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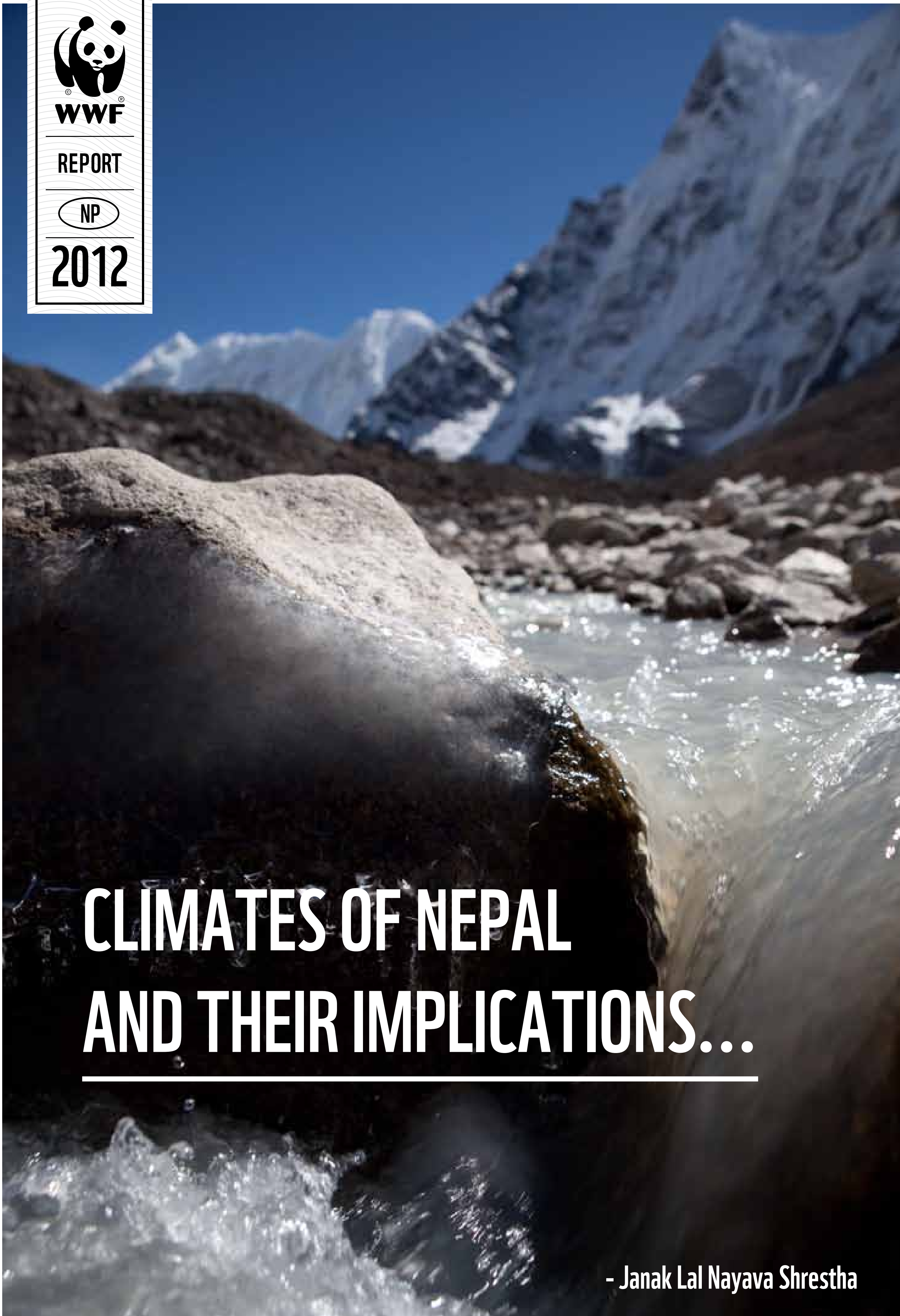

CLIMATES OF NEPAL AND THEIR IMPLICATIONS...

- Janak Lal Nayava Shrestha

WWF CLIMATES OF NEPAL AND THEIR IMPLICATIONS

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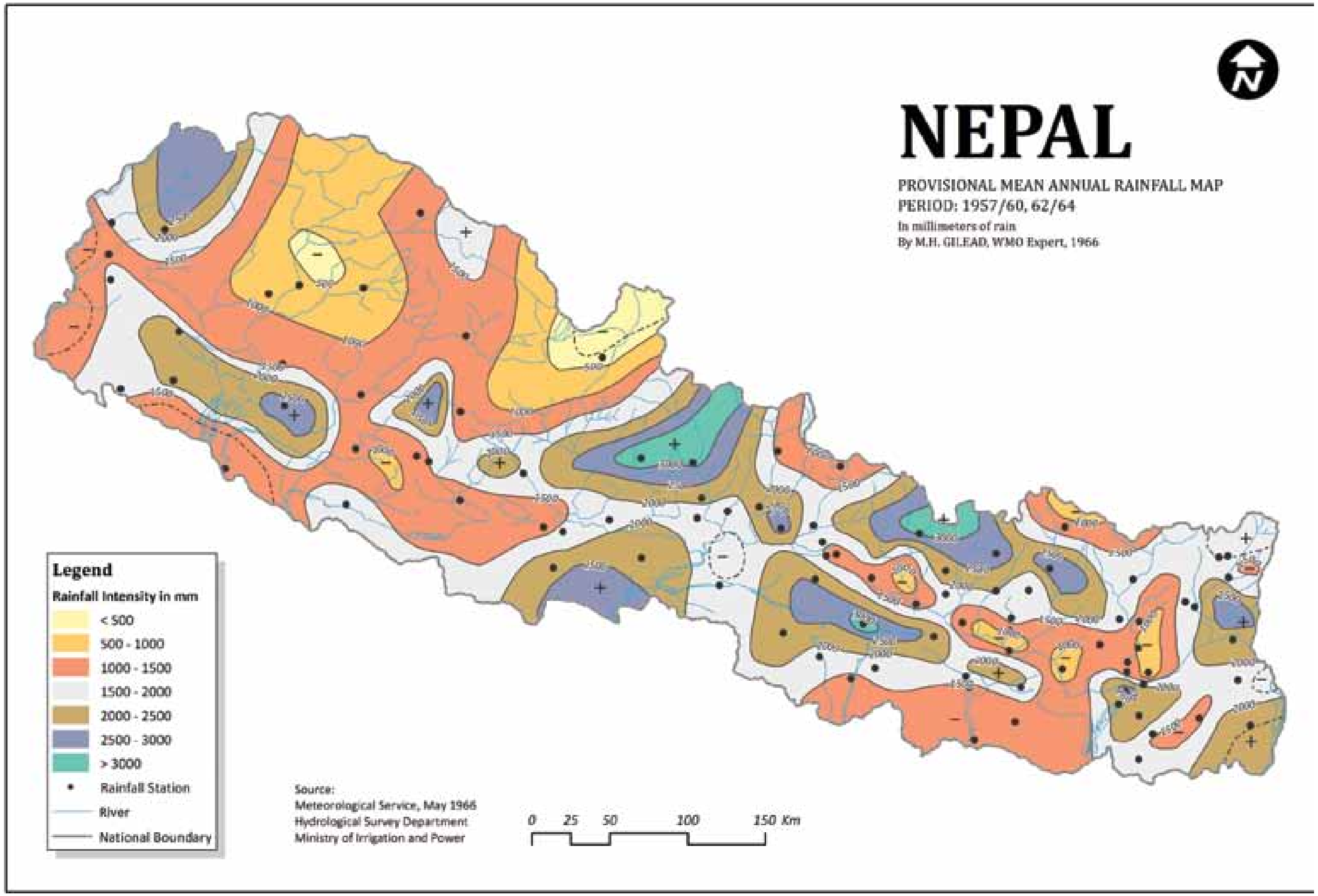

NEPAL
PROVISIONAL MEAN ANNUAL RAINFALL MAP
PERIOD: 1957/60, 62/64
In millimeters of rain
By M.H. GILEAD, WMO Expert, 1966
Legend
Rainfall Intensity in mm
< 500
500 - 1000
1000 - 1500
1500 - 2000
2000 - 2500
2500 - 3000
> 3000
Rainfall Station
River
National Boundary
Source:
Meteorological Service, May 1966
Hydrological Survey Department
Ministry of Irrigation and Power
0 25 50 100 150 Km

Collected Published Papers on Climates of Nepal and their implications ....

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Government of Nepal

MINISTRY OF ENVIRONMENT

Ref.

Foreword

November 16, 2011

Climate change is basically about unintended changes that have taken place in the atmosphere. Nepal is among the countries that are highly vulnerable to climate change impacts, where the notion of 'climate' and 'weather' are still poorly understood. Relevant scientific papers that explain Nepal's climate systems are limited and scattered in various documents and journal articles, therefore not easily accessible to ordinary readers. In that context, the compilation of published research articles written by Dr. Janak Lal Nayava is timely and could be very useful to many of those interested in learning and analyzing Nepal's climate systems and weather patterns.

Dr. Nayava is a prominent climate scientist of Nepal who served as Chief Meteorologist at Department of Hydrology and Meteorology till 1988. Thereafter, he has served as a technical expert in various national and international organizations including FAO. Dr. Nayava has been writing and publishing articles on climates of Nepal and their implications since 1974. Since his articles were published in different National and International Journals, the Nepalese readers seemed not aware of all those publications. This is high time to communicate those research papers to Nepalese readers. To meet this gap, Dr. Nayava has presented his sixteen papers into a book form. His efforts to communicate about the subject matter are timely and praiseworthy.

I hope this book will be useful for users, decision makers and planners in diverse field.

I thank WWF Nepal for publishing this book.

Krishna Gyawali
Secretary

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Preface:

This preface is especially for general readers: the defination given here under may help them to understand better. It is understood that the climatic parameters, such as global solar radiation, maximum temperature, minimum temperature, precipitation, wind and potential evapo-transpiration are integral parts of climate, understanding of which in relation of this country's climate are very essential.

Radiation: The ultimate source of energy and the solar radiation received at the earth's surface consists of two parts: direct solar radiation and diffused sky radiation. The sum of these two radiation components is known as the global radiation. It is understood that the intensity of solar radiation reaching the earth's surface at different slopes and aspects has enormous impact on crop production and management: such as engineering design, natural resource management, cold storage, building, road, canal, alternate energy and air conditioning. The duration and intensity of radiation are important for photosynthesis, which plays a vital role in plant growth. The global solar radiation on different aspects with cloudless sky as well as average conditions of sky at Kathmandu have been presented with figures. Please refer paper no. 3.

Temperature: Temperature is important in all biological processes and it is hazardous in extreme temperature. When temperature is below 0^0C, frost might occur and as a result, plants are damaged due to freezing. The unexpected occurrence of frost in agricultural is serious. The study of climatology and topographic data can help to predict the zone of frost free area. At high temperature, above 40^0C, serious damage might occur in plants and crops due to thermal stress. Below 15^0C, crops productivity will be decreased and tropical crops usually cease to grow at 15^0C, between these two extremes, there is an optimum temperature, say 20^0C to 30^0C which favors rapid growth. Development of models on temperature and the temperature patterns of the hottest and coldest week have been presented in paper no. 7 and the 30 year trends of temperature at a few places have also been presented in paper no. 14, 15 and 16.

Precipitation: Water plays very important role in aspects such as town planning, agriculture, natural resource management and industry. Intensity of rainfall should be well understood in constructing roads, bridges, flood forecasting and sewerage installations. The seasonal rainfall plays a vital role in water conservation. The intensity of the summer monsoon rains in Nepal and the date of the onset of the monsoon are both important factors in the country's economy, because it is the main season for the country's major crop. A case study of post monsoon rainfall on paper no.1, the general feature of the atmospheric circulation over Nepal, mean and annual monsoon rainfall over Nepal on paper no. 5, areal rainfall in the Kathmandu valley on paper no. 6, temporal variations of rainfall in Nepal in paper no. 10 and finally probable maximum temperature were dealt on paper no. 11.

Wind: wind plays crucial role in the development of various projects, such as wind speed direction being useful factors for transmission lines, construction of bridges and it is a crucial factor in choosing the site of a runway. Wind is one the main factors in the study of air pollution and in locating new sites for industry and town planning. Knowledge of wind profile is necessary for the construction of tall buildings and television towers. The choice of best sites and best design of wind power installation is to a large extent a climatological question. Wind breaks and shelter belts can be made to reduce the serious damage of wind. The transpiration and carbon dioxide assimilation of plants depend upon the wind velocity. Wind is also a crucial factor for success in mountaineering expeditions in Nepal Himalayas. Mean wind speed values the Western Nepal have been studied and the spatial variations of wind at each month have been tested. These mean maps of wind speeds will give the general pattern of wind at the study area. Refer to paper no. 13

Humidity: Humidity will indicate whether climate is dry or moist which will help to find suitable to find suitable crops according to humidity index. Humidity is used to measure the comfort of the human index and humidity is measured in many sophisticated factories to avoid the corrosion and damping effect.

Evaporation: Evaporation from soil and plant surface is a phenomenon of greatsignifi cance in agrometeorology. As a matter of fact, evapo-transpiration is one of the main parameters in water balance and energy balance studies. These studies are very necessary for irrigation planning and practices, water conservation, water supply and agricultural planning. The estimation of evapo-transpiration by climate models for western Nepal is presented in paper no. 12.

Others: Certain extreme meteorological conditions bring severe hazards such as drought, flood, cold waves, heat waves, storms and hurricanes, which directly affect our daily lives and loss of property and lives. Timing of occurrence and duration of fog are both important factors to aviation for better planning of their schedule. The best location and routing of motorways can be determined from climatological data on the frequency of fog, frost, high winds and drifting snow. Climatological investigations can provide information on their likely frequency, magnitude and duration. Thus topoclimatology, monitoring and evaluation of crop yield and production and finally climate change and its impact on economic perspective are also dealt. Now the study of applied climatology is related to many fields (refer paper no. 3, 8, 9, 14, 15 and 16). These types of studies involving close cooperation between climatologists, engineers, agronomists, economists and planners help to obtain the maximum benefit from the weather and climatic factors related to their projects.

These studies are of course tips of the iceberg. To find out the information of work accomplished is very important for researcher to begin their work. Any comments and suggestions are most welcome for the further development. Thank you.

Janak Lal Nayava Shrestha
drjanaklal@hotmail.com

About the book and author:

In early 1960's Nepal felt to initiate to establish the meteorological service in Nepal, due caused by necessity of aviation route forecast for International flights and meteorological facilities needed at International Airport at Kathmandu as per International Civil Aviation Organization (ICAO) rule.

In 1964, Mr. M. Gilead, Director of Israel Meteorological Service (IMS) was deputed to Government of Nepal as an advisor by World Meteorological Organization (WMO) to advice for the establishment of Meteorological Service in Nepal. Under this venture, Department of Hydrology and Meteorology (DHM) was established in 1966 and the same year DHM became the member of WMO. During his tenure in Nepal, I was awarded WMO fellowship and went to Israel in 1966 and I had a very individual, intensive operational course covering basic foundations of meteorology. I still feel indebted and thankful to Mr. Gilead and the Israel Meteorological Service.

1967-1971: Meteorologist, DHM, Kathmandu
1971-1972: Acting Deputy Director, DHM, Kathmandu
1972-1974: On study leave at Birmingham University, England for M.Sc. (Meteorology and Climatology) under a WMO Fellowship
1975: Promoted to Senior Meteorologist, DIHM
1977-1980: Australian National University (ANU), Canberra, ACT, under the ANU Fellowship for Ph.D. Candidate
1983 and 1987: Attended WMO congresses, Geneva.
1983-1988: National Project Coordinator in Agrometeorology and Meteorological Instrument ProjectWMO/UNDP-NEP/78/019
1986-1988: Coordinator for SAARC Region in climatology and agro-meteorology
1988: received a medal from Prime Minister for working in SAARC Region.
1982: promoted to Class I Officer as Chief Meteorologist
1988-1992: FAO Technical Adviser in Agrometeorology for the National Early Warning System for Food Security, Ministry of Agriculture, Malawi
1995 to 1999: Executive Director of the Center for Climate and Agrometeorological studies
1993-2003: visiting lecturer in Tribhuvan University, Kathmandu
1993- at present Resource Consultant in various firms
2000-2003: Consultant Meteorologist, Tahal Consulting Engineers Ltd in association with GEOCE Consultants (P) Ltd, ARMS (P) Ltd, and CEMAT Consultants (P) Ltd, Kathmandu., World Bank Project.
2002-2004: Vice Chairman, Society of Hydrologists and Meteorologists- Nepal
2005 -2006: Chairman, Society of Hydrologists and Meteorologists-Nepal
2009: Sun Kosi High Dam Multi purpose Project during June to September, 2009.
2009-2010: National Coordinator for Strengthening Capacities for Disaster Preparedness and Climate Risk Management in Agriculture Sector, FAO.
2008-2011: Chief Editor, Journal of Hydrology and Meteorology, Kathmandu

Countries visited: Israel, India, UK, Australia, New Zealand, Phillipines, Thailand, USA, Canada, Sweden, Switzerland, France, Germany, Iran, People's Republic of China, Malawi, Zimbabwe, Botswana, Namibia, Kenya, South Africa and Italy.

Working experience with WMO experts: Mr. G. Steinitz, (1967-69), Dr. Venho, (1967-69), Dr. V. Zirovsky (1969-73), Mr. R.Rannaleet (1969-73), Mr. G. Shak (1974-1978) and many more.

When I joined the DHM on 2nd day of my return from Israel in 1967, I had an opportunity to work closely with Mr. G. Stenitz. Since Nepal had to start meteorology from foundations, we had to perform different actions in the steady balance. Installations of meteorological net-work, spot training, designing, preparing form, quality control, computing data, preparing, processing and publishing climatological records. In this connection, I had visited more than 50 districts of Nepal for site selection and installation of meteorological stations.

Since India Meteorological Department (IMD) had established 104 hydro-met stations during 1940's and 1950's in Nepal and IMD had a supplementary meteorological Office at Kathmandu airport. For continuity of data, DHM installed meteorological stations very close to all IMD hydromet stations within 1971/72. At the same time DHM started Main Meteorological Office at Kathmandu Airport. This was one of the challenging tasks in the beginning of our professional career in meteorology. In this way I was one of the active founding members of meteorological service in Nepal.

When I became Chairman of Society of Hydrologists and Meteorologists-Nepal in 2005/2006, I had delivered a several talk programs on Challenges facing Nepalese Agriculture, based on cereal crops in the following places: Department of Statistics, Department of Agriculture, Department of Irrigation and National Planning Commission (NPC). The talk lasted nearly 2 hours in each places. In the NPC, the then Vice Chairman Dr. Shanker Sharma was present and very co-ordial discussions were taken place.

I have a quite a passion of going through the meteorological data and wrote several articles and now presented as a book from my collected papers for readers. This book contains collected papers of mine, mine and et al in chronological order based on climates of Nepal and their implications to various development issues, written in different time and space and published in the different national and international scientific Journals as well as the papers submitted in International Congress and workshop, which were also published. Though some of the papers were published in late 1970's and early 1980's, but it seemed that their importance and audiences are increasing more and more in the recent time in Nepal due to global warming. I hope that this book on collected published papers on Climates of Nepal and their implications might be useful for diverse users, decision makers and planners. In addition to those articles, which were published earlier, a few updates with recent activities and references have been added for further information.

In the begining of this book, the first rainfall map of Nepal which was hand drawn in 1966 by Mr. M. Gilead, WMO expert in Nepal. This map was especially digitized using GIS for this publications.

I sincerely once more thanked to the Australian National University, Canberra for their support in my research. Finally, I would like to express my humble and sincere thank to my late parents Mr Ratna lal Shrestha and Mrs Dhana Laxmi Shrestha and my family for bringing me in this world and led light of education as far as they could. I thank to my wife Mrs Ganga Devi Shrestha for her sacrifice as an Officer in Nepal Industrial Development Cooperation to be hand with me in Australia.

Janak Lal Nayava Shrestha

Acknowledgements

I am grateful to all my previous publishers who have given me their kind permissions to print all my articles compiled in a book form. I take this opportunity to thank Mr. Samir Ojha for organizing the layout of the book. I also sincerely wish to thank Mr. Anil Manandhar, Country Representative, Mr. Ugan Manandhar, Program Manager-Climate Change, Energy & Freshwater and Mr. Akash Shrestha, Communications & Marketing Manager at WWF Nepal for their support in publishing this book. Finally I thank Mr. Krishna Gyawali, Secretary and Mr. Batu Krishna Uprety, Joint Secretary, Ministry of Environment, Government of Nepal for their kind cooperation and encouragement to publish this book.

ACRONYMS

ANU	Australian National University
APROSC	Agricultural Projects Services Center
ARMS	ARMS (P) Ltd
CEMAT	CEMAT Consultants (P) Ltd
CBS	Central Bureau of Statistacs
DHM	Department of Hydrology and Meteorology
DFID	Department for International Development
DFAMS	Department of Food and Marketing Services
DIHM	Department of Irrigation, Hydrology and Meteorology
DoA	Department of Agriculture
DoI	Department of Irrigation
GEOCE	GEOCE Consultants (P) Ltd
HMG	His Majesty's Government
IMD	India Meteorological Department
ICAO	International Civil Aviation Organization
FAO	Food and Agriculture Organization of the United Nations
MoAC	Ministry of Agriculture and Cooperatives
MoE	Ministry of Environment
NAPA	National Adaptation Program of Action
NARC	Nepal Agriculture Research Council
NPC	National Planning Commission
SAARC	South Asian Association for Regional Committee
SMRC	South Asian Meteorological Regional Committee
TU	Tribhuwan University
UK	United Kingdom
UN	United Nations
UNFCC	United Nations First Communications report on Climate change
UNDP	United Nations Development Program
WMO	World Meteorological Organization

Heavy Monsoon Rainfall In Nepal*

J.L. NAYAVA**

Department of Irrigation and Meteorology, Kathmandu

In Nepal, 80 percent of the annual precipitation falls between June and September under the influence of summer monsoon (Table 1, Fig. 1), so the monsoon rainfall is very important from the agricultural point of view. Thus, the intensity of the summer monsoon rains and the date of the onset of the monsoon are both important factors for the country's economy, because it is the main season for planting rice. Consequently knowledge of the date of onset of the monsoon can help farmers to optimize the rice harvest, i.e. farmers can grow their rice seedlings which can be easily transplanted. If they plant too early, the seedlings might be seriously damaged and the production will be poor. Normally, in Nepal, the onset of the monsoon occurs in the second week of June (see Fig. 2). However, in any one year farmers need to know the probable date of the onset at least three or four weeks ahead so that they can plant the seed in time. Hence, the prediction of the onset of the monsoon is one of the challenging problems for the Meteorological Service. The date of onset and retreat varies from year to year.

The rainfall in Nepal varies greatly from place to place due to sharp topographical variations. As the rain bearing winds approach Nepal from the south-east in the summer monsoon season, most rain falls over the foothills of the lower Himalayas, increasing with altitude on the windward side and sharply decreasing on the leeward side of each successive range.

TABLE 1. Seasonal rainfall in Nepal (1965-69)

Station	Elevation	Winter		Pre- Monsoon		Monsoon		Post-Monsoon		Annual
	(m)	Nov. -	Feb.	Mar. -	May.	June -	Sep	October		(mm)
		(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	%	
Barakshetra	146	39	2	191	7	2231	86	120	5	2581
Butwal	263	33	1	90	4	2141	92	62	3	2326
Dhangarhi	280	50	4	45	3	1290	93	6	0	1391
Okhaldhunga	2103	23	1	230	12	1549	82	93	5	1895
Kathmandu	1323	39	3	131	10	1082	83	55	4	1307
Pokhara	918	61	2	315	9	2798	85	26	4	3301
Silgarhi-Doti	1360	113	11	136	13	783	73	30	3	1062
Namchebazzar	3450	49	6	85	10	635	76	65	8	834
Jumla	2387	61	10	98	16	438	71	21	3	617
Jomosom	2165	39	16	55	12	114	45	43	17	251

* This article was published in Weather, Vol.29, 1974, pp. 443-450

** On study leave at Birmingham University under a WMO Fellowship.

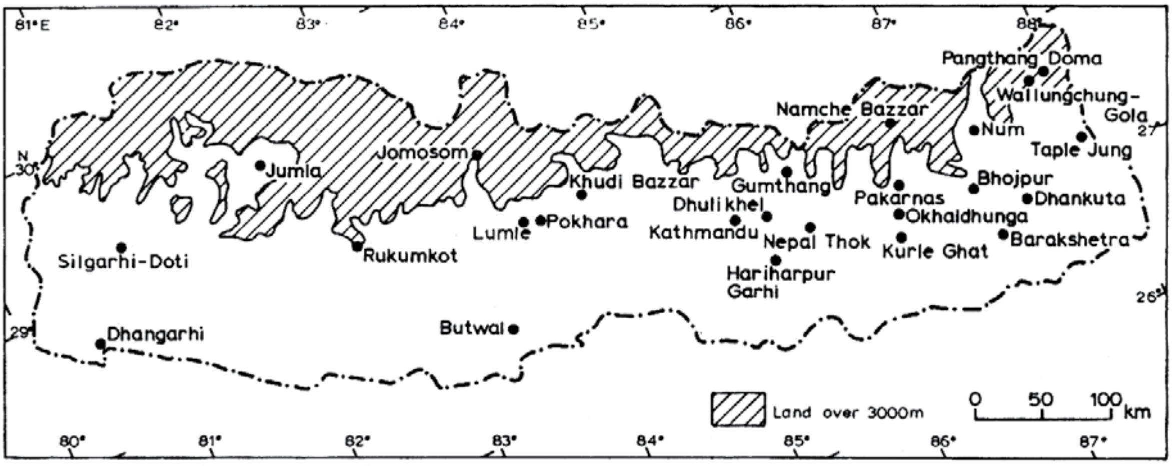

Fig. 1. Key map for rainfall at selected stations in Nepal - see Table 1

Summertime rainfall varies diurnal and the mountains are usually covered by low clouds for much of the day. Rainfall over Kathmandu shows a marked peak in the late night between 2310 and 0310 local time and low in the late morning between 0910 and 1210 local time (Dhar 1960). At Barakshetra, two maxima and two minima were observed during the study period. Marked maxima occurred between 1310 and 1410 (local time) and between 2310 and 0410. Two minima occurred between 0810 and 1010 hours and between 1910 and 2210 hours (Dhar 1960). Intensity of rainfall is very important for constructing bridges and sewage installations and for flood forecasting. Maximum rainfall in 24 hours, date and number of rainy days are given in Table 2. During the period 1965-69, Gumthang (Fig. 1) recorded the highest daily rainfall in Nepal 505.2 mm on 25 August 1968.

TABLE 2. Maximum rainfall in 24 hours during the period 1965-69 in Nepal

Station	Maximum rainfall in 24 hours and date where known			Average number of rainy days per year (over 1 mm)
	Amount (mm)	Percentage of mean annual total	Date	
Barakshetra	313	12	21 July 1967	110
Butwal	402	17	Aug. 1968	93
Dhangarhi	168	12	17 Sep. 1968	55
Okhaldhunga	130	7	July 1965	119
Kathmandu	134	10	9 July 1967	106
Pokhara	261	8	July 1965	136
Silgarhi-Doti	135	13	6 June 1967	72
Namchebazzar	115	14	4 Oct. 1968	116
Jumla	91	15	15 July 1969	64
Jomosom	72	28	4 Oct. 1968	32

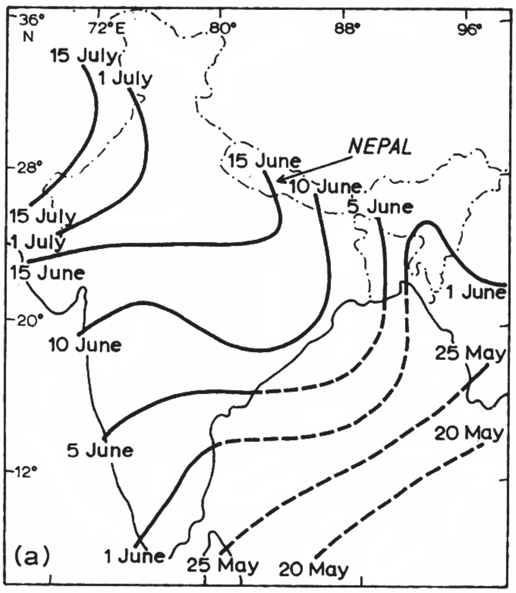

Fig. 2a. Normal dates of onset of monsoon (after Das 1972)

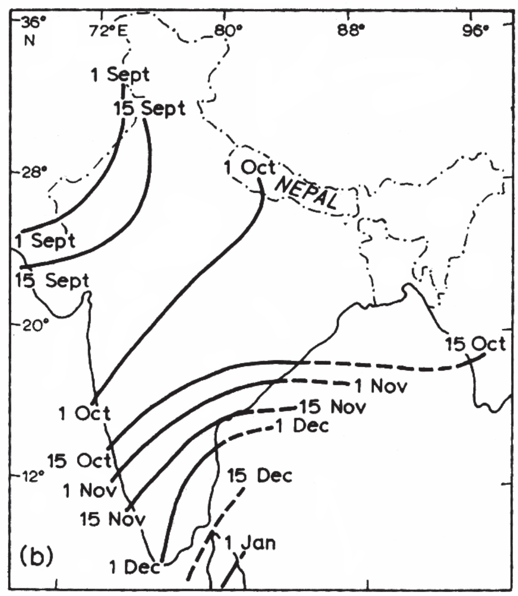

Fig. 2b. Normal dates of retreat of monsoon (after Das 1972)

In winter, more precipitation falls in northern Nepal than in the south and much of this falls as snow. There is also a decrease from west to east. This precipitation originates from disturbances in the westerlies.

The Pre- and post-monsoon rains are more intense at higher altitudes and much snow falls in the great Himalayas in the pre-monsoon season. Pre-monsoon rain in Nepal is associated with thermal convection combined with orographic effects, resulting in strong thunderstorm activity leading to heavy precipitation over narrow bands within the region.

THE HEAVY RAINFALL

In 1968, post-monsoon rainfall over Nepal was much above average, with many heavy (more than, say, 50 mm) daily falls, particularly over eastern Nepal where it was the heaviest and most widespread for at least 20 years. As a result, eastern Nepal was flooded badly in various places with much loss of life and damage to property.

The present study discusses the three-dimensional circulation in the region 60-110^0E, 10-50^0N and associated rainfall in Nepal during the period 28 September to 7 October 1968. The main agents of precipitation over Nepal are poorly known. However, orography and cyclonic disturbances known as 'monsoon depressions' are likely to have important roles in the formation and release of precipitation.

During July and August, a series of depressions form in the Bay of Bengal and move in north-westerly direction, causing heavy precipitation along their tracks (Ramage 1971). Heavy rainfall extends about 250 km from the depression track in the left sector (Mooley 1973). Many investigators have studied these depressions, but so far only Koteswaram and George (1958), Ramage (1971) and Rao and Desai (1973) have mentioned the occasional noth-eastwards recurvature of some depressions and their subsequent movement toward the Himalayas. On rare Occasions, a depression moves due north from the Bay of Bengal to north Bengal and Assam at the height of the monsoon season, producing heavy rainfall to the north and north-east of the depression centre. A recurvature of depressions over India has been related the movement of waves in the circumpolar westerlies near 30^0 N. Recurvature tends to occur most often in September.

Synoptc evolution

The formation, intensification, movement and decay of a depression in the Bay of Bengal and associated rainfall over Nepal were studied using surface, 500 mb, 200 mb, relative topography and wind data extracted from German daily weather maps.

On 29 September, a small low appeared over the Bay of Bengal at about 10^0 N, 90^0 E (Fig. 3a). During the next two days, the circulation of this low expanded as it moved north-eastwards into central India (Fig. 3b) and intensified into a depression. By 3 October, Nepal and much of India had come within the circulation of this depression (Fig..3c). Later the depression moved northwards and weakened considerably (Fig. 3d) until 7 October, when satellite and conventional observations indicated that the depression had disappeared.

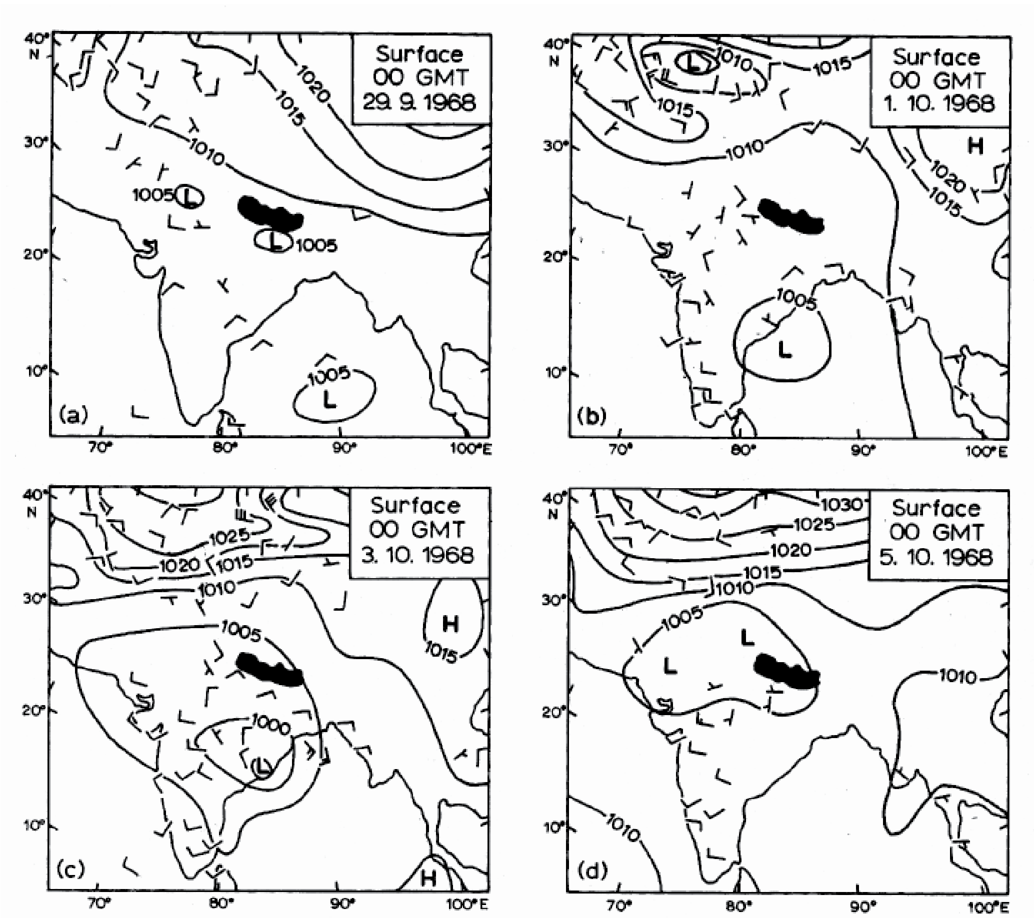

Fig. 3. Surface charts - 29 September to 5 October 1968

As soon as the low formed over the Bay of Bengal, an anticyclone at 500 mb over central India, northern Bay of Bengal, and south-east China disappeared as a low formed over southern India (Fig. 4a). At 200 mb, an anticyclone shifted eastwards towards south-east china (Fig. 5a). As the low intensified and moved north-westwards, a new low appeared at 500 mb over northern parts of the Bay of Bengal (Fig. 4b). The anticyclone at 200 mb became more elongated covering central India, northern Bay of Bengal and south-east China (Fig. 5b). During the next two days, a sharp 500 mb trough passed through Nepal and central India (Figs. 4c and d) as the polar westerlies at 200 mb intensified and moved equatorwards, bringing the subtropical westerly jetstreams ever closer to Nepal (Fig. 5c). As the depression moved north, the anticyclonic circulation at 200 mb over the depression intensified and became orientated in a south-west-north-east direction (Fig. 5d).

Associated with thes developments, widespread rain fell in most parts of Nepal except in the north-west. A westward extension of the area affected by heavy rain is clearly evident in Figs. 6a-d. In

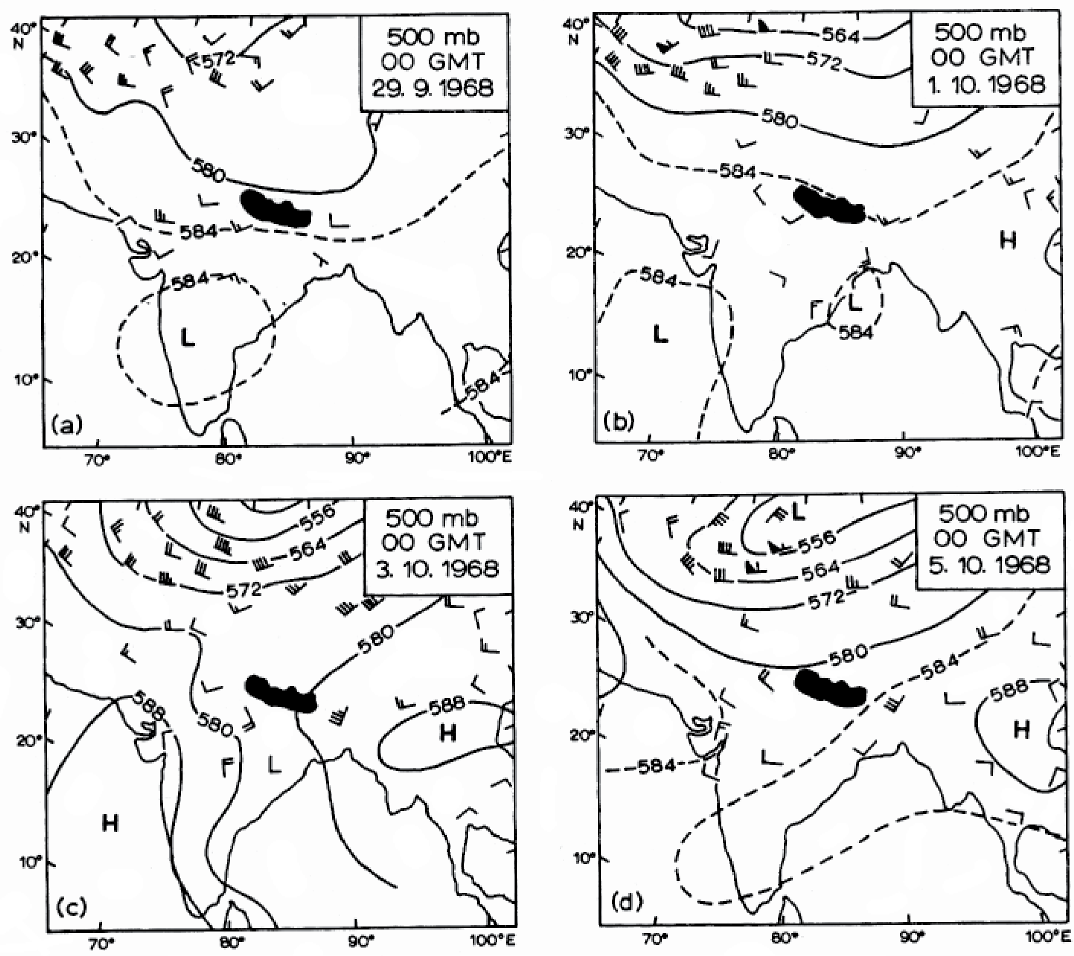

Fig. 4. 500 mb charts - 29 September to 5 October 1968

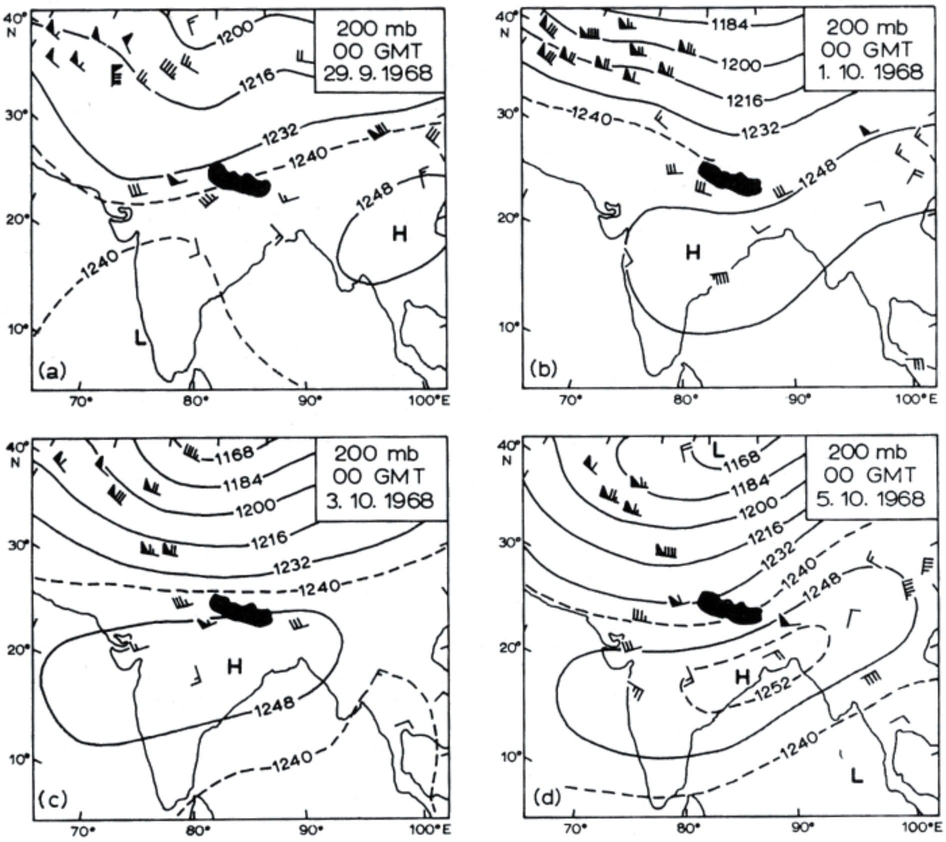

Fig. 5. 200 mb charts - 29 September to 5 October 1968

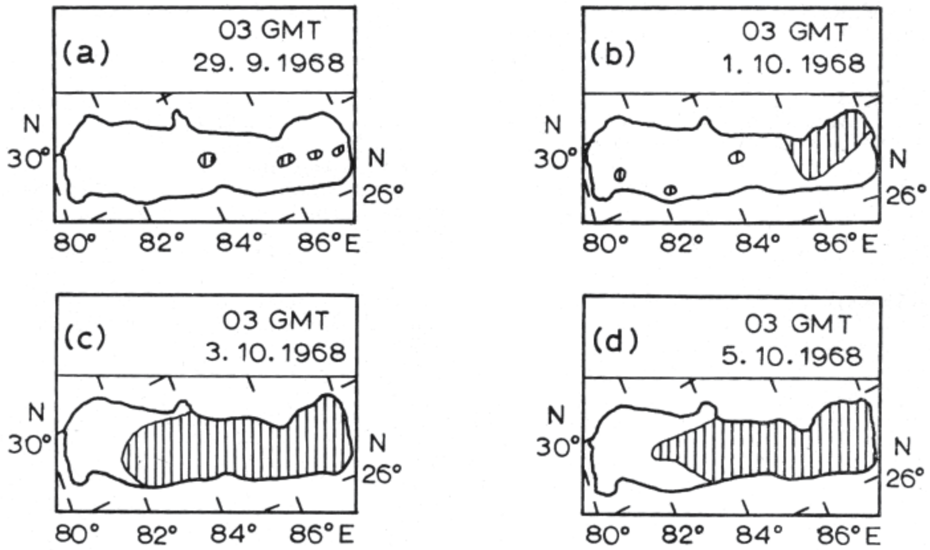

Fig. 6. Rain areas in Nepal - 29 September to 5 October 1968

particular, rain fell heavily over eastern Nepal, because of strong orographic lifting of moist warm air. Table 3 shows that 10-20 percent of 1968 total rainfall fell at several stations on 4 October 1968. Rain also fell heavily in central northern parts of Nepal. For example, at Jomosom ($28^0 47$ N,83^0 43 E) which is situated in the driest (under 250 yr^{-1}) area of Nepal, a record 200mm (58 percent of the annual rainfall for 1968) fell during the period 1-7 October 1968. Over 300 mm were recorded at a number of places (Table 4).

This widespread rain, which caused serious flooding and loss of life in eastern Nepal, produced one of the wettest post-monsoon weeks ever recorded in Nepal. The total rainfall recorded at some stations during the first week of October is listed in Table 4.

DISCUSSION

Some tentative conclusions may be made from this study:

(1) The exceptionally heavy rain recorded in Nepal during the post-monsoon season of 1968 was caused by a depression moving north-westwards and then northwards from the Bay of Bengal. Troughs at 500 mb over and near the country also appear to have an important effect on intensity of rainfall.

(2) Findings by other workers are supported in this study. Synoptic features which are most marked below about 500 mb seem to have the most direct effect upon distribution of rainfall (cf. Raghavan (1973)). Although

TABLE 3. Daily rainfall at selected stations in Nepal on 4 October 1968

Station	Rainfall (mm)	% of 1968 rainfall	Station	Rainfall (mm)	% of 1968 rainfall
Taplejung	134	6	Kurleghat	83	9
Pangthandoma	160	9	Dhulikhel	221	12
Wallunchungola	159	8	Namchebazzar	115	11
Nepalthok	125	14	Pakarnas	135	6
Dhankuta	166	17	Kathmandu	80	6
Bhojpur	140	9	Jomosom	72	21

TABLE 4. Total rainfall at selected Nepalese stations during the period 1-7 October 1968

Station	Rainfall (mm)	% of 1968 rainfall	Station	Rainfall (mm)	% of 1968 rainfall
Taplejung	263	12	Kurleghat	188	20
Pangthandoma	307	17	Dhulikhel	240	13
Wallunchungola	313	16	Namchebazzar	219	20
Nepalthok	306	35	Pakarnas	281	14
Dhankuta	369	37	Kathmandu	132	9
Bhojpur	284	18	Jomosom	200	58

here data are few, convergence below 500 mb superposed by divergence at 200 mb would appear to be the main mechanism by the heavy rains, The circulation in the upper troposphere contributes to the generation and intensification of the depression as well as to its movement (Koteswaram and George 1958); the life times of major rainfall- producing features are of the order of four to five days and their horizontal scale is about 1000-3000 km (Murakami 1974). Orography and local convection are also important determinants of rainfall (Ramage 1971).

(3) Precipitation release by depressions is more marked over eastern and central Nepal than in western parts of the country. The paucity of rainfall over western Nepal during this study period is difficult to explain because of a lack of data.

ACKNOWLEDGEMENTS

The author wishes to express his thanks to the Department of Irrigation and Meteorology, Kathmandu, for supplying the necessary rainfall data, and special thanks go to Dr. E.T. Stringer and Dr. M.G. Hamilton, University of Birmingham, for offering their useful comments and suggestions.

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Climates of Nepal*

Janak L. Nayava **

Introduction

This is an attempt to classify the climate of Nepal on the basis of Thornthwaite's classification of climates. Among the various climatic elements, temperature and precipitation are of prime importance in classifying the world into climatic zones. Many writers have classified the world into different climatic zones using various climate elements. Among these Koppen's and Thornthwaite's classification have been widely accepted. Broadly their classifications are both based on average values of temperature and precipitation, but Koppen's classification leaves undecided the problem of when the mountain climate exists. As Nepal is predominantly a mountainous country (Fig.1), Thornthwaite's first classification is used to delimit climatic zones in Nepal. Temperature and precipitation data for Nepal for the period 1965-1969 have been used to produce a series of different climates zone. A longer period of data is not available.

Theoretically, Thornthwaite's first classification of Climates is based on the following principles.[1]

(a) Thermal efficiency ratio: T/E ratio = $\frac{T-32}{4}$ when T is the average temperature for a particular month. (^{0}F.)

(b) Thermal efficiency T/E index = Sum of the twelve monthly T/E ratios.

(c) Determination of P/E index for stations without evaporation data

P/E index = $\sum_{1}^{12} 115\left(\frac{P}{T-10}\right)^{\frac{10}{9}}$ when T is the temperature in ^{0}F and P is precipitation in inches.

These two ratios give a series of climatic zones as shown in the following Tables 1 and 2.

Table 1. Temperature Province and the ratio of thermal efficiency index.

Temperature Province	T/E index
A' (Tropical)	128 and above
B' (Mesothhermal)	64-127
C' (Microthermal)	32-63
D' (Taiga)	16-31
E' (Tundra)	1-15
F' (Frost)	0

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1. C.W. Thornthwaite, "The climates of North America according to new classification," Geogr. Review, vol, XXXI (1931), pp 633-655.

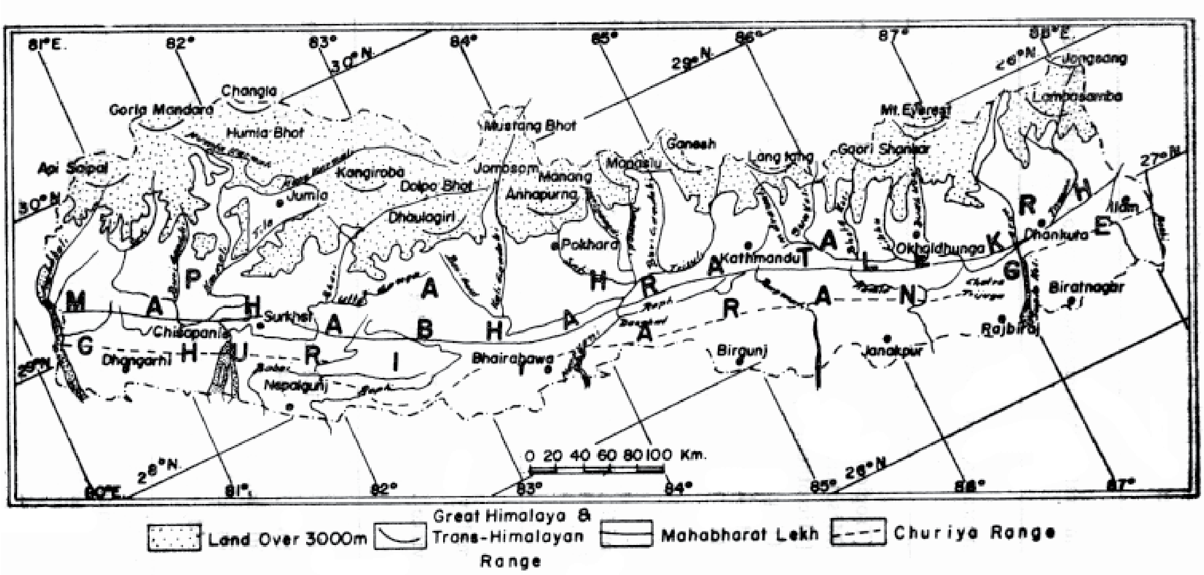


Fig. 1. Map of Nepal

Table 2. Humidity Province and value of the precipitation effectiveness index.

Humidity Province	P/E index	Characteristic Vegetation
A (wet)	128 & above	rain forest
B (Humid)	64-127	forest
C (Subhumid)	32-63	grassland
D (Semiarid)	16-31	steppe
E (Arid)	Under 16	desert

The following results were obtained by computing the data* for 15 stations in Nepal using Thornthwaite's first classification (Table 3).

In the graph below, $^{T}/_{E}$ index plotted with respect to altitude for each of these stations (Fig. 2).

From the above table and graph, one can deduce that Nepalese low lands about 100-500 m above sea level experience a tropical climate; this covers all parts of Tarai, Bhitri (Inner) Tarai and the lowlands of pahar (Hill) zones. Summer months (March-September) are very hot with average maximum temperatures exceeding 30^0 C. Winter (December-February) temperatures are about 18^0C. The average rainfall in these areas is 1000-2500 mm. Due to orography, rainfall increases with altitude on the windward side up to the snow line. On the leeward side, rainfall sharply decreases due to the subsidence of air passing over the mountain range.

Between 500 m and 2700 m, a mesothermal climate prevails; i.e. the upper zones of Churiya range, Mahabharat lekh and Pahar zone. Summers are hot, with maximum temperatures well above 25^0 C and winters are cold.

Average rainfall varies from 250 mm to 6500 mm on the leeward and windward sides respectively. At Lumle, near Pokhara annual rainfall exceeds 6500 mm, which is purely orographic. The Mustang

* The data have been obtained from the H.M.G. Dept. of Hydrology & Meteorology published Climatological Records of Nepal in 1968, 1971 and 1972 and H.M.G. Dept. of Irrigation, Hydrology & Meteorology, Climatological Records of Nepal, 1973.

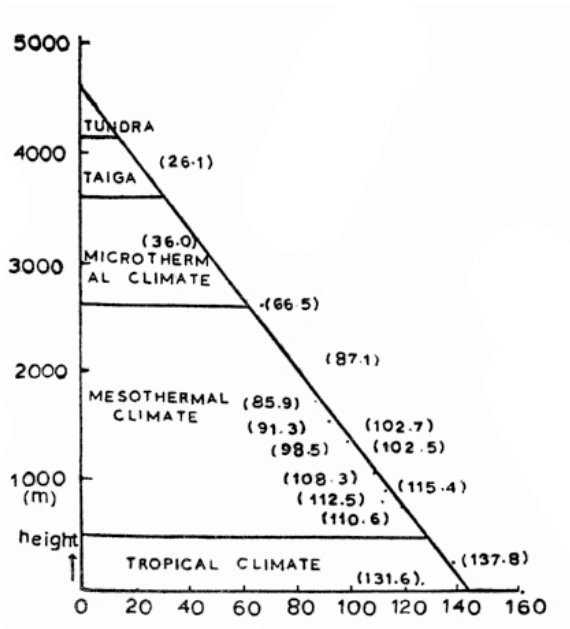
Table 3. Results of Thornthwaite's First Classification

No	Station	Elevation (m)	T/E index	Thornthwaite's Temperature Province	P/E Index	Thornthwaite's Humidity Province
1	Barakshetra	146	131.6	Tropical	142.5	Wet
2	Butwal	263	137.8	Tropical	124.9	Humid
3	Khudibazar	823	110.6	Mesothermal	186.6	Wet
4	Pokhara	918	112.5	Mesothermal	200.3	Wet
5	Pusma Camp	950	115.4	Mesothermal	86.3	Humid
6	Gorkha	1135	108.3	Mesothermal	90.7	Humid
7	Kathmandu	1329	98.5	Mesothermal	74.7	Humid
8	Taplethok	1372	102.5	Mesothermal	158.7	Wet
9	Sallyan	1457	102.7	Mesothermal	51.3	Subhumid
10	Bhojpur	1524	91.3	Mesothermal	77.4	Humid
11	Taplejung	1768	85.9	Mesothermal	129.2	Wet
12	Okhaldhunga	2103	87.1	Mesothermal	127.3	Wet
13	Jomosom	2615	66.5	Mesothermal	47.9	Subhumid
14	Wolangchungola	3048	36.0	Microthermal	172.8	Wet
15	Thyangboche	3867	26.1	Taiga	89.7	Humid

area (Jomosom) in the northern part of the Great Himalaya, although falling in this mesothermal climatic zone, has a peculiar dry climate, and it looks like semi-desert. The annual rainfall is only about 250 mm. This dry region is due to the alignment of the neighbouring mountains which prevent a large inflow of moist air into the region. A dry upper wind and the high temperatures both help to prevent precipitation.

Similarly in the altitude zone 2700 m-3600 m, there is microthermal climate which lies mostly in the northern side of Pahar (Hill) zone. Maximum temperatures in summer are 15-18^{0}C and minimum temperature in winter fall well below 0^{0}C. The average rainfall is 1000 mm to 3000 mm.

The zone from 3500 m to 4100 m is the Taiga province which is mainly in the Great Himalayan range. Summers are cool and winters are severe with an average temperature of -10^0 C. The average precipitation is about 1000 mm. Finally the zone from 4100 m has tundra type of climate (Fig. 3.)



T/E INDEX

Fig. 2. The classification of Climate of Nepal by Taking Thermal Efficiency Index and Altitude

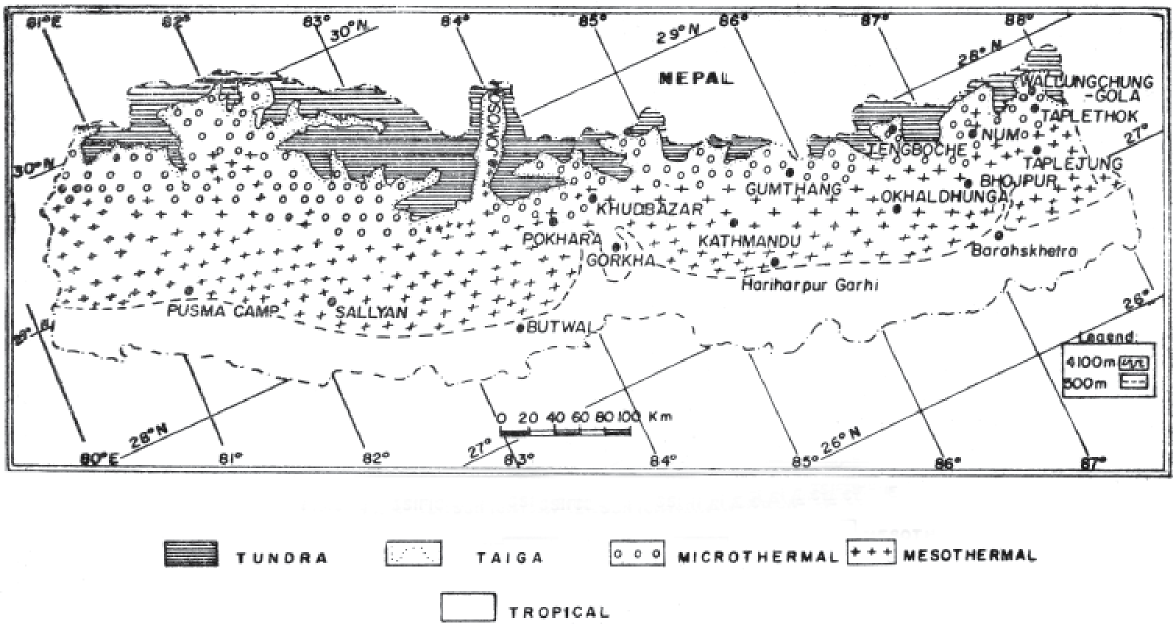


Fig. 3. Classification of the Climate of Nepal

The above mentioned heights for the climatic boundaries are very tentative. The practice of locating the boundaries of commonly recognized climatic types by referring to distribution of vegetation, soils and other natural features in no way argues against the reality of the types or of boundaries. If the classification is to extend to the microclimatic scale, as it must be of practical value in agriculture and biological problems, it must also take into consideration of the variation with height, diurnal march of temperature and frequency of precipitation of varying intensity and amount, evaporation from soil, atmospheric moisture and wind velocity in the zone where the plant actually live.[2] Additionally, Thornthwaite (1948) emphasized that evapotranspiration is an important climatic factor for the classification of climatic zones.[3]

Conclusion

This paper shows that it is possible to derive a classification of the climate of Nepal using. Thornthwaite's model. This result so obtained suggests that further research along these lines could be of economic value for the execution of Nepalese five-years plans.

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2. C.W. Thonthwaite, "Problems in the classification of climates," Geogr, Rev., XXXIII pp.233-255.
3. C.W. Thornthwaite. "An approach toward rational classification of climate, Geogr. Rev., XXXVIII (1948), pp.55-94.

Topoclimatology of the Kathmandu Valley*

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This study of topoclimate is concerned mainly with the Kathmandu valley. The region was selected because of the existence of a relatively dense network of meteorological stations, namely, one synoptic station, five agroclimatological stations, six rainfall stations and one radiosonde station. The location, elevation and date of establishment of the meteorological stations are shown in Table I. In addition to the existing stations, there were a few meteorological stations operating for short periods from which the data has been published (Department of Irrigation, Hydrology and Meteorology 1977 b.) The climate of Kathmandu Valley has been studied by Malla (1968), Department of Housing and Physical Planning (1968) and Binnie and partners (1973).

The topographic relief of the study area (Figure 1) is based on 35×35 grid points, extracted from the Nepal 1: 63360 scale map published by the Surveyor General of India, 1957. The grid points which are separated by 900 m, were analyzed by the computer programme CONOMAP to produce a weighted second degree polynomial surface. The program was written by Ingram for the CDC 6400 and Benson Lehner plotting system at Mc Master University. Canada and was converted to the Univac 1108 and Calcomp 565 plotting system by Bryant at Australian National University (Ingram and Bryant 1974). The boundary line of the catchment area of Kathmandu valley was determined from the 1:63 360 scale map with a contour interval of 100 feet (30.48 m). The catchment drains the valley through a small gorge (Chobhar) in the south west. Use of the map based on 35×35 grid points has resulted in the exclusion of a small area in the west. Most of the results of this topoclimatological study are mapped using the grid line intersections.

GENERAL FEATURES OF THE ATMOSPHERIC CIRCULATION OVER NEPAL

Studies of lower and upper tropospheric atmospheric circulation in Nepal suggests that rain falls within four distinct seasons (Nayava 1974) ; *pre-monsoon* (March to May); *Summer monsoon* (June to September); *post monsoon* (October); and *winter* (November to February). In the *pre-monsoon* season, moderate to strong westerly winds prevail throughout Nepal. Scattered rainfall occurs during this period and there is a marked increase in temperature of about 3-4^0 C in the month of March. Due to outbreaks of warm air and atmospheric instability, the sub-tropical jetstream weakens over Nepal. As summer approaches fogs become less frequent in the valley and haze predominates from the southern to the middle regions of Nepal.

The *summer monsoon* is the most important season in Nepal for agriculture with nearly 80 to 90 per cent of the annual precipitation falling between June and September. During the summer monsoon, the easterly wave dominates the upper level of the atmosphere and the subtropical westerly jetstream shifts to the northern side of the Tibetan plateau, around an anticyclone called the

* This article was published in Proceedings of Tenth New Zealand Geography Conference and Forty-Ninth Anzaas Congress, 1979, pp 33-38.

Tibetan High produced by the thermal effect of the heat source (Koteswaram 1958; Flohn 1968). At the surface, an elongated zone of low pressure develops along the Indo-Gangetic plains of North India, which lie northwest to southeast. This area of low pressure is known as the monsoon trough or equatorial trough, which, of course, advances northwards in the summer monsoon months and retreats southwards in the post-monsoon period. Therefore, the onset and withdrawal of monsoons are associated with northward and southward movement of the equatorial trough (Ananthakrishnan and Rajagopalachari 1964). When the monsoon trough lies over the foothills of the lower Himalayas, approximately 25^0 N latitude, the heaviest widespread rainfalls occur throughout Nepal. The rainfall in Nepal varies greatly from place to place due to sharp topographical variations. As the rain bearing winds approach Nepal from the southeast in the summer monsoon season, most rainfalls in the foothills of the lower Himalayas increase with altitude on the windward side and sharply decrease on the leeward side of each successive range. Ultimately, the foothills of the great Himalayas receive less rain than the other areas. At the same time, rain increases eastwards and decreases westwards.

The *post-monsoon* season is the harvesting season of rice, the main crop of Nepal. Strictly speaking this is the transitional period from one season to another, and at this time the sub-tropical westerly jetstream retreats from the northside of the Tibetan plateau to the southern side of the Nepalese Himalayas, and frequent fogs appear over the valley. In the *winter season*, the lower troposphere wind blows mostly from west-north- west in western Nepal and east-north-east in eastern Nepal. They are dry, continental, winds associated with stable conditions. In the upper troposphere the subtropical jetstream lies over the southern side of the Himalayas. Morning fogs occur frequently in most of the valleys in Nepal and the westerly disturbances bring cold spells and rain, most intensive in the west.

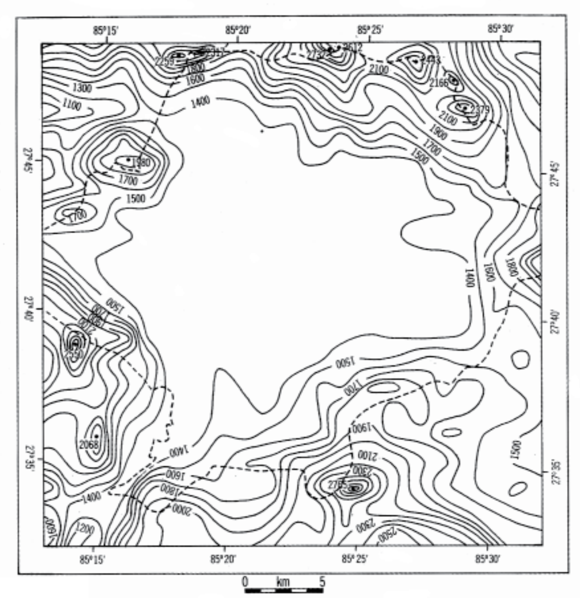

Figure 1. Topography of the study area

THE VALLEY CLIMATE

Radiation: Computed values of daily total solar radiation at the top of the atmosphere over Kathmandu vary sinusoidially from 505 to 979 langleys per day over a twelve month period (List 1954). During November to February, Kathmandu receives on average 58 per cent of the total solar radiation at the top of the atmosphere in each month, whereas it only receives an average of 45 per cent during the period from June to September. In June, when the solar radiation at the top of the atmosphere is greatest, the percentage of solar radiation which reaches the surface is relatively low due to high levels of scattering and reflection by the constituent of the atmosphere. This is largely result of low cloud which prevails during this period. The highest monthly mean value of solar radiation, 476 langely per day, occurs during May, just before the onset of the summer monsoon.

Table 1
Current Meteorological Stations Operating In Kathmandu Valley

No.		Elev. m	Lat. Long Deg. Min	Date Est.	Type of Stations
1052	Bhaktapur	1330	2740-8526	May 1971	Rainfall
1022	Godavari	1400	2736-8523	May 1952	A/C*
1030	Tribhuwan Int'l Airport Kathmandu	1336	2742-8522	Sep 1967	Synoptic
1014	Indian Embassy (Kathmandu)	1324	2743-8519	Oct 1879	A/C*
1039	Pani Pokhari (Kathmandu)	1335	2744-8520	Apr 1971	A/C*
1029	Khumaltar	1350	2739-8520	May 1967	A/C*
1043	Nagarkot	2150	2742-8531	May 1971	A/C*
1035	Saankhu	1463	2745-8525	Sep 1970	Rainfall
1012	Sundarijal Power House	1364	2745-8525	May 1940	Rainfall
1013	Sundarijal Reservoir	1576	2745-8525	May 1940	Rainfall
1015	Thankot	1630	2742-8513	Sep 1966	Rainfall
1056	Tokha	1790	2747-8521	Dec 1972	Rainfall

* Agroclimatological station.

Insolation: Solar radiation is estimated for 394 selected gird points by using the computer programme developed by Fleming (1971). The programme is designed to use the district average data for variables such as sunshine hours, precipitable moisture, latitude and longitude. The necessary average data are used from a single representative site, Tribhuwan International Airport, Kathmandu. At each selected grid point, the slope, aspect, and azimuth are determined and used in the programme. Fleming (1971) estimated solar radiation by adopting Monteith (1962) and Idso (1969, 1970) models combined wih Goodspeed's (1970) solar position programme. Goodspeed's defines solar position as a vector and Fleming defines slopes in terms of the normal incidence vector. The combined programme of Fleming (1971) estimates mean monthly value of both clear day and average solar radiation for the horizontal and inclined surfaces. The value of solar radiation is calculated for the middle of each month which is considered as the mean value for a particular month.

Calculation of clear day radiation follows the model of Idso (1969, 1970). The transmittance of an atmosphere which plays an important role in solar radiation calculation, is caused by scattering by water vapor, scattering by dust free atmosphere, absorption by water vapour and

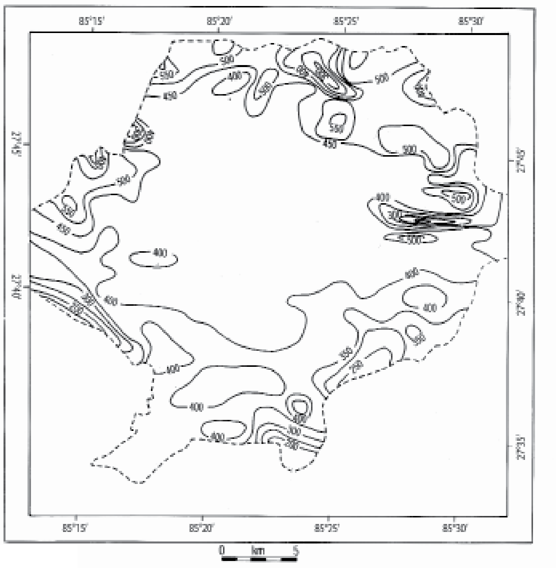

Figure 2. Clear day global solar radiation (ly/day) January.

absorption by dust. The cumulative transmittance is made up form separate calculations for each of the above components. The principal effects are derived from water vapour and dust. There are at present no precipitabler water data for Kathmandu, since regular radiosonde ascents only commenced in 1977. The annual cycle of precipitable water was estimated by linear relationship proposed by Spencer (1965) for Australia as follows:

$$u = pe \qquad (1)$$

Where u is precipitable water content in mm; e is surface vapour pressure in mb: p is a local constant. Spencer suggests that p=1.0 for Australian data and in this programme p=1.0 is used although p and e can be evaluated by further experimental evidence.

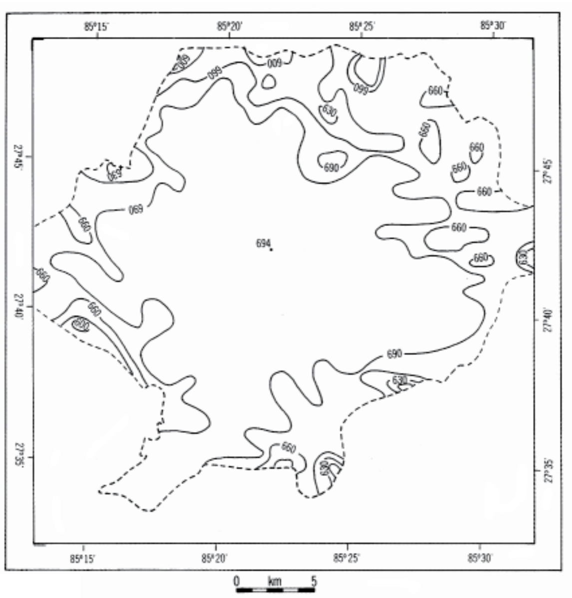

Figure 3. Clear day global solar radiation (ly/day) July.

Atmospheric dust factors can be derived from atmospheric turbidity measurements which also were not available. However, the monthly dust factor was estimated by comparison with the observed and estimated global solar radiation at Kathmandu.

Month	J	F	M	A	M	J	J	A	S
Dust factor	1.0	1.5	2.5	3.0	2.5	1.5	1.0	1.0	1.0

Month	0	N	D
Dust factor	1.0	1.0	1.0

Because of the necessity to combine the direct and diffuse radiation receipt on inclined surfaces, modification of the Angström formula is used, based on the work of Hounam (1963) expressed as:

$$\frac{Q}{Q_0} = a' + (1 - b)\,\frac{n}{N} \qquad (2)$$

Where,

Q = total global solar radiation received at the earth's surface,

Q_o = total global solar radiation on a clear day at the surface,

n = actual duration of sunshine,

N = Maximum possible duration of sunshine,

a' = constant (=ratio Q/Q_o on overcast day)

b' = constant (= ratio 1-a', since $Q=Q_o$ on a cloudless day)

The values of estimated global solar radiation for horizontal and inclined surfaces for 394 grids points on clear days over Kathmandu Valley in January and July are shown in Figures 2 and 3. Insolation on a clear day in January varies from 200 to 550 langleys per day depending on slope, aspect and elevation. In July, it varies only from 600 to 694 langleys per day on a clear day, whereas average estimated insolation during these two months in Tribhuwan International Airport, Kathmandu are about 324 and 446 langleys per day.

Temperature: At Kathmandu, summers are hot with the temperature occasionally rising above 30^0C. Winter are cold with early morning temperatures frequently falling below freezing point. Mean temperatures range from 9.4^{0}C in January to 23.4^{0}C in July, with a mean annual temperature of 17.5^{0}C which varied between 17.4^{0}C to 17.9^{0}C during the nine years of records from 1968-1976 at Tribhuwan International Airport, Kathmandu. The diurnal range during the period from November to May is greater than the annual range. Mean daily maxima vary between 15.4^{0}C in January and 29.3^{0}C in May. Similarly, mean daily minima range from 1.9^{0}C in December and 20.2^{0}C in July. The extreme maximum temperature during the period of record was 33.0^{0}C which occurred on 12 June, 1972 and the extreme minimum temperature was -2.3^{0}C on 15 January 1969 and 13 January 1970. During the summer monsoon, the mean maximum and mean minimum temperatures are almost uniform, between 26.0^{0}C to 27.5^{0}C and 18.0^{0}C to 20.0^{0}C (Figure 4).

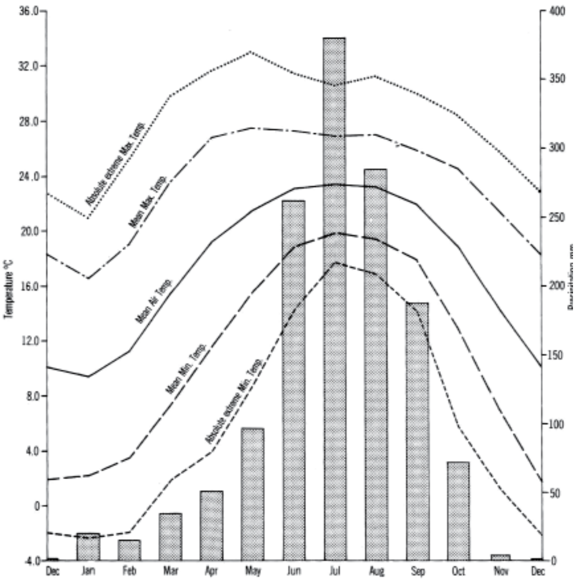

Figure 4. Mean monthly temperature and precipitation at Kathmandu 1968-1976.

Comparing the above temperatures with the Kathmandu Indian Embassy where data is available for a longer period (1901-1975) mean daily maxima are 3.2^{0}C higher in January and 0.2^{0}C higher in May for the same period and the mean daily minima 1.9^{0}C falls in January instead of December. However, comparing the nine year data with the 75 year data at the same station, mean daily maxima are 0.4^{0}C higher in January and 1.0^{0}C lower in May. Mean daily minima are approximately the same. The extreme maximum temperature during 1901-1975 was 37.8^{0}C on 2 June, 1958 and the extreme minimum temperature was -3.9^{0}C on 16 January 1964.

Thirsty-six meteorological stations, recording temperature throughout Nepal were used to develop equations to predict maximum and minimum temperature at the gird intersections in the Kathmandu valley. The period 1970-1975 was chosen to maximise the number of available temperature records. Multiple regression was used to determine the best equations to represent the mean monthly maximum and minimum temperatures. The dependent variables considered were latitude, longitude, elevation and cloudiness index. Three models were developed, all giving satisfactory results. One model accounts for latitude, longitude, elevation and rain as the cloudiness index, the second model considers latitude, longitude and elevation and the last model, elevation is the sole dependent variable. The percentage of variance expressed by the regression are not significantly different among the three models except in the case of the regression between elevation and minimum temperature in the winter months, where the variance explained is slightly lower. Since the latitude and longitude are not very different in the Kathmandu valley, the last model was adopted for further study of temperature distribution in Kathmandu valley.

Annual mean temperature decreases by about 5^{0}C per kilometer with increasing elevation in the Kathmandu valley. It is well known that temperature varies not only with altitude, but also with many mesoscale factor such as slope, aspect,

Table 2
Per Cent of Seasonal Rainfall In Kahtmadu (T.A)

Year	Pre-monsoon rainfall	Monsoon Rainfall	Post-monsoon rainfall	Winter rainfall	Total
1968	180.4	1000.3	160.4	38.6	1379.7
1969	161.9	965.0	40.3	12.0	1179.0
1970	154.6	1081.6	56.2	67.9	1362.3
1971	318.9	1101.7	81.2	9.5	1511.3
1972	160.8	968.0	86.1	46.5	1261.4
1973	154.9	1454.0	119.3	71.6	1799.8
1974	162.2	983.2	45.6	34.0	1225.0
1975	119.2	1221.1	34.2	56.0	1430.5
1976	222.0	1199.0	24.3	44.7	1490.6
	181.7	1108.3	72.2	42.3	1404.4
	(13%)	(79%)	(5%)	(3%)	

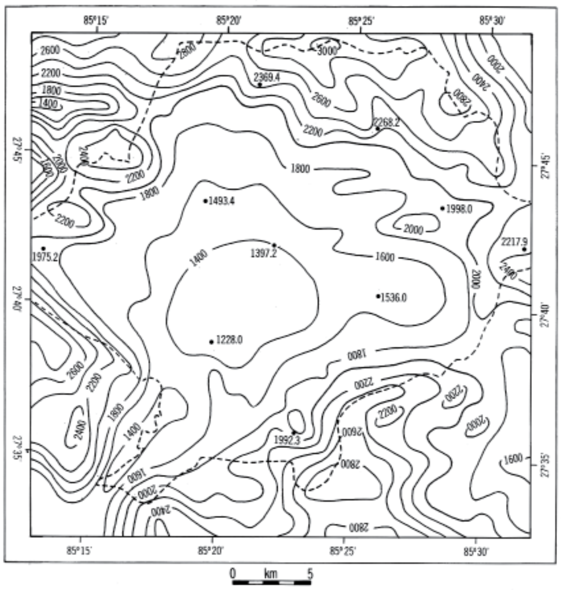

Figure 5. Mean annual precipitation (mm) 1968-1976.

exposure and wind. Though the temperature distribution for the valley is estimated from a linear regression model based on elevation, the estimated temperatures are in good agreement with most of the observed data with the exception of the valley floor where estimated minimum temperatures $1-2^0C$ higher than the observed values.

Precipitation: Mean annual rainfall at Tribhuwan International Airport, Kathmandu, during 1968-1976 was 1404.8 mm. Monthly and annual totals vary considerably from year to year as can be seen in Figure 4 and Table 2. However, 79 per cent of rainfall occurs in the summer monsoon which normally begins in the second week of June and retreats in the third week of September. The annual mean rainfall at the Kathmandu Indian Embassy during 1968-1976 was 1500.6 mm but 50 year records from 1927-76 shown that the mean annual rainfall is only 1372.2 mm. The mean annual rainfall at Kathmandu valley varies from 1400 to 3000 mm due to the sharp topographical variations (Figure 5).

The rainfall at Kathmandu valley was analysed by Body's (1973) computer programme which provided a good estimate of area rainfall, althouth there was a sparse network of gauges in the investigating area. The programme considers the effect of orography which is an important factor in areas like Nepal where sharp topographical variations occur within small distances. There is very little difference between the observed station rainfall and the rainfall interpolated from the computer produced isohyets, with the one exception of the rainfall station at Tokha, althouth the quality of the observed rainfall data here is poor. The highest daily rainfall recorded during the last 56 years was 173.2 mm on 27th July, 1954. Snow has been observed only on the surrounding peaks of the Kathmandu Valley. The average mean snow line in Nepal is about 6000 m above sea level.

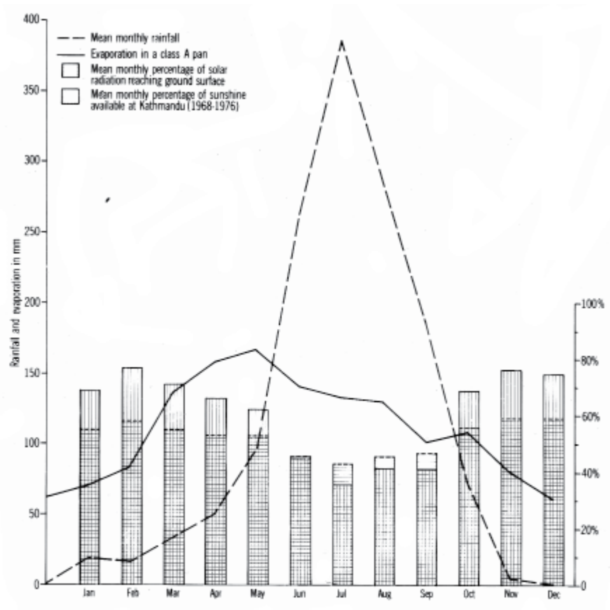

Figure 6. Relationship between rainfall solar radiation and evaporation at Kathmandu 1968-1976.

Cloud and sunshine: During the summer monsoon period, skies are cloudy with less than 45 per cent of possible sunshine. The mean monthly percentage of sunshine during 1968-1976 is shown in Figure 6. During the premonsoon and summer monsoon seasons convection type cloud predominates over the mountain tops in the valley. However, conditions of complete overcast are not usual in the day time. During the end of the pre monsoon and summer monsoon afternoons, the cumulonimbus clouds form as a result of the instability of warm humid air masses, often leading to thunderstorm. Stratus and nimbostratus cloud are observed when the monsoon trough lies near Kathmandu.

More than 70 per cent of possible sunshine occurs during the post-monsoon and winter periods. These periods are almost cloudless except for fog in the morning. Fog occurs mainly from October to February, there being about fifteen days of fog each month during that period. The highest frequency of fogs occurs between 0540 and 0840 local standard time and only rarely does fog persist until noon.

Humidity: At Tribhunwan International Airport, Kathmandu, during 1968-1975, 80 to 100 per cent relative humidity was recorded for most mornings through the year. However, in the afternoon, humidity falls to 40 to 50 per cent during October to February and 20 to 30 per cent during March to May. During the summer monsoon season humidity remains at 70 to 80 per cent throughout the day. Monthly values of relative humidity during 1968- 1975 are shown in Figure 7.

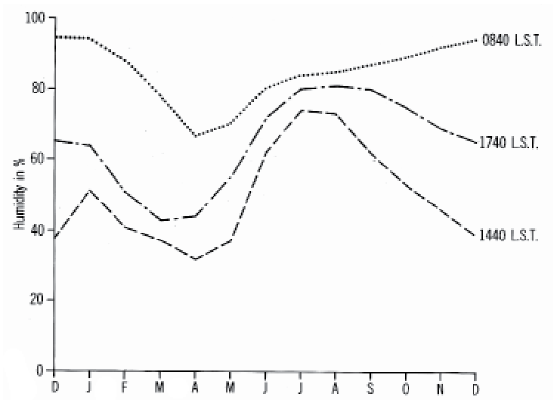

Figure 7

Figure 7. Average monthly relative humidity at Kathmandu 1968-1975.

Evaporation: At Kathmandu, monthly mean evaporation from a class A pan during 1968-1976 and the rainfall for the same period are compared in Figure 6, which shows that November to May had more evaporation than rainfall. The rest of the year, June to October has abundant rainfall and low evaporation. The distribution of potential evapotranspiration is also studied using a single representative site, Tribhuwan International Airport, Kathmandu, which has fully equipped meteorological station. Potential evapotranspiration for 1975 was calculated by Penman's method. The linear regression model between calculated potential evapotranspiration and calculated global solar radiation is derived for the representative site and gave a correlation coefficient for the regression of 0.91. The derived model is used to obtain the variation of potential evapotranspiration using calculated global solar radiation for 394 grid points in the Kathmandu Valley, assuming wind speed to be constant at all the points.

The computed distribution and variation of average potential evapotranspiration over Kathmandu Valley in January and July are shown in Figures 8 and 9. The potential evapotrnspiration in January varies from 0.0 to 90.0 mm depending upon slope, aspect and elevation. In July, potential evapotranspiration is relatively constant over the whole valley with values in the range from 80.0 to 96.0 mm per month.

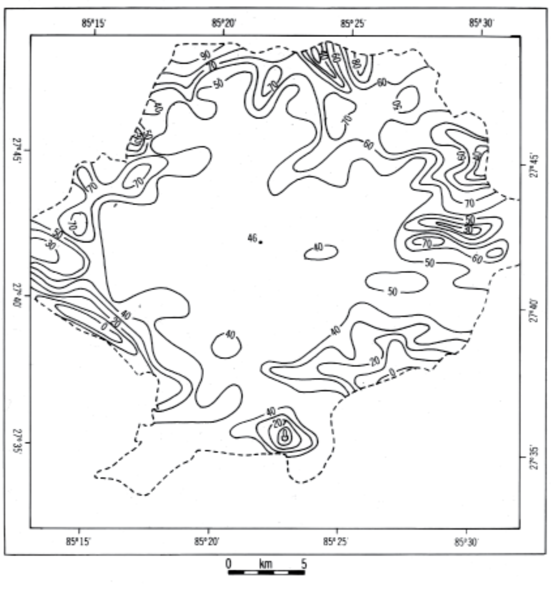

Figure 8. Potential evapotranspiration (mm) January.

CLASSIFICATION OF CLIMATE

The major climate elements of monthly average global solar radiation, precipitation and maximum and minimum temperature were selected for the same 394 sampled grid points to provide the basis for a topoclimatological study of the valley and adjacent slopes by the computer programme TAXON. The classification program MULCLAS was used to sort out the most similar points in group to produce a dendogram showing the relative degree of similarity between individual points and groups of individual points. Detailed information on these techniques can be found in Williams and Lance (1968 a,b), Williams (1976), Austin and Nix (1978) and Dale et al. (1978).

A dendogram of 15 groups, as shown in Figure 10, is developed using the MULCLAS classification of 394 grid points with 48 attributes (12 attributes each from mean monthly insolation, precipitation, maximum and minimum temperature). Four major groups can be separated from the dendogram to classify the climates of the Kathmandu valley (Figure 11). The valley floor and mountain top, the south facing slopes , the north facing slopes, and the north facing steep slopes can be classified as humid, subhumid, wet or wettest zones of the Kathmandu valley. It is interesting to note that global solar radiation plays a dominant role in the classification of the climates of Kathmandu valley.

CONCLUSION

The monthly mean insolation, precipitation, and maximum and minimum temperature were estimated for a grid net using a large number of grid points, (394 in most cases) to study the topoclimatology of Kathmandu Valley. Each grid point, therefore, is representative of approximately 1.5 km^2, whereas the official stations cover larger areas. The estimation procedures used regression methods and theoretical models as described earlier, and took into account all available data. The main source of observed data was from the Department of Hydrology and Meteorology (Department of Irrigation, Hydrology and Meteorology 1968, 1971, 1972; Department of Irrigation, Hydrology and meteorology 1977 a,b,c).

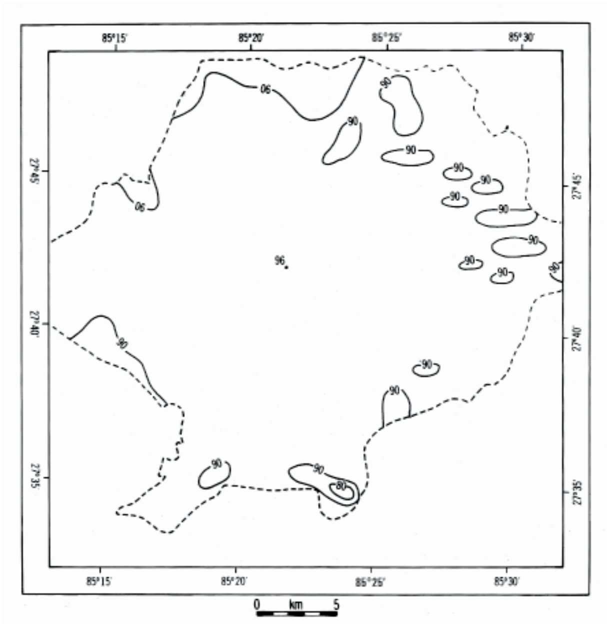

Figure. 9. Potential evapotranspiration (mm) July.

Considering global solar radiation to be the primary factor, the climate of the slopes can be studied by an examination of radiation distribution on slopes of varying aspect. Wind is also an important factor because it affects the distribution of rainfall as well as temperature. Basically, the valley is calm and less windy than the surrounding peaks and ridges, where with an increased wind speed, a greater proportion of the available radiant energy is used for evaporation and heating of the air.

This mesoscale classification of climate and the grid point data will be used further in crop model studies in the Kathmandu valley. On a broad scale, these analyses will assist in understanding climate and crop relations, so that better agricultural planning and implementation can be achieved in Nepal.

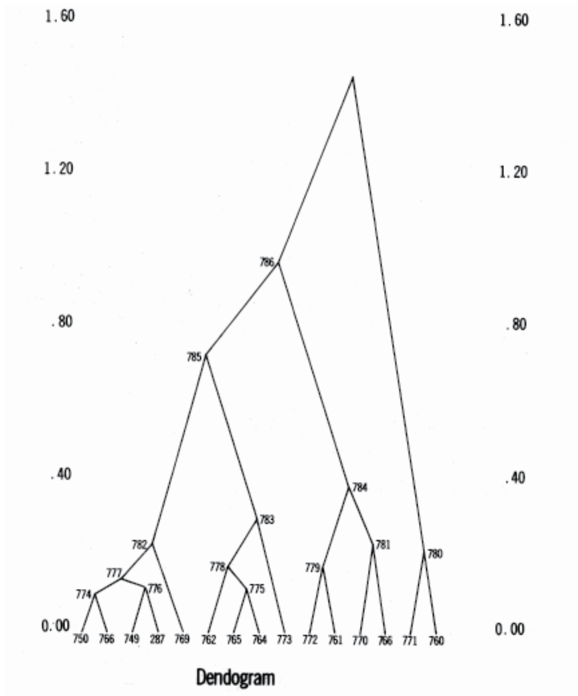

Figure 10. Dendogram

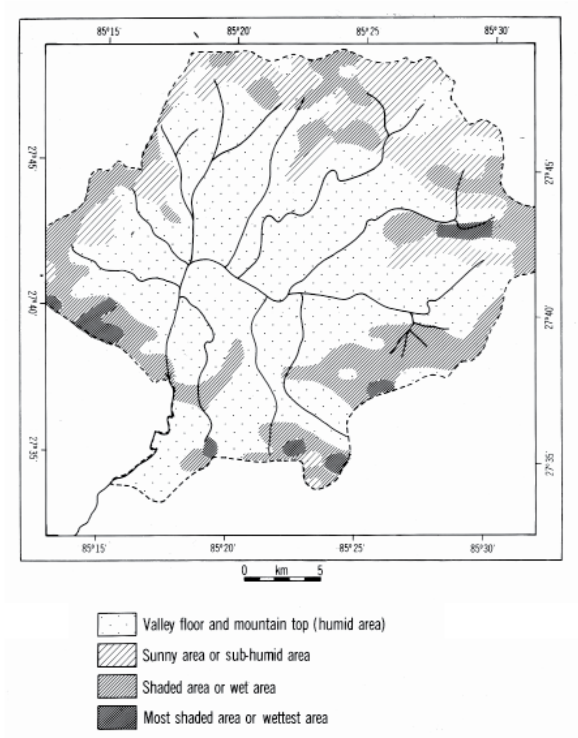

Figure 11. Classification of climates in mesoscale.

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A TOPOCLIMATOLOGICAL INVESTIGATION OF SOLAR RADIATION IN THE KATHMANDU VALLEY, NEPAL*

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ABSTRACT

A limited set of observations of total global radiation at Tribhuwan International Airport has been used to estimate the parameters in a computer model of radiation input to sloping surfaces. The computer model separates direct, diffuse and circumsolar diffuse components, and derives clear day radiation estimates for horizontal and sloping surfaces using efficient vector methods. Direct and diffuse components are combined with sunshine-hour data to estimate average or mean monthly insolation on horizontal and sloping surfaces. The relative merits of extraterrestrial clear day, and average day radiation indices are discussed. Topographic data for the Kathmandu valley were used to estimate average slope and azimuth at a grid of 394 points. These slope data were input to the computer model and mean monthly isopleths of clear day and average day insolation plotted and discussed.

INTRODUCTION

The global solar radiation received at any surface is the primary factor entering the heat budget of that surface, whether it be a field, a region, a continent, or the whole earth. The radiation received varies with latitude, time of day, aspect, slope, and time of year, as well as being influenced by variations in the transmissivity of the atmosphere. As solar radiation is measured over only a limited network world wide, and usually only on a horizontal surface, there are many techniques used to extrapolate radiation data. In Nepal there are only limited global solar radiation data for one site, Tribhuwan International Airport.

The spatial distribution of mean monthly total global solar radiation over Nepal has been estimated using correlation with sunshine hours, cloudiness and precipitation (Nayava, unpublished paper). At the mesoscale, local differences in solar radiation due to slope and aspect become important. There are no observations of solar radiation input on inclined surfaces available in Nepal, however, and so methods of extrapolating the single horizontal surface observations are required.

This paper reports the results of applying a simple computer model of the atmosphere coupled with variants on the Angström equation to derive monthly indices of radiation on slopes relative to total global solar radiation on a horizontal surface. The indices are then used to transfer the single set of horizontal observations to a grid of points in the Kathmandu valley.

RADIATION ON INCLINED SURFACES RELATIVE TO HORIZONTAL SURFACES

The ratio of radiation input on an inclined surface to that on a horizontal surface, integrated over 24 hours, is termed the radiation index. The simplest index to derive is that from simple slope geometry

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in the absence of an atmosphere. Calculations for such simple indices were discussed by Kondratyev and Manolova (1960) and Lee (1963).

Position on the globe does influence the attenuation of the direct solar beam so that the intensity of the direct beam varies relatively over the day. Ohmura (1968) and Garnier and Ohmura (1968 a, b) proposed a method using observe atmospheric attenuation coefficients and integration of the direct component only to derive radiation indices. These indices were then applied to actual total global solar radiation observations on a horizontal surface to map variation in solar input. There are, however, problems of systematic bias if simple clear day transmission factors are used, particularly if the diffuse component is ignored, as was pointed out by Basnayake (1968). Schulze (1975) took a further step and derived empirical formulae under cloudless conditions that took into account both the direct and diffuse components.

Fleming (1971) has developed a computer program, which will be described in greater detail in the next section, aimed at overcoming most of these objections, for clear day conditions. A simple atmospheric model based on the work of Monteith (1962) and Idso (1969, 1970) is used to derive instantaneous values of direct, circumsolar diffuse, and uniform diffuse radiation on clear days and integrates them for horizontal and inclined surfaces. Later developments of the program then further modify the clear day data for average conditions using a variant of the Angström equation and assumptions as to the relative proportions of direct and diffuse radiation. The program can also account for horizon cut-off effects, and foreground albedo. The Fleming technique is believed to represent a practical limit in realistic modelling of the differences in input to inclined and horizontal surfaces at mesoscale. Certainly, more detailed atmospheric attenuation models are available, e.g. Dave (1977) and Klucher (1979) and the non-uniform distribution of diffuse radiation has been described in more detail, e.g. Steven (1977) and Steven and Unsworth (1979, 1980).

In this paper clear day values of radiation input and index were calculated for the middle of each month and considered to be the mean for that month. Average values for the month were then estimated from mean monthly values of sunshine hours.

THE BASIC COMPUTER MODEL

As the computer model has not been formally reported in the literature, and in particular the adaptations to estimate average radiation input, a detailed description will be set out. The computer program uses the vector methods for the description of solar position described by Goodspeed (1970), together with vector definition of any inclined surface in terms of a vector, normal to its face.

The clear day atmospheric model

The atmospheric attenuation model of Idso (1969, 1970) is used to calculate the direct and diffuse components at the surface, and recognises four component processes that are set out below with their equations.

(i) absorption bv water vapour:

$$a(u^*) = 0.77u^{*0.3} \quad \text{... 1}$$

where a (u*) is the absorption in the water vapour column u*, and u* = u. m;

where m is the relative geometrical air mass and has value 1.0 for a solar elevation of 90^0, u is the precipitable water content of the atmosphere in mm of water.

(ii) scattering by water vapour:

$$t_s (u^*) = 0.975u^* \quad \text{… 2}$$

Where t_s (u*) is the transmissibility of the atmospheric column, taking water vapour into account.

(iii) Rayleigh scattering of dry air:

$$t_s(A) = 0.9^{m^*} + 0.026(m^* - 1) \quad \ldots 3$$

Where m* is the equivalent dry air mass and is a function of m, local atmospheric pressure p, and the standard atmospheric pressure, p_o, i.e. 1013 mb;

thus $m^* = m.p/p_o$

t_s (A) is the transmissibility due to molecular processes.

(iv) Scattering by dust:

$$t_s(D) = 0.95^{mD} \quad \ldots 4$$

Where D is a normalised dust factor that is extensively discussed by Idso (1970), who shows that in arid and semi-arid areas it is a function of mean daily wind speed. Fleming (1971) showed that by matching attenuation rates with the data of Rao and Seshadri (1960), D = 2.0 can be equated with a dust concentration of 300 ppm;

t_s (D) is the transmissibility due to dust particles.

The attenuated direct beam component, I_{dir} is then calculated as Eqn 5

$$I_{dir} = I_o(1 - a(u^*)).t_s(u^*).t_s(A).t_s(D) \quad \ldots 5$$

Where I_o is the extraterrestrial direct beam intensity, i.e.

$I_c.R_c^2/R_o^2$ where I_c is the solar constant, 1353 Wm^{-2},

R_c is the mean sun-earth distance and R_o is the sun-earth distance on the day in question.

The clear day diffuse radiation associated with the three scattering effects is assumed to be produced by a 50 per cent forward scattering modified by a solar altitude factor so that for a horizontal surface Eqn 6 holds

$$I_{dif.\,hor} = 0.5(I_o(1 - a(u^*)) - I_{dir}).\ \sin \mathbf{alt} \quad \ldots 6$$

Where **alt** is the solar altitude.

The direct component is, of course, $I_{dir.hor} = I_{dir}.\sin$ **alt**.

In the case of an inclined surface it is assumed that a proportion of the factor $(I_o(1-a(u^*)) - I_{dir})$ is to be considered 'circumsolar' and so is associated with the direct component for slope effects. The circumsolar percentage in this paper is taken to be 0.25. For the inclined surface the appropriate equations are 7 and 8 for the direct and diffuse components.

$$I_{dir\,.inc} = (I_{dir} + 0.25\,(I_{dif..hor})).(\underline{n}..\underline{r}) \quad \ldots. 7$$

where $\underline{n}$ is the normal vector to the surface;
$\underline{r}$ is the solar position vector;

and $(\underline{n}.\underline{r})$ is the vector dot product.

$$I_{dif.inc} = 0.75\ I_{dif\,.hor} \cos^2(\theta/2) \quad \ldots 8$$

Where θ is the angle of inclination of the inclined plane.

The program also allows for foreground reflection to be taken into account for steep slopes using a simple reflectivity and view factor calculation. Horizon cut-off the direct solar component can also be taken into account but was not used in this study. Daily totals, Q_o and Q_{oinc} are determined by summation of values calculated in zone mean time at 12- minute or 0.2-hour steps, commencing at midnight.

The estimation of average radiation

Average or mean monthly radiation is calculated from the mid-month clear day radiation estimate using a correlation with sunshine hours.

(i) for horizontal surface:

the basic equation is that of Angström (1924) and Hounam (1963)

$$Q/Q_o = (\alpha+(1-\alpha) . n/ N) \qquad .... 9$$

Where Q is estimated mean monthly total daily global solar radiation,

Q_o is estimated mid- monthly clear day total global solar radiation on a horizontal surface;

n is the mean monthly observed sunshine hours;

N is the maximum daily sunshine hours, i.e. total theoretical duration the sun is visible above the horizon plane;

and α is a local parameter related to the average diffuse radiation level when the sun is obscured by clouds. Values in the literature range between 0.3 and 0.5.

(ii) for inclined surfaces:

from Eqn 9 it is apparent that when n/N equals zero all radiation must be diffuse and slope correction factor in Eqn 8 should apply, i.e. for n = o,

Qinc = $\alpha.Q_o\cos^2(\theta/2)$. In the case of n/N = 1.0 we have a clear day and the previously calculated clear day value, Q_{oinc} obtains. By analogy with Eqn 9 a factor 'β' equivalent to 'α' but applying to the inclined surface, can be defined.

$$Q_{inc} = (\beta+(1-\beta)n/N)Q_{oinc} \qquad ... 10$$

From the limiting cases show above, therefore, we can define β as equal to $\alpha. \cos^2(\theta/2).Q_o/Q_{oinc}$.

In the case of steep slopes, or where there are significant horizon cut- off effects, the value of β becomes large and may even exceed 1.0, and Eqn 10 becomes of doubtful validity. An alternative method of calculation is available in the program. The diffuse component on the average on a horizontal surface $Q_{dif.hor}$ is assumed to be $Q-Q_{odir.hor}$. n/N, where Q is calculated from Eqn 9 and $Q_{odir.hor}$ is the direct component on a horizontal surface on a clear day. Thus Eqn 11 is derived.

$$Q_{inc} = Q_{odir.inc}\, n/ N + Q_{dif.hor}\cos^2(\theta/2) \qquad ... 11$$

Where $Q_{odir.\ inc}$ is the direct component on the inclined surface on a clear day;

$Q_{dif.\ hor}$ is the diffuse component on the average day on a horizontal surface as defined above.

For steep slopes a component for foreground reflection is also usually calculated.

PARAMETER DERIVATION

To apply the computer program to the Kathmandu valley it is necessary to derive or justify the adoption of appropriate monthly values of the model parameters u, p, D and α. Unfortunately there is only limited total global solar radiation at Tribhuwan International Airport, and no data on the direct component at normal incidence or the diffuse component.

u, the precipitable water content

Regular radiosonde ascents at Kathmandu only commenced in 1977 and no reliable estimates of precipitable water are available. Spencer (1965) showed that a simple linear relationship to surface vapour pressure was valid in Australia and this was adopted here.

$$u = k.e$$

Where u is precipitable water in mm;

k is a local constant, perhaps varying seasonally;

and e is surface vapour pressure in mb.

Spencer's value of k = 1.0 was used.

p, atmospheric pressure

Altitude is the overriding determinant with respect to atmospheric pressure and simple scaling based on altitude and the standard atmosphere was used.

D, the normalized dust factor

There are no turbidity measurements in Nepal and no direct observations even of surrogate factors. The existing daily records of solar radiation at Tribhuwan International Airport, however, were examined and estimates of clear day radiation for the fifteenth day of each month made. The computer model was then run for the same dates using the adopted values of precipitable water, u, and values of D= 1.0, 2.0 and 3.0 and compared with the previous estimates. From the comparison an annual pattern of values of D was adopted, and used in all further calculations (see Table 1).

Qualitatively, the values in Table 1 seem reasonable with values of 1.0 adopted through the monsoon season and rising to a value of 3.0 at the end of the dry season of the Indian sub-continent, when simple observations confirm greatly increased amount of smoke and dust haze. Mani, Chacko and Iyer (1971) have confirmed that atmospheric particle concentrations increase in pre-monsoon months to three of four times the winter values.

Table 1 Mean monthly climatic parameters and average radiation data (1976)

Month	Dust factor	Vapour pressure (mb)	Sunshine hours (n)	Day length (N) (hours)	Observed Q $jm^{-2}(10^4)$	Observed Q $jm^{-2}(10^4)$
January	1.0	8.3	6.8	10.33	1356.5	1303.3
February	1.5	7.9	8.2	11.11	1747.2	2031.8
March	2.5	7.0	8.7	11.58	2081.5	1825.5
April	3.0	11.8	8.6	12.49	2232.6	1930.5
May	2.5	17.1	8.1	13.31	2215.0	1992.0
June	1.5	21.1	5.6	13.53	1923.4	1769.0
July	1.0	23.6	5.1	13.44	1865.6	1849.3
August	1.0	22.9	3.4	13.08	1611.3	1665.7
September	1.0	22.0	5.2	12.21	1675.3	1700.8
October	1.0	15.3	8.6	11.32	1860.2	1794.1
November	1.0	13.9	7.4	10.48	1431.8	1499.1
December	1.0	8.2	8.0	10.24	1375.7	1418.4

α = the Angström coefficient

While direct estimates from the observational data of Q_0 were made and already used in the derivation of the dust factor D, and computer model estimates of Q_0 were also available, a semi-independent estimate of α was sought through the extraterrestrial radiation version of the Angström equation.

$$Q = (a + bn/N)\, Q_A$$

Where a and b are constants;

n and N are as previously defined;

and Q_A is the extraterrestrial daily total of radiation on a horizontal surface.

Q_A is also calculated by the computer program but is also available in many tabulations such as McCullough (1968). All available data at Kathmandu were processed to derive values of a = 0.31 and b = 0.40. Brooks and Brooks (1947) examined sunshine hour recorders and showed that the Campbell- Stokes recorder ceased burning at a solar elevation of less than 5^0 so that even wholly clear days show a maximum sunshine hours ratio of 0.95. Thus Q_O may be considered to equate to $0.68Q_A$. The value of Q at n/N = 0 is $0.30Q_A$, and the substitution of these two values in Eqn 9 gives a derived value of α of 0.44.

Table 1 sets out observed mean values of vapour pressure (mb), sunshine hours, the adopted values of dust factor D, and observed values of mean monthly radiation and the computed value using the full atmospheric model and α equal to 0.44. Overall, the value of α = 0.44 is confirmed.

APPLICATION OF THE MODEL TO SLOPING SITES

The computer model was first applied to graded set of slopes and azimuths for each month, and the patterns of interaction of atmospheric factors, slope and azimuth investigated for both clear days and for average, or mean monthly values of sunshine hours. Then the average slope and azimuth for a grid of locations over the Kathmandu valley were determined form a topographic map and the model used to derive the spatial variation in radiation.

The graded set on clear days

Table 2 set out the clear day results form January and July with azimuth and angle of slope advancing by 10^0. From the full set of monthly data, Fig. 1 was derived and shows the annual variation for five azimuths, N, NE/NW, E/W, S, and SE/SW, and six slope angles 0^0, 10^0, 20^0, 30^0, 40^0, and 50^0. There is a slight annual asymmetry derived from the variation in atmospheric factors altering the direct and diffuse components and their combined total. It is obvious, however, that monthly radiation indices would not be very different from those derived by Lee from extraterrestrial radiation alone.

The data in Table 2 for January (i.e. winter) show most markedly the effect of slope and azimuth. Steep slopes close to zero azimuth receive no direct radiation at all and as the slope angle increases the contribution of the foreground reflection exceeds that of the diffuse radiation from the clear sky obscured and so the received total increases to a secondary maximum.

In the Table 2 data for July, even north-facing vertical surfaces receive some direct radiation component in the morning and evening and so the effect of foreground diffuse radiation is concealed.

The graded set under average conditions

Figure 2 shows the equivalent plots to Fig. 1, but taking into account the actual sunshine hours, and so the altered proportion of direct and diffuse radiation. The patterns are, of course, dominated by the very asymmetrical annual curve for a

Table 2 Clear day totals of global solar radiation (Jm^{-2} (10^4)), Kathmandu, $27^0 42'$ N, considering surface reflection reflected at higher slopes.

Angle	Azimuth in degrees																		
of slope	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
									JANUARY										
0	1703	1703	1703	1703	1703	1703	1703	1703	1703	1703	1703	1703	1703	1703	1703	1703	1703	1703	1703
10	1326	1331	1347	1377	1372	1456	1510	1565	1623	1686	1745	1803	1858	1908	1950	1987	2013	2035	2033
20	920	933	992	1033	1113	1205	1305	1414	1527	1640	1757	1866	1971	2063	2146	2213	2264	2297	2305
30	519	544	615	715	833	967	1113	1264	1423	1577	1736	1887	2029	2163	2280	2377	2452	2498	2510
40	209	234	322	452	602	766	941	1125	1310	1498	1686	1870	2042	2205	2351	2433	2569	2628	2644
50	188	188	188	282	435	607	795	992	1197	1402	1611	1812	2004	2188	2356	2498	2611	2678	2699
60	105	105	105	138	259	418	607	803	1013	1226	1439	1653	1854	2046	2226	2389	2515	2590	2615
70	138	138	138	155	243	377	548	741	941	1155	1364	1573	1774	1971	2151	2322	2456	2450	2565
80	176	176	176	184	247	360	510	686	874	1071	1272	1469	1657	1845	2021	2188	2330	2418	2448
90	213	213	213	216	264	356	481	636	803	983	1163	1339	1510	1678	1841	2000	2142	2230	2259
									July										
0	2908	2908	2908	2908	2908	2908	2908	2908	2908	2908	2908	2908	2908	2908	2908	2908	2908	2908	2908
10	2887	2887	2887	2887	2883	2883	2879	2879	2874	2853	2866	2866	2862	2858	2853	2849	2949	2845	2845
20	2778	2774	2787	2782	2782	2778	2778	2774	2774	2770	2766	2757	2749	2741	2732	2720	2715	2707	2707
30	2611	2611	2607	2602	2602	2607	2611	2615	2619	2619	2611	2602	2586	2569	2548	2527	2510	2498	2494
40	2360	2360	2356	2351	2360	2372	2393	2410	2423	2427	2423	2406	2381	2347	2314	2280	2247	2226	2218
50	2042	2042	2038	2038	2063	2100	2142	2176	2201	2205	2197	2176	2138	2092	2038	1987	1937	1900	1887
60	1531	1531	1531	1540	1602	1674	1741	1787	1816	1828	1816	1782	1732	1669	1598	1519	1448	1393	1377
70	1205	1209	1205	1276	1381	1481	1561	1619	1653	1657	1648	1607	1544	1464	1368	1268	1167	1092	1067
80	862	862	925	1067	1197	1310	1397	1460	1494	1502	1481	1431	1356	1259	1146	1021	895	795	757
90	623	665	782	925	1054	1163	1247	1310	1339	1343	1318	1264	1180	1075	950	808	657	536	490

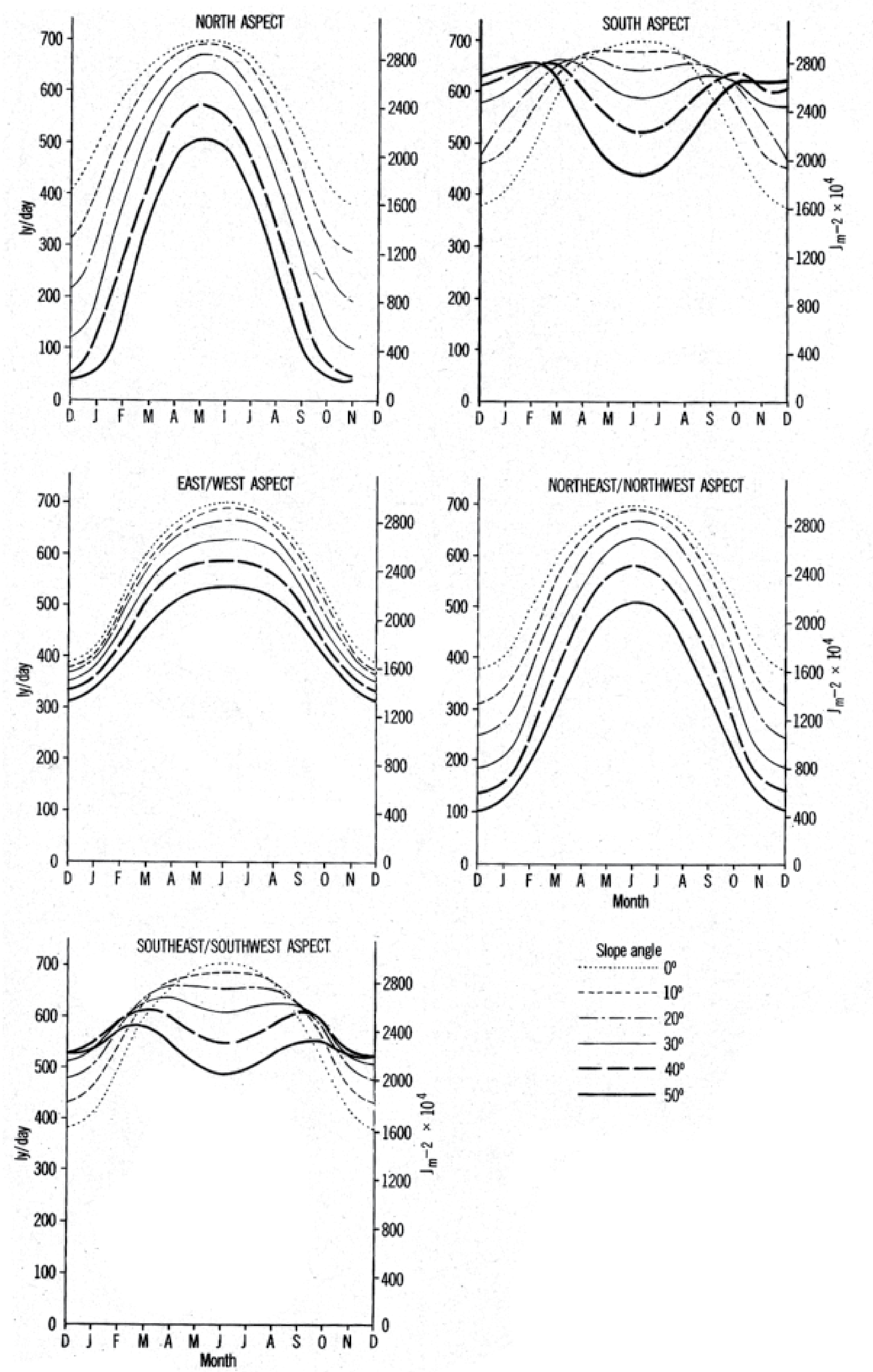


Fig. 1 Global solar radiation on different aspects with cloudless sky in 1y/dav (Jm^{-2}) at latitude $27^0$42'N (Kathmandu).

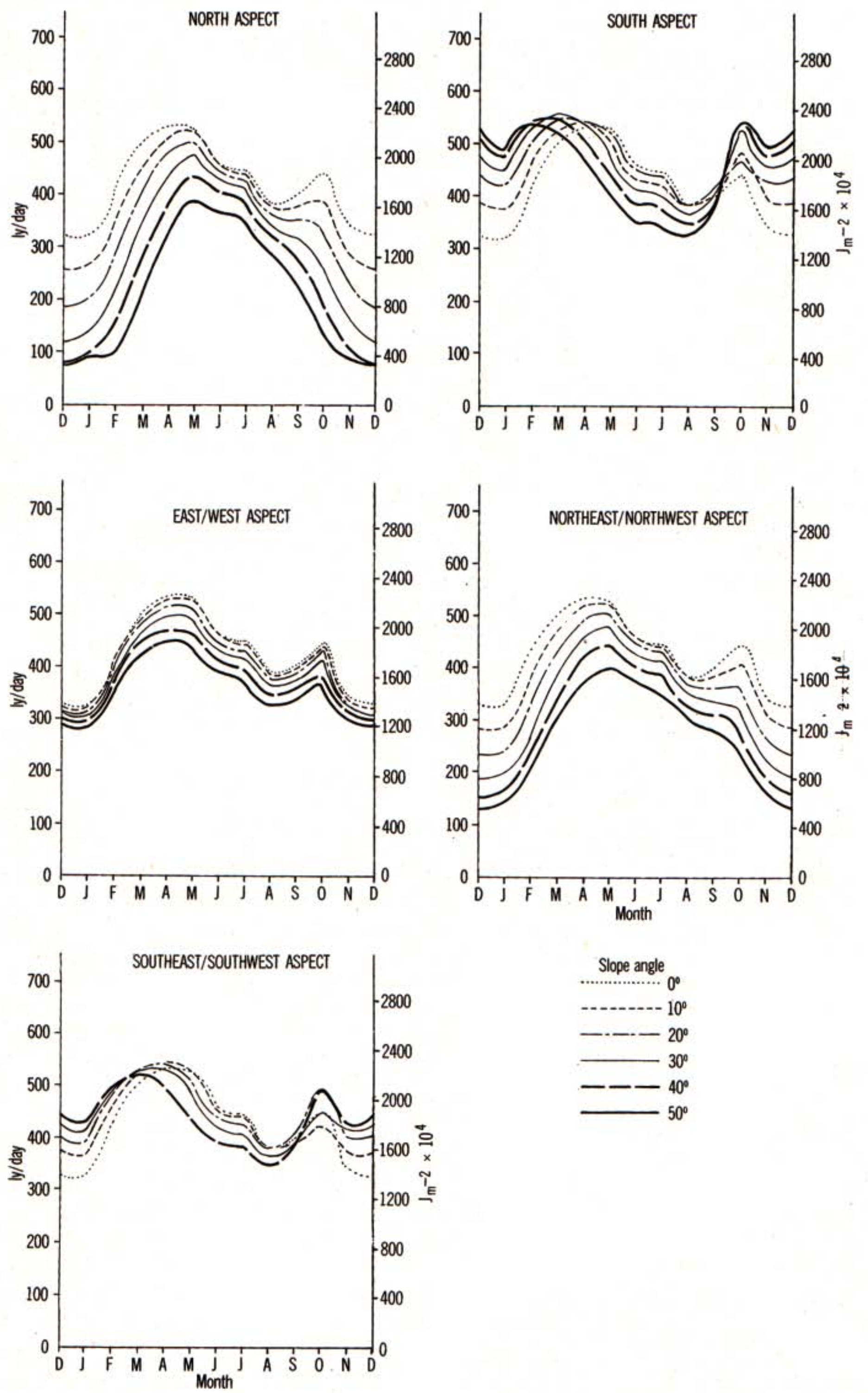


Fig. 2 Global solar radiation on different aspects with average conditions of sky in ly/dav (Jm^{-2}) at latitude 27^0 42'N (Kathmandu).

horizontal surface. Increased cloudiness during the monsoon period increases the diffuse radiation relative to direct radiation and so the differences between slope and aspect are greatly reduced. In the south and southeast/southwest, patterns that exhibit crossing curves on the clear day figure still do so but the time of year at which cross-over occurs is significantly altered.

The monthly radiation index values are obviously very different from those derived for clear days, and so the application of indices derived from extraterrestrial or clear day data to mean monthly observations are obviously subject to considerable bias.

SPATIAL DISTRIBUTION OF RADIATION IN THE KATHMANDU VALLEY

A topographic map of the Kathmandu valley at scale 1:63 360 was available with a contour interval of 100 feet. The valley has a flat floor and is surrounded on all sides by steep ranges. A grid of interval 300 m was placed over the valley and 394 gird intersection points defined within the region of agricultural and human significance. This region is bounded by the dashed line in Figs 3 to 6. At each grid intersection average values of slope and azimuth were determined and the point allocated to a classification matrix. For each combination of slope and azimuth occupied in the matrix the computer model was run using the parameters set out in Table 1 and elsewhere in this paper. Values are therefore available of mean monthly radiation and clear day radiation for each of the grid intersections. These were analysed, and are shown in Figs. 3 to 6.

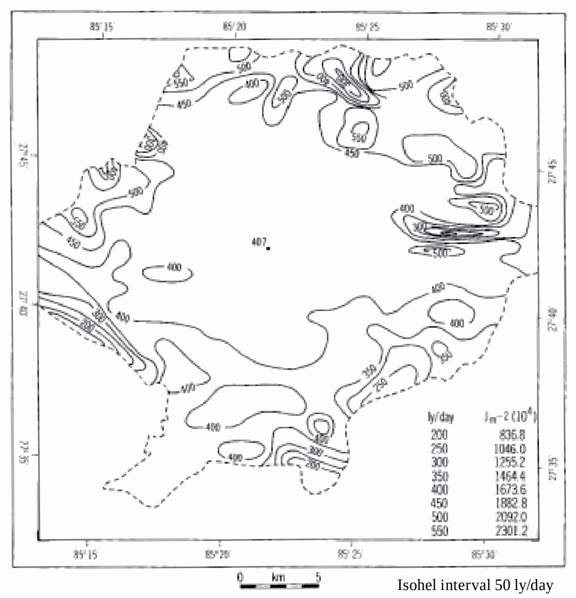
Figures 3 and 4 are plots of clear day radiation for January and July and Figs 5 and 6 the corresponding plots for mean monthly radiation. Significant spatial differences in insolation occur particular in the two plots for the winter month of January. South facing slopes, i.e. equatorwards facing, show values as high as 550 langleys per day, 23 MJ m^{-2}, while the flat floor of the valley receives 400 langleys per day, 16 MJ m^{-2}, on a clear day or 320 langleys, 13 MJ m^{-2}, on an average January day. Conversely northward-facing slopes receive as little as 150 langleys, 6 MJ m^{-2}. In the summer and monsoon month of July the whole valley shows remarkable uniformity under average conditions with a range of 410 to 450 langleys per day, 17 to19 MJ m^{-2}, and even under clear sky conditions the range is only 600 to 700 langleys, 25 to 30 MJ m^{-2}.

CONCLUSIONS

It has been shown that a simple computer model of atmospheric attenuation processes can be developed to separate the significant components of the radiation input, direct, diffuse and circumsolar diffuse radiation. When these components are integrated for horizontal and sloping conditions, and the ratio expressed as a radiation index, the results are significantly different from simple geometrical indices.

The computer model requires the estimation of parameters related to precitpitable water, dust content and air mass, but the results of application of the model in Nepal suggests that even limited data on total global radiation and vapour pressure can be used to arrive at a reasonable array of parameter values. Having determined a reasonable array of parameter values the model was applied to a graded set of slopes and azimuths and also a grid of actual average slope characteristics for the Kathmandu valley.

The results from the graded set of slopes and azimuths, taking into account actual sunshine hours, showed a much more limited range of daily totals than the extraterrestrial or clear day models. This was confirmed on a topoclimatological basis when isopleths of radiation were plotted for the Kathmandu valley. The maximum range of insolation differences exists on clear days in



Isohel interval 50 ly/day

1 ly/day = 4.184 x 10^4 jm^{-2}

Fig. 3 January: clear day global solar radiation, Kathmandu Valley

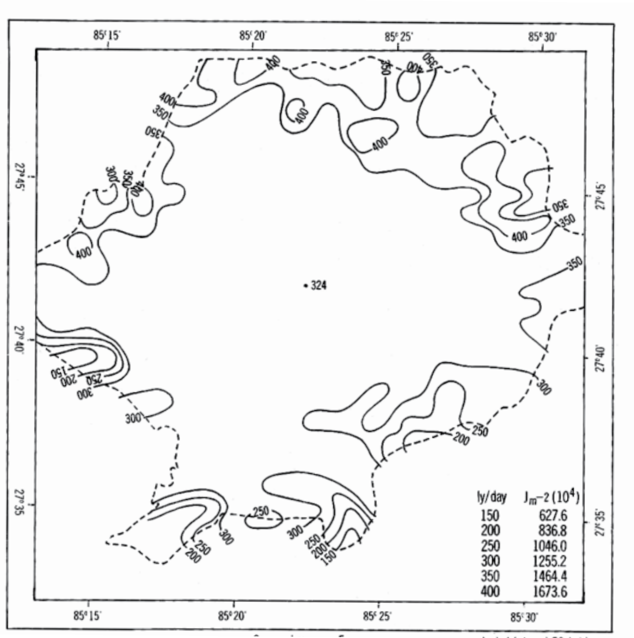
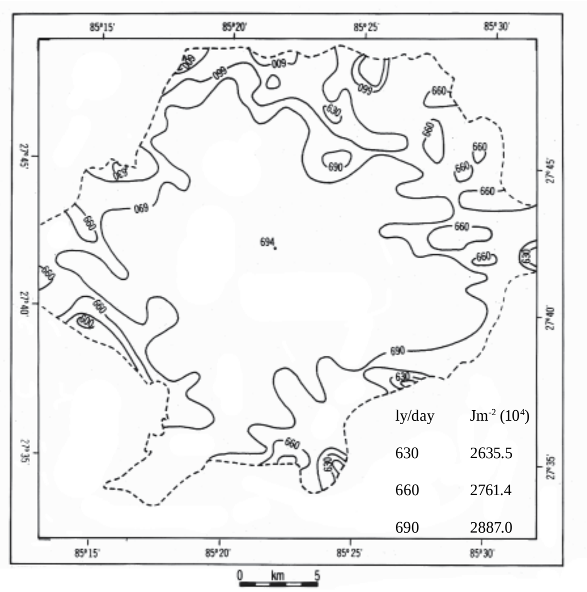


Fig. 5 January: average day global solar radiation, Kathmandu Valley



Isohel interval 30 ly/day

1 ly/day = 4.184 x 10^4 jm^{-2}

Fig. 4 July: clear day global solar radiation, Kathmandu Valley

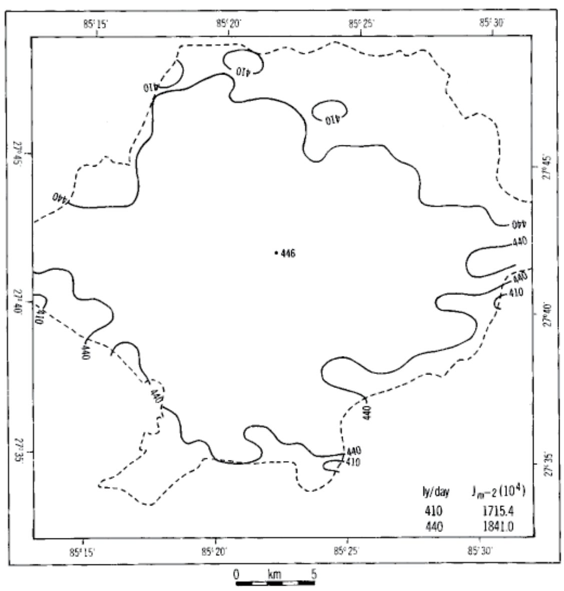


Fig. 6 July: average day global solar radiation, Kathmandu Valley

winter when equatorwards facing slopes in the Kathmandu valley received up to 50 per cent extra insolation.

ACKNOWLEDGMENTS

I am deeply indebted to Mr. P.M. Fleming for permitting me to use his program and also his critical suggestions and comments on my manuscript. I sincerely acknowledge Dr N.S. Mc Donald for his suggestions and remarks on this paper. Finally, I offer my sincere thanks to Mr. K. Cowan for his assistance in cartography and Gennesse Winch for her typing of the original manuscript.

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The Himalayan Review
Nepal Geographical Society

Estimation of Temperature over Nepal*

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Temperature is a significant factor limiting plant growth. Knowledge of the characteristics of the seasonal distribution of temperature and the extreme occurrence of high and low temperatures are important factors for agricultural planning.

REVIEW OF EXTRAPOLATION METHODS

Nepal has only a few temperature recording stations[1] with a long period of data. The variation of temperature over a region, given a few point observations is often achieved by multiple regression methods. Hopkins studied least square regression of mean monthly air temperatures in central and southern Alberta and Saskatchewan with latitudes, longitude and elevation from 44 stations as independent variables[2]. Later Hopkins used 206 climatological stations to further investigate the spatial variation of temperature[3]. He remarked that linear equation could be used to interpolate acceptable estimates of climatological averages for points between stations. Based on 22 years climate data, Hopkins Jr. estimated mean monthly maximum and minimum temperatures in New England and New York with elevation and latitude as independent prameters[4]. In Newfoundland and Labrador, Solomon et al estimated mean monthly temperatures using latitude, elevation and distance from the coast as the independent variables[5]. Lee estimated mean monthly and mean annual temperatures from elevation and latitude within a uniformly humid temperate climates in northeastern USA, based on 30 years monthly and annual means of temperature[6]. Thompson revealed

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that maximum and minimum temperature distribution over the tableland stations around 1000 m elevation in northeastern New South Wales, Australia, was primarily controlled by the relief variation and slope orientation[7]. Thompson used mesoscale classification of airflow to study the mesoscale variation of temperature and rainfall in the same area[8]. Johnson, Kalma and Caprio estimated mean air temperatures from elevation, latitude and distance from the coast from the 22 stations network for south eastern New South Wales[9].

DERIVATION OF EXTRAPOLATION MODELS

Thirty five meteorological stations recording temperature throughout Nepal have been used to develop an equation to predict maximum ant minimum temperatures at different places. The period 1970-75 was chosen to maximize the number of available temperature stations as shown in Fig.1, but still gap is occurred in the north west of Nepal, due to the non existence of temperature stations on that area. Maximum and minimum temperatures from the six year period together with and 55 year mean (1921-75) from Kathmandu (Indian Embassy), 15 year mean from Butwal and 19 year mean from Pokhara were compared (Fig. 2). On average, the annual march of temperature of the six year period and the long term 15, 19, and 55 year means have a difference of less than 1^0C for the maximum and minimum temperature. Hence the network of recent six year mean temperatures of Nepal is acceptable as the base for the estimation of the average mean monthly maximum and minimum temperatures for the 168 station network.

Three models have been developed, all of which give satisfactory results with regression coefficients usually greater than 0.9.

(a) One model takes account of latitude, longitude, elevation and rain as the independent variable; the latter is considered to be a measure of the mean cloudiness.
(b) a second model considers latitude, longitude and elevation, and
(c) in the last model, elevation is the sole dependent variable.

The coefficient of coreelation explained by the regression is not significantly different between these three models as shown in Table 1, except that correlation shows a lower value in winter months, particularly in model III and with mean temperature as the dependent variable.

These three models have been run to select the most suitable variables for the different months for predicting the best mean monthly maximum and minimum temperatures for the 168 stations. Model predicted temperatures were verified with the observed temperatures in order that suitable variables might be chosen. Finally, the first model was chosen for January to November to predict mean monthly maximum temperatures. When the first model was used for December to predict the monthly maximum temperatures, the predicted value was much higher in a few

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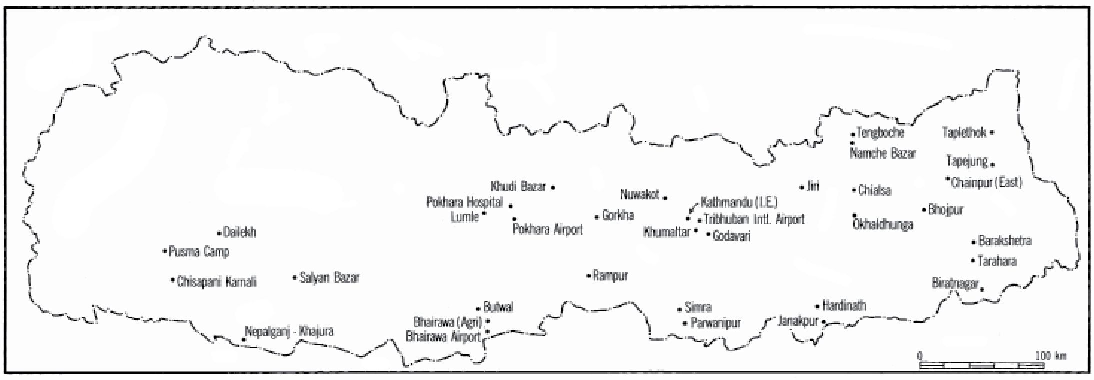

Figure 1. Selected temperature Stations

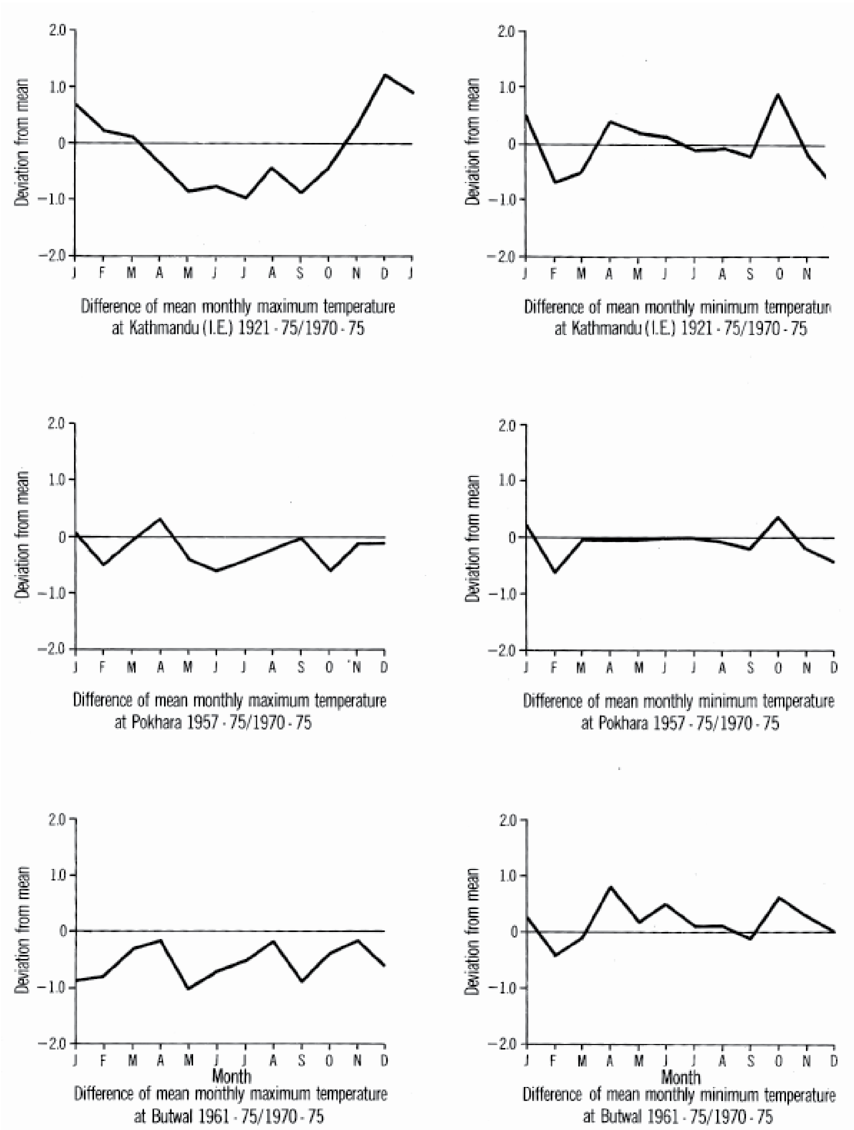

Figure 2. Deviation of temperatures

places. Therefore, the second model being closer to reality was chosen to predict mean monthly maximum temperatures for December.

Similarly, the first model was chosen for March to October to predict mean monthly minimum temperatures. The second model was considered a most appropriate for November to February to predict mean monthly minimum temperatures. The coefficients used to predict temperatures are shown in Tables 2 and 3.

Finally, after having established a set of estimated mean monthly maximum and minimum temperatures for the station net work, the estimated temperature was replaced by the observed temperature records of the 35 stations. The combined observed and estimated mean monthly maximum temperatures are shown in author's thesis[10]. This broad picture of variation of mean monthly maximum and minimum temperatures and extremes are shown in a few selected places (Fig. 3).

For comparision, predicted and observed mean monthly maximum and minimum temperatures for January and July for 35 stations have been studied which shows that there is no fixed pattern nor trend which can identify positive or negative increments of temperature either in Tarai, the Hill or the Mountain Regions of Nepal.

Generally, either the four months January, April, July and October or the two months January and July are the months selected to describe the spatial variation of temperature elements, but in this study, mean maximum temperature of the hottest weeks and men temperature of the coldest week have been chosen. This represents the range of temperature during the year and this is the most useful information for the selection of different species of crops.

Table 1: Coefficient Correlation of Temperature Model

	Model	Jan.	Feb.	Mar.	Apr.	May	Jun.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
I	T Max: Lat. Long. Elev. & Rain	0.96	0.97	0.98	0.97	0.97	0.98	0.97	0.97	0.98	0.97	0.95	0.95
	T Min: Lat, Long, Eiev, & Rain	0.89	0.84	0.83	0.90	0.96	0.98	0.97	0.97	0.97	0.96	0.85	0.79
II	T Max: Lat. Long. Elev.	0.96	0.97	0.98	0.97	0.96	0.96	0.97	0.97	0.97	0.96	0.95	0.95
	T Min: Lat, Long, Eiev	0.85	0.84	0.83	0.90	0.96	0.98	0.97	0.97	0.97	0.96	0.84	0.75
III	T Max: Elev.	0.95	0.96	0.98	0.95	0.92	0.94	0.97	0.97	0.97	0.96	0.94	0.94
	T Min: Elev	0.80	0.81	0.79	0.89	0.96	0.98	0.97	0.97	0.97	0.96	0.82	0.75

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Table 2: The selected Regression Coefficients used to predict Minimum Temperature

	Regress Coefficients for minimum temperature (C)					
Month	b	c	$-d\times10^{-3}$	e	a	R^2
January	3.40	1.45	5.94	0.95×10^{-1}	-207.70	0.86
February	3.33	1.12	5.71	0.13×10^{-2}	-174.35	0.84
March	4.35	1.26	5.26	-0.93×10^{-2}	-209.84	0.83
April	0.37	-4.11×10^{2}	5.98	1.60×10^{-2}	14.00	0.90
May	-0.52	-0.28	5.86	8.15×10^{-4}	62.25	0.96
June	0.37	8.48×10^{-2}	5.64	-1.14×10^{-3}	8.73	0.98
July	0.31	9.16×10^{-2}	5.32	5.94×10^{-4}	9.87	0.97
August	0.62	0.14	5.44	0.94×10^{-3}	-2.82	0.97
September	0.53	0.17	5.50	-2.02×10^{-4}	-4.71	0.97
October	-5.15×10^{-2}	9.01×10^{-2}	5.78	2.12×10^{-2}	15.59	0.96
November	0.50	0.25	5.31	5.46×10^{-2}	20.26	0.84
December	4.03	1.25	5.55	-0.15	-193.59	0.75

N.B. Each equation is of the form T=a+ b (X 1) + c(X 2) +d (X3) + e (X4)
Where T is the mean monthly minimum temperature; X1 is the latitude; X2 is the longitude; X3 is the elevation (m); X4 is the rainfall (mm); and b to e are the appropriate regression coefficients for the month and a is the appropriate constants for the month.

Table 3: The Selected Regression Coefficients used to predit Maximum Temperature

	Regress Coefficients for minimum temperature (C)					
Month	b	c	$-d\times10^{-3}$	-e	-a	R^2
January	1.14	0.40	5.60	1.76×10^{-2}	41.45	0.96
February	2.05	0.57	6.43	3.77×10^{-2}	77.69	0.97
March	2.18	0.60	6.92	5.03×10^{-2}	77.87	0.98
April	2.47	0.41	7.36	2.91×10^{-2}	64.93	0.97
May	2.54	0.21	6.99	1.34×10^{-2}	49.30	0.97
June	2.20	0.21	6.31	0.60×10^{-2}	41.21	0.98
July	1.39	0.31	5.61	0.19×10^{-2}	29.81	0.97
August	1.25	0.31	5.40	0.10×10^{-2}	26.81	0.97
September	1.60	0.37	5.75	0.33×10^{-2}	41.54	0.98
October	1.48	0.49	6.01	0.86×10^{-2}	49.24	0.97
November	-0.19	0.22	5.79		-15.62	0.95
December	-0.29	0.28	5.26	-0.17	-12.49	0.95

N.B. Each equation is of the form T=a+ b (X 1) + c(X 2) +d (X3) + e (X4)
Where T is the mean monthly maximum temperature; X1 is the latitude; X2 is the longitude; X3 is the elevation(m); X4 is the rainfall (mm); and b to e are the appropriate regression coefficients for the month and a is the appropriate constants for the month.

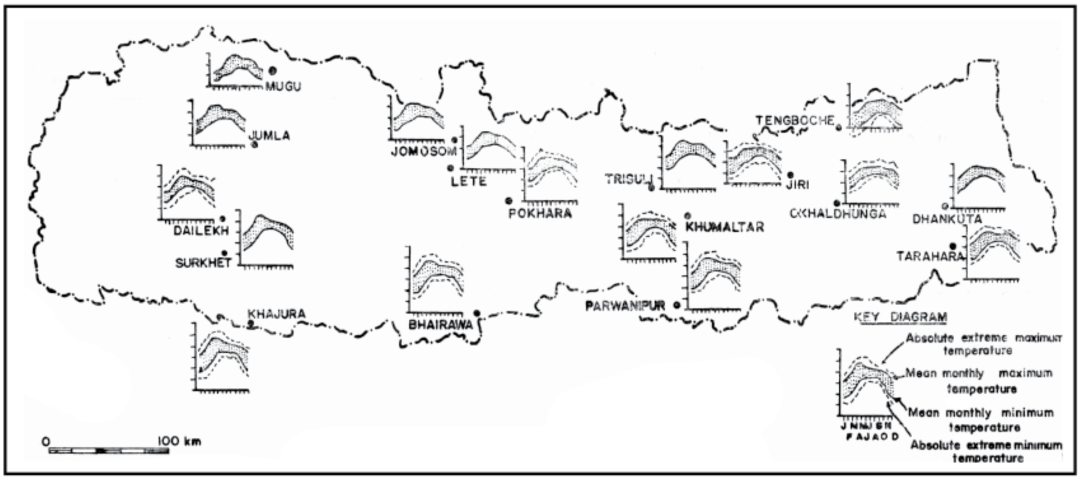

Figure 3. Variation of temperatures

INTERPOLATION OF WEEKLY DATA AND DERIVATION OF EXTREME MEAN VALUES

In the coldest month, January, monthly mean minimum and maximum temperatures over Nepal range from -9.7^{0}C and to 10.8^{0}C and from 3.8^{0}C to 23.4^{0}C respectively. The lowest monthly minimum temperature was recorded in Tengboche, 3857 m above mean sea level. Generally above that elevation, the monthly mean minimum temperature will be much lower than -9.7^{0}C.

In the hottest month, mean monthly minimum and maximum temperatures range from 0.9^{0}C to 23.9^{0}C and from 11.9^{0}C to 39.3^{0}C. The records show that the hottest month generally lies in the month of May in the Tarai, the Inner Tarai and the river valleys of the Hill Region, slowly the warm air from the low land affects the Hill and Mountain regions in the following months and ultimately the hottest month lies in June or July in the Hill and Mountain Regions. The extreme maximum temperature was recorded 46.0^{0}C, which occurred on 9th June 1966 at Karnali, in Far western Nepal, and the extreme minimum temperature was -17.9^{0}C on 15th January, 1974 at Tengboche.

Mean maximum temperatures for the hottest week and mean minimum temperatures for the coldest week are derived from the six year (1970-1975) monthly mean values using Interp 5[11]. Generally estimated weekly values were derived using fourier techniques but the opportunity was taken to use a more recently developed technique, which further reduced bias and error.

These derived values of mean maximum temperature of the hottest week and mean minimum temperature of the coldest week analyzed. The spatial variation of isotherms for the highest weekly maximum temperatures and the lowest weekly mean minimum temperatures are shown in Figs. 4 and 5. The highest weekly maximum temperature varies from 16.0^{0}c to 38.0^{0}C. In the Eastern Tarai, the temperature is 4.0^{0}C lower than the Far Western Tarai. The distribution of temperature is complex due to the complexity of landscapes. The coldest weekly minimum temperature varies from -10.0^{0}C to 10.0^{0}C respectively (Fig. 5). In contrast to the hottest month, the minimum temperature is highest in the Eastern Tarai exceeding that in the western Tarai by 2.0^{0}C.

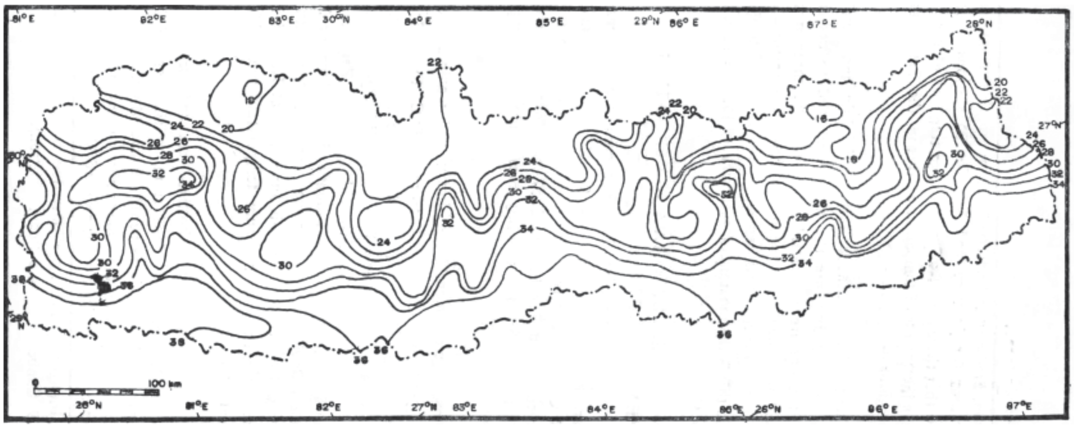

Figure. 4. Mean maximum temperature, hottest week

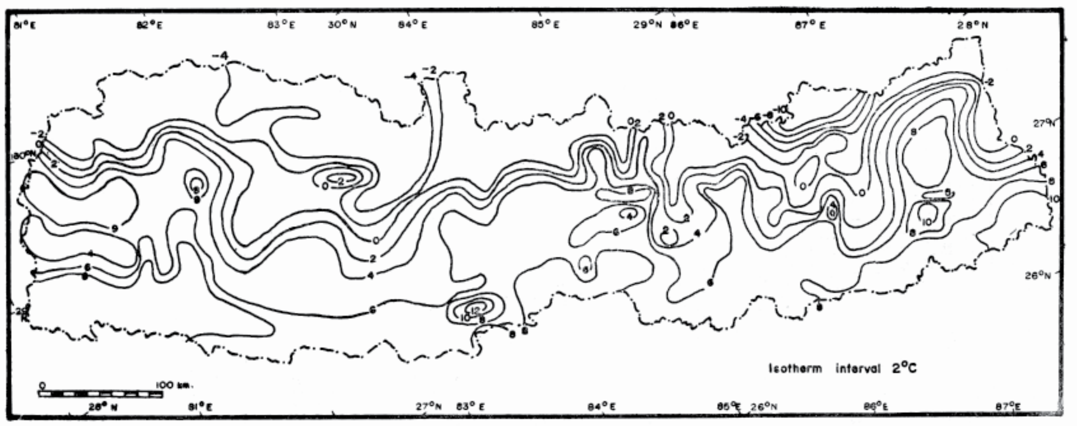

Figure 5. Mean minimum temperature, coldest week

By analyzing highest and lowest temperatures, extreme temperatures, which are hazardous for certain crops for maximum production can be determined. In other words, it helps to classify the temperature regimes in Nepal. Fig. 5 demonstrates that even in the coldest week, the mean minimum temperature is generally 8^0C in the Tarai Regions. From this observation, it seems that that the Tarai could be a frost free zone, this is a vitally important consideration for many crops, especially tropical crops, which are frost sensitive.

DISCUSSION

The mean monthly temperature values for 168 locations in Nepal will be further used to investigate the temperature regimes and crop growth studies. In addition, mean monthly maximum and minimum temperatures for 168 locations can be used individually to discuss the temperature pattern at each location. Furthermore, if its geographical coordinates are known, mean monthly maximum and minimum temperatures can be predicted in any place in Nepal, but caution should be taken in extrapolating data, because, for example, the minimum temperature on the valley floor could be higher than the ridges due to valley air drainage. This error is due in part to the omissions of temperature inversions, slope aspects, cloud incidence and vegetation. However the major factors are inversions which are common in the winter months, resulting in nocturnal air drainage and radiation fog.

Areal rainfall in the Kathmandu valley*

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(Received 26 April 1980)

ABSTRACT: The mesoscale variation of rainfall in the Kathmandu valley and surrounding regions have been estimated for 1225 grid points by computer program, which considers the effect of orography, an important factor in areas like the Kathmandu valley where sharp topographical variations occur within small distances.

1. Introduction

The Kathmandu valley lies in the hilly region of Nepal where a number of mountain ranges extend generally east-west parallel to the Great Himalayas. The east-west and north-south axis of this valley are about 30 and 20 kilometers respectively. The catchment area is approximately 607 square km. The valley floor which lies at between 1280 and 1400 m, is surrounded by hills and mountain ranges rising steeply on all sides completely enclosing the valley. The most prominent peaks rising from the valley are Sheopuri (2689 m) in the north and Phulchowki (3132 m) in the south. The Kathmandu valley is situated at Lat. 27^0 32'-$27^0$49' N and Long. 85^0 12'-85^0 32' E.

The mesoscale study of rainfall in Kathmandu valley and surrounding regions has been undertaken. Rainfall is the primary data for hydrological, agricultural, forestry and water management studies. Generally, areal rainfall data are required rather than single point observations. It is mainly done by drawing isohyets in the data field, considering terrain features. Here, the mathematical approach has been taken to generate the areal rainfall data and analyse the patterns.

2. Methods for areal rainfall analysis

The variation of rainfall over a region that has few observation sites can be estimated by computer analysis. Cressman (1959) introduced the technique for determining a regular scalar field of grid values for an irregular field of observation to analyse the pressure in the atmosphere at various levels. Since then, this technique has been widely developed and extensively used in the numerical prediction in synoptic meteorology and in climatological studies. Gandin (1963) modified the above technique by the direct use of the distance autocorrelation function and fields of mean and standard deviation of the element being nanalysed. Maine and Gauntlett (1968) presented the application of this procedure to the determination of grid point field for monthly rainfall. The ideal behind these techniques is to successively adjust a first guess field, so that the grid point values are consistent with the station observations in their vicinity. The error which is determined between the first guess field and observed rainfall, is applied at the grid point in accordance with the following influence function.

$$I = (r^2 - l^2) / (r^2 + l^2) \qquad (1)$$

*** This article was published in Mausam, 1981. 32, 4, p.p. 343-348*

* This work has been done in the Australian National University, Canberra.

Where, r is the radius of influence adopted to grid scale units and l is the distance of the subject grid point from the station in grid scale units.

Body (1973) developed an approach to estimating areal rainfall distribution, considering the orographic influence on rainfall. A regression relationship is determined between the rainfall observed at a station and two parameters related to the station's cartesian coordinates. Initially eight possible terms are supplied namely x, y, z, x^2, x/z, y/z, x/z^2, *and* y/z^2. The terms proved to be the most appropriate set for a study of monthly rainfall conducted by Body (1978) for the South Coast region of New South Wales. Their transposition to the Kathmandu valley was not tested but would appear reasonable as rainfall is affected by orography normal to generally east-west air flow in each case. For each station, two relevant parameters are selected automatically by the program as those which provide the smallest deviation from the individual station value. Within two parameters, the first plays the primary role and second as secondary. This is noted here as an order of preference. The number of terms in the equation is limited to two because at higher orders, the field is distorted to fit individual stations and, therefore, contains spurious relations which give incorrect estimates in regions away from observations or in orographic conditions outside these encountered in the data field. Then Body's (1973) program was used to study the rainfall in the Kathmandu valley. The data required by the program was first, an estimated elevation at points in grid net. In this case, the grid net contained 35× 35 points (1225), each separated by 900 metres. The others were the observed rainfall data and the location of the stations according to the adopted grid net. The elevations of all grid points have been extracted from Nepal, 1: 63,360 scale map, published by Surveyor General of India, 1957. The main procedures of programs are as follows.

The program estimates from the multiple regression equation using elevation (z), x and y values, the rainfall at each grid point, thus giving field A. Therefore, field A gives preliminary rainfall values for each grid point, which are further adjusted to get the best fit value in grid pints by series of selected radii 25.0, 11.0, 5.5 and 2.0 which are chosen for subsequent passes. The program computes interpolated value for rainfall at each of the observation points from field A on first pass current value at all subsequent passes. For each observation point, the program determines the error, E, between the interpolated and the observed value and for each grid point *(x, y).* The program determines the correction factor:

$$C_{x,\,y} = \sum_{i=1}^{m} E_i W_i \Big/ \sum_{i=1}^{m} W_i \qquad (2)$$

Where, $W_i = (l\text{-}d_i/p)^2$

Where d_i is the distance between the point (x,y) and i^{th} observation station within radius p.

The program computes a new value at each grid point, i.e.

$$\text{New rainfall}_{(x,\,y)} = \text{old rainfall value}_{(x,y)} + (1\text{-}Mv_1)\ C_{x,y}$$

Where Mv_i is the multiple regression value determined in regression analysis.

This whole procedure is repeated for the number of passes selected and adjusts the value at each grid point and finally the program draws isohyets of given intervals, which are supplied by the program user.

3. Data and constructing the isohyets maps

The basic rainfall data has been computed and checked and missing values have been estimated by linear regression based on the nearest Station. A complete mean monthly rainfall records for 11 stations for 1971-76 has been standardized. The basic data, the rainfall stations are shown in Table 1 and 2 and their locations are shown in Fig. 1. The analysis was based for the six year period (1971-76) rather than the conventional 30 year period. The hydro-meteorological observation network in Nepal was expanded in the beginning of 1970, providing eleven stations representative of the different altitude and aspects in the Kathmandu valley and surrounding regions. In comparison with the longer period data for 56 years (1921-76) the recent six-year data, for Kathmandu (Indian Embassy) shows 13 per cent higher rainfall. The contour map of Kathmandu valley based on their grid points is shown in Fig. 2.

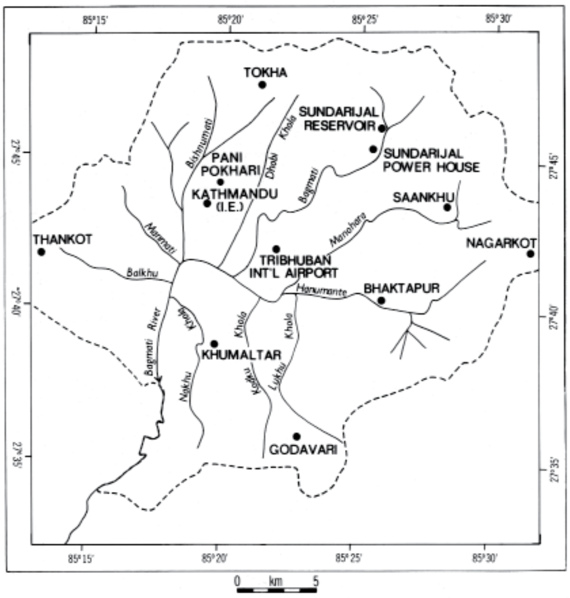

Fig. 1. Operating meteorological stations in Kathmandu Valley

Maps of mean monthly, mean monsoon and mean annual precipitation for the Kathmandu valley and surrounding regions have been studied based on the grid point values as calculated from the computer program (Body 1973).

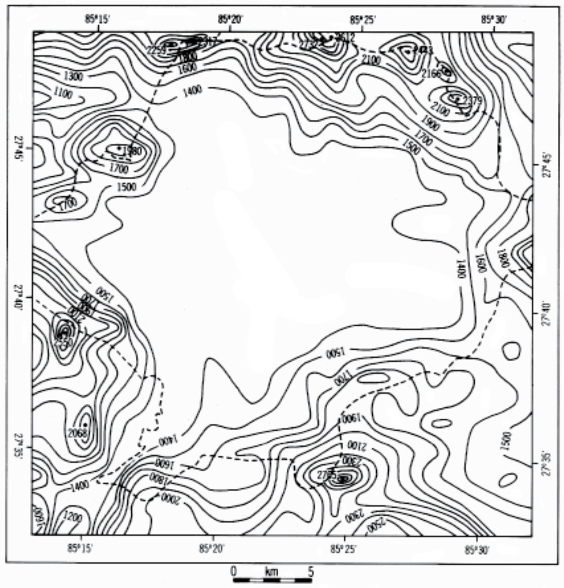

Fig. 2 Topography of the study area (Kathmandu Valley)

During the analysis of preparing the prelimiminary field A, the multiple regression value determined in regression analysis and selected two relevant parameters out of eight possible terms in each month are also produced, which is shown in Table 3. The table shows that the percentage of variance accounted for is very high during the summer months compared with the winter months. It is also interesting to note that the two terms considered in the analysis mostly differ from month to month (see Table 3). The rainfall in winter months (December, January, February), and rainfall in the transition season (October), does not relate with the elevation factor. On the other hand, the rainfall from March to August is strongly related with elevation. There is very little difference between the observed station rainfall and rainfall interpolated from the computer produced isohyets with the one exception of the rainfall station at Tokha, although the quality of the observed rainfall data here is poor. The rainfall values in independent data, namely Sundarijal power house has been compared with the interpolated values, which are in a good agreement with actual

Table 1

Mean rainfall (mm) from Kathmandu valley and surrounding regions (1971-76)

Station	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Des	Mean (mm)
Bhaktapur	1330	18.0	23.3	34.6	66.1	122.1	320.4	340.3	335.0	235.7	86.2	5.3	1.9	1588.9
Godavari	1440	19.5	23.5	32.2	63.2	123.9	400.7	564.2	407.6	345.0	88.5	4.9	2.1	2075.3
Indian Embassy	1324	18.3	19.0	28.5	68.1	123.7	325.1	392.7	312.7	218.8	67.8	5.3	1.6	1581.6
Kakani	2064	15.6	22.8	51.8	71.9	171.9	521.6	701.0	703.2	502.6	139.4	5.3	1.8	2908.9
Khumaltar	1350	19.5	19.8	21.0	57.0	95.0	235.4	328.5	232.4	178.0	65.4	2.9	2.1	1257.0
Nagarkot	2150	17.2	26.0	48.0	74.4	143.6	456.6	569.4	566.5	357.9	124.6	9.0	2.7	2395.9
Saankhu	1463	18.5	23.2	43.8	64.5	123.3	376.4	489.5	475.5	311.4	109.0	6.9	2.2	2044.2
Sundarijal (water Res-ervoir)	1576	13.4	18.9	40.4	67.0	173.5	391.1	556.7	579.1	360.9	91.2	18.6	3.0	2313.8
Thankot	1630	23.5	25.4	33.0	77.5	187.4	425.0	539.5	405.8	373.9	103.0	6,4	2.3	2202.7
Tokha	1790	12.7	16.9	36.0	84.4	183.0	464.1	635.6	733.9	316.5	73.7	20.4	0.5	2577.7
Tribhuwan International Airport	1336	17.6	18.3	31.4	60.9	97.3	284.4	375.4	299.2	195.7	65.1	5.9	1.9	1453.1

Source: Climatological Records, Nepal,1975, Published by Dept. of Irrigation, Hydrology & Meteorolgy, Kathmandu

Table 2.

Seasonal rainfall (mm) in Kathmandu valley and surrounding regions

Station	Elev. (m)	Winter (Nov-Feb)		Pre-monsoon (Mar-May)		Monsoon (Jun-Sep)		Post monsoon (October)		Annual (mm)
		(m)	%	(m)	%	(m)	%	(m)	%	
Bhaktapur	1350	48.5	3.1	222.8	14.0	1231.4	77.5	86.2	5.4	1588.9
Godavari	1400	50.0	2.4	219.3	10.6	1717.5	82.8	88.5	4.3	2075.3
Indian Embassy	1324	44.2	3.0	220.3	13.9	1249.3	78.9	67.8	4.3	1581.6
Kakani	2064	45.5	1.6	295.6	10.2	2428.4	83.5	139.4	4.8	2908.9
Khumaltar	1350	44.3	3.5	173.0	13.8	974.3	77.5	65.4	5.2	1257.0
Nagarkot	2150	54.9	2.3	266.0	11.1	1950.4	81.4	124.6	5.2	2395.9
Saankhu	1463	50.8	2.5	231.6	11.3	1652.8	80.9	109.0	5.3	2044.2
Sundarijal (water Reservoir)	1576	53.9	2.3	280.9	12.1	1887.8	81.6	91.2	3.9	2313.8
Thankot	1630	57.6	2.6	297.9	13.5	1744.2	79.2	103.0	4.7	2202.7
Tokha	1790	50.5	2.0	303.4	11.6	2150.1	82.5	73.7	2.8	2577.7
Tribhuwan Intl. Airport	1336	43.7	3.0	189.6	13.0	1155.0	79.5	65.1	4.5	1453.1
Average percentage			2.3		12.3		80.5			

observation occurs. Similar studies of monthly and annual rainfall for the period 1968-76 for the Kathmandu valley have been studied and these also gave a similar pattern (Nayava 1979). For a matter of convenience, the observed rainfall of the 11 stations in the Kathmandu valley is given in bold number in rainfall maps.

Table 3.

The relevant terms for the rainfall analysis

Month	Multiple regression value (Mv_1)	Two relevant terms
Jan	.59	X^2, Y
Feb	.61	X^2, X
Mar	.71	$X^2, Y/Z^2$
Apr	.53	$X/Z^2, Y/Z$
May	.73	$Y/Z^2, X$
Jun	.78	$X/Z^2, Y/Z^2$
Jul	.83	$Y/\ Y/Z^2$
Aug	.93	$X^2, Y/Z^2$
Sep	.68	X^2, Z
Oct	.47	X^2, X
Nov	.46	$X^2, Y/Z$
Dec	.30	X^2, X
Annual rainfall	.86	$X^2, Y/Z^2$
Monsoon rainfall	.86	$X, Y/Z^2$

4. Distribution of rainfall in the Kathmandu valley

Generally there are four distinct rainfall seasons in the Kathmandu valley. Pre-and post-monsoon rains in Kathmandu are associated with thermal convection combined with orographic uplift and the seasonal shift of the large circulation over Nepal. In winter, precipitation falls as snow on higher peaks of Kathmandu valley. This precipitation originates from disturbances in westerlies. In the summer monsoon, as the rain-bearing winds approach Kathmandu from the southeast, most rainfalls on the windward side, increasing with altitude and decreasing on the leeward side.

4.1 pre-monsoon

Rainfall during this period, March to May, is only 12 per cent of the annual total in the Kathmandu valley. Most of this is due to scattered thunderstorm activity in the afternoon and late evening. Due to the outbreaks of warm air and atmospheric instability, the sup-tropical westerly jet-stream is weakening over Nepal.

4.2 Summer monsoon

In Kathmandu, 81 per cent of the annual precipitation falls between June and September under the influence of summer monsoon. Fig. 3 shows the mean monsoon rainfall in the Kathmandu valley. The rainfall in Kathmandu valley varies greatly from place to place due to sharp topographical variations. In the summer monsoon period, generally, Sundarijal is the windward side of the Kathmandu valley. The intensity of the summer monsoon fluctuates year by year. A delay in the arrival of the summer monsoon and any weakness in its circulation has a significant effect on agriculture. Generally, the average dates on the onset and retreat of the

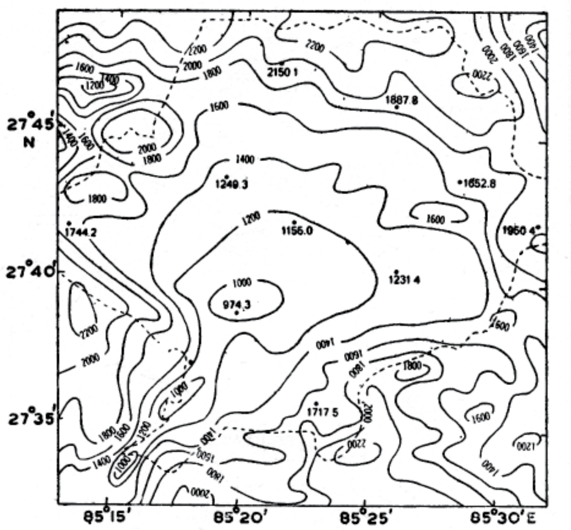

Fig. 3. Mean monsoon precipitation (mm) 1971-1976

monsoon for the period 1948-1975 are 12 June and 21 September respectively (Dep. Of Irrig., Hydrol.& Met. 1977)

4.3 Post monsoon

Rainfall during October is only 5 per cent of the annual total and is due to the scattered thunderstorm activity in this transitional season from summer monsoon to winter.

4.4 Winter

The period from November to February is almost dry. Western disturbances account for only 2 per cent of the annual rainfall total.

4.5 Mean annual rainfall

Mean annual rainfall (Fig.4) has similar patterns of distribution to that of the mean monsoon rainfall. Mean annual precipitation varies from 1300-2800 mm as shown in Fig. 4. The observed rainfall data and computer produced isohyetal lines based on rainfall interpolated are as expected in good agreement. The percentage of seasonal rainfall in Kathmandu Tribhuwan Airport (T.A) is also shown in Table 4.

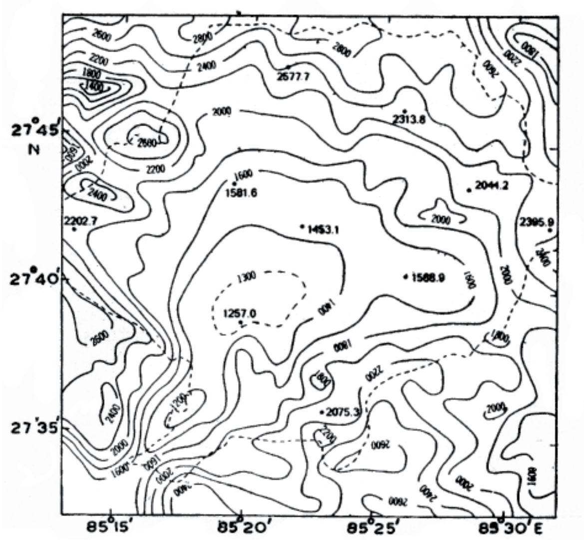

Fig. 4. Mean annual precipitation (mm) 1971-1976

Table 4.
Variation of seasonal rainfall (mm) in Kathmandu (Tribhuban International Airport)

Year	Pre-monsoon	Monsoon	Post monsoon	Winter	Total (mm)
1968	180.4	1000.3	160.4	38.6	1379.7
1969	161.9	965.0	40.3	12.0	1179.2
1970	154.6	1081.6	58.2	67.9	1362.3
1971	318.9	1101.7	81.2	9.5	1511.3
1972	60.8	968.0	86.1	46.5	1261.4
1973	154.9	1454.0	119.3	71.6	1799.8
1974	162.2	983.2	45.6	34.0	1225.0
1975	119.2	1221.1	34.2	56.0	1430.5
1976	222.0	1199.6	24.3	44.7	1490.6
	181.7	1108.3	72.2	42.3	1404.4
	13%	79%	5%	3%	

5. Conclusion

Each gird point is representative of about 0.81sq. km which contrasts with the distribution of official stations which may be separated by many kilometers. The monthly mean precipitation is estimated for a large number of grid points in a grid net for studying the mesoscale variation and distribution of rainfall in the 936 km area of Kathmandu valley and its surrounding regions. The advantages achieved from examination of rainfall on the close grid net are clearly seen in the diagram in which sharp variations in the topography of Nepal are associated with a large rainfall.

Acknowledgements

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Nepal Geographical Society

Rainfall In Nepal*

- Janak L. Nayava**

Rainfall is a most important climatic element for agricultural development. Conventional 30 year rainfall data are available at only a few places in Nepal. Therefore, a study has been undertaken to find the average normal rainfall period compared to a 30 year normal rainfall in Nepal, and the available rainfall data has been standardized for a large number of places. The nature of the rainfall–its amount, seasonal distribution, intensity, frequency of occurrence, variability and areal variation is a major factor affecting agricultural potential. To understand the nature of the rainfall, it is essential to have an understanding of its general causes.

GENERAL FEATURES OF THE ATMOSPHERIC CIRCULATION OVER NEPAL

Studies of lower and upper tropospheric atmospheric circulation in Nepal suggest that the rainfall distribution can be analysed with four distinct seasons[1] pre-monsoon (March to May); summer monsoon (June to September); post-monsoon (October); and winter (November to February).

In the pre-monsoon season, moderate to strong westerly winds prevail throughout Nepal. Scattered rainfall occurs during this period and there is marked increase in temperature of about 3-4^{0} C in the month of March. Due to the outbreak of the warm air and the atmospheric instability, the subtropical westerly jet-stream weakens over Nepal. As summer approaches, fogs become less frequent in the Valley and haze predominates from the southern to the Hill Regions of Nepal.

The summer monsoon is the most important season in Nepal for agriculture with nearly 60 to 90 percent of annual precipitation falling between June and September (Fig. 1). The author, in an earlier study of the summer monsoon in Nepal and South Asia was able to detect the basic types of monsoonal circulation patterns which allows to the summer monsoon to be generally classified according to (a) active or normal (b) very active and (c) weak.

a) During the summer monsoon, the easterly wave dominates the upper level of the atmosphere and the subtropical westerly jet–stream shifts to the northern side of the Tibetan plateau, around an anticyclone called the Tibetan High produced by the thermal effect of this heat source.[2] At

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1 J.L Nayava, "The summer monsoon in Nepal and Southern Asia" Unpublished M.Sc. dissertation, Birmingham University, U. K., 1974.

the surface, an elongated zone of low pressure develops along the Indogangetic plains of North India, which lies northwest to southeast. This area of low pressure is known as the monsoon trough or equatorial trough, which, of course, advances northwards in the summer monsoon months and retreats southwards in the post-monsoon period. Therefore the onset and withdrawal of monsoons are associated with northward and southward movement of the equatorial trough.[3]

Generally, depressions form in the Bay of Bengal twice per month, during the summer monsoon season, corresponding to a period of about 17 days.[4] Depressions usually move WNW and cease activity as they move over the Indogangetic plain. On rare occasions, a depression may move due north from the Bay of Bengal and Assam at the height of the monsoon season bringing heavy rainfall to the north and northeast of the monsoon depression. The recurvature of such a depression is often found to be due to the effect of a westerly wave moving east, north of latitude 30^0N. Recurvatures of monsoon depressions are common towards the end of the summer monsoon.[5]

b) During the period of very active monsoon, the westerlies occasionally move south to the Tibetan plateau and even as far as Delhi and the easterly jetstream often shifts northwards. The easterlies are very strong up to 20^0N. During that time, Pacific anticyclone circulation extends up to the northwest of Burma and the mid-latitude Saudi Arabian Subtropical high extends a ridge eastwards even to the northwest of India. Hence, Nepal finds itself in the col position (Fig. 2). If the Saudi Arabian ridge pushes more towards the east, i.e WNW (200mbs) wind dominates western Nepal, then rainfalls are heavy towards the central and the eastern part of Nepal. If the Pacific ridge pushes more towards the west higher intensity of rainfall occurs all over Nepal. At that time, the monsoon trough lies over 25^0N latitude. Examples of three dimensional circulation over Nepal are shown in Figs. 2 and 3. During such periods less rain falls in central India, being instead concentrated either in part or the whole of Nepal depending upon the mid-latitude anticyclones. Under these conditions, one part of Nepal could be drier and the other part may be much wetter. Actually, such a period is known as a "break in the monsoon" in India.

c) During a weak monsoon over Nepal, easterlies are weak and lie over 15^0N in the Indian

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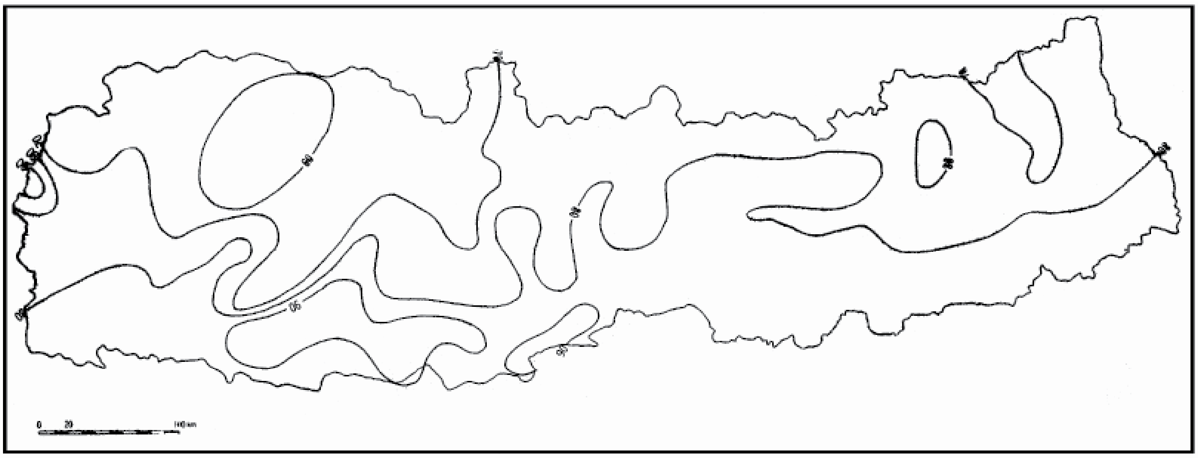

Fig. 1. Monsoon rainfall as a percentage of annual rainfall.

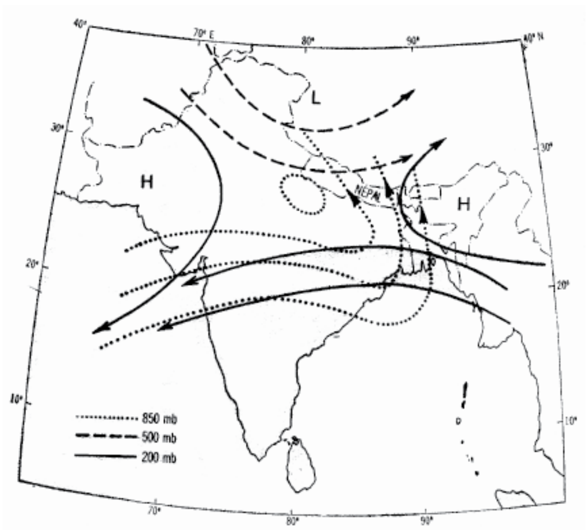

Fig. 2. Three dimensional atmospheric circulation over Nepal and adjacent countries on 30th June 1975, 00 GMT

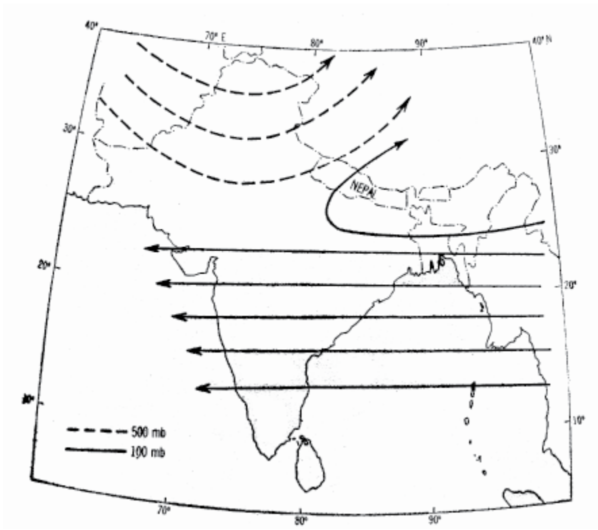

Fig. 3. Three dimensional atmospheric circulation over Nepal and adjacent countries on 22nd June 1975, 00 GMT

subcontinent. The fluctuation and intensity of the monsoon are very much related to variations in the easterly current.

The post-monsoon season is the harvesting season of the main crop, paddy. Strictly speaking, this is the transitional period from one season to another and at this time the subtropical westerly jetstream retreats from the northside of the Tibetan Plateau to the southern side of the Nepalese Himalayas. Frequent fogs again appear over the valleys.

In the winter season, the lower tropospheric wind blows mostly from the west-north-west in the western Nepal and east-north-east in the eastern Nepal. They are continental, dry and the wind is calm and brings settled and dry periods in Nepal. On the other hand, in the upper troposphere, the subtropical westerly jetstream lies over the southern side of the Himalayas. Almost daily morning fogs appear in most of the valleys in Nepal. Occasionally, the westerly disturbances bring cold spells and rain, particularly to the north-west corner of Nepal.

RAINFALL DATA

Conventional 30 year mean rainfall data are available at only a few places in Nepal. There are, however, 68 stations covering the different regions with a minimum of twenty years of records.[6] To establish whether any bias is introduced by using 20 years averaged data instead of the normal 30 years, the mean rainfall at Kathmandu for 5, 10, 15 …… years starting from 1921 were calculated. The percentages deviations of these means from the long term mean are plotted against time as shown in Fig. 4. This information indicates that 20 years average rainfall is close to the 30 years normal rainfall. Therefore, the years 1956-1975 inclusive were chosen as the period to investigate the mean monthly and annual rainfall in Nepal. In addition, there are a hundred stations whose records cover only part of this period and the missing data for 100 stations have been estimated by linear regression based on the nearest station which has a longer period of record to develop a complete record for the 168 stations for 1956-1975[7]. The standardized mean monthly values have been used to study the macroscale variation and distribution of rainfall over Nepal. At the same time, the seasonal rainfall at selected places (Table 1) has been shown for better illustration of seasonal rainfall over Nepal. This shows that the percentage of seasonal rainfall is broady similar except in the far western Mountain Regions, where the percentage of rainfall differs greatly from other places, for example, Jumla receives 69 percent of its rainfall from the summer monsoon, whereas the other regions receive 80 to 90 percent from the summer monsoon rainfall. Mean monthly rainfall at the selected places has also been presented to show the pattern of rainfall

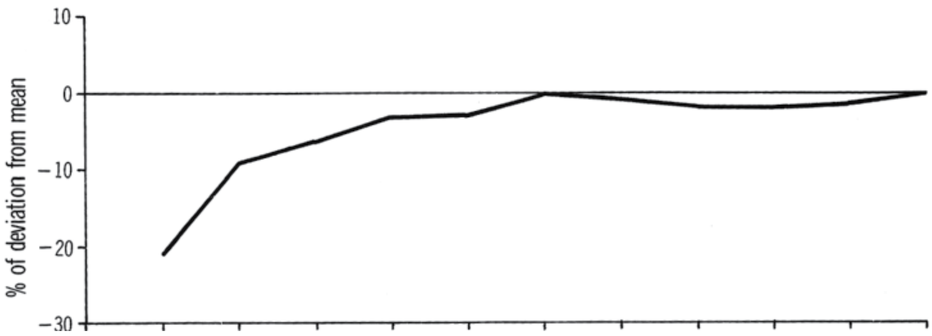

Fig. 4. Percentage deviations from the available long term mean against time.

6 Department of Hydrology and Meterology; "**Climatological Records of Nepal, 1966**" (Kathmandu: HMG of Nepal 1968) ; **"Climatological records of Nepal 1967-68"** (Kathmandu: HMG of Nepal, 1974); "**Climatological Records of Nepal, 1969**" (Kathmandu: HMG of Nepal, 1972); Department of Irrigation, Hydrology & Meteorology, "**Climatological Records of Nepal 1970"** (Kathmandu: HMG of Nepal 1973): **"Climatological Records of Nepal, 1921-75"**, Vol. II (Kathmandu: HMG of Nepal, 1977).

7. Mean monthly and annual rainfall standardized to 1956-1965 for 168 stations and their locations are under publication (see key Fig. 5 for 168 meteorologial station network).

by Fig. 6. This demonstrates that the rainfall falls mostly in the summer monsoon season and this varies greatly from place to place within a small distance. In other words, Nepal has distinct wet and dry seasons.

ANALYSIS

Mean monsoon and Annual Rainfall

Mean monsoon rainfall and mean annual rainfall are shown in Figs. 7 and 8. The rainfall in Nepal varies greatly from place to place due to sharp topographical variations. As the rain bearing winds approach Nepal from the southeast in the summer monsoon season, heavier rainfall falls in the foothills of the Churiya range increasing with altitude on the windward side and sharply decreasing on the leeward side. The heaviest rainfall falls on the Hill Regions, especially in the Pokhara region, Ultimately, the foothills of the Great Himalayas receive less rain than the other areas (Fig.7).

There are a few isolated rainfall maxima exceeding 2500 mm i.e. Dharan. Barakshetra, Num, Harihapur-Gadhi, Gumthang, Butwal, Pokhara, Lumle, Rukumkot and Chispani Karnali. In particular, Lumle near Pokhara receives about 5180 mm rain, whereas Pokhara Hospital in the valley floor, receives an annual total of only 3584 mm-a reflection of sharp topographical differences over short distances. In similar situations of heavy rainfall at Cherapungi, Assam, simpson (1921)[8] remarks that heavy fainfall is due to the rapid rise of warm saturated air blowing with a great velocity so heavy precipitation falls on the top of the hills.

On the other hand, in contrast to the heavy rainfall, there exist very low rainfall areas, such as Jomosom, 273 mm, annual total on the northern side of the great Himalaya in a rain shadow area. This lower rainfall is due to the alignment of the neighboring mountains which prevent a large inflow of moist air into the region.

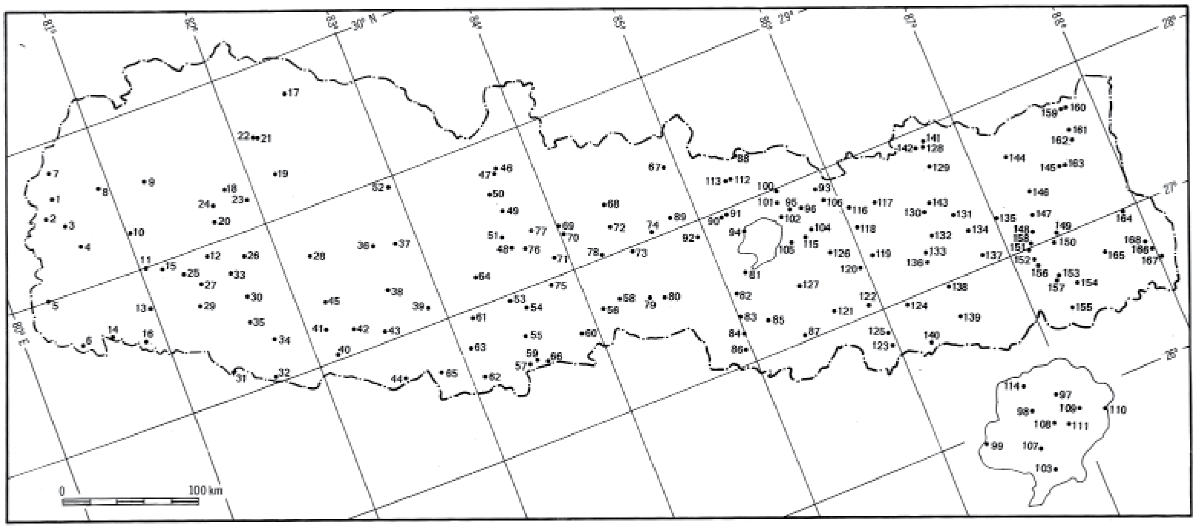

Fig. 5. 168 Meteorological Station Net-work.

8 C.G. Simpson, "The south west Monsoon" **Quart. J. Roy. Meteor. Soc**., Vol. 47, (1921), PP. 151-172.

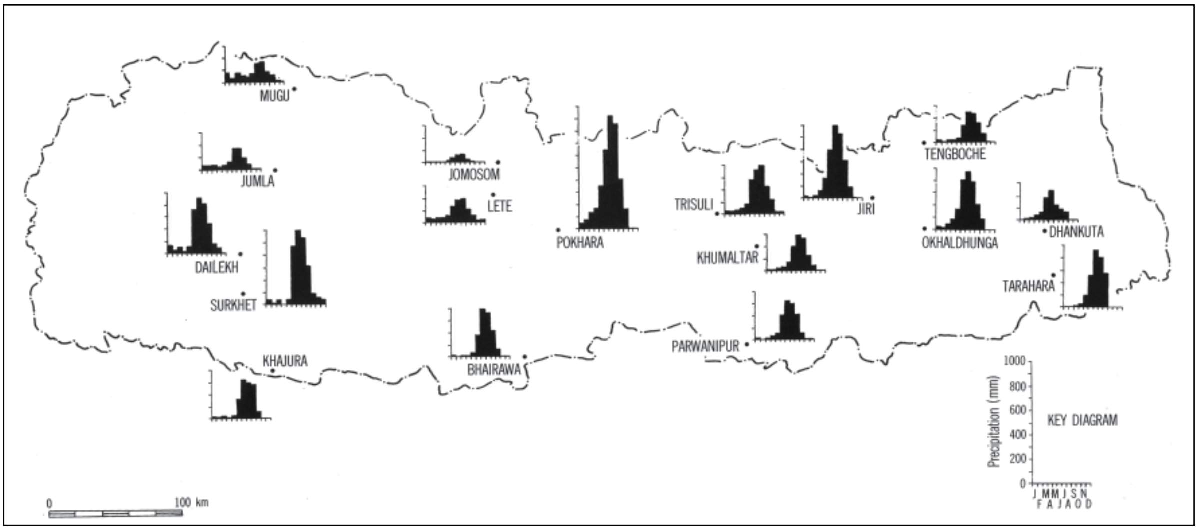

Fig. 6. Variations of mean monthly rainfall at selected places

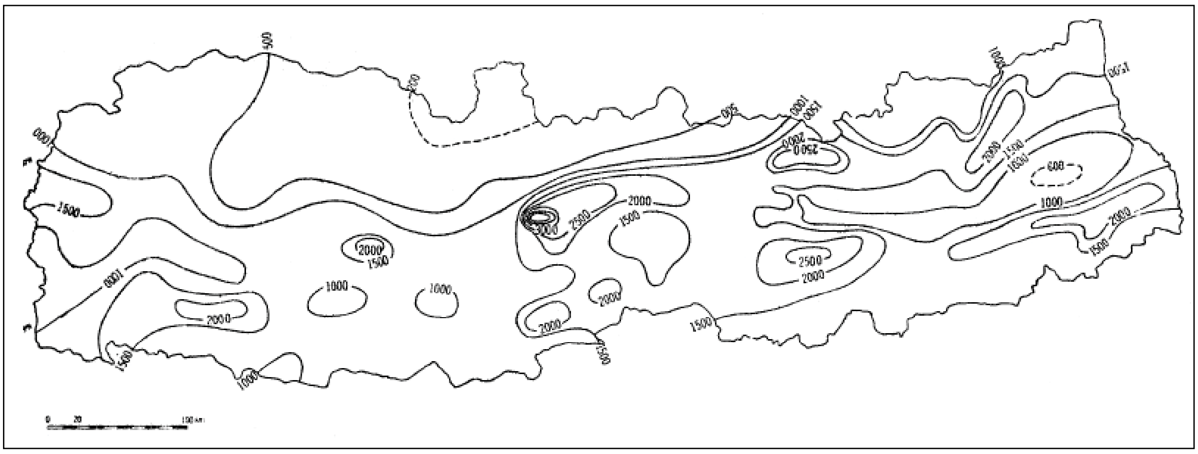

Fig. 7. Mean monsoon rainfall (mm) June-September, 1956-1975, Nepal

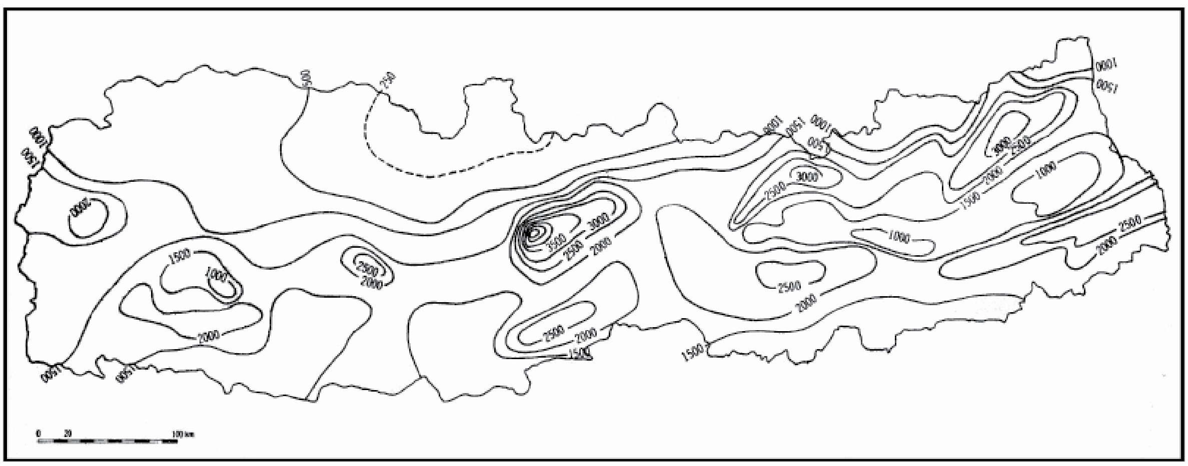

Fig. 8. Mean annual precipitation (mm), 1956-1975, Nepal

THE DATE OF THE ONSET AND CESSATION OF MONSOON

The monsoon rainfall is very important from the agricultural point of view. Thus, the intensity of the monsoon are both important factors for the country's economy, because it is the main season for planting paddy. Normally, in Kathmandu, the onset of the monsoon occurs on the 12th June and retreats on the 21st September respectively (Fig.9) (Department of Irrigation, Hydrology and Meteorology, 1977). Confidence can be placed in these data as they are consistent with the broadscale analysis by Das (1979) on the onset and retreat of the monsoon over the Indian subcontinent (Figs. 10 to 11).

INTENSITY OF RAINFALL

Since most of the rainfall falls in the summer monsoon, the general rainfall intensity is estimated by calculating the ratio of rainfall and wet days (1.0 mm) against altitude in each monsoon month (1971-75) as shown in Fig. 12. These average values of rainfall intensities show that the rainfall is always decreasing or increasing slowly with increasing altitude. This may be due to windward and leeward effects accompanied by the complex nature of topography in Nepal. In other words, this does not show any fixed pattern of trend from which specific conclusions can be drawn.

In addition, the maximum rainfall in 24 hours and average number of rainy days per year (over 1 mm) for a few selected stations from Nayava (1974) have been shown in Table 2. This shows that, generally the intensity of rainfall is much higher in lower elevations than in higher elevation.

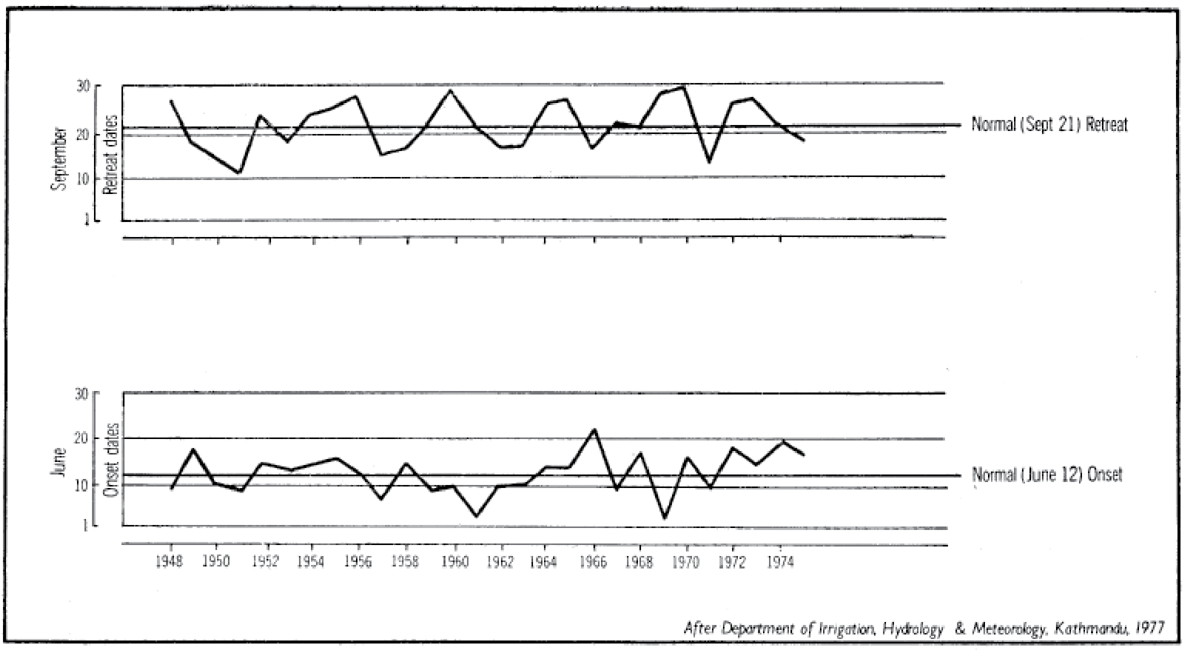

Fig. 9. Normal date of the onset and retreat of summer monsoon.

9. P.K. Das the "Monsoons", (London: Edwart Arnold Ltd., 1968), pp. 162.

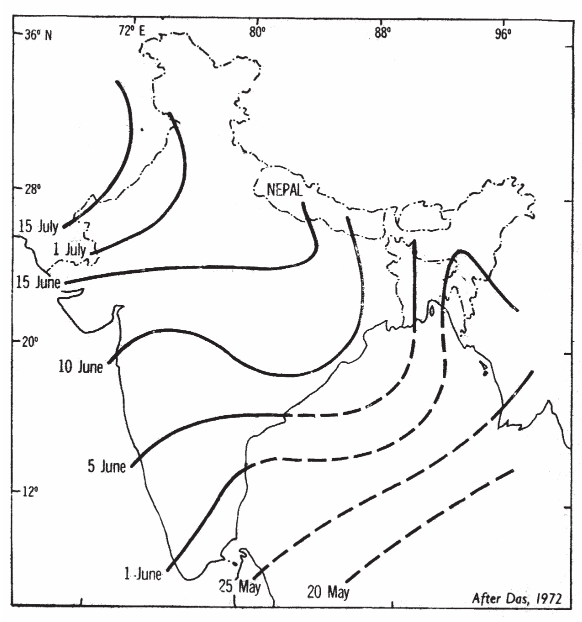

Fig 10. Normal dates of onset of monsoon.

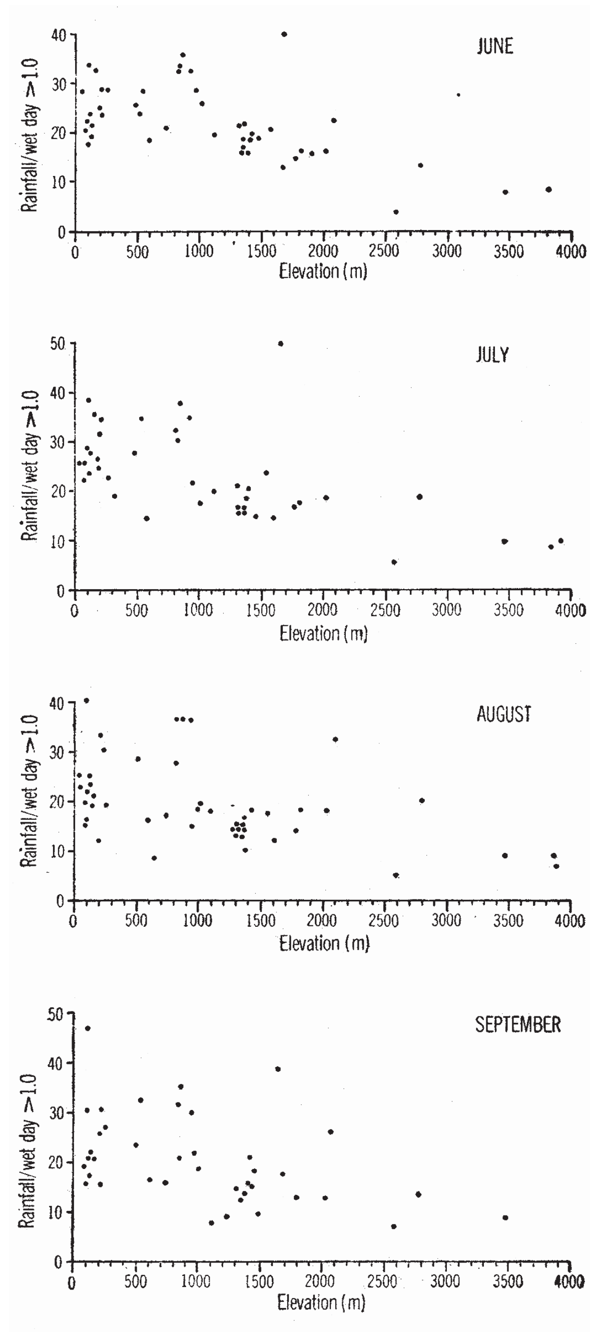

Fig. 12. The ratio of rainfall and wet day710 mm, against altitude, 1871-1975.

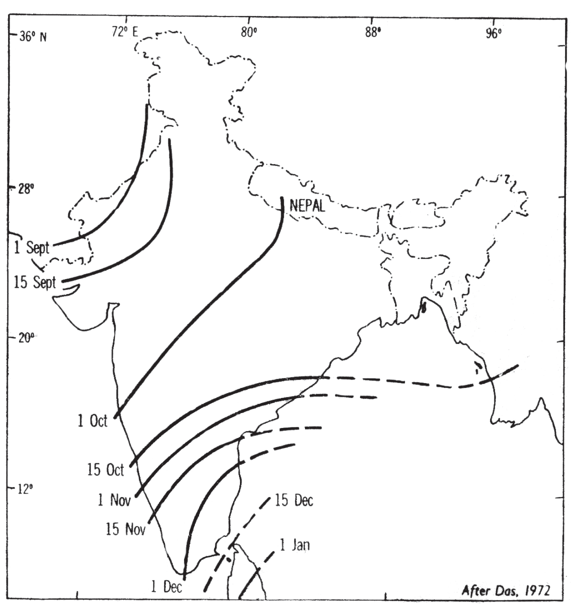

Fig. 11. Normal dates of retreat of monsoon.

Stations	Elevation (m)	Winter (Nov.-Feb)		Pre-monsoon (Mar-May)		Summer Monsoon (June-Sep)		Post Monsoon		Annual (mm)
		(mm)	%	(mm)	%	(mm)	%	(mm)	%	(mm)
Bhairawa	120	8	1	41	3	1183	92	59	5	1292
Dailekha	1402	103	6	121	7	1470	83	87	5	1780
Dhankuta	1160	28	3	115	14	646	75	68	8	867
Jiri	2003	28	1	247	11	1831	83	94	4	2199
Jomsom	2744	17	6	29	11	212	78	15	5	273
Jumla	2300	80	11	1O3	14	504	69	46	6	733
Khajura	190	58	5	68	6	968	84	62	5	1155
Khumaltar	1350	34	3	136	12	883	80	48	4	1101
Lete	2384	134	14	141	14	636	65	62	6	973
Mugu	3803	151	17	177	20	483	55	62	7	873
Okhaldhunga	1810	41	2	294	15	1488	78	85	4	1907
Parwanipur	115	33	3	104	9	1031	84	55	4	1223
Pokhara	918	72	2	519	14	2831	79	162	5	3584
Surkhet	720	83	4	90	4	1938	88	92	4	2204
Tarahara	200	0	0	136	8	1419	86	104	6	1659
Tengboche	3857	40	4	86	9	784	80	72	7	982
Trisuli	595	81	5	166	11	1260	80	62	4	1568

Table 1. Seasonal rainfall in Nepal at selected stations

Maximum rainfall in 24 hours and date where known

Station	Amount (mm)	Percentage of mean annual total	Date		Average number of rainy days per year (over 1 mm)
Barakshetra	313	12	21 July	1967	110
Butwal	402	17	Aug.	1968	93
Dhangarhi	168	12	17 Sept.	1968	55
Okhaldhunga	130	7	July	1965	119
Kathmandu	134	10	9 July	1967	106
Pokhara	261	8	July	1965	136
Silgarhi Doti	135	13	6 June	1967	72
Namchebazzer	115	14	4 Oct.	1968	116
Jumla	91	15	15 July	1969	64
Jomosom	72	28	4 Oct.	1968	32

Table 2. Maximum rainfall in 24 hours during the period 1965-69 in Nepal, after Nayava (1974)

DISCUSSION

These mean monthly rainfall data, standardized for 168 places in Nepal, will be further used to investigate the distinctive feature of rainfall regimes and soil moisture studies which are one of the basic data to find out the potentiality of agriculture in different regions with respect to availability of weekly rainfall amount. These standardized mean monthly rainfall data are one of my contributions to climatic analysis and agro-climatology. This makes possible a more detailed description on the macroscale variation and distribution of rainfall over Nepal.

Environmental Impacts on Agricultural Development*

Janak lal Nayava**

Background and Approach

For the past fifteen years, the Nepal Meteorological Service has put most of its efforts in providing basic day to day information for the aviation industry as prescribed by the World Meteorological Organization and the International Civil aviation Organization. Along with this service, general public weather forecasts for twenty four hours are issued for Kathmandu and other regions. Recently, special weather forecasts for mountaineering expeditions are also issued. In addition to these existing facilities, there is need to encourage the applications of meteorology and climatology to other fields, among the most essential being engineering and agricultural science as they appertain to the economic development of the country. Since Nepal's economy is based on agricultural productivity, it is essential to study the role of climate in relation to crop production. Research should allow a more informed judgment to be made when selecting different crops, appropriate to meeting the demand for food of the increasing population. Furthermore, when a new crop is being introduced to developed areas or a developed crop on new areas, one has to explore the weather and climate of those areas in order to maximize productivity. Climatological analysis can save years of easily trial and error.

Recognizing that climate and weather play a dominant role in the crop strategies, a study for Nepal has been attempted to demonstrate how using a model approach, much climatic based information relevant to regional agricultural planning can be generated (Nayava, 1980). Due to the mountainous nature of the country, a study of topo-climatology (Nayava, 1979) has also been considered in order to obtain a more detailed understanding of climate as a basis for assessing the potential for agricultural development at the meso or regional scale.

Climate

Although Nepal is a small country, it has a great variety of topography which plays an important role in creating a diversity of weather and climate. Nepal experiences tropical, mesothermal, microthermal, taiga and tundra climate (Nayava, 1975). The highest mean maximum temperature of 39.3^{0}C was recorded in far western Nepal and the lowest mean minimum temperature was -9.7^{0}C at Tengboche meteorological station at 3857 m. The extreme minimum temperature was -17.9^{0}C at Tengboche. The highest mean annual rainfall during 1956-1975 was 5180 mm at Lumle and the lowest 273 mm at Jomosom.

In Nepal, 60-90% of the annual precipitation falls between June and September under the influence of the summer monsoon. The rainfall varies greatly from place to place due to sharp topographical variations (Nayava, 1974, 1980). As the rain bearing winds approach from the southeast in the summer monsoon season, more rainfall occurs over the foothills of the Churia Hills, increasing with altitude on the windward side and sharply

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decreasing on the leeward side. The heaviest rainfall falls on the Hill Regions, especially in the Pokhara Valley and ultimately the great Himalaya receive less that the other areas. There is also a longitudinal gradient in total monsoon rainfall; it is heaviest in the eastern part of Nepal. In general, the distribution of rainfall follows the rainfall and model produced by Hagen (1961).

In winter, most precipitation originates from disturbances in the westerlies, precipitation, then greatest in the northwest, decreases in amount in both southerly and easterly direction. At high elevations (i.e., above approximately 3000m) most of the precipitation at all seasons falls as snow. The pre- and post-monsoon rains are intense at higher altitudes than the Tarai and much snow falls in the great Himalayas. Pre- and post-monsoon rain is associated with thermal convection combined with orographic effects, and results in the strong thunderstorm activity leading to heavy precipitation over narrow bands within the region.

Population and Agriculture

Nepal is predominantly an agricultural country where over 90 percent of the population is engaged in agriculture. The census of 1981 indicates that it has about 15 million people with an annual rate of growth of 2.6 percent in the period 1971-1981. After making allowance for double cropping, the area under agriculture is 2,326,000 hectares or 16 percent of the total land area. The importance of agriculture to Nepal is further emphasized by the fact that 65 percent of gross domestic product (GDP) is derived from agriculture.

Present Land Use

The present land use including a brief statement of agricultural activities in Nepal is reviewed herein order to understand the cropping patterns and crop yields.

Each of the present five development regions of Nepal are divided into three sub- regions, Tarai (Plains), Hill and High Hill. The latter region is referred to as the Mountain region in this study. About 80 percent of the total land lies in the Hill and Mountain Regions with remaining 20 percent is in the Tarai. The major land use categories are shown in Table 1. Land is divided roughly equally between forest, land cultivation, pasture, and land not used.

Table 1. Land use 1974/75 in Nepal

Use	Area (Hectare)	Percent
Forest	4,823,000	34.20
Waste land	2,629,000	18.64
Cultivated	2,326,000	16.49
Land under perpetual snow	2,112,100	16.49
Pasture	1,785,700	14.97
Water	400,000	2.83
Residential area and Roads	30,000	0.21
Total	14,105,900	100.00

Source: Department of Food etc., Kathmandu, 1977.

Regional Variation of Agriculture

When one tries to examine the relationship between climate and agriculture, it is important to know the present crop yield. The areas under annual cultivation and production of a variety of crops for each of the 75 agricultural districts have been published in the Agricultural Statistics of Nepal, 1972, 1977, by the Ministry of Food and Agriculture and Department of Food and Agricultural Marketing Services, Kathmandu. For each crop, area, production and yields under cultivation are averaged over the period of data availability 1968-1977, for each of the district regions of Tarai, Hill and Mountains of Nepal and the general distribution of cultivated land, production and yield in three distinct geographical regions are tabulated as show in Table 2. Significantly, agriculture is most important in the Tarai where two thirds of the available land is cultivated. In the other regions, a small percentage of land is cultivated e.g 30 percent in the Hill Region and 6 percent in the Mountain Region.

Paddy cultivation occupies over half of the agricultural land. Other major crops are maize (19%) and wheat (11%). Small areas of millet, barley, potato, mustard, sugarcane, jute and tobacco complete the main agricultural pattern. Besides these crops, tea, cardamom, pulses, varieties of vegetables and fruit are grown on a small scale.

As shown in Table 2, yield per hectare does not vary greatly from region to region, and one has to examine data at the district level to find appreciable variations. The crops are grown over a wide range of environments varying in altitude from 100-4000 m. traditional crops are grown, no matter how small the yield.

Despite the importance of agriculture in Nepal, crop yields are per unit area have remained static during 1968-77 (Table3). However, Shahi (1976) claimed that a yield of 3-4 tonnes per hectare of paddy can be produced by improved HYV in the Tarai. Similarly, the annual report of the National Wheat Development Program, Nepal 1975-1976, mentions that technology for producing more than three tonnes per hectare in the Tarai is available, but has not been implemented.

Seasonal Cropping Patterns

There are two cropping seasons in Nepal. One is the wet season including the summer season which generally begins in April and ends in October, but the main intensive agriculture period lies only in July-September due to summer monsoon rainfall. The wet season crops are paddy, maize, millet and Jute. The other is the dry season crops which are wheat, barley, mustard, tobacco and potato. Potato is considered here as a dry season crop in the Tarai Region and a wet season crop in the Hill and Mountain Region.

Figure 1 shows the seasonal cropping pattern in 1968-1977. This has been generalized from the available district-wise crop data. This study indicates that the Tarai Region is more cultivated than the other regions. The dominant features of the cropping pattern are wet season in agriculture in the whole of Nepal except in the far western Mountain regions of Nepal, where dry season agriculture is also dominant in the cropping pattern. This is mainly due to high altitude and lower rainfall in the far Western Mountain Region, where barley or wheat is cultivated which takes nearly ten months for maturity.

Land Tenure Characteristics of farming and Irrigation

Many owner farmers and tenants utilize an average of less than one hectare per family (Table 4). The annual crop production provides a major portion of the total farm family income. Over the ten year period from 1968-1977, there was a general increase of cultivated land due to the pressure of increasing population in all regions. The highest increment in agricultural land use has been achieved by forest clearing in the Tarai, an area previously regarded as unsuitable for settlement due to extremely high temperatures and the presence of malaria. The latter has now been controlled to a large degree. Only after the 1950's more people began to settle in the Tarai. Hjort (1975) shows the population and land area in the main region of Nepal, noted as follows in Table 5.

Irrigated land area in Nepal accounts for only 7.7 percent. As most agriculture is rain-fed, this 7.7 percent seems to be made up of both canals and casual hill-side system. The percentage of irrigation is a crudely approximation

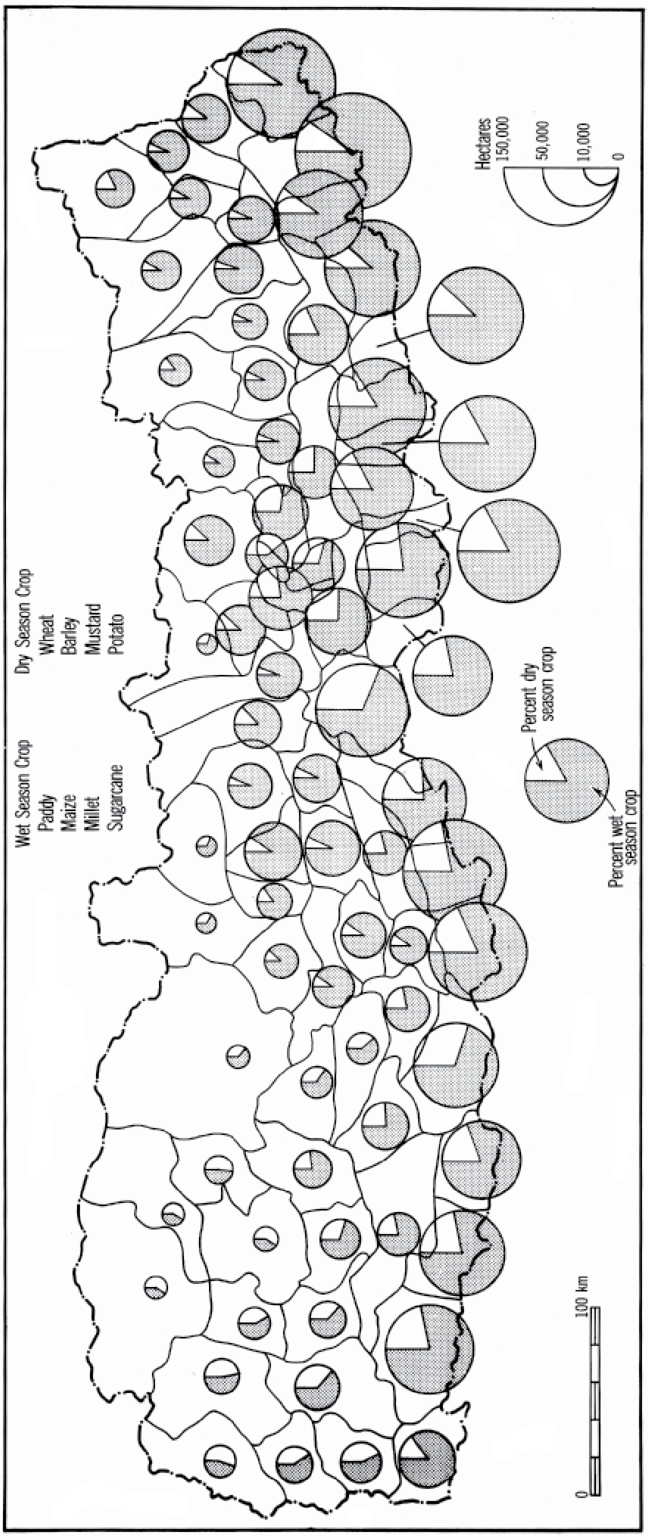

Figure 1. Seasonal cropping in Nepal.

Table 2. The distribution of cultivated land, production and yield in three distinct geographical regions of Nepal, 1968-1977.

Regions	Crop	Area (Hectares)	Production (Tonnes)	Yield (Tonnes/Hectares)	% of land cultivation
Tarai	Paddy	996,110	1,802,991	1.81	43.89
Hill		184,037	457,881	2.44	8.12
Mountain		19,888	45,189	2.23	0.87
Grand Total		**1,200,035**	**2,306,061**		**52.88**
Tarai	Maize	136,178	218,896	1.57	6.00
Hill		263,706	497,079	1.88	11.62
Mountain		40,572	75,351	1.82	1.79
Grand Total		**440,456**	**791,326**		**19.41**
Tarai	Wheat	152,427	155,294	1.01	6.72
Hill		85,313	98,027	1.13	3.75
Mountain		24,609	26,482	1.05	1.08
Grand Total		**262,349**	**279,803**	**0.90**	**11.55**
Tarai	Millet	18,992	16,961	0.90	0.84
Hill		83,073	96,874	1.16	3.66
Mountain		15,034	18,040	1.20	0.66
Grand Total		**117,099**	**131,875**		**5.16**
Tarai	Sugarcane	12,292	207,928	16.38	0.54
Hill		2,130	28,778	13.53	0.10
Mountain		119	1,514	2.86	0.00
Grand Total		**14,541**	**238,220**		**0.64**
Tarai	Barley	7,224	5,052	0.07	0.32
Hill		10,046	9,744	0.96	0.45
Mountain		9,263	9,445	1.00	0.41
Grand Total		**26,533**	**24,241**		**1.18**
Tarai	Potato	11,889	77,414	6.62	0.52
Hill		26,730	150,401	5.56	1.18
Mountain		10,814	52,726	4.86	0.48
Grand Total		**49,433**	**288,541**		**2.18**
Tarai	Mustard	78,832	45,662	0.57	3.47
Hill		25,608	12,730	0.49	1.12
Mountain		1,641	670	0.42	0.07
Grand Total		**106,081**	**59,062**		**4.66**

measurement. The authorities have been raising questions as to why the yield is low in Nepal and what can be done to improve the yields. Hagen (1976) discussed many constraints to achieve agricultural production goals in Nepal. So, research has to be promoted to find what can be done to maximize production. As far as the author can ascertain there has been no research in the efficiency of irrigation in Nepal. Further studies should examine the optimal use

Table: 3. Variation of major crops in area (million hectare), production (million tonnes) and yield (tonnes/ hectare) in 1967-68 to 1976-1977.

	Paddy			Maize			Wheat		
Year	Area	Prod	Yield	Area	Prod	Yield	Area	Prod	Yield
1967-68	1.15	2.12	1.84	0.41	0.75	1.83	0.19	0.20	1.05
1968-69	1.16	2.18	1.88	0.42	0.76	1.81	0.21	0.23	1.10
1969-70	1.17	2.24	1.91	0.43	0.79	1.84	0.23	0.26	1.13
1970-71	1.18	2.30	1.95	0.45	0.83	1.84	0.23	0.19	0.83
1971-72	1.20	2.34	1.95	0.44	0.76	1.73	0.24	0.22	0.92
1972-73	1.14	2.01	1.76	0.45	0.82	1.82	0.26	0.31	1.19
1973-74	1.23	2.42	1.97	0.45	0.81	1.80	0.27	0.30	1.11
1974-75	1.24	2.45	1.98	0.46	0.83	1.80	0.29	0.33	1.14
1975-76	1.26	2.60	2.06	0.45	0.75	1.67	0.33	0.39	1.18
1976-77	1.26	2.38	1.89	0.46	0.80	1.74	0.35	0.36	1.03

Table 4. Farm holding and distribution by size after land

Size of Holding	Household in percentages	Area in percentages
Less than 1 ha	63.5	10.5
1-3 ha	19.5	18.0
3-5 ha	7.1	12.0
3-10 ha	5.8	21.0
10-15 ha	2.1	11.0
15-20 ha	0.9	7.0
20-30	0.5	5.5
30 and above	0.6	15.0
Total	**100.0**	**100.0**

Source: M.A. Zaman, Evaluation of land Reform in Nepal, 1972.

Table 5. Distribution of population and cultivated area

Region	No. of districts	Population percentage	Total Land area percentage	Cultivated area percentage
Mountain	16	9.6	33.0	4.8
Hill	36	47.2	43.5	27.3
Tarai	20	38.0	23.0	65.6
Kathmandu valley	3	5.2	0.5	2.7

of water and the implications of irrigation with regard to yield. A doubt has been expressed about the efficient use of irrigation facilities. The problem is not the scarcity of water in irrigated areas, but the lack of knowledge of its best utilization (Karmacharya and Pyakurel, 1976). The researchers remark that this is mainly due to lack of irrigation experts at the field level. The irrigation service should be extended beyond the construction of dams and canals for the supervision of the efficient use of water in farm lands.

Agricultural Extension Program

A number of reports have been published about the impact of the agricultural extension program on agricultural production in Nepal (Ministry of Food, Agriculture and Irrigation, 1974, 1975). Similarly, Nepal Rastra Bank (1972) has discussed at considerable length, in selected districts, the potential changes in cropping pattern and net farm income that might result from the availability of credit at existing levels of technology. However, the impact of climate on crop variety and production for the different regions was not mentioned.

Crop Weather Analysis

Recently, considerable attention throughout the world has been devoted to crop-weather relationships and in particular to exploiting the potentialities of the climate for food production. WMO and FAO in both the national and international arenas have considerably increased their studies of the meteorological role in global food production as part of their early warning system on possible food shortages (WMO, 1975). Modified Crop-Weather model (Fitzpatrick and Nix, 1980) suitable to Nepalese thermal regimes have been developed (Nayava, 1980). At Present, crop yields are uniformly low and do not reflect environmental gradients. This suggests that a considerable scope exists for greatly increased crop yields in the more favourable environment (Nayava, 1981).

A Detailed Study of Topo-Climatology of the Kathmandu Valley

Due to the mountainous nature of the country, topo-climatology of the Kathmandu Valley has been studied (Nayava, 1979). This valley of 585 km^2 in area, is a basin the rims of which rise to as much as 2765 metres from a relatively flat valley floor at 1300-1400 metres. Data for rainfall and maximum and minimum temperature were estimated for 1225 points on a 900 m grid. Global solar radiation and potential evapo-transpiration were estimated for 394 points (Nayava, 1980). Finally the major climatic elements of solar radiation, rainfall, maximum and minimum temperature provided the basis of topo-climatological study of the valley. The varieties of climatic regions associated with the Kathmandu valley were identified as follows using numerical taxonomy. Broadly, the Kathmandu valley can be divided into four mesoscale climatic zones: (I) the humid valley floor and mountain top (II) the subhumid south facing slopes (III) the wet, gentler north facing slopes and (IV) Wettest of all, the steeper north facing slopes.

A study of the topo-climatology of a smaller area is made in order to obtain a more detailed understanding of climate as a basis for assessing the potential for agricultural development on the meso or regional scale. The Kathmandu Valley was selected because it contained a reasonable network of meteorological stations including one synoptic station, five agro-climatological stations and six rainfall stations.

This case study has broadened the understanding of the natural climatic potentials prevailing within short distance due to the mountainous nature of the country. A similar sort of variation of meso-scale climate may be expected in other parts of the hilly regions of Nepal; this has to be taken into account in the selection of crops according to climatic potential for optimum production.

Due to unavailability of detailed agronomic data and vegetation map of Kathmandu valley, the yields for different aspects have not been worked out. However, a few examples of crop yields virsus aspects have been stated. Recent studies of agricultural development in Jumla indicate that the warmer condition of the south eastern aspect of Jumla causes earliness in crop maturity and good yields (Whiteman, 1980). He further remarked that Jumla received only 50 percent of the normal monsoon rainfall during 1979. In consequence of this low rainfall, the crops were virtually a complete failure on the south facing slopes and 90 percent of normal on the north facing slopes. Klenert (1974) remarks that if sun-loving plants such as the grape vines are cultivated in a shady location, the qualities of new vines and the quantities of grapes are badly affected. In this way, climatic environment has a greater role to play in Hill than the Tarai regions due to the complexity of topography within a short distance. In other words, ecological conditions vary widely from region to region due to complexity of weather and climate in the Hill and mountains of Nepal. Therefore, climate and weather data should play a vital role in any agro-ecological classification of environment. Clearly fundamental research and the impacts of weather and climate on agriculture must be attempted to facilitate successful planning. This type of research will have many years of trial and error.

Discussion

The greatest potential area for agricultural development is no doubt, Tarai, but so far the yield per hectare in the Tarai is poor compared to Hill and Mountain regions. During the last decade, Nepal has implemented various agricultural projects in Tarai to produce more yields per hectare in the Tarai, but so far the results are not satisfactory. It is probably due to environmental or suitable cultivars or management or some other factors. The questions is not fully answered under these circumstances, one has to be very careful in agricultural development due to the complexity of weather and climate in Nepal. If development is sought, the selection of suitable crops with respect to agro-climatic conditions in an area is vitally important for optimum production, otherwise, it would be impossible to make reliable recommendations if the nature and extent of environmental variations in the hills are not understood (Whiteman, 1979). Therefore, clearly fundamental research on the impacts of weather and climate in agriculture must be attempted to facilitate successful planning. Whiteman (1979) makes the following remarks in Hill agriculture development project in Nepal.

It should be remembered that the farmers have been practicing arable agriculture for centuries in the Jumla district, and in order to survive in their marginal cropping environment they have fund of knowledge in managing their arable resources to a high degree of efficiency which resulted in adapted cropping systems. Dramatic improvements are neither obvious nor easy. It is for this reason that a rather more fundamental approach has to be adopted by examining the environmental resource base for production as a necessary prerequisite to generating improvements. There is always the danger when under pressure to fulfill prematurely set targets to push an innovation which is merely a novelty and not an improvement, and so jeopardize credibility with our client farmers.

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Monitoring and Evaluation of Crop Yield and Production in Nepal*

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Abstract

Since last more than three decades of (1961/62 to 1996/97) assessments of crop yield and production were mainly based on expansion of agricultural land through clearing of forest; unfortunately the expansion is almost saturated. Therefore, it is conceived that the introduction of modern agro-technological package is most essential to have the optimum yield from the same parcel of land; and at the same time monitoring of crop yield must be strengthened under proper agencies. During the past decades, evaluations seem to poor. It is esteemed that Crop Estimation should be conducted along with the monitoring and evaluation headed by the member of Planning Commission who should be the Chairman of Technical Committee.

Introduction

At present, there are 33 Branch Statistical Office to take care of all the 75 districts of Nepal to survey crop area, yield and production. Statistical heads these offices with a number of supervisors and enumerators to conduct the crop and livestock survey. This survey will take place twice a year during November/December and April/May for summer and winter crops. The data collected by Branch Statistical Offices are sent to the Central Bureau of Statistics (CBS, Katmandu), who is currently authority to estimate crop data. Ultimately, CBS publishes all crop data by district as well as national basis. It is interesting to point out that the Ministry of Agriculture still forecasts the crop area, yield and production as national basis during September/October. This forecast is mainly based on reports from District Agriculture Development Officer. When the Department of Agriculture and Marketing Services (DFMAS) used to estimate the area, yield and production, the DFMAS began a close collaboration with Department of Irrigation, Hydrology and Meteorology to incorporate water balance studies during 1984/85. At that time DFAMS had operating Early Warning Project for food security which is funded by FAO. It seems now that it is rather not followed up after the termination of Early warning Project in DFMAS during 1987/88. FAO mission was here to revive the project during 1996/97 and so far it has not implemented yet.

Crop yield and production in the national level

Since first five year plan, there has been a top priority given in agricultural development in Nepal. Now, we have been running 9th five year plan (1997 -2001). Do we think that the targets have been achieved? If it is so, which factors had not played a good role and what had been done during that time to solve the problem? Is that problem solved or partly solved or new problem raised? Recently, since the last fiscal year (1997-1998) the Government of Nepal has been running the 20 year's plans and programs for agriculture

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development in Nepal as shown in Agriculture Perspective Plan in Nepal (APROSC and JINA 1995). It is necessary to mention that until the end of the 1970's, Nepal was the exporting country of the country of the agricultural products, especially paddy Figures 1a and 1b). Now, Nepal has been importing paddy either as a food for works from donor countries or she has been herself importing for consumption (Figures 2a and 2b). The growth rate of production seemed to be mainly based on expanding agricultural land through clearing the forest. Now unfortunately the expansion is almost saturated.

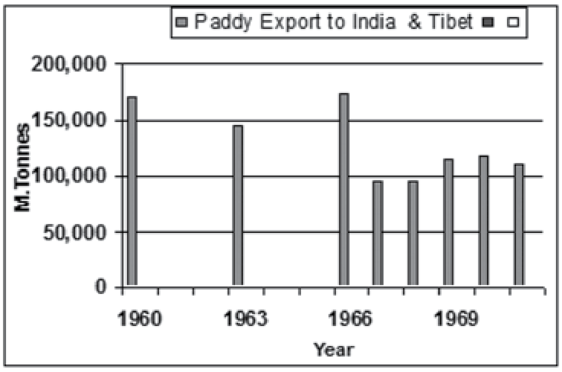

Figure 1a. Paddy Export to India & Tibet

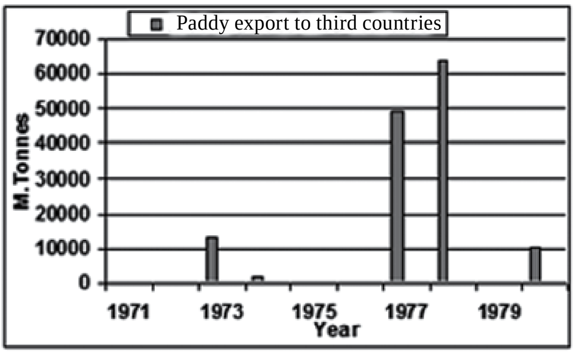

Figure 1b. Paddy Export to third countries

When one study the trend of area cultivated land for cereal crops (paddy, maize, millet, wheat and barley) in Nepal during 1961/62 to 1996/97, the cultivated land was expanded from 1,725,000 hectares to 3,261,860 hectares which was about 89% of the land expanded for cereal crops

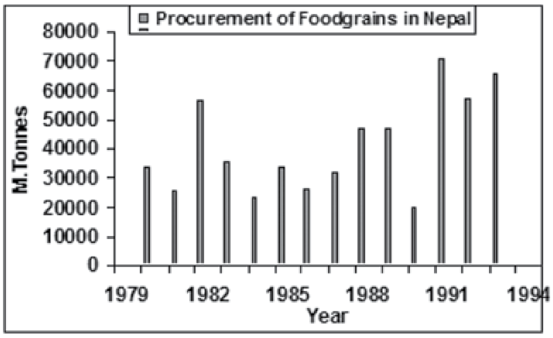

Figure 2a. Procurement of Foodgrains in Nepal

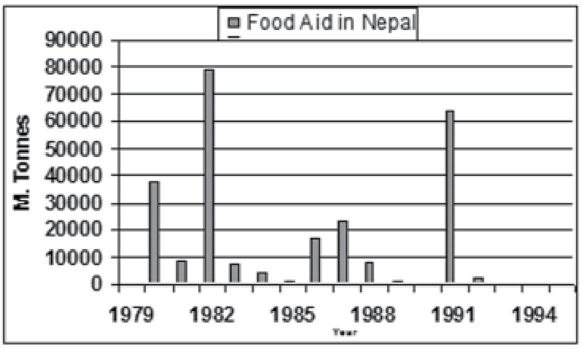

Figure 2b. Food Aid in Nepal

production. At the same period, the cereal crops production was increased from 3,139,000 metric tones to 6,394,620 metric tones which was about 104% increase of cereal crops production (Figures 3a and 3b). The rate of productivity increment versus the rate of population increment seemed not equal and the later increment seemed to be 123% and, therefore, the pressure in land use are higher than before (Figure 4). Realizing these conditions, the productivity should increase through yield from the same parcel of land and not from the expanding the land through clearing of forest. In general, the rate of yield of maize had significantly decreased in Nepal as shown in Figure 5. A lot of efforts have been taking place to increase the yield (NARC 1977). On the contrary, the rate of yield for paddy has been little increasing as shown in Figure 6. Under these conditions, one has to think twice why the yield was decreasing for maize and only a little increasing for paddy during the last 30

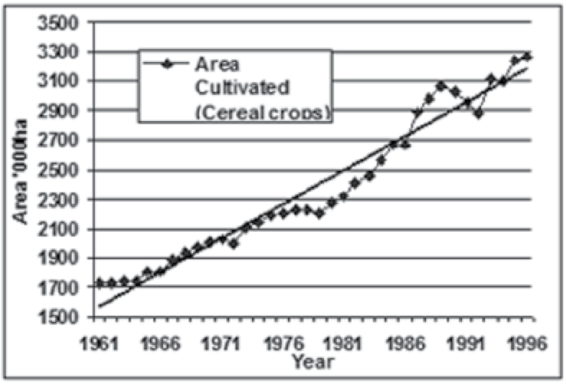

Figure 3a. Area Cultivated of Cereal Crops

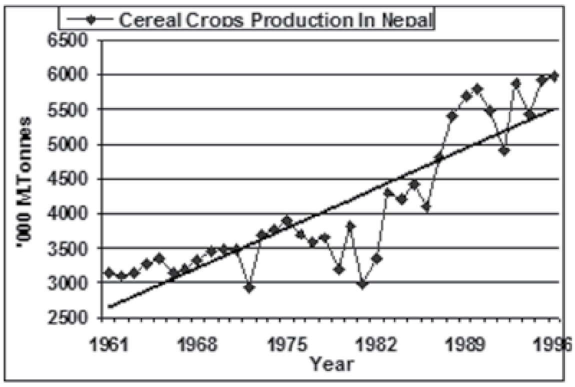

Figure 3b. Cereal Crops Production in Nepal

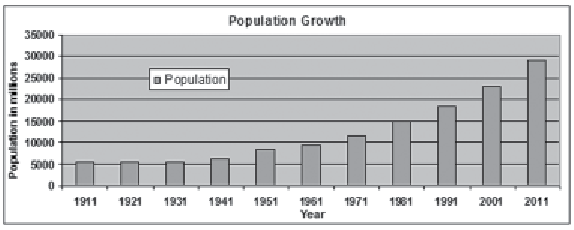

Figure 4b. Population Growth in Nepal

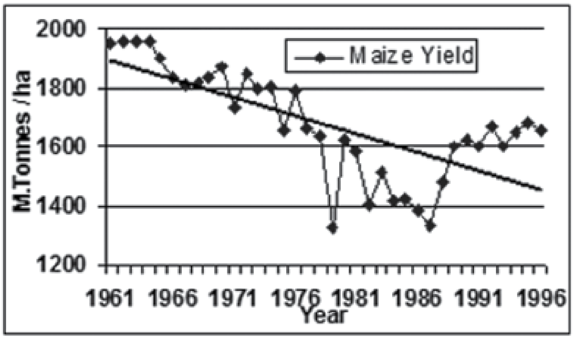

Figure 5. Maize Yield in Nepal

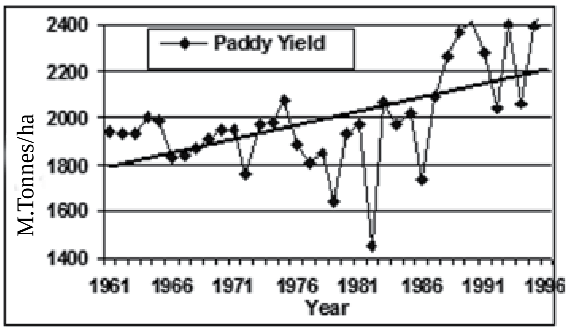

Figure 6. Paddy Yield in Nepal

years and what can be done to achieve potential or maximum yield to pace with the increasing population. Concerning the yield for maize in the beginning of 1960's, the yield seemed to be over estimated.

Sources of data

In case of crop data of Nepal from 1961/62 to 1996/97, one should know all those data were previously collected and published either by the Ministry of Agriculture and Department of Food and Marketing Services. Since 1992, the responsibility of collecting crop data was transferred to the Central Bureau of Statistics, National Planning Commission. In addition to the above decision, there is also important point to note that Agricultural Statistics of Nepal from 1974/75 to 1991/92 was revised by National Planning Commission Secretariat during May, 1994 and it has been mentioned that estimated agricultural cropped area and production were changed significantly due to the recent availability of information from cadastral survey and land resources mapping survey. Therefore, the researcher should be aware of those changes and thus further analysis is based on revised data series. Revised cultivated areas for cereal crops and subsequent production during 1974/1975 to 1996/1997 are presented in Figures 7a and 7b. It is just to mention that the most of the pronounced rise and fall of production is mainly

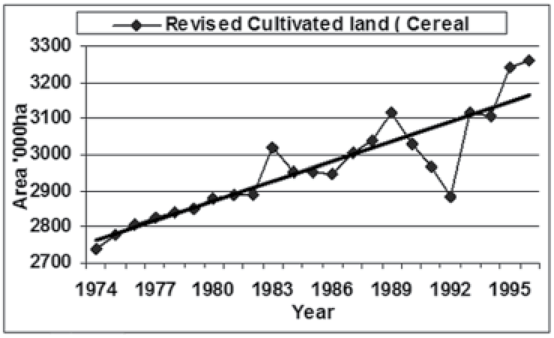

Figure 7a. Revised Cultivated land for Cereal crops

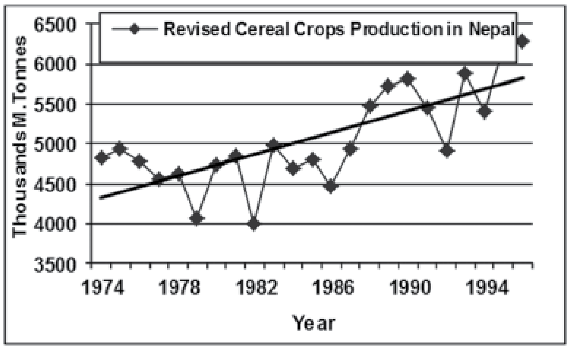

Figure 7b. Revised Cereal Crops Production in Nepal

due to active and weak monsoon rainfall as shown in Figure 8a. Therefore, the relation between agro-meteorological data and crop estimation are very relevant to each other and crop yield assessment by agro-meteorological analysis should be considered for objective analysis for crop estimation.

Trends of Yields by eco-regional basis

When one study the development of agriculture in Nepal, it is better to study along with the three distinct ecological belts which are Mountain, Hill and Tarai. The land area and altitude range of three belts are shown in Table 1. The distribution of cultivated land, production and yield in three distinct geographical regions of Nepal during 1968-77 has also described by author (Nayava 1985).

Furthermore, the development in agriculture is also affected by the population pressure on land and, therefore, the population in Mountain, Hill and Tarai Regions during the last three decades is shown in Table 2. At present, there are more than 20 million populations in Nepal. The Table shows that the population is decreasing in Mountain and Hill Regions and on the other hand the population is increasing in Tarai Region.

When one tries to examine the trend of yield during 1974/75 to 1996/97 for paddy, maize and wheat separately in Mountain, Hill and Tarai Regions, the yield for paddy in Mountain and Hill Regions during 1974/75 to 1986/87 were decreasing and later the yield has been slowly recovering and however, the previously achieved yield have not yet regained. On the other hand, the Tarai had also decreasing tendency initially and after 1980/81 the yield has been increasing and now the yield is higher than the other Regions as shown in Figure 9. On the other hand, the yield for maize has been decreasing in the Mountain and Hill Regions and whereas the yield for maize in Tarai has been slowly increasing (Figure 10). At the same period, the wheat yield for Mountain, Hill and Tarai Regions have been increasing (Figure 11). The general tendency of decreasing yield in Mountain and Hill Regions are mainly due to soil erosion. In each and every year of the monsoon rain, the topsoil has been washing out and a very little fertilizer is used in Mountain and Hill Regions. In addition to that, the increasing yield for paddy in Tarai may be due to complex inter-relationship causes such as using new seed varieties, irrigation and fertilizer. The cultivated area of paddy, maize and wheat in Mountain, Hill and Tarai Regions during 1996/97 are shown in Table 3.

Fertilizer and irrigation facilities for crop production

The fertilizer in Mountain, Hill and Tarai Regions is used less than 20 kg per hectare and this is the

Table 1. Percentages of land area in different regions

Regions	land Area (%)	Altitude Range (Meter)	Suitability for Cultivation (%)
Mountain	35	4877-8848	2
Hill	42	610-4877	4
Tarai	23	100-610	All

Source: DFAMS

Table 2. Percentage of population in different regions

Regions	1970/71 (%)	1980/81 (%)	1990/91 (%)
Mountain	10	9	7
Hill	52	48	46
Tarai	38	43	47
Total	100	100	100

Source: Central Bureau of Statistics, 1994

Table 3. Cultivated land for major crops

Regions	Paddy		Maize		Wheat	
	Hectare	(%)	Hectare	(%)	Hectare	(%)
Mountain	41,820	3	62,410	8	41,470	6
Hill	365,240	25	556,040	70	242,600	37
Tarai	1063,120	72	174,750	22	381,090	57
Total	**1,470,180**	**100**	**793,200**	**100**	**665,160**	**100**

Source: Central Bureau of Statistics, 1994

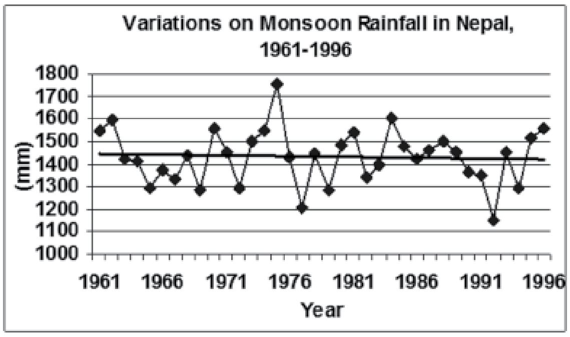

Figure 8. Variations on Monsoon Rainfall in Nepal.

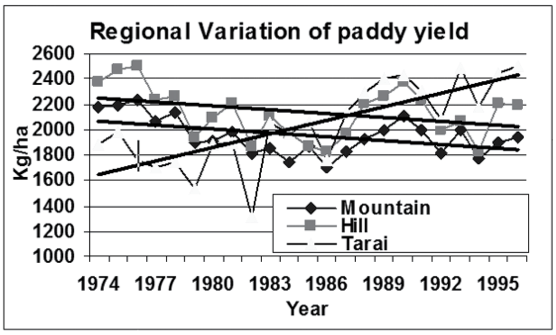

Figure 9. Regional Variation of paddy yield

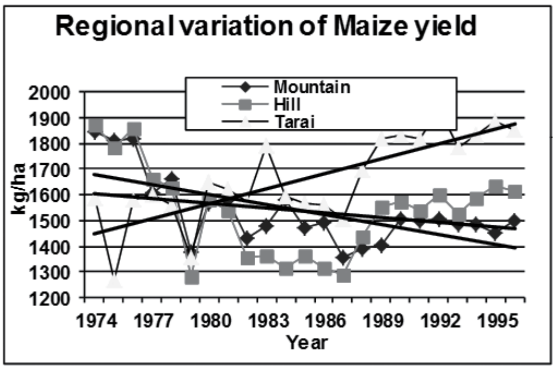

Figure 10. Regional Variation of Maize yield

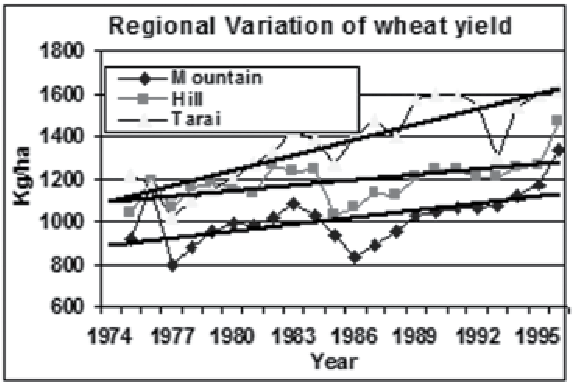

Figure 11. Regional Variation of wheat yield

lowest in SAARC Regions. The use of chemical fertilizer and use improved seeds during 1963/64 to 1996/97 are presented in Figures 12 and 13.

The extension of irrigation facilities during 1974/75 to 1994/95 are shown in Figure 14. Land under irrigation increased significantly between 1981/82 and 1991/92 from 583,900 hectares to 882,400 hectares. It seems that over one third of all agricultural land by 1991/92 was irrigated. Though the lot of efforts and financial inputs have been providing for Irrigation, a very little work has been done about an efficiency of uses of water and their relation to yield and productivity. After the democracy in Nepal during 1991/92, the first irrigation policy 1992 has been published by HMG, Ministry of Water Resources. After that initiation, farmer's level water user's committee has organized at a few places. But, until now, the

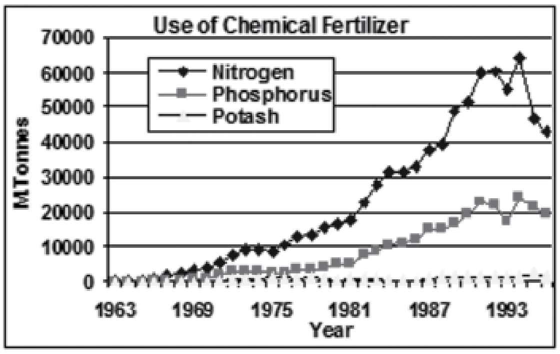

Figure 12. Use of Chemical Fertilizer

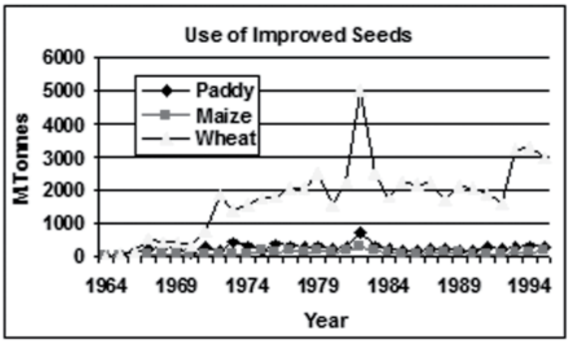

Figure 13. Use of Improved Seeds

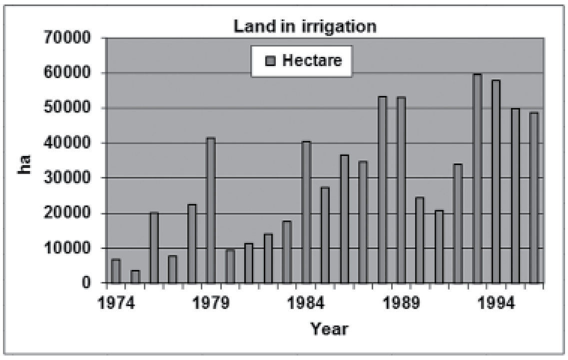

Figure 14. Irrigation Facilities

contribution of irrigation for increment of yields in farmer's fields has not recorded. Thus, we can say that the evaluation of irrigation projects for water managements have not taken place. This is due to engineers are oriented in construction rather than the proper water management to the needed areas. The whole concept of establishing and infrastructure of Department of Irrigation should be reviewed in terms of proper water management.

Similar remarks on irrigation were raised by author in 1985. So far, the progress in this direction is very little (Nayava 1985).

The number of area of farm holdings, farm size and land tenure are better described in National sample Census of Agriculture, Nepal 1991/92 (CBS 1994). Average land holding size is less than a hectare in Nepal. In 1991/92, 43 percent of all land holding were less than 0.5 hectare in size (CBS 1994). Small holdings are often disadvantages in terms of use of inputs and modern agricultural technology.

Main factors for an increment of yield

There are many complex factors to have the potential yield in parcel of land. These factors are as follows:

a) Soil fertility; b) Agronomical practices; c) seed development and availability; d) Good laboratory for Pathology and Entomology; e) Climate and weather role in agricultural activities in rain-fed and irrigated conditions; f) Management and training; g) Availability of fertilizer and distribution h) Availability of financial resources; i) Pricing policy and market; and j) Road accessibility and storage facilities.

From the above mentioned components, one can easily feels the complexities involved in increase the yield. Therefore, one should try to understand all the components and should discuss among the professionals who directly involved in these endeavors. Since the writer of this article is an Agro-meteorologist, it is his duty to mention that the development of crop species should be tally with climatic factors to have the optimum production. Nepal is one of a unique country in the world where the agricultural practices have been doing even in high slopes, where the slope and azimuth play a very important role in receiving solar radiation in the different seasons due to change of season. It is necessary to mention that the quantitative measurement of solar radiation may assist to predict the rate of photosynthesis, evapo-transpiration and potential growth of crops. Nayava (1980) has estimated the solar radiation in slopes and aspect in the Kathmandu valley. According to his studies, significant spatial differences in insolation occurred in the month of January. South facing slopes, show value as high as 550 langleys per day while the flat floor of the valley receives 400 langleys per day. On the other hand, northward facing slopes receive as little as 150 langleys per day. Nayava (1980) has also studied mesoscale variation of rainfall in the Kathmandu valley. These types of mesoscale studies are very important tools for plant breeders and agronomist.

Realizing those factors, the Agronomist should develop the species or cultivars, which is suitable to proper agro-climatic condition in order to achieve optimum production in a given environment with modern technical facilities. In addition one should be aware of impact of El Nino event for crop production, global warming and their effects on climate change to develop the new cultivars in Nepal. It is also a quiet an important phenomenon to study the inter–relationship between agriculture impacts and the recent persistent of cold waves in Tarai Regions in the winter months of 1998 and 1999. Considering all those factors can we achieve the optimum production? Are we talking these optimum productions in the experimental farmland or farmer’s farmland? Are we talking these results in rain-fed or irrigated conditions? How much ordinary or high improved seeds are available? How much fertilizer is required for optimum production and how much we used in different species for different districts? How much yields one could expect in rain-fed or in an irrigated condition in different districts? Did it achieve the expected yield? If so why it could not achieve the goal and what are the reasons behind this?

Regarding this matter, National Agriculture Research Council (NARC) and Department of Hydrology and Meteorology should work closely together for future development of agriculture. Realizing the large variation in topography within a small distance, the importance of agro-topo-climatology is conceived. Since the beginning of 1960's, Department of Hydrology and Meteorology has established the agro-meteorological stations in most of the agriculture farms, but the utilization of those data in agricultural farms are very meager.

The meteorological and agro-meteorological networks provide the information on rainfall, temperature, sunshine, wind, class-A-pan evaporation and solar radiation. Eventually these data will be used to estimate solar radiation, potential evapotranspiration that are the main factors for crop water requirements and crop water efficiency. The study of the above mentioned climatic parameters and standard methods of estimating solar radiation, potential evapotranspiration and their application are described in Nayava's Ph.D. thesis (1981). Furthermore he has studied the existing climatic potential prevailing over the country. The climatic potential is an essential ingredient in many applied studies such as engineering, agriculture, water conservation and management and forestry etc. In his study, the author has attempted to apply those climatic data to enhance in agricultural development.

(The main factors for an increment of yield are the Climate based availability of improved seeds, management of water, manures and fertilizer. Of course marketing and road are also basic factors to sustain the potential yields).

Recommendations

The present system of monitoring and evaluation are based on field reports, which are subjective, and it depends upon the individual judgement. Here in this article, the writer wants to mention about strengthening the monitoring and evaluation of crop yield and production in Nepal At the same time, new methodology of crop reporting system should be introduced and this system is not only because of its obvious general application to crop monitoring., but also because it can provide field reports on time of planting, crop growth stages, overall crop conditions and other factors essential for the practical application of the crop water balance model. Introducing agro-meteorology and remote sensing application to crop yield forecasting should provide invaluable tools in the future. Thus, objective assessment of crop yield will verify the present subjective methods and will support for better estimation of crop yield. Since Nepal's economy is heavily based on agriculture, timely, accurate and easily accessible information on the current and projected food and agricultural information is invaluable to government decision makers and on the other hand, unavailability of accurate information can lead to marginal decision. Considering this matter, the strengthening the Crop Estimates may result in significant economic benefits.

There are more than eight thousands Junior Technical assistants (JTA) working on 75 districts of Nepal under the Department of Agriculture. Each and every district should be divided into 20 sub-divisions and select one JTA as enumerators at each divisions and they are responsible for crop monitoring activities in their respective areas and send their weekly crop varieties, area of planting and date, crop phenology, crop condition, time of manure and fertilizer application and approximate quantities of different fertilizer, time of weeding, occurrences diseases, the expected yield and other critical weather events which may damaged the expected yield. In addition to that rain-fed and irrigated areas as well as quantities of irrigated water should also be mentioned. Based on these reports, ADO's are responsible to aggregate the reports of sub divisions and send a final copy to the Department of Agriculture as well as Department of Hydrology and Meteorology. Based on these reports, ADO's are responsible for preparing pre –formatted quarterly reports. They should submit these reports in Crop Estimation meeting, which will be held four times in a year in the month of January, April, July and October.

At the same time, the Agro-meteorological Division under the Department of Hydrology and Meteorology (DHM) should have a collaborative working plan with the Department of Agriculture (DoA) to perform the agro-meteorological studies at district level. The DHM should receive weekly crop reports from District Agricultural Development Office and they should incorporate those weekly reports with water balance studies to assess the crop yields. The Ministry of Agriculture should take initiative to coordinate DHM and DoA to rehabilitate the program.

Recently, FAO (1986) has also developed the yield assessment by an agro-meteorological analysis. This schematic diagram for yield assessment model can be presented as shown in Figure 15. These methods provides a first qualitative monitoring of crop condition by successive weekly steps of water requirement, water surplus and water deficit during the cropping season and also allows the preparation of quantitative yield assessment. This type of work in Nepal is very important to see whether the expected yield is achieved in each district. Realizing this matter of interest, recently Gerald J.Gill et. al. (1998) mentioned that the co-ordination of DHM and DoA should work closely to take the responsibility of this matter and proposed a few short term and longer term measures. Some of the points are mentioned as follows:

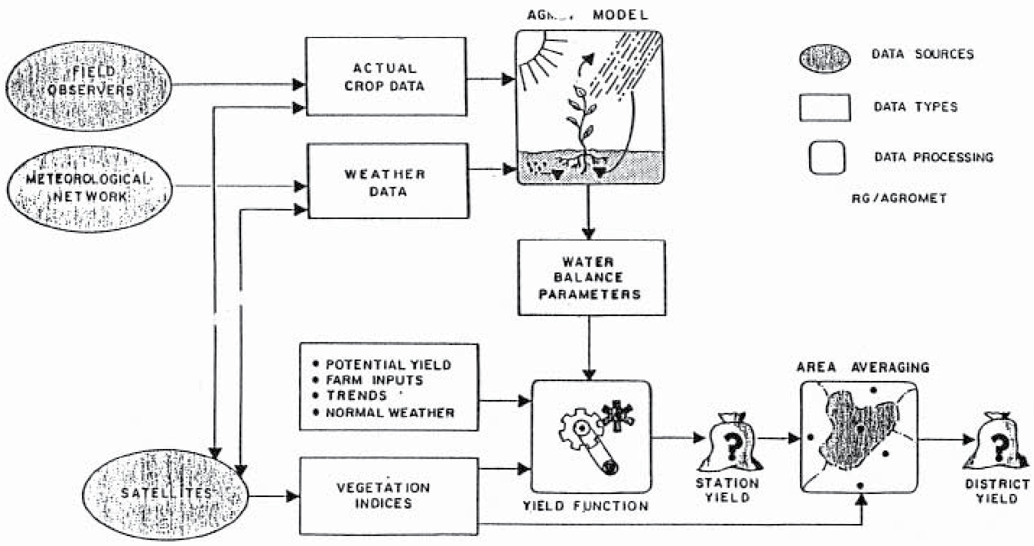

Figure 15. Operational Crop Yield Forecasting (FAO, 1991)

Short term measures

"The condition with respect to both the rainfall situation and the state of crop in the ground should be monitored very closely at the district level over the coming months, so as to give the earliest possible indication of looming problems. This requires close co-ordination of the work of the two HMG agencies responsible for collecting this data, namely the Department of Hydrology and Meteorology and Department of Agriculture".

Longer Term measures

The monitoring situation with respect to agricultural meteorology must be improved with increased co-ordination and collaboration between DoA and DHM. The possibility of establishing an agro-meteorology Unit should be explored so as to institutionalize this collaboration….".

Finally, the Ministry of Agriculture should held a meeting with all the seventy five District Development Agriculture Officer for the Crop Estimates meeting. The member of Planning Commission should chair these Crop Estimates meetings. All the other concerned Government agencies, such as Central Bureau of Statistics, Department of Hydrology and Meteorology should be invited to participate in these meetings.

Those meetings will highlight the following areas as follows:

a) expected or actual planted area in rain-fed or irrigated conditions;
b) expected or actual yield;
c) expected or actual production;
d) remarks on timely rainfall and its distribution, presentation of effective rainfall on all selected sites, presentation of water balance studies on all selected sites;
e) availability of seeds;
f) availability of fertilizer and utilization;
g) incidence pest and diseases and control; and
h) schedule and quantities of irrigated water and any other problems.

Those district-wise data and discussion can help to provide for preparing the food balance sheet of the country. This balance sheet contains domestic production, total domestic availability, apparent consumption, carry over requirements, total requirements, surplus or deficit, exports for marketing year, imports for marketing year, stocks at the end of year, closing stocks. For Nepal, the food balance sheet for the district level is utmost importance, because most of the districts in the Hill and Mountain Regions have always been the food deficit area and the Tarai has always been a food surplus area. From these balance sheets, the government can plan how much the food can be bought in the different districts of Tarai and then subsequently transferred in nearby districts.

Those data can help the pricing policy for decision- makers and also plan for the agriculture policies in regional and district basis. We should not forget that agriculture is one of the most important areas to absorb the manpower of Nepal and without agricultural development in Nepal, poverty alleviation program will never be successful. Once you have all those data, one can easily find out what are the government targets for crop production, how much so far we have been achieved. If there are any problems not achieving the goal, one can identify the causes and effects in district-wise and try to solve the problem immediately or the further work has to be identified, so that the goal of production can be achieved. These types of monitoring and evaluation of crop production will help the agriculture perspective plan. This will also help to evaluate all the activities of District Agriculture

Officer including seed and fertilizer availability and efficiency of irrigation facilities.

Nothing is easy in this world. Therefore, one has to have a sound and viable planning for any kind of work whether it is small or big. Since the nature of the agriculture program is longer-term measures, the special attention should be taken whether this program is sustainable or not in the Nepalese context. Otherwise, a failure of the project may take place and consequently causes a financial crisis. To avoid these problems, one should study well in advance in each and every angle of the project's design for smooth and successful running of the project and care should be taken in advance for sustainability of the project after the termination. In addition to the planning, the success of the project depends upon the Government's policy and decision and their staffs who take the responsibilities of to run the project.

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The Probable Maximum Precipitation for Western Nepal*

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Abstract

The framework of the hydrological study for Western Nepal (part of the Nepal Irrigation Sector Project), prepared for the Institutional Development of Hydrology and Meteorology (DHM), Ministry of Science and Technology, includes the determination of the probable maximum precipitation (PMP) of 77 basins. The paper presents the study that was undertaken for the purpose of point and areal PMP determination in Western Nepal, including presentation of the Hershfield Method (1961) adapted to point PMP having durations longer than 24 hours. The analysis is based on rainfall data available in 109 rainfall stations in that part of Nepal during the period 1956-1998. Based on the point PMP depth values thus obtained, a map of equal PMP depth values is presented for Western Nepal.

Keywords: PMP, point rainfall, areal rainfall

INTRODUCTION

The framework of the hydrological study for Western Nepal (a part of the NISP Project), prepared for the Institutional Development of Hydrology and Meteorology (DHM), Ministry of Science and Technology, includes the determination of the probable maximum precipitation (PMP) of 77 basins.

WMO (1986) defines the PMP as "the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year with no allowance made for long-term climatic trends."

It also states "procedures for estimating PMP cannot be standardized as they vary with the amount and quality of data available, basin size and location, basin and regional topography, storm types producing extreme precipitation and climate."

The preferable meteorological approach presented by WMO (1986) cannot be applied for Western Nepal because of the scarcity of the synoptic information that is required for the application of such a procedure. Therefore, having a sufficient network of daily rainfall recorders in the studied area, it was recommended to determine the required PMP depths by the application of the statistical method proposed by Hershfield (1961).

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Following is a brief presentation of the study that was undertaken for the purpose of PMP determination in Western Nepal.

DATA

There are a total of 148 daily rainfall stations in Western Nepal. Out of these, 109 stations with sufficient data were selected for the PMP study. Because it was required to establish 24-, 48- and 72-hour PMP depths in the region, the annual maximum rainfall for these durations was tabulated for the 109 selected stations from the time of their establishment up to the year 1998. The areal distribution of the selected rainfall stations is shown in Figure 1. Figure 2 presents the mean annual precipitation (1967-1996) in Western Nepal. Table 1 presents basic information on the selected rainfall stations.

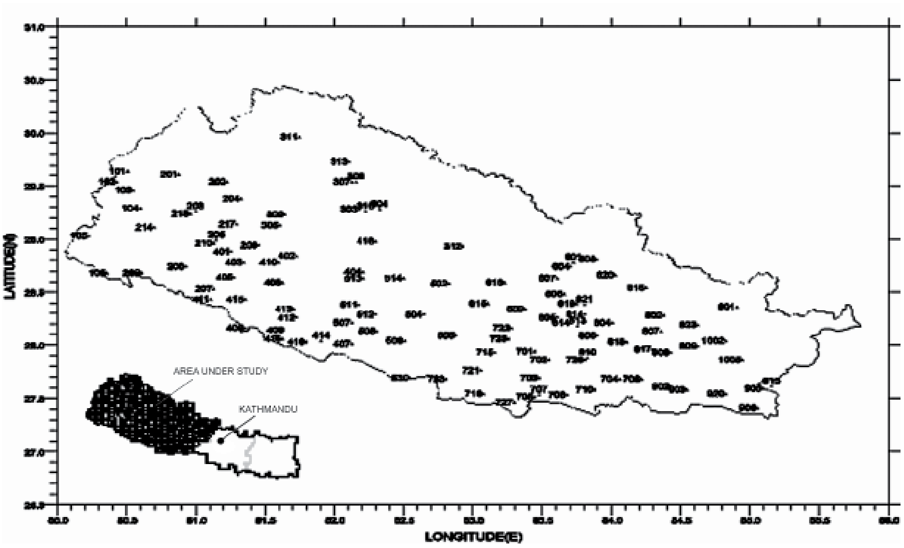

Figure 1. Location of the Rainfall Stations for the PMP Study

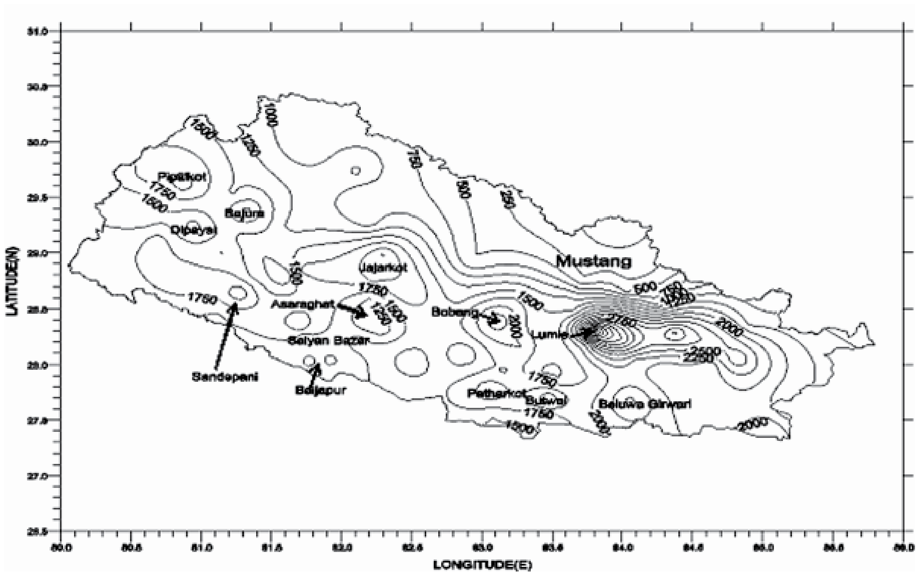

Figure 2. Mean Annual Precipitation (mm) 1967 - 1996 in Western Nepal

Table 1. Basic Information on the Selected Rainfall Stations

Number of Rainfall Stations with Data for Period More Than	Period of Available Data
40 years – 30	1956 – 1998
30 years – 25	1960 – 1998
25 years – 48	1970 – 1998
15 years – 6	1980 – 1998

DETERMINATION OF 24-HOUR POINT PMP DEPTH VALUES

As mentioned above the Hershfield Method (1961) to determine the 24-hour PMP depths was applied in this study that following the procedure presented by WMO (1986).

The basic relationship used in this procedure is represented by Equation (1):

$$PMP = Xn + Km*Sn \quad (1)$$

Where in Equation (1) Xn and Sn are the mean and standard deviation of a series of maximum annual rainfall depth of certain duration. Km is a factor that is dependant on the mean annual maximum rainfall and varies between 5 and 20 for durations between 5 minutes and 24 hours.

Application of the Hershfield Method (1961) to the selected 109 rainfall stations in Western Nepal enabled the determination of the point PMP depths for these stations. The results of the computed point PMP depths were presented elsewhere (TAHAL, 2000-2002).

The relationship between Point PMP Depth and Rainfall Station Elevation for Western Nepal is presented in Figure 3. The relationship is expressed by Equation (2):

$$PMP = 1077.3*exp(-4*10**-4*ELEV) \quad (2)$$

Where in Equation (2), PMP is in mm and ELEV (rainfall station elevation) is in m. The correlation coefficient was found to be about 0.78. It should be pointed out those 7 points (presented in Figure 3 as series 2) being too far away from the relationship line was omitted from the correlation.

It should be mentioned that similar relationships and correlation coefficients which are not presented here, were established between the maximum 24-hour rainfall depth and rainfall station elevation, the mean 24-hour rainfall depth (Xn) and rainfall station elevation, and the standard deviation of the 24-hour depth series (Sn) and rainfall station elevation. The relationship between the Km values and rainfall station elevation showed an increase of Km with elevation. A linear regression was found in this case to represent this relationship, with a correlation coefficient of about 0.76. The different behavior of Km from the above-mentioned rainfall series patterns with elevation can be understood through its inverse relationship with Mean Annual Maximum Rainfall (RMAX), the latter having an inverse relationship with elevation. The isolines of the 24-hour point PMP depth values for the selected rainfall stations are graphically presented in Figure 4.

DETERMINATION OF 48- AND 72-HOUR POINT PMP DEPTH VALUES

It was required to determine 48- and 72-hour PMP depths for the large size watersheds that had a relatively long time of concentration. Because the Hershfield Method refers PMP with time duration of not more than 24 hours, it was necessary to develop in this study the Km – RMAX relationships (similar to Figure 4.1 in WMO, 1986) for the two new durations in this study. The procedure to determine the above-mentioned relationships was as follows:

1. Km values were read from Figure 4.1 in WMO, 1986 and then tabulated for an each PMP duration (1 hour, 6 hours and 24-hours).
2. A relationship was determined for each Km related to the same RMAX. All the relationships had the format of Equation (3):

Km = a*LN (T) + b (3)

Where in equation (3), Km is the coefficient for any RMAX and T is the PMP duration in hours. Table 2 gives the values of the 'a' and 'b' parameters of equation (3), the high correlation coefficient values obtained, and the results of equation (3) application for the new Km value determination.

Table 2. Equation (3) Parameters and the 48- and 72- Km Values

RMAX (mm)	a	b	Correlation Coeff. - r	Km (48- hour)	Km (72- hour)
50	2.2473	10.644	0.9968	19.3	20.3
100	3.2296	5.2167	0.9965	17.7	19.0
150	3.5591	2.5374	0.9999	16.3	17.8
200	3.4559	0.9417	0.9998	14.3	15.7
250	2.9452	1.0210	0.9799	12.4	13.6
300	2.6868	0.4490	0.9687	10.9	11.9
350	2.3472	0.1782	0.9162	9.3	10.2
400	2.0642	0.1804	0.8958	8.2	9.0

Two linear relationships were separately developed between the values in Table 2 of Km (48-hour) and Km (72-hour) and the values RMAX in that table. These relationships are represented by Equations (4) and (5):

Km (48-hour) = 20.985 – 0.0330*RMAX
r = 0.9982 (4)

Km (72-hour) = 22.319 – 0.0339*RMAX
r = 0.9972 (5)

The above two relationships expressed by Equations (4) and (5) are presented in Figure 5 and Figure 6, respectively, and may also be used for RMAX values beyond the presented range of these figures.

The above mentioned Hershfield procedure was applied to determine the 48- and 72-hour point PMP depth values for the large size basins, using now the new Km – RMAX relationships in Figure 5 and Figure 6.

The 48- and 72-hour Point PMP depth values thus obtained where presented elsewhere (TAHAL, 2000-2002).

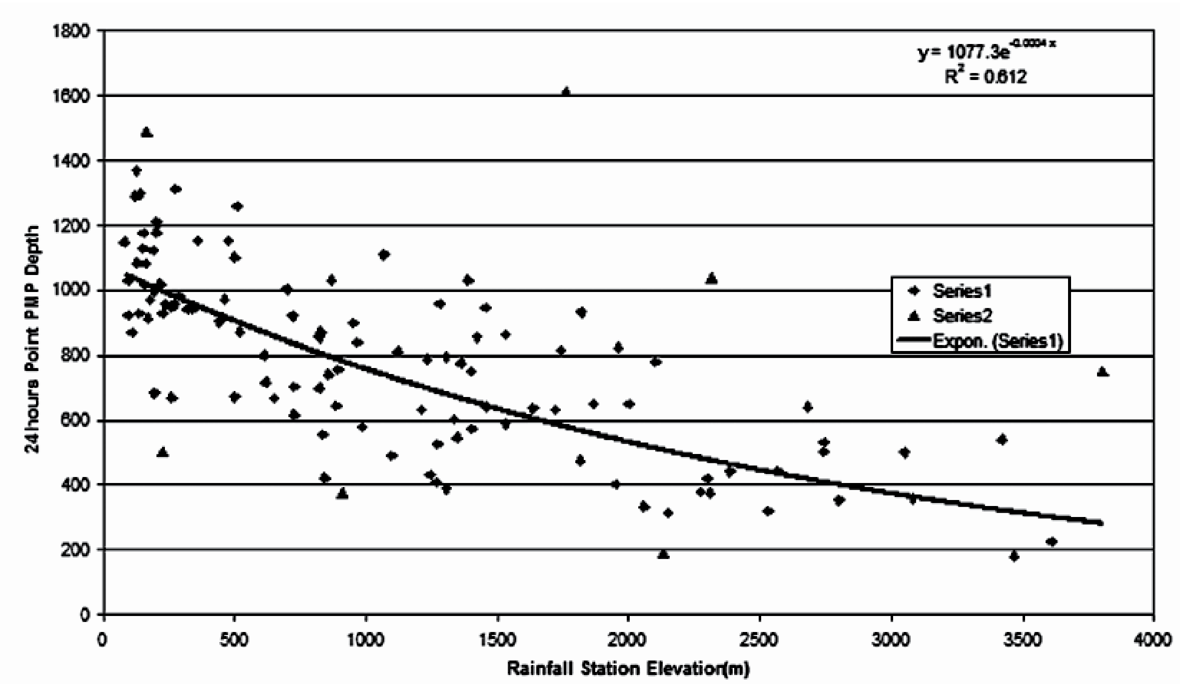

Figure 3. 24 Hours Point PMP Depth – Rainfall Station Elevation Relationship in Western Nepal

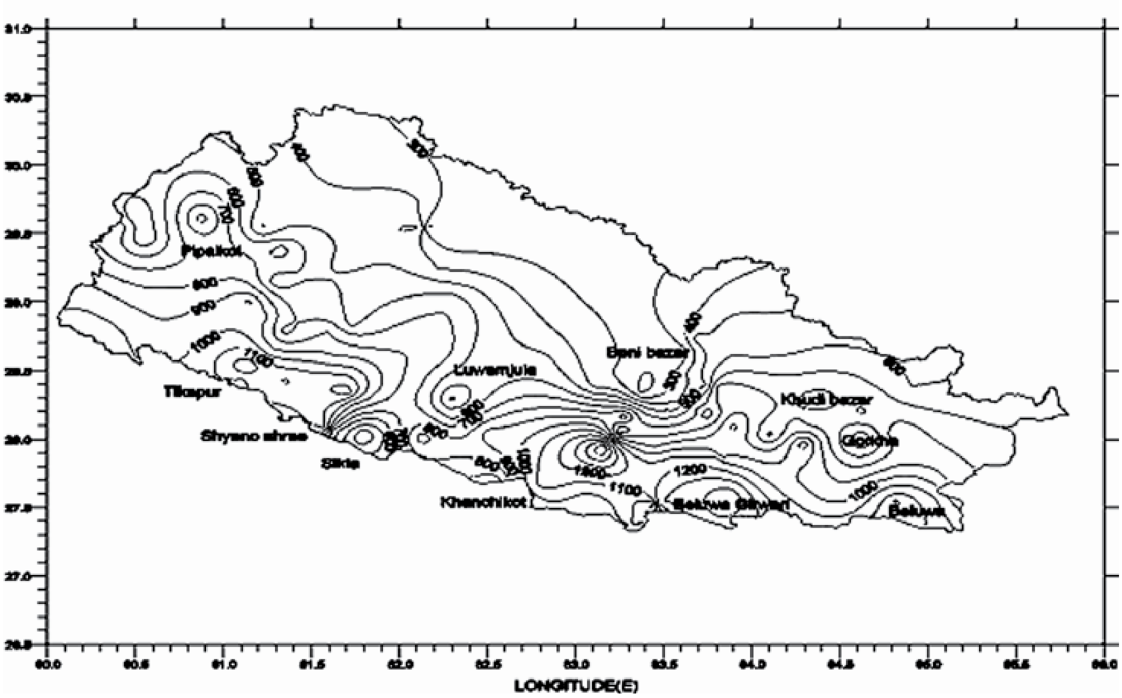

Figure 4. Point PMP (mm) Values for 24 hours in Western Nepal

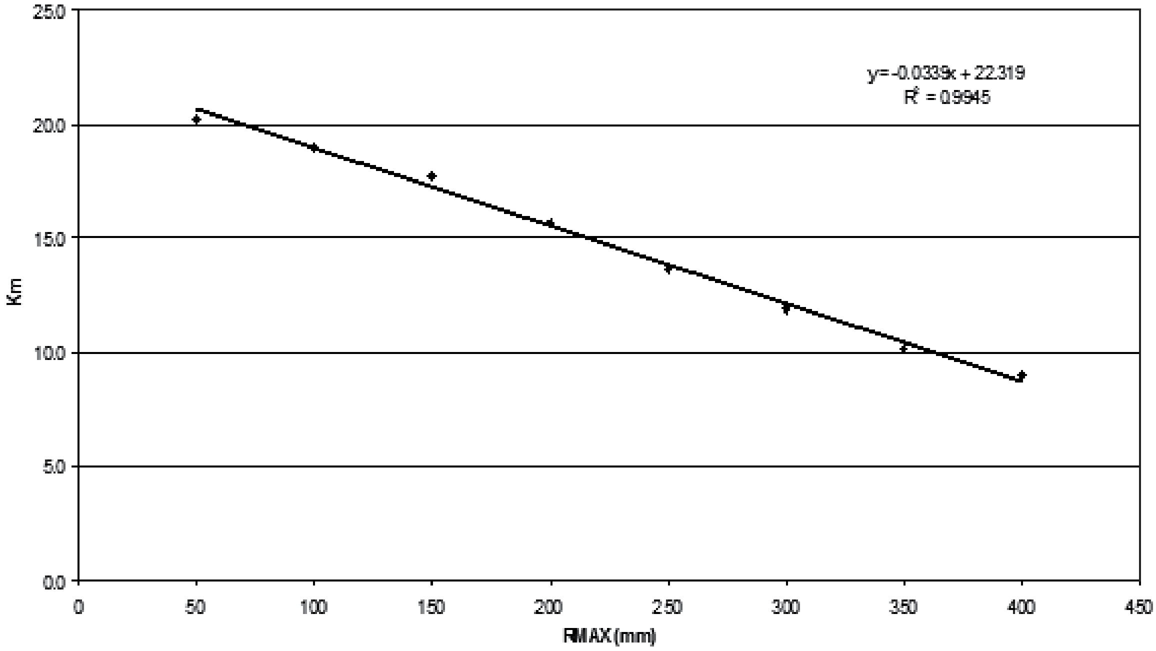

Figure 5. Km – RMAX Relationship for 48 Hours Point PMP Depth

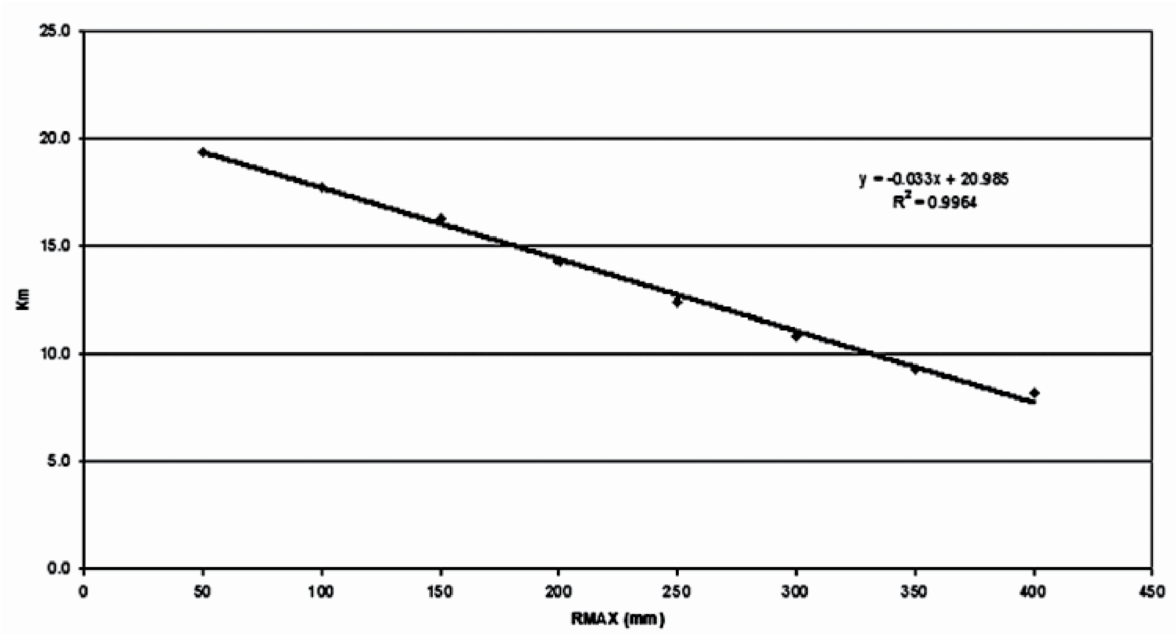

Figure 6. Km – RMAX Relationship for 72 Hours Point PMP Depth

Table 3. Areal Basin PMP Depth Values

Basin	Station No.	Location	Catchment Area (km^2)	PMP	
				Duration (hours)	(mm)
Chameliya	120	Nayalbodi	1,150	24	482
Surnaya	169.8	Gujargaun	154	24	389
Tila	220	Nagma	1,741	24	387
Sinja Khola	225	Diware	790	24	328
Tila	230	Serighat	3,320	24	413
Karnali	240	Asaraghat	18,256	72	567
Chham Gad	245	Gitachaur	241	24	552
Karnali	250	Benighat	23,480	72	607
Budhi Ganga	255	Kakarsant	1,411	24	593
West Seti	260	Banga	7,460	72	939
Thuli Gad	262	Khanayatal	775	24	745
Thulo Bheri	265	Rimna	6,866	72	561
Bheri	270	Jamu	12,310	72	678
Karnali	280	Chisapani	45,390	72	695
Sharada	286	Daredhunga	795	24	700
Mari	330	Nayagaon	1,920	24	505
Jhimruk	339.3	Chernata	653	24	560
W. Rapti	350	Bagasoti	3,675	48	794
W. Rapti	360	Jalkundi	5,086	48	858
Myagdi Khola	404.7	Mangla Ghat	1,112	24	302
Modi	406.5	Nayapul	647	24	650
Andhi Khola	415	Borlangpul	195	24	845
Badi Gad	417	Rudrabeni	1,961	24	608
Kali Gandaki	420	Kota Gaon	11,345	72	855
Mardi	428	Lahachok	142	24	863
Madi	438	Shishaghat	830	24	702
Khudi	439.3	Khudi Bazar	136	24	799
Dordi	439.4	Aambote Bagar	289	24	779
Chepe	440	Garam Besi	302	24	736
Daraundhi	441	Naya Sanghu	376	24	712
Budhi Gandaki	445	Arughat	2,546	72	770
Phalankhu	446.7	Betrawati	152	24	636
Tadi Belkot	448	Belkot	650	24	553
E. Rapti	460	Rajaiya	574	24	1,047
Manahari	465	Manahari	427	24	1,131
Lothar	470	Lothar	167	24	1,235

It should be pointed out that the 48-hour and 72-hour point PMP depth values had a similar relationship with the rainfall station elevation to the one demonstrated in Figure 3 for the 24-hour point PMP depth values.

DETERMINATION OF THE AREAL BASIN PMP DEPTH VALUES

The procedure to determine the areal basin PMP depth values was as follows:

1. In each basin the Thiessen polygons procedure was applied in order to establish the sub-basin area that was represented by any one of the basin rainfall stations.

2. Using the Depth-Area Curves presented in Figure 4.7 in WMO (1986) the point PMP depth value of each rainfall station was reduced accordingly.

3. The areal basin PMP depth value was finally determined based on the reduced step 2 values and the sub basin area fraction of the various participating rainfall stations determined in step 1 above. Table 3 gives the final area basin PMP depth values.

CONCLUSIONS AND DISCUSSION

The above is a brief presentation of the study that was performed in order to determine the point and areal PMP depth values in Western Nepal. The procedure applied in the study to determine the 24-hour point PMP depth values was the Hershfield Method (1961) as described in WMO (1986). For the longer 48- and 72-hour point PMP depth values, part of the above-mentioned procedure was updated to obtain new Km-RMAX relationships.

The 24-hour point PMP depth reduction with rainfall station elevation may be clearly seen from Figure 3. This conclusion may be justified although there is a relatively high scatter around the fitted curve in Figure 3.

A possible explanation of this phenomenon is the general mean annual rainfall reduction with elevation (the elevation in Figure 2 increases from south to north), and the reduction with elevation of the rainfall series patterns: 24-hour maximum rainfall depth, mean rainfall depth (Xn) and standard deviation (Sn) values (the relationship between these three variables and elevation mentioned earlier). Bearing in mind that in Equation (1), Xn and Sn decrease with elevation, where Km increases, it may be concluded that the Km increase has a lesser effect on the final computation results than the reduction effect of the Xn and Sn.

Furthermore, in Western Nepal, 78 percent of the annual precipitation falls between June and September. The rainfall in Nepal varies greatly from place to place due to sharp topographical variations. As the rain-bearing winds approach Nepal from the southeast in the summer monsoon season, most of the rain falls over the foothills of the Churiya Range or the first foothill slopes of the southern parts of Nepal. Similarly, the rainfall intensity and point PMP depth value have a tendency to increase in the foothills of the Churiya Range as well as at elevations of around 1,400 m in the southern slopes of the Mahabharat lekh, where the rainfall intensity and point PMP depth value are high relative to the regular decline of these variables with rainfall station elevation. Above the elevation of 1,500 m, the rainfall intensity and point PMP depth value decrease, as presented in Figure 3 showing PMP behavior with elevation. This shows that the moisture-bearing air is mostly concentrated within 850 to 1000 mbs (low level land of Nepal, i.e. in the elevation range between 100 m and 1,500 m).

It is interesting to note that there is a series of troughs located in Figure 4 that follow the patterns of the major river valleys of Kali Gandaki, Bheri, Karnali and West Seti. This phenomenon may be explained by the windward and leeward effects of rainfall together with topography.

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Temporal variations of rainfall in Nepal since 1971 to 2000*

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ABSTRACT

A preliminary study has been undertaken to find the impact of the recent global warming on the rainfall patterns in Nepal. The study has been selected at a few rainfall stations in Nepal during 1971-2000. There seemed to be no fixed trend in annual rainfall in Nepal except in the Far Western Nepal, where there seemed to be rather slightly decreasing trend in the annual rainfall. During the monsoon months, the rainy days seemed to be decreasing and the intensity of rainfall appeared to be increasing.

1. INTRODUCTION

At present, there are four seasons in Nepal. These are Winter (November-February); Pre-monsoon (March-May); Summer monsoon (June to September) and Post monsoon (October). Among these seasons, 70 to 90 % of rainfall occurs under the influence of summer monsoon (Nayava, 1980). At the same time, most important agriculture activities have been taking place during the summer monsoon. Therefore, the onset of the monsoon rainfall and its amount, frequency and distribution in time and space are all important factors. Therefore, the preliminary studies for a few rainfall stations have been attempted to see the annual variations of rainfall and their trends during 1971-2000.

Similarly, the rainy days and the amount of rainfall during the monsoon months have also been studied to find out whether these trends of annual and monsoon rainfall have been affected by the present climate change.

2. DATA

At present, there are more than 150 rainfall stations, which have the thirty years (1971-2000) of rainfall records in Nepal (DHM, 1999, 2000, 2001). Among those stations, 17 rainfall stations have been selected representing the Mountains, Hills and Terai Regions (Figure 1). These physiographic regions fall in the Cool Temperate, Warm Temperate and Tropical Climates categories respectively (Nayava, 1982). The time series rainfall data for the 17 selected rainfall stations were tabulated for the period 1971-2000. Data were checked and verified. The long term mean rainfall for those thirty years were calculated. These selected rainfall stations and the mean monthly rainfall data were shown in Table 1. Similarly, the observed rainy days for the each and every month from 1971 to 2000 were computed for a few places.

3. METHOD

3.1 Analysis of annual rainfall in Nepal

The temporal variations of annual rainfall at each station were plotted during 1971-2000 and studied. At the same time, the trend analysis of annual rainfall has been performed for all those selected places. The rainy days and the mean monthly rainfall during the monsoon months were also analyzed. To do this statistical analysis of rainfall, 'EXCEL' from the Microsoft

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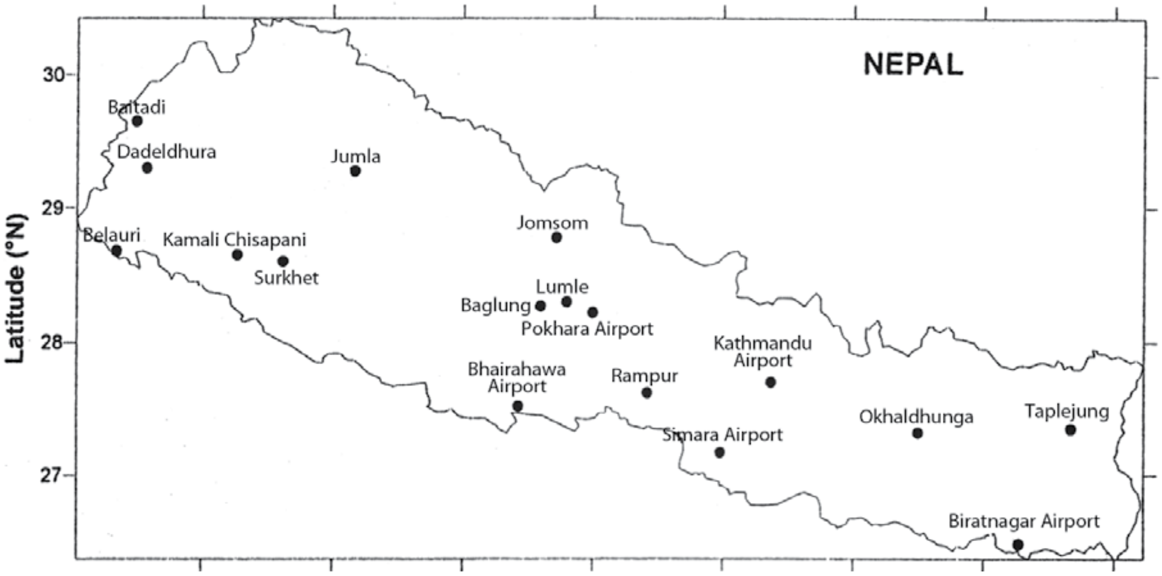

Figure 1. Selected rainfall stations in Nepal

Table 1: Mean monthly rainfall (mm) at the selected rainfall stations in Nepal during 1971-2000

Index	Station Name	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
102	Baitadi	1635	45	57	59	52	140	209	326	288	166	47	9	32	1429
104	Dadeldhura	1848	43	61	61	54	86	193	332	307	173	40	8	27	1384
106	Belauri Shantipur	159	21	32	20	20	51	227	496	454	271	49	5	20	1664
303	Jumla	2300	31	41	59	44	58	77	178	181	103	37	10	16	835
405	Chisapani Kar-nali	225	36	38	24	27	76	285	664	637	376	57	9	22	2251
406	Surkhet	720	34	35	29	31	79	256	448	418	198	49	10	21	1609
601	Jomsom	2744	8	11	23	19	17	24	40	44	37	31	9	6	258
605	Banglung	984	20	22	30	50	146	319	530	451	268	60	10	16	1922
705	Bhairhawa	109	16	15	18	22	66	261	549	377	258	68	7	15	1673
804	Pokhara	827	23	32	60	121	369	699	941	850	637	175	21	24	3952
814	Lumle	1740	32	46	62	103	317	877	1441	1369	854	207	30	23	5361
902	Rampur	256	17	14	21	49	151	348	555	431	300	84	8	18	1996
909	Simra	130	14	15	17	55	125	263	547	402	272	76	5	13	1804
1030	Kathmandu	1336	14	18	30	57	116	263	357	320	187	57	8	15	1440
1206	Okhaldhunga	1720	12	13	25	52	153	316	458	391	234	63	13	15	1744
1319	Biratnagar	72	11	13	16	48	164	321	534	368	305	89	11	8	1887
1405	Taplejung	1732	18	26	52	141	249	305	427	383	283	86	18	12	1991

Source: DHM (1999a-c: 2000)

software has been used. The detailed analyses are follows:

a) Starting from the Far Western and Mid-Western Regions of Nepal, Jumla was selected as representing the Mountain Region. Dadeldhura, Baitadi and Surkhet were representing the ridges and valley in the Hilly Region. Similarly, Chisapani Karnali and Belauri Shantipur were representing the Inner Terai and Terai. The inter-annual variations of rainfall from station to station were quite different. The extreme highest and lowest of the annual rainfall also varied from station to station as shown in Figure 2. Generally, the annual variations seemed to be very high in Karnali. Since past 3 decades, the recent (1991-2000) decadal variations of rainfall in Jumla seemed much different compared to 1971-1990. The trends of annual rainfall during 1971 to 2000 in almost all of those places seemed to be decreasing as shown in Figure 2.

b) Similar study was attempted in the Western Region of Nepal. The selected places were Jomsom as representing the Mountain as well as rain-shadow area; Lumle, Pokhara and Banglung as representing ridges, valley floor and river valley in the Hill Region and Rampur and Bhairhawa

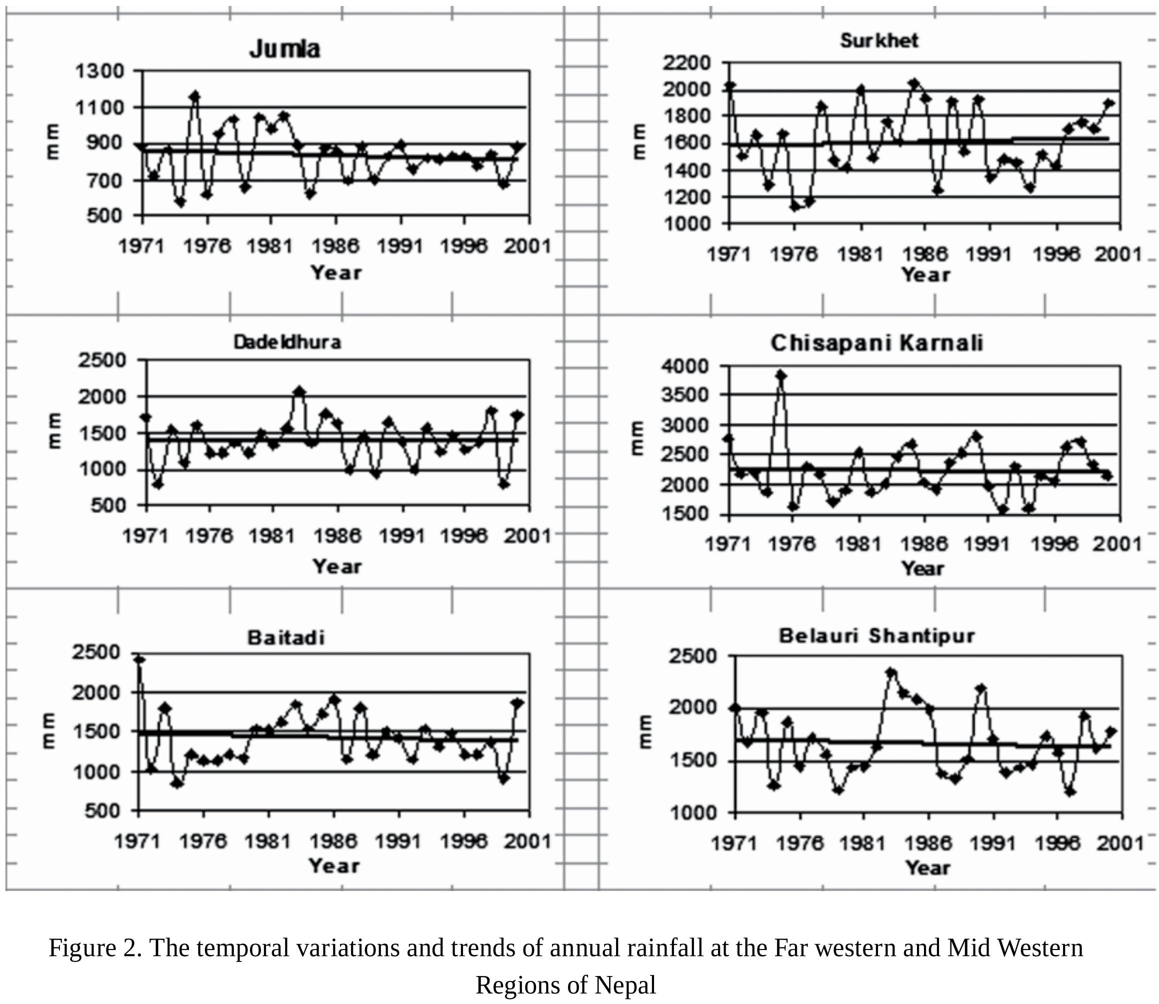

Figure 2. The temporal variations and trends of annual rainfall at the Far western and Mid Western Regions of Nepal

as representing the Inner Terai and Terai region respectively.

The inter-annual variations of rainfall from station to station were also quite different in Western Region of Nepal. However, the inter annual variations of rainfall seemed to be higher at Pokhara compared to the other stations. Among the six selected stations in Western Region of Nepal as shown in Figure 3, the extreme highest annual rainfall seemed different from one place to other places and however the extreme lowest annual rainfall seemed to be in 1972 except two places at Jomsom and Lumle. Among those places, Jomsom and Rampur showed either increasing or decreasing trend of annual rainfall and rest of the places such as Lumle, Pokhara, Banglung and Bhairhawa showed the increasing trend of annual rainfall as shown in Figure 3.

c) A similar study was done in the Central and Eastern Regions of Nepal. Taplejung, Okhaldhunga and Kathmandu were representing the ridges and valley floor in the Hill Region and Simra and Biratnagar as representing the Terai.

The inter-annual variations of rainfall seemed quite different in all those places. The extreme highest and lowest annual rainfall was also varied in all those places in the Central and Eastern Regions of Nepal as shown in Figure 4. The annual rainfall trends at Kathmandu, Okhaldhung, Simra and Biratnagar showed a slightly increasing trend where as the annual trend of rainfall at Taplejung showed slightly decreasing as shown in Figure 4.

3.2 Analysis of monthly rainfall, June-September

It seemed that the most of the researchers have analyzed the annual trend of rainfall in terms of either regional or national scale. Of course, it depends upon the application in mind. This analysis of rainfall is made particularly for its application in agriculture activities in local scale. Therefore, the number of days of rainfall and distributions are equally important. Since, Nepal's agricultural activities depends upon the monsoon rainfall which accounts for about 70 to 90% of annual rainfall, the monsoon months of June to September were selected for the trend analysis of rainfall for Jumla, Surkhet and Bhairhawa in Nepal. At the same time, the uses of rainfall and their implications in agriculture will be highlighted.

The monthly information of rainfall and agronomic data are not adequate for proper analysis to find their relationship, say as monthly rainfall may be quite enough, in the contrary the rainfall occurred only either in the beginning or the end of the month and the prolonged dry spell may had occurred between those spells, the serious damage or loss of yields in crop may have happened and therefore, while studying the interaction between the weather and agriculture. Food and Agriculture Organizations of the United Nations (1986) has considered the ten days of weather data and ten days report of agronomic data. This period is most reasonable period for collecting the required information on weather and agronomic in national and international scale. Those data will be used in Water balance model developed by FAO (1986), which compared available water and water requirements of a given crop for each decade of the growing season. A shortfall or large excess of later in any decades will result in a reduction of "crop index", which the model generate as a means of monitoring crop condition and forecasting yields.

3.2.1 Jumla

The number of rainy days (greater than 1.0mm) and the mean monthly rainfall for Jumla at each month from June to September during 1971 to

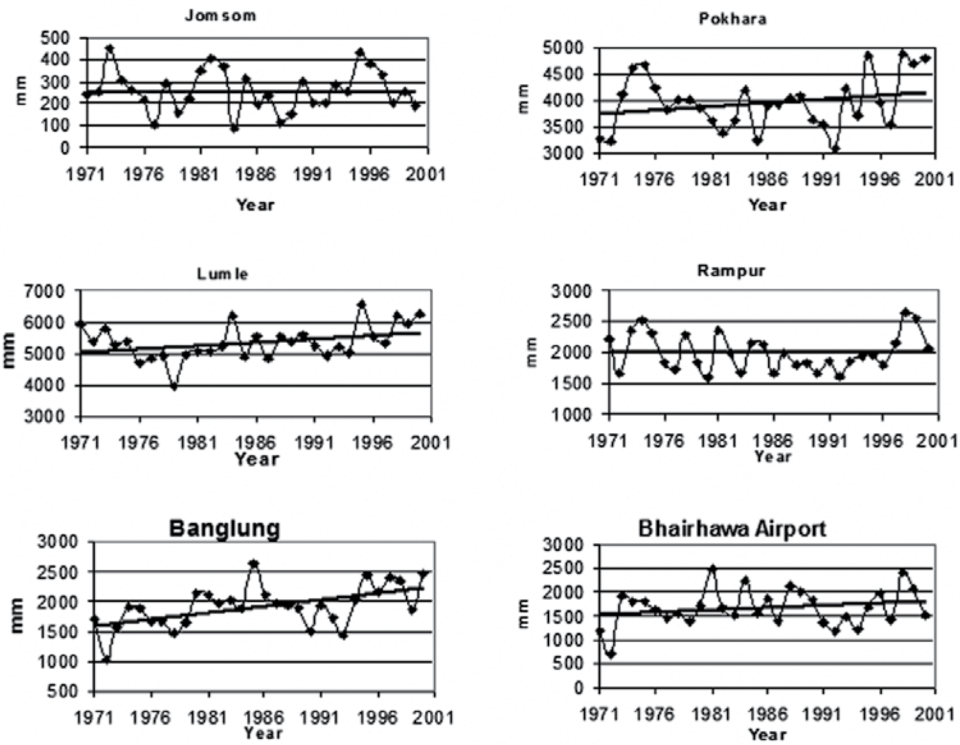

Figure 3. The temporal variations and annual trends of rainfall at the Western region of Nepal

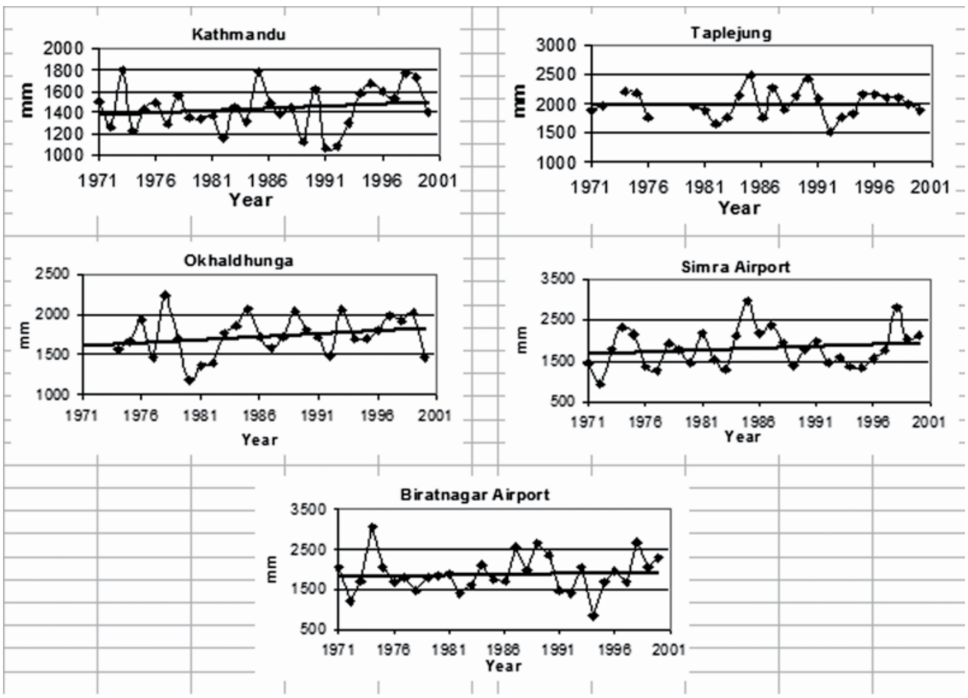

Figure 4. The temporal variations and trends of annual rainfall at the Central and Eastern Regions of Nepal

2000 have been analyzed as shown in Figure 5. The trend of number of rainy days and the mean monthly rainfall in the month of June seemed no change, but the trend of rainy days in the month of July was very much decreased and to the contrary mean monthly rainfall at the same month seemed to be a little increase. It showed that the intensity of rainfall has increased during that month of July. The trend of rainy days as well as the mean monthly rainfall in August slightly decreased. At the end, the trend of rainy days in the month of September rather increased and the mean monthly rainfall in September also observed slightly increase.

3.2.2 Surkhet

The number of rainy days (greater than 1.0mm) and the mean monthly rainfall for Surkhet at each month from June to September during 1971 to 2000 were analyzed as shown in Figure 6. The trend of number of rainy days and the mean monthly rainfall in the month of June seemed to be a little increase as shown in Figure 6. On the contrary, the trend of number of rainy days in July increased and the mean monthly rainfall in the month of July seemed no change. Similar to Jumla, the intensity of rainfall has increased during the month of July. During the month of August, the trend of rainy days as well as mean monthly rainfall seemed increase. Similar to Jumla, the trend of rainy days and the mean monthly rainfall in the month of September seemed a little increase.

3.2.3 Bhairhawa

Similar to Jumla and Surkhet, the number of rainy days (greater than 1.0mm) and the mean monthly rainfall for Bhairhawa at each month from June to September during 1971 to 2000 were analyzed as shown in Figure 7. During the month of June, the trend of rainy days as well as mean monthly rainfall seemed a little increase. The trend of number of rainy days in the month of July seemed no change and the trend of mean monthly rainfall seemed a little decrease. At the same time, the trend of rainy days in the month of August seemed to decrease, where as the trend of mean monthly rainfall seemed increase. At the end, the trend of rainy days in the month of September seemed to be quite decrease and it seemed that the last ten years the pattern of rainy days have shifted in a very much lower side. On the contrary, the trend of mean monthly rainfall also seemed to be a little decrease.

4. RESULTS

There were no fixed trends of annual rainfall in the Mountain, Hill and Terai Regions of Nepal. However, it is quite interesting to note that the particular cross-section in the Far and Mid-Western Regions of Nepal, the annual rainfall in all the places such as Jumla, Dadeldhura, Baitadi, Surkhet, Chisapani Karnali and Belauri Shantipur showed decreasing trend.

The trend of number of rainy days decreased in the month of July at Jumla and the contrary mean monthly rainfall have increased during that month and this showed that the intensity of rainfall may have increased. The trend of rainy days as well as mean monthly rainfall have decreased during the month of August at Jumla.

Similarly, the number of rainy days seemed decreasing in the month of July in Surkhet and the number of rainy days seemed decreasing in the month of August in Bhairhawa.

During the month of September, the trend of rainy days have very much decreased and it showed that the last ten years the pattern of rainy days have shifted in a very much lower side.

During 1971-2000, the year 1973, 1975 and 1984 seemed to be generally much more rainfall than

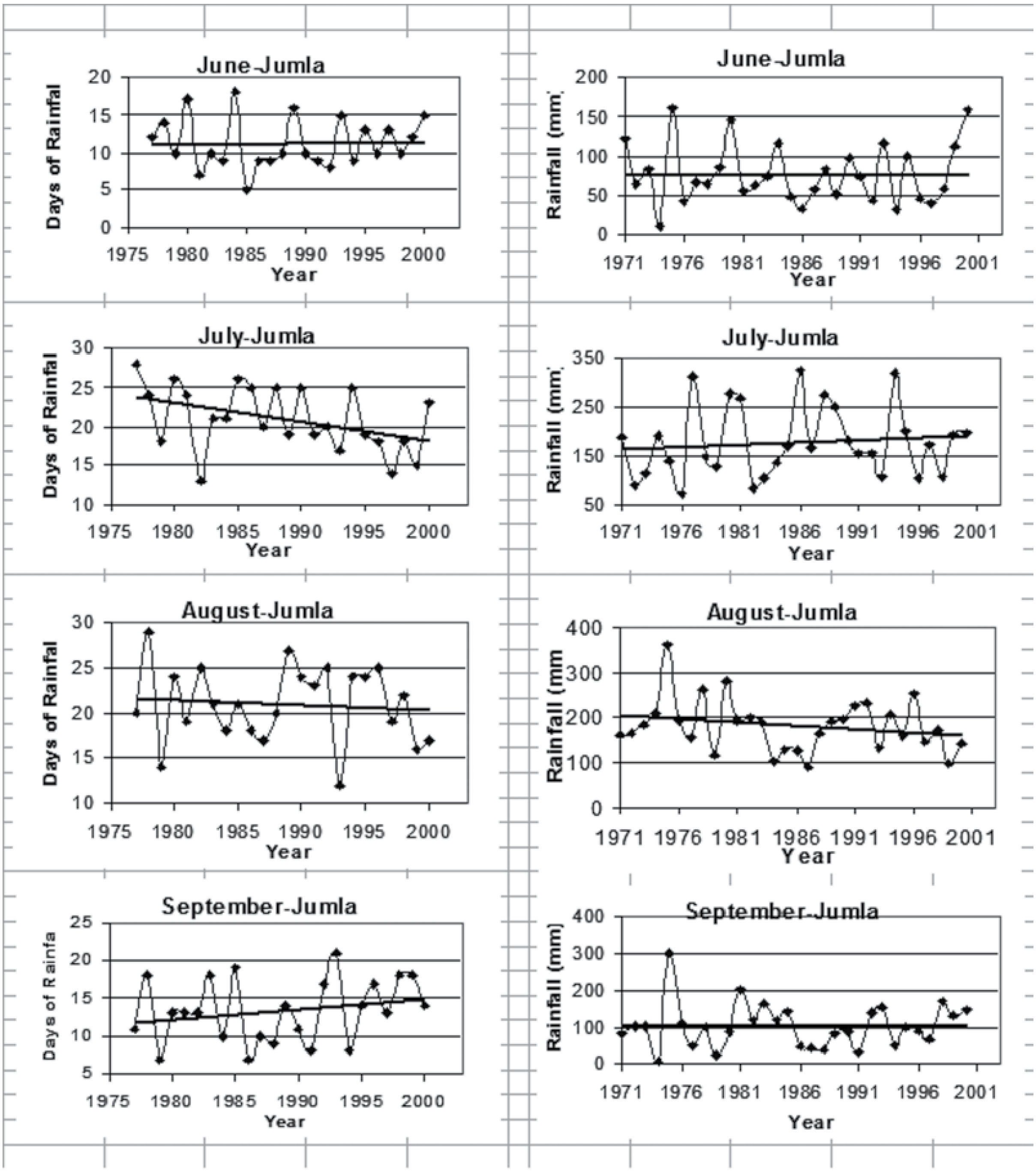

Figure 5. The temporal variations of rainy days and mean monthly rainfall during the monsoon months and their trends at Jumla

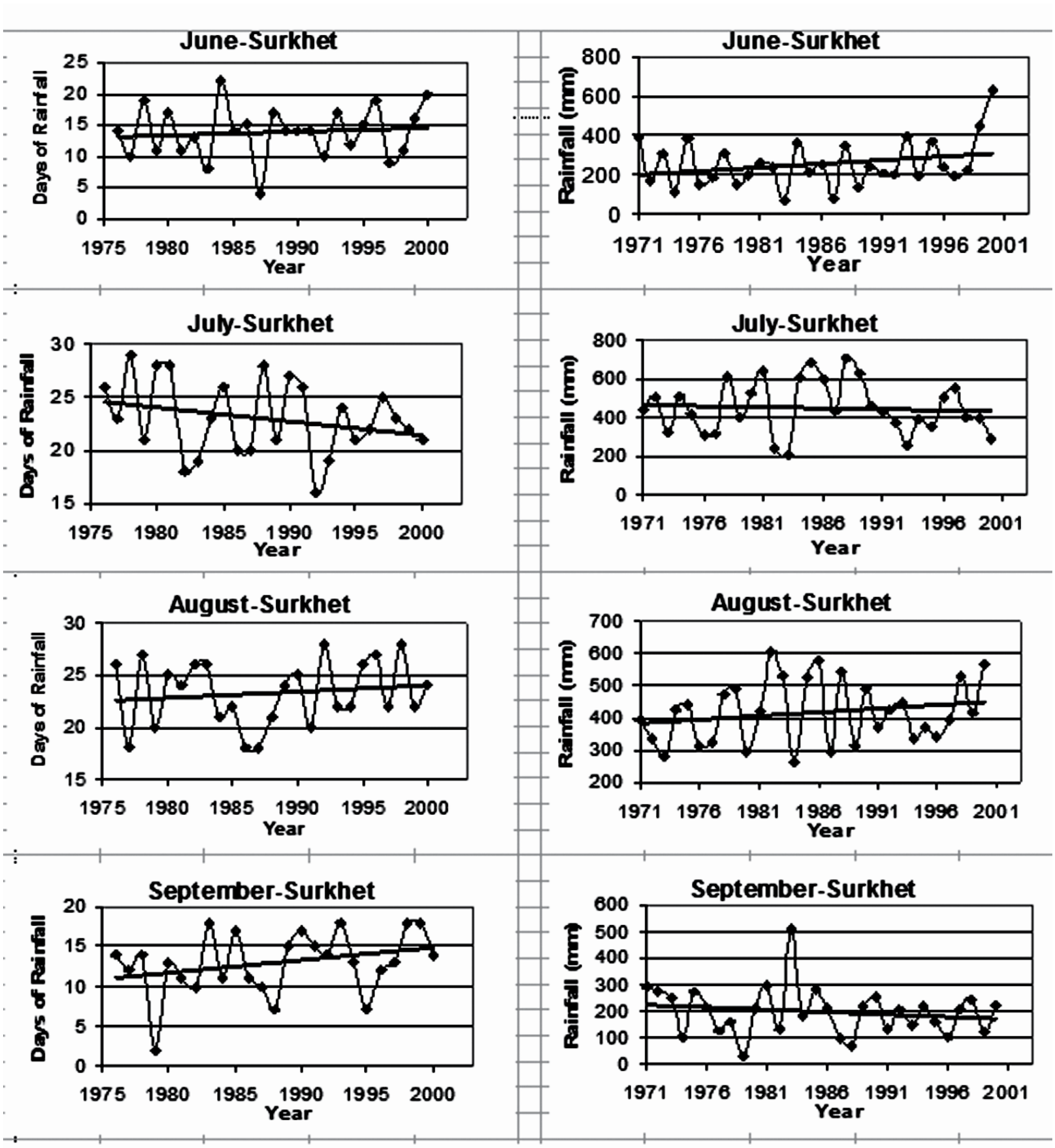

Figure 6. The temporal variations of rainy days and mean monthly rainfall during the monsoon months and their trends at Surkhet

normal throughout the country and on the contrary, at the same period, 1972, 1982 and 1992 seemed to be much lower rainfall than the normal throughout the country. Due to the longitudinal difference of 80 from the east to west and 30 from the south to north in Nepal, the country had experienced not equal distribution of rainfall in the west or east in the same year. For

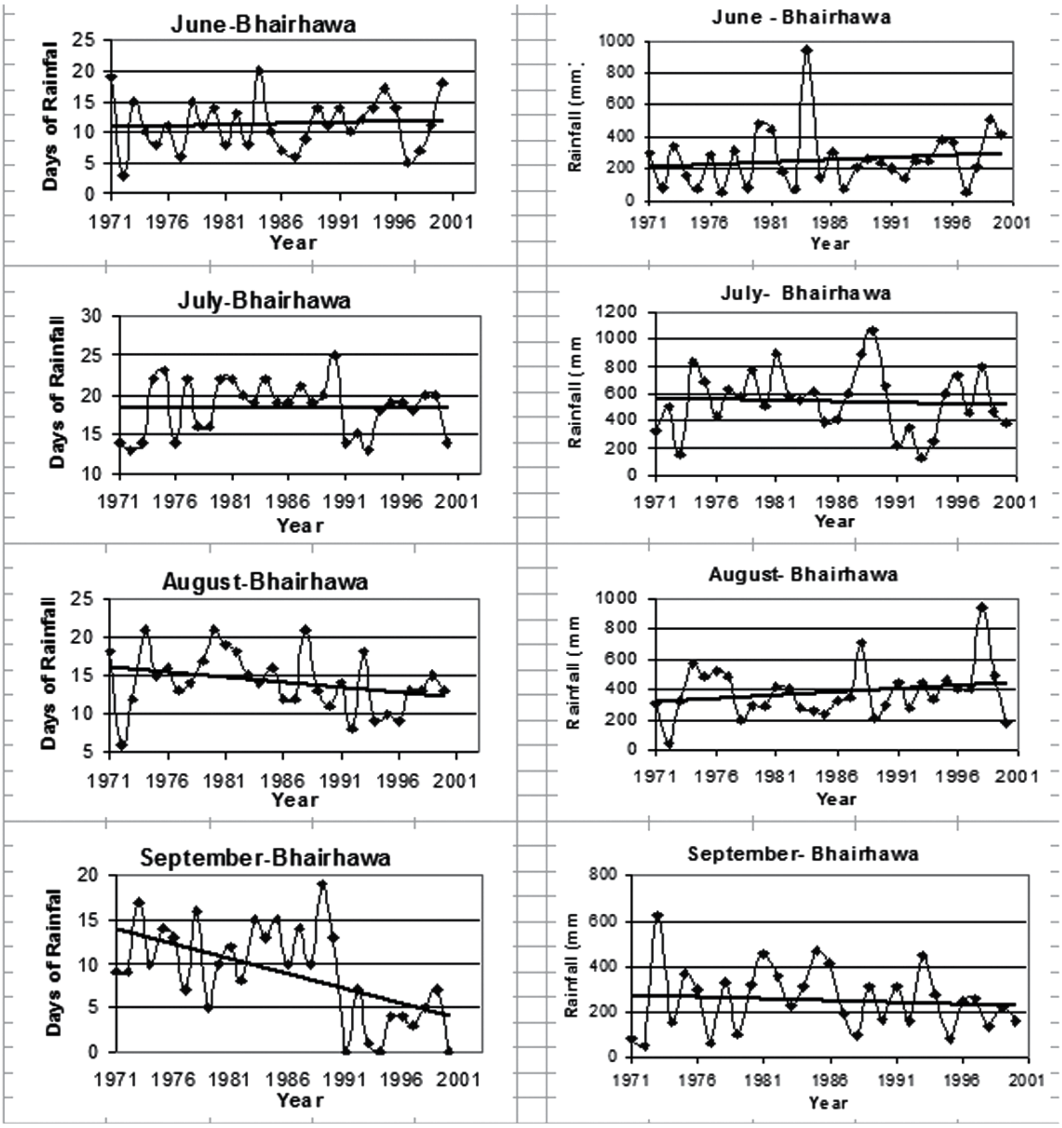

Figure 7. The temporal variations of rainy days and mean monthly rainfall during monsoon months & their trends at Bhairhawa.

example, the western parts of Nepal had observed much lower rainfall than the normal in 1979 and agricultural activities were badly affected in those areas. It has been noted that 1992 had also dry year throughout the country and the government of India had declared a drought in Bihar state of India and monsoon rainfall was very much delayed in the western part of Nepal. The western parts of Nepal had suffered a drought in 1992. It has been strange coincidence that along with the other years every ten years after 1972, Nepal seemed to have observed significantly below normal rainfall either in the Eastern or in the Western regions.

5. DISCUSSION

Shrestha et al, (1998) have also studied the annual rainfall data on Nepal over the past three decades and they have remarked that the annual rainfall data show large inter-annual and decadal well as regional within Nepal. They have also mentioned the lack of long term increasing trend in the rainfall records and the model by Meehl et al., (1994) suggest an increase of 5-15% in monsoonal precipitation with green house gas – induced global temperature increase.

This is a very preliminary analysis to come up with definite conclusions, but it clearly showed that the number of days of rainfall seemed to be very much decreasing on the month of September at Bhairhawa as shown in Figure 7. The normal rainy days of Bhairhawa during the monsoon months is 59 days. Altogether, there are 80 rainy days in a year. If number of rainy days is reduced in Bhairhawa during the month in September, there may be water stress in paddy crop and consequently reduced the yield of paddy at Bhairhawa. It may be necessary to mention here that the onset of summer monsoon in Eastern Region of Nepal falls on 10th of June and slowly it advances in the Western Regions of Nepal and it takes about a week to cover the whole Nepal under the influence of summer monsoon. Similarly, the withdrawal of summer monsoon takes place on 21st of September from Nepal. Therefore, the influence of summer monsoon over Nepal is only about 101 days. The nature of these kinds of study was very essential realizing these important issues.

Gerald et al. (1998) have analyzed the connection between past El Nino events and summer rainfall and rice production in Nepal, paying particular attention to last major El Nino event in 1982 when the intensity of the event was about the same as in the current year 1998. They found strong relationship between these three parameters. They have made recommendations that the concerned authorities should address this scenario while formulating national plans and policies in agriculture. They further recommended to adopt necessary measures to monitor the state of the crops in relation to El Nino and summer rainfall variations and come up with some methods to forecast the looming problem in advance. The monitoring situation with respect to agricultural meteorology must be improved with increased coordination and collaboration between the Department of Hydrology and Meteorology and the Department of Agriculture (Gerald et al., 1998).

Similarly, this study have also suggested that the present systems of yield assessments are subjective and, therefore, the objective method should be introduced in the monitoring and evaluation of crop yield and production in Nepal and this process will lead to much better assessments of yield and any impact of weather will also be evaluated (Nayava, 2000). When the impacts of weather and agriculture studied in wider areas, Food and Agriculture Organization of United Nations (FAO, 1986) recommends that ten days (decadal) of meteorological data and ten days of crop conditions should be considered along with other relevant information. Now, it is high time that such a system should introduce to find out the weather impacts on agriculture. This will support the future climate and agriculture scenario based on the past and current knowledge of weather, climate and agriculture inter-relationship. If we have these systems, we are in a better position to evaluate the past, present and future crop yields data in a very systematic and scientific manner.

Thus, to do any future forecast, one should have the present and past status of concerned data and should test those data and understand the trend and behavior of those patterns.

6. ACKNOWLEDGEMENT

The author wishes to thank to the Department of Hydrology and Meteorology for providing

the unpublished data of rainfall from 1999-2000.

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The estimation of evapotranspiration by climate models for Western Nepal*

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ABSTRACT

Evapotranspiration values are used in many agricultural and engineering applications. There are many empirical formulas to compute evapotranspiration. In Nepalese conditions, Penman and Monteith method is the best to estimate evapotranspiration. All the climatic parameters required to estimate evapotranspiration by Penman and Monteith method for all the rainfall points were not available. Therefore, various models were developed to expand the climatic parameters for all the rainfall points and thus evapotranspiration were finally calculated.

Keywords: Western Nepal, Penman and Monteith method, CROPWAT

1. INTRODUCTION

One of the important parameters in calculating the crop water requirement is evapotranspiration (ETo). Meteorological data are the main inputs to estimate evapotranspiration. The "CROPWAT" computer program developed by FAO (1998) based on the modified Penman and Monteith Method has been used in this project to estimate evapotranspiration. The project's objective was to strengthen the institutional development of Hydrology and Meteorology and to study the water availability of 77 basins of Western Regions of Nepal. The following data are necessary in calculating ETo: Minimum Temperature (0C); Maximum Temperature (0C); Relative Humidity (%); Wind speed (Km/day); and Sunshine (Hours).

In Western Nepal, the above parameters required to compute evapotranspiration have not been recorded in all the meteorological stations. For example, only 15 meteorological stations have recorded all these parameters to estimate evapotranspiration. This Project intends to estimate evapotranspiration for all the sites of the meteorological rainfall stations. Therefore, regression programs have been used to extend climatic parameters to the places where observed data are not available.

2. DATA AND METHODOLOGY

Here, in this article, data, methodology, analysis and discussion of each above-mentioned climatic parameter have been separately described as follows:

2.1 TEMPERATURE

At present, there are 54 climatological stations at the Study Area in Western Nepal. The period of record varies from one station to another. All available mean monthly maximum and mean monthly minimum temperature values from 1982 to 1996 were compiled for all the 54 stations. Among them, only 38 climatological stations have complete temperature records from 1982 to 1996. The recorded mean monthly maximum and minimum temperatures used to develop the temperature models are shown in the Meteorology Technical Report No. 4 for the Institutional

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Development of Hydrology and Meteorology (TAHAL, 2002).

Multiple regression analysis was performed in this study by considering the data of 38 stations for fifteen years. The multiple regression equations considered latitude, longitude and elevation as independent variables and temperature as the dependent variable. Equation (1) is given below and the variables for each month and the coefficients of determination value (R^2) are given in Tables 1 and 2. The multiple regression formula used for estimating the mean monthly maximum or mean monthly minimum temperature was as follows:

$$Y = A + B * (X) + C * (X1) + D * (X2) \ldots\ldots(1)$$

Where Y = mean monthly maximum or mean monthly minimum temperature in °C;
X = latitude;
X1 = longitude;
X2 = elevation in meters; and
A, B, C and D = monthly constants.

Latitudes and longitudes are given in degrees with minutes converted to decimals.

Table 1: Constants for the Maximum Temperature Model

MONTH	A	B	C	D * 10^{-3}	R^2
January	-90.95	1.77	0.78	-5.8	0.93
February	-78.62	1.57	0.74	-6.7	0.96
March	-27.08	0.82	0.44	-7.0	0.96
April	45.63	0.07	-0.13	-7.4	0.97
May	70.32	0.38	-0.52	-6.9	0.95
June	-6.63	1.61	-0.02	-6.4	0.93
July	-85.39	2.29	0.67	-5.8	0.90
August	-86.21	2.04	0.77	-5.8	0.92
September	-76.17	2.05	0.63	-5.9	0.93
October	-39.44	1.31	0.43	-6.3	0.95
November	-41.99	1.12	0.49	-6.3	0.95
December	-52.17	1.18	0.53	-5.5	0.94

Table 2: Constants for the Minimum Temperature Model

Month	A	B* 10^{-2}	C * 10^{-2}	D* 10^{-4}	R^2
January	40.20	-75.0	-11.3	-38.2	0.76
February	41.23	-68.1	-12.6	-41.1	0.78
March	63.94	-97.6	-25.2	-42.3	0.79
April	144.42	-209.1	-79.4	-44.4	0.82
May	141.49	-164.7	-86.0	-53.3	0.93
June	90.36	-77.8	-51.2	-51.8	0.98
July	35.29	-10.7	-14.4	-51.3	0.99
August	37.19	-2.8	-12.1	-51.1	0.98
September	45.90	-32.8	-13.9	-52.7	0.98
October	79.39	-130.9	-26.3	-51.0	0.93
November	77.99	-132.7	-31.2	-42.0	0.80
December	61.18	-114.4	-21.8	-38.0	0.76

Using those equations, the mean monthly maximum temperature and mean monthly minimum temperature values for all the 12 months have been calculated for all the sites of the 110 rainfall stations in the Project study area. The estimated mean monthly maximum and mean monthly minimum temperature values for all the 54 climatological stations were replaced by the recorded temperatures, where available. The recorded and estimated temperature data were also compared and studied.

The recorded maximum temperature was found to be generally 1°C lower than the estimated maximum temperature except in the valley area where an observed maximum temperature was generally 0.5 to 2°C higher than the estimated maximum temperature. On the other hand, the observed minimum temperature was found to be generally lower than the estimated mean minimum temperature in the hilly region as well as in the valley area. Specially, 3 to 4°C differences occurred in the winter months. This is purely due to inversion in the valley floor. These errors are due to the omission of slope aspect, cloud incidence, vegetation and inversion in the regression model.

The regression coefficient for the maximum temperature model was generally higher than 0.9. On the other hand, the regression coefficients for minimum temperature in the winter months were generally less than 0.8. This is mainly due to the omission of the inversion factor in the model. It should be pointed out that the estimated temperature values were not corrected further as the variations did not cause a major change in the final computed ETo value, which was the purpose of this study.

Nayava(1981) has developed multiple regression equations to estimate mean maximum temperature and mean monthly minimum temperature considering 35 climatological stations in Nepal of which only 14 stations were in Western Nepal. Similar studies for extrapolating temperature data were done by Kenting Earth Science Ltd (1982). These studies have considered only elevation as an independent factor. ICIMOD and DHM (1996) have also used the multiple regression method to estimate the mean monthly maximum temperature and mean monthly minimum temperature and have used those data in preparing the Climatic and Hydrological Atlas Map of Nepal.

2.2 RELATIVE HUMIDITY

Average mean monthly relative humidity for 0845 and 1745 NST have been tabulated for the periods from 1985 to 1996 for all the 54 climatological stations. The daily average relative humidity for 0845 and 1745 and the daily average relative humidity for 0545,0845, 1145, 1445 and 1745 were compared at Jumla, Surkhet and Bhairhawa and the relative humidity of those two periods are very similar to each other. Therefore, relative humidity for 0845 and 1745 NST have computed for the above mentioned period for all the 54 climatological stations as shown in the Meteorology Technical Report No. 4 for the Institutional Development of Hydrology and Meteorology (TAHAL, 2002).

The average of the relative humidity taken at the above-mentioned hours is taken as the mean relative humidity. Several statistical methods have been tested to expand the relative humidity data for other points where recorded data are not available. None of the methods gave satisfactory results. Ultimately, mean monthly relative humidity were plotted and analyzed for each month in separate maps. The mean relative humidity for other sites are interpolated where actual observed data are not available. The interpolation was based on a set of preliminary monthly maps of equi-relative humidity lines prepared for this purpose.

2.3 WIND SPEED

During the end of 1970's, there were only 12 climatological stations, which observed wind data in Nepal. Out of these only 3 climatological stations fall in the study area. Due to the limited data, wind was classified in three groups as light, medium and strong winds (Nayava, 1981). McDonald (1982,1992) used similar three groups (Medium Irrigation Project, Design Manual, Hydrology and Manual in Irrigation Design and in Agrometeorology and Hydrology). Recently, WELINK (1998) has used only light wind in all the ET_o calculations in the Gandaki Water Basin Study.

There were 24 meteorological stations in which wind data have been recording in the study area. The Department of Hydrology and Meteorology has published wind data only up to 1990 and almost wind data up to 1998 were obtained from the Department of Hydrology and Meteorology (DHM). The period of record varies from station to station. It is very difficult to consider the same period of data for all the stations. All the available wind data from 1967 to 1990 are computed as shown in the Meteorology Technical Report No.4 for the Institutional Development of Hydrology and Meteorology (TAHAL, 2002). It should be also mentioned that the data have been recorded at different heights. After computing mean wind speed data for each station, wind data have been converted to the standard 2 m height by using a proper conversion graph (McDonald, 1982).

There are many theoretical methods to study the wind profile at different heights. Various methods were tested to simulate the wind speed values where observed data are not available. In this study, all the available statistical approach were tested, but only the polynomial analysis was found to be appropriate to estimate the wind speed values for all the twelve months at all rainfall stations below altitudes of 2500m. Wind data from Chisapani Karnali, Mustang (Lomangthan), Kangiroba, Annapurna and Langtang stations were not included due to unsatisfactory results. The wind equation developed is given below (Equation 2) and its constants for each month and the coefficient of determination (R^2) are given in Table 3.

Table 3: Constants for the Wind Model

Month	A	$-A1 * 10^{-2}$	$A2 * 10^{-5}$	R^2
January	48.065	5.00	6.0	.95
February	63.517	4.89	6.0	.96
March	81.228	3.87	6.0	.93
April	110.140	5.33	6.0	.87
May	123.060	8.56	7.0	.85
June	120.530	14.33	10.0	.91
July	107.020	15.72	100.0	.93
August	93.747	14.44	10.0	.95
September	71.655	10.44	8.0	.96
October	45.370	4.92	6.0	.96
November	39.642	4.48	6.0	.97
December	41.476	4.63	6.0	.97

$Y = A + A1 * E + A2 * E2$ ...... (2)

Where Y = wind speed (km/day);

E = elevation (meter); and

A, A1, and A2 = appropriate monthly constants.

Wind data have been generated for all the rainfall station sites for all the months. The estimated data have, however, been substituted by the recorded data where available. While checking the recorded and estimated wind values at higher elevations, it seems that the estimated wind speed is much higher in higher elevations. Therefore, the mean wind speed for Annapurna-Machhapuchre Base Camp, Langtan-Kyanggin and Kanjiroba meteorological stations have been tabulated for each month and used in the stations whose elevations are above 2500m. Considering the above criteria, the following wind speeds are considered for all the months and for all the areas in the range of 2500m to 4000m (Table 4).

Table 4: Mean Monthly Wind Speed Values (km/ day) for Sites having Elevation at the Range of 2500-4000m

JAN	FEB	MAR	APR	MAY	JUN
269	274	264	265	267	239
JUL	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
220	203	220	244	246	244

2.4 SUNSHINE HOURS

There were 16 meteorological stations, which have records of sunshine hours in the study area. Sunshine data are available only up to 1990 and all the available sunshine hours data have been tabulated for the study area as shown in the Meteorology Technical report No. 4 for the Institutional Development of Hydrology and Meteorology (TAHAL, 2002)

Nayava (1981) had established a relationship between the ratio of recorded sunshine hours (n) and possible sunshine hours (N) and related it to the monthly rainfall. There are 16 meteorological stations. These data show that more sunshine hours are observed in the Terai. The amount of sunshine hours slowly decreases in the Hill and Mountain Regions due the greater frequency of clouds in those Regions. Empirical relationships have been tested considering the ratio of n/N and rainfall at each of the sixteen places. While doing so the data of Thakmarpha Station did not give satisfactory results and therefore it was omitted from further consideration. As a result only 15 stations have been considered for the determination of constants for Equation 3. This empirical method is suitable to derive sunshine hours in the absence of real data for the Western Nepal.

While looking at the sunshine patterns in Western Nepal, the whole region was tentatively divided into 10 sub-regions, each of which was characterized by different sunshine hours patterns (Fig. 1).

Thus ten separate polynomial equations have been developed for each sub-region. The polynomial equation is as follows (Equation 3) and the variables for each equation and coefficient of determination (R2) are given in Table 5.

Y = A + A1 *P + A2 * P2 ……..……..(3)

Where Y = ratio of sunshine hours and day lengths (n/N) on a monthly basis;
P = rainfall (mm/month); and
A, B, C = monthly constants.

Table 5: Constants for the Sunshine Model

Group	A	B * 10^{-3}	C * 10^{-6}	R^2
1	0.63	- 0.5	100.0	0.85
2	0.74	-1.6	30.0	0.94
3	0.83	-4.6	0.1	0.91
4	0.48	-3.3	-’0.8	0.74
5	0.69	-0.9	30.0	0.90
6	0.79	-1.4	80.0	0.98
7	0.67	-0.5	10.0	0.94
8	0.66	-0.6	100.0	0.84
9	0.54	-5.0*10^{-3}	-70.0	0.77
10	0.75	1.3	70.0	0.95

2.5 EVAPOTRANSPIRATION

There are many empirical formulas to estimate evapotranspiration, but for Nepalese Condition, it is considered that Penman method gives the best estimates. “A limitation to use of Penman method in Nepal is the scarcity of meteorological records required. However, this can be overcome by the use of extrapolation models based on the work of Nayava (1981). And the model derives the estimates of temperature, dew point and sunshine duration for sites where only rainfall record are available” (MacDonald, 1982).

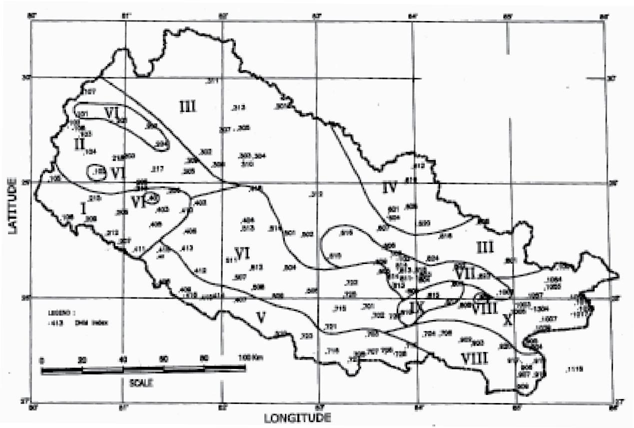

Figure 1. Sunshine hour groups in Western Nepal

Finally, these observed and estimated data of mean monthly maximum temperature, mean monthly minimum temperature, mean monthly relative humidity, mean monthly wind speed and mean monthly sunshine hours were used to compute evapotranspiration (ET_o) by the 'CROPWAT' software developed by FAO (1998) for all the 110 rainfall stations at the 77 selected basins under study. These all those data to compute evapotranspiration for all the selected 110 rainfall stations in the Western Regions of Nepal are given in the Meteorological Technical Report No.4 for the Institutional development of Hydrology and Meteorology (TAHAL, 2000). The evapotranspiration values have later used to estimate crop water requirements and this process have done by multiplying the crop coefficient factor and the evapotranspiration value. The crop coefficient varies with the crop variety and also varies at the stage of the crop growth cycle.

The evapotranspiration values were estimated for all the 110 rainfall stations for all the months in the Western Nepal. At each month, the evapotranspiration values were analyzed by SURFER program and here only the evapotranspiration for the months of coldest (January), the hottest (May) and mean annual evapotranspiration were presented for discussion.

In the month of January, evapotranspiration values were estimated 51 to 55 mm at the most part of the western Nepal and at the same time ETo values were estimated 53 to 71 mm in the Mountain regions of Jumla and Dolpo (Fig. 2).

In the month of May, ETo values were estimated 165 to 190 mm at the Terai, 130 to 185 mm at the Hill and 115 to 165 mm at the Mountain Region in the Western Nepal (Fig. 3).

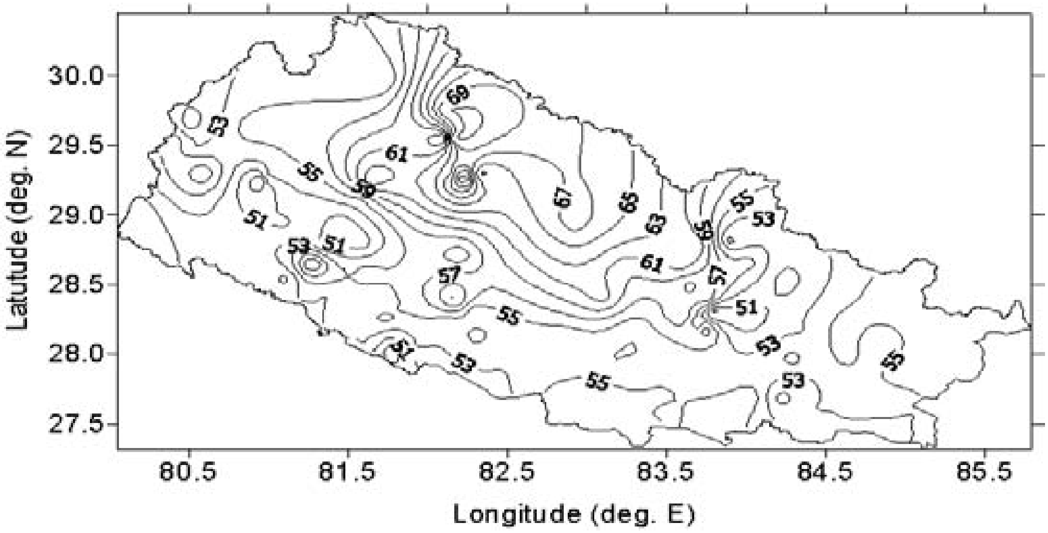

Figure 2. Mean Monthly Evapotranspiration (mm) for the Coldest Month, January in Western Nepal.

Similarly, Mean annual ETo values were estimated 1200 to 1350mm at the Terai, 1100 to 1300mm at the Hill and Mountain and 950 to 1100mm in the rain shadow area of Mustang areas in the Western Nepal (Fig. 4). It is very interesting to note that ETo were estimated 1200 to 1300mm in the Jumla and Humla areas and this is due to high wind in that Region.

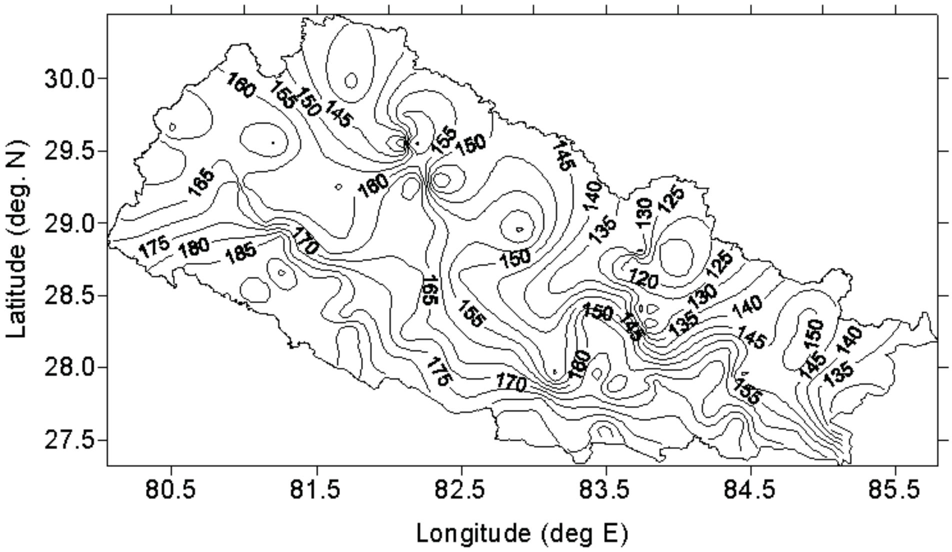

Figure 3: Mean Monthly Evapotranspiration (mm) for the Hottest Month, May in Western Nepal

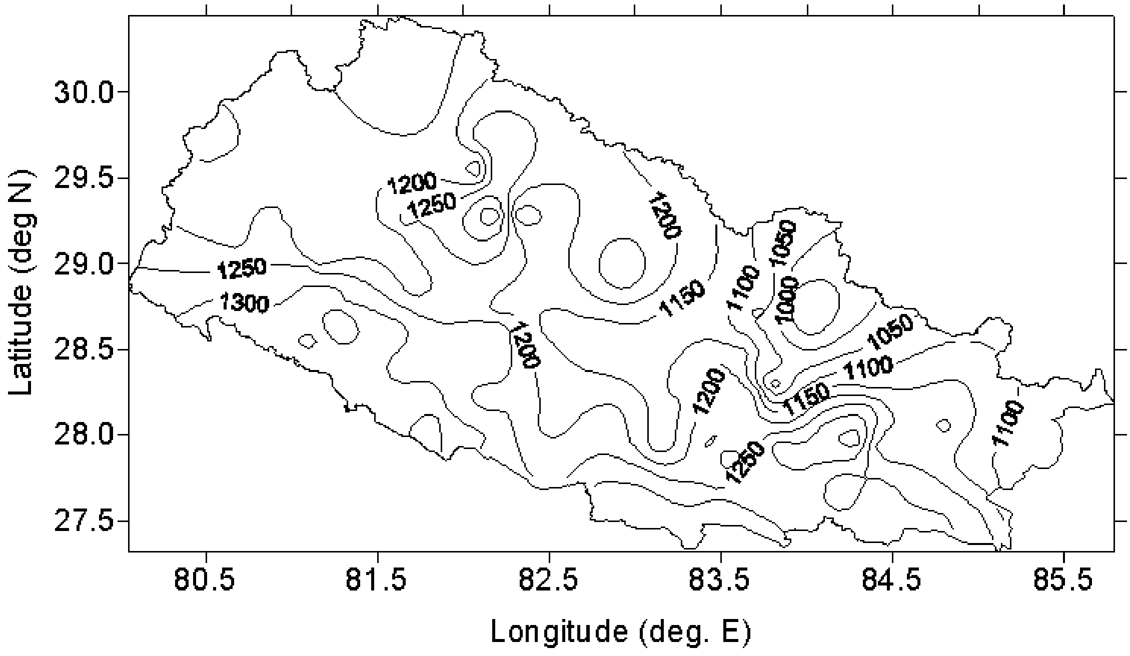

Figure 4. Mean Annual Evapotranspiration (mm) in Western Nepal

3. RESULTS AND DISCUSSION

Since the last two decades, the coverage of meteorological stations is better than the earlier and the models developed for temperature, wind and sunshine are quite encouraging. The estimated evapotranspiration are also compared with the Class A pan data and the results are very good and their relationships are shown in Fig 5.

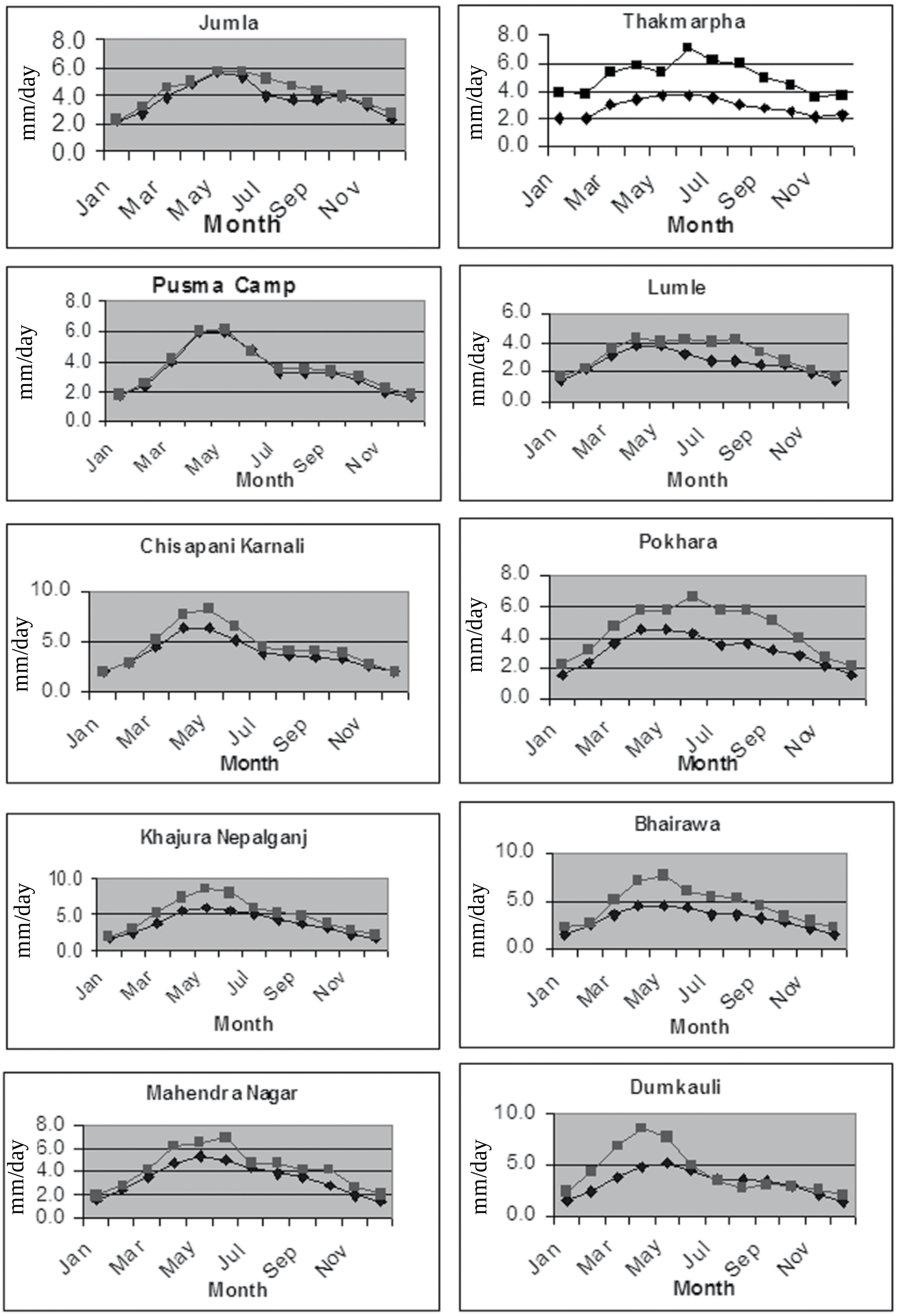

Figure 5. Comparision of mean monthly Class A Pan values with ETo (Penman-Monteith) values at selected places in Western Nepal.

The Penman and Monteith equations are described in all the standard textbook of agricultural climatology and Cropwat, FAO publications. Therefore, the equations are not presented here.

The higher values of ET_o as shown in Figures. 4 and 5 in Mountain Regions are due to aerodynamic effect. This phenomenon is better supported by the following explanation. It is known that the Penman equation consists of two terms, namely the energy term Qn and the aerodynamic term Ea. Stanhill (1962,B) explained the two terms are weighted according to mean air temperature as shown in Table 6.

Table 6. Weighting factors for the energy and aerodynamic terms in Penman Formula

Mean air temperature (^{o}C)	Energy term	Aerodynamic term
0	0.40	0.60
10	0.56	0.44
20	0.69	0.31
30	0.79	0.21
40	0.86	0.14

It is to note that the sunshine duration data are very sparse and very irregular and hope that this will improve in coming years by the concerned authorities.

4. ACKNOWLEDGEMENT

The author wishes to thank Tahal Consulting Engineers Ltd. for allowing me to write this article. The author is grateful to the Department of Hydrology and Meteorology for providing the manuscript to copy the unpublished data of wind and sunshine from 1991 to 1998.

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The analysis of wind speed values for the Western Nepal*

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Abstract: Wind speed is one of the most important parameter for estimating evapotranspiration(ETo). ETo is applied in various applications such as crop water requirements and water management studies. In Nepal, wind speeds required for such analysis are very scanty. However, wind speeds were measured at 24 meteorological stations in Western Nepal. Wind speed values were recorded at the different heights and these values were converted into standard 2 m height. When this study was undertaken, there were altogether 148 daily rainfall stations in Western Nepal. Out of that total 110 rainfall stations having sufficient data had selected for the hydrological studies. Thus, these values of wind speed at standard height are necessary parameters to estimate ETo for all the 110 rainfall stations.

All the available statistical approaches were tested for this study. Polynomial relation was found to be appropriate to estimate the wind speed values for all the twelve months at all rainfall stations below altitudes of 2566 m. At the higher altitude from 2567 to 3863 m, a tentative wind speed values were assumed for all the twelve months. At the same time, the observed and simulated wind values were used to prepare the spatial variations of wind at each month. These mean monthly maps of wind speeds will give the general pattern of wind at the study area.

Keywords: western Nepal, evapotranspiration, wind estimation

1. INTRODUCTION:

Wind speed and direction are applied in many agricultural and engineering works. Wind is one of the main factors in the study of air pollution and in locating new sites for industry, aerodrome and town planning. Windbreaks and shelterbelts can be made to reduce the serious damage of crops by wind. The knowledge of wind profile and the maximum speed of gust and direction are necessary for the construction of tall buildings, television towers and installation of high-tension wires from poles to poles. The choice of best site and best design of wind power installation is to large extent a climatological question. Similarly, the wind speed values are one of the main parameters to estimate evapotranspiration (ET_o) ,which is the basic parameter for estimating crop water requirements. In the past, water balance studies were conducted for Western Nepal. In those studies, wind data are one of the important parameters to estimate ET_o. However, due to a very thin network of wind stations in western Nepal, the study was primarily conducted from the wind data collected at few stations. Under the present situation when wind data are quite sparse, it is important to devise some methodology for extending wind data from a particular station to other stations for which estimation of ET_o is to be conducted.

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2. DATA USED:

During the end of 1970's, only 12 climatological stations used to observe wind in the whole of Nepal. Out of these 3 climatological stations were observed wind in Western Nepal. Due to the limited data, wind values were classified in three groups such as light, medium and strong winds (Nayava, 1981). MacDonalds (1982, 1992)) used the same three groups in their documents in Medium Irrigation Project, Design Manual, Hydrology and Manual in Irrigation Design and In Agrometeorology and Hydrology. Recently, WELINK (1998) had used only light wind in all their ET_o calculations in their Gandaki Water Basin Study.

There are 24 meteorological stations in the study area, where wind observations are made (Figure 1). Department of Hydrology and Meteorology (DHM) had published the wind data up-to 1998. The period of record varied from station to station. It was very difficult to consider the same period of data for all the stations. All the available wind data from 1967 to 1998 were computed. It should be mentioned that the data had recorded at different heights. The wind speed values for each station were converted to the standard 2 m height by using the proper conversion graph presented by MacDonald (1982). The converted wind speed values are presented in Table 1. The equation for conversion of wind from different height to the standard 2 m height is also given by Allen et al. (1998).

In addition to the observed data, the author conducted field survey, which included discussion with field staffs. Following information was collected during the survey. A strong wind prevails from midnight to late morning at Chisapani Karnali during October to March. At the same period, wind speed values are generally lighter in afternoon. During April to September, wind speed values are generally lighter except on a few occasions in April and May. It was also discovered that wind speeds are calm during the overcast days in Chisapani Karnali (see Wind data of Chisapani Karnali in Table 1).

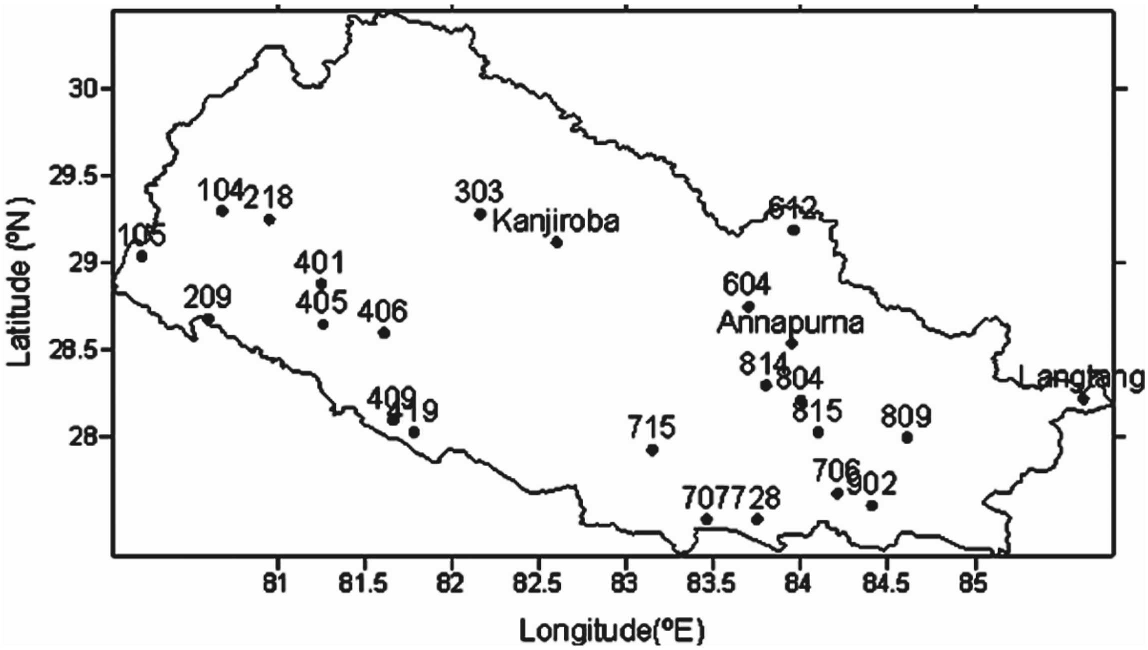

Figure 1. Wind networks in the Western Nepal.

Table 1. Wind data at 2 m height (m s^{-1}) in Western Nepal

Index	Station Name	Lat. (°N)	Long. (°E)	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Period
707	Bhairhawa (Agri.)	27.53	83.46	120	0.48	0.63	0.90	1.42	1.72	1.52	1.45	1.21	0.88	0.51	0.43	0.41	1986-98
728	Simari	27.53	83.75	154	0.58	0.70	0.96	1.47	1.48	1.31	1.23	1.00	0.88	0.53	0.39	0.45	1981-87
706	Dumkauli	27.68	84.21	154	0.20	0.50	0.80	1.00	0.70	0.50	0.30	0.20	0.10	0.10	0.20	0.1	1971-72
209	Dhanga-dhi	28.68	80.60	170	0.61	0.75	1.01	1.26	1.42	1.37	1.04	0.77	0.63	0.46	0.47	0.48	1989-98
105	Mahendra Nagar	29.04	80.22	176	0.48	0.61	0.74	0.95	0.96	0.79	0.77	0.64	0.52	0.42	0.40	0.43	1977-98
409	Khajura (Nepal-gunj)	28.10	81.66	190	0.50	0.84	1.08	1.46	1.82	1.85	1.45	1.19	0.84	0.53	0.43	0.54	1976-92
419	Sikta	28.03	81.78	195	0.46	0.56	0.84	1.08	1.22	0.85	0.48	0.32	0.44	0.50	0.33	0.39	1981-98
405	Chisapani Karnali	28.65	81.26	225	2.07	1.98	2.21	2.35	2.07	1.47	0.91	0.98	1.16	1.51	1.95	2.17	1968-98
902	Rampur	27.61	84.41	256	0.45	0.63	0.98	1.33	1.28	1.03	0.89	0.90	0.85	0.54	0.35	0.43	1978-98
815	Khairini Tar	28.03	84.10	500	0.42	0.54	0.70	0.81	0.76	0.72	0.58	0.53	0.50	0.41	0.36	0.34	1977-98
218	Dipayal Doti	29.25	80.95	617	0.26	0.44	0.57	0.82	0.94	0.94	0.70	0.47	0.49	0.54	0.41	0.24	1982-98
406	Surkhet	28.60	81.61	720	1.00	1.25	1.38	1.59	1.56	1.33	0.96	0.80	0.73	0.80	0.75	0.79	1975-98
804	Pokhara Airport	28.21	84.00	827	0.59	0.82	1.03	1.07	0.93	0.73	0.68	0.64	0.61	0.54	0.50	0.5	1987-98
401	Pusma Camp	28.88	81.25	950	1.05	1.37	1.86	2.29	2.30	1.42	0.74	0.66	0.78	0.95	0.92	0.88	1968-98
809	Gorkha	28.00	84.61	1097	0.72	0.88	1.08	1.10	0.99	0.66	0.52	0.68	0.67	0.69	0.65	0.72	1983-98
814	Lumle	28.30	83.80	1740	1.54	1.65	1.74	1.63	1.62	1.56	1.52	1.49	1.47	1.46	1.43	1.47	1970-98
715	Khan-chikot	27.93	83.15	1760	1.94	2.21	2.72	2.87	2.52	2.21	1.89	1.66	1.80	1.68	1.70	1.79	1977-98
104	Dadeld-hura	29.30	80.68	1848	1.99	2.19	2.42	2.44	2.54	2.12	1.88	1.75	1.76	1.99	1.82	1.9	1978-92
303	Jumla	29.28	82.16	2300	2.68	3.17	3.92	4.00	3.97	3.92	3.56	3.04	3.28	3.70	3.42	2.8	1978-84
604	Thakmar-pha	28.75	83.70	2566	4.25	4.60	4.32	4.03	4.34	4.76	4.68	4.39	4.06	3.69	3.79	3.89	1970-90
612	Mustang, Lomang-tan	29.19	83.96	3705	1.54	1.93	1.61	1.79	1.80	1.84	1.65	1.46	1.51	1.41	1.23	1.56	1984-90
	An-napurna (MBC)	28.54	83.95	3470	3.40	3.20	3.10	3.10	3.20	2.70	2.50	2.10	2.20	2.70	2.90	3.20	1987-96
	Langtang, Kyangjing	28.22	85.62	3920	2.80	3.10	3.10	3.10	3.00	2.80	2.60	2.60	2.50	2.90	2.80	2.10	1987-96
	Kanjiroba, Hurikot	29.12	82.60	3770	3.00	3.40	3.50	2.00	2.20	1.40	2.70	2.50	2.70	3.00	2.50	5.00	1992-96

Similarly, a higher wind speed experienced from afternoon to late evening at Dadeldhura during December to March. At the same place, a lighter wind prevailed during the summer months.

3. METHODOLOGY AND ANALYSIS

There are many theoretical methods to study the wind profile at different heights. A study of wind profiles for the adiabatic conditions had performed by Prandtl (1932) and similarly wind profiles for diabatic processes for natural conditions had studied by Deacon (1949). Many studies in wind profile had been studied by different authors (Monin and Obukhov, 1954; Swinbank, 1964; Panofsky and Townsend, 1964. For Nepal Conditions, it is very difficult to have one theoretical formula to cover such a vast range of altitude. However, the available wind data have been analyzed with many statistical packages to expand the wind speeds data for other stations, where wind observations are not available.

Various methods were tested to simulate the wind speed values where observed data were not available. Polynomial equations were found to be the best to estimate the wind at all rainfall stations below altitudes of 2566 m. Wind data from Chisapani Karnali, Mustang (Lomangthan), Annapurna, Langtang, and Kanjiroba stations were not included due to unsatisfactory results. The relation developed is given in equation 1 below. Values of constants and the coefficient of determination (R^2) for each month are given in Table 2.

$$Y = A + A1 * E + A2 * E2 \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where Y = wind speed (m s-1);
E = elevation (m); and
A, A1, and A2 = appropriate monthly constants.

The relationship between elevation and wind speed at the different months in Western Nepal are shown in Figure 2a and Figure 2b.

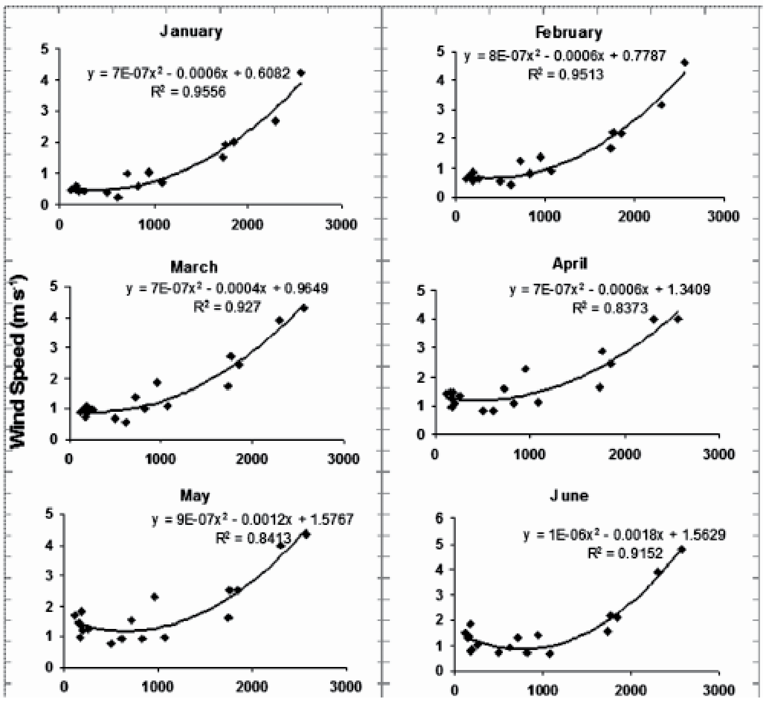

Figure 2a: The relationship between elevation and wind speed in months January to June in western Nepal

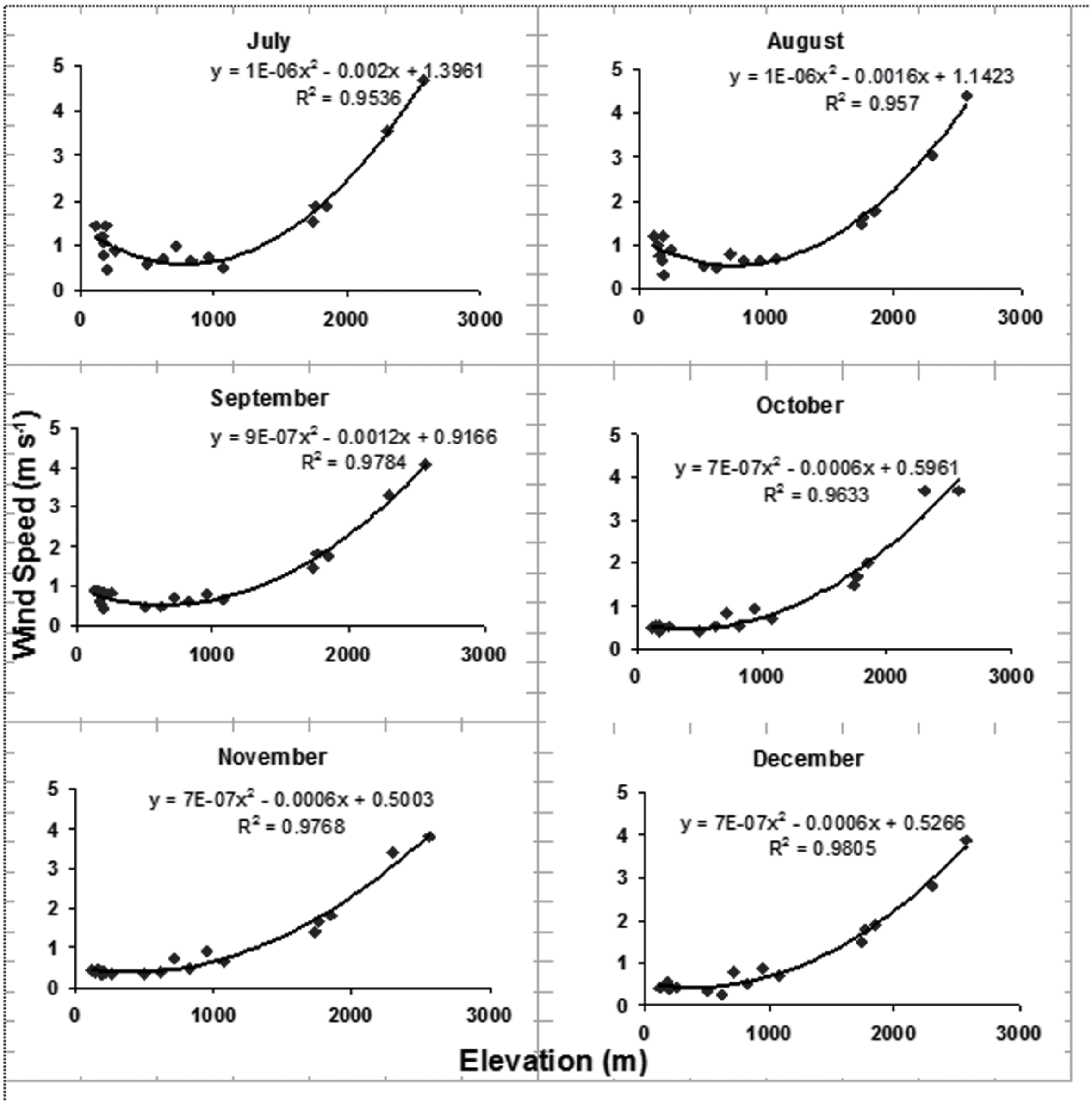

Figure 2b: The relationship between elevation and wind speed in months July to December in western Nepal

In the above wind model, the wind stations up to the elevation (2566 m) were considered and the highest station considered in the analysis was Thakmarpha. Therefore it is not recommended to estimate the wind by this model at higher elevations than the Thakmarpha. However, there are a few meteorological stations, which are higher than the Thakmarpha and therefore the wind values have to be assumed separately for higher altitude stations. Therefore, the mean wind speeds for Annapurna-Machhapuchre Base Camp, Langtan-Kyanggin and Kanjiroba meteorological stations,which are

Table 2. Constants of the wind model for Western Nepal

Month	A	$-A1 * 10^{-3}$	$A2 * 10^{-7}$	R^2
Januar	0.6082	0.6	7	0.96
Februa	0.7787	0.6	8	0.95
March	0.9694	0.4	7	0.93
April	1.3409	0.6	7	0.84
May	1.5767	1.2	9	0.84
June	1.5629	1.8	10	0.91
July	1.3961	2	10	0.95
August	1.1423	1.6	10	0.96
Septe	0.9116	1.2	9	0.98
Octobe	0.5961	0.6	7	0.96
Novem	0.5003	0.6	7	0.99
Decem	0.5266	0.6	7	0.98

situated at much higher elevation, are estimated separately for each month and those mean monthly values were used in the stations, whose elevations are above 2566 m. These estimated values are given in Table 4, which represents the wind speed values used for all the months and for all sites, whose elevation in the range of 2567 m to 3803 m, the latter being the elevation of the highest climatological station, Mugu.

The observed and simulated wind speed values for 110 rainfall stations in Western Nepal for all the months were prepared and analyzed by the SURFER graphical software. Here only the results of January and July are presented for discussion.

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In January as shown in Figure 3, the wind speeds were generally more than 2.6 m s^{-1} at the High Mountain Regions in the Western Nepal and at the same time, it showed more than 4.25 m s^{-1} at Thakmarpha. During that month, a few pocket areas such as Dadeldhura, Chisapani Karnali, Khanchikot and Daman indicated 2.0 m s^{-1}. In Terai area of Western Nepal, wind speed was less than 0.6 m s^{-1}

Similarly, in July as shown in Figure 4, the wind speeds at the High Mountain Regions in

Table 3: Mean monthly wind speed values (m s^{-1}) for sites Having elevation in the range of 2567-3803 m

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
3.08	3.23	3.19	2.71	2.77	2.31	2.59	2.40	2.59	2.86	2.71	2.82

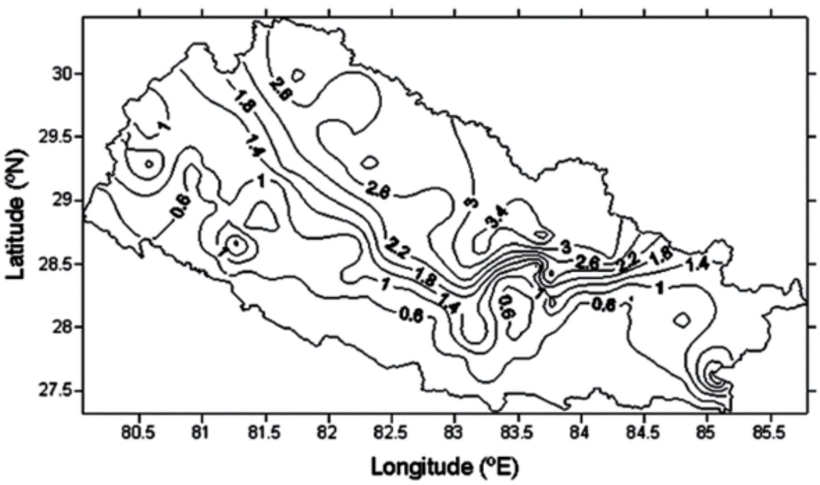

Figure 3: Mean Monthly Wind Speed (m s^{-1}) for the Coldest Month, January in western Nepal

Western Nepal were more than 2.2 m s^{-1} except Thakmarpha, where the wind speeds were observed more than 4.68 m s^{-1}. During that month, a few pocket areas such as Daleldhura, Khanchikot and Daman observed more than 1.88 m s^{-1} and the Terai observed 0.6 to 1.0 m s^{-1}.

4. RESULTS AND DISCUSSION:

Wind data have been generated for all the rainfall stations for all the months. The estimated data were, however, substituted by the recorded data where available. This study was a part of water resources studies in terms of irrigation planning at Western Nepal. Generally, planning of irrigation in very high altitude areas has very less priority and therefore a very crude tentative wind speed have been considered for the high altitude (2567 to 3803 m). For the other purpose, the tentative values may not be valid and therefore further research need to be done to solve the problem.

It was noted that the seasonal variations of wind speed occurred in all the places. The highest wind speeds were observed in April and May in all the stations except High Mountain areas where the high wind speed occurred during December and January. During this time, generally sub-tropical westerly jet-stream prevailed up to 500 mbs in the Himalayan Region. At the same time, significant diurnal variation also occured especially at wind pocket areas. It is understood that river valley of Chisapani Karnali, Bagmati at Karmaiya and Butwal experienced very high wind speed during the night time and in the contrary a very strong local wind occured in afternoon at Thakmarpha, Jomosom and Jumla. This type of local wind is created by the results of difference of heating and cooling between the surrounding mountains and the valleys. During the day, the air over the mountain heats up and in a narrow valley this may sets up an up valley winds(known as Anabatic wind) and at night the reverse occurs producing down valley winds (known as Katabatic wind).

Wind speed data are very much localized and its observation may not represent the area of study as a whole. Therefore, investigation has to be done in the study area to consider the best possible wind speed, which represents the study

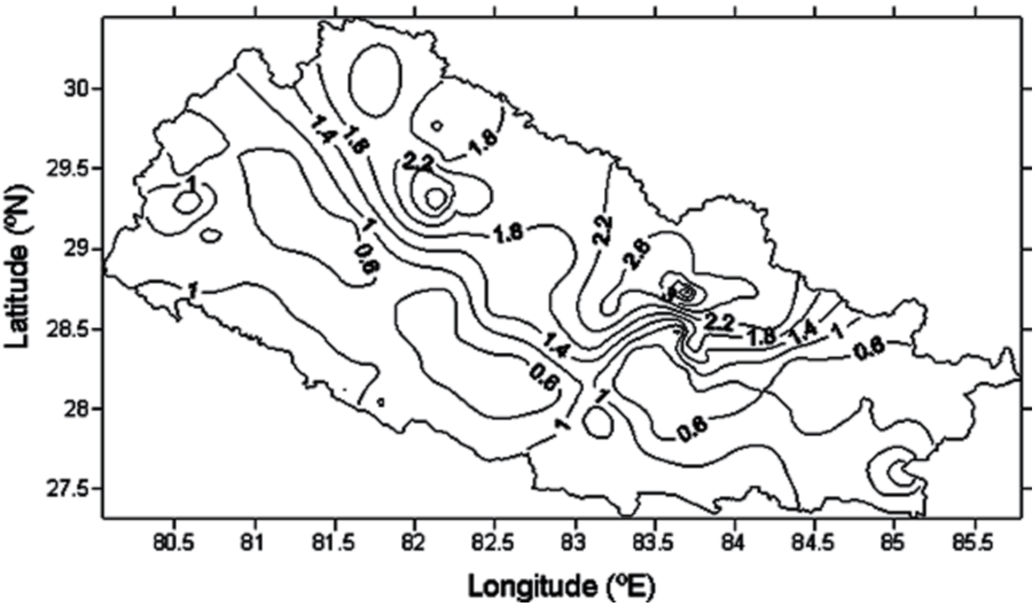

Figure 4: Mean Monthly wind Speed (m s-1) in July at the western Nepal.

area. Also the wind speeds play a secondary role in the estimation of ETo by Penman and Monteith equation and therefore the estimated wind values are quite satisfactory for the present analysis.

5. USIONS AND SUGGESTIONS:

More wind stations (manual and automatic) are necessary for better analysis of wind data in Nepal due to extreme topographical differences within a short distance. Sincere advice to the Department of Hydrology and Meteorology, Nepal take necessary initiate to process and publish their data regularly within the subsequent year.

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Variations of Rice Yield with Rainfall in Nepal during 1971 – 2000*

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ABSTRACT

This study attempts to show the relationship between rice yield and rainfall in Nepal during the period 1971-2000. During the period, there was a shortfall in rice production in almost 10 years showing the crucial relationship between rainfall and rice yield. The minimum deficit year accounts for 70,000 metric tons in 1997 compared to the previous year and maximum deficit accounts for more than 800,000 metric tons in 1982 compared to the previous year during the study period. In terms of monetary value, the deficit comes to US$ 13 million and US$ 120 million respectively during the minimum and maximum deficit years. Since rice occupies an important role in the national economy, a detailed study of rainfall and rice yield should be carried out.

Keywords: Rice yield, Rainfall, Nepal

1. INTRODUCTION

Water requirement of rice cultivation is greater than that of any other crops of a similar duration. It varies with the type of soil, climatic condition, cultural practices and the duration of the variety grown. On an average, the amount of water required for rice is 500–650mm depending upon the prevailing conditions such as solar radiation, temperature, growth duration, variety, location etc. Generally 4 to 5 mm of water per day is needed for evapotranspiration. Rice is grown in lowland as well as upland of Hills and Tarai region. According to the 2001 Census of Agriculture, the total cropped area under rice cultivation was 1.5446 million hectares. In percentage, it is 45.1% of the total cropped area under cereal grains. The land under irrigation is 1.1683 million hectares in 2001/2002, but how much the rice area under irrigation was not known. The rice is still the most popular cereal grain being cultivated by more than three-fourths of the total holdings. The area under rice is still increasing.

The contribution of agriculture sector to GDP is approximately 38% of which the rice weighs 20.75%. The dependency on agriculture in the country's economy is about 66% of the total population engaged in this sector (MoAC, 2006). Nepal, topographically divided into three ecological zones, namely, Tarai, Hills and Mountain, which has been further divided into Eastern, Central, Western, Mid Western and Far Western development regions.

Nepal is one of the unique places on the earth, where the land rises from 65 m to 8848 m, which is the highest place in the world. Therefore, Nepal experiences almost all types of climates owing to the topographical differences within a short distance. Generally 80 percent of rainfall occurs in the summer monsoon during June to September.

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The low land Tarai extends up to 610 m covering inner Tarai and foothills of Churia range. It comprises 23 % of land area and accommodated 48.43% of population in 2001. The Hills extends from 610 m to 4877 m and covers 42% of land area and accommodated 44.28% of the total population. Similarly, the Mountain covers 35% of land and accommodated 7.29% population of the country as shown in Figure 1 (CBS, 2006). According to the National Census of Nepal, 2001, population in Nepal was 23,151,423 and the population and land distribution at different ecological zones of Nepal is shown in Figure 2.

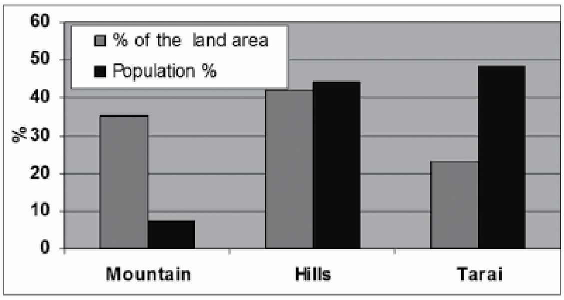

Figure 1: The distribution of land area and population in different ecological zones in Nepal

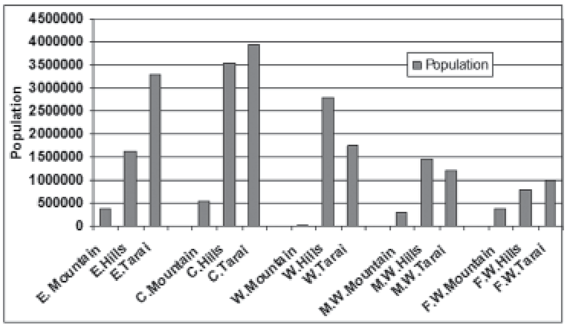

Figure 2: Population distribution at different regions in Nepal

2. RICE GROWING SEASON AND SUMMER MONSOON

The main rice growing season of Nepal falls during the months from June to October, which also coincides with the summer monsoon. Around 70 to 90 percent of annual rainfall occurs during the monsoon season from June to September. The summer monsoon starts from Eastern region of Nepal and after two to three days it reaches to the Kathmandu Valley (around 12 June), which lies in the Central region. Then onwards, and after a week or so, it covers whole Nepal. The timely onset of monsoon is very important as the transplanting of rice seedling depends upon the arrival of monsoon rain. The preparation of rice nurseries starts almost a month ahead of transplanting. If the monsoon is delayed or weak in nature, the seedling can be damaged. During the time of transplanting, the top soil should be submerged, otherwise transplanting will not take place. Generally 100-200 mm of water is required for puddling the wet soil. Therefore it is not only the onset of monsoon, the rainfall characteristics such as depth, frequency, intensity and distribution in time and space are all the important factors for the positive impact on growth of rice and for that matter entire agriculture. Taking into consideration the importance of monsoon rain, this study attempts to cover whole of Nepal both on regional and ecological basis with respect to variations of rice yield with rainfall during the period 1971-2000.

3. SCENARIOS

The rice cultivated area in different regions in Nepal is shown in Figure 3.

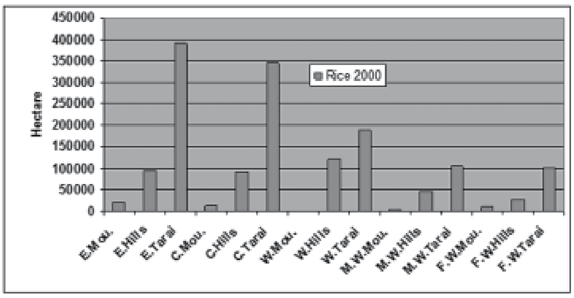

Figure 3: Rice cultivated in the year 2000 at different regions in Nepal

The simplified mathematical model of growth indices developed by Fitzpatrick and Nix (1970) was calibrated in the Nepalese environment by Nayava (1981) and the result is presented with the example of Rice Research Centre, Parwanipur data in Central Nepal (Figure 4a and Figure 4b). Due to the prevailing climates, the country can have two to three crops in a year in lower altitude. The main crop is cultivated in summer monsoon during the months from July to October; the second crop as wheat is cultivated from November to March and the third crop is cultivated from March to June. The second and third crops mainly depend upon irrigation application, other wise only one crop can be cultivated in rain-fed condition with optimum expected yield.

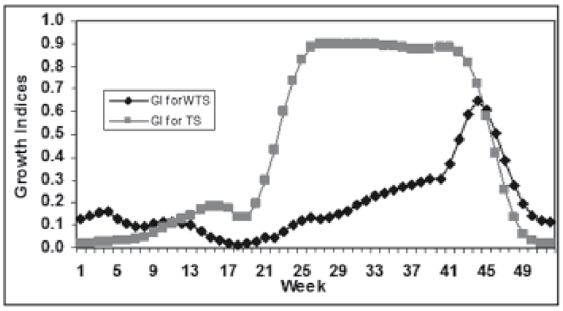

Figure 4a: Growth indices in Parwanipur at rain-fed conditions

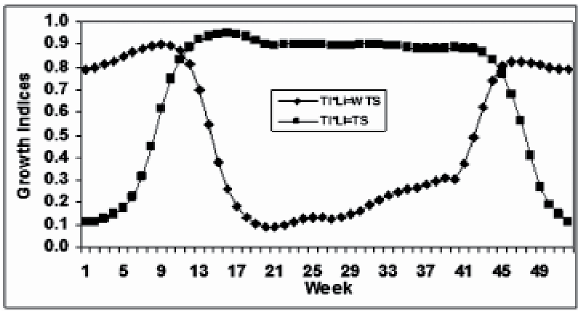

Figure 4b: Growth Indices in Parwanipur at irrigated conditions

The growth Indices (G.I.) considers light (LI), thermal (TI) and moisture regimes (MI) into a linear function with a scale ranging from zero to unity. In this analysis, growth indices (G.I.) have been defined as most favorable G.I. (higher than 0.8), fairly favorable G.I. (0.4 to 0.8) and least favorable G.I. (less than 0.4). The most favorable is the optimum climatic potential for cultivation where all environmental indices such as light, thermal and moisture have almost non-limiting condition for growth. However the moisture index greater than 0.9 is considered most favorable for rice cultivation. Therefore the presented Figure 4a and Figure 4b show that the three crops (two tropical species (TS) as rice and one warm temperate species (WTS) as wheat) can be easily managed if irrigation facilities could be extended.

4. FOOD SECURITY

Rice is grown on 45% of the total cropped area under cereal grains in Nepal. The success and failure of rice cultivation has significant impact on Nepalese economy as well as food security in Nepal. Generally, Tarai region is self sufficient in food but due to poor networks of road in Hills and Mountain, most of the districts of Hills and Mountain have food deficit. National Agriculture research Council (NARC) has developed 11 varieties of early rice and 38 varieties of main season rice depending upon the local climate (NARC, 2005). Traditionally, Nepal cultivates rice even in high elevation located area, such at Jumla, 2300 m from mean sea level.

5. DATA

This study has used thirty years (1971 - 2000) of monthly rainfall for the selected 170 rainfall stations in Nepal. These data were made available from Department of Hydrology and Meteorology (DHM). Source of the rice data is the Department of Food and Agricultural Marketing Services (DFAMS), Nepal Planning Commission (NPC), Central Bureau of Statistics (CBS) and Ministry of Agriculture and Cooperatives (MoAC). The analysis has been conducted at three levels: National, Development region and Ecological zones level. However, in order to save the repetition the analysis of Central development region and Western development region has been shown in one place and Mid-Western development region has been merged with the Far Western development region. In addition to consider the rainfall and rice yield for thirty years, the other available data has been considered up to the 2005/06. Initially, the thirty years of rainfall and crop data were used for the study. While the study was on progress, the crop data were available till 2005/06 and rainfall data were not published for that period and therefore the available data were used for the analysis.

6. ANALYSIS

6.1 NATIONAL LEVEL

While observing the rice yield in Nepal during 1971 to 2000, there is clear indication of sharp reduction of the rice yield in the years **1972, 1976, 1977, 1979, 1982, 1986, 1992, 1994, 1997** and **1999** as shown in Figure 5. At the same period, the deficit of monsoon rainfall from the normal rainfall (1450mm) was clearly shown in **1972, 1977, 1979, 1982, 1983, 1986, 1990, 1991, 1992, 1994** and **1997**. This shows that there is a positive correlation between rainfall and rice yield. Whenever the rainfall is below normal, there is deficit of the rice yield in Nepal. This phenomenon was prevailed throughout the study period except in 1999, where the rice yield was increased despite the monsoon rainfall below the normal.

Similarly, the increment of yield is due to use of high yielding seeds, which occupy 71% of the cultivated area during 1999/2000 (MoAC, 2000). The area with improved seeds has gone up to 85% during 2005/2006 (MOAC, 2006). The higher yield is also due to the improved management practices of cultivated land and smaller land holding size with increase in population. The following Figure shows a positive correlation between rainfall and rice yield (Figure 5).

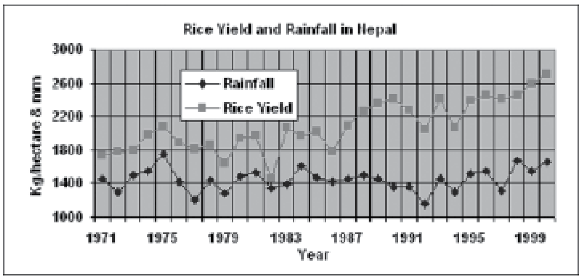

Figure 5: Rice Yield and Rainfall in Nepal

It is not only the increase of rice yield after 1995, the area of rice cultivation has also increased after 1994/1995. During that period, the cultivated rice area was 1,42,0920 hectares. This cultivated area was gone up to 1,56,0044 hectares during 2000/2001. During those six years, the cultivated area of rice has been increased to 139,124 hectares. Recently, the rice area has been increasing, but the reasons of increasing the cultivated area of rice are not clear. During 1990/1991 the rice yield was about 2400 kg/hectare and the rice yield was more than 2700 kg/hectare during 2000/2001.

According to the Ministry of Agriculture and Cooperatives and the Central Bureau of Statistics, increased area of rice cultivation is due to double cropping of rice, but Agriculture Census 2001/2002 do not tally their argument. This sudden increase rice area is mentioned in Monograph, Agricultural Census, Nepal, 2001/02. The report mentioned that the increase of rice area may have come from non –agricultural land, some may have come from land under permanent pasture (CBS, 2006).

It is interesting to note that rainfall pattern and yield are very close to each other from the early 1970's to 1986 as shown in the Figure 5. After 1986, the gap between rainfall and yield are far more than earlier part. This may be the improvement of technology of producing a better yield.

6.2 REGIONAL BASIS

6.2.1 EASTERN REGION OF NEPAL

The rice yield in the Eastern region of Nepal for the period 1971 to 2000 was tabulated along with the rainfall in the Eastern region for the same period for 27 stations and plotted in Figure 6. This also shows that the deficit of rice yield coincides with the below monsoon normal rainfall.

The rice area, production and yield for the eastern region for the last three decade and the latest data on rice 2005/06 are shown in Table 1. The table shows that the increase of area was noted during 1990/91 to 2000/01 and the increase of yield was also observed during 1990/90 to 2000/01.

Table 1: Rice area, production and yield in the Eastern region

Year	Area	Production (M tons)	Yield (kg/ha)
1980/81	460202	872109	1895
1990/91	463405	1045852	2257
2000/01	505514	1393288	2756
2005/06	508122	1421046	2797

6.2.2 CENTRAL AND WESTERN REGIONS OF NEPAL

The rice area, production and yield for the Central and Western regions for the last three decades and the latest crop data 2005/06 are shown in Table 2. The area of rice in the Central and Western regions during 1990/91 to 2000/01 was increased and the yield in the Central and Western regions was noticeably increased during 1980/81 to 1990/91.

The rice yields in the Central and Western regions of Nepal were also plotted in Figure 7a and Figure 7b. This shows that the deficit of rice yield in the Central region was observed in 1977, 1982, 1986, 1992, 1994 and 1998. At the same period the deficit of rice yield in the Western region were observed in 1977, 1979, 1982, 1986, 1991, 1992, 1994 and 1997.

The higher yield of rice was observed in the Central region. One of the reasons may be due to higher input of fertilizer use, which was made possible by an easy access of road facilities in Tarai, Hills and Mountain in the Central region compared to the other regions of Nepal. During 2002/03, the sales of chemical fertilizer were 107, 19376 and 51263 M.Tons in Mountain, Hills and Tarai regions in Nepal. The sales were 84%, 80% and 32% respectively in Central Mountain, Central Hills and Central Tarai (MoAC, 2003). The road network has made possible to transport fertilizer in this region manifested in higher sales compared to other regions.

6.2.3 MID WESTERN AND FAR WESTERN REGIONS OF NEPAL

The rice area, production and yield for the Central

Table 2: Rice area, production and yield in the Central and Western regions

Year	Central			Western		
	Area (ha)	Production (M.tons)	Yield (kg/ha)	Area (ha)	Production (M.tons)	Yield (kg/ha)
1980/81	436729	881336	2018	289801	556981	1922
1990/91	433778	1163961	2683	286063	664310	2322
2000/01	448340	1285108	2866	309550	798939	2581
2005/06	432740	1225238	2831	312209	789977	2530

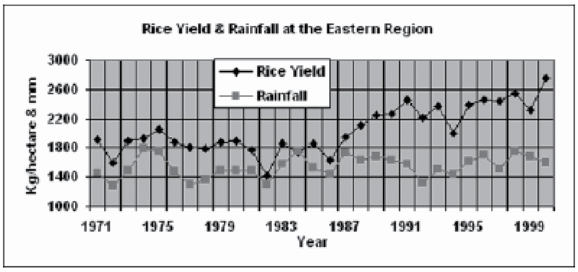

Figure 6: Rice Yield and Rainfall at the Eastern Region

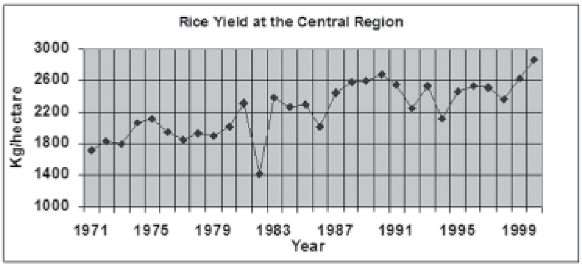

Figure 7a: Rice yield at the Central region

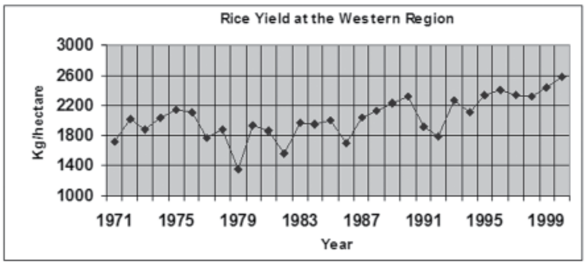

Figure 7b: Rice yield at the Western region

and Western regions for the last three decades and the latest crop data 2005/06 are shown in Table 3. The rice area was increased from 1980/81 to 1990/91 and also increased to 2000/2001in both Mid Western and Far Western regions and similarly the yield was also increased in both the regions.

Table 3: Rice area, production and yield in the Mid Western and Far Western regions

Year	Mid Western			Far Western		
	Area (ha)	Production (M.tons)	Yield (kg/ha)	Area (ha)	Production (M.tons)	Yield (kg/ha)
1980/81	128895	254357	1973	118443	208599	1761
1990/91	144757	336905	2327	124972	286583	2293
2000/01	157662	414080	2626	138978	325050	2339
2005/06	156094	427912	2741	140282	345106	2460

The rice yields in the Mid Western and Far Western regions of Nepal were also plotted in Figs. 8a, 8b. This shows that the deficit of rice yield in the Mid Western region was observed in 1979, 1982, 1984, 1986, 1991, 1992, 1994 and 1997. At the same time, the deficit of rice yield in the Far Western region were observed in 1972, 1974, 1977, 1979, 1982, 1987, 1992, 1994, 1997 and 1999.

While looking at the trend of rice yield in all the five regions of Nepal, the deficit of yield occurred more in the Eastern and the Far Western regions but the Far Western region seemed more affected than the other regions of Nepal. This could be because of the deficit of monsoon rainfall below the normal rainfall in 1972, 1974, 1977, 1979, 1982, 1987, 1990, 1992, 1994, 1997 and 1999.

6.3 ECOLOGICAL ZONES

There are three distinct ecological belts in Nepal, namely Tarai, Hills and Mountain. The cultivated rice area, production and yield for three decades and latest crop data during 2005/06 are shown in Table 4.

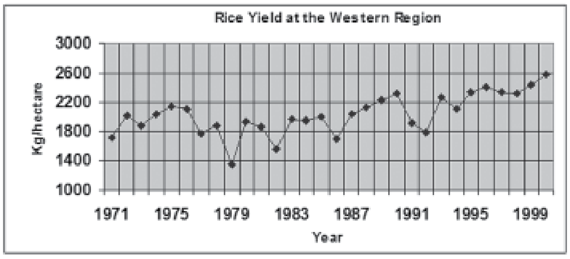

Figure 8a: Rice Yield at the Mid Western Region

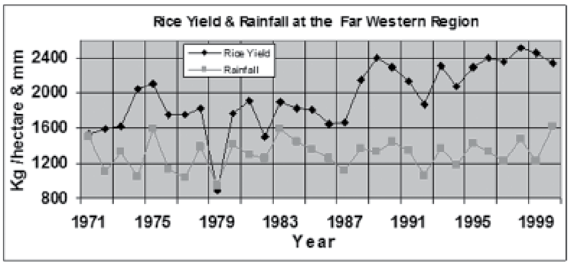

Figure 8b: Rice Yield and Rainfall at the Far Western Region

Mountain has the decreasing trends of rice yields (Figure 9).

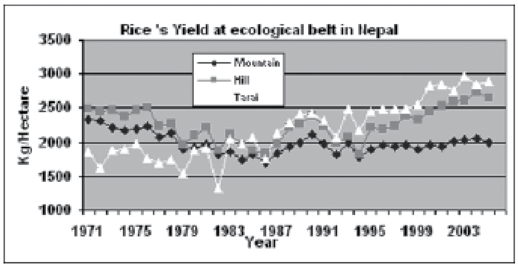

Figure 9: Rice Yield at ecological zones in Nepal

Looking at the trend of rice yield during 1971 to 2000, the yield seemed to be almost similar (say as less than 2000 kg/hectare) from 1971 to 1986 except an abrupt decrease of yield when rainfall was below normal in some years. From 1987 to 2000, the rice yield increased from 2000 to 2400 kg/hectare. The causes of recent increment of yield is attributed to the uses of high yielding seeds, which has been confirmed by personal discussion with the concerned authorities as has been mentioned elsewhere earlier.

Table 4: Rice area, production and yield in three ecological belts

Year	Mountain			Hills			Tarai		
	Area (ha)	Prod. (M.tons)	Yield (kg/ha)	Area (ha)	Prod. (M.tons)	Yield (kg/ha)	Area (ha)	Prod. (M.tons)	Yield (kg/ha)
1980/81	38177	72828	1908	339718	712269	2097	1056175	1988216	1882
1990/91	39727	83810	2110	345098	821085	2379	1068150	2592716	2427
2000/01	52892	103651	1960	379039	931442	2457	1228113	3181372	2820
2005/06	64676	128658	1989	381591	1011218	2650	1103180	3192024	2893

In course of the studying of the rice yield in the different ecological belts, the Hills regions have shown a distinct deficit in 1979, 1982, 1986, 1992 and 1994. Nonetheless, Tarai also shows a deficit along with the Hills region in 1972. The Mountain region shows a deficit in 1977. No change was marked in the Hills region.

It is interesting to note that the rice yield in the Tarai is in increasing trend, while in the Hills the trends of rice yield had first decreased and then increased after 1986. The

The rice production in Nepal during 1971 to 2000 was presented in Figure 10. During the deficit years, the production shortfall of rice varies from 70,000 metric tons to eight hundred thousands metric tons in Nepal. In terms of monetary valuation, it varies from more than US$ 13 million (NRs. 837.5 million) to US$ 123 million (NRs. 8028.5 million) per year depending upon the severity of

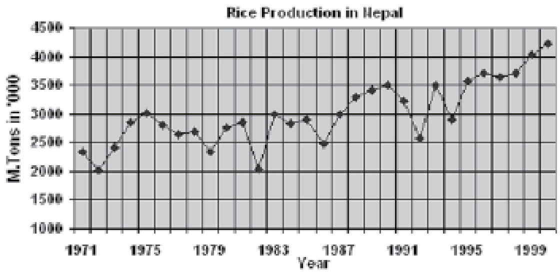

Figure 10: Rice Production in Nepal

deficit of rainfall compared to the normal rainfall. At present Nepal produced rice worth of more than US$ 789 million (NRs. 50511.4 million). Therefore, the impact of rainfall on rice yield and production is very important subject in the present scenario. Thus, a detailed study of rainfall has to be considered. The results will certainly benefit the future planning and will save millions of dollars.

7. DISCUSSION AND SUGGESTIONS

Despite the claim of the Government of Nepal that one third of the cultivated land have been brought under irrigation, rice cultivation in Nepal is still very much dependent upon the rainfall. Had it been so, the rice production in the country should not have fluctuated with the rainfall as the study has shown. Irrigation in Nepal is mostly from the rain fed rivers, which tend to dry in case of low rainfall creating problem in irrigating the rice field.

It is very interesting to note that there is association between weak rainfall in Nepal and El Nino phenomenon, a periodic oceanic event strongly linked to large scale atmospheric oscillation. Various researchers have worked out the variation of El Nino and rice production in Nepal over the period 1960-1997 (Gill et al., 1998). They have shown the years 1972, 1977, 1979, 1982, 1986, 1992 and 1994 are bad years in terms below normal rainfall which also coincides with the low rice production years. Therefore a collaborative work between the various stake holders including Department of Agriculture and Department of Hydrology and Meteorology is necessary.

Therefore the study of rainfall and rice yield should be studied in detail to see when, how and where the rice yield had been affected and what measures can be adopted to minimize the future loss of rice yield in Nepal. Gill et al. (1998) also pointed out that there is a low rainfall cycle in every ten years which mostly effected the Eastern region in the years 1962, 1972, 1982 1992 and 2002.

During those years the late onset of rainfall had occurred and the planted area of rice especially in the Eastern Tarai was reduced compared to the previous year. Therefore, the future study should not only be confined to rainfall but should also consider the detailed relationship between climatic parameters and rice yield at the district level considering all the relevant information from crop growth cycle. Under these conditions, the effect of climate change on agriculture will also be better understood and can be better planned for better management of agriculture system in future.

8. CONCLUSION

The study of rice yield and the monsoon rainfall for the last 30 years from 1971 to 2000, through crude analysis, showed that the rice yield in Nepal was badly affected in ten years, particularly, in the years 1972, 1976, 1977, 1979, 1982, 1986, 1992, 1994, 1997 and 1999. During those years, the monsoon rainfall was lower than normal. Therefore, the impact of rainfall on rice yield and production is quite evident. As such, it is a burning issue in the present scenario. The general observations of the rainfall, rice area and rice production in Nepal during those years are given below:

Year	General Remarks
1972	Late onset and very weak rainfall during onset/ reduced area of rice in the Eastern and Central regions. Finally lower production of rice was observed in those regions.
1976	Poor distribution of rainfall during September, especially in all the Western regions. Production of rice was noted lower in the Western regions.
1977	Late onset and poor distribution of rainfall in September. Rice production is effected Generally in the Eastern and Central regions.
1979	Late onset, early withdrawal and poor distribution of rainfall in the Western regions. Very badly decreased the rice production in the Western regions.
1982	Late onset and poor distribution of rainfall during August in the Eastern region. Reduced area of rice planted and lower production of rice was observed.
1986	Poor distribution of rainfall during August and September in all the Western regions. Badly effected rice production in the Western regions.
1992	Late onset and weak rainfall during August and September in the Eastern region. Reduced area of rice and lower production were noted.
1994	Over all very poor monsoon rainfall in Nepal. Reduced rice production was noted in Nepal.
1997	Weak rainfall distribution in the month of August in the Eastern region. Reduced rice production.
1999	Poor distribution of rainfall in September in the Eastern region. Reduced rice production.

Recently, the El Nino events are predicted a few months ahead by World Meteorological Organization. Seasonal rainfall forecast is also issued by different International agencies. Usefulness of this kind of information to the agricultural activities in Nepal should be explored. At the same time the collaborative works between the concerned Departments should be stressed to study the rainfall and rice yield in Nepal.

ACKNOWLEDGEMENTS

The author wishes to dedicate this article to Professor Henry Nix for his valuable guidance to do the climatological models and crop weather modeling during my research period in the late 1970's in the Australian National University, Canberra. The author wishes to thank Professor, Dr. Kanhaiya R,B. Mathema, Central Department of Economics, Tribhuban University, Mr Rabi Singh, former Deputy Director General, CBS and Mr B.M.S, Basnyat, Principle Scientist, NARC for his valuable comments and suggestions in this paper. The author wishes to thank Mr. Tung S. Bastola, Director General, Central Bureau of Statistics and Mr. Hem Raj Regmi, Senior Statistician, Ministry of Agriculture and Cooperatives for fruitful discussions about the recent increase of rice area and yield.

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Impact of climate, climate change and modern technology on Wheat production in Nepal: a case study at Bhairahawa*

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ABSTRACT

The relation between climate and wheat production in Nepal was studied for the period 1970/71-2007/08. Due to the topographical differences within short north-south span of the country, Nepal has wide variety of climatic condition. About 70 to 90% of the rainfall occurs during the summer monsoon months (June to September) in Nepal and the rest of the months are almost dry. Wheat is cultivated during the dry winter period and therefore, the supplementary irrigation plays a vital role in its cultivation. Varieties of wheat have been developed to suit the local climatic conditions. Due to the availability of improved seeds, modern cultivation practice and a supplementary irrigation; the wheat cultivation has increased substantially throughout Nepal. The national area and production of wheat has remarkably increased from 228,000 ha to 706,481 ha and 193360 mt to 1,572,065 mt during 1970/71 to 2007/2008 respectively. Future planning to increase the wheat production in Nepal should give due consideration to the effect of global warming also. The present rate of annual increase of temperature was 0.06^{0}C in Nepal. Trends of temperature rise were not uniform in Nepal. An increase of annual temperature at Bhairahawa during 1970-2008 was only 0.018^{0}C. However, the wheat growing seasons at Bhairahawa, the trend of annual maximum temperature during November to April was -0.0068^{0}C during the study period. Though modern facilities such as irrigation, improved seeds and fertilizers are available to some extent, weather and climate still plays an important role in the increase of area and production of wheat in Nepal

Keywords: climate change, plain low land (phant), global warming, trend

1. INTRODUCTION

For any crop grown in an area, it is better to have description of physiographic, types of soils and their field capacity and climates of the area. Due to the topographical differences at the shortest distance almost all types of climates prevail in Nepal. In Nepal wheat is grown in the temperate climate and subtropics. Wheat is the third largest cereal crop in Nepal. Now the country produces 1.57 million mt and exports wheat to the other countries.

It is desirable that the minimum and maximum temperature during the wheat growing period should be 3^0 C to 32^0 C respectively and the mean

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daily temperature for optimum growth is between 20⁰C and 25⁰C(Briggle, 1980). Knowledge of genetic characteristics and particularly growth and development pattern of wheat varieties is essential for meeting the combination of various climatic requirements for growth development and yield formation. It is known that the upper limit of crop production is set by the climatic condition specially temperature regimes and the genetic potential of the variety grown. The extent to which this limit can be reached will always depend on how finely the engineering aspects of water supply are in tune with the biological needs for water in crop production (FAO, 1979). For higher yields, water requirements are 350-500 mm depending on climate and length of growing period in Nepal. There should be adequate water during the establishment period. Water deficit during the filling period results in reduced grain weight. However, during the ripening and drying–off period, rainfall or irrigation have negative impact on the yield. The area under wheat cultivation in different regions of Nepal is shown in Figure 1. For administrative purposes, the country is divided into five Regions. Each Region has Tarai, Hills and Mountain.

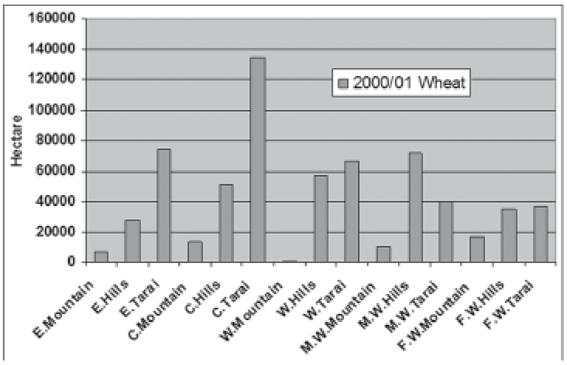

Figure 1: Wheat cultivation in the different regions in Nepal

2. DATA

This study has used thirty eight years (1970/71 – 2007/08) of crop data in Nepal. Weather data were made available by the Department of Hydrology and Meteorology (DHM). Source of the wheat data is the then Department of Food and Agricultural Marketing Services (DFAMS), Nepal Planning Commission (NPC), Central Bureau of Statistics (CBS) and Ministry of Agriculture and Cooperatives (MoAC).

Taking into consideration the winter rainfall and the growing season of wheat, this study attempts to cover whole of Nepal and three ecological belts and a case study at one National Wheat Research Centre at Bhairahawa in Tarai, where the irrigation facilities are available.

3. ANALYSIS

3.1. NATIONAL LEVEL

While observing the wheat yield and their production in Nepal during 1970/71 to 2007/08, the area was about 228,400 (Two hundred twenty eight thousands and four hundred) hectare during 1970/71 and in 2007/08, the area has increased to 706,481 (seven hundred and six thousand four hundred eighty one) hectare. There is clear indication that the area under wheat cultivation has increased more than three folds in 2007/2008 during the study period. The wheat production was 193,360 (one hundred ninety three thousand and three hundred sixty) mt in 1970/71 and now the production is 1,572,065 (on average 1.57 million) mt in 2007/08. The wheat production during the study period of 1970/71-2007/08 has increased more than eight fold. The wheat production during 2008/2009 will be much lower in Nepal compared to the previous year due to the long period of dry spell and warm period during this wheat season. Especially, wheat depended on rainfall would be badly affected in Hills and Mountain in Nepal.

National Agriculture Research Council (NARC, 1997) mentioned that performance in wheat production in Nepal has increased remarkable due to wide spread cultivation of high yielding varieties since 1972. Although attempts on variety development were initiated since late fifties, the systematic breeding works began only after the establishment of National Wheat Development Program in 1972. In fact Department of Agriculture had launched a "Grow More Wheat Campaign" in 1965/66 with the introduction of Mexican wheat varieties introduced via India. The new varieties of seed were launched since then and now occupy 96% in 2006/2007(MOAC, 2006). There are altogether 30 varieties developed for different environment in Nepal (NARC, 2007). The national wheat area and production from 1970/71 to 2007/08 are shown in Figure 2. Initially during the first decade, the yield was almost constant and in the later part the yield increased to more than 2 mt per hectare as shown in Figure 2. This is clearly due to improved modern technology and adoption of high yielding varieties as well as supplementary irrigation.

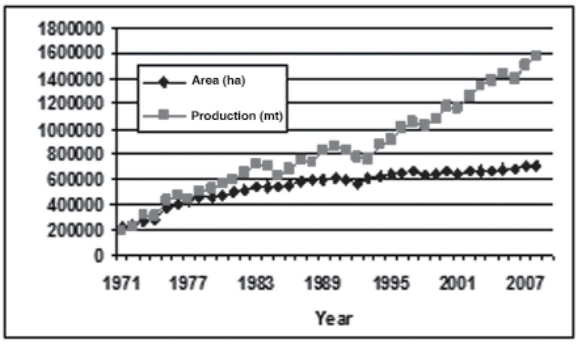

Figure 2: The National wheat area and production

The Department of Irrigation have claimed that there are more than one million hectares was irrigated in Nepal during 2007/08 (MOAC, 2008). Traditionally there are a hundreds of small temporary water channels managed by local farmers since long before. It is estimated that as of 2002 government agencies and farmers have developed irrigation infrastructure covering about 1,121,441 ha. Of this farmer managed but intervened by Department of Irrigation system cover about 59%, farmer managed system(not yet intervened) cover 27% and the rest 14% area is irrigated by those farmer managed irrigation systems supported by ADB/N (Sharma, 2004).

Recently available data reveals that net command area of government assisted farmer managed systems is 334,237 ha and area farmer developed and farmer managed systems is 276,219 ha. Furthermore, area under ground water projects (most of them managed by farmers) is reported to be 230,275 ha area irrigated by Agency Managed Irrigation Systems (AMIS) is 280,710 ha (DOI, 2004). It will be interesting to find out that how much different irrigation systems had all year round facilities and how much irrigated systems had a capacity of serving irrigation in winter time.

There was the special program on Food Production in support of Food Security In Nepal (SPIN) implemented by the Departments of Agriculture and Irrigation and FAO in several irrigation systems of two hills (Syangja and Ilam) and two Tarai (Nawalparasi and Jhapa) districts during 1995 to 1998. The study showed that the wheat crop yield showed an increase of 110% over the base yield with the introduction of improved package of technology (Sharma 1998).

By the end of this century, the average increase of temperature is either to be between 1.5^{0}C to 4.5^{0}C in the world (IPCC, 2007). It is interesting to know that the annual warming in the Himalayan region between 1967 and 1994 was 0.06^{0}C. Trends of temperature rise were not uniform in Nepal, but the Himalayan region seemed to have much more increase of temperature than the lower elevation (Shrestha et al. 1999). Retreat of glaciers and forming the new lakes are a fresh example of global warming affect in Nepal. Bursting the glaciological lake means flooding followed the disaster of that area. This is a really hot topic and understanding the holistic system of Himalayan water and their future role of water supplies for agriculture and hydro power and so and so for. There seemed to be no fixed pattern of annual rainfall in Nepal except slightly decreasing trend in the Far Western Nepal and the intensity of rainfall appeared to increase (Nayava, 2004). The inter-annual variation of monsoon rainfall and their affect in rice yield and production are very interesting and the lesson can be learnt for those studies (Nayava, 2008).

3.2. ECOLOGICAL BELTS

The wheat area and production in three ecological belts are as follows:

MOUNTAIN

In course of studying wheat cultivation in three ecological belts, the Mountain region showed that the increase of area has almost doubled and the yield increased to the little above 50% during the last 38 years. The gap of the area and production showed a change after 1995 in the Mountain (Figure 3). This can be attributed to the improvement of technology of wheat farming as shown in Figure 3. The production of wheat in the Mountain region increased from 28,900 mt to 83,739 mt during the last 38 years from 1970/71 to 2007/08. During the wheat growing season (November to May) in the Mountain region, the rainfall is about 150 t0 250 mm, but the nature of rainfall was very erratic. The average annual temperature during the growing season in Mountain was 6^0C to 18^0C. The annual temperature trend in the Mountain region at selected place in Jumla, 2300 m was observed only 0.035^0C during the 1977-2008. In fact Mountain region as defined include only 7.6% of the total wheat area and contributes 5.3% of the total wheat production in the country.

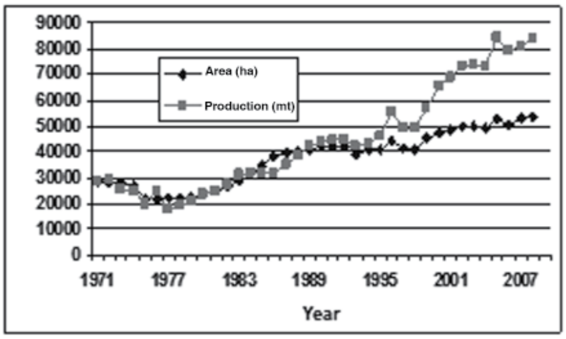

Figure 3: The wheat area and production in Mountain

HILLS

During the wheat growing season (November/ December to April/May) in the Hills Region, the rainfall is about 100 to 200 mm with higher distributions in the Western Hills than the Eastern Hills. Therefore, the cultivation of wheat area is more in the Western Hills than the Eastern Hills as shown in Figure 2. Mean annual temperature during the growing period in the Hills ranged from 9^o C to 24^o C. The annual temperature trend in the Hills Region at selected places in Surkhet was observed only 0.028^o C during the 1977-2008. The Hills region showed nearly three fold increase of area and the yield showed 100% increase during the same period from 1970/71 to 2007/08. The gap of the area and production showed a change after 1988 in the Hills (Figure 4). The production of wheat in the Hills region increased from 82,800 mt to 447,791 mt during the study period. In fact Hills region as defined include only 34.57% of the total wheat area and contributes 28.5% of the total wheat production in the country.

In the mid Hills, there is significant area under wheat that is very similar to Tarai in terms of varieties grown. For example Tarai, Tars and many river basin areas of mid Hills, Tarai varieties are grown. If one sees wheat in the mid and Far-Westen Hills districts, all good production

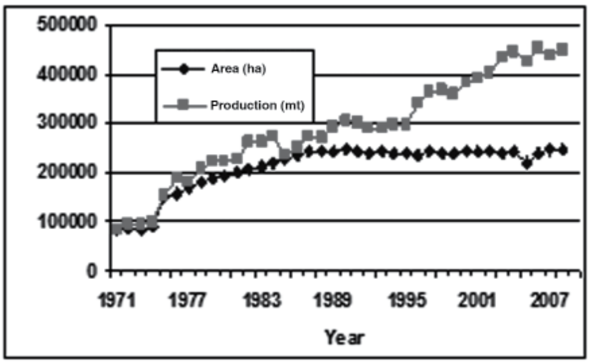

Figure 4: The wheat area and production in Hills

comes from river basins and plain areas in the foot hills (they call Phant such as Dipayal phant, Sakayal phant, Bandungrasain phant etc. in Doti, Dadeldhura districts). In general there are 57.8% the area of wheat which lies in the Tarai and similar environment contributes about 66.2% of the country's total wheat production. Rest goes to Hills and Mountain.

TARAI

The wheat is grown during winter (November/December to March/April) in Tarai. During this period about 2 to 5 percent (less than 100 mm, more precisely 30-90 mm) of seasonal rainfall occur in the Tarai. These winter rains are very irregular and erratic in nature. In Nepal, 70 to 90% of rainfall occurs in the summer monsoon and the rest of the months are almost dry. Distribution of winter rainfall is more in the Western Tarai than in the Eastern Tarai. The winter rain caused by westerly disturbances originates from the Mediterranean Sea. Annual mean temperature during the growing period of wheat in Tarai is 15^0C to 30^0C. The annual temperature trend in the Tarai Region at the selected place in Bhairahawa was observed only 0.005^0C during the 1977-2008. In fact Tarai region as defined include only 57.82% of the total wheat area and contributes 66.2% of the total wheat production in the country.

During the last 38 years period from 1970/71 to 2007/08 (Figure 5), the production of wheat in the Tarai region increased from 81,600 mt to 1,040,535 mt. It is interesting to note that the wheat yield in Tarai was initially lower. After the introduction of high yield varieties and irrigation facilities, the yield increased more than those of the Hills and Mountain. In Tarai alone area under wheat increased by 350% and its yield increased three fold. The harvesting of wheat is about a week earlier in Western Tarai than in the Eastern Tarai due to the temperature differences.

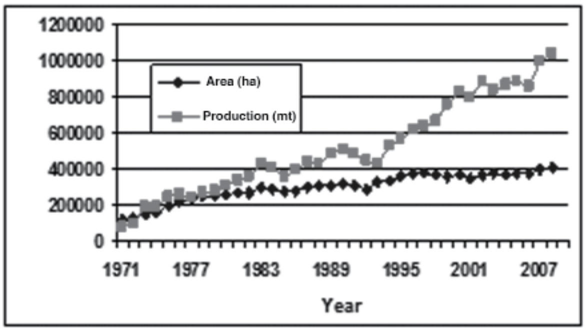

Figure 5: The wheat area and production in Tarai

In terms of development of wheat at three different ecological belts, the productivity is measured by yield and therefore the yield at three ecological belts are presented in Figure 6, which shows that the yield is much higher in Tarai than in the Hills and the Mountain region. In cereal production, the progress in wheat has had remarkable achievement in Nepal. Especially wheat in Tarai had very much improved due to partial irrigation and use of high yielding varieties. Due to recent global warming, Tarai may be badly affected. The above discussions were the general studies of climate and wheat in three distinct Regions of Nepal. But one has to go very much detailed study at a place for the impact of climate constraints and their change and therefore Bhairahawa has been considered for a meso-scale study to find the relationship between climate and wheat.

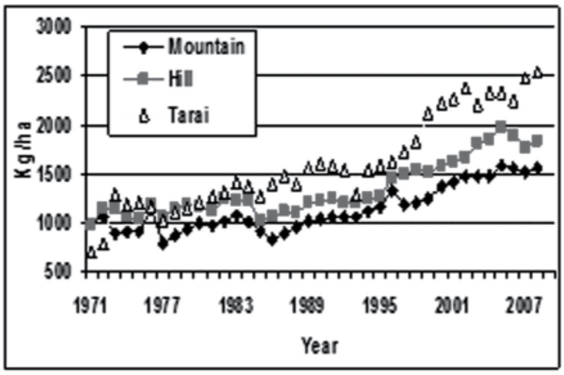

Figure 6: The wheat yield at three ecological belts

4. A CASE STUDY: NATIONAL WHEAT REASEARCH CENTRE, BHAIRHAWA IN TARAI

The simplified mathematical model as growth indices developed by Fitzpatrick and Nix (1970) was calibrated in the Nepalese environment by Nayava (1981) and is presented with data from the Wheat Research Centre, Bhairahawa, a district in Western Nepal (Figure 7a and Figure 7b). Bhairahawa is a low land in plain area and dominantly prevails with alluvial clay soil.

The growth Indices (G.I.) considers light (LI), thermal (TI) and moisture regimes (MI) into a linear function with a scale ranging from zero to unity. In this analysis, growth indices (G.I.) has been defined as most favorable G.I. (higher than 0.8), fairly favorable G.I. (0.4 to 0.8) and least favorable G.I. (less than 0.4) are defined. The most favorable is the optimum climatic potential for cultivation where all environmental indices such as light, thermal and moisture have almost non-limiting condition for growth, say as growth index higher than 0.8. The Figure 7a indicate that only one tropical species (TS) can be grown under optimum condition during the week 25 to 43 (June 18 - 24 to October 23 - 29) as rain-fed condition in summer season. Figure 7b show that the three crops (two tropical species during the week 11 to 44 (March 12 - 18 to October 30 - November 5) and one warm temperate species (WTS) as wheat during the week 44 to 12 (November 30 - December 5 to March 19 - 25) can be easily managed with proper irrigation facilities. Cold temperate species (CTS) can not be grown in rain-fed as well as irrigated condition.

Thus, only one crop as tropical species can be cultivated in the rain-fed condition for optimum yield during the summer monsoon as shown in Figure 7a. The second and third crop can be managed only by irrigation application as described earlier and is shown in Figure 7b. However, wheat sowing in Tarai can be delayed up to the second week of December without significant reduction in yield. Wheat seeds sown beyond these dates resulted yield reduction of 30 to 50 kg/day/ha (NARC, 1997). When weather and climate relate with agriculture, one has to study the diurnal

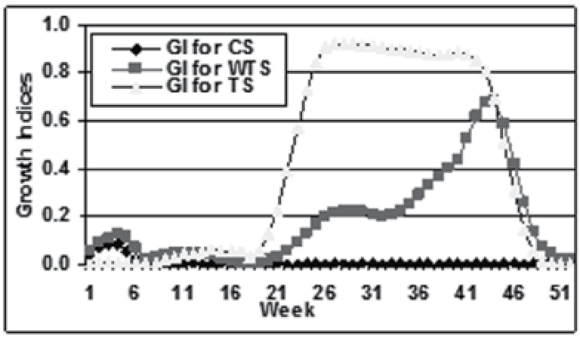

Figure 7a: Growth Indices at Bhairahawa, 109 m at rain-fed conditions

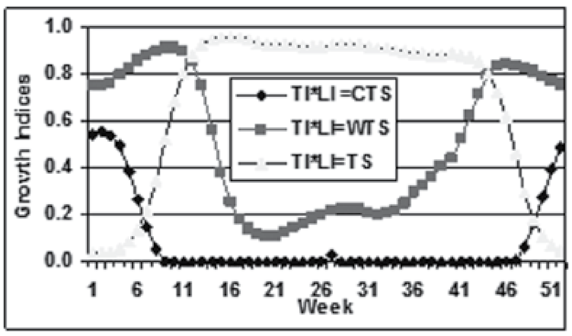

Figure 7b: Growth Indices at Bhairahawa, 109 m at Irrigated conditions

variation as well as short term climate data such as weekly and ten days mean with reference to daily data are needed to see the relation between climatic parameters with crop cycle. As a matter of fact, the energy and moisture balance are very necessary for crop under study.

The Figures 7a and 7b reveal that without the supplementary irrigation, the present yield and production in wheat yield is not possible in Nepal especially in the Tarai region. Whatever one grows, whether under rain-fed or irrigated conditions, one should be aware of weather and climatic conditions to have expected production. Without efficient use of water, our target production may never be achieved. It is high time to document the use of irrigation facilities in Nepal in detail, so that one should know how much water has been really used and what strategy has to be considered in future.

It is very interesting to note that the wheat yield in Tarai, Hills and Mountain justify the crop weather model patterns as described earlier. According to crop weather model, the Tarai is most favorable, the Hills and Mountain are only favorable. The results were tallied by yield pattern in different ecological belt as discussed earlier.

The crop data are available only in district wise and the Bhairahawa belongs to the Rupandehi district. The development of wheat started from Bhairahawa Agricultural farm in Rupandehi district during the early 1970's. Initially the area of wheat as well as yield in Rupandehi district was very low as shown in Figures 8 & 9 and only later the development of wheat took place as already described.

In that present scenarios of climate change, detailed study of crop and climate relation during the particular cropping period are required, whether that period has any changes from normal pattern or possible departure which may affect the crop in stand.

During the wheat growing season in November/December to March, the normal rainfall during 1970/71-2006/07, the rainfall was 88.6 mm and the number of rainy days was 7 days. Below normal or less than 87 mm of rainfall was experienced in 26 years out of 37 years. Only 7 years showed more than 100 mm of rainfall. During those 37 years, 7 years had less than 25.0 mm of rainfall. Though such a poor rainfall and a few rainy days, the cultivation of wheat area has been increasing as shown in Figure 8 and at the same time the yield per hectare has also been increasing as shown in Figure 9. It is purely due to the development and uses of high yielding varieties as well as availability and uses of irrigation facilities.

It has been mentioned that depending upon the availability of water, irrigation in wheat crop is

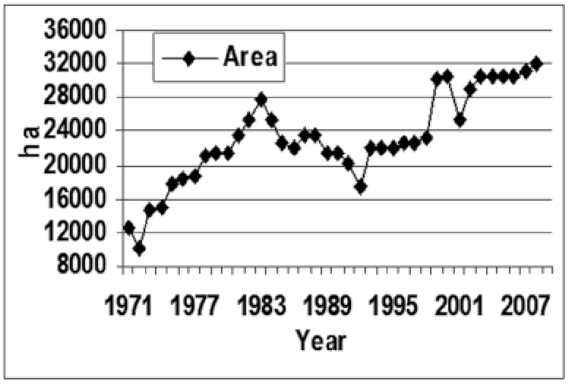

Figure 8: Wheat area in Rupandehi

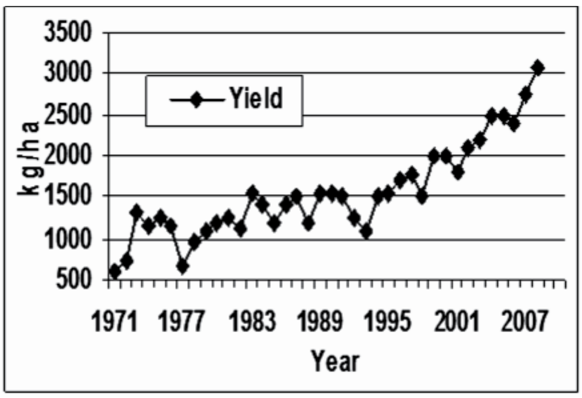

Figure 9: Wheat yield at Rupandehi

recommended at the crown root initiation stage (25-30 days after showing), at the heading stage and at the grain filling stage (NARC, 1997).In general, it seems that the increase of land area and yield were both due to irrigation facilities. Otherwise, it was not possible to get higher yield without irrigation. A supplementary irrigation by ground water project in Bhairahawa is worth mentioning. On the contrary, the relationship between rainfall and wheat yield is very complex due to non availability of data on irrigation applications. It is certain that rainfall distribution in February and March had a very good impact on yield. There seemed that the most of the up and down cultivation of wheat area was a result of October rainfall and it helped as residual moisture during planting time. In addition to supplementary water, the improved varieties of seeds may have had a role for higher yield in Bhairahawa. From 1998, the wheat yield increased from 1800 to above 2500 kg / hectare. The use of HYV seeds can increase yield by 15 to 25% (Cox, 2000). This jump in wheat yield is partly due to application of increased fertilizer inputs over time too. The causes of recent increment of yield are attributed to the uses of high yielding seeds which have been confirmed by personal discussion with the concerned authorities, however the concerned authorities should take seriously this matter in future estimation.

The production of wheat in Rupandehi district was shown in Figure 10. It is very unfortunate that when and how much water had been added by the irrigation was not available. This is a matter of study required in future. The production of wheat in Rupandehi district was shown in Figure 10.

5. CLIMATE CHANGE AND THEIR EFFECTS ON WHEAT

In the present scenarios of climate change, the overall impact of agriculture has to be explored and this is very enormous task and very complex,

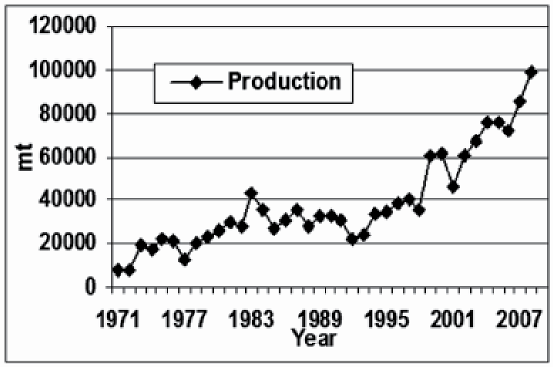

Figure 10: Production of wheat in Rupandehi district

but the country should immediately start planning and take action, before it is too late. The maximum and minimum temperature trend during the wheat growing season from November to April was also analyzed as shown in Figures 11- 12. The maximum temperature showed negative trends which was -0.0068^{0}C/yr during 1970-2008 at Bhairahawa as shown in Figure 11. On the contrary, the minimum temperature showed 0.030^{0}C/yr at the same period as shown in Figure 12. However, the mean annual temperature during November to April showed 0.012^{0}C/yr during 1970 to 2008 as shown in Figure 13. It showed that the increase of temperature seemed more in the recent decade than the former decade. Due to frequent cold waves in the Tarai as mentioned before, the temperatures were dropped considerably during winter months. Cold waves had occurred during late December and January and these have not much affected, but for wheat yield and production are concerned, temperature regimes from November to whole of March are very important especially for the Tarai region where as in the Hills, yield is more affected by drought rather than temperature regimes.

It is interesting to note that after peak area of wheat achievement in 1983, the decrease of wheat cultivation was noted up to 1998 and latter the area of wheat has been increasing trend as shown in

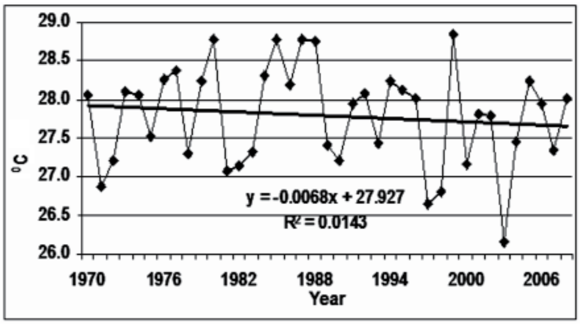

Figure 11: Trend of maximum temperature during (November – April)

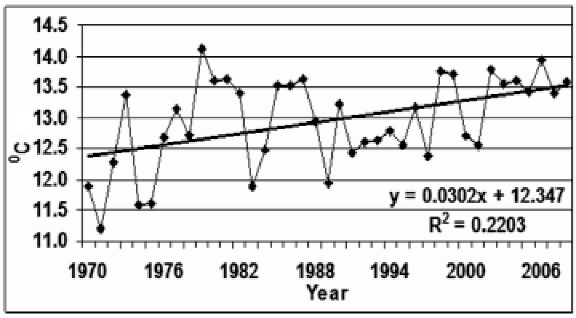

Figure 12: Trend of minimum temperature during (November - April)

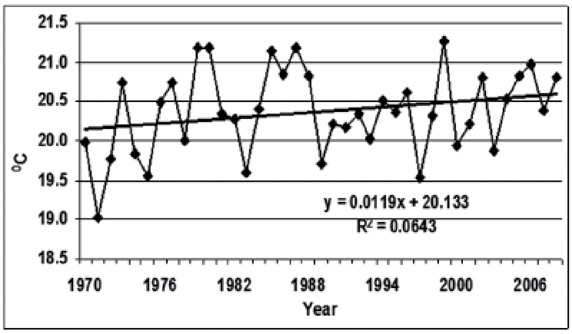

Figure 13: Trend of mean temperature during (November-April)

Figure 8. Another puzzling factor, the yield showed sharp up and down in different years. While looking at the upward trend of yield in Figure 9, the sharp decreased of yield during 1976/77, 1981/82, 1984/85, 1987/88, 1991/92, 1992/93, 1997/98, 2000/01 and 2005/06 are note worthy to discuss and find out the causes. It is known that the temperature is a limiting factor for any plant growth. The temperature regimes during post anthesis are very critical. The minimum temperature during February and March in Bhairahawa was very critical and it affected the yield. The weekly minimum and maximum temperature in Bhairahawa Agricultural Farm during February and March in 2000 to 2007 was observed. During 2006, no rainfall was observed during winter months and the increased in minimum temperature was noted and that affected wheat yield. Thus up to 60% variations of productivity of wheat depended on weather fluctuation. This is a matter for study in future at different temperature regimes in Nepal and extensive field works are necessary to collect the information on fertilizer application, irrigation, time of weeding and their cultural practices.

The mean temperature during November to March at Bhairahawa since 1971-2007 was observed to be between 15.1^{o}C to 22.7^{0}C. During the occurrence of cold waves in 1982/83, 1992/93, 1997/98, 1998/1999, the mean temperature in January was observed to be 13.8^{0}C, 13.7^{o}C, 13.7^{0}C and 14.5^{0}C respectively. The drop of maximum temperature as much as 10^{0}C was noted during the cold waves, it seemed that those cold waves occurred mostly during the vegetative period of wheat and therefore that cold wave did not affect much in the wheat performance significantly. But those cold waves had much affected in the vegetables.

Recently the effect of climate change to agriculture in Nepal was also studied by different researchers. The latest report shows that the there is positive role in percentage change in wheat yield in all the agro-ecological zones. With doubling of carbon dioxide, wheat production is likely to increase with adoption of more heat tolerant varieties (Sharma, 2007). The study of present variation of climatic parameters such as rainfall and temperature in the crop yield should be regularly studied and discussed. The diurnal variation as well as short term temperature such as weekly and ten days mean with reference to daily temperature are needed to see the relation between climatic parameters with crop cycle. Recently the trend of minimum temperature was observed to have increased during February and March in 2006 and the rainfall was nil during November to February, 2006. This resulted poor wheat yield in Bhairahawa. Similar study should attempt in different places of Nepal to verify those cases. Unless the full investigations of crop under study, the adaptation and mitigation would be premature to be prescribed.

6. MARKETING /VALUE CHAIN APPROACH IN WHEAT CROP

Agriculture sector provides livelihood for more than 80 percent of population and accounts for about 36 percent of the Gross Domestic Product. Among various crops and commodities contribution from the cereals is significant. After rice and maize, wheat is the third largest and important cereal crop which contributes about 20 percent of the total cereal production in the country. Besides developing and or capitalizing on research, technology, extension/training, farm roads, round the year irrigation system, credit services, market oriented agri-business approaches to each and every crop/commodity is a must in order to secure competitive edge for Nepal. It is more important under the regional and other world trade regimes particularly governed by the World trade Organization (W.T.O).

Nepal needs to take comparative advantage of its ecological sites/belts to make its produce competitive. One significant aspect which Nepal should consider is to see how the India's agricultural/economic policy is framed particularly when viewed in terms of porous open border with between these two countries. It is generally observed that the prices of India's agricultural produces are low due to relatively higher agricultural subsidies. India provides both for activities associated with inputs and outputs. Also review of agricultural policy in the SAARC region necessary in order to make Nepalese produce competitive in these countries as well. Overseas markets for niche products such as tea, coffee, honey, cardamom are also important where access to these products so far has been due to their organic nature more by default. This however, needs improvement supported by research, supervision and creating international standard laboratory facilities in the country.

Wheat crop is relatively new in Nepal. It basically envelops cultivation of the exotic high yielding varieties. Both area and production under the crop are increasing over the years. Its production has been more than quadrupled from 223 thousand mt in 1972 to the present year's production level. And similarly the area has increased to a considerable extent. Wheat tremendously helped in increasing the food supply level vis –a vis the food security of the country. In addition to that, wheat flour export to Tibet and Bangladesh has remained significant. However, there is a need to focus on the areas. Such a variety selection to match the industrial (processing) demand and secondly the production concentration or the production area zoning, thirdly meeting the consumer demand and fourthly meeting the export demand. For this, production and productivity level efficient networking of value-chain stakeholders, sound marketing and or agri-business approach has to be raised and developed as well as enhanced together with enterprise friendly related rules and regulations in order that wheat crop remains as a commercially viable entity in the national economy. During 2007/2008, the total production of wheat was 1.57 million mt. At present rate, Nepal produced wheat worth of more than US$ 400 million (NRs.27272.5 million).

7. DISCUSSION

Nepal started preparing the 'National Adaptation Program of Action' (NAPA) on climate change about six years ago. However, nothing substantial has been accomplished so far. The Nepal's NAPA seems to be focusing more on the effects on tourism, biodiversity, abnormal rain, storm, rapid melting of snow and glacier formation. Though these aspects are important too, the most important effect of climate change would be on agriculture (food production). Therefore, the country should be more concerned on the negative impact of climate change on the agriculture. Shortening of winter season, summer season getting hotter and erratic rainfall patterns as a result of climate change could have serious adverse impact on agriculture.

The issues of development of wheat yield and production lie in the following main points.

I) one of the reasons for increase in wheat yield is the use of improved seeds. About 97% of seeds used in Nepal during 2007/2008 (MOAC, 2008) was improved. There are altogether 21 varieties of wheat developed for different environment in Nepal (NARC, 1997). In previous years there was general recommendation for seed rate of 100 kg/ha. Recent experiments have shown that additional seeds of 25 to 50 kg is required under late sown and under farmers broadcast system (NARC, 1997).

II) The other reason for improvement in wheat cultivation can be attributed to better irrigation facilities.

It seemed that the first irrigation used to provide during the crown root stage, but how much water had been provided, the records were not available. As a second application, during the grain filling stage of the wheat, it seems that very few farmers used to apply, but this is the critical period for water deficits in wheat. At this time the weather is very dry and the rain-fed rivers are almost dry. Therefore the occurrence of rainfall during that period seemed to be very important for the wheat production in Nepal. But due to the non availability of when and how much water had been added by the irrigation and at the same time the wheat yield and production data were just aggregated at district level. In that circumstance, how much rainfall affected in wheat production was a complex issue. Therefore, It is very necessary to stress that it is very important to have the data, when, where and how much water had been added. If the irrigation was available through out in Rupandehi, the fluctuation of the cultivation of wheat as well as the yield may not have varied as shown in Figures 8 and 9. Thus the collection of field observation of irrigation application is very much required, so that one can make the possible suggestions which can be laid down for the future planning and development.

It has been commonly observed that farmers put heavy irrigation in their wheat fields during first irrigation, that creates anaerobic situation for wheat plants and wheat plants start yellowing. This happens due to poor knowledge of wheat agronomy among farmers and poor drainage in the Tarai. After yellowing the wheat crop shows a fatal illness for a period of at least one week which is very important for yield attributing components in wheat. Because just after first irrigation (after 25 to 30 days of planting, the spike initiation starts and that decides the size and number of florets in the spike). This has to be taught to farmers to improve wheat yield and many farmers know this.

III) The third factor should be the fertilizer application and their quantities. Modern wheat varieties are very much responsive to fertilizer application and require 100:50:50 kg/ha NPK under irrigated conditions whereas in rain-fed wheat the addition of 25 kg/ha K in the previously recommended doses of 60:40 kg/ha NP is beneficial. Experiments show that irrigation provided a sizeable increase in yields (NARC, 1997). It is understood that Nepal uses least amount of fertilizer in this region.

IV) The fourth factor is land fragmentation, small land parcels and small landholdings scattered across many places have been the major causes for under utilization of ground water irrigation. Moreover, marketing of commercial crops is not organized so as to benefit small to medium farmers, and the current high cost of crop production makes the growers unable to compete with similar products imported from India. Winter crops only less than 30 % of projected command area of major irrigation projects get assured irrigation.

V) The fifth factor should be the better management of the field due to training and publicity given by extension workers from the Department of Agriculture. The farmers are not oriented towards maximizing the farm production, mainly due to lack of integrated water management and advanced agricultural technology and inputs. Irrigation and agriculture sector programs are not coordinated and theoretical ideas of crop intensification and diversification in areas where water is available for crops have not been put into practice by the agencies concerned (Shah & Singh, 2003). This is the serious comment which has to be tackle for the future development in agriculture.

8. CONCLUSION AND RECOMMENDATION

The area of wheat cultivation in Nepal has increased drastically, by three folds, especially at the Tarai region as described earlier. Previously area of cultivation was very limited and the yield was less than 1 mt/hectare in Tarai. Now, with availability of the high yielding varieties as well as improved irrigation facilities in Tarai, wheat yield has increased more than three times in the Tarai. However, during the same period wheat yield showed 100% increase in the Hills and only 50% increase in the mountains.

Weather still plays a prominent role in crop productivity, but the coordination with related Departments is very poor. On the other hand, Department of Hydrology and Meteorology was focused only in aviation weather forecasting since the establishment of their services in 1960's. They should expand their boundaries for their services in agriculture. Department of Agriculture/ Ministry of Agriculture and Co-operatives need a better coordination with the different Department in future for their challenging role of Agriculture development in Nepal. The Ministry of Finance and Planning commission Secretariat should pay their attentions, if ever Department of Hydrology and Meteorology requests for the extra budget to play a supporting role for the development of Agriculture in Nepal.

The Ministry of Agriculture and Cooperatives in the Government of Nepal should be very serious and immediately establish a Monitoring and Evaluation Committee on climate change impact on agriculture. A country can not wait until the last minute and they have to fully prepare before any catastrophic consequences. Nepal has very few studies on weather, climate and crop relation studies. It is high time to study the variation and trend of past climate data and their relation to crop in detail. Any extreme occurrence of weather and climate event may damage the crop. Now it is known only that the global warming has been taking place since 1970's and the global temperature may increase by 1.4 to 5.8^0 C during this century (Global Circulation Models projection). This information is not enough for agriculture and therefore one has to know, what is going on at the different places in the country and what can be done. The present study showed that the mean annual temperatures were increased 0.0051^0C, 0.0288^0C and 0.035^0C in Bhairahawa, Surkhet and Jumla during 1977-2008, but the mean temperature during the wheat growing season in Bhairahawa, surkhet and jumla were 0.012^0C, 0.0323^0C and 0.0368^0C during 1977-2008.

To address all the above mentioned issues, the concerned authorities i.e. the Ministry of Agriculture and Cooperatives should immediately take action and create a high level Monitoring and Evaluation Committee, which should also consider the objective method (i.e early agro-meteorological crop yield assessment developed by FAO 1986) of monitoring and evaluation of crop yield and production in Nepal. The importance of objective method was also discussed (Nayava, 1999). In addition to subjective method of monitoring and evaluation of crop yield and production, the objective method of monitoring and evaluation should be introduced. This will play a supporting role to monitor and evaluate the crop yield assessment in future. The high level Monitoring and Evaluation Committee will also discuss and assess the effect of climate change on crop yield and production at the district level. At the same time each district Irrigation Offices should also collect the information of irrigation application and their quantity and frequency. Finally, all the concerned agencies should bring their information and discuss and finalize the crop yield and production for that year. These kinds of discussion should evaluate whether each and every contributory factors such as planting date, weather condition, irrigation, fertilizer applications and any other factors during the crop growth cycle. In addition this will help to evaluate and pinpoint drawback and achievement of agricultural activities in each district. In other words, the integrated approach from different supporting agencies as well as stake holders will play a vital role in this present context for the agricultural development in Nepal. Any drawbacks to meet the target of that year in each district have to be fully discussed and materialized.

9. ACKNOWLEDGEMENTS

The authors sincerely acknowledge the Department of Hydrology and Meteorology, Kathmandu for providing the necessary climate data for this paper. The authors wish to thank Mr Jagannath Thapaliya, former Chief Economist, Ministry of Agriculture and Cooperatives for his suggestions to include marketing/value chain approach in wheat crop. The authors are grateful to Dr. Khem Raj Sharma, Department of Irrigation for his suggestions.

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Impact Of Climate Change On Production And Productivity In Nepal: A Case Study Of Maize Research And Development In Nepal*

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ABSTRACT

The relation between climate and maize production in Nepal was studied for the period 1970/71-2007/08. Due to the topographical differences within north-south span of the country, Nepal has wide variety of climatic condition. About 70 to 90% of the rainfall occurs during summer monsoon (June to September) and the rest of the months are almost dry. Maize is cultivated from March to May depending on the rainfall distribution. Due to the availability of improved seeds, the maize yield has been steadily increasing after 1987/1988. The national area and yield of maize is estimated to be 870,166ha and 2159kg/ha respectively in 2007/08. The present rate of annual increase of temperature is 0.04^0C in Nepal. Trends of temperature rise are not uniform throughout Nepal. An increase of annual temperature at Rampur during 1968-2008 was only 0.039^0C. However, at Rampur during the maize growing seasons, March/April – May, the trend of annual maximum temperature had not been changed, but during the month of June and July, the trend of increase of maximum temperature was 0.03^0C to 0.04^0C /year

Keywords: climate change, global warming, hill, mountain, Nepal, Tarai

INTRODUCTION

Ecologically, the country is divided into three regions running east to west: Mountain, Hills and Tarai (Plain). Based on the area, these regions constitute 35, 42 and 23 percent of the total land area, which is 147,181 sq. km. Administratively the country is divided into 5 development regions and 75 districts. The area of development regions are shown in Fig.1.

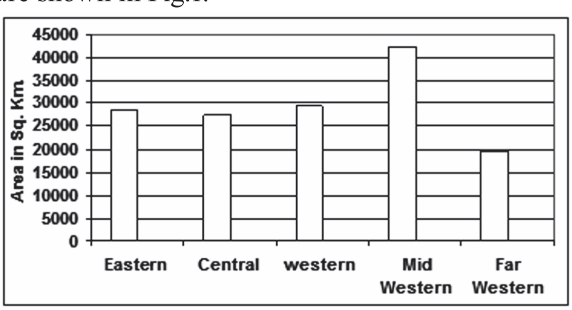

Fig. 1: Regional area of Nepal

Economic growth of the country has not improved over time to cope up with the population growth, which is 2.3 percent per annum. Around 68 percent of Nepal's population depends upon agriculture and contribution of this sector to the GDP is about 40 percent. Though priority is given to agriculture sector, the crop production in the country is not sufficient to meet the demand of the peoples.

According to the Population Census 2001, the number of agricultural holdings in the country is 3.2 million and total cultivated area is 23.21 million hectares. Starting from 1995, Nepal is implementing the twenty year long Agricultural Perspective Plan (APP) to overcome the problems of food insecurity and poverty. The population distribution along with the administrative region is shown in Fig. 2.

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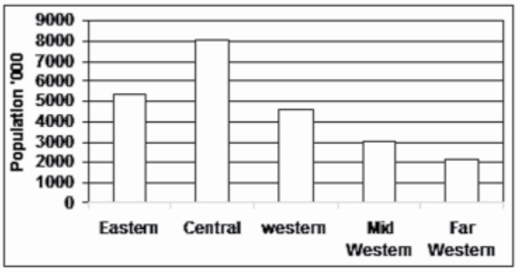

Fig. 2: Population distribution in administrative region

In Nepal maize is grown in the sub tropical to cool temperate climates. For higher yields, crop water requirement is 500-600mm depending upon the climate and duration of the crop, there should be adequate water during the crop establishment period. Water deficit during the grain filling period results in reduced grain weight. However, during the maturity and harvesting period, rainfall has negative impact on maintaining grain quality.

Knowledge of genetic characteristics and particularly growth and development pattern of maize varieties is essential for meeting the combination of various climatic requirements for growth development and yield formation. It is known that the upper limit of crop production is set by the climatic condition specially temperature regimes and the genetic potential of the variety grown. The extent to which this limit can be reached will always depend on how finely the engineering aspects of water supply are in tune with the biological needs for water in crop production (FAO, 1979). The area under maize cultivation in different regions of Nepal is shown in Fig. 3.

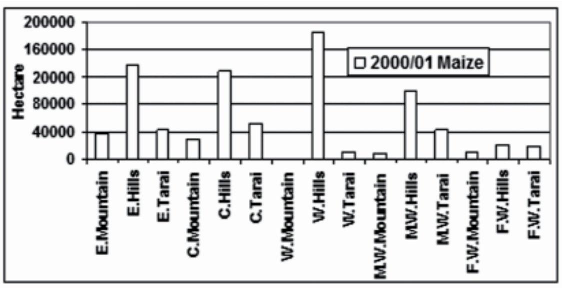

Fig. 3: Maize cultivation in the different regions in Nepal

DATA

This study is based on data of thirty six years (1970/71 – 2007/08). Climate data were provided by the Department of Hydrology and Meteorology (DHM, 1999a, 2001, 2002, 2005, 2007 and 2009). Source of the maize data is the then Department of Food and Agricultural Marketing Services (DFAMS, 1977), National Planning Commission (NPCS, 1994), Central Bureau of Statistics (CBS, 1999, 2003, 2006) and Ministry of Agriculture and Cooperatives (MoAC, 2002, 2004, 2005, 2006, 2007 and 2008).

Taking into consideration the growing season of summer maize, this study attempts to analyze relationship between rainfall and maize production for whole of Nepal and three ecological belts with a case study at the National Maize Research program in Rampur, which lies in inner Tarai of central Nepal.

ANALYSIS

NATIONAL LEVEL

Maize is the second most important cereal crop in Nepal and is also staple food for Hills people. Area under this crop is approximately 870,166ha with an average productivity of 2159 kg/ha in 2007/08. About 70% maize area is in the Hills. Maize occupies 34% of total cultivated cereal crops and contributes 30% as a total edible food in Nepal. Maize is generally grown under rain-fed condition in Nepal. Maize is an important crop for making edible oil and is also significant source of bio-fuel production in the world. Maize is very sensitive to frost. The favorable condition of growing maize is light to medium textured, deep well drained soils free from water-logging. The cool temperature delays maturity in the crop. Cold stress occurs when temperature is below 10°C and development of plant growth ceases. Similarly, heat stress occurs when temperature is higher than 35°C.

While observing the maize area in Nepal during 1970/71 to 2007/08, the area was about 445,750 ha during 1970/71 and the area has increased to 870,166 ha in 2007/08. There is clear indication that the area under maize cultivation has increased nearly two folds in 2007 during the study period. The maize production was 833,318 MT in 1970/71 and now the production is 1,878,648 MT in 2007/08. The maize production during the study period of 1970/71-2007/08 has more than doubled and that the increase in production was due to increase in area.

National Agriculture Research Council mentioned that performance in maize production in Nepal has not increased much even though use of improved seeds has increased substantially since 1972. Although attempts on variety development were initiated since middle of sixties, the systematic development work began only after the National Maize Development Program established in 1972 at Rampur.

The seeds of new varieties have increased since then and now area under improved maize is 86% (MOAC, 2008). There are altogether 23 varieties developed for different production environments in Nepal (NARC, 1997, 2005). Maize seeds are planted with 25 cm between plant to plant distance and 75 cm apart between rows to row. The ridges should be made very nicely and maintained to avoid water logging. In general, the first weeding is performed when the plants are 5-8 leaf stage and feeling up is done at the knee high stage

The national maize area and production from 1970/71 to 2007/08 are shown in Figure 4. Initially during the first and half decade, the production had been decreasing and only after 1986, the production had been steadily increasing trends. In the later part, the yield increased to more than 2 ton per hectare showing progress in maize yields, which is shown in Fig. 4. It seemed that the increase in yield was mainly due to adoption of high yielding varieties.

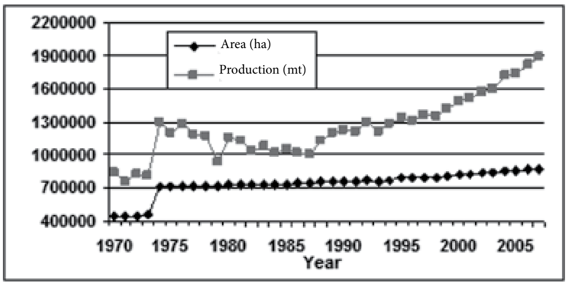

Fig. 4 : National Maize area and Production

ECOLOGICAL BELTS

The Maize area and production in three ecological belts are as follows:

MOUNTAIN

In course of studying maize cultivation in the three ecological belts, the Mountain region showed least increment among the three belts The production of maize in the Mountain region increased from 77,800 MT to 183,253 MT during the last 36 years from 1970/71 to 2007/08., But the yield has remained almost constant during the last 27 years and only after 2000 the yield seemed to increase in mountain as shown in Fig. 5. General maize plantation starts from March to April and it is totally dependent upon the

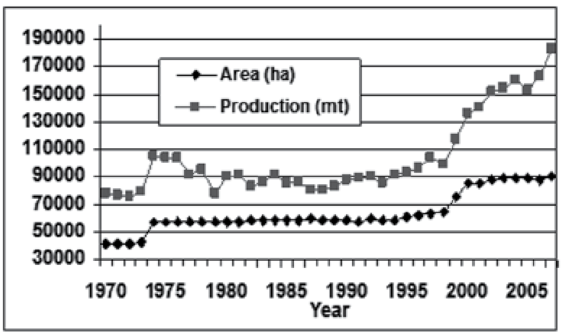

Fig. 5: The maize area and production in Mountain

rainfall. The average annual temperature during the growing season in Mountain was from 18°C to 21°C. In fact, area under maize in mountain was 9.6% of the total maize area and contributed 10.3% of the total maize production in the country. In mountain regions, maize matured in around 180 days.

HILLS

The maize growing season in the Hills Region is from March/April to July/August. Maize is planted in rain-fed condition in the Hills and depends upon the rainfall distribution. The land preparation starts with rainfall. Maize is generally planted from mid February to the end of April. Maize area is more in the Western Hills compared to the other Hills in Nepal as shown in Fig. 6. The maturity period of maize in the hills ranged from 140 to 150 days.

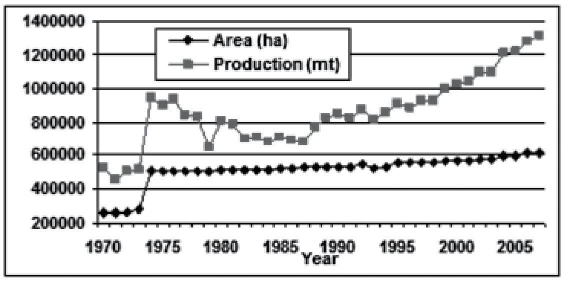

Fig. 6: The maize area and production in Hills

Mean annual temperature during the growing period in the Hills ranged from 21°C to 27°C. Hills regions showed nearly three fold increases in area during the period from 1970/71 to 2007/08. The gap in area and production showed a progressive change after 1988 in the Hills (Fig. 6). The production of maize in the Hills increased from 524,700 MT to 1312,254 MT during the study period. In fact Hills region has about 70.4% of the total maize area and contributes 69.7% of the total maize production in the country.

TARAI

Maize is grown during April- July in Tarai. During this period, about 500 to 800mm rainfall occur in the Tarai. Annual mean temperature during the growing period of maize in Tarai is 21°C to 33°C. In fact Tarai region has only 9.1% of the total maize area and contributes 20.4% of the total maize production in the country.

During the last 36 years period from 1970/71 to 2007/08 (Fig. 7), the production of maize in the Tarai region increased from 230,700 MT to 383,141 MT. It is interesting to note that the maize yield in Tarai was initially low. In Tarai, area under maize increased by 60% and its yield increased only 71%.

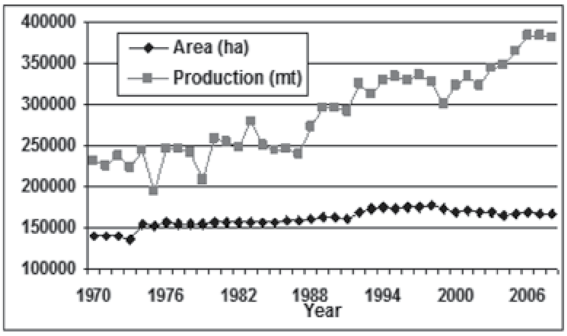

Fig. 7: The maize area and production in Tarai

Maize is planted in all three seasons (summer, winter and spring) in the Tarai Region. The planting of summer maize starts from April to May and harvests on August to September. The growing season of winter maize covers from November/ December to March/ April. Similarly, the growing season of spring maize is in March/April and harvests on June to early July. For the summer and winter crops, farmers prefer to grow long duration varieties, where as for the spring maize short duration varieties are preferred. Winter and spring maize is planted, wherever the irrigation facilities are available.

After the introduction of high yielding varieties, the yield increased in Tarai comparatively more than those of the Hills and Mountain. The yield at three ecological belts are presented in Fig. 8, which shows that the yield is higher in the Tarai than in the Hills and the Mountain region.

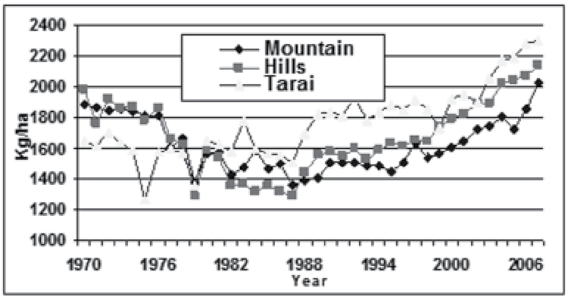

Fig. 8: The maize yield at three ecological belts

A CASE STUDY: NATIONAL MAIZE RESEARCH CENTRE, RAMPUR

The simplified mathematical model known as growth indices developed by Fitzpatrick and Nix (1970) was calibrated in the Nepalese environment

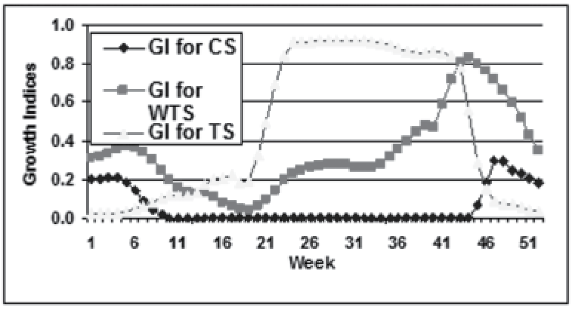

Fig. 9a: Growth Indices at Rampur in rain-fed conditions

by Nayava(1981) and is presented with data from the meteorological station, Rampur, 256m, a district in Central Nepal (Fig. 9a and Fig. 9b).

The growth Indices (G.I.) considers light (LI), thermal (TI) and moisture regimes (MI) into a linear function with a scale ranging from zero to unity. In this analysis, growth indices (G.I.) has been defined as most favorable G.I. (higher

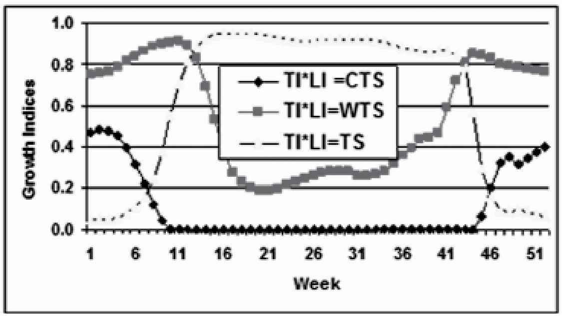

Fig. 9 b: Growth Indices at Rampur in Irrigated conditions

than 0.8), fairly favorable G.I. (0.4 to 0.8) and least favorable G.I. (less than 0.4) are noted. The most favorable climatic condition for cultivation where all environmental indices such as light, thermal and moisture are non-limiting factor for growth, in other words, the index should be higher than 0.8. As a matter of fact, the energy and moisture balance are very necessary for crop under study. The Figure 10a indicate that only one tropical species (TS) can be grown under optimum condition during the week 23 to 42 (June 4 - 10 to October 16 - 22) as rain-fed condition in summer season. Figure 10b show that the three crops (two tropical species during the week 12 to 42 (March 19 - 25 to October 16 – October 22) and one warm temperate species (WTS) as wheat during the week 43 to 13 (October 23 - October 29 to March 26 – April 1) can be easily managed with proper irrigation facilities. Cold temperate species (CTS) can not be grown in rain-fed as well as irrigated condition.

Thus, only one crop as tropical species can be cultivated in the rain-fed condition for optimum yield during the summer monsoon as shown in Fig. 10a. The second and third crop can be managed only by irrigation application as described earlier and is shown in Figure 10b. It is necessary to have short period of data such as weekly or decade to study the relation between crop and climate data, because normal (Long Term Average) and monthly data may be equal, but the rainfall may had fall within one or two days at the end of the month and where a long intervals of three to four week dry period may have wilted the crop. On the other hand, a short period of squall or hailstorm will just damaged the whole crop in the ground. FAO suggests 10 days period would be just right for crop weather analysis.

It is interesting to note that the maize yield in Tarai, Hills and Mountain justify the crop weather model patterns as described earlier. According to crop weather model, the Tarai is most favorable, the Hills and Mountain are relatively less favorable. The results were tallied by yield pattern in different ecological belt as discussed earlier.

In Nepal adaptation of modern farming technique and varietal improvement Maize started from Rampur Agricultural farm in Chitwan district during the early 1970's. A long time series of area, yield and production data of maize are only available at district level in Nepal. Rampur comes under Chitwan district and therefore, Chitwan district data has been analyzed and presented here. The area of maize remained almost constant throughout 1974 to 1994, but 1995 to 2003 showed much higher in area and a later four years showed less (Fig. 10). Why it was so, the reasonable explanation was not available. Similarly the yield showed decreasing tendency up to 1987 and later showed the increased trend as shown in Fig. 11.

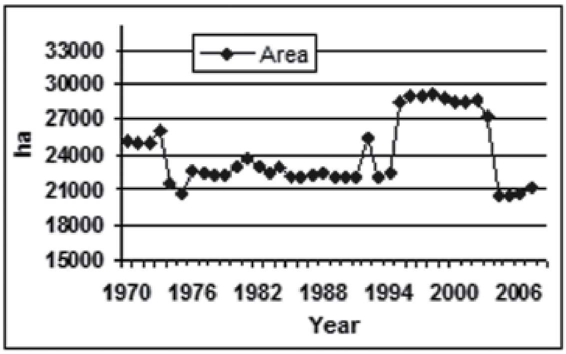

Fig. 10: Maize area in Chitwan

The recent increase of increase of yield may not be only due to introduction of high yielding seeds, but may have been due to climate change factor. Discussions are very much required to draw any conclusion.

This increase in maize yield is due to use of high yielding seeds which have been confirmed by personal discussion with the concerned authorities. While looking at the Figure 10, the cultivated area seemed just jumped during 1990's and later lower than the 1980's and therefore the concerned authorities should take note of this matter in future estimation. The production of maize in Chitwan district is shown in Fig. 12

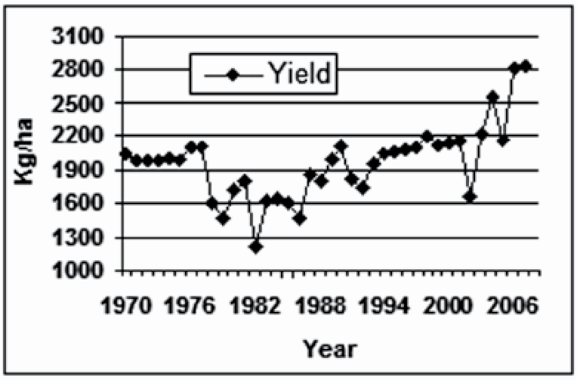

Fig. 11: Maize yield at Chitwan

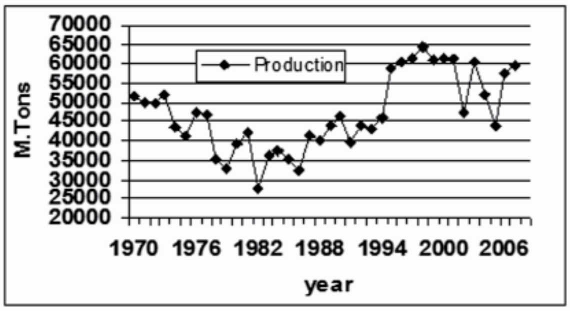

Fig. 12: Production of maize at Chitwan district

It is interesting to note that the shortfall of production of maize was noted in 1974, 1975, 1978, 1979, 1982, 1985, 1986, 1988, 1991, 1993, 1999, 2002 and 2005. This shortfall is as compared to the preceding year. The 13 years had shortfall of production out of thirty eight years. The decade rainfall and number of rainy days during that decade in the February to May during those years was presented in Table 1. The table indicates that the rainfall during the emergence period in all those years was very poor and therefore production may have been affected. When one relates the rainfall data with crops, the rainfall characteristics such as depth, intensity and distribution in time and space are all important factors.

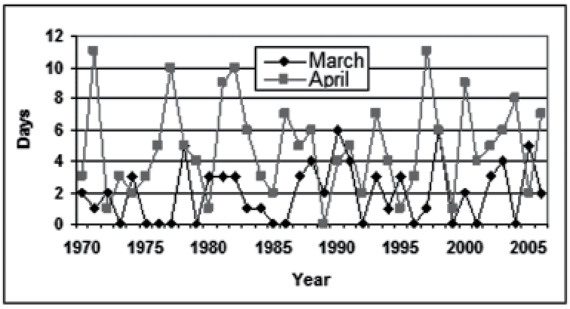

Fig. 13: Number of days of rainfall during March and April at Rampur

Table 1: Decade Rainfall and rainy days >1.0 mm in Rampur at the lower production year of maize

		February			March			April			May	
Year	Decade	Decade	Decade	Decade	Decade	Decade	Decade	Decade	Decade	Decade	Decade	Decade
	1	2	3	1	2	3	1	2	3	1	2	3
1974	0.0/0	0.6/0	0.0/0	0.0/0	0.0/0	71.3/3	3.8/1	0.0/0	8.0/1	21.1/3	45.1/7	44.0/2
1975	10.0/3	4.3/1	0.0/0	0.3/0	0.5/0	6.4/1	0.0/0	0.0/0	21.1/5	0.0/0	65.8/5	66.3/5
1978	16.0/2	10.2/1	0.0/0	1.0/0	32.8/4	0.0/0	0.0/0	29.5/4	6.9/1	41.5/5	163.2/7	62.2/4
1979	7.7/1	7.0/1	0.0/0	0.5/0	0.2/0	0.0/0	1.5/1	12.4/2	10.6/1	0.0/0	1.7/1	6.8/1
1982	7.8/2	0.5/0	0.0/0	51.0/3	0.0/0	0.9/0	3.4/1	47.1/5	28.7/4	0.0/0	15.8/2	5.2/1
1985	11.1/1	0.0/0	0.0/0	0.0/0	0.0/0	0.0/0	5.2/1	0.0/0	6.2/1	21.5/4	89.9/6	83.0/6
1986	2.8/1	17.4/2	0.0/0	0.0/0	0.0/0	0.0/0	1.8/1	16.7/1	26.8/5	6.9/2	50.7/6	27.8/2
1988	0.0/0	0.8/0	1.9/1	12.2/1	26.0/3	0.0/0	0.0/0	53.7/3	38.5/3	16.9/3	69.9/5	133.6/7
1991	0.0/0	0.0/0	8.4/1	12.2/2	0.6/0	10.9/2	11.9/2	0.0/0	9.1/3	11.3/3	38.3/3	64.3/8
1993	0.0/0	9.1/1	0.0/0	0.0/0	0.0/0	49.4/3	0.0/0	55.4/3	27.1/4	48.8/2	73.5/6	63.2/4
1998	0.0/0	0.0/0	0.0/0	0.0/0	0.0/0	0.0/0	10.1/1	0.0/0	9.1/3	143.5/7	2.0/1	4.6/1
2002	0.0/0	13.2/1	15.1/2	11.2/1	0.0/0	34.4/2	10.5/1	0.0/0	40.0/4	104.4/5	168.3/7	119.2/5
2004	0.0/0	0.0/0	0.0/0	0.0/0	0.0/0	0.0/0	90.0/4	0.0/0	90.2/4	4.1/1	22.6/2	84.7/7
2005	2.2/1	1.4/1	1.2/1	0.0/0	35.6/3	3.3/2	0.0/0	0.0/0	28.7/2	36.1/2	83.6/5	13.8/3

The water requirement of crops at the different stages, effective rainfall, water holding capacity of the soil and the crop coefficient are all required. Number of days of rainfall during those months of March and April and the amount of rainfall during those months are also presented in Figs. 13 and 14. Similarly, the amount of rainfall during the months of May, June and July are also presented in Fig. 15. If maize planted in May and June, this shows that the amount of rainfall and the soil

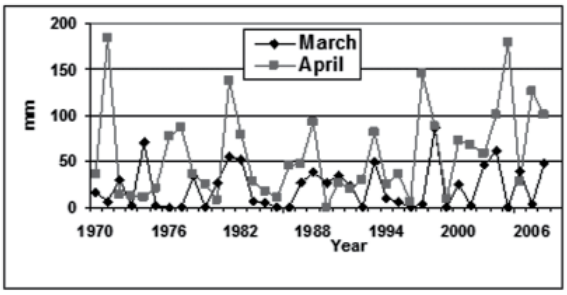

Fig. 14: Amount of rainfall during March and April at Rampur

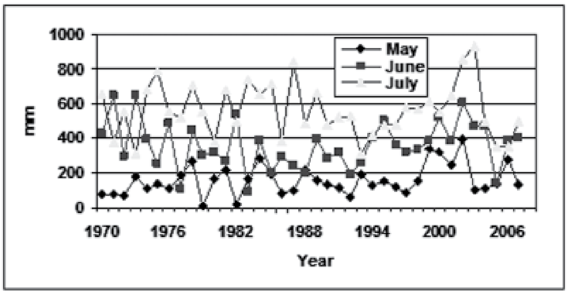

Fig. 15: Amount of rainfall during June, July and August at Rampur

moisture will be quite enough for emergence and vegetative period of maize, On the contrary, the rainfall in March and April is erratic and may not be sure to have enough soil moisture for emergence period.

CLIMATE CHANGE AND THEIR EFFECTS ON MAIZE

In the present scenarios of climate change, the impact on agriculture has to be explored and this is very enormous and complex task, but the country should immediately start planning and take action, before it is too late. The mean annual temperature trend at Rampur during 1968 to 2008 is shown in Fig. 16. It showed that the increase

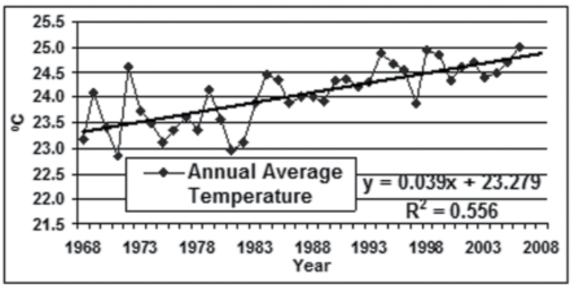

Fig. 16: Trend of annual average temperature at Rampur

of temperature seemed to be more in the recent decade than the former decade and the trend was 0.039^{0}C per year.

The maximum temperature trend at Rampur during the maize growing season from March to July was also analyzed as shown in Figs 17- 21. The trend of maximum temperature during April and May showed negative trend (Figures 18 and 19) and the month of June and July showed the positive trend as shown in Figs 17 and 18.

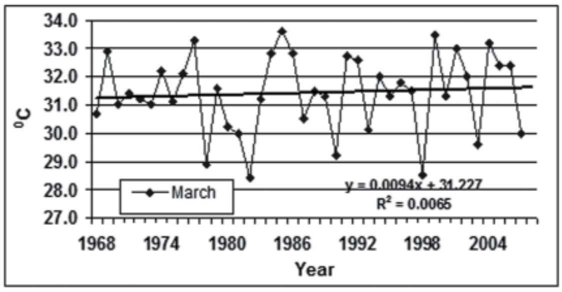

Fig. 17: Trend of maximum temperature during March

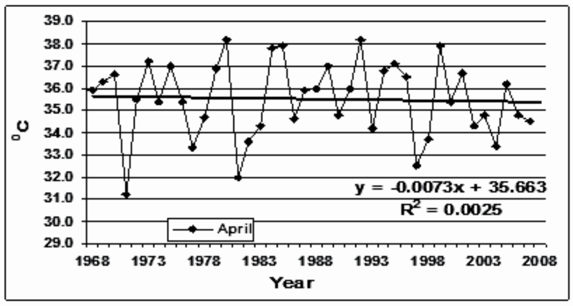

Fig. 18: Trend of maximum temperature during April

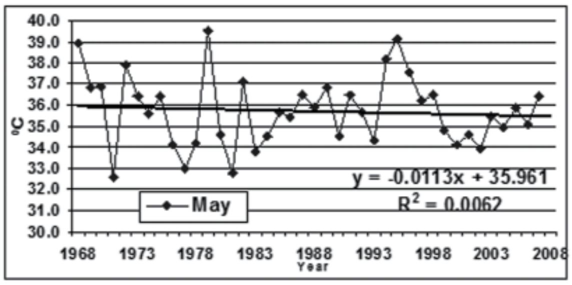

Fig. 19: Trend of maximum temperature during May

Recently the effect of climate change to agriculture in Nepal was also studied by

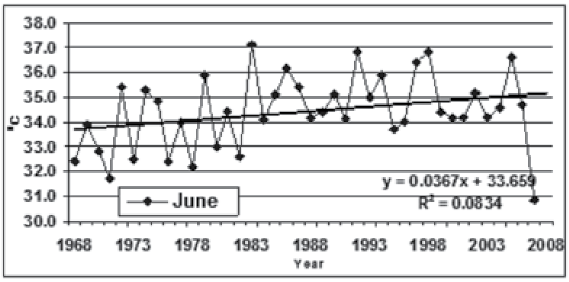

Fig. 20: Trend of maximum temperature during June

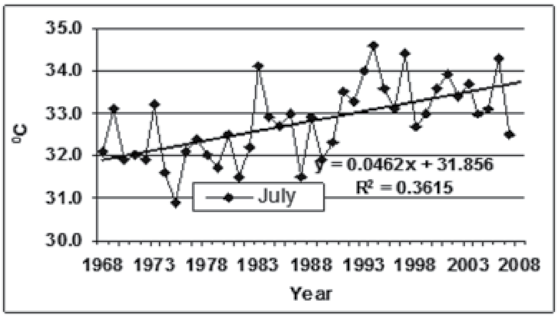

Fig. 21: Trend of maximum temperature during July

different researchers. The APN report shows, when the temperature rises up to 1^0C, there is a positive role in percentage change in maize yield in all the agro-ecological zones. When the temperature rises up to 2^0C and at the same time carbon dioxide is doubled, the yield will decrease in Tarai, Hills will not be much affected. On the contrary, Mountain environment will have better yield if the carbon dioxide is doubled and temperature rises up to 4^0 C, the maize yield in Tarai will suffer 25% lesser than the present yield . Therefore the study of present variation of climatic parameters such as rainfall and temperature in the crop yield should be regularly studied and discussed.

PROBLEMS ENCOUNTERED

- ☐ Gray Leaf Spot is a great threat
- ☐ Gray leaf spot, a new disease of maize is a great threat in the mid hills of Nepal. Local varieties are more susceptible to this disease than improved varieties. Improved varieties such as Manakamana-3, Shitala, Deuti, Ganesh -1 and Ganesh -2 are less susceptible and thus these varieties need to be promoted in eastern and central hills of Nepal.

- ☐ Post harvest losses (storage)
- ☐ Post harvest losses due to diseases and storage pests should be minimized. Grain weevils are the major storage pest of maize in Nepal.
- ☐ Climate Change (Drought)

- ☐ Drought is prolonging year after year in Nepal. Development of drought tolerant varieties is the answer to the drought problem. Adjustment of planting season could help to escape the critical stage of crops to escape from the drought.

- ☐ One of the drought tolerant characters in a variety is having less anthesis and silking interval (ASI) in maize. Shorter ASI will escape drought in maize cultivation. Varieties with long ASI are more vulnerable to drought. In the context of climate change, development of drought tolerant varieties is one of the options to overcome the drought and answer to the problem of climate change.

DISCUSSION

- ☐ Despite the importance of maize, the yield has not been increased to satisfactory level. The production seemed to increase due to more land brought under cultivation he low yield of maize may be due to the following reasons.

- ☐ It is noted earlier that out of 38 years, 13 years had poor rainfall during the maize emergence period that affected maize production in those years.

- The second possible factor may be due to lower sunlight during the grain formation stage of maize and thereby, lower photosynthetic rate. Sunshine hours at Rampur, Kathmandu, Okhaldhunga, and Chialsa had low during July and August. During those months there is highest rainfall in Nepal. The long term average sunshine hours at Rampur, 256m; Kathmandu, 1336m, Okhaldhunga, 1720m and Chialsa, 2770 of Nepal at the different elevations are presented in Figure 22.

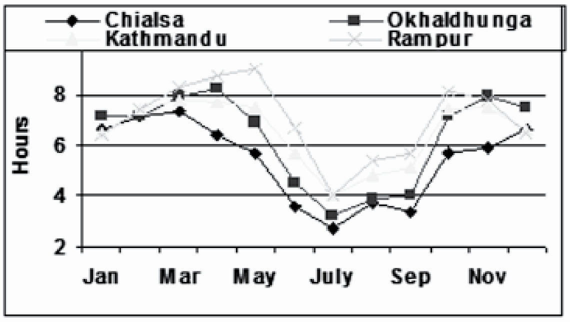

Fig. 22: Sun shine hours at the different places

- During the maturity period, the high rainfall and high humidity caused maize disease such as BLSP and Turccicum blight resulting low maize production.

- Drought period is prolonging year after year in Nepal and same as the onset of monsoon. Planting of maize in rain-fed conditions depend upon the rainfall, one need to rethink on maize planting based on rainfall pattern. May to June planting and October/ November harvesting would be suitable for maize cultivation in Nepal. For this, experiment of maize planting on these months should be conducted.

RECOMMENDATION AND CONCLUSION

- The study of maize yield and production with relation to pre-monsoon rainfall (March- May) for the 1971-2008, through crude analysis, showed that maize yield in Chitwan was badly affected in thirteen years particularly in the years, 1974, 1975, 1978, 1979, 1982, 1985, 1986, 1989, 1991, 1993, 1999, 2002, and 2005. During those years the pre-monsoon rainfall was much below lower than normal rainfall. Therefore the impact of rainfall on maize yield and production is quite evident. Maize planting in the Chitwan should be adjusted according to the change in rainfall pattern in the recent decades.

- According to the crop weather model show in figure 9a, the most favourable condition of tropical species at rain-fed condition lies in June to October and therefore the maize should be planted during that period.

- The present system of monitoring and evaluation of crop from Ministry of Agriculture and Cooperatives should be strengthened by updating the cultivated areas.

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World Meteorological Day, 2005 को उपलक्ष्यमा सोहम-नेपालका चेयरम्यान डा. श्री जनक लाल नायबाले दिनुभएको वक्तव्यः

आदरणीय सभापतिज्यू, आदरणीय प्रमुख अतिथिज्यू, विश्वविद्यालय अनुदान आयोग (UGC) का अध्यक्षज्यू, विभागीय महानिर्देशकज्यू, सोहमका सदस्य साथीहरू उपस्थित अतिथि महानुभावहरू,महिला तथा सज्जनवृन्द सबैमा मेरो र सोहमको तर्फबाट हार्दिक स्वागत गर्दछु ।

World Meteorological Day को उपलक्ष्यमा दुई शब्द बोल्ने मौका दिनु भएकोमा आयोजक सबै सहभागी साथीहरूलाई धन्यवाद दिन चाहन्छु । वास्तवमा यसरी समारोहमा कुनै वक्तव्य दिने मेरो बानी छैन । शुरूमा Technical विषयमा नै केही बोल्ने विचार गरेको थिएँ, तरसाथीहरूले यसमा easily लिएन । त्यसैले भएका र गर्नुपर्ने धारणाहरू प्रकट गर्ने जमर्को गरेको छु । यसमा शब्दमा तल-माथि भएमा म माफी चाहन्छु ।

आजको विश्व मौसम दिवस मनाउने सिलसिलामा, विश्व मौसम संस्थाले नेपालमा दिएको सहायता, मेरो अनुभव र विश्व मौसम दिवसको यस वर्षको Theme : Weather, Climate,Water and Sustainable Development भित्रै बोल्ने कोशिस गर्दछु ।

सर्वप्रथम विश्व मौसम दिवस मनाउने हामी सबैको आजको ईच्छा हो । Many many returns and this type of happy day शुभकामना फलोस् फुलोस्, दूधले नुहाओस् ।

नेपालमा उपरोक्त जस्तै theme मा काम गर्ने र गराउने उद्देश्यले तत्कालीन जलस्रोत तथा जलवायु विज्ञान विभाग ईस्वी 1966 मा गठन भएको थियो र सोही वर्ष WMO को सदस्यता पनि प्राप्त भएको थियो । तर विभाग full-fledged हुन केही वर्ष लाग्यो । उक्त विभागलाई ईस्वी 1969 मात्र meteorological authority in Nepal श्री ५ को सरकारबाट प्राप्त भएको थियो । त्यसबेला यहाँ अरू देशको हाम्रै जस्तो काम गर्ने संस्था थियो । त्रिभुवन अन्तर्राष्ट्रिय विमानस्थलमा अन्तर्राष्ट्रिय हवाई यातायातलाई मौसम briefing गर्न Indian Meteorological Department (IMD) द्वारा संचालित Supplementary Meteorological Office (SMO) बाट काम हुँदै आएको थियो । HMG को तत्कालीन विभागले अप्रिल 2, 1970 मा मात्र त्रिभुवन अन्तर्राष्ट्रिय विमानस्थल (TIA) मा Main Meteorological Office (MMO) शुरू गरेकै दिन भारतबाट संचालित SMO बन्द भयो ।

यस्तै नेपाल अधिराज्यको विभिन्न स्थानहरूमा करिब-करिब ईस्वी 1950 देखि 104 वटा Hydromet station हरू IMD बाट संचालन गरी काम गर्दै आएका थिए । ती केन्द्रहरू कुनै-कुनै नेपाल-चीन सिमानामा Check post इत्यादिमा पनि भई यसबारे high level मा समेत कुराहरू चलेका थिए । यसबारे ईस्वी 1970 तिर तत्कालीन विभागमा मैले Deputy Director को हैसियतले मन्त्रीपरिषद (cabinet) मा समेत यसबारे मा तत्कालीन जलविद्युत मन्त्रालयका श्रीमान सचिवज्यू कृष्ण राजभण्डारीको साथ जाने मौका पाएको थिएँ ।

धेरै छलफल र निष्कर्ष पछि तत्कालीन विभागबाट ईस्वी 1970/71 र 1971/72 मा नेपालको जहाँ-जहाँ IMD को केन्द्रहरू छन्, सोही स्थानहरूमा हामीले हाम्रो केन्द्रहरू सफलताका साथ स्थापना गर्ने काम सु-सम्पन्न भएका थिए । IMD बाट उनीहरूको 104 केन्द्रहरू चलाउन पछि सम्म पनि धेरै प्रयास गरियो । तर श्री ५ को सरकारको तर्फबाट केन्द्रहरू स्थापित भएकोले IMD को जरूरत नभएको परराष्ट्र मार्फत् जानकारी गर ाएपछि बिस्तारै बन्द भयो । यस किसिमबाट हामी आफ्नो खुट्टामा आफैं उभियौं । आफ्नो स्वराष्ट्रमा अरूको अस्तित्वको काम हट्यो । यसमा त्यसबेला विभागीय निर्देशक श्री गोकुललाल अमात्यको पनि प्रमुख भूमिका भएको जानकारी दिन चाहन्छु । हालसम्म पनि उपरोक्त केन्द्रहरू सुचारू रूपले चल्दै आएका छन् र यसबाट प्राप्त तथ्यांकहरू देशको विभिन्न विकासको काममा प्रयोग भई राखेको राम्ररी देख्न सकिन्छ । यहि हो, नेपालमा पनि निरन्तर चलि राखेको विकासको काम हामीले गर्वसाथ भन्न सक्छौं ।

नेपालले weather, climate, water सम्बन्धी अत्यावश्यक तथ्यांकहरू संकलन गरी निरन्तर विकासगरी राखेको ज्वलन्त उदाहरण यो संस्थाले स्थापना कालदेखि ईस्वी 1987 सम्म WMO को निरन्तर Technical Assistance सहायता गरि राखेको स्मरण गराउँछु ।

ईस्वी 1980 तिर WMO को world circulation paper मा WMO को Technical Assistance मा developing countries मा सबभन्दा सफल राष्ट्र नेपाल भनी कोट पनि गरेको थियो,जुन पढ्दा मलाई गर्व महशुस भएको थियो ।

तर बिडम्वना एउटा कुरा के छ भने नेपालमा Department of Hydrology and Meteorology कहिले priority मा परेन, Project दिने राष्ट्र, Agency तयार भएपनि देशको योजनामा low priority ले यो विभागको विकासमा धेरै वाधा अड्चन गरिराखेको छ । आवश्यक वजेट नहुँदा, project नहुँदा नेपाल राष्ट्रले एउटा Radiosonde पनि राख्न सकिएन ।

मेटियोरोलोजीमा खासगरी मौसम भविष्यबाणीको खाली सतहका हावापानीको तथ्यांक मात्र हैन सतह भन्दा माथि विभिन्न उचाईहरूमा हावाको दिशा र वेग, Pressure, तापक्रम, dewpoint temperature ईत्यादिको तथ्यांक आवश्यक पर्दछन् । जुन Upper air station हरूबाट प्राप्तहुन्छन् । यस्ता केन्द्रहरू सार्क राष्ट्रहरूमा पाकिस्तानमा–१६, बंगलादेशमा-६, भारतमा-३७, श्रीलंकामा-४, मालदिभ्समा-१ र त्यस्तै छिमेकी राष्ट्र चीनमा ९० स्थानहरूमा छन् । नेपालमा शून्य ।

यस अवस्थामा मौसम भविष्यबाणीको जे-जति अनुभवहरूबाट काम गर्दै आएका छन्, बहुत सराहनीय छन्, तैपनि समयअनुसार परिवर्तनको निकै अत्यावश्यक छ ।

नेपालमा priority पाएका विभागहरूले वैदेशिक बैंकहरूबाट लिएको चुर्लुम्म डुबाएको ऋण केलाएर हेऱ्यो भने, नेपालमा योजनाकार, अर्थविदहरू, राजनीतिज्ञहरूको ख्वै कसले के मूल्याङ्कन गर्ने हो । ख्वै नेपालीको भाग्य

यस्तै रहेछ । नेपालीको बिडम्वना । यसमा गहिरिएर विचार गर्ने हो, काम गर्ने हो भने, सबै तहबाट आफ्नो निश्चित समयमा कुनैपनि Project को monitoring and evaluation र policy मा नडग्मगाई निस्वार्थ, राष्ट्रको सेवक भनी काम गर्न सक्नुपर्‍यो ।

कुरै-कुरामा भाषण अन्तै मोडियो । वास्तवमा priority र low priority ले नेपालमा Hydrology र Meteorology development को बाधा, यो कसरी बुझाउने हो, सम्बन्धित मन्त्रालय र राष्ट्रिय योजना आयोगबाट यसमा आवश्यक ध्यान आकर्षण गराउन चाहन्छु ।

नेपालको परिप्रेक्ष्यमा हालको जलवायु मौसम विज्ञान विभागको, विभागको दृष्टिबाट धेरै सानो आकार भएता पनि यसको तथ्यांक र अनुसन्धानबाट खास गरी नेपालको जलस्रोत विकास र कृषि विकासमा महत्वपूर्ण देन छ । नेपालको नदीनालाहरु बाट राखिएका जलमापन केन्द्रहरूका तथ्यांकहरू अध्ययन गर्नको लागि हालै National Irrigation Sectorial Project (NISP) अन्तरगत यस विभागद्वारा Strengthening the Department of Hydrology and Meteorology बाट काठमाडौं देखि पश्चिम ७७ वटा वेसिनमा Water Availability को अध्ययन सुरू गरी पूरा भएको थियो र यस्तै अध्ययन यस विभागबाट पूर्वमा पनि हुन नितान्त आवश्यक छ । यस किसिमको अध्ययनबाट भएका तथ्यांकहरू संकलनमा के-कति कमजोरी छन् अब सुधार्न के कति कदम चाल्नुपर्ने, भएको केन्द्रहरू भन्दा, अरू बढी चाहिने हो कि इत्यादि धेरै बिश्लेषण गरिएका हुन्छन् र आफूले गरि राखेकोमा आवश्यक सुधारका मार्गहरू पनि अंकित गराउँछन् । त्यसकारण तथ्यांक मात्र नबटुली त्यसमा अध्ययन, अनुसन्धानको पनि निकै खाँचो छ ।

यस्तै विचारले अभिप्रेरित भई गत तीन वर्ष अघि SOHAM-Nepal, Society of Hydrologists and Meteorologists-Nepal स्थापना भयो । यो एउटा विशुद्ध भावनाको तपाईहरुकै संस्था हो, यसमा नेपालका विभिन्न स्थानहरूमा काम गर्नुहुने हाल नेपालको र विदेशी मुलुकहरूको समेत गरी करिव 150 जना Professional Hydrologists र Meteorologists को सदस्यता लिएका छन् ।

यो SOHAM संस्थाको गत तीन वर्षको स्थापनाकाल पछि, यस विषय सम्बन्धी अध्ययन, अनुसन्धान, सोच र विचारहरूलाई एक-आपसमा Communicate गर्न SOHAM-Nepal ले गत तीन वर्ष देखि नै talk forum संचालन गर्दै आएका छौं । आजको यो fast and dynamic age मा व्यक्ति-व्यक्तिमा विचार साँघुरिएर नराखी, एउटा समूहबाटै आफ्नो विषय बस्तुलाई सामूहिक प्रचारप्रसार गरी देशको सर्वाङ्गीण विकासमा केही सेवा र इकाईहरूमा समय-समयमा घचघच्याउन जरूरी ठानेको छु । यस्तै विचारबाट कृषि विकासमा मेटियोरोलोजीको सम्बन्ध विषयमा मेरो आफ्नो विशेष understanding र अभिरूचि समेत भएकोले एक Comprehensive package जस्तै तयार पारी Soham-Nepal को Chairman को हैसियतले विभिन्न सम्बन्धित विभागहरू र सम्बन्धित High level र donors मा समेत interaction program बनाई Talk program सुरू गर्दै आएका छौं, आशा छ राम्रै होला, हेरूं के हुन्छ ।

नेपालको अन्नबालीको विकासमा एक लाईनमा भन्नुपर्दा गत ईस्वी 1970/71 देखि 2000/01 अन्नबाली उत्पादन र नेपालको सोही अवधिको (मौसम) मनसुन वर्षा केलाएर हेर्दा, 1972, 76, 77, 79, 82, 86, 92,

94, 97 र 99 उपरोक्त 10 वर्षहरूमा नेपालमा सामान्य मनसुन वर्षा भन्दा कम वर्षा हुँदा अन्नबालीमा प्रत्यक्ष असर परेको थियो ।

यसमा अन्नबालीमा मात्र कति नोक्सान भयो भनी मूल्यमा रूपान्तर गरी हेर्दा वर्षमा रू पाँच अरब भन्दा बढी नोक्सान भएको प्रत्यक्ष देखिन्छ । यसमा मेटियोरोलोजी, Hydrology को गहन अध्ययन गरी सो सम्बन्धी सेवा गर्न सकिए 10% मात्र अन्नबाली कम हुन नदिएमा रू पचास करोड बच्न सकिन्छ । के यस्तो काममा सम्बन्धित इकाईहरूको ध्यान आकृष्ट गर्न सकूँला ।

वास्तवमा जुनबेला मैले मेटियोरोलोजीमा काम गरेको थिएँ, सुरू देखिनै नेपालको प्रत्येक एग्रोमेट केन्द्रहरूमा, स्थापना, निरीक्षण, तालिमको सिलसिलामा, कृषिविज्ञहरूको साथ समय-समयमा विचारको आदानप्रदान भईनै राखेको थियो । खास गरी ईस्वी 1980 को दशकमा नेपालको Station design of First Irrigation Manual, LRMP, Agro forestryको डकुमेन्टहरू तयार गरेको बेला विदेशी सल्लाहकारहरू सँग धेरै निकट सम्बन्धहरू कायम भएका थिए । कुनै पनि कृषि विभागको ठूलो सभा, Conference, साथै NARCको जग हालेको बेलासमेत निम्तोमा भाग लिई सम्पर्क भईनै राखेका थिए । तर हाल 1988 पश्चात् हालसम्म कृषितर्फ सम्पर्क शून्यता, छाएको देखियो, बुझियो ।

हाल Climate Change मा खास गरी कृषिको adaptation मा यस किसिमको भविष्य Predict गर्न, past र present scenario मा खास गरी agrometeorological aspect मा हामीले के-कस्तो practical अध्ययन गरेका छौं, हेर्नुपर्छ, मेरो अनुभवमा यसमा शून्यप्राय: छ । यसकारण अहिलेको वास्तविकता बुझ्ने प्रयास गरी Weather and their impacts on agriculture अध्ययन गरौं, अनि यसको आधारमा भविष्यको prediction गरौं । Without proper understanding of present scenario, future prediction will be uncertain ।खाली project for project मा भएको रकम बालुवामा नराखौं ।

यस्तै WMO मा Secretary General ले यसै WMO Day मा सम्बोधन गर्नुभएको वाक्यहरू जस्तो "Another outstanding development is the seasonal prediction of phenomena such as EL Nino and La Nino. Thanks to the enhance knowledge and network of facilities that are available today it is possible to produce useful forecasts to such phenomena a few months to a year ahead"

नेपालमा कृषिमा पर्ने प्रत्यक्ष असरहरूमा SOHAM-Nepal को काम गर्न सक्ने क्षमता छ,यसमा सेवा दिन HMG लाई कस्तो Support चाहियो, त्यसमा सहभागी भई काम गर्न तयार छौं ।

अन्त्यमा, यो संस्थाबाट World Meteorlogical Day 2004 मा 1st Journal of Hydrology and Meteorology को विमोचन हाल यही सभा संचालन गर्दै आउनुभएका विज्ञान तथा प्रविधि मन्त्रालयका सचिवज्यू डा. श्री स्वयम्भूमान अमात्यबाट भएको स्मरण गर्न चाहन्छु । यो साल पनि दोस्रो issue प्रकाशित गर्न हरसम्भव प्रयास गरिएको थियो, यो साल SAARC Countries बाट समेत लेखहरू प्राप्त भएको र लेखहरू 12 वटा छन् । यसमा आवश्यक review इत्यादिले गर्दा बढी समय लिएको छ, तैपनि वैशाखमा

प्रकाशित गरी अब आउने SOHAM-Nepal को वार्षिक सभामा सबै सदस्य महानुभावहरू समक्ष पुऱ्याउने लक्ष्य राखिएको छ । यसमा लेखहरु दिई सहयोग गर्ने सबै contributers र reviewers गरिदिनु हुने सबै महानुभावहरूलाई हृदय देखिनै धन्यवाद दिन चाहन्छु ।

अन्त्यमा WMO को Theme अनुसार देश विकासको काममा एक ईंट्टा भए पनि थप्न ईश्वरले हामी सबैलाई सद्बुद्धि दिउन् र केही गरौं भन्ने सकारात्मक सोच राखौं । समूहमा बाँच्ने प्रयास गरौं, राष्ट्रियता जोगाऔं । यति बेला दुई शब्द यहीँ टुंग्याउँछु ।

धन्यवाद !

23 मार्च 2005
काठमाडौं, नेपाल

डा. जनक लाल नायबा
Chairman
Society of Hydrologists and Meteorologists-Nepal

Further works and references on Climates of Nepal

Climates of Nepal were written during 1974 and this is my first article in my life. In this article, I had described the very preliminary description of a climate in Nepal. Later, in late 1970's, in my Ph.D. thesis on "Climates of Nepal and their implications on agricultural development" the classification of rainfall and temperature regimes of 30 groups (as shown in Fig. xx) have been determined using computer software by Taxon methodology (1971). These regimes in groups yields homo climates which can be useful in many ways, such as investigating the climate and vegetation interaction in transferring new high yielding varieties (HYV) to similar sort of climates (rainfall and temperature regimes). The analysis of major rainfall and temperature indicates that the first two regimes lie in Tarai and inner Tarai; the third, fourth and fifth regimes lie in the Hill and sixth in the Mountain. Broadly the first two regimes lie in the "tropical climate", the next three in its "mesothemal" and the last in its "microthermal climate". This analysis has used the meteorological station only up to 3857 m, Tengboche. So, naturally, other climatic types dominate above this altitude. Since snow line is subject to great local variations ranging from 4500 m to 6000 m (Hagen, 1961), the altitude above Tengboche and below the snow line can be called the taiga and above the snow line can be called alpine climate.

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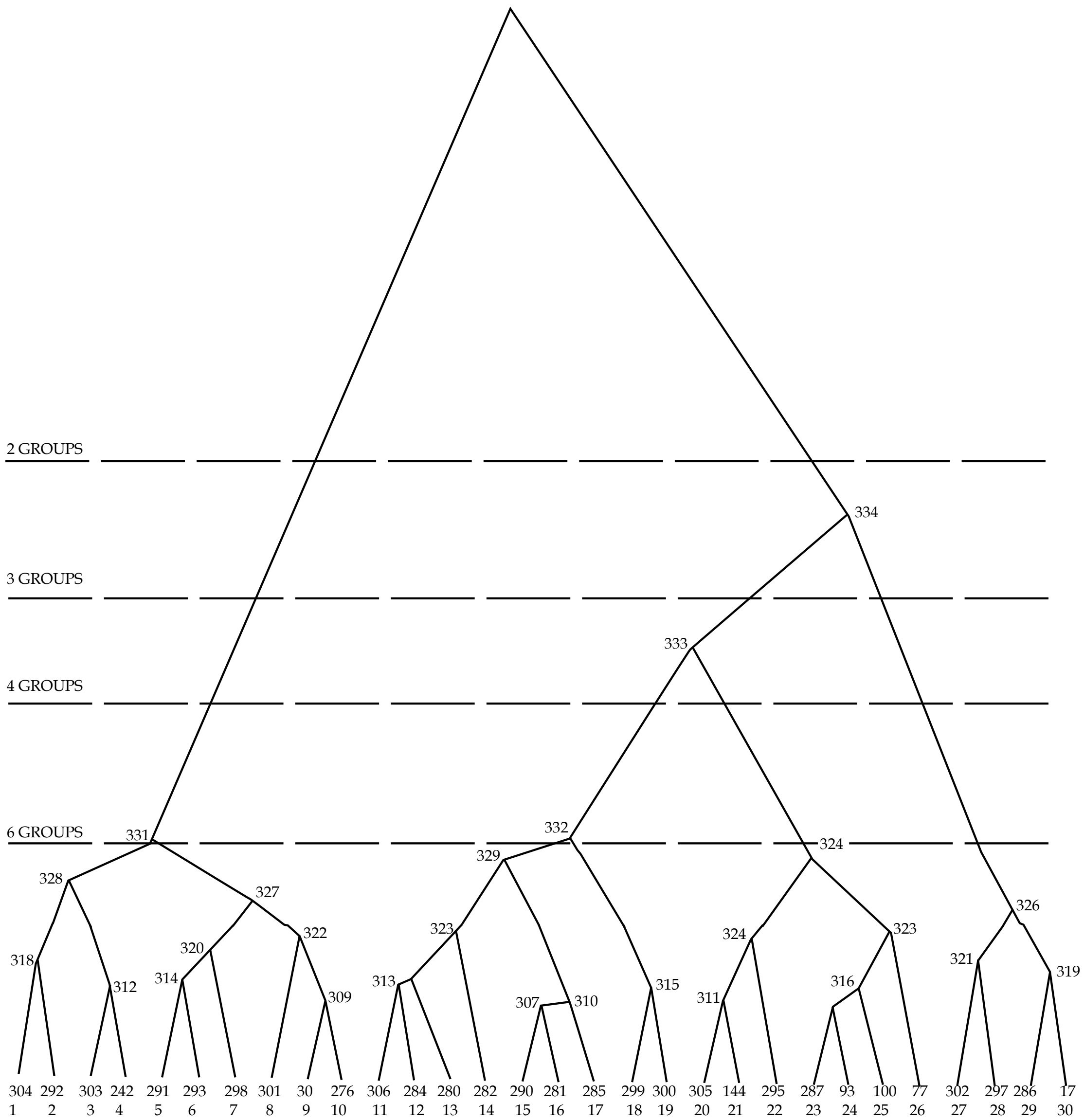

Fig. xx Dendrogram of 30 groups of MULCLAS classification of
168-meteorological station network

1961

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