Hydrological Sciences Journal

ISSN: 0262-6667 (Print) 2150-3435 (Online) Journal homepage: http://www.tandfonline.com/loi/thsj20

Determination of snowmelt factor in the Himalayan region

PRATAP SINGH & NARESH KUMAR

To cite this article: PRATAP SINGH & NARESH KUMAR (1996) Determination of snowmelt factor in the Himalayan region, Hydrological Sciences Journal, 41:3, 301-310, DOI: 10.1080/02626669609491504

To link to this article: http://dx.doi.org/10.1080/02626669609491504

Published online: 24 Dec 2009.

Determination of snowmelt factor in the Himalayan region

PRATAP SINGH & NARESH KUMAR
National Institute of Hydrology, Jal Vigyan Bhawan, Roorkee 247 667, Uttar Pradesh, India

Abstract Information on the snowmelt factor (SMF) is required for the estimation of snow and glacier melt runoff. In the present study, SMF is computed for a normal snowpack over a glacier at an altitude of about 4000 m in the Garhwal Himalayas. The effect of natural dusting on SMF is also examined. For this purpose, natural dust available at the site of the experiment was uniformly spread over the snow surface to form a 2 mm thick layer. The melt runoff from the snow blocks and air temperature at 2 m above the snow surface were observed. Mean daily SMF values for normal and dusted snow blocks were computed to be 5.94 and 6.62 mm $°C^{-1}$ day^{-1}, respectively. Mean daily SMF for the dusted snow block was found to be always higher than that of the dust free snow block. Maximum hourly values of SMF for the normal and dusted snow blocks were obtained in the range of 0.583-0.632 and 0.785-0.824 mm $°C^{-1}$ h^{-1}, respectively, while the minimum value was zero for all cases. Maximum hourly value of SMF occurred at about 1400 h for both blocks. A comparison of the daily SMF with information already available in the literature is presented.

Détermination du facteur de fonte de neige dans la région Himalayenne

Résumé Il est nécessaire d'avoir des renseignements sur le facteur de fonte pour estimer le débit provenant de la fonte des neiges et des glaciers. Dans cette étude, le facteur de fonte est calculé pour un manteau neigeux ordinaire sur un glacier situé à une altitude d'environ 4000 mètres dans l'Himalaya de Garhwal. L'effet de l'empoussiérage naturel sur le facteur de fonte a également été examiné. Dans ce but, de la poussière naturelle disponible sur le site expérimental a été uniformément répandue à la surface de la neige afin de former une couche de 2 mm d'épaisseur. On a mesuré le débit de fonte des blocs de neige et la température de l'air à 2 m au dessus de la surface de la neige. Les valeurs moyennes journalières du facteur de fonte calculées pour la neige naturelle et pour la neige empoussiérée ont respectivement été de 5.94 et 6.62 mm par °C et par jour. La moyenne journalière du facteur de fonte de la neige empoussiérée s'est toujours révélée supérieure à celle de la neige sans poussière. Le maximum horaire du facteur de fonte pour la neige normale et pour la neige empoussiérée ont respectivement été compris dans les intervalles de 0.583-0.632 et de 0.785-0.824 mm par °C et par jour, alors que la valeur minimale était systématiquement nulle. Dans les deux cas le maximum horaire du facteur de fonte a été atteint à 14 heures. Les résultats concernant le facteur de fonte journalier ont été comparés avec les données disponible dans la littérature.

Open for discussion until 1 December 1996

INTRODUCTION

Snowmelt runoff is an overall result of many different processes of heat transfer to the snowpack. The quantity of snowmelt is also dependent upon the condition of the snowpack itself. As a consequence, the determination of snowmelt runoff is complex and certain simplifying assumptions are used in the practical computation of snowmelt. The temperature index is generally considered to be a good index of the heat transfer processes associated with melting of a snowpack. Air temperatures are generally the most readily available data. Moreover, the temperature index approach often gives snowmelt estimates comparable to those determined from a detailed evaluation of the various components in the energy balance (US Army Corps of Engineers, 1971; Anderson, 1973). For these reasons, the temperature index is the most widely used method of snowmelt computation. However, no single universally applicable temperature index of snowmelt exits, but whenever a temperature index approach is used, knowledge of the snowmelt factor is required.

An appreciable quantity of the flow of Himalayan rivers is derived from snow and glacier melt runoff (Singh *et al.*, 1995). Availability of the detailed climatic data required for snow and glacier melt runoff modelling using the energy balance approach is very poor in the Himalayas. All the hydrological studies are based on the temperature index approach in the Himalayan region. As discussed above, for a proper exploitation of available snow and ice reservoirs and their full utilization, a knowledge of several parameters associated with the melting of snow is needed. One of the important parameters is the snowmelt factor (SMF). However, this parameter does not take into account gains or losses to the snowpack during the period of consideration, but it works well for all practical purposes because the sum of gains and losses is usually small on a daily basis. This parameter is used with air temperature to compute snowmelt expressed in depth of water. It is given in the following form:

$$M = D_f(T_a - T_o) \qquad (1)$$

where M = depth of melt water (mm per unit time); T_a = mean air temperature (°C); T_0 = base temperature (usually 0°C); and D_f = snowmelt factor (mm °C^{-1} per unit time). The value of the SMF varies with the melt period because of changes in snow properties which influence the melting process.

In spite of its importance, no information is available on the SMF for any Himalayan basin at any time of the year. Further, all studies, either for simulation or for forecasting of snow and glacier melt runoff, are made on a daily basis. Hourly simulations have not been carried out for any Himalayan basin simply because no hourly data are available. However, a 6-hourly melt factor was recently determined from isolated snow blocks (Singh *et al.*, 1995). It is felt that values of daily SMF are more useful for the Himalayan basins in comparison to the hourly or 6-hourly values. Consequently studies were planned and carried out to estimate the SMF at the Dokriani glacier snowpack. However, hourly SMF was also calculated and discussed for the same period.

Augmentation of snow and ice melt under dusting conditions

Albedo governs the amount of radiant energy absorbed by a snowpack and hence is very important for determining the rate of melting. The blackening of snow surfaces reduces the albedo of snow significantly. Only a few studies are reported in the literature pertaining to the accelerated melting of a snowpack due to dusting. The first experiment on artificial dusting of glaciers was conducted by Avsiuk (1953) between 1950 and 1952. Four series of experiments were carried out, each taking three or four days. It was concluded that the most efficient melting occurred when coal dust was used between 5 and 10 g m^{-2}. Dusting at this recommended rate caused the albedo of the young firn and snow surfaces to decrease on the average to 0.25-0.30, old firn to 0.15-0.20 and ice to 0.07-0.10. At the same time, melting in comparison with dust free surfaces increased three to four times for young firn and snow, up to three times for old firn and by 30% for ice. Avsiuk (1953, 1962) indicated that by dusting the whole area of a glacier at the beginning of an ablation period, the annual river runoff from the mountains of Soviet Central Asia could be increased by 50-55%.

Kotlyakov & Dolgushin (1972) reported results of some experiments carried out near ports on the shore of the North Arctic Ocean, and on Siberian rivers and lakes of the northern part of the European territory of the USSR. A three to four times faster melting of the snow cover on ice as compared with the usual melting of snowpack was observed. The best results were achieved by dusting at the rates of 300-350 g m^{-2} with crushed coal and slag or 400 g m^{-2} with a sand and coal mixture.

Studies related to the SMF of a normal snowpack or dusted snowpack are not available for the Himalayan basins. In this study, the effect of natural dust on the diurnal and mean daily SMF or on the accelerating of melt rate has been determined. The location of the experimental site is shown in Fig. 1. It is to be mentioned that, in general, access to the Himalayan glaciers is very difficult because of the very rugged terrain. For example, more than 25 km of trekking was needed to carry out the present investigations. Further, climate, accommodation and commodity problems at high altitude make such studies very difficult in nature which results in limited observations.

SETTING UP OF SNOW BLOCK EXPERIMENTS

It is possible to compute the hourly or daily SMF at a point by measuring air temperature and melt water from a snow block. In the present study, degree-days for a day have been calculated from the positive hourly means only. The point measurements can be used for information on how well a specific station represents the hydrological characteristics of a given basin. Singh *et al.* (1995) made some calculations of the SMF by studying the isolated snow blocks for a part of the day. As discussed above, these values are of limited use.

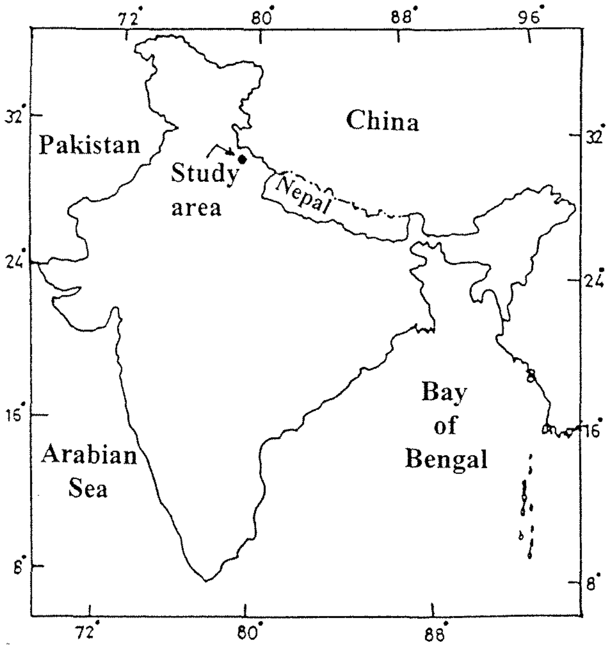

Fig. 1. Location map of study area.

Moreover, a study of an isolated snow block to determine the SMF does not represent the actual melting situation of the snowpack because an isolated snow block receives additional energy from all the exposed sides of the block. In the case of natural melting of a snowpack, energy is received through only the upper surface of the snowpack. Therefore, to obtain more reliable and accurate information on the SMF, snow blocks were monitored in the snowpack only. All the experiments were carried out under fair weather conditions. Details of dust free and dusted snow block experiments are given below.

Normal snow blocks

A snow block was extracted from the glacier snowpack at an altitude of about 4000 m without disturbing its natural structure. The dimensions of the block were 30 cm × 30 cm × 30 cm with a density of 0.60 g cm^{-3}. The snow block was compact enough at this density. This block was completely wrapped in white plastic sheet on all sides except the upper one and replaced in the snowpack. All the boundaries were in contact with the snowpack and the plastic sheet around all sides ensured that melt runoff only from the snow block under study was collected. There was no loss of melt water in the form of infiltration or percolation because of the plastic sheet underneath.

After setting up the experiment, only the upper surface of the block was exposed to radiation and melting occurred as under the natural conditions of the snowpack. Observations were made hourly over 24 h from 0800 h on 4, 5 and 6 June 1995. To get a better representation of temperature within each hour, air temperatures were observed every 15 min at 2 m height above the snow surface and were used to compute the average temperature for each hour. The melt water was collected in a bucket every hour and measured immediately after its collection to minimize evaporation losses from the collected volume of water.

Dusted snow blocks

Dusting or blackening of snow and ice surfaces by dark material reduces their albedo. It results in a higher absorption of solar radiation leading to an accelerated melt rate and a higher water yield. The accelerated rate of melt depends on the radiation absorbing property of the dusting material. There are several materials that have been used such as charcoal powder, boiler ash, wood ash and common salt etc, but in the present study the natural dust available at 4000 m altitude over the snow surface was used as the dusting material. It is the material which in fact affects the melt rate of the Himalayan snowpack in reality. The dust consisted mainly of moraine and debris powder having particles coarse in size. No treatment was given to the dust in terms of changing the size of the particles.

To study the effect of dusting on the SMF, a snow block was extracted and replaced in the snowpack like the normal snow block. The size and density of the dusted snow block were similar to those of the normal snow block, except that the upper surface of the block was covered by a uniform 2 mm thick layer of the natural dust. Although various depths of this dust were found at different locations over the snowpack, for this experiment a uniform depth of 2 mm thickness was selected simply because this depth was found at several locations. The dust-free and dusted snow blocks were adjacent so that both blocks experienced the same weather conditions. The frequency and period of observations for the air temperatures and melt water runoff were exactly same for both snow blocks.

All the experiments described above were carried out for a period of three days. It was preferred to set up a new experiment at 0800 h every day and take observations for the next 24 h. Study of the same blocks for the next day was not continued because the objective of the experiment was to study the effect of a uniform dust layer on the daily SMF. It was noticed that if the experiment was extended beyond 24 h, a part of the dust spread over the snow surface percolated into the snow block with the melt water leaving a non-uniform dust layer over the snow block. Moreover, due to the accelerated melt rate, the dusted snow block sank relatively faster and the surface level of both blocks was changed. Under those circumstances, the dusted block was not exposed to the same radiation as the normal snow block.

RESULTS AND DISCUSSION

Diurnal variation in snowmelt factor

Diurnal variation in the SMF for both a normal snow block and a dusted snow block was computed and is demonstrated in Fig. 2. It is clear that for both snow blocks the SMF varied with time. In both cases, it started rising at about 0800 h and attained its maximum value at about 1400/1500 h. After that it started reducing and reached zero by about 2000 h. Runoff from the dusted snow block was observed about an hour later than the normal snow block. The results indicate that the SMF for a dusted block followed a sharper rise and recession as compared with a normal snow block. In the first part of the day (up to about 1400 h) this factor was higher for the dusted snow block, but in the later part of the day it was lower in comparison to the normal snow block. The maximum value of the SMF for the normal and the dusted snow blocks for 4, 5 and 6 June 1995 were found to be 0.632, 0.583, 0.615 and 0.785, 0.824, 0.791 mm $°C^{-1}$ h^{-1}, respectively. It was observed that the maximum value of the SMF occurred at about 1400 h for both blocks. The hourly observed air temperature and melt runoff from the snow blocks are shown in Table 1. Throughout the experiment, the air temperature was above 0°C.

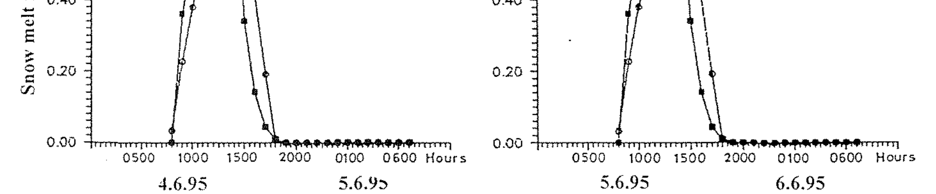

Fig. 2. Diurnal variation in snowmelt factor for normal and dusted snow blocks (a) observed on 4.6.95/5.6.95; and (b) observed on 5.6.95/6.6.95.

The diurnal variation in the SMF for both the normal and the dusted snow blocks can be explained on the basis of the change of albedo at, or the energy absorbed by, the melting surface. A dusted snow surface has a lower albedo value and absorbs more energy than the normal snow surface. The albedo of a snow surface varies with the angle of incidence of the radiation and also depends on the characteristics of the energy receiving surface. A higher

Table 1 Air temperatures recorded over the snow surface and runoff observed from the normal and dusted snow blocks under same weather conditions

Date	Hours	Air temperature at 2 m above surface (°C)	Runoff from normal snow block (ml)	Runoff from dusted snow block (ml)
4.6.1995	0800-0900	16.7	50	0
	0900-1000	18.8	360	600
	1000-1100	19.5	730	1030
	1100-1200	20.8	870	1270
	1200-1300	21.0	930	1340
	1300-1400	20.8	1000	1470
	1400-1500	19.0	1080	1320
	1500-1600	18.1	870	540
	1600-1700	16.6	670	250
	1700-1800	14.9	260	70
	1800-1900	11.9	120	20
	1900-2000	10.2	50	0
	2000-2100	9.6	0	0
	2100-2200	8.5	0	0
	2200-2300	8.3	0	0
	2300-2400	7.2	0	0
5.6.1995	2400-0100	6.3	0	0
	0100-0200	7.7	0	0
	0200-0300	7.5	0	0
	0300-0400	7.0	0	0
	0400-0500	6.4	0	0
	0500-0600	6.2	0	0
	0600-0700	10.4	0	0
	0700-0800	15.5	0	0
	0800-0900	16.8	50	0
	0900-1000	19.0	390	620
	1000-1100	20.4	700	950
	1100-1200	21.2	920	1230
	1200-1300	20.6	990	1300
	1300-1400	19.8	1000	1470
	1400-1500	19.6	1030	1340
	1500-1600	18.2	870	560
	1600-1700	16.3	610	210
	1700-1800	15.0	260	60
	1800-1900	12.5	110	10
	1900-2000	11.0	40	0
	2000-2100	10.2	0	0
	2100-2200	9.2	0	0
	2200-2300	8.3	0	0
	2300-2400	7.0	0	0
6.6.1995	2400-0100	6.7	0	0
	0100-0200	6.9	0	0
	0200-0300	7.0	0	0
	0300-0400	7.2	0	0
	0400-0500	7.0	0	0
	0500-0600	8.3	0	0
	0600-0700	9.6	0	0
	0700-0800	14.7	0	0
	0800-0900	17.3	60	0
	0900-1000	19.2	380	620
	1000-1100	20.5	760	1020
	1100-1200	21.5	930	1300
	1200-1300	21.3	1010	1340
	1300-1400	20.5	990	1460
	1400-1500	19.5	1080	1320
	1500-1600	18.7	900	570
	1600-1700	16.9	700	290
	1700-1800	15.6	250	60
	1800-1900	13.0	100	10
	1900-2000	11.2	30	0
	2000-2100	10.3	0	0
	2100-2200	9.4	0	0
	2200-2300	9.0	0	0
	2300-2400	8.6	0	0
7.6.1995	2400-0100	7.2	0	0
	0100-0200	7.0	0	0
	0200-0300	7.6	0	0
	0300-0400	7.5	0	0
	0400-0500	7.8	0	0
	0500-0600	7.0	0	0
	0600-0700	8.7	0	0
	0700-0800	12.0	0	0

The dimensions of both snow blocks were 30 cm × 30 cm × 30 cm.

value of albedo is associated with a larger angle of incidence (US Army Corps of Engineers, 1956). However, this variation may also be partially the result of changes in the structure of the snow itself during the day. For example, when the melt rate is at its maximum, the higher concentration of the liquid water in the top layers of the snowpack decreases the albedo. A lower value of the SMF for the dusted snow block in the later part of the day as compared with the normal snow block can be explained by the water storage characteristics of the snow blocks. A large pore system is developed in the dusted snow block because many minute dust particles sink into the snowpack with the melt water. Consequently, melt water from the dusted snow block is drained more rapidly than in the normal snow block. The normal snow block retains melt water for a longer period and drains more slowly. This results in a lower hourly value of the SMF for the dusted snow block in the later part of the day.

Daily snowmelt factor

The daily values of the SMF for normal and dusted snow blocks were calculated. In order to obtain these values, hourly (0800-0700 h) air temperatures and runoff data were used to evaluate average temperature and total runoff during the observation period. The calculated mean daily values of the SMF are shown in Table 2(a). It can be seen that, in all cases, the daily SMF for a dusted snow block was higher than that of the normal snow block. Over a period of one day, dusting of the snow surface accelerated melting of the snowpack. Based on the field observations, average values of the SMF for the normal snow block and the dusted snow block were computed to be 5.94 and 6.62 mm $°C^{-1}$ day^{-1}, respectively, an increase of about 11.50% in the daily SMF due to a natural dusting of 2 mm thickness. However the magnitude of the acceleration in melting depends on the type and depth of the dusting material. It is to be pointed out here that the SMF is considered a substitute for

Table 2 Mean daily snowmelt factors for normal and dusted snow blocks: daily average temperature used in the derivation of these values was computed (a) as a mean of hourly (0800-0700 h) temperature data; and (b) as a mean of daily maximum and minimum temperatures

Date	Normal snow block (mm $°C^{-1}$ day^{-1})	Dusted snow block (mm $°C^{-1}$ day^{-1})
(a)		
4.6.1995	6.03	6.75
5.6.1995	5.85	6.50
6.6.1995	5.95	6.62
Average	5.94	6.62
(b)		
4.6.1995	5.70	6.39
5.6.1995	5.47	6.07
6.6.1995	5.52	6.14
Average	5.56	6.20

sensible heat which is proportional to the difference of air temperature and snow surface temperature. Dusted surfaces are warmer than the normal snow surface which is assumed to be at 0°C. Because of the smaller difference in air and surface temperatures for the dusted snow surface, a higher value of the SMF is to be expected for the dusted surface.

Daily maximum and minimum temperatures are the most readily available data for high altitude basins. An attempt was made to compute the SMF for both snow blocks using average temperature of the day as a positive daily mean of the maximum and minimum temperatures and compared with the SMF derived from the average temperature of the day based on the mean of the 24 hourly positive values of temperature. The results are shown in Table 2(b). The SMF for both snow blocks were found to be lower when the average temperature of the day was taken as the mean of the daily maximum and minimum temperatures. The SMF for both normal and dusted snow blocks was reduced by 6.40% by considering the average temperature of a day as the mean of the daily maximum and minimum temperatures. On the basis of this marginal reduction in the SMF, it can be concluded that the average temperature of a day as the mean of the daily maximum and minimum temperatures can be used in the snowmelt runoff calculations when hourly data are not available. This type of situation is very common in Himalayan basins.

The mean daily value of the SMF for a normal snow block can be compared with the earlier reported results. Yoshida (1962) reported a SMF in the range of 4.0-8.0 mm $°C^{-1}$ day^{-1} for the Tadami River basin in Japan. Anderson (1973) made a detailed study of the seasonal variation in the SMF and found it in the range of 1.32-3.66 mm $°C^{-1}$ day^{-1}. A comparison of the SMF for the normal snow block with these reported values suggests that the values herein lie in the range suggested by Yoshida (1962), but are on the high side of the results reported by Anderson (1973).

CONCLUSIONS

Mean daily SMF has been determined by monitoring a known surface area of a snow block within the snowpack at an altitude of about 4000 m over a glacier in the Garhwal Himalayan region. The effect of a 2 mm thick layer of natural dust available at that altitude was studied. The mean daily values of the SMF for the normal and dusted snow blocks were computed to be 5.94 and 6.62 mm $°C^{-1}$ day^{-1}, respectively. A sharp rise and fall was observed in the hourly SMF of the dusted snow block as compared with a normal snow block. The water storage characteristics of a snowpack changed under dusting conditions which resulted in faster draining of melt water from the dusted snow block as compared with a normal snow block. The maximum hourly SMF for the normal and dusted blocks were computed to be 0.632 and 0.824 mm $°C^{-1}$ h^{-1}, respectively, which occurred at about 1400 h for both blocks. The minimum hourly SMF was zero for both blocks.

Consideration of average temperature of a day as a mean of daily maximum and minimum air temperatures instead of the mean of 24 hourly positive air temperature values, did not change the daily SMF value significantly. The average temperature of a day as a mean of daily maximum and minimum temperatures can be used in the snowmelt runoff calculations when hourly data are not available. It is suggested that such studies should be extended to study seasonal variation in the SMF under different conditions in the Himalayan region.

Acknowledgements The authors are grateful to the Department of Science and Technology, New Delhi, India, for providing funds to carry out this study. The authors are also thankful to S. M. Seth, Director, NIH and K. S. Ramasastri, NIH, for their valuable suggestions.

REFERENCES

Anderson, E. A. (1973) National Weather Service River Forecast System - snow accumulation and ablation model. NOAA Tech. Memo. NWS HYDRO-17, US Dept. Commerce, Washington, DC, USA.

Avsiuk, G. A. (1953) Artificial augmentation of snow and ice melting of mountain glaciers. In: *Proc. Inst. Geography, A. S., USSR*, Vol. 56.

Avsiuk, G. A. (1962) Artificial augmentation of melting of mountain glaciers to increase the runoff of rivers in Soviet Central Asia, A. S. Series, Geography, N5. Moscow, Russia.

Kotlyakov, V. M. & Dolgushin, L. D. (1972) Possibility of artificial augmentation of melting by surface dusting of glaciers. In: *Role of Snow and Ice in Hydrology*, (Proc. Banff Symp., September 1972), 1421-1426. IAHS Publ. no. 107.

Singh P., Ramasastri, K. S., Singh, U. K., Gergan, J. T. & Dobhal, D. P. (1995) Hydrological characteristics of the Dokriani Glacier in the Garhwal Himalayas. *Hydrol. Sci. J.* **40**(2), 243-257.

US Army Corps of Engineers (1956) Snow Hydrology, Summary Report of the Snow Investigations, US Army Corps of Engineers, North Pacific Division, Portland, Oregon, USA.

US Army Corps of Engineers (1971) Runoff evaluation and streamflow simulation by computer. Part-II, US Army Corps of Engineers, North Pacific Division, Portland, Oregon, USA.

Yoshida, S. (1962) Hydrometeorological study on snowmelt. *J. Meteorol. Res.* **14**, 879-899.

Received 30 August 1995; accepted 20 November 1995