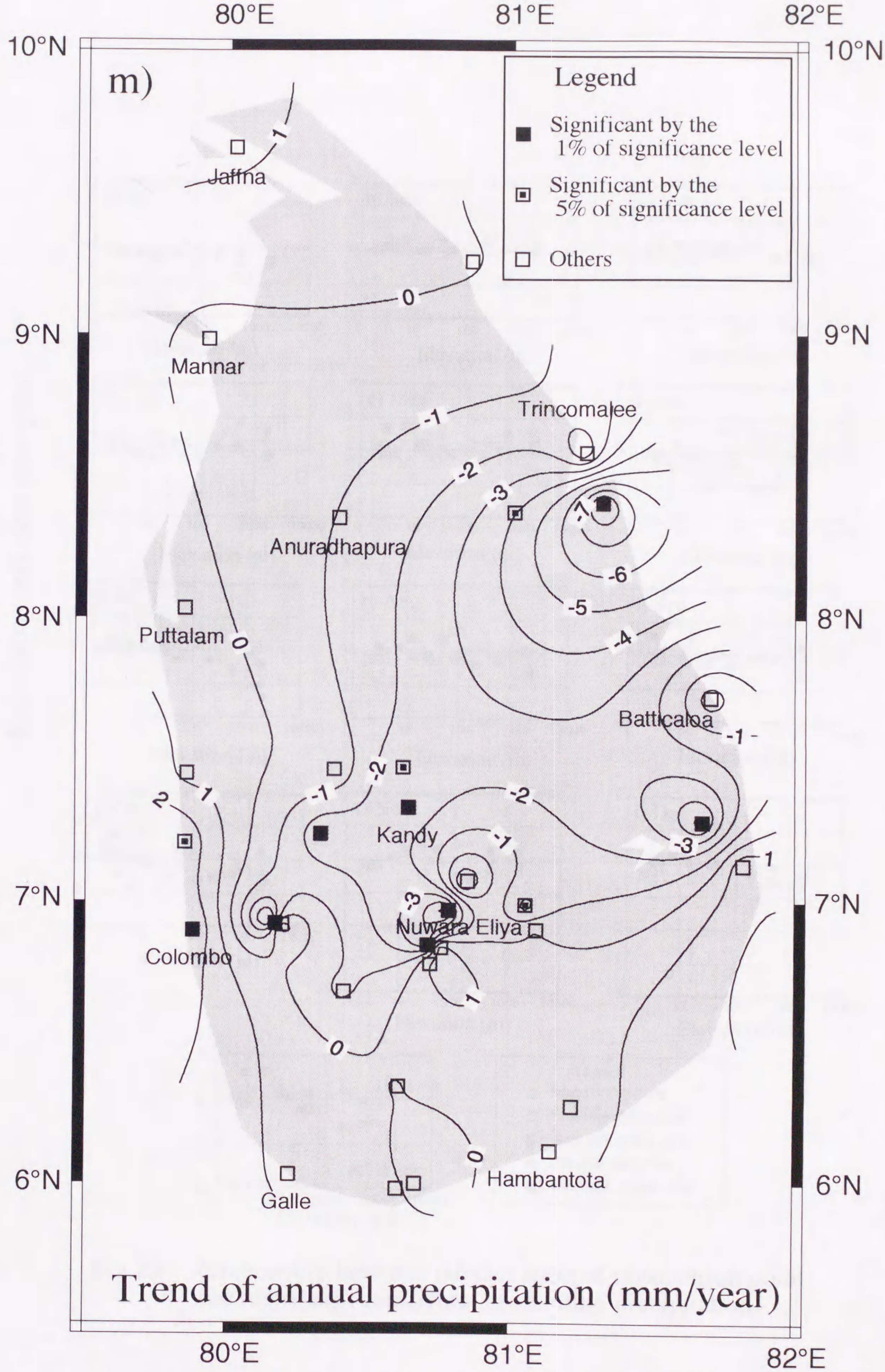


Fig.24 Isopleth of the regression coefficients of annual precipitation

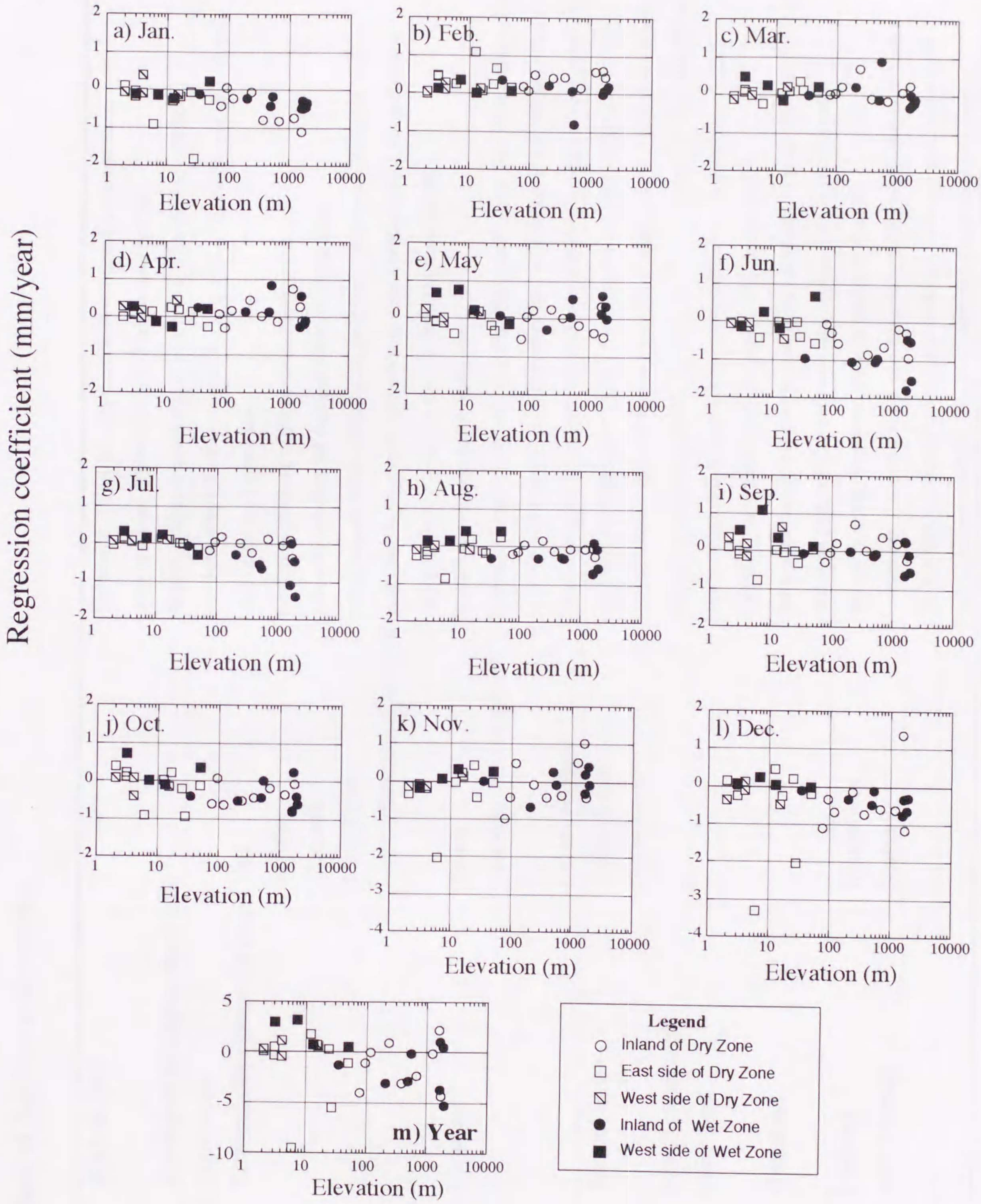


Fig.25 Relationship between the elevation of observation point and regression coefficient of monthly precipitation

Table 9 Legend of land use and remarks

Urban land	Buid-up land		Residential, industrial, commercial, institutional, administrative, tranceportion, power, plants and urban open spaces.
	Associated non-agricultural land		Minimg, archaeological sites, transmitters, salterns, and quarries.
Agricultural land	Homesteads		Family residential units surrounded by gerdens, fruit trees and open space.
	Tree and other perennial crops	Tea	Land under tea cultivation.
		Rubber	Systematic planting of rubber trees in plantations.
		Coconut	Systematic plantinf of coconut palms in plantations.
		Mixed tree and otherperennial crops	Continuous plots of coffee,cacao,jack, kitul, palmyrah, cinnamon, cadju, and other fruit trees or spices partly mixed with coconut, tea and rubber, many of these tree-crops are also found in homesteads.
	Cropland	Paddy	Rainfed or irrigated paddy cultivation.
		Sparsely used cropland	Chena(Shifting cultivation). recently abandoned chena, land under development, sparsely used rainfed cropland, neglected or abandoned tea, rubber and coconut lands.
		Other cropland	Tabacco, vegetables, sugar cane and rainfed highland crops in continuous plots.
Forestland	Natural forest	Dense forest	Dense natural forest cover with a crown closure of more than approx. 75%.
		Open forest	Natural forest cover with a crown closure of approx. 45% - 75% and a dense undergrowth.
	Forest plantations		Man-made, mostly mono-cultural forests of teak, eucalyptus, pines and others.
Rangeland	Scrubland		Low growing vegetation with more than 50% area coverage, including trees with less than approx. 45% crown closure.
	Grassland		Damana, savannah and patana grassland, villus and other temporarily flooded land, and open park country with less than approx. 50% scrub coverage.
Wetland	Forested	Mangroves	Tree cover along sea coasts, lagoons and river mouths.
	Non-forested	Marsh	Permanently wet and muddy, uncultivable and frequently inundated areas.
Water			Sea, lagoons, tanks,major rivers and wetlands, showing max. water level.
Barrenland			Rock outcrops, sandbars, beaches, earth slides and other bare land.

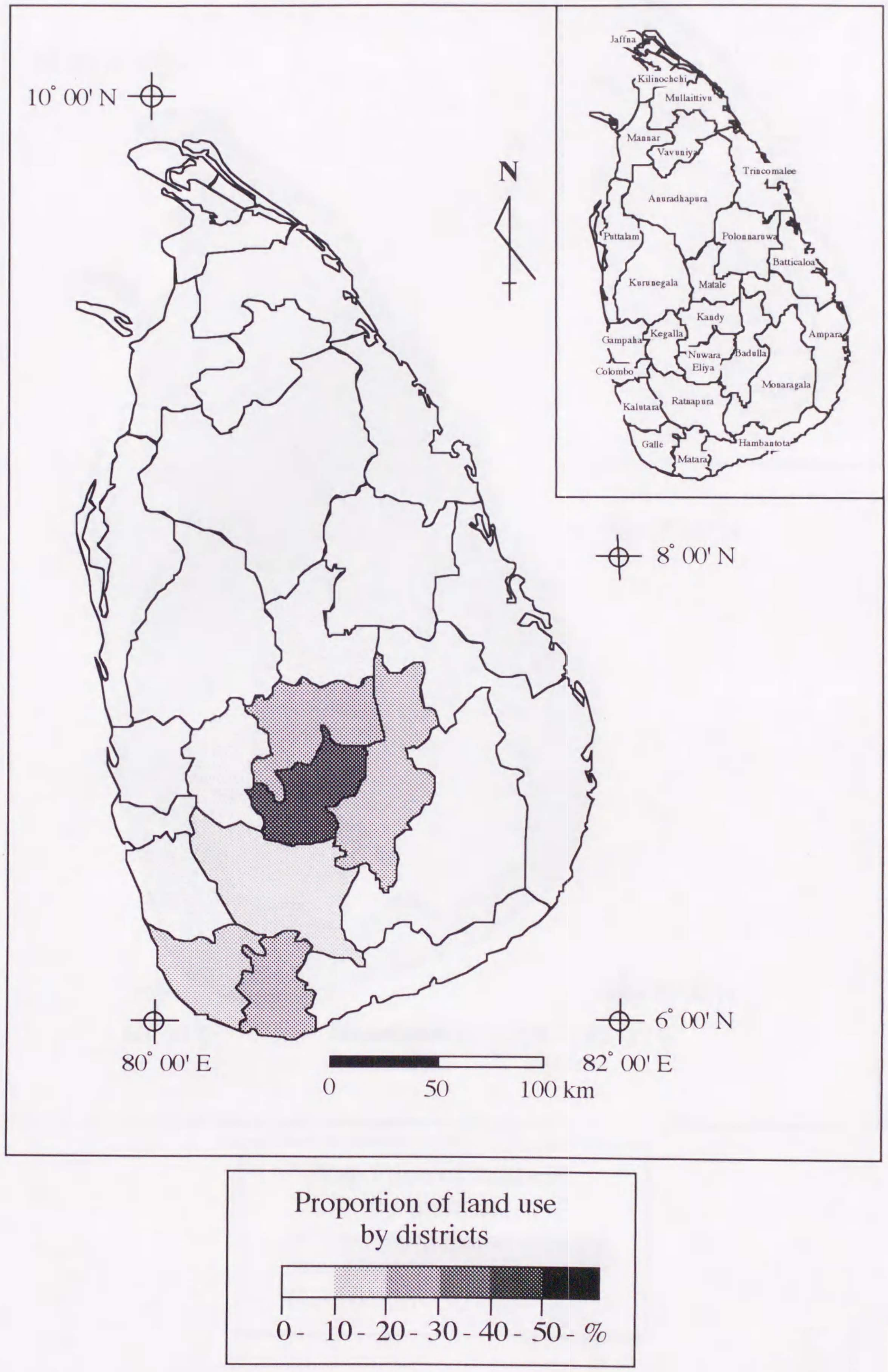


Fig.26 Proportion of tea cultivation by districts in 1983

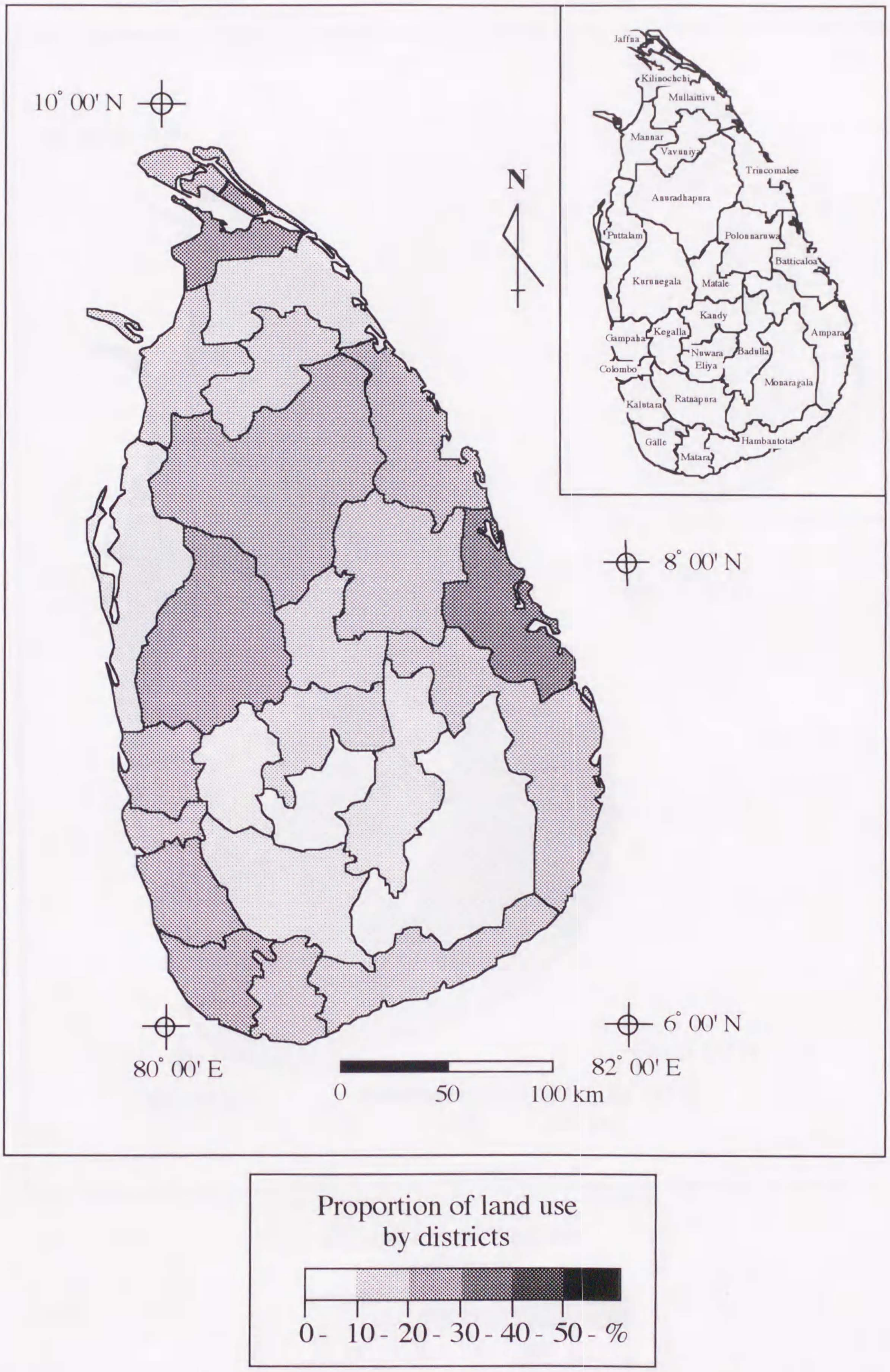


Fig.27 Proportion of paddy area by districts in 1983

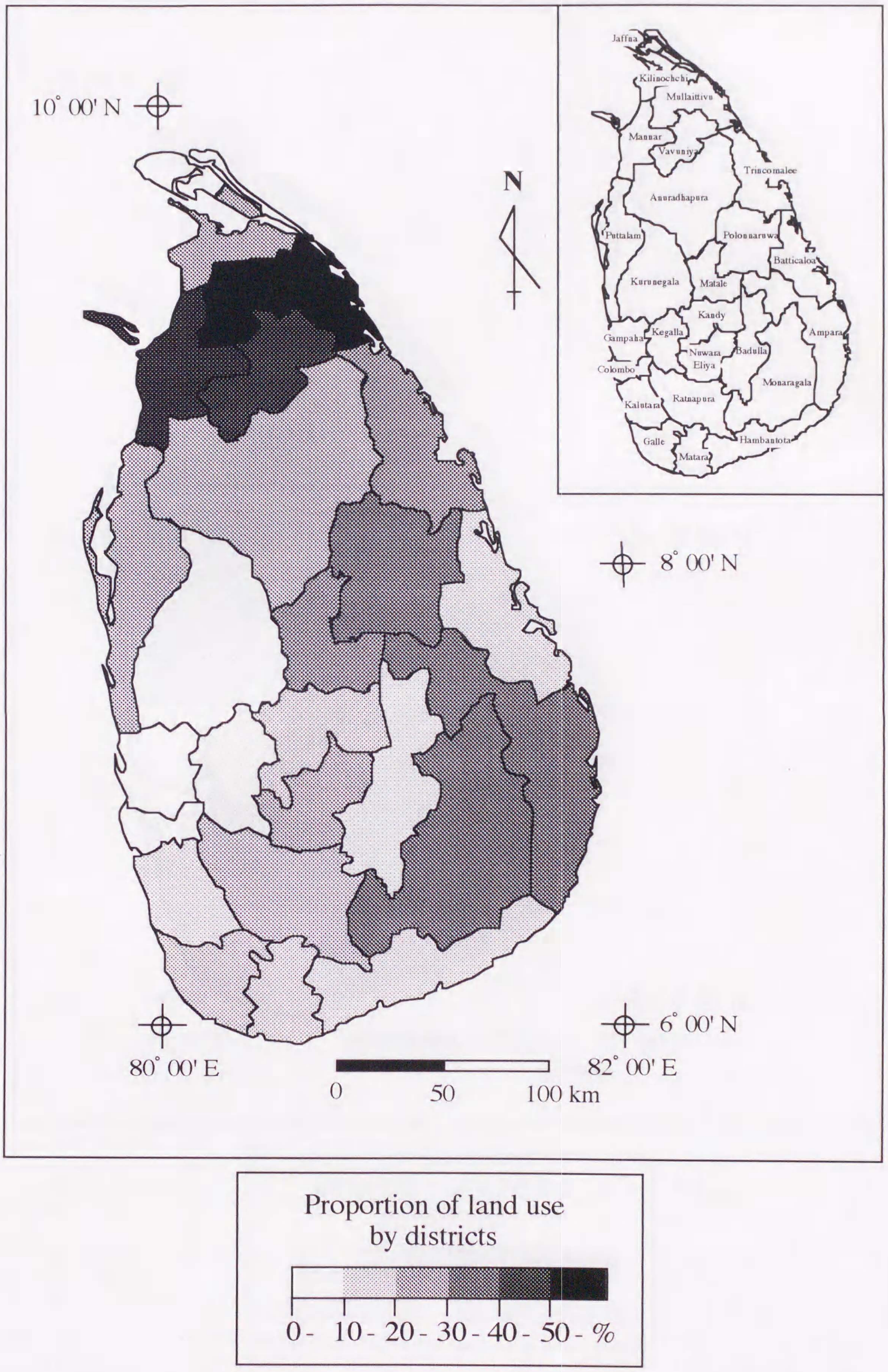


Fig.28 Proportion of dense forest area by districts in 1983

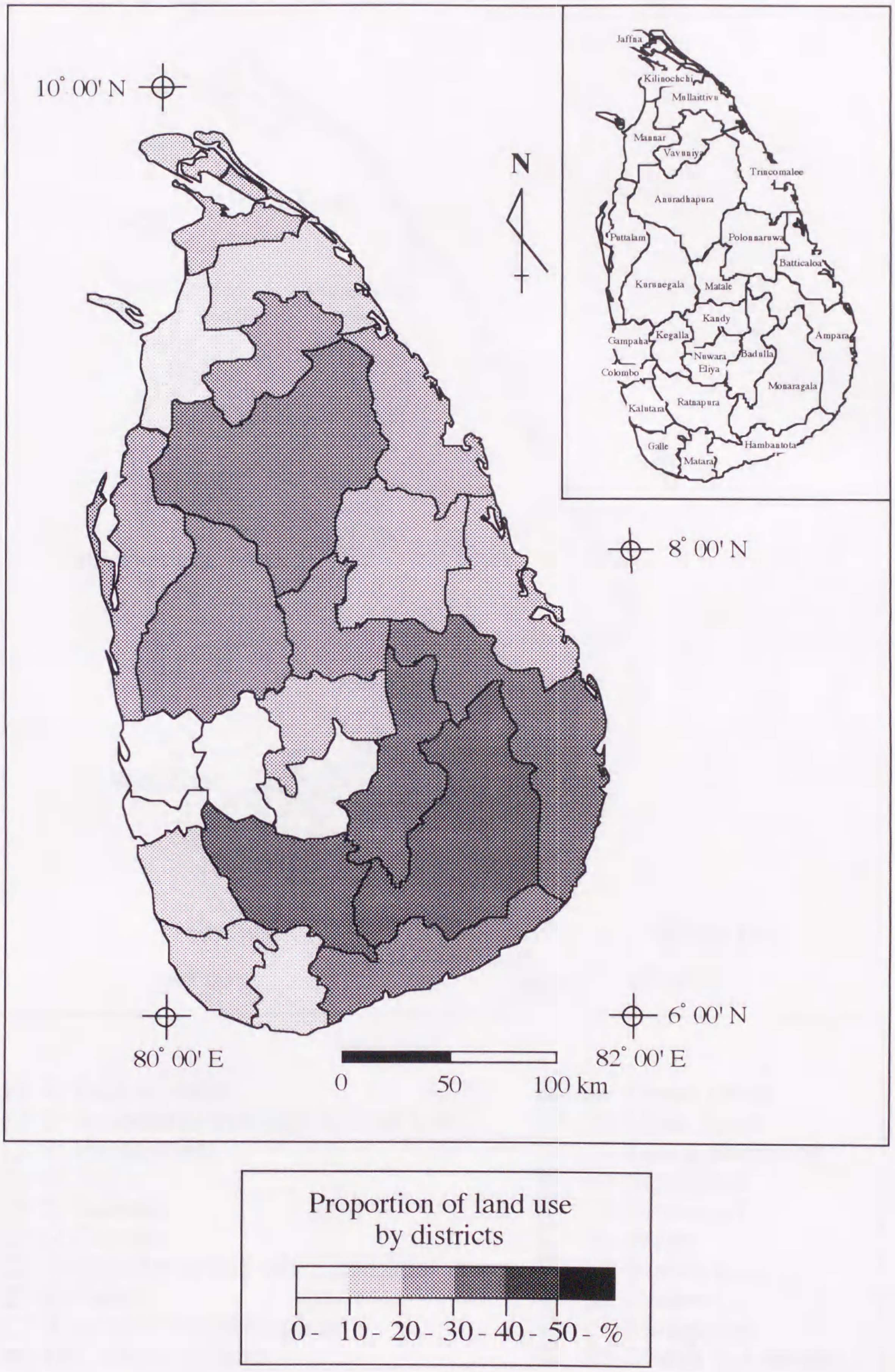


Fig.29 Proportion of sparsely used cropland by districts in 1983

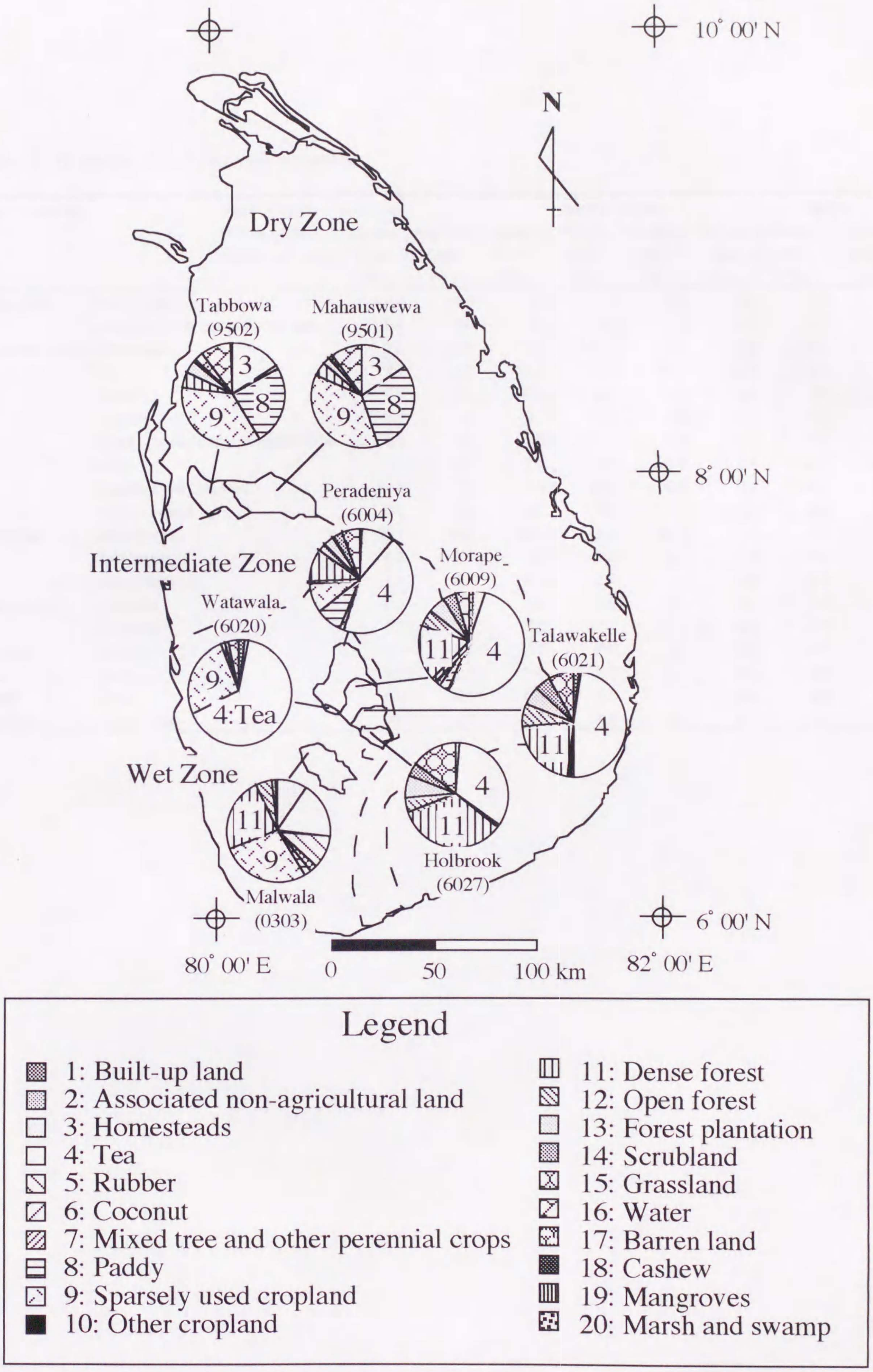


Fig.30 Land use on the selected watersheds in 1983

Table 10 Proportion of land use on the watersheds

Type of land use	Name of river	Kalu Ganga	Mahaweli Ganga					Mi Oya	
	Station name	Malwala	Peradeniya	Morape	Watawala	Talawakelle	Holbrook	Mahauswewa	Tabbowa
	Number of station	0303	6004	6009	6020	6021	6027	9501	9502
		(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Urban land	Built-Up land	0.0	0.9	0.9	1.6	1.5	0.0	0.0	0.1
	Associated Non-Agricultural Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Agricultural land	Homesteads	9.5	10.6	3.9	0.8	0.6	1.0	15.3	15.7
	Tea	17.3	43.1	51.9	65.6	47.8	33.4	0.0	0.0
	Rubber	9.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Coconut	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
	Mixed Tree and Other Perennial Crop	2.5	1.8	0.5	0.0	0.0	0.0	0.0	0.0
	Paddy	2.6	8.1	2.6	0.0	1.0	0.4	29.6	25.3
	Sparsely Used Cropland	27.3	9.6	1.4	25.6	0.6	0.6	36.0	34.9
	Other Cropland	0.0	0.6	1.2	0.0	1.1	0.0	0.0	0.1
Forestland	Dense Forest	23.7	10.1	18.0	1.6	21.4	33.6	5.2	4.9
	Open Forest	5.2	2.9	5.4	0.0	6.7	4.8	0.0	0.5
	Forest Plantation	1.4	3.2	5.1	1.6	6.5	6.9	2.2	3.7
Rangeland	Scrubland	0.6	3.4	4.3	0.0	5.1	4.6	0.9	1.2
	Grassland	0.0	5.5	4.6	3.2	7.4	14.4	0.4	2.8
Wetland	Mangroves	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
	Marsh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Water	Water	0.0	0.1	0.1	0.0	0.2	0.0	9.8	9.5
Barrenland	Barren Land	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.3

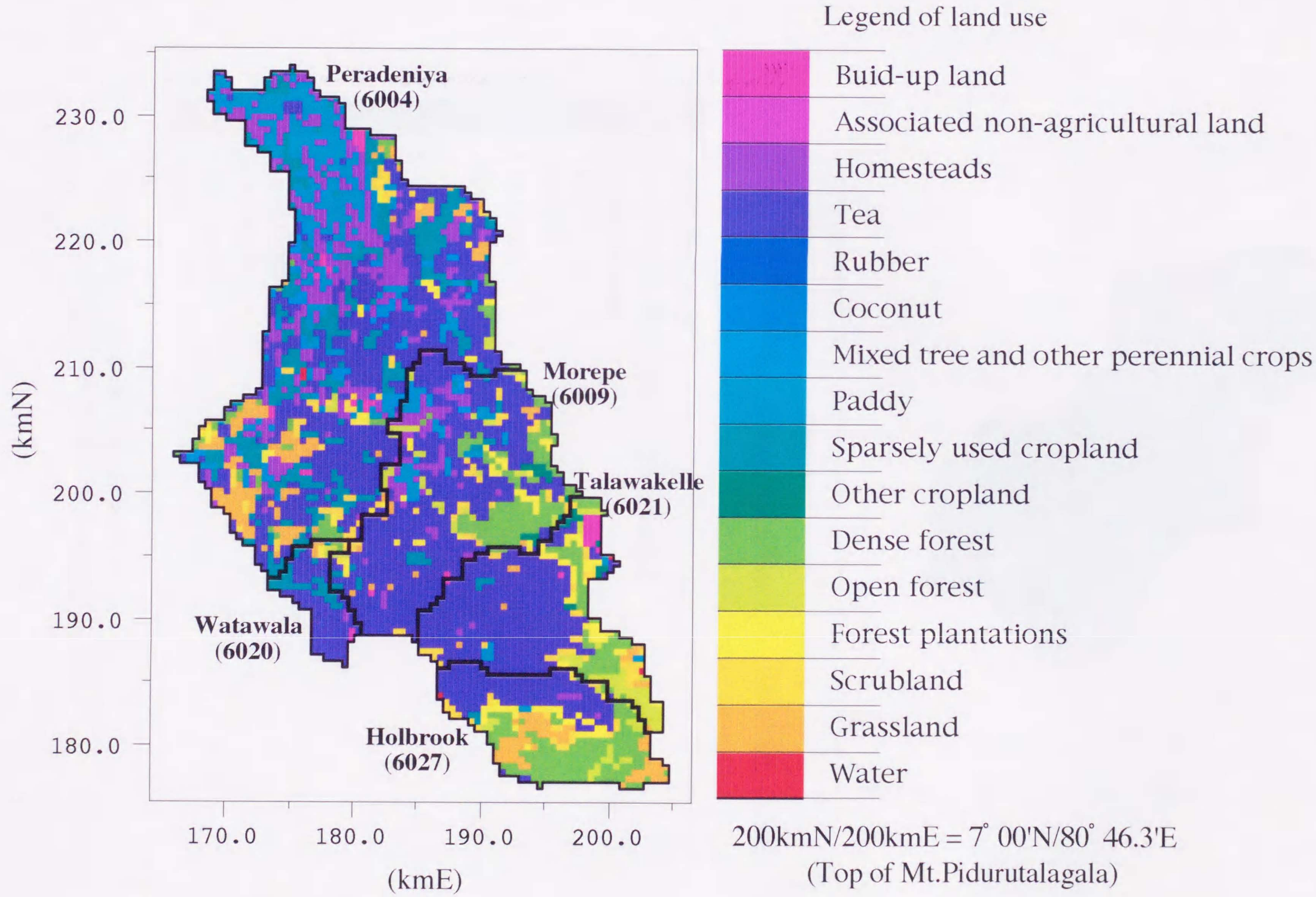


Fig.31 Distribution map of land use of upper Mahaweli Ganga River catchment in 1983

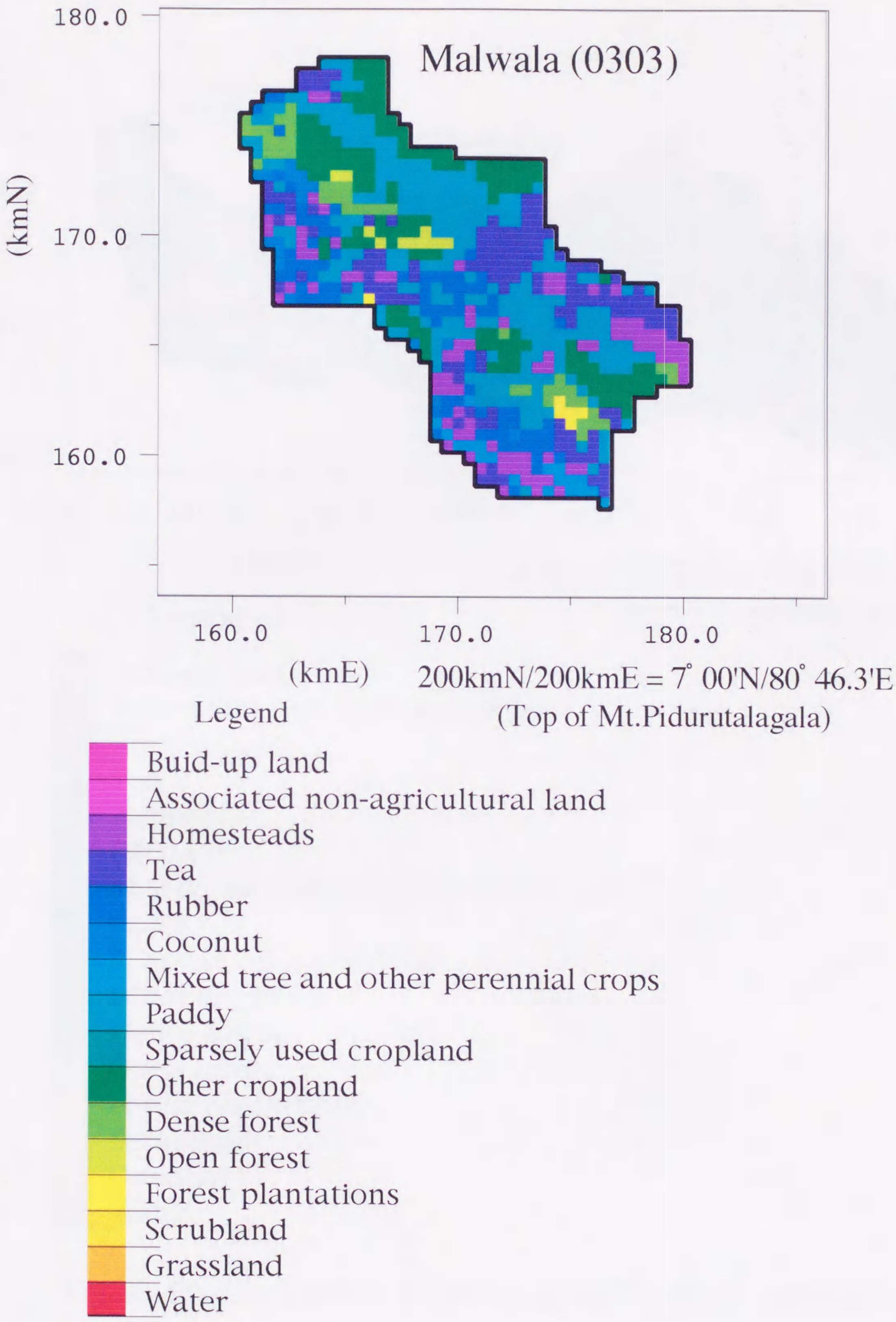


Fig.32 Distribution map of land use of Malwala(0303) watershed in 1983

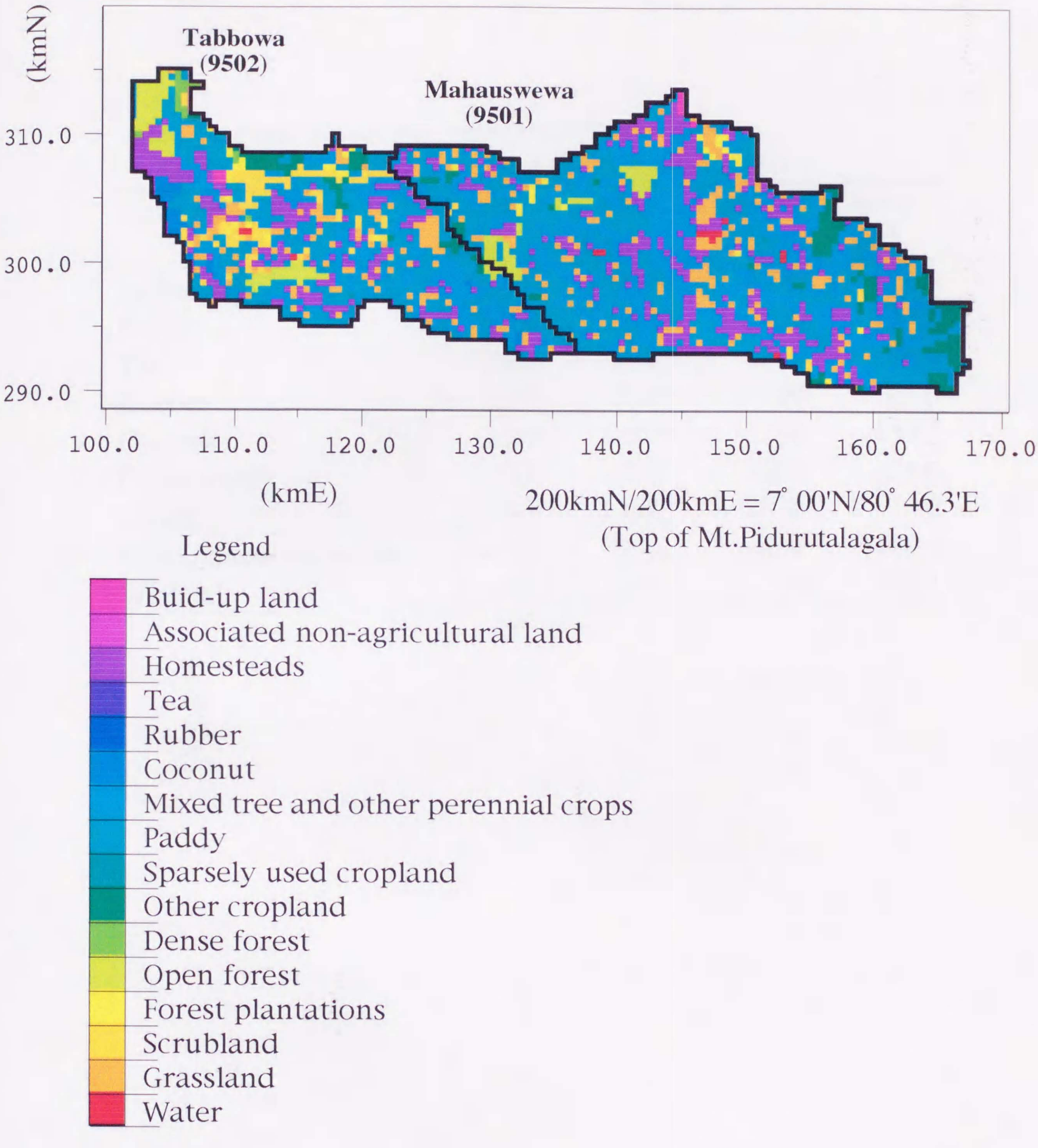


Fig. 33 Distribution map of land use of Mi Oya River catchment in 1983

Table 11 Land use change between 1956 and 1984
(after Natural Resources of Sri Lanka,1991)

Land use	at 1956 (km^2)	at 1984 (km^2)	Change (km^2)	Change (%)
Settlements	5770	9900	4130	171.6
Paddy	5150	7580	2430	147.2
Tea	2580	2220	-360	86.0
Rubber	2270	2360	90	104.0
Coconut	2510	3280	770	130.7
Other crops	910	2180	1270	239.6
Forest	29430	21680	-7750	73.7
Grass, chena and scrub	14270	15700	1430	110.0
Wetland	330	350	20	106.1

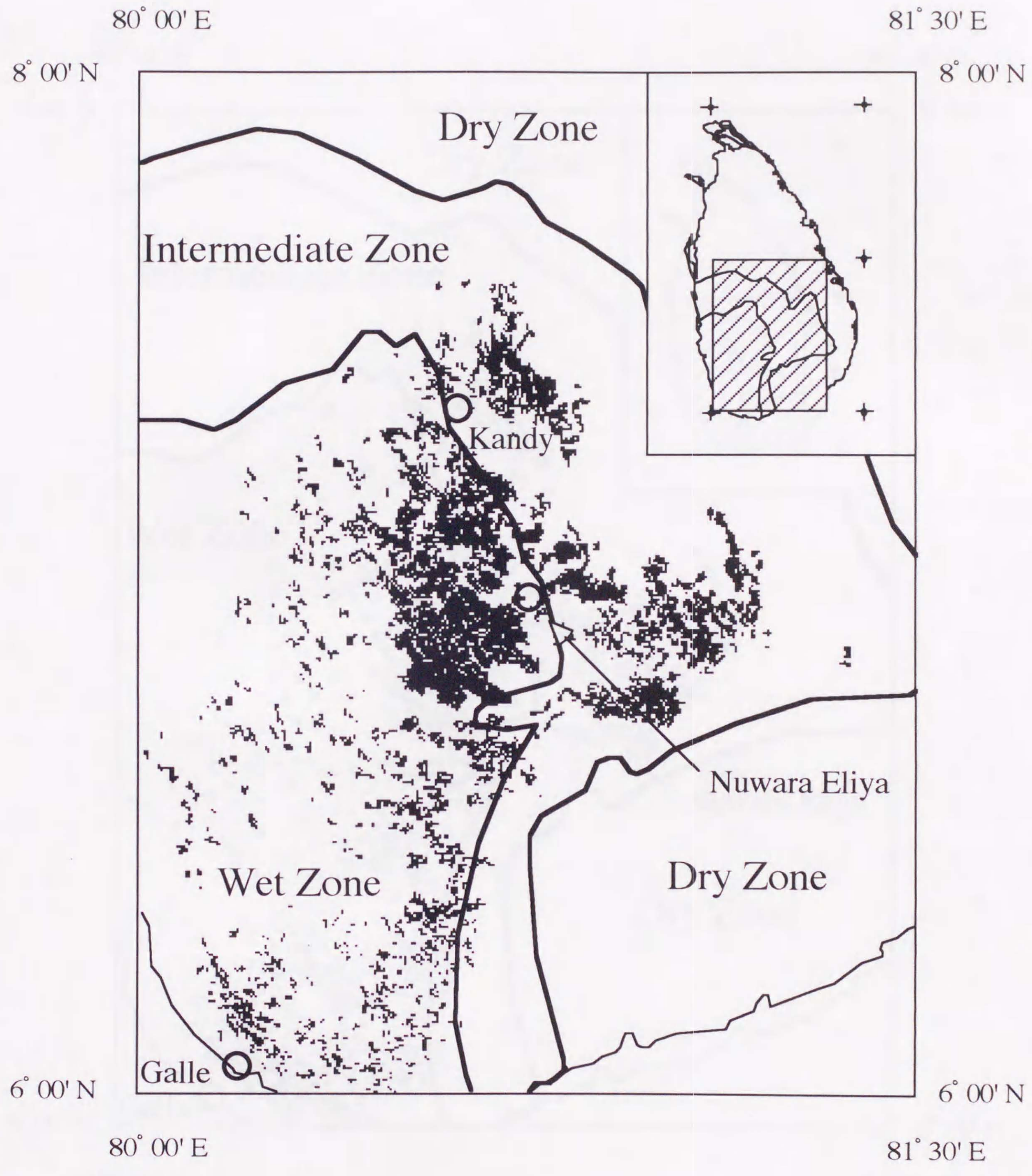


Fig.34 Distribution map of tea cultivation area in 1956

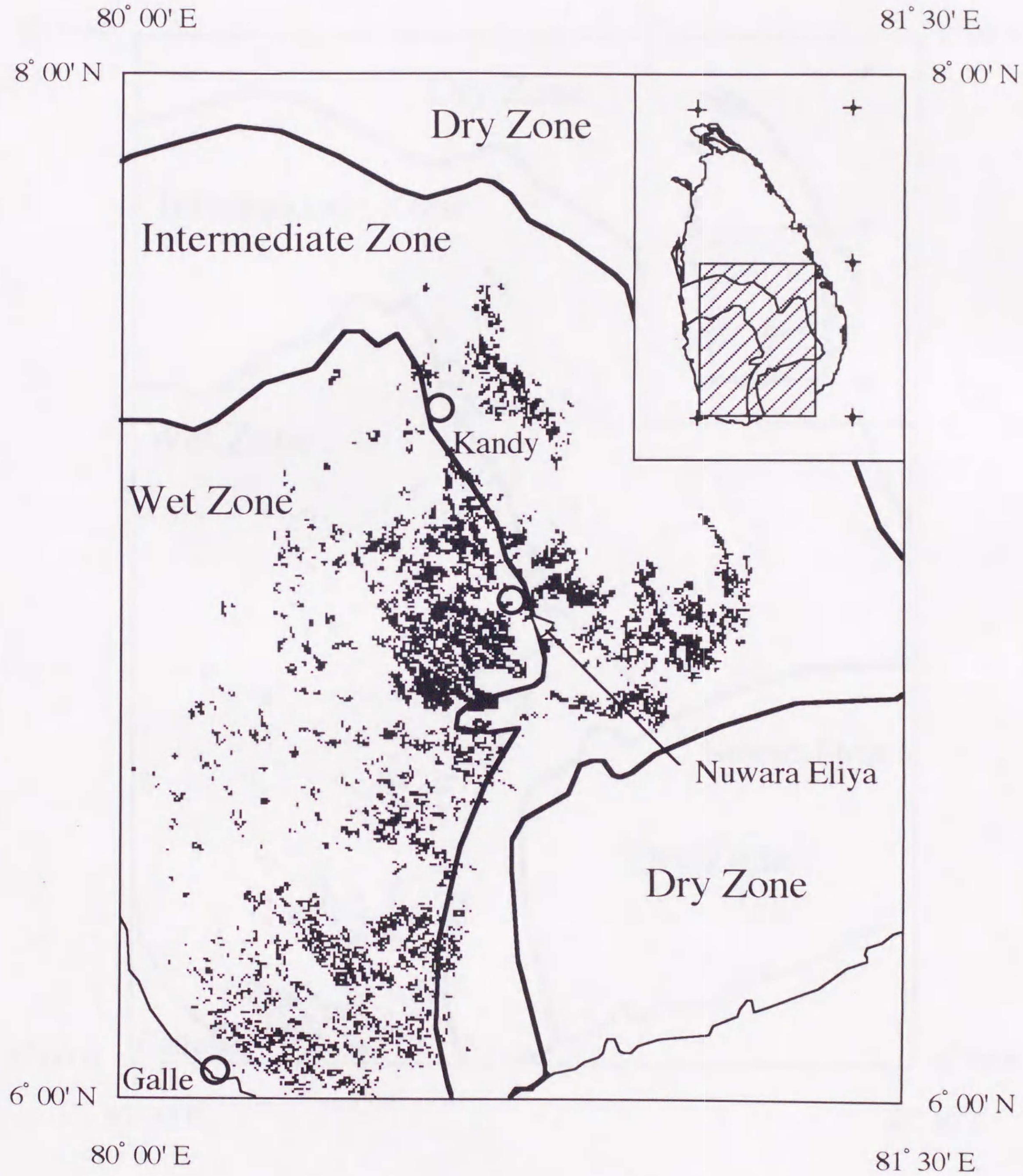


Fig.35 Distribution map of tea cultivation area in 1979/83

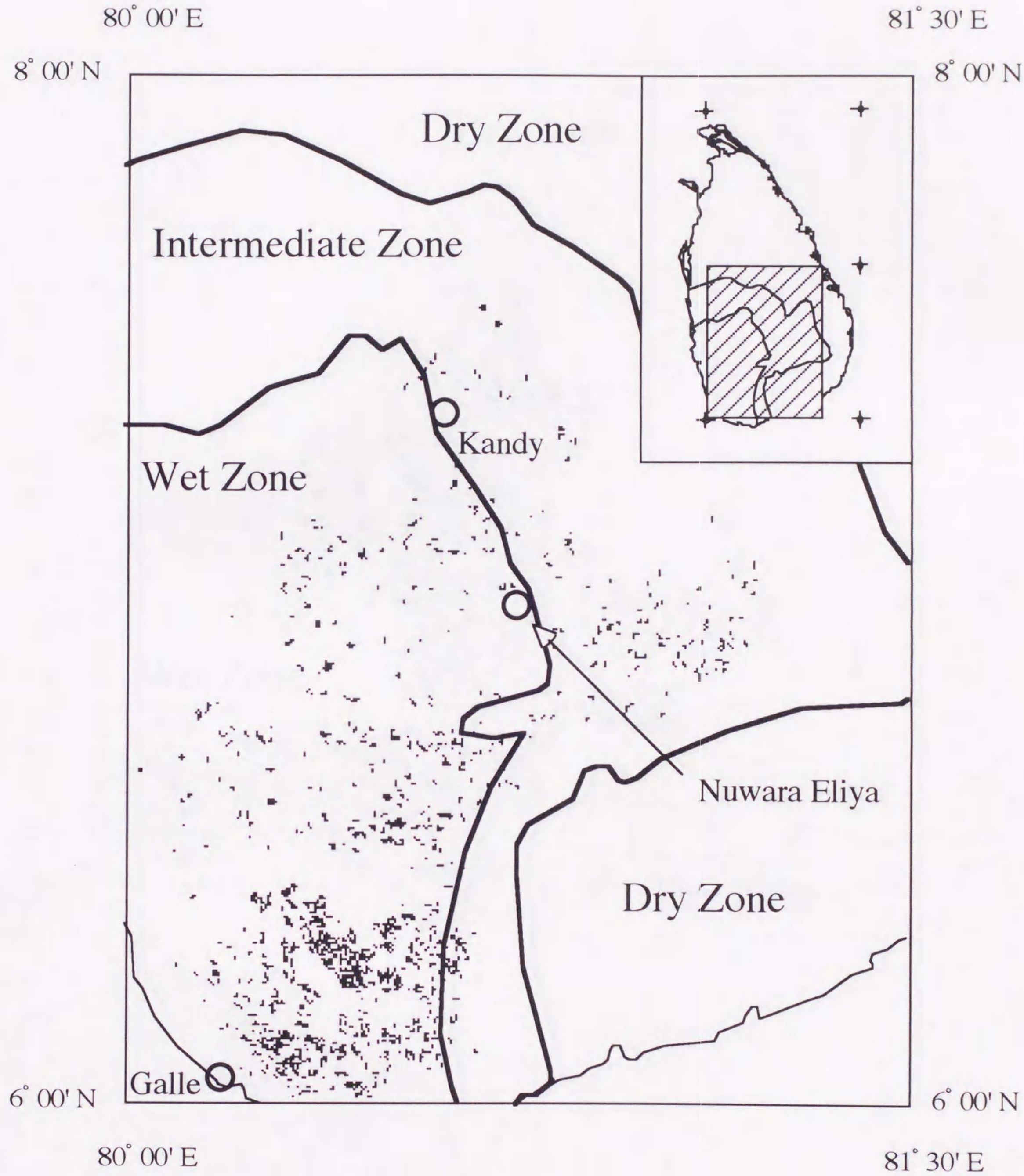


Fig.36 Distribution map of the area where the land use changes to tea cultivation between 1956 and 1979/83

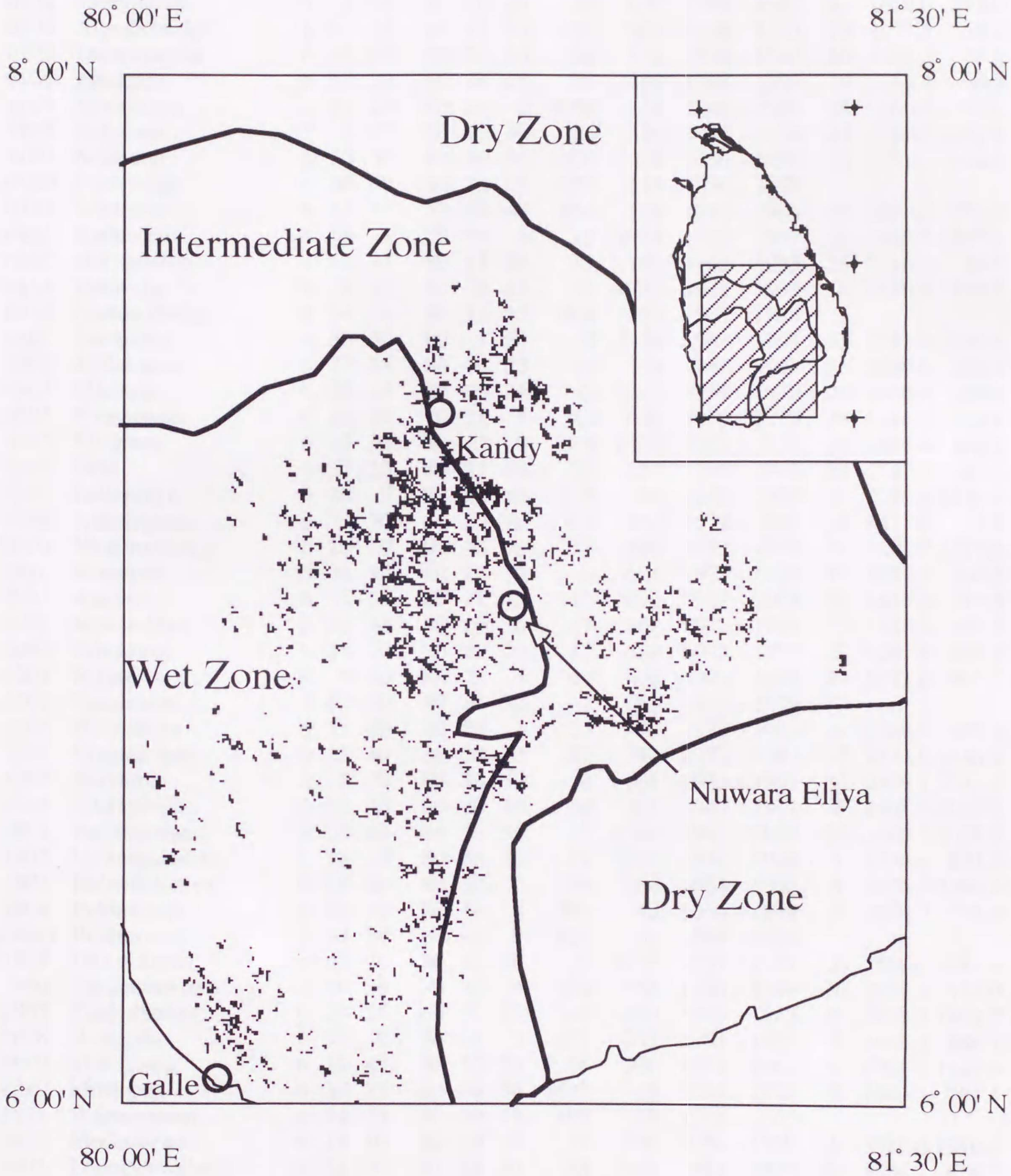


Fig.37 Distribution map of the area where the land use changes from tea cultivation to others between 1956 and 1979/83

Table 12 Annual water loss of all watersheds

No.	Station	Lat. (N)			Long. (E)			Elev.	Area	Observation	Year	Annual water loss (mm)		
		°	'	"	°	'	"	(m)	(km^2)	Period		Max.	Min.	Average.
0101	Nagalam Street	6	57	30	79	52	30	0	2085	1924 - 1960	35	1771.4	493.8	1062.5
0102	Glencourse	6	58	30	80	10	51	18	1463	1948 - 1993	44	1583.3	207.7	854.7
0103	Metiyadola	7	1	34	80	16	26	20	606	1948 - 1982	33	1479.6	293.0	1075.7
0104	Algoda bridge	6	56	55	80	15	40	26	345	1948 - 1993	15	1677.5	734.1	1206.7
0105	Deraniyagala	6	55	30	80	20	15	82	152	1948 - 1993	26	1532.5	39.2	866.1
0106	Kitulgala	6	59	30	80	24	45	56	388	1948 - 1993	38	1353.4	98.7	583.8
0107	Mossakelle	6	50	15	80	33	0	1158	122	1948 - 1969	14	1166.7	77.0	596.0
0108	Imbulana	7	3	47	80	15	40	26	329	1948 - 1974	25	1969.7	1082.6	1551.8
0109	Norwood	6	50	30	80	36	30	1100	95	1956 - 1993	10	1491.1	668.0	1099.4
0109A	Castlereigh	6	50	40	80	36	0	1027	114	1956 - 1958				
0110	Laxapana	6	53	15	80	30	40	854	168	1954 - 1986	17	3249.3	478.2	1348.0
0111	Kaduwela	6	56	5	79	59	5	10	1884	1960 - 1967	2	1618.1	1287.6	1452.9
0112	Holombuwa	7	11	35	80	15	45	53	155	1962 - 1993	25	2316.8	29.0	1426.7
0114	Hanwella	6	54	35	80	4	45	16	1782	1973 - 1993	14	1530.3	279.6	980.5
0115	Norton Bridge	6	54	30	80	31	15	900	131	1983 - 1986				
0301	Putupaula	6	36	40	80	3	55	2	2598	1943 - 1993	45	2542.5	390.3	1142.0
0302	Millakanda	6	37	25	80	10	25	17	769	1950 - 1993	25	2220.0	222.9	1215.9
0303	Malwala	6	41	15	80	25	24	18	329	1954 - 1979	24	2400.9	128.3	1001.8
0304	Nambapana	6	41	11	80	25	5	13	629	1956 - 1979	20	1446.8	166.4	919.0
0305	Ellagawa	6	43	52	80	13	0	4	1393	1956 - 1993	33	1838.4	149.1	1035.9
0306	Dela	6	37	20	80	27	10	29	220	1956 - 1993	29	1747.7	85.2	970.2
0307	Lellopitiya	6	40	5	80	29	30	104	76	1958 - 1966	5	1749.8	1293.0	1543.1
0308	Kukulegama	6	33	20	80	20	30	200	334	1973 - 1993	14	1411.8	12.8	732.3
0309	Maguru Ganga	6	28	0	80	15	40	28	136	1973 - 1979	5	1890.7	1217.8	1534.4
0310	Ratnapura	6	40	30	80	24	0	14	604	1977 - 1993	15	1055.3	168.1	775.2
0901	Agaliya	6	11	15	80	11	45	10	696	1927 - 1993	53	1456.6	114.5	792.3
0902	Jesmin Dam	6	20	40	80	20	0	27	361	1973 - 1993	15	1126.3	45.7	458.3
0903	Udugama	6	13	30	80	19	20	17	498	1973 - 1979	5	1201.9	295.5	782.5
1201	Bopagoda	6	9	20	80	29	5	18	442	1940 - 1993	49	2573.6	902.2	1605.7
1202	Namimana	5	57	30	80	33	30	2	958	1972 - 1979				
1203	Hulanduwa	6	11	40	80	27	5	24	70	1972 - 1979	6	1688.7	987.5	1368.2
1204	Bingamahara	6	12	40	80	28	40	26	333	1973 - 1989	15	2533.9	1358.7	1777.5
1205	Kadduwa	6	2	10	80	30	50	6	601	1975 - 1993	13	2339.1	1121.5	1723.1
1601	Julampitiya	6	11	40	80	44	40	62	141	1947 - 1961	7	1468.6	1067.9	1217.9
1801	Embilipitiya	6	20	40	80	53	55	31	1580	1942 - 1968	24	1889.1	1024.9	1460.7
1802	Liyanagahatota	6	14	0	80	56	30	17	2284	1942 - 1948	5	1130.4	801.7	950.1
1803	Halmillaketiya	6	18	40	80	52	0	46	166	1954 - 1962	5	2076.4	1496.8	1691.3
1804	Belihul Oya	6	43	0	80	46	0	594	49	1956 - 1960	3	2640.7	775.4	1740.6
1804A	Belihul Oya	6	44	30	80	45	0	820	42	1984 - 1986				
1805	Uda walawe	6	27	10	80	50	30	76	1155	1957 - 1961	3	1606.0	1343.5	1474.1
1806	Samanalawewa	6	40	30	80	48	5	364	353	1958 - 1986	16	1625.9	455.9	1056.0
1807	Timbolketiya	6	24	25	80	47	55	64	269	1958 - 1967	8	2658.1	1972.7	2237.6
1808	Weragala	6	39	0	80	54	0	117	261	1963 - 1971	7	1660.3	886.1	1218.7
1809	Mahagama	6	19	45	80	55	30	36	366	1951 - 1965	9	1781.7	1147.9	1429.5
1810	Mawigala	6	35	35	80	48	50	427	23	1964 - 1979	4	2004.3	792.1	1444.6
1811	Waguregama	6	34	15	80	49	55	108	99	1963 - 1965				
1812	Modarawana	6	19	10	80	49	0	70	109	1956 - 1958	1	1916.6	1916.6	1916.6
2201	Lunugamwehera	6	21	10	81	13	10	35	913	1944 - 1979	33	1656.7	626.9	1196.2
2202	Poonagala	6	43	50	81	1	40	487	5.5	1955 - 1962	5	1550.2	661.5	1050.2
2203	Wellawaya	6	43	55	81	6	25	154	160	1956 - 1993	32	2094.8	184.6	873.9
2204	Kuda Oya	6	31	30	81	7	25	81	291	1967 - 1990	22	1417.7	384.1	1003.4
2601	Kataragama	6	25	10	81	19	45	34	787	1944 - 1993	47	1773.7	656.2	1301.8
3101	Kumbukkana	6	48	25	81	17	35	137	259	1957 - 1961	1	1638.1	1638.1	1638.1
3102	Nakkala	6	53	30	81	17	45	160	216	1973 - 1993	12	1280.1	189.5	809.8
3103	Maligawila	6	41	35	81	22	40	81	375	1974 - 1989	8	1240.3	884.7	1094.4
3104	Maligawila	6	42	0	81	24	35	70	302	1974 - 1979	2	1062.6	990.1	1026.3
3501	Wedagama	6	45	40	81	44	35	9	404	1946 - 1957	11	1976.7	907.7	1340.3
3601	Siyambalanduwa	6	54	20	81	32	40	55	295	1945 - 1993	17	1731.7	689.3	1283.9
3602	Heda Oya Damsite	6	52	10	81	36	55	38	409	1951 - 1957	4	1191.7	514.0	953.4
3603	Lahugala	6	53	0	81	41	45	24	471	1958 - 1960				
3701	Hulange	6	56	40	81	39	10	35	145	1953 - 1962	8	2215.2	672.8	1206.0
4201	Thottama	7	6	30	81	41	25	34	95	1945 - 1968	14	1729.8	677.6	1262.1

Table 12 (continued)

No.	Station	Lat. (N) °	'	"	Long. (E) °	'	"	Elev. (m)	Area (km²)	Observation Period	Year	Annual water loss (mm) Max.	Min.	Average.
4401	Inginiyagala	7	12	30	81	32	0	42	995	1937 - 1949	8	1881.5	233.9	837.8
4402	Pitakumbura	7	8	45	81	17	55	195	188	1984 - 1991	2	857.3	833.5	845.4
5101	Periya Aru	7	30	0	81	29	20	36	119	1942 - 1979	31	1638.2	479.0	1161.8
5201	Weragoda	7	33	35	81	19	50	48	225	1945 - 1991	18	2047.3	599.2	1238.8
5202	Nilobe	7	30	40	81	22	40	44	159	1944 - 1981	29	1569.3	67.7	793.5
5203	Maha oya	7	32	0	81	21	30	39	300	1946 - 1961	11	1711.8	405.3	1250.6
5204	Rugam	7	38	10	81	27	0	23	1295	1953 - 1960	3	1989.0	1565.1	1754.1
5205	Pollebedda	7	28	0	81	23	50	48	137	1980 - 1988	7	1515.8	669.7	1101.4
5401	Welikanda	7	56	10	81	15	0	29	1068	1946 - 1979	25	1576.6	476.0	1134.2
5402	Kandegama Dam site	7	38	18	81	12	40	61	453	1951 - 1979	5	1521.1	1100.0	1398.3
5403	Maduru Oya Bridge	7	23	0	81	11	30	118	158	1981 - 1986				
6001	Manampitiya	7	54	40	81	5	10	32	7418	1941 - 1993	37	1970.7	1072.4	1423.1
6002	Galoya Junction	8	8	25	80	51	10	84	199	1941 - 1959	13	1537.1	754.0	1174.9
6003	Angamedilla	7	51	0	80	54	10	67	1363	1952 - 1993	25	1755.1	261.5	1164.4
6004	Peradeniya	7	15	30	80	35	25	463	1167	1943 - 1993	45	1899.2	888.5	1191.5
6005	Gurudeniya	7	16	30	80	40	33	425	1418	1944 - 1978	33	1878.2	673.5	1109.5
6006	Nalamda	7	40	15	80	38	15	243	126	1943 - 1960	13	1686.1	760.5	1107.5
6007	Weragantota	7	19	0	80	59	10	76	4092	1945 - 1993	46	2175.5	467.4	1310.0
6008	Elahera	7	40	45	80	45	25	133	774	1946 - 1993	36	3025.8	100.8	1027.6
6009	Morape	7	3	40	80	37	20	640	555	1946 - 1981	29	1381.9	481.4	976.0
6010	P.W.D. Bridge	8	13	25	80	53	20	88	45	1946 - 1976	19	1702.9	219.3	1019.0
6011	Gampola	7	9	50	80	34	20	493	951	1951 - 1978	7	1365.1	441.3	982.3
6012	Kandakaduturai	8	4	0	81	9	10	23	7529	1952 - 1965				
6013	Nadumodara	8	10	25	81	12	20	15	8618	1952 - 1961				
6014	Ulhitiya	7	34	15	81	0	35	78	357	1953 - 1980	7	2572.3	1370.8	1787.0
6015	Teldeniya	7	17	40	80	46	0	411	160	1954 - 1978	22	2761.9	741.0	1728.8
6016	Randenigala	7	12	10	80	56	10	141	2365	1954 - 1983	28	1905.9	837.7	1275.0
6017	Kandaketiya	7	10	30	81	0	20	126	387	1954 - 1979	15	1715.4	142.6	1168.8
6018	Gadugudawaa	7	16	15	81	3	5	106	91	1953 - 1958	2	1367.0	1219.8	1293.4
6019	Meegahakiula	7	9	30	81	3	35	121	196	1955 - 1966	10	1687.2	757.2	1316.8
6020	Watawala	6	56	50	80	32	10	829	42.8	1957 - 1977	19	2921.4	855.6	2030.8
6021	Talawakelle	6	56	25	80	39	45	1200	297	1954 - 1993	31	1305.6	435.0	902.7
6022	Bawagama	7	2	55	80	31	55	578	169	1957 - 1966	6	2035.5	1170.9	1657.6
6023	Talawakanda	7	0	30	80	58	25	575	520	1957 - 1991	33	1766.2	889.5	1276.2
6024	Allai Kantalai	8	19	0	81	10	0	8	9606	1958 - 1986	12	1996.6	1283.2	1620.7
6025	Mallanda	7	3	40	80	32	10	578	188	1958 - 1966				
6026	Bowatenna	7	39	10	80	41	25	212	520	1958 - 1962	3	1390.0	1238.5	1320.2
6027	Holbrook	6	52	50	80	41	40	1346	121	1959 - 1978	17	1728.1	555.9	1060.4
6028	Victoriya	7	14	25	80	47	0	366	1653	1958 - 1978	9	1590.5	229.1	1128.2
6029	Welimada	6	54	15	80	54	30	1070	179	1959 - 1978	18	1406.9	179.1	764.8
6030	Wellewella	7	36	25	80	50	0	140	194	1960 - 1973	12	1663.1	144.9	959.1
6032	Moragahamulla	7	16	57	80	48	26	427	73	1963 - 1979	15	2159.1	948.1	1708.5
6033	Rantembe	7	11	52	80	57	14	114	3113	1979 - 1986	6	1967.2	1439.1	1684.1
6034	Calidoniya	6	54	0	80	42	0	1280	183	1983 - 1993	9	1007.5	510.6	764.1
6071	Elgin Falls	6	52	45	80	48	15	1827	23	1920 - 1960	19	1529.3	31.1	315.1
6072	Uduwalwala	7	28	30	80	55	15	77	115	1954 - 1962				
6077	Hembarawa	7	31	30	80	58	25	64	4530	1953 - 1978	17	1578.6	433.1	1192.3
6078	Hanguranketa	7	11	30	80	45	45	533	103	1954 - 1960	5	1889.3	1422.1	1634.4
6079	Geli oya	7	12	45	80	36	15	467	1066	1955 - 1962	5	1277.9	848.6	1107.7
6081	Dastota	7	51	0	81	2	0	34	5501	1957 - 1959				
6082	Pallewatta	7	21	30	80	57	45	86	116	1958 - 1960	1	1983.6	1983.6	1983.6
6084	Teldeniya	7	5	30	81	2	50	271	280	1958 - 1960				
6085	Watumulla	7	5	50	80	51	15	870	34	1958 - 1960	1	1774.9	1774.9	1774.9
6087	Uraniya	7	13	0	81	7	3	182	34	1977 - 1979	1	788.2	788.2	788.2
6701	Huruluwewa	8	13	35	80	43	40	120	200	1942 - 1949	6	1478.9	626.0	987.4
6702	Pangurugaswewa	8	44	55	80	52	45	21	1311	1946 - 1981	29	1846.6	844.9	1241.0
6703	Horowapotana	8	34	36	80	52	42	44	942	1951 - 1993	35	1963.8	845.3	1254.2
6704	Wahalkada	8	43	36	80	51	5	31	91	1951 - 1974	21	1786.3	740.9	1254.5
6705	Illukwewa	8	20	10	80	44	5	98	315	1972 - 1979	4	1432.2	852.6	1174.7
6901	Yakawewa	8	43	25	80	40	50	70	110	1979 - 1993	13	1318.5	813.4	1093.6
7501	Oddusu Dam	9	13	0	80	41	30	10	303	1976 - 1979	2	1275.3	1196.0	1235.7
8101	Parasan Kulam	8	59	45	80	33	0	65	133	1980 - 1985	5	1012.4	703.9	866.3

Table 12 (continued)

No.	Station	Lat. (N)			Long. (E)			Elev.	Area	Observation	Year	Annual water loss (mm)		
		°	'	"	°	'	"	(m)	(km^2)	Period		Max.	Min.	Average.
8801	Chinnaralayan kaddu	8	57	30	80	20	20	40	560	1980 - 1985	5	1144.4	767.7	945.0
9001	Kappachchi	8	35	55	80	16	20	36	2117	1948 - 1989	33	1675.9	815.6	1171.3
9002	Tekkam	8	44	55	80	11	0	18	3071	1945 - 1959	13	1688.0	787.6	1232.0
9003	Rambawa	8	27	10	80	30	25	77	364	1955 - 1972	3	1497.8	957.0	1206.7
9301	Kadigala	8	7	20	80	15	40	57	1564	1945 - 1964	13	1807.2	877.1	1326.8
9302	Nochchiyagama	8	11	50	80	5	50	24	1948	1957 - 1984	16	1543.6	810.5	1150.2
9303	Galewela	7	48	30	80	36	25	171	41	1958 - 1993	11	1666.1	109.4	751.2
9305	Dambulla	7	47	45	80	35	50	179	18	1971 - 1979	6	1664.1	702.6	1317.4
9306	Ibbnkatuwa	7	50	40	80	38	0	157	70	1971 - 1979	4	1507.5	906.1	1255.0
9307	Kumbukwewa	8	7	15	80	17	30	64	1160	1977 - 1983	3	998.5	942.1	977.7
9308	Kumbukwewa	8	7	0	80	17	40	65	117	1977 - 1983	2	724.2	680.6	702.4
9501	Mahauswewa	7	57	50	80	4	8	35	595	1954 - 1985	28	1487.4	759.4	1121.9
9502	Tabbowa	8	2	50	79	55	5	10	1078	1960 - 1979	17	1552.9	815.0	1243.4
9901	Hettipola	7	36	30	80	5	35	40	233	1944 - 1983	21	2196.8	937.9	1460.6
9902	Batalagoda	7	31	0	80	28	0	122	210	1945 - 1947	1	1547.8	1547.8	1547.8
9903	Alawala Anicut	7	28	20	80	27	10	125	102	1945 - 1962	6	1655.4	948.3	1373.5
9904	Chilaw	7	36	0	79	48	58	0	2611	1949 - 1993	23	1582.0	383.6	1206.6
9907	Moragaswewa	7	41	45	79	59	50	15	2002	1978 - 1989	8	1268.4	602.4	968.2
10201	Alawwa	7	17	30	80	14	25	49	804	1947 - 1993	41	2311.4	1168.2	1713.9
10202	Badalgama	7	18	10	79	58	50	12	1360	1953 - 1993	36	1814.2	986.2	1421.6
10203	Giriulla	7	19	30	80	6	55	27	1191	1958 - 1993	28	1541.8	1093.5	1333.0
10301	Attanagalla	7	6	45	80	8	10	24	114	1950 - 1993	7	1985.3	712.0	1662.8
10302	Karasnagala	7	6	45	80	10	15	28	53	1971 - 1986	13	1626.3	92.4	1183.5
10303	Alawala	7	6	55	80	10	40	30	13	1971 - 1984	6	1559.6	587.1	1186.3

Table 13 Average water balance of 33 watersheds

No.	Name	Elev. (m)	Area (km²)	Period	Areal Pre. (mm)	Discharge (mm)	Water loss (mm)	Runoff ratio
Southwest coast of Wet Zone								
0101	Nagalam Street	0	2085	1925 - 1960	3724.1	2657.4	1066.7	0.71
0301	Putupaula	2	2598	1944 - 1994	3815.6	2712.3	1103.3	0.71
0901	Agaliya	10	696	1927 - 1993	3508.5	2747.0	761.5	0.78
10202	Badalgama	12	1360	1944 - 1993	2401.4	1027.4	1374.0	0.43
1201	Bopagoda	18	442	1940 - 1993	3268.6	1678.2	1590.4	0.51
Average					3343.6	2164.5	1179.2	0.65
Southwest inland of Wet Zone								
0105	Deraniyagala	82	152	1948 - 1993	4794.2	4411.0	383.2	0.92
0108	Imbulana	26	329	1948 - 1973	3592.5	2067.4	1525.1	0.58
0303	Malwala	18	329	1955 - 1978	4046.2	3032.5	1013.7	0.75
0305	Ellagawa	4	1393	1957 - 1993	3699.3	2719.2	980.1	0.74
0306	Dela	29	220	1956 - 1992	2786.3	1915.5	870.8	0.69
10201	Alawwa	49	804	1944 - 1993	2517.4	829.9	1687.5	0.33
Average					3572.7	2495.9	1076.7	0.70
Central highland								
6004	Peradeniya	463	1167	1943 - 1983	2970.7	1838.0	1132.7	0.62
6020	Watawala	829	42.8	1957 - 1977	3976.2	1966.6	2009.6	0.49
6027	Holbrook	1346	121	1959 - 1978	2405.6	1363.7	1041.9	0.57
6029	Welimada	1070	179	1959 - 1978	1846.6	1079.2	767.4	0.58
Average					2799.8	1561.9	1237.9	0.56
Southeast of Dry Zone								
2201	Lunugamwehera	35	913	1944 - 1979	1610.4	419.9	1190.5	0.26
2204	Kuda Oya	81	291	1967 - 1990	1439.4	436.0	1003.4	0.30
2601	Kataragama	34	787	1944 - 1993	1570.6	262.7	1307.9	0.17
3102	Nakkala	160	216	1973 - 1993	1611.8	1129.3	482.5	0.70
3501	Wedagama	9	404	1946 - 1957	1592.9	245.3	1347.6	0.15
4201	Thottama	34	95	1945 - 1968	1809.0	477.1	1331.9	0.26
5101	Periya Aru	36	119	1942 - 1979	1905.3	830.7	1074.6	0.44
5202	Nilobe	44	159	1944 - 1981	1896.2	1114.1	782.1	0.59
5203	Maha oya	39	300	1946 - 1961	2173.4	878.5	1294.9	0.40
Average					1734.3	643.7	1090.6	0.37
Northern lowland of Dry Zone								
6002	Galoya junction	84	199	1940 - 1958	1564.9	307.4	1257.5	0.20
6010	(Alut Oya) P.W.D.	88	45	1946 - 1994	1557.7	587.5	970.2	0.38
6704	Wahalkada	31	91	1953 - 1974	1514.9	266.3	1248.6	0.18
6901	Yakawewa	70	110	1979 - 1993	1326.3	215.5	1110.8	0.16
9001	Kappachchi	36	2117	1948 - 1989	1329.6	153.5	1176.1	0.12
9002	Tekkam	18	3071	1945 - 1959	1391.2	163.3	1227.9	0.12
9502	Tabbowa	10	1078	1960 - 1979	1373.7	132.3	1241.4	0.10
9901	Hettipola	40	233	1944 - 1992	1890.9	487.4	1403.5	0.26
9904	Chilaw	0	2611	1949 - 1993	1663.7	515.7	1259.9	0.29
Average					1512.5	314.3	1198.2	0.21

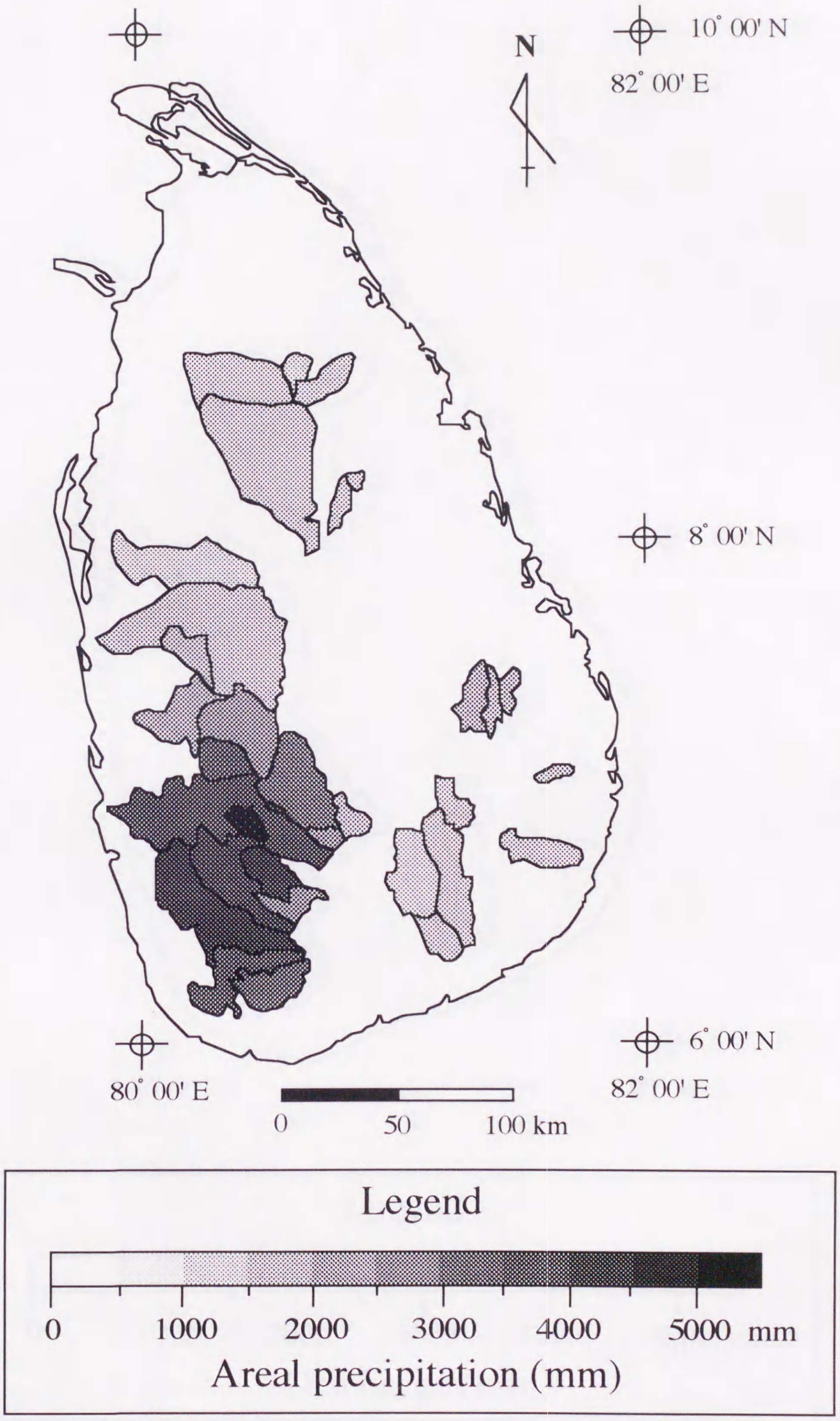


Fig. 38 Distribution of average annual areal precipitation

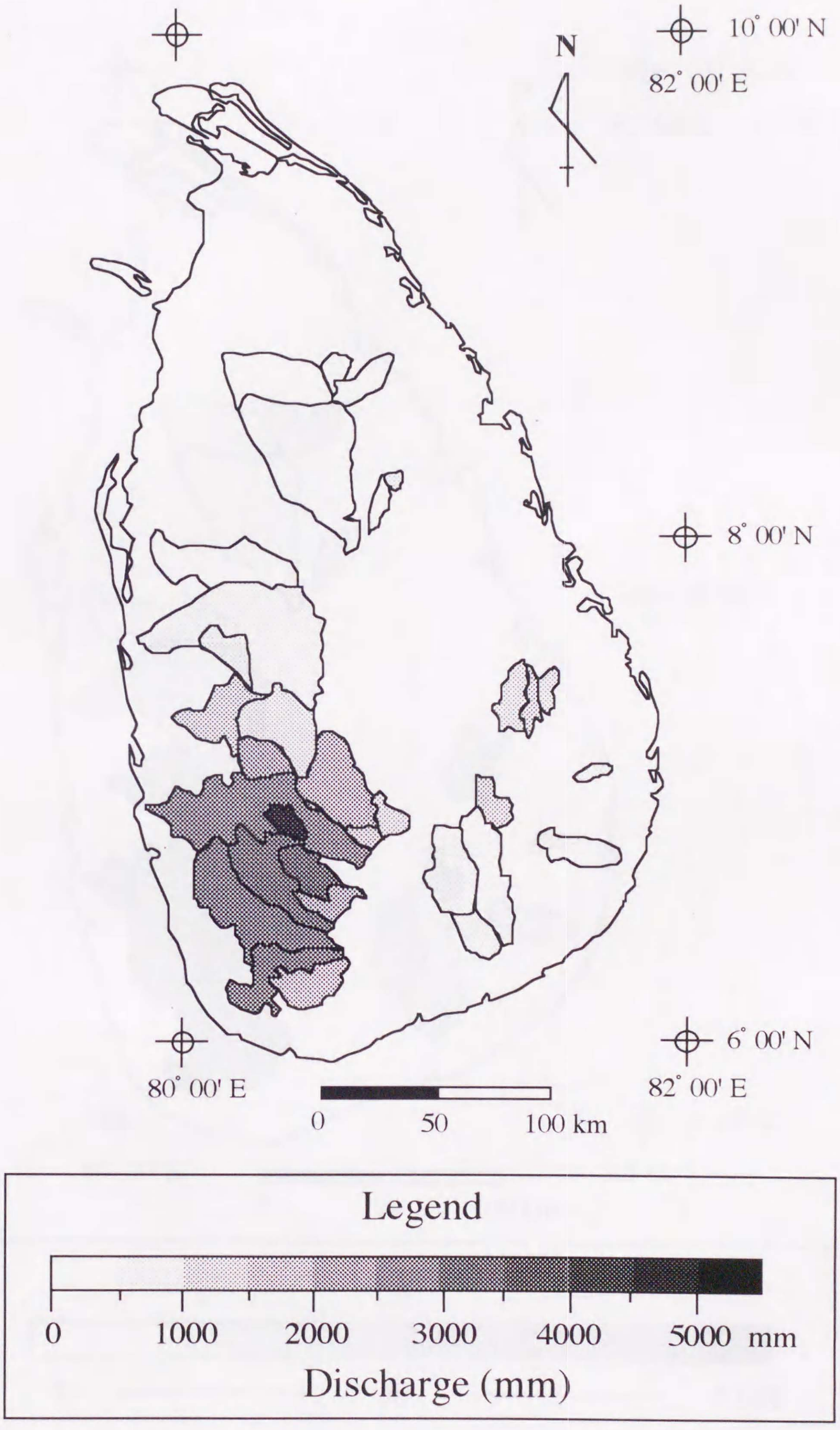


Fig. 39 Disrtibution of average annual discharge

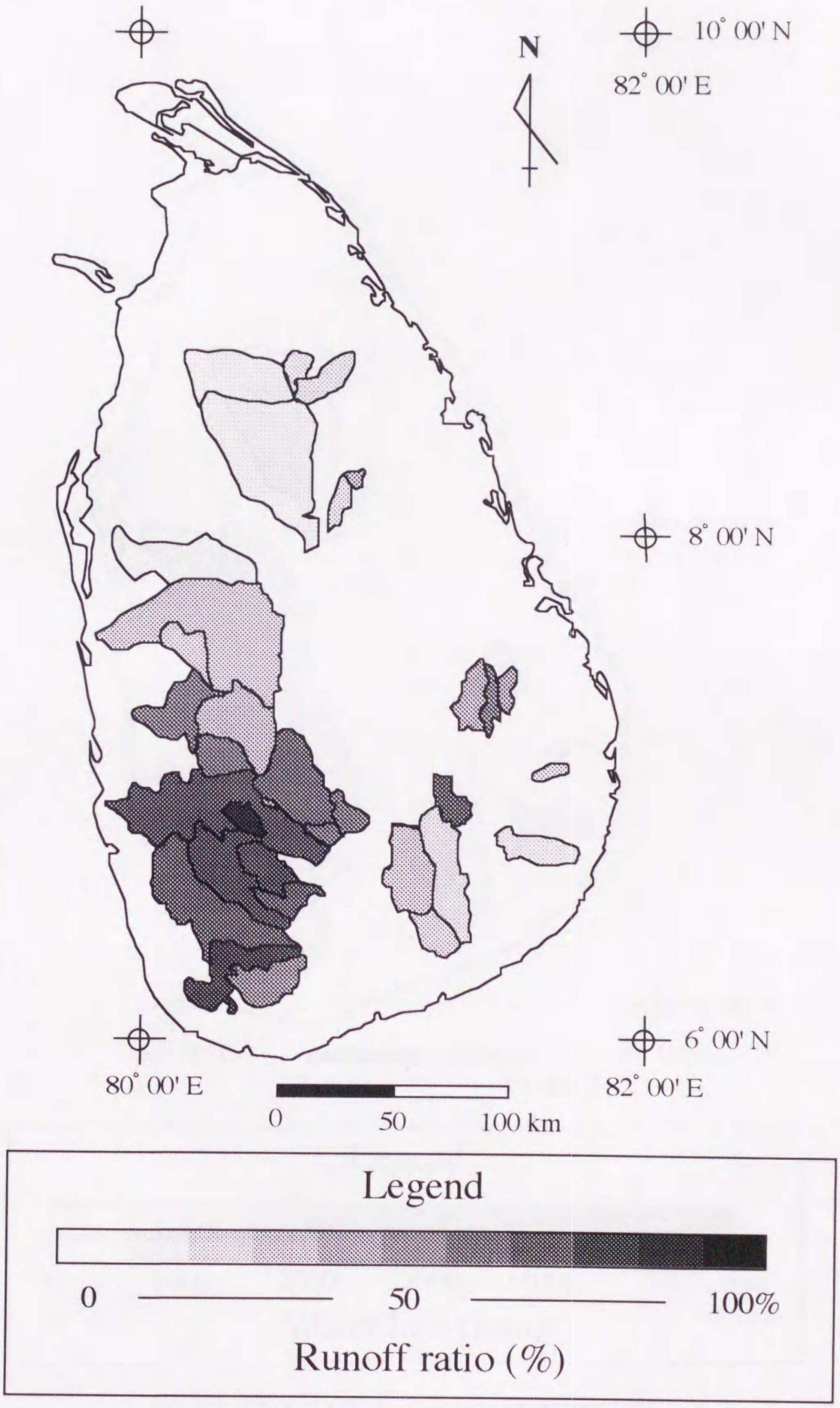


Fig. 40 Distribution of average annual runoff ratio

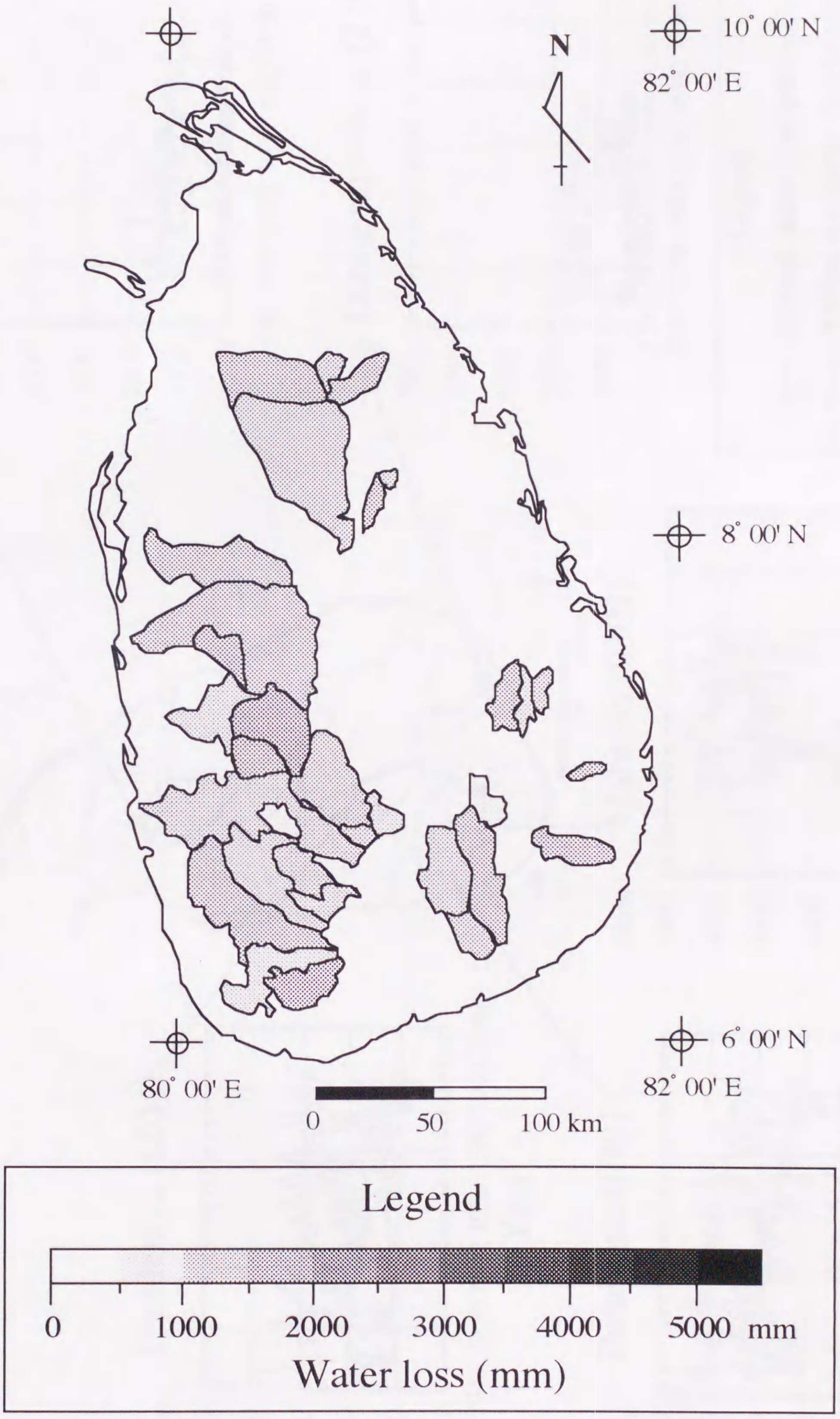


Fig.41 Distribution of average water loss

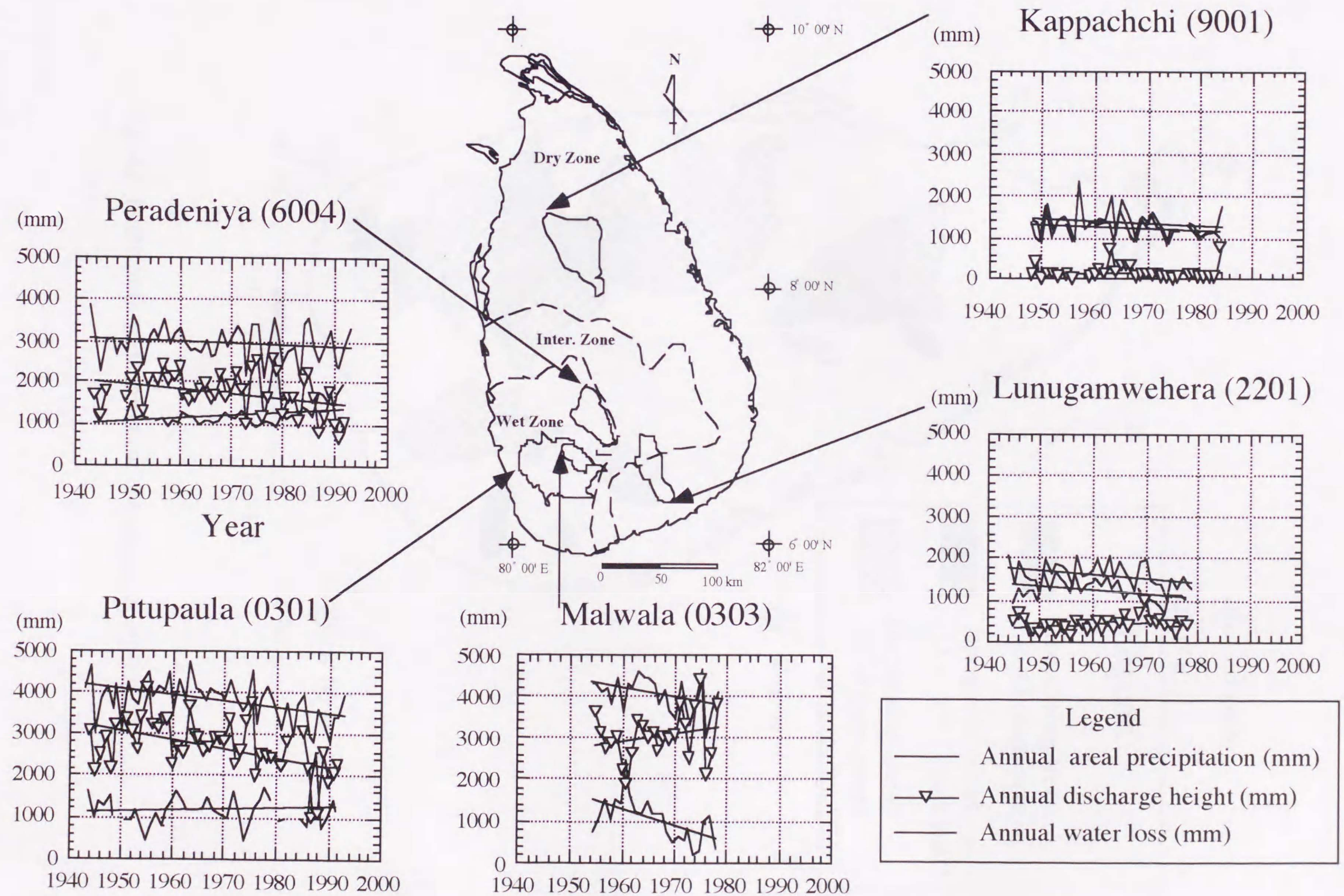


Fig. 42 Temporal variations of water balance

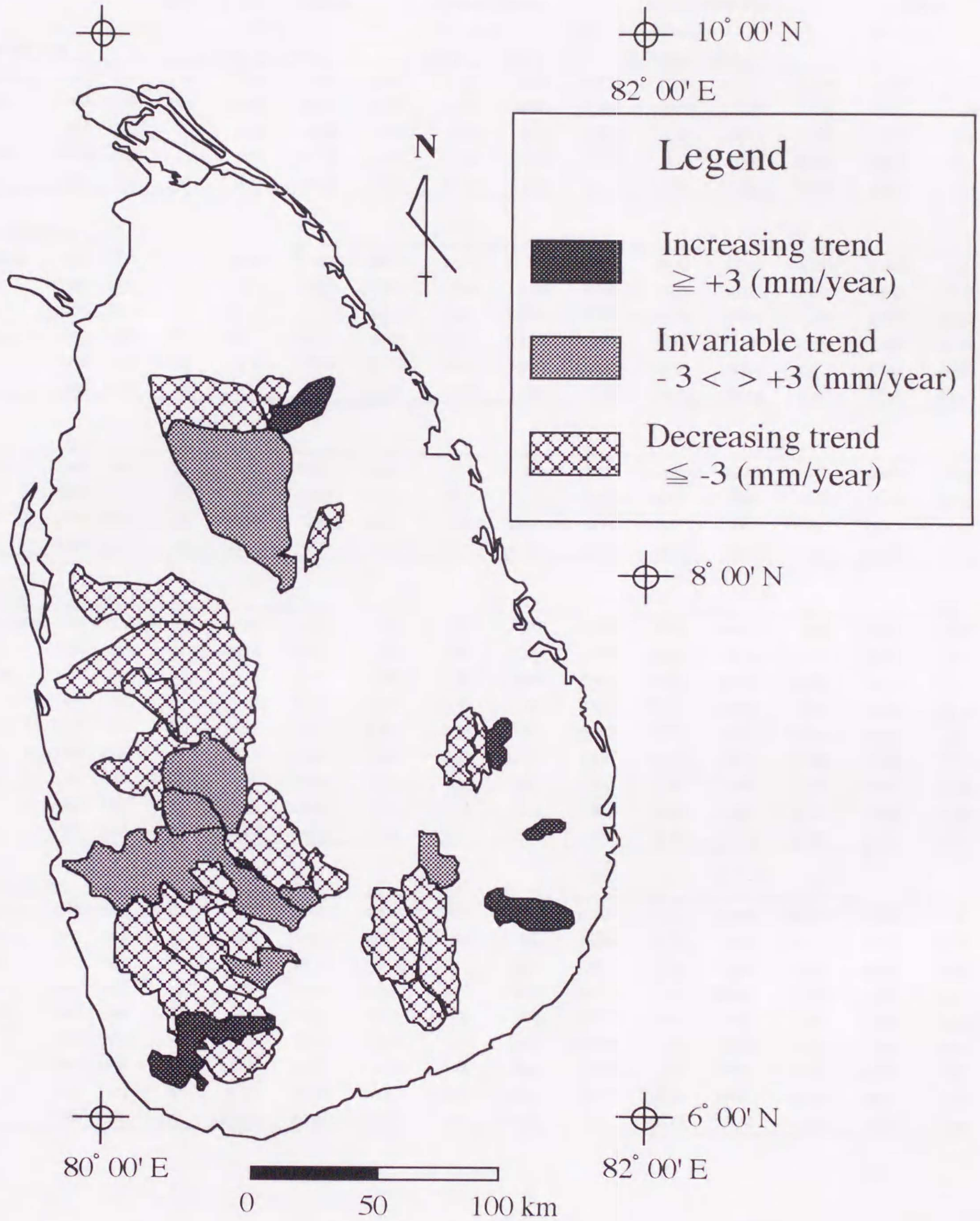


Fig. 43 Distribution of trend on the areal precipitation

Table 14 Trend of water balance

No.	Station name	Period	Number of years	Regression line of annual precipitation (Y=aX+b)		Coefficient (r^2)	Regression line of annual discharge (Y=aX+b)		Coefficient (r^2)	Regression line of annual water loss (Y=aX+b)		Coefficient (r^2)	Regression line of rate of flow (Y=aX+b)		Coefficient (r^2)
Southwest coast of Wet Zone				a (mm/year	b (mm)		a (mm/year	b (mm)		a (mm/year	b (mm)		a	b	
0101	Nagalam Street	1925 - 1959	35	-2.96	9469	0.007	-15.36	32491	0.175	12.40	-23023	0.231	-0.003	7.33	0.263
0301	Putupaula	1944 - 1992	45	-16.45	36178	0.235	-20.84	43707	0.225	3.69	-6123	0.019	-0.002	5.58	0.098
0901	Agaliya	1928 - 1992	57	4.88	-6043	0.033	-2.80	8241	0.015	8.23	-15411	0.149	-0.002	5.06	0.139
10202	Badalgama	1954 - 1992	36	-9.50	21136	0.126	-9.18	19100	0.125	-0.10	1623	0.000	-0.003	5.51	0.104
1201	Bopagoda	1941 - 1992	49	-8.10	19208	0.075	-12.17	25603	0.133	3.86	-5987	0.032	-0.002	5.09	0.099
Southwest inland of Wet Zone															
0105	Deraniyagala	1949 - 1992	32	-23.98	52064	0.185	13.03	-21231	0.024	-33.65	66732	0.221	0.007	-12.35	0.218
0108	Imbulana	1949 - 1973	25	-2.75	9017	0.004	3.75	-5295	0.006	-6.51	14310	0.037	0.002	-2.45	0.023
0303	Malwala	1955 - 1978	24	-22.17	47623	0.138	19.31	-34941	0.055	-41.48	82563	0.336	0.009	-16.02	0.258
0305	Ellagawa	1957 - 1992	35	-26.52	56057	0.388	12.57	-22091	0.052	-39.68	79308	0.570	0.009	-16.25	0.424
0306	Dela	1958 - 1992	33	-5.96	14533	0.030	48.54	-93937	0.569	-56.73	112838	0.837	0.020	-38.54	0.797
10201	Alawwa	1948 - 1992	41	-1.92	6280	0.007	-14.75	29869	0.288	14.59	-27008	0.357	-0.006	11.67	0.369
Central highland															
6004	Peradeniya	1944 - 1983	36	-4.89	12556	0.021	-2.77	7283	0.005	-2.82	6652	0.060	0.000	0.79	0.000
6020	Watawala	1958 - 1976	19	8.56	-12845	0.006	57.28	-110704	0.332	-48.72	97854	0.303	0.013	-26.02	0.508
6027	Holbrook	1960 - 1977	18	2.56	-2680	0.002	-11.82	24625	0.015	14.37	-27306	0.033	-0.007	13.69	0.037
6029	Welimada	1960 - 1977	18	-4.45	10605	0.009	42.10	-81789	0.486	-46.55	92391	0.608	0.024	-47.12	0.691
Southwest of Dry Zone															
2201	Lunugamwehera	1945 - 1978	33	-6.48	14315	0.057	4.13	-7671	0.063	-9.93	20669	0.162	0.004	-6.80	0.159
2204	Kuda Oya	1968 - 1989	22	-22.18	45321	0.293	5.89	-11219	0.050	-28.07	56539	0.571	0.011	-20.81	0.348
2601	Kataragama	1945 - 1992	47	-12.12	25431	0.283	-1.94	4086	0.058	-10.23	21439	0.321	0.000	-0.17	0.002
3102	Nakkala	1974 - 1992	16	-9.89	21225	0.072	61.76	-121380	0.387	-73.29	145835	0.556	0.042	-82.79	0.514
3501	Wedagama	1947 - 1957	11	17.57	-32715	0.027	0.83	-1371	0.001	16.74	-31328	0.033	-0.001	2.94	0.007
4201	Thottama	1946 - 1967	14	12.01	-21627	0.064	11.20	-21390	0.091	-16.73	33943	0.095	0.007	-13.78	0.107
5101	Periya Aru	1943 - 1977	32	-8.95	19458	0.055	-2.06	4869	0.002	-5.07	11056	0.020	0.001	-0.66	0.001
5202	Nilobe	1945 - 1981	31	-17.11	35469	0.197	2.70	-4216	0.004	-15.66	31463	0.147	0.006	-11.81	0.081
5203	Maha oya	1947 - 1957	11	23.95	-44621	0.055	-26.04	51703	0.030	49.99	-96326	0.203	-0.019	37.60	0.099
Northern lowland of Dry Zone															
6002	Galoya junction	1942 - 1958	13	-5.47	12223	0.006	3.36	-6241	0.013	-16.22	32804	0.095	0.004	-7.97	0.057
6010	P.W.D. Bridge	1947 - 1975	20	-5.87	13071	0.017	-1.23	2988	0.000	-12.12	24654	0.037	-0.002	3.75	0.002
6704	Wahalkada	1953 - 1973	21	12.11	-22231	0.051	4.65	-8843	0.031	7.46	-13390	0.029	0.003	-6.07	0.049
6901	Yakawewa	1980 - 1992	13	-16.66	34390	0.063	-5.37	10879	0.011	-11.29	23512	0.078	0.000	0.55	0.000
9001	Kappachchi	1948 - 1984	33	-5.37	11916	0.032	0.46	-753	0.001	-4.02	9082	0.041	0.000	-0.18	0.000
9002	Tekkam	1946 - 1958	13	0.19	1016	0.000	1.89	-3525	0.002	-1.70	4546	0.001	-0.002	4.10	0.009
9502	Tabbowa	1961 - 1978	17	-15.51	31921	0.124	-2.48	5026	0.023	-13.04	26928	0.154	-0.001	1.73	0.008
9901	Hettipola	1945 - 1982	21	-3.75	9270	0.026	11.25	-21539	0.227	-15.08	31001	0.203	0.007	-12.76	0.278
9904	Chilaw	1952 - 1992	23	-11.22	23788	0.244	-8.82	19092	0.173	11.94	-23004	0.274	0.009	-17.66	0.428

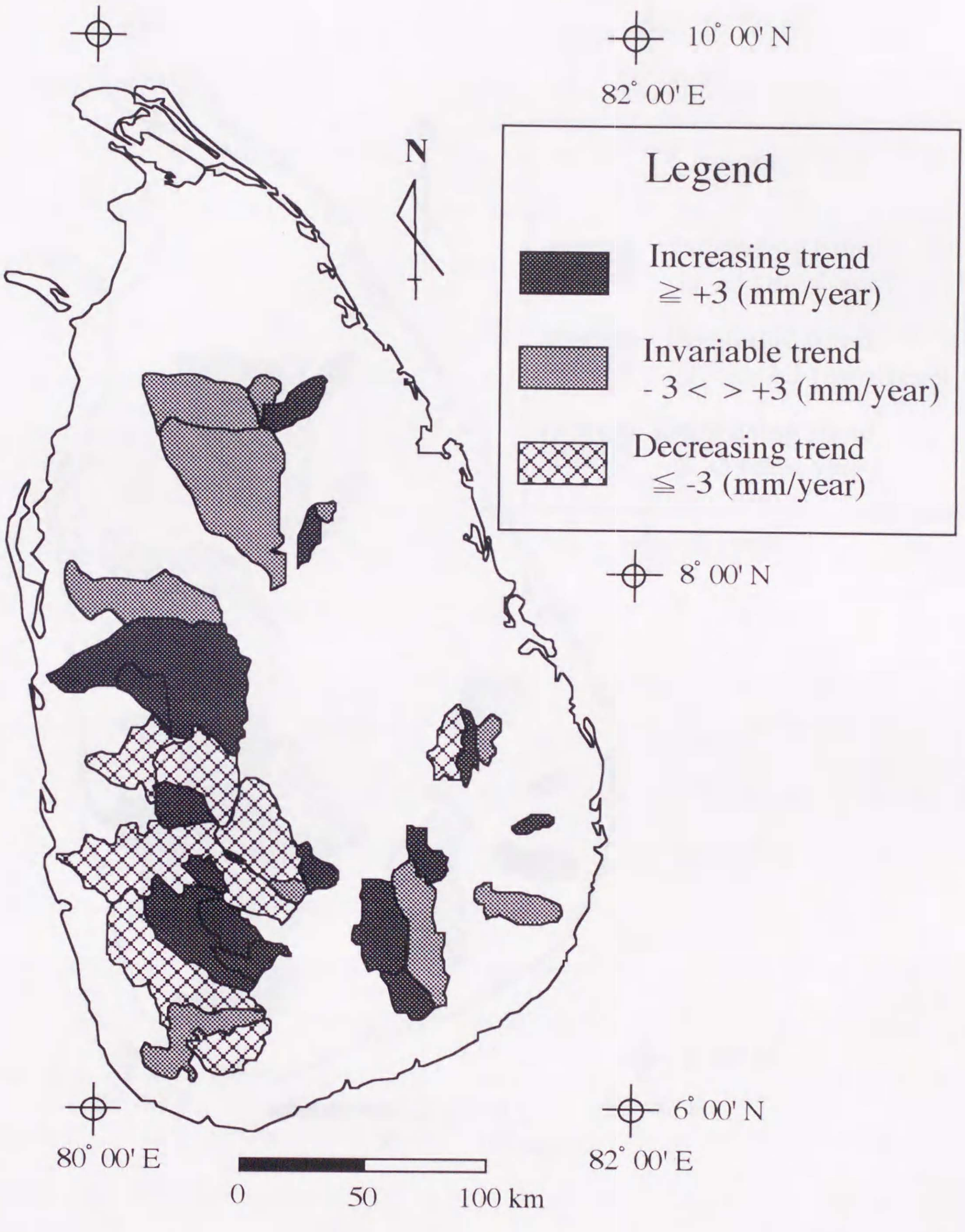


Fig. 44 Distribution of trend on the discharge

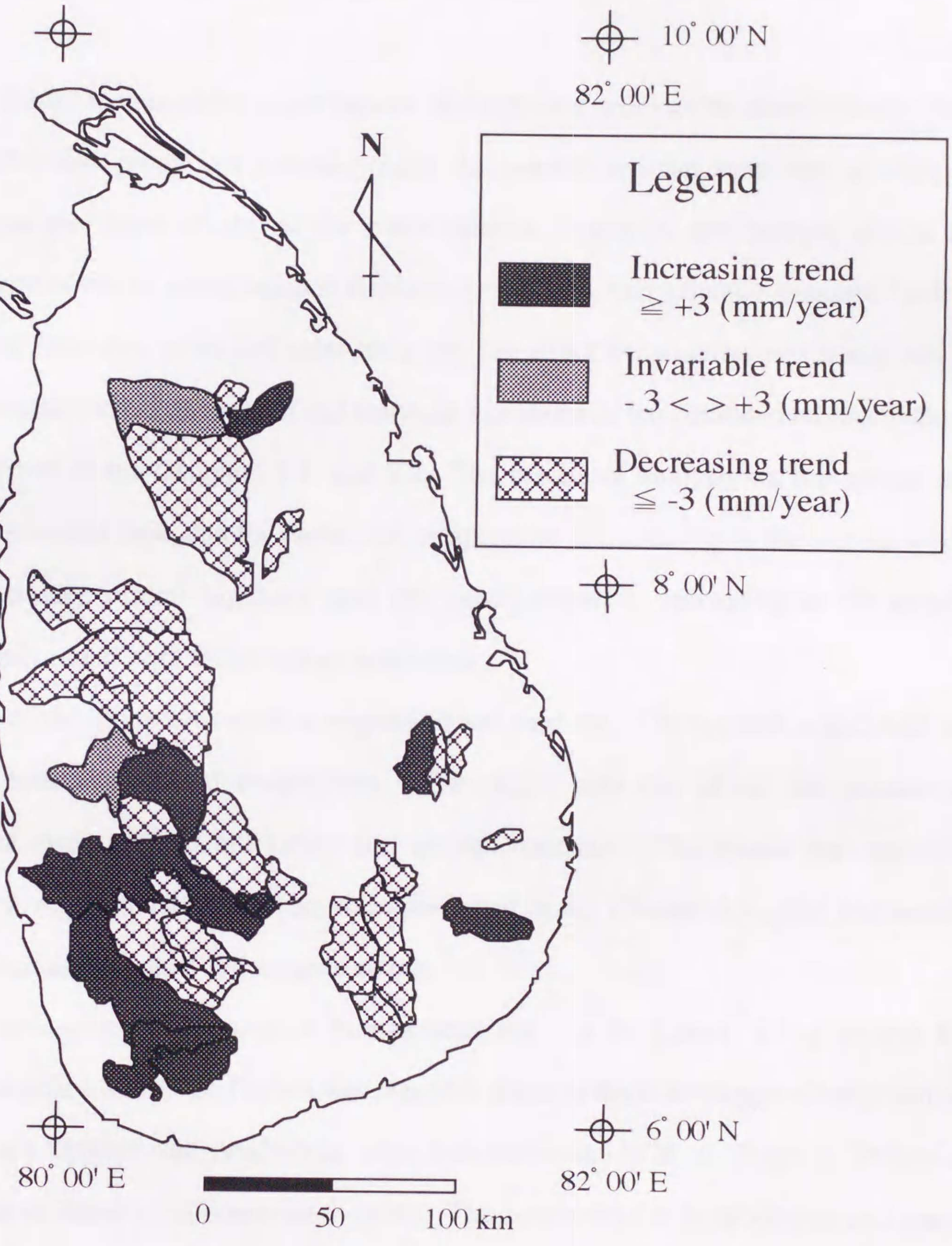


Fig. 45 Distribution of trend on the water loss

Chapter 6

Discussion

The causes to control the water balance of catchment area can be classified into three groups. The first group is a climatic factor. In general, we can state that all climatic elements can give some effects on the water balance, especially precipitation affects the water balance as one of water balance elements as input. Other climatic elements such as temperature, humidity, wind and solar radiation can affect evaporation and transpiration. In these climatic factors, the spatial and temporal variations of temperature and precipitation were described in the Chapters 5.1. and 5.2. The results of analysis on the spatial and temporal variations show that the surface air temperature is increasing in the almost whole island, especially central highland, and the precipitation is decreasing at the central highland and around near Trincomalee, east coast.

The second group is a factor of vegetation and land use. The vegetation and land use can affect transpiration and evaporation. This factor also can affect the process of hydrological cycle such as infiltration and storage capacity. The spatial and temporal variations of vegetation and land use were described in the Chapter 5.3., and the results show the decrease of forest and tea cultivation.

The third group is a factor of human activities. In Sri Lanka, a big project for irrigation so called Mahaweli Project was planned. Such as the first project of irrigation on the Mahaweli Project, the headworks were completed in 1976 at Polgolla Diversion downstream of Peradeniya observation point. The reservoirs for hydropower and water resources built on some streams can affect the discharge of stream and the pattern of discharge. In this study, the temporal variations of the water balance of catchment area are analyzed from the watersheds and period without effect of the third group (Chapter 5.4.).

The abnormal distribution of the water balance variation was discovered from the spatial and temporal analyses of water balance. Only the watersheds located in the southwest inland of the Wet Zone show the converse trend between areal precipitation and discharge.

To clear what factors make this abnormal distribution of discharge trend, the relationship between climatic factor and land use change will be examined in this chapter. To contrast the effect of both factors, trend of areal air temperature and water balance elements are recalculated only for the period between 1956 and 1983 when the land use change data are available.

6.1. Effect of climate change on the water balance

The 40 watersheds are selected to clear the relationship between the environmental change and water balance in the period from 1956 to 1983. Figure 46 indicates the distribution of trend of discharge of the 40 watersheds between 1956 and 1983 classified into the same category as Fig.44. The results of comparison with Fig.44 indicate that some watersheds show different trend of discharge in the Dry Zone, but many watersheds located in the southwest inland of the Wet Zone show similar trend of discharge. The trends of annual areal air temperature of watershed and annual areal precipitation are compared to the water balance variation at 40 watersheds to clear the relationship between the climate change and the water balance variation.

The relationship between the trend of areal annual air temperature and trend of annual water loss from 1956 until 1983 is shown in Fig.47. The trend of areal air temperature of watershed was calculated from the isopleths of regression coefficients using the grid method. About three-fourths of 40 watersheds indicate the decreasing trend of water loss. The trends of water loss show no relation with climatological region as can be seen in Fig.47. In general, it is said that the evapotranspiration increases when the air temperature increases. However, it is indicated that other effects such as sunshine exceed the effect of air temperature on the evapotranspiration in the humid tropics (Reading, A. J., *et al*, 1995). In Sri Lanka, it is considered that the effect of the air temperature change was cancelled out by other effects.

The relationship between the trend of annual areal air temperature and trend of annual runoff ratio is shown in Fig.48. In this figure, the symbols are classified by the climatological regions. The watersheds located in the Intermediate Zone show the largest variation of trend of annual runoff ratio. However, all the watersheds located in the Dry Zone indicate the trend of annual runoff ratio between -0.01 and +0.01. The reasons why the watersheds located in the Dry Zone show little variation of water balance are considered as follows The Dry Zone of Sri Lanka has almost flat and low topography and stable land use such as paddy. Therefore, it is difficult to consider a sudden change of discharge in the Dry Zone.

The 40 watersheds in the Sri Lanka are classified into three groups as A to C Groups using the trend of runoff ratio based on an index of variation of water balance. The distribution of watersheds classified into A to C Groups are shown in Fig.49.

The six watersheds located in the Wet Zone and three watersheds in the Intermediate Zone, which show the trend of runoff ratio with larger than +0.01, are classified into A Group. The distribution of the watersheds classified into A Group correspondes to the region where the water balance show the converse trend in areal precipitation and discharge.

Ten watersheds located in the Dry Zone, 14 watersheds in the Wet Zone and five watersheds in the intermediate Zone are classified into B Group. These watersheds are classified using the values of trend of runoff ratio between -0.01 and +0.01.

In the C Group, the only two watersheds that the trend of runoff ratio is less than -0.01 are classified, and the two watersheds located in the Intermediate Zone. These watersheds show increase of the water loss strongly.

The relationship between the trend of annual areal precipitation and the trend of annual water loss is shown in Fig.50-a. These symbols indicate the climatological regions. The solid line in the figure shows the slope of +1 and the y-interception of 0. In general, this relation shows a positive correlation. Accordingly it is considered that the areal precipitation affect the evapotranspiration.

Figure 50-b illustrates a schematic diagram of relationship between the trend of areal annual precipitation and the trend of annual water loss. The relations are classified into three areas by two symbolic lines with the slope of +1 and 0. The watersheds distributed on the line with slope of 0 show the constant annual water loss. These watersheds also show the similar trend of areal precipitation and discharge. The watersheds distributed on the line with slope of +1 show the similar trend of areal precipitation and water loss. This relation indicates that the discharge occurs constant amount. The watersheds distributed in the area of the negative slope indicate that the trend of discharge exceeds the trend of areal precipitation. The watersheds distributed in the area of the slope between 0 to +1 indicate that the decreasing trend of discharge shows less than the trend of areal precipitation. The watersheds distributed in the area of the slope with greater than +1 indicate the converse trend in areal precipitation and discharge.

Figure 50-c shows same relation as Fig.50-a of the 40 watersheds classified into A to C Groups. Excluding near the origin, each watershed classified into A, B and C Groups almost distributes in the area of the slope with larger than +1, between 0 and +1, and with less than 0 , respectively.

As the results of those relationships, the watersheds classified into the A and C Groups show the abnormal variations of water balance, and it is considered that the some local effects such as land use change would exceed the effect of climate change in those A and C Groups. On the other hand, the watersheds classified into B Groups would have little effect of land use change. In those watersheds, it is considered that the effects of climate change will be cleared from the water balancé variations.

The water balance variations of the watersheds of B Group could be classified into two types,or Type I and Type II, using the season when the precipitation decreases. The schematic diagram of the seasonal relationships of water balance is shown in Fig.51.

The Type I is the case that the precipitation decreases in the dry season. On the other hand, the Type II is the case of wet season. In the case of Type I, the decrease of precipitation occurs in the dry season when the precipitation is less than potential evapotranspiration. Therefore, it is considered that the actual evapotranspiration is limited by the amount of the precipitation. As a result, the variation of precipitation affects the actual evapotranspiration directly. The variation of each annual water balance element will show the decrease of areal precipitation, decrease of water loss and invariance of discharge.

In the case of Type II, the decrease of precipitation occurs in the wet season when the precipitation amount is sufficient for the evapotranspiration. Therefore, the actual evapotranspiration will occur up to the potential amount. As a result, it is considered that the variation of precipitation does not affect the actual evapotranspiration. The variation of each annual water balance elements will show the decrease of areal precipitation, invariance of water loss and decrease of discharge.

The water balance variation classified into the Type I is suited to the relation with the slope of +1, and the Type II is suited to the slope of 0 in Fig.50-b. As a result that the watersheds of B Group situate between the slopes 0 and +1 in Fig.50-c, it is considered that the watersheds could be classified by either of the two types.

In general, the distribution of precipitation in the tropics shows the large spatial and temporal variations. The trends of water balance elements between 1956 and 1983 and results of t-test are shown in Table 15. The results of t-test indicate that less than half of the 40 watersheds are significant at the 5 % of significance level. In particular, the trends of discharge are significant at the 5 % of significance level in only eight watersheds. Therefore, it is considered that the inter-annual variation of each element of water balance indicates the large deviations.

This result shows that the watersheds could be classified into the Type I and Type II, distributed on and near the slopes of one and zero, respectively. Using the values of slope of this relation, the 40 watersheds reclassified into A to C Groups, and the B Group into Types I and II. The new classified diagram is indicated in Fig.52. The watersheds of B Group are reclassified into both Type I with the slopes from -0.5 to +0.5 and Type II with the slopes from +0.5 to +1.5. The watersheds distributed in the area that the slope indicates more than +1.5 are reclassified into the A Group, and the slope indicates less than -0.5 are reclassified into the C Group.

The distributions of each group are shown in Fig.53. The eight watersheds are classified into the A Group, and these watersheds distribute mainly on the southwest inland of Wet Zone. This classification on the A Group is almost same classification using the trend of annual runoff ratio in Fig.48. Four watersheds located near the origin in Fig.53 are added newly into the C Group. The 26 watersheds are selected into the B Group. The 15 watersheds located mainly in the Dry and Intermediate Zone are classified into the Type I. The remaining eleven watersheds situated mainly in the central highland and the Wet Zone are selected into the Type II.

The trends of monthly areal precipitation and monthly discharge of the watersheds classified into the A, B-I (B Group and Type I), B-II (B Group and Type II) and C Groups are shown in Fig.54. In the case of B-I Group, many watersheds shows decreasing trend of monthly areal precipitation in the northeast monsoon season from December to March . However, the monthly discharges indicate the invariable trend in the entire season. The northeast monsoon season is the dry season on the whole island of Sri Lanka. On the other hand, in the case of B-II Group, many watersheds indicate the decreasing trend of monthly areal precipitation in the intermonsoon seasons and the southwest monsoon season.

The spatial and temporal variations of monthly precipitation in Sri Lanka are determined in the Chapter 5.2. The precipitation was notably decreased in the southwest monsoon season on the central highland area, and in the northeast monsoon season in and around eastern area of the Dry Zone. These results such as spatial and temporal variations support the classification of B-I and B-II Groups.

The water balance variations in the Dry and Intermediate Zone are considered as follows. As for the effect of climate change on the water balance, the decrease of precipitation from 1950's until 1980's mainly occurred in the dry season. And it caused the decrease of evapotranspiration. However, the trend of discharge was invariable. On the other hand, as for the effect of climate change on the water balance in the Wet Zone, the decrease of precipitation from 1950's until 1980's occurred in the wet season. And it caused the decrease of discharge. However, the trend of evapotranspiration was invariable.

6.2. Effect of land use and land use change on the water balance

In order to clear unstabilization factors on the water balance of watersheds classified into A and C Groups, the overlay analysis is made between the distributions of watersheds of A and C Groups and proportion of major land use by districts.

Figure 55-a to Fig.55-d show the proportion by districts of tea cultivation, paddy, dense forest and sparsely used cropland areas, respectively, overlaid upon the distribution of the watersheds. Figure 55-a shows a high correlation between the proportion of tea cultivation and the distribution of A and C Group watersheds excluding Nuwara Eliya District. Therefore, it is considered that the land use of tea cultivation will affect the water balance of those watersheds. Figure 55-d shows that the land use of sparsely used cropland indicates a relatively high proportion in Ratnapura District, Badulla District, Matale District and Kandy District in the Wet Zone where the watersheds classified into A and C Groups are distributed. Sparsely used cropland consists of shifting cultivation, abandoned tea, land under development and others.

The distribution and structure of the shifting cultivation called "Chena" in Sri Lanka were reported by Johnson and Scrivenor (1981). They indicated that the "Chena" was also cultivated only the Ratnapura Distict in the Wet Zone. The cultivation for rice in a dry field had been permitted for the workers on the vacant land of estate. This cultivation had been limited only a harvest, and after harvest the area fallowed in five or six years. This land use type was classified into the shifting cultivation.

In order to confirm this fact, the proportion of these land uses on the five watersheds located in the Wet Zone are calculated using numeric data of 500m × 500m square grid (Fig.56). The land uses are classified into three type such as tea cultivation, sparsely used cropland and others. Two watersheds are classified into A Group, and the three are classified into B Group. The results indicate that the percentage of sparsely used cropland of almost all watersheds of B Group are less than ten percent, and two of three watersheds indicate the proportion of one percent as Morape watershed(6009) and Talawakelle watershed(6021). On the contrary, the percentage of sparsely used cropland on the watersheds of A Group shows high value as over 25 percent as Malwala watershed(0303) and Watawala watershed(6020). However, it is not clear relation with the percentage of tea cultivation. Therefore, some land use of the category such as sparsely used cropland makes rapid change of vegetation and land surface. As the results, it is considered that the land use affects the evapotranspiration and discharge systems.

To estimate a relationship among the increasing trend of discharge, land use and its change, the relationships are illustrated between the proportion of the tea cultivation area and the regression coefficient of discharge trend on the six watersheds in Fig.57-a. And the same relationship between the proportion of abandoned tea cultivation area from 1956 until 1983 and the regression coefficient of discharge trend on the six watersheds are shown in Fig.57-b. These six watersheds are located in the Wet Zone and classified into the A Group.

As the result, the relationship between proportion of the area where the land use changes from tea cultivation and trend of discharge shows the relatively high coefficient. It is considered that many abandoned tea area will be cultivated arable land in the central highland of Sri Lanka. In general, it is easy to occur the surface runoff and decrease of transpiration in the newly cultivated arable land in the mountainous region. Therefore, it is considered that the land use change from tea cultivation is one of factors to increase of discharge amount.

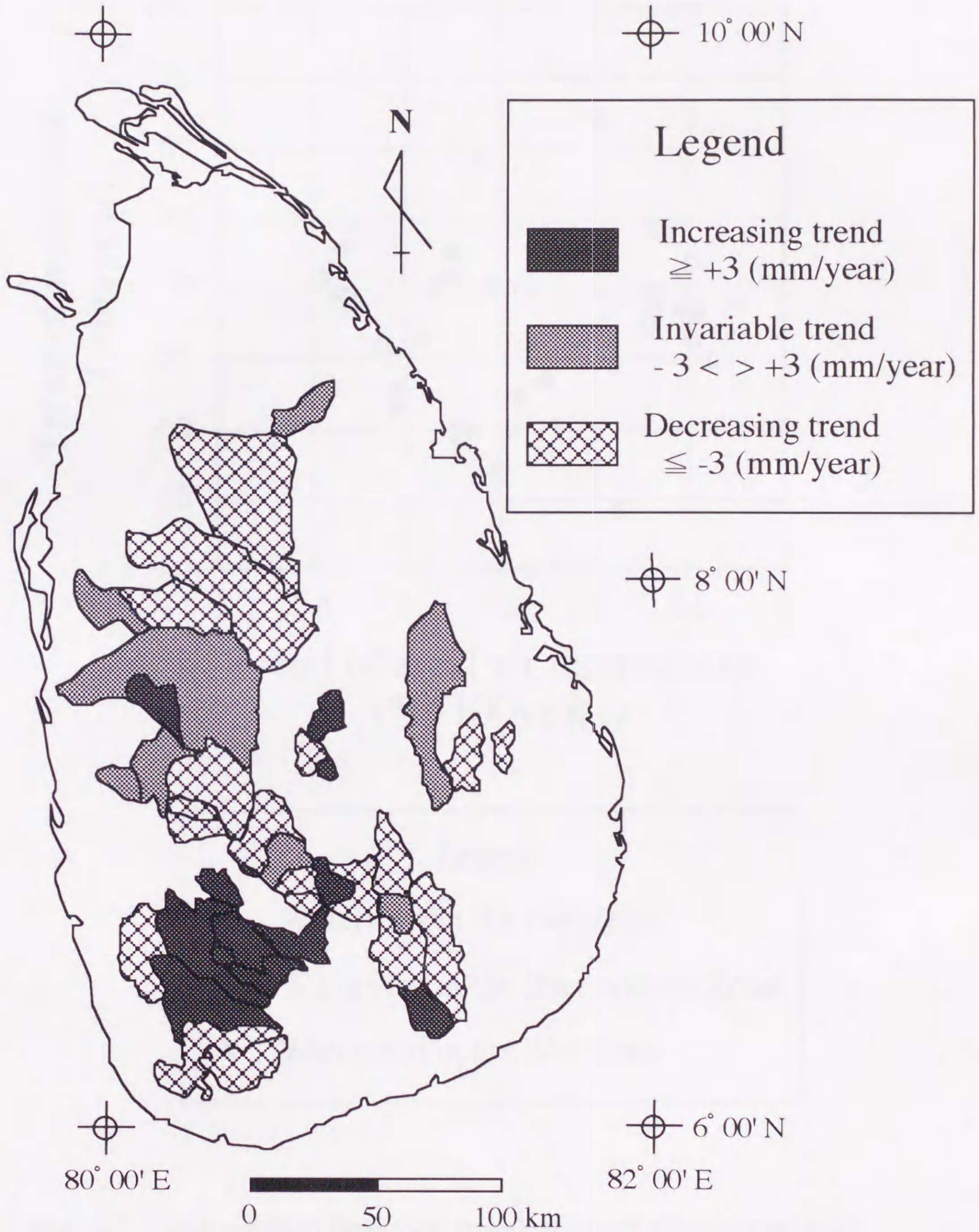
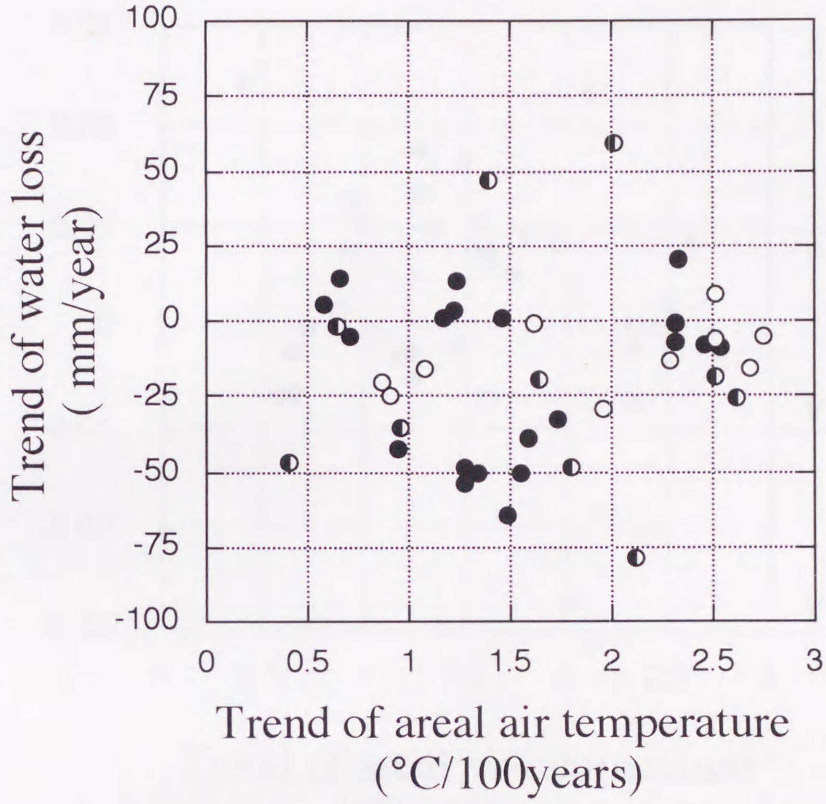


Fig. 46 Distribution of trend in the discharge between 1956 and 1983



Legend

- ○ Watershed in the Dry Zone
- ◐ Watershed in the Intermediate Zone
- ● Watershed in the Wet Zone

Fig. 47 Relationship between trend of areal air temperature and water loss from 1956 until 1983

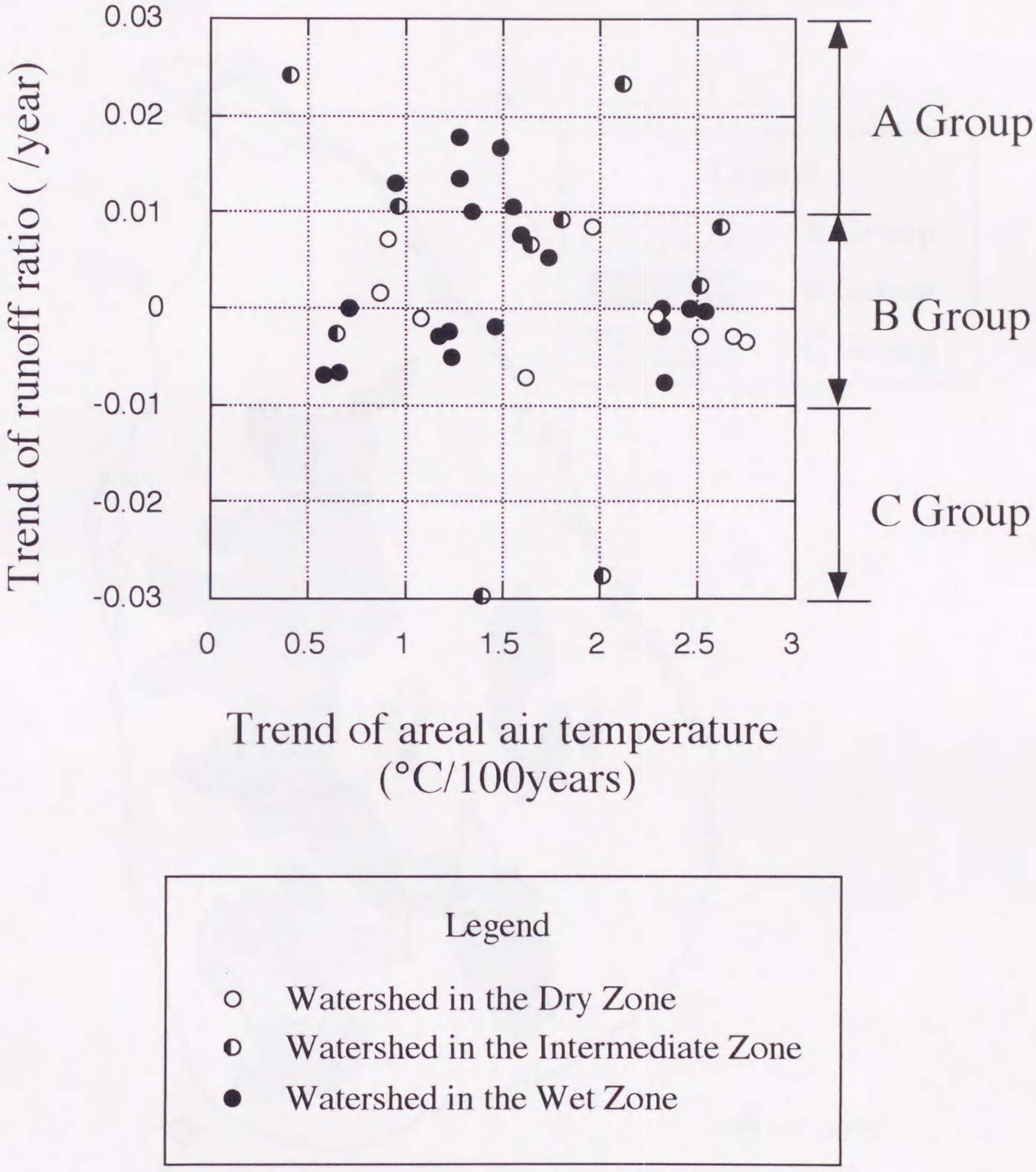


Fig. 48 Relationship between trend of areal air temperature and runoff ratio between 1956 and 1983

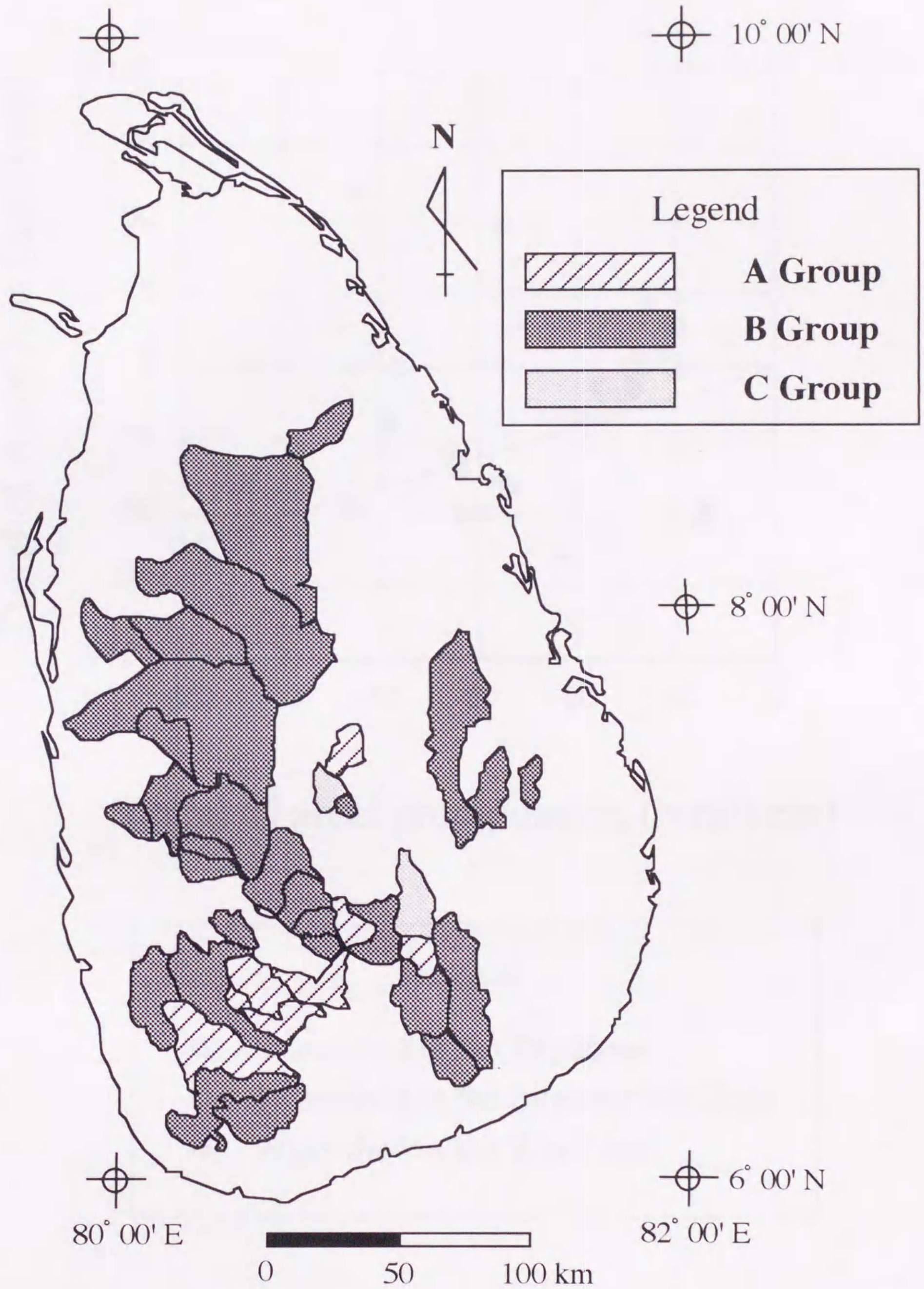


Fig. 49 Distribution of the watershed on the A, B and C Groups

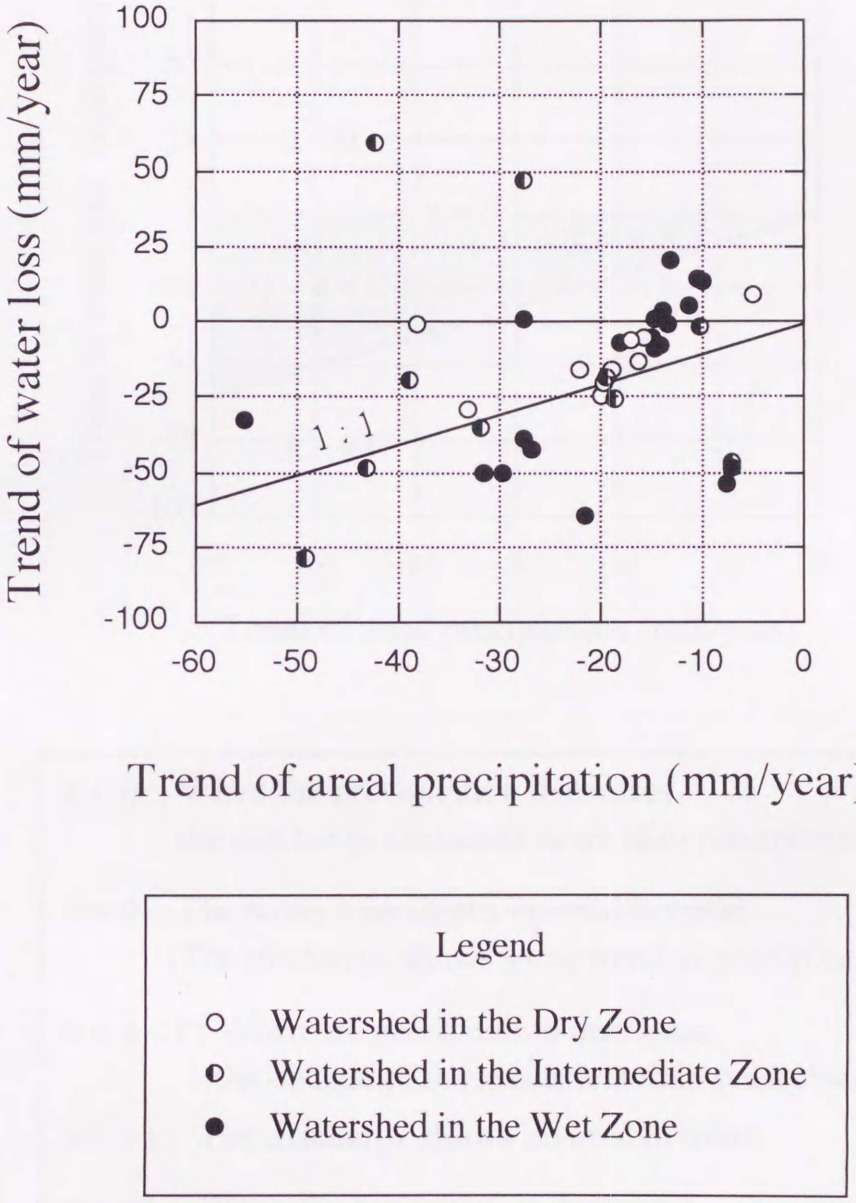
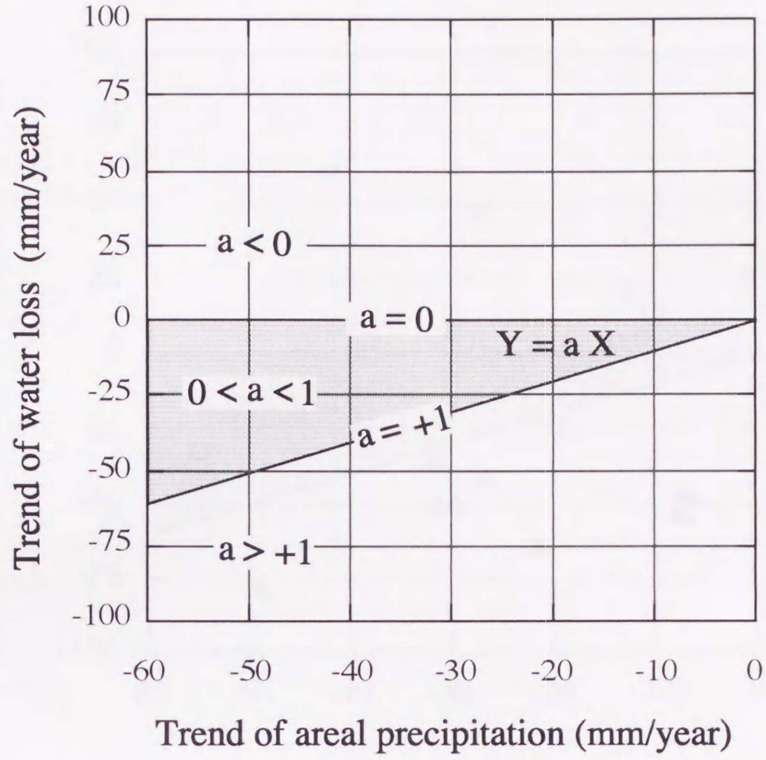


Fig.50-a Relationship between trend of areal precipitation and water loss from 1956 until 1983
These watersheds were classified by the climatological zone.



a < 0 : When the precipitation decreases,
the discharge decreases more than precipitation.

a = 0 : The water loss shows invariable trend.
(The discharge shows same trend as precipitation.)

0 < a <1 : When the precipitation decreases,
the discharge decreases less than precipitation.

a = +1 : The discharge shows invariable trend

a > +1 : When the precipitation decreases,
the discharge increases.

Fig.50-b Schematic diagram of relationship between trend of areal precipitation and water loss

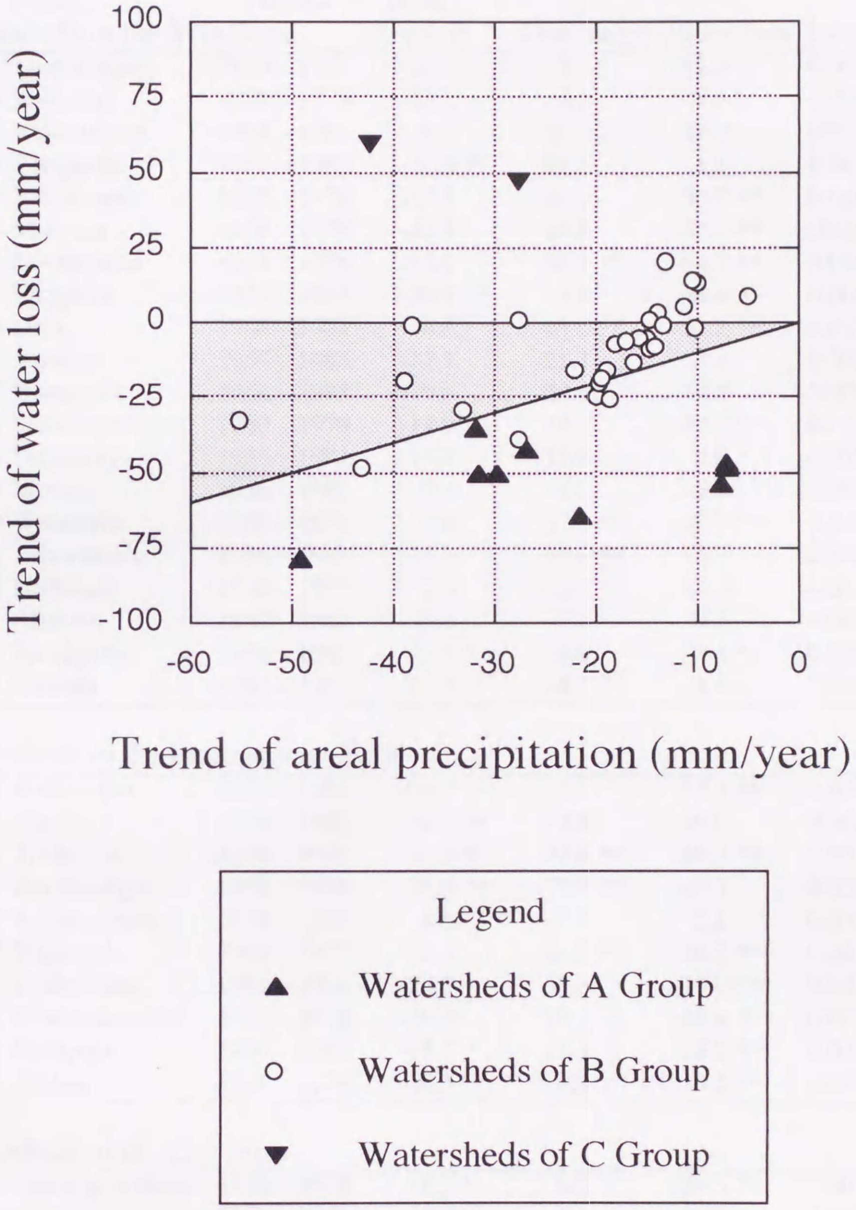


Fig.50-c Relationship between trend of areal air temperature and water loss from 1956 until 1983
These watersheds were classified by the A, B and C Groups

Table 15 Trend of water balance between 1956 and 1983

No.	Name	Period	Trend Areal P.	Discharge	Water loss	Runoff ratio
Watersheds in the Wet Zone						
0105	Deraniyagala	1956 - 1976	-20.9	12.4	-32.3	0.0054
0108	Imbulana	1956 - 1973	-12.2	-5.2	-6.9	0.0001
0112	Holombuwa	1963 - 1981	-6.0	-26.2	20.3	-0.0077 *
0301	Putupaula	1956 - 1982	-22.8 **	-21.1	1.3	-0.0018
0302	Millakanda	1957 - 1978	-17.3	26.4	-50.7 **	0.0102 **
0303	Malwala	1956 - 1978	-21.5	28.8	-50.3 **	0.0106 **
0304	Nambapana	1957 - 1978	-10.4	50.1 **	-64.7 **	0.0168 **
0305	Ellagawa	1957 - 1983	-30.1 **	5.8	-38.8 **	0.0076 **
0306	Dela	1958 - 1983	-8.8	43.0 **	-54.2 **	0.0178 **
0901	Agaliya	1957 - 1983	-17.1	-21.7	3.6	-0.0025
1201	Bopagoda	1956 - 1983	-9.9	-20.0	12.9	-0.0050 *
1806	Samanalawewa	1959 - 1979	-14.9	25.2	-42.4 **	0.0129 *
6004	Peradeniya	1956 - 1983	-14.8	-15.6	0.8	-0.0028
6009	Morape	1956 - 1981	-7.9	-4.2	-5.6	-0.0001
6020	Watawala	1958 - 1976	8.6	57.3 **	-48.7 **	0.0135 **
6021	Talawakelle	1956 - 1983	-11.2	-29.1 **	5.7	-0.0068 **
6027	Holbrook	1960 - 1977	2.6	-11.8	14.4	-0.0067
10201	Alawwa	1956 - 1982	-8.6	-7.2	-0.5	-0.0019
10202	Badalgama	1956 - 1983	-14.7 *	-4.8	-8.4 *	-0.0002
10203	Giriulla	1961 - 1981	-13.7	-4.3	-8.1	0.0001
Watersheds in the Intermediate Zone						
2203	Wellawaya	1959 - 1983	-34.7 **	2.2	-35.3 **	0.0106
5202	Nilobe	1956 - 1981	-39.3 **	-7.8	-19.6	0.0067
6015	Teldeniya	1956 - 1976	-33.5 *	-92.8 **	59.3 **	-0.0277 **
6017	Kandaketiya	1959 - 1978	-33.3 **	-77.9 **	47.1	-0.0296 **
6023	Talawakanda	1958 - 1983	-9.6	-7.5	-2.1	-0.0027
6029	Welimada	1960 - 1977	-4.5	42.1 **	-46.5 **	0.0242 **
6030	Wellewella	1961 - 1972	-22.2	56.8	-79.0 **	0.0234 **
6032	Moragahamulla	1964 - 1978	-38.2	10.2	-48.4 **	0.0092 *
9901	Hettipola	1956 - 1982	-13.7 *	11.4	-25.9 **	0.0086 **
9904	Chilaw	1961 - 1978	-18.3 *	0.0	-18.3 **	0.0025
Watersheds in the Dry Zone						
2201	Lunugamwehera	1956 - 1978	-18.7 *	6.2	-24.5 **	0.0073 **
2204	Kuda Oya	1968 - 1983	-27.0	-6.3	-20.7 *	0.0015
2601	Kataragama	1956 - 1983	-22.0 **	-6.1 *	-16.3 **	-0.0011
5101	Periya Aru	1956 - 1977	-33.4 **	-31.4	-0.6	-0.0072
5401	Welikanda	1956 - 1978	-33.0 **	0.2	-29.0 **	0.0085 *
6704	Wahalkada	1956 - 1973	11.5	2.3	9.2	0.0024
9001	Kappachchi	1956 - 1983	-11.0	-6.6	-5.6	-0.0034
9302	Nochchiyagama	1964 - 1983	-20.4 *	-7.5	-15.8	-0.0029
9501	Mahauswewa	1956 - 1983	-13.9 *	-5.7	-6.1	-0.0030
9502	Tabbowa	1961 - 1978	-15.5	-2.5	-13.0	-0.0008

(Remarks * : significant at the 5 % of significance level)

(Remarks ** : significant at the 1 % of significance level)

Type I Decrease of precipitation in the **Dry season**

$P_{\text{Dry season}} \ll PEt_{\text{Dry season}}$

$P_{\text{Dry season}} = Et_{\text{Dry season}}$

Decrease of precipitation in the **Dry season**

Decrease of evapotranspiration in the **Dry season**

Precipitation	Decrease
Evapotranspiration	Decrease
Discharge	Invariable

Type II Decrease of precipitation in the **Wet season**

$P_{\text{Wet season}} \gg PEt_{\text{Wet season}}$

$Et_{\text{Wet season}} = PEt_{\text{Wet season}}$

Decrease of precipitation in the **Wet season**

No change of evapotranspiration in the **Wet season**

Precipitation	Decrease
Evapotranspiration	Invariable
Discharge	Decrease

Fig.51 Schematic diagram of seasonal water balance

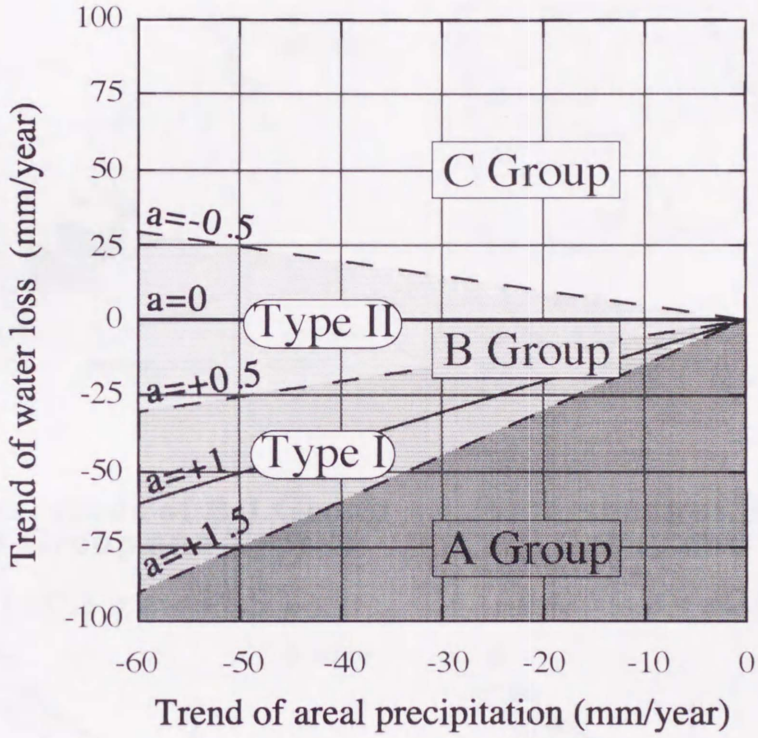


Fig. 52 Classification diagram of the groups

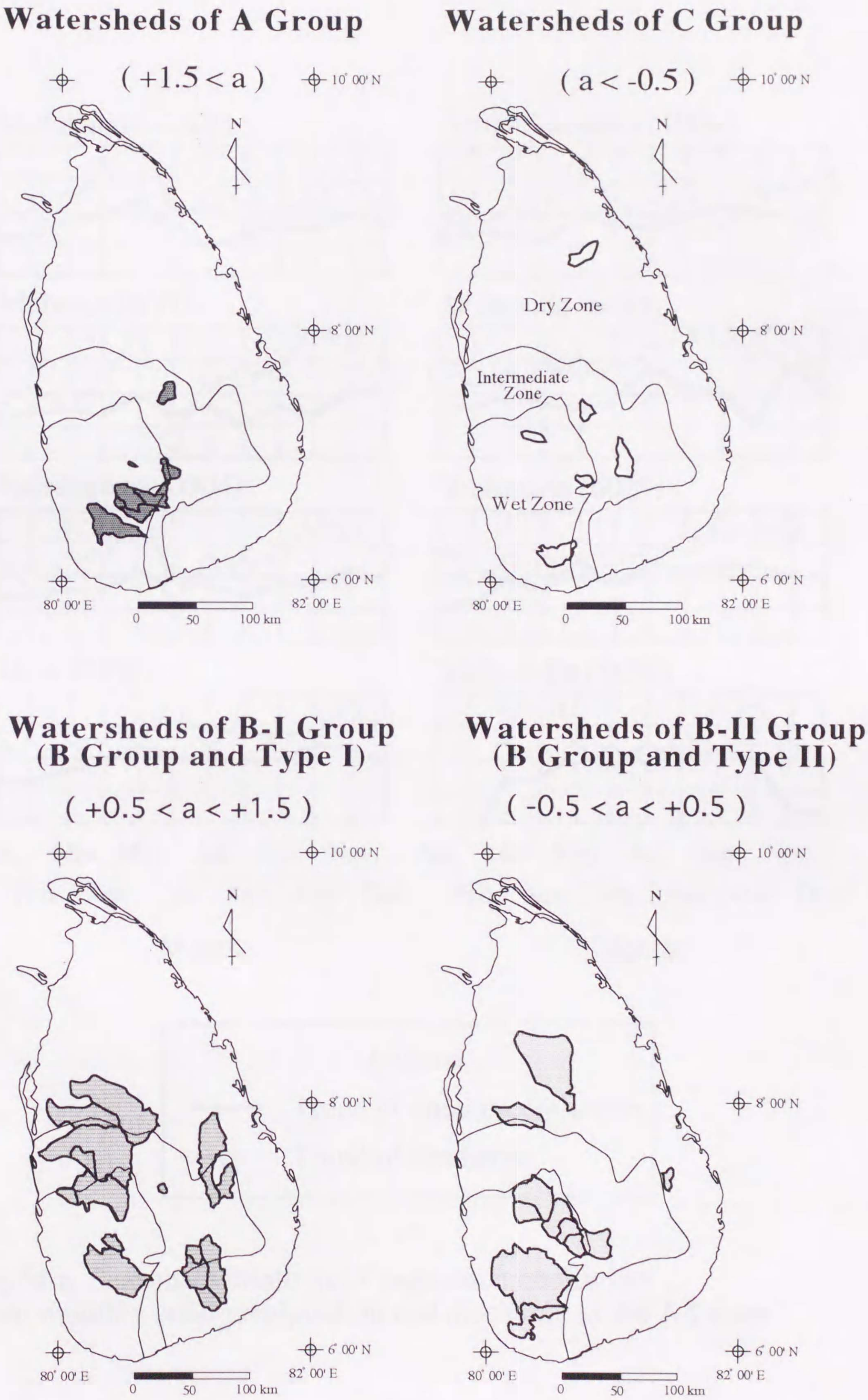


Fig.53 Distributions of watersheds on each group

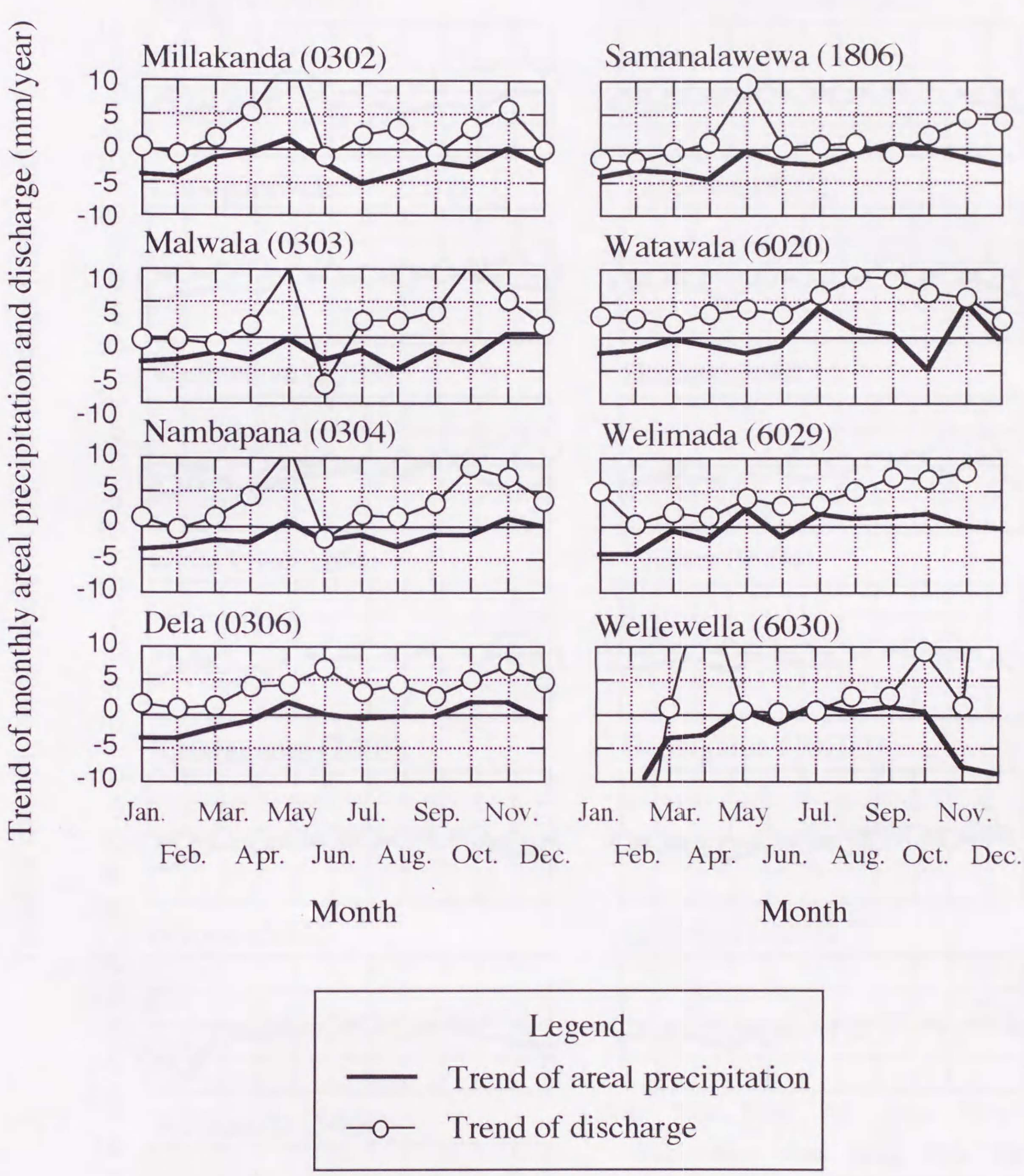


Fig.54-a Seasonal variations of regression coefficient of monthly areal precipitation and discharge of the A Group

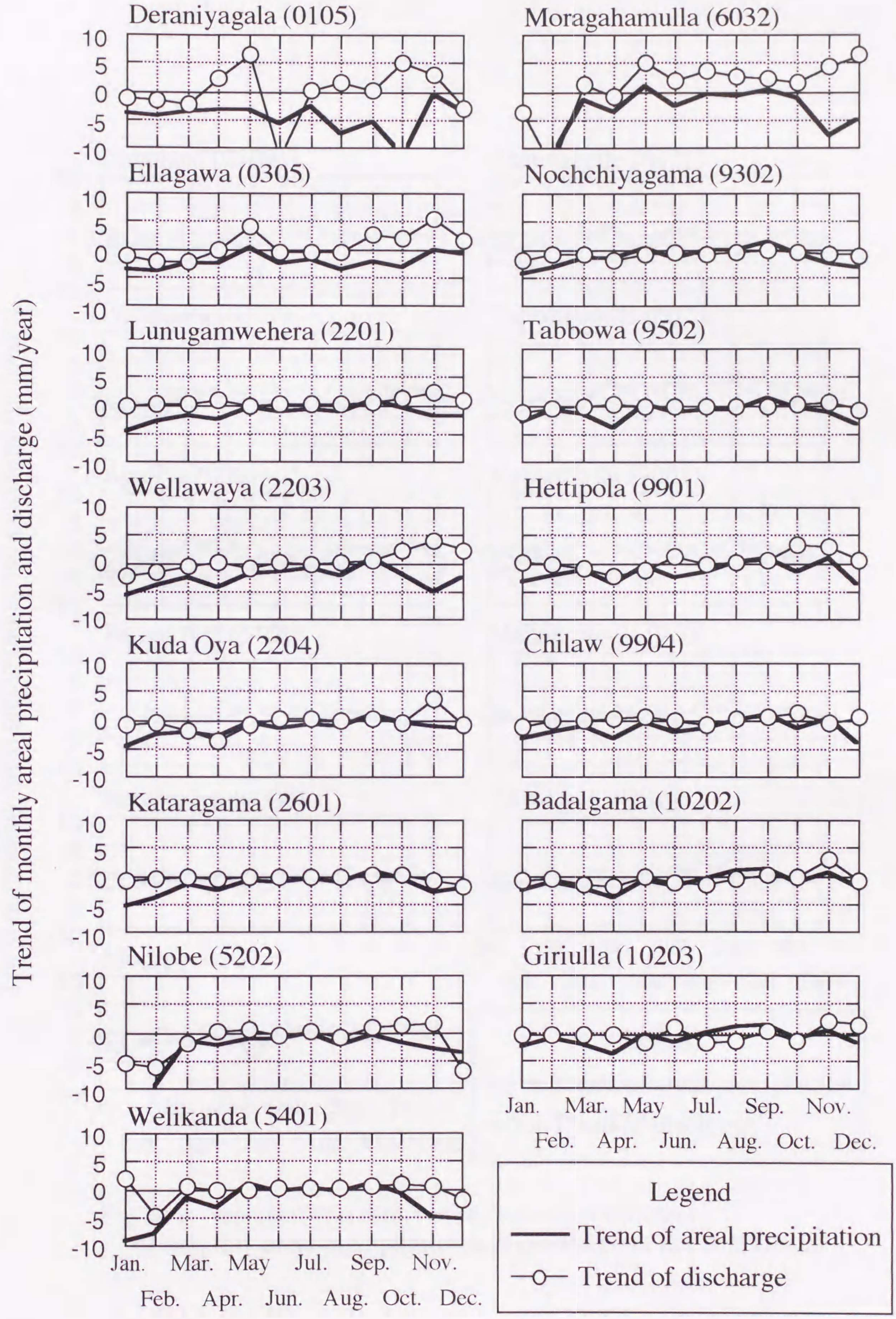


Fig.54-b Seasonal variations of regression coefficient of monthly areal precipitation and discharge of the B-I Group

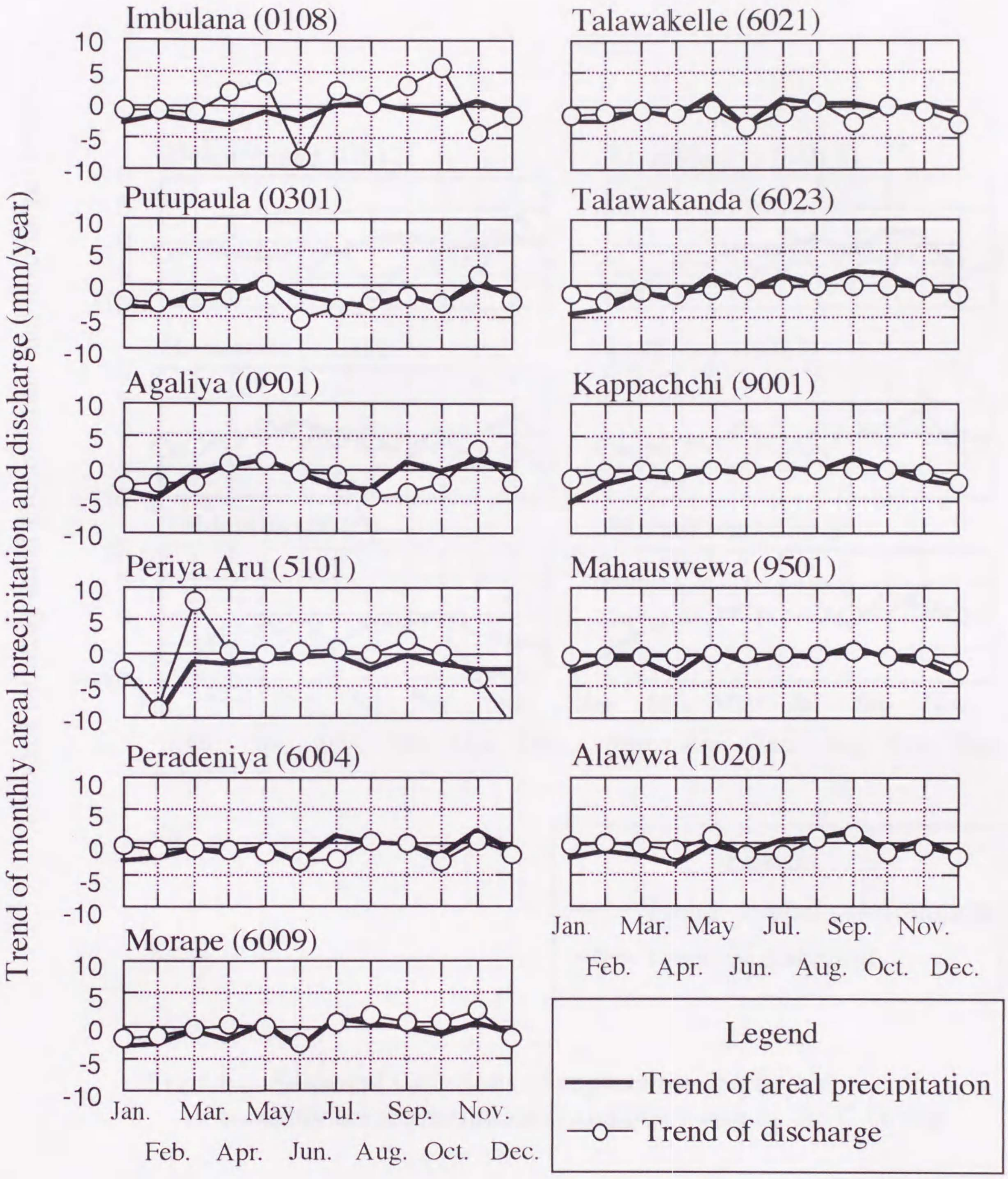


Fig.54-c Seasonal variations of regression coefficient of monthly areal precipitation and discharge of the B-II Group

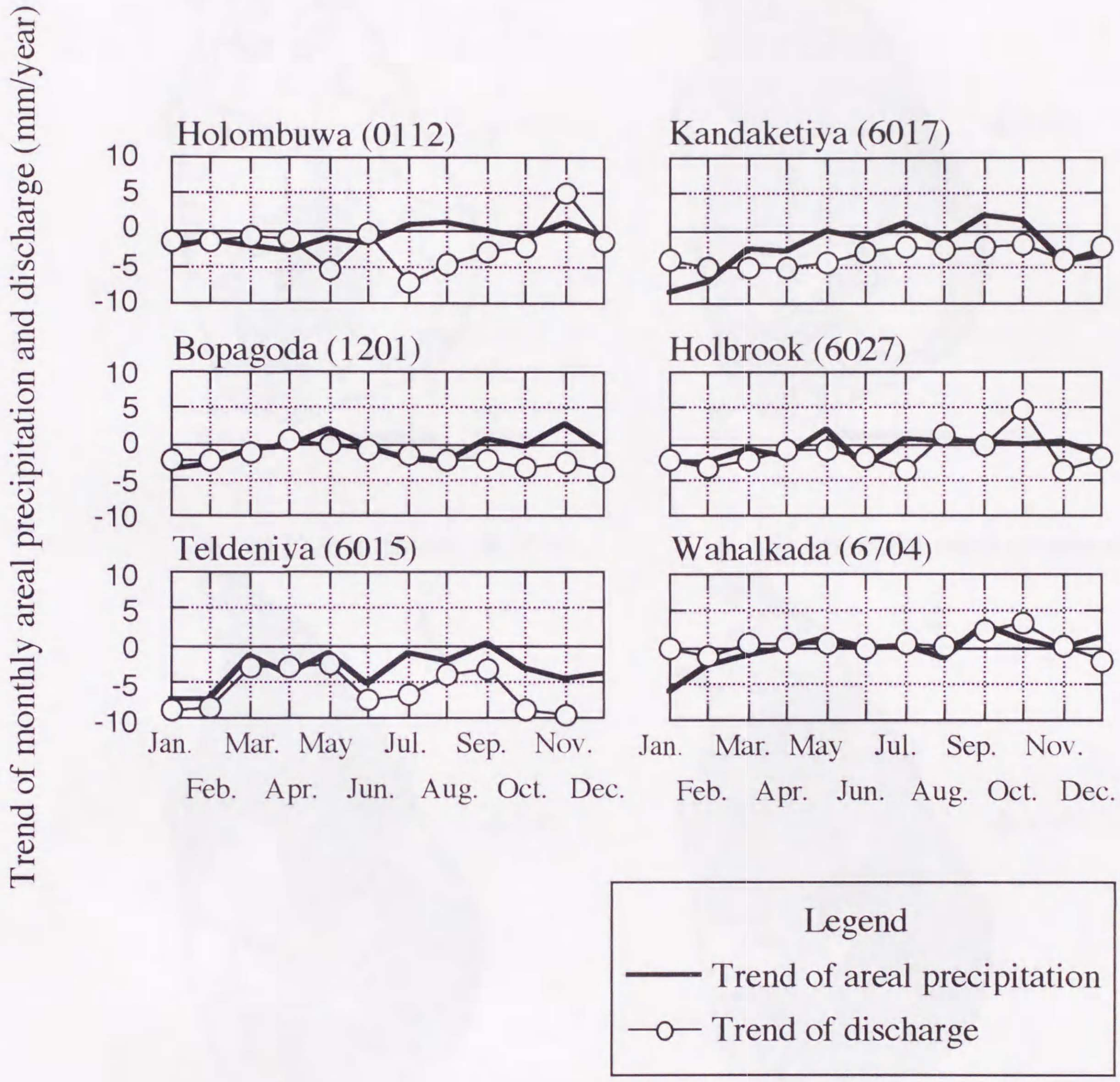


Fig.54-d Seasonal variations of regression coefficient of monthly areal precipitation and discharge of the C Group

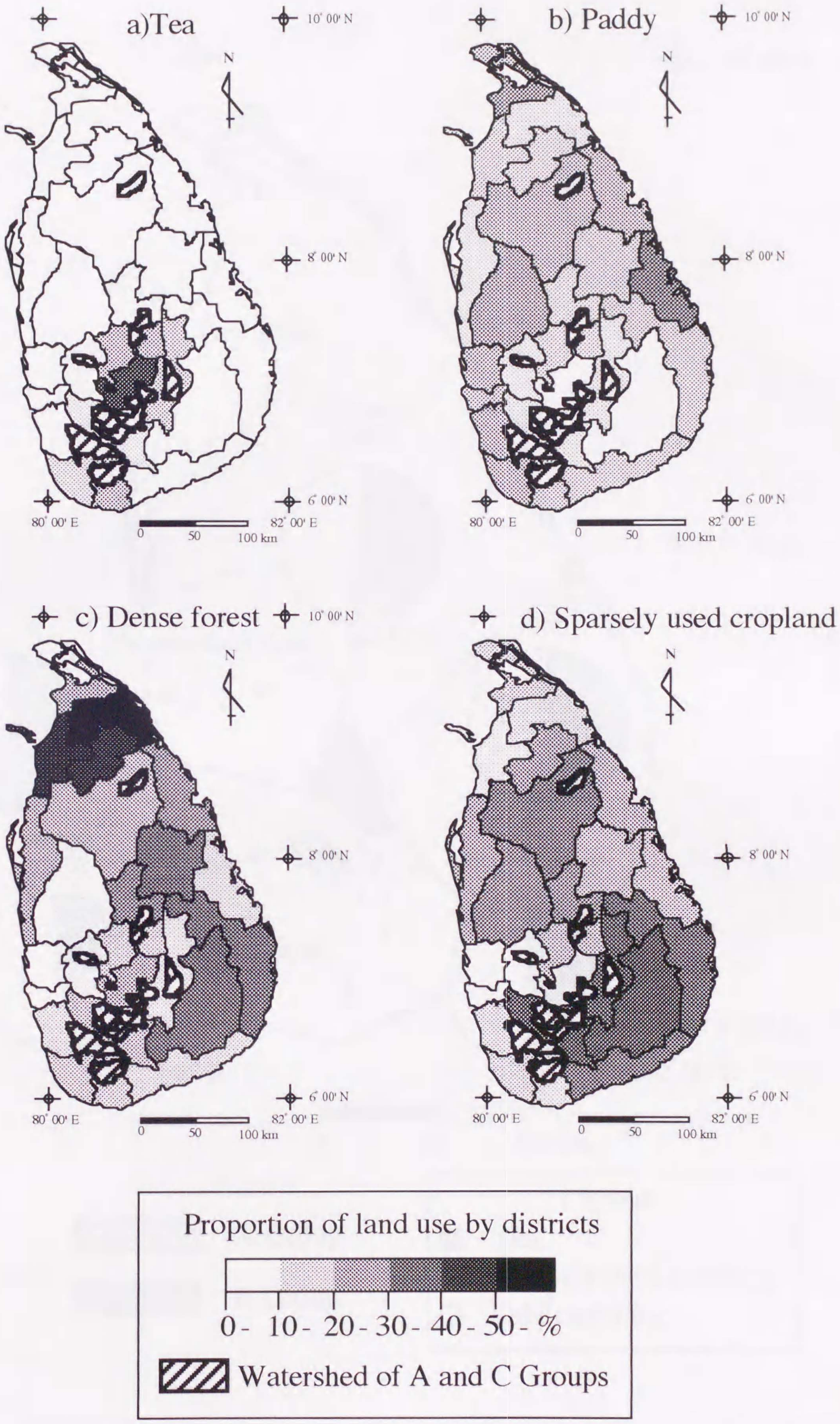


Fig.55 Distribution of proportion of major land use in 1983, and A and C Groups

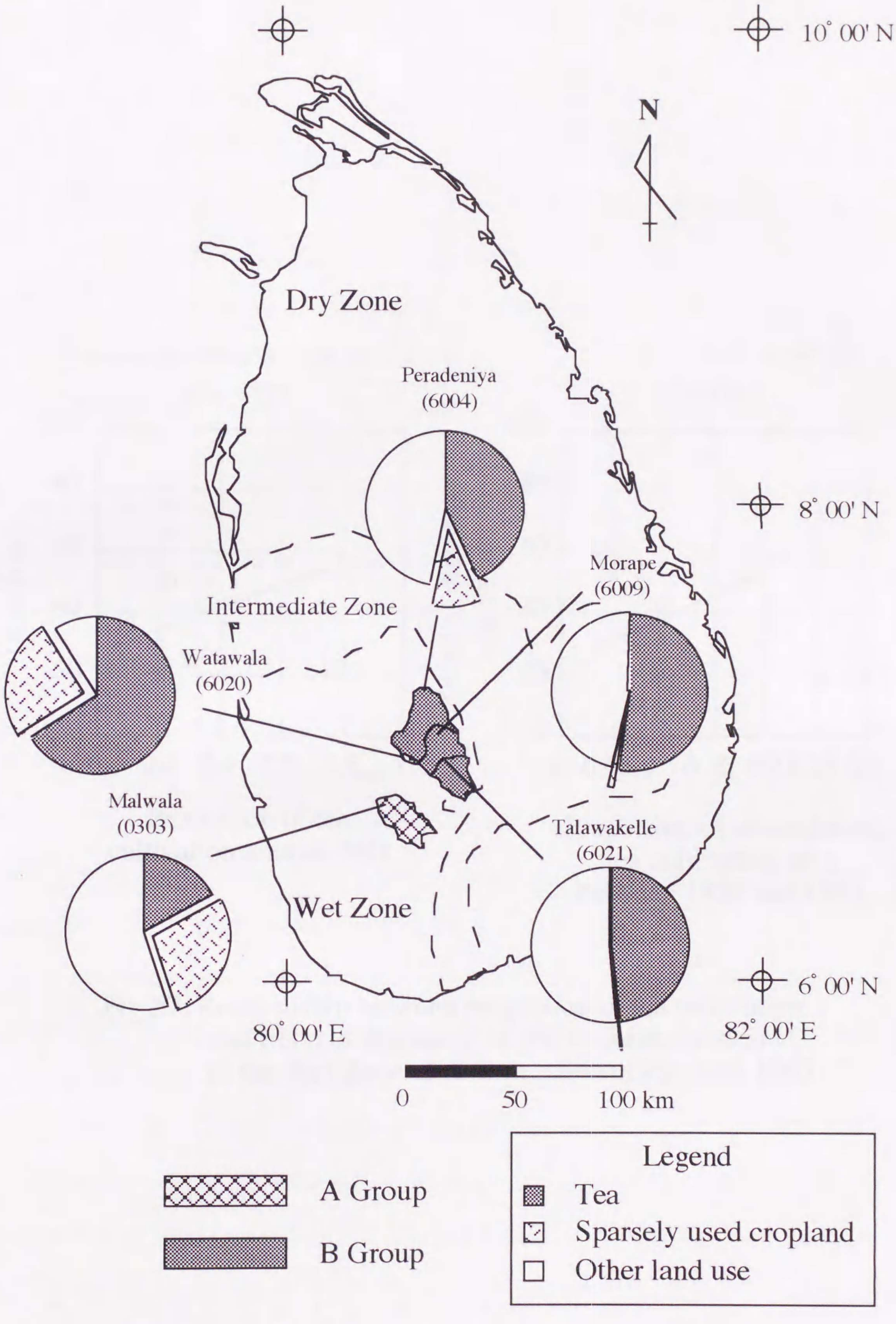


Fig.56 Proportion of major land use on the selected watershed in 1983

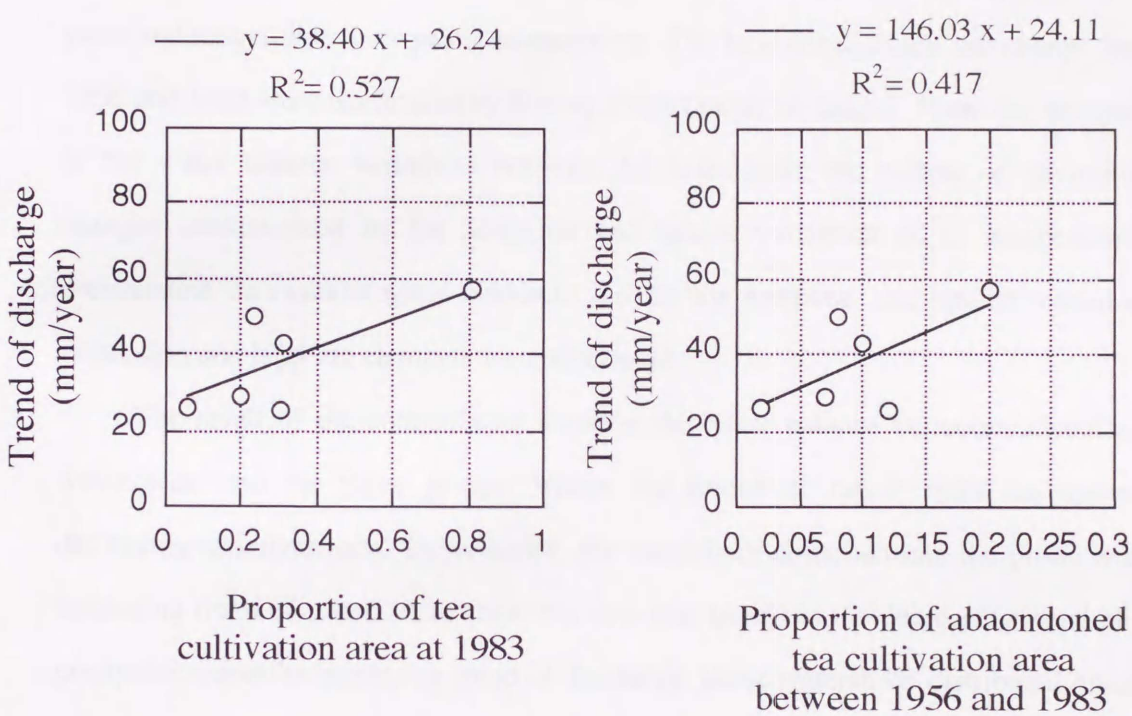


Fig.57 Relationship between proportion of tea cultivation and trend of discharge on the watersheds located in the Wet Zone of A Group from 1956 until 1983.

Chapter 7

Conclusions

In the present study the effects of environmental change on the water balance were investigated by the long-term climatological and hydrological data. In Sri Lanka, climatological and hydrological conditions have been observed for longer than one hundred years and longer than forty years, respectively. The land use and land use change between 1956 and 1983 were researched by Survey Department, Sri Lanka. From the comparisons of the water balance variations between the watersheds, the effects of environmental changes characterized by the temporal and spatial variations of air temperature and precipitation as climatological elements and by the temporal and spatial variations of vegetation and land use elements were discussed.

The result of the comparisons between the water balance variations classified the watersheds into the three groups, whose the trends of runoff ratio are increasing, decreasing and invariance. In particular, the watersheds classified into the group with the increasing trend of runoff ratio show the converse trends as the decreasing trend of areal precipitation and the increasing trend of discharge, those watersheds distributed mainly in the southwest inland area.

The temporal variation on the water balance can be related with effect of some climatic factors. However, it is clear that the land use change such as shifting cultivation and abandoned tea made the discharge increasing more than climate change.

The results of this study are summarized as follows :

1) The spatial variation of trend of annual air temperature indicates the distribution of low values less than +0.4°C/100 years on the coastal area excluding around Puttalam located on the west coast in Dry Zone. However, the distribution of high values are shown in the central highland.

2) The spatial variation of trend of annual precipitation indicates the decreasing trend in and around central highland, and the eastern coastal area in the Dry Zone. In particular, the

decrease of precipitation in and around central highland mainly occurs in the southwest monsoon season.

3) The water balance analyses from long-term observation determine that the actual evapotranspiration of watersheds indicates the similar values in comparison with the varied distribution of precipitation and surface air temperature.

4) The results of water balance analyses suggest that the watersheds show the converse trend between the areal precipitation of watershed and discharge in the southwest inland of Wet Zone.

5) The variations of water balance are classified into three categories as A, B and C Groups, and into two subgroups in the B Group of Type I and Type II using the relation between the trend of areal precipitation and the trend of water loss. The watersheds of A Group with large temporal variation of water balance are mostly watersheds with the converse trend between the areal precipitation and discharge in the southwest inland area.

6) In the Dry and Intermediate Zone, the decrease of precipitation from 1950's until 1980's occurred in the dry season. And the effect of decrease of areal precipitation on the water balance appeared as the decrease of evapotranspiration and the trend of discharge was invariable. On the other hand in the Wet Zone, the decrease of precipitation occurred in the wet season, and the effect of the decrease of precipitation appeared in the decrease of discharge. However, the trend of evapotranspiration was invariable.

7) The land use on the watersheds classified as A and C Groups shows a relative high proportion of "sparsely used cropland" and tea cultivation in the Wet Zone. This category of land use consists of shifting cultivation, abandoned shifting cultivation, tea, land under developments and others. It is considered that the effect of this land use changes evapotranspiration and discharge systems. Consequently the water balance in those area will be unstable.

8) It is clear that the land use change from tea cultivation makes to increase the discharge of watershed.

References

Bruijnzeel, L.A. (1988): Estimate of evaporation in plantations of *Agathis dammara* Warb. in south-central Java, Indonesia. *J. Trop. For. Sci.*, **1**, 145-161.

Bruijnzeel, L.A. (1989): Nutrient cycling in moist tropical forests : the hydrological framwork. *Mineral nutrients in tropical forest and sabanna ecosystems.* Proctor, J. (ed.), Blackwell Scientific Publications, Oxford, 473p.

Bruijnzeel, L.A. (1990): *Hydrology of moist tropical forests and effects of conversion : a state of knowledge review.* UNESCO IHP Humid Tropics Programme, Paris, 224p.

Bultot, F., Coppens, A., Dupriez, A., Gellens, D. and Meulenberghs, F. (1988): Repercussions of a CO_2 doubling on the water cycle and on the water balance. A case study for Belgium. *J. Hydrology*, **99**, 319-347.

Calder, I.R., Wright, I.R. and Murdiyarso, D. (1986): A study of evaporation from tropical rain forest - west Java. *J. Hydrology*, **89**, 13-31.

Cohen, S.I. (1986): Impacts of CO_2-induced climatic change on water resources in the Great Lakes basin. *Climatic Change*, **8**, 135-153.

Demaree, G.R. and Nicolis, C. (1990): Onset of Sahelian drought viewed asa fluctuation-induced transition. *Q.J.R. Meteorol. Soc.* **116**, 221-238.

Doley, D. (1981): Tropical and subtropical forests and woodlands. *Water deficits and plant growth VI.* Kozlowski, T.T. (ed.), Academic Press, New York, 209-323.

Domrös, M. (1978): Aspects of aridity and drought in the monsoon climate of Sri Lanka. *Indian J. Met. Hydrol. Geophys.*, **29**, 384-394.

Domrös, M. (1979): Monsoon and land use in Sri Lanka. *Geojournal.*, **3.2**, 179-192.

Domrös, M. (1981): Dry years and their relationship to crop production in Sri Lanka. *Geojournal.*, **5.2**, 133-138.

Domrös, M. (1984): Climate and Agricultural land use in Sri Lanka. *Climate and Agricultural Land Use in Monsoon Asia*, Yoshino, M.M. (ed.), University of Tokyo Press., 398p.

Farmer, B.H. (1952): Peasant colonization in Ceylon. *Pacific Affairs.*, **25**, 389-398.

Farmer, B.H. (1954): Problems of land use in the Dry Zone of Ceylon. *Geographical Journal*, **120**, 21-33.

Flaschka, J., Stockton, C. and Boggess, W. (1987): Climatic variation and surface water resources in the Great Basin region. *Water Resources Bulletin*, **23**, 47-57.

Glantz, M. and Wigley, T. (1987): Climatic variations and their effects on water resources. *Resources and World Development*, D. Mclaren and B. Skinner (eds). Wiley. Chichester, 625-641.

Glantz, M.H.(ed.) (1988): *Societal Response to Regional Climatic Change : Forecasting by Analogy*. Westview Press. Boulder, 428p.

Gleick, P.H. (1986): Methods for evaluating the regional hydrologic impacts of global climatic changes. *J.Hydrology*. **88**, 99-116.

Gleick, P.H. (1987): The development and testing of a water balance model for climate impacts assessment. *Water Resour. Res.*, **23**, 1049-1061.

Griffiths, G.A. (1989): Water Resources. Chapter XX, *New Zealand report on Impacts of Climate Change*. North Canterbury Catchment Board and Regional Water Board. New Zealand, 21p.

Hulme, M., Marsh, R. and Jones, P. D. (1992): Global change in a humidity index between 1931-60 and 1961-90. *Climate Research*, **2**, 1-22.

IPCC (1990a): *Climate change - The IPCC Scientific Assessment*. Canbridge University Press, 365p.

IPCC (1990b): *Climate change - The IPCC Impacts Assessment*. Australian Government Publishing Service, 143p.

IPCC (1992): *Climate change 1992 The supplementary report to the IPCC Scientific Assessment*. Press Syndicate of the University of Cambridge, 200p.

Johnson, B.L.C. and Scrivenor, M.Le.M. (1981): *Sri Lanka; Land, People and Economy*, Heinemann Educational Books Ltd., London, 154p.

Jones, P.D. and Bradley, R.S. (1992): Climatic variations in the longest instrumental records. *Climate Since A.D.1500*. Bradley, R.S. and Jones, P.D. (eds.), Routldge Publish. 706p.

Karl, T. and Riebsame,W. (1989): The impact of decadal fluctuations in mean precipitation and temperature on runoff : a sensitivity study over the United States. *Climatic Change*, **15**, 423-447.

Kayane, I. and Nakagawa, S. (1983): Evaportranspiration and water balance in Sri Lanka. *Climatological Notes, Inst. Geosci. Univ. of Tsukuba*, **33**, 127-138.

Kayane, I., Yamashita, S., Nakagawa, S. and Nomoto, S. (1983): Salinization of groundwater in the Dry Zone of Sri Lanka. *Climatological Notes, Inst. Geosci. Univ. of Tsukuba*, **33**, 147-154.

Kayane, I., Nakagawa, K., Edagawa, H. and Madduma Bandara, C.M. (1995): Hydrological consequences of global warming revealed by the century-long climatological data in Sri Lanka and southwest India. *An interim report of IGBP Activities in Japan. 1990-1994.*, Scoence Council of Japan. 65-81.

Keeling, C.D., Bacastow, R.B., Bainbridge, A.E., Ekdahl, C.A., Guenther, P.R., Waterman L.S. and Chin, J.F.S. (1976): Atmospheric carbon dioxide variations at Mauna Loa Observatory, Hawaii. *Tellus*, **28**, 538-551.

Kuraji, K. (1996): Water balance studies on the moist tropical forested catchments. *J. Jpn. For. Soc.* **78(1)**, 89-99.(in Japanese)

Madduma Bandara, C.M., and Kuruppuarachchi, T.A. (1988): Land use change and hydrological trends in the upper Mahaweli basin. *Workshop on Hydrology of Natural and man-made Forests in the Hill Country of Sri Lanka*, 18p.

Masterplan for the Electricity Supply of Sri Lanka (1987): *Water Resources Database*, 975p.

Mather, J. and Feddema, J. (1986): Hydrologic consequences of increase in trace gases and CO_2 in the atmosphere. *Effects of Changes in Stratospheric Ozone and Global Climate*, J. Titus (ed.). USEPA. Washington, 251-271.

Matsuyama, H. (1992): The water budget in the Amazon river basin during the FGGE period. *J. Meteorol. Soc. Japan*, **70** , 1071-1084.

Matsuyama, H., Oki, T., Shinoda, M. and Masuda, K. (1994): The seasonal change of the water budget in the Congo river basin. *J. Meteorol. Soc. Japan*, **72** , 281-299.

Miyashita, Y. (1994): Hydrochemical evolution of groundwater in the tropical monsoon. Master degree's thesis, Master program in Environmental Sciences, the University of Tsukuba, 100p. (in Japanese)

Nakagawa, K., Edagawa, H., Nandakumar, V. and Aoki, M. (1995): Longterm hydrometeorological data in Sri Lanka. Data book of "Hydrological Cycle in Humid Tropical Ecosystems" Part I. *Rep. Spec. Res. Proj. Global Environ. Change, Univ. of Tsukuba*, 474p.

Nakagawa, S., Kayane, I., Yamashita, S. and Nomoto, S. (1983): Micrometeorological observations of the Dry and the Wet Zones in Sri Lanka. *Climatological Notes, Inst. Geosci. Univ. of Tsukuba*, **33**, 165-175.

Nemec, J. and Schaake, J. (1982): Sensitivity of water resource systems to climate variation. *Hydrological Sciences*. **27**, 327-343.

Nozaki, Y. (1993): *Global Warming and the Oceans : The Role of Carbon Cycling*. University of tokyo Press.196p. (in Japanese)

Oyebande, L. (1988): Effects of tropical forest on water yield. *Forests, Climate and Hydrology : regional impacts*. Raynolds, R.C. and Thompson, F.B. (eds.), UNESCO, Paris, 16-50.

Perera, L.K., Tsuchiya, K. and Toyota, H. (1992): Identification of forest cover changes by Landsat MSS data and environmental effects of such changes in central south Sri Lanka. *J. Geography*, **101**(4), 307-318.

Reading, A. J., Thompson, R. D. and Millington, A.C. (1995): *Humid tropical Environments*, Blackwell Publish. 429p.

Revelle, R. and Waggoner, P. (1983); Effects of a carbon dioxide-induced climatic change on water supplies in the western United States. *Changing Climate*. National Academy of Sciences, National Academy Press. Washington, 845-850.

Sanderson, M. and Wong, L. (1987): Climatic change and Great Lakes water levels. *The Influence of Climate Change and Climatic Variability on the Hydrologic Regime and Water Resources*, S. Solomon *et al.* (eds.) IAHS Publication. **168**, 477-487.

Schwarz, H.E. (1977): Climatic change and water supply : How sensitive is the Northeast? *Climate, Climatic Change and Water Supply*. National Academy of Sciences, Washington, DC., 111-120.

Shuttleworth, W.J. (1979): *Evaporation*. Report no.56, Institute of Hydrology, Wallingford, 61p.

Shuttleworth, W.J. (1988): Evaporation from Amazonian rainforest. *Proc. R. Soc. Lond.*, B**233**, 321-346.

Singh, B. (1987): The impacts of CO_2-induced climate change on hydro-electric generation potential in the James Bay Territory of Quebec. *The Influence of Climate Change and Climatic Variability on the Hydrologic Regime and Water Resources*, S. Solomon *et al.* (eds.) IAHS Publication. **168**, 403-418.

Song, X. (1996): A study on the relation between water cycle and groundwater quality in Sri Lanka. Doctor degree's thesis, Doctoral program in Geoscience, the University of Tsukuba, 151p.

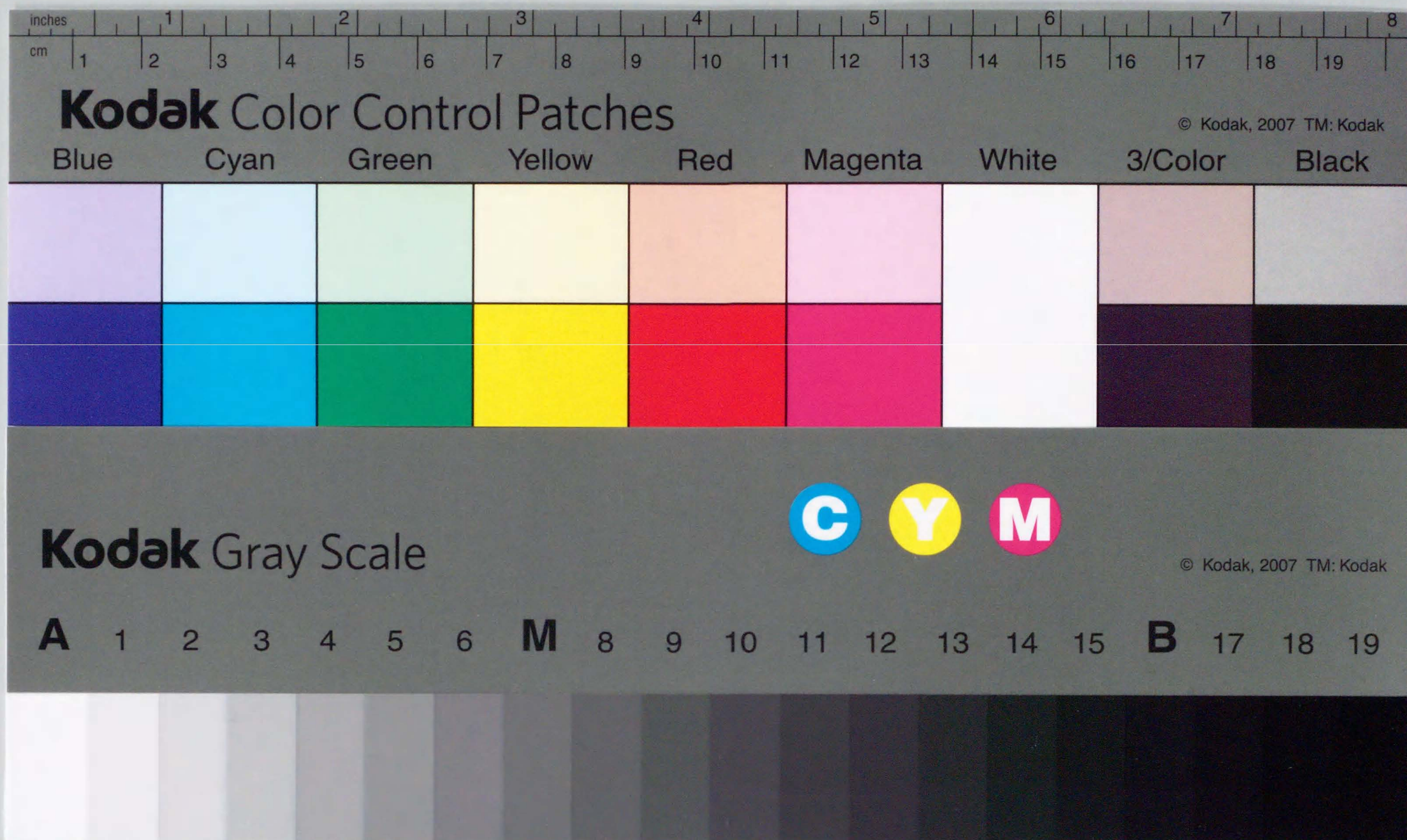
Stewart, J.B. (1984): Measurment and prediction of evaporation from forested and agricultural catchments. *Agricultural Water Management*, **8**, 1-28.

The Natural Resources, Energy and Science Authority of Sri Lanka. (1991): Natural Resources of Sri Lanka. *The Natural Resources, Energy and Science Authority of Sri Lanka*. 280p.

US Environmental Protection Agency (1984): *Potential Climatic Impacts of Increasing Atmospheric CO_2 with Emphasis on Water Availability and Hydrology in the United States*. Office of Policy Analysis. Washington, DC.

Yoshino, M. and Suppiah, R. (1982): Climatic Records of Monsoon Asia. *Climatological Notes*, Institute of Geoscience, Tsukuba University, **31**, 80p.

Yoshino, M. (ed.). (1984): *Climate and agricultural land use in monsoon Asia.* Univ. of Tokyo Press, Tokyo, 398p.


Kodak Color Control Patches
© Kodak, 2007 TM: Kodak
Blue
Cyan
Green
Yellow
Red
Magenta
White
3/Color
Black
inches
cm
Kodak Gray Scale
C Y M
© Kodak, 2007 TM: Kodak
A 1 2 3 4 5 6 M 8 9 10 11 12 13 14 15 B 17 18 19