

THE VANISHING ELEPHANT

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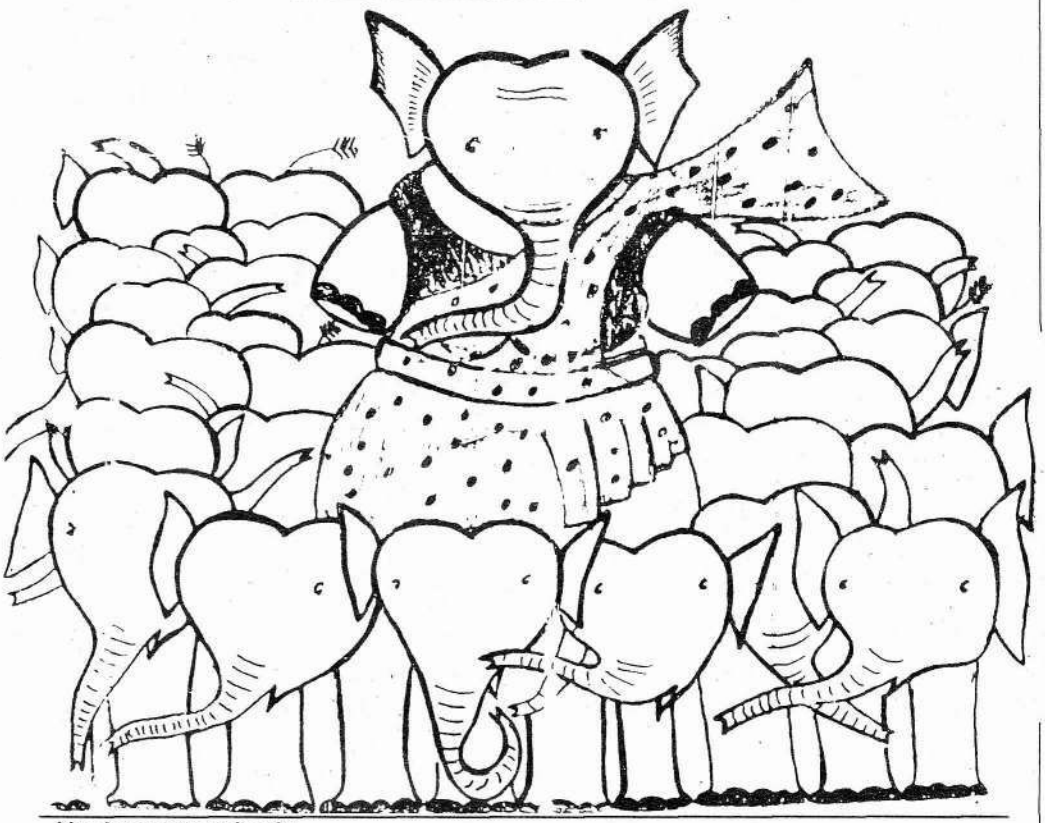
One of the main trends observed in the process of animal evolution is increase in size. This trend reached a culmination in the dinosaurs, or terrible lizards. The same trend is visible in the mammals, as well. The blue whale, an aquatic mammal, is the largest living animal, attaining a length of over 30 meters. On land too there are giants. Some have become extinct like the giant ground sloth, and others are still living like the rhinocerous, giraffe and the elephant. Elephants are an important group of animals. Many reasons can be given for this.

For instance, this animal is almost a national symbol. It is a threatened species and also a charismatic species. Though everyone knows the elephant most persons know very little about it. Main reason for my interest is that for many years I have been working on elephants - their breeding and physiology. Elephants are remarkable for their intelligence, powers of memory, amenability to training, behavioural patterns and social organization. It is well known that in many Asiatic societies, including our own, elephants have played for centuries prominent roles in the pageants of monarchs, in religious ceremonies, as well as in the theatre of war. Alexander the Great is reputed to have crossed the Alps with them. Our own Maligawa Tusker, Raja which died at the age of about 80 years, played for many years, the star role in the Kandy Perahera carrying the sacred tooth relic. In everyday life in our societies man and the elephant have been very closely associated for many thousands of years. This close association of man and elephant is one of the contributory factors which impaired their rate of extinction in Sri Lanka. Usually small islands like ours can not sustain large animals like elephants.

In this article, I will refer, briefly first, to their origin, past and present distribution, and to some major features of interest about the life of the elephants. I will also discuss the human/elephant conflicts that are

FIGURE 1: SOCIAL LIFE OF ELEPHANTS



Live in groups or herds
Sri Lanka herds usully consist of 15-40 individuals, Matriarchal, and led by the oldest, largest, reproducing female.

Table : Differences between Asian and African elephants.

	Asian elephant	African elephant
1. Weight	about 5000 Kg	about 6000 Kg
2. Height at shoulder	2.0 - 3.5 m	3.0 - 4.0 m
3. Heighest point	at top of head	at top of shoulder
4. Shape	back - convex or level head - has two prominent bulge	back - concave head - has no bulges
5. Ears	smaller and do not exeed height of neck	larger and do exeed height of neck
6. Skin	smoother and depigmentation seen (with aging)	more wrinkled and not depigmented at any age
7. Number of ribs	upto 20 pairs	upto 21 pairs
8. Teeth	narrow plate like loops on chewing surface.	diamond - shaped loops on chewing surface
9. Tusks	only in males	in both males and females
10. Trunk	tip has only one finger like process	tip has two finger like processes
11. Number of nail-like structures in limbs	fore limb - 5 hind limb - 4	fore limb - 4 hind limb - 4
12. Musth	shown only by males	shown by both males and females
13. Domestication	easy	difficult
14. Intelligence	more	less

now eroding the existing population and threatening their future survival. I also propose to devote a part of this article to my own studies on captive breeding in Sri Lanka and to the phenomenon of musth.

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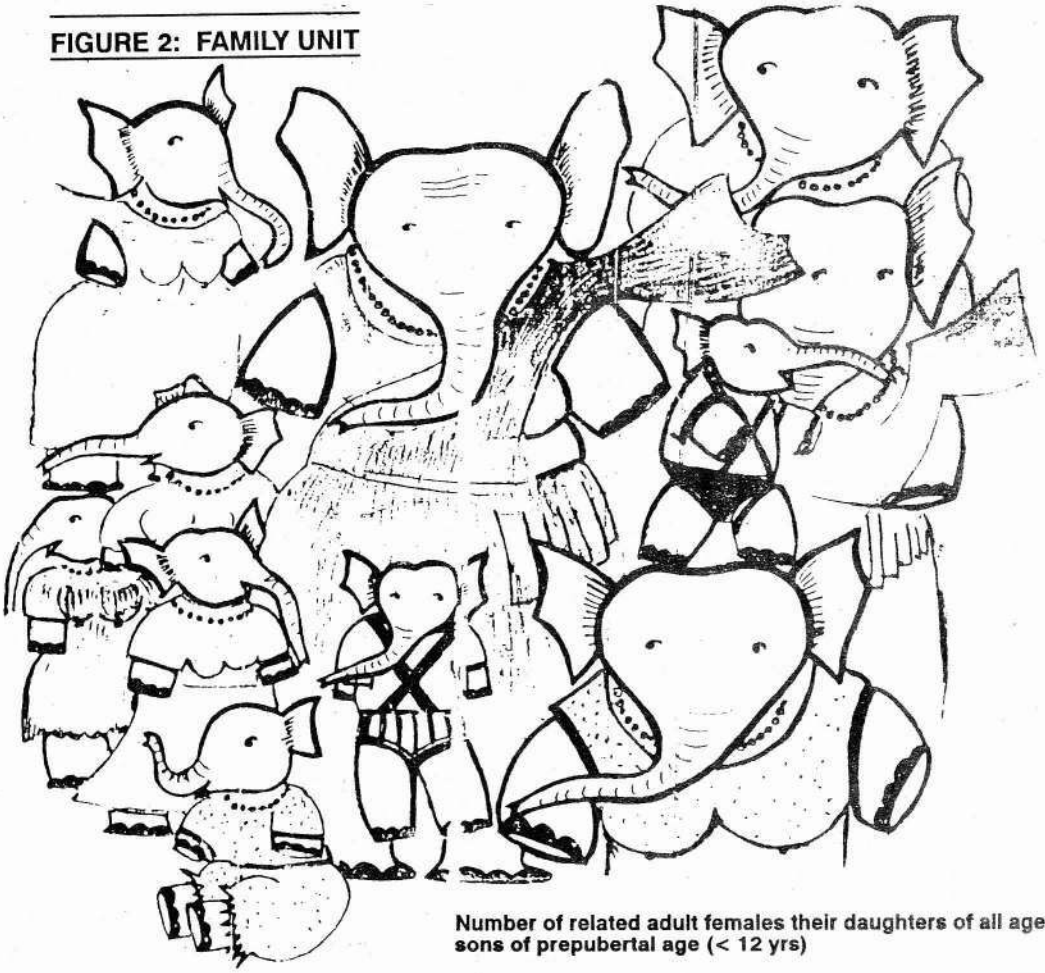
The prehistory of the elephant is fairly well documented, from its origin from little modified pig-like mammals, to the mastodonts, wooly mammoths and the present day elephants. Their origin lies in and around Egypt of today. Though they live only in restricted areas today, in the past, elephants were widely distributed through the tropics and sub-tropics of Africa and whole of Asia. They never entered Australia. They have a broad relationship to the herbivorous groups of mammals. However, their closest living relatives are the small, rabbit-like cony living in arid rocky hill sides in Africa and the Middle East and the sea-cows, which are marine. The elephant, the sea-cow and the cony are a good illustration of how the processes of evolution transform a basic animal form in vastly different directions in adaptation to varied environments.

In spite of their long history the animals have not diversified. There are only two genera of elephant living today. *Loxodonta* (the elephant of Africa) and the *Elephas* (the elephant of Asia). There are 2 sub species of African elephant the 'cape' elephant *(Loxodonta africana africana)* and the 'forest or bush' elephant *(Loxodonta africana cyclotis)*. On the otherhand, 4 sub speicies of living Asian elephants are recognized:

- *Elephas maximus indicus* (Indian elephant).
- *Elephas maximus maximus* (Sri Lankan elephant).
- *Elephas maximus sumatranus* (Sumatran elephant).
- *Elephas maximus hirsutus* (Malayan elephant).

FIGURE 2: FAMILY UNIT



Number of related adult females their daughters of all ages, sons of prepubertal age (< 12 yrs)

I wish now to turn briefly to some of special and interesting features about the structure and life of the elephant. They are huge [(growing to a height) 3-4 meters at the shoulder and achieving weights of up to 5-6 tons (5000-7500 kg)]. The skeleton is engineered for berating heavy weight (graviportal) and the limbs are massive pillars. Joints are highly flexible and the soles of the feet are large (flat) and padded. This form enables them to walk on loose sand and in swamps without getting stuck by distributing their weight at about 600 grams per square centimeter. They can climb slopes, swim well and run for short distances at a speed of up to 30 km/H. Another feature of interest is that, inspite of their size they are able to move almost without sound. On the other hand, the same limbs can push down large trees and trample men in to the dust.

In Sri Lankan elephants, 2 races are recognized: The so called, Vil Aliya (Tall and long) and the Gata aliya (short and stout).

There are important differences between the Asian and the African elephant. These differences are indicated in the above table.

Though elephants ranged widely over two large continents, today, their populations have become greatly reduced. It is estimated that the total number of African elephants is around 600,000 and Asian elephant between 30,000 and 40,000. The Sri lankan population is about 2500 in the wild and in addition 550 captive animals. While it is true that in the natural course of evolution the animal species, gradually reach extinction, human activity has increased the rate at which the elephant populations are disappearing. In the case of the African elephant the major threat derives from the demand for ivory. The animals are slaughtered for the ivory. The meat too is consumed as food and favoured for supposed aphrodisiac properties. In the case of the Asiatic elephant the major threat comes from transformation of the natural habitat for agricultural and other developments. In recent times the problem has become very acute. In the absence of adequate corrective measures it is feared that the elephant might finally disappear from the earth in the 21st century.

The head of the animal is very large but its weight is reduced by the bones being porous. The head has to bear the weight of the tusks as well as that of the trunk and this is anchored to the body by the massive musculature of the neck. The trunk itself is a highly specialized and a unique structure. It is also very ver

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satile in function. It is formed by the union and the extension of the upper lip and the nose. It reaches a length of about 2.5 meters. A group of about 100,000 muscles control its movements ranging from very delicate movements to movements involving immense power. In its versatility it parallels the human hand. Amongst the functions that it performs are breathing, sucking of water, collection and manipulation of food, carrying objects, attacking adversaries, touching and caressing other elephants in play and in sexual behaviour.

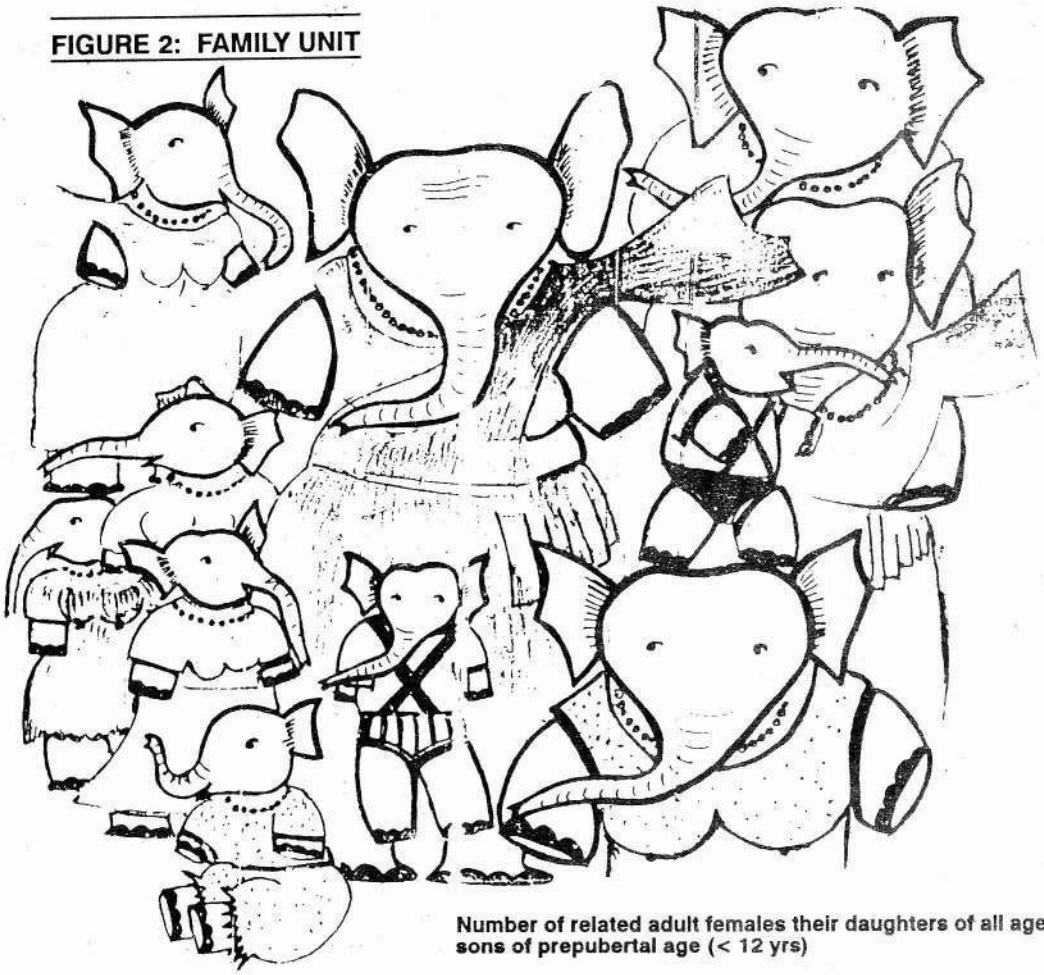
The other well known feature of elephants is their tusks. The tusks are formed by the continuously growing upper incisors. They appear both in males and females of the African elephant but only in males of the Asian elephant. Here too, there is variation: about 90% of the males in the Southern India are tusked. In Sri Lanka, only about 11% are tuskers. Tusked males are called Atha, males with tushes are called Aliya and males without tusk or tushes are called Pussa. Females with tushes are called Athinna and females with out tushes are called Alidena. Some times when foreign materials get into pulp cavity of tusk, dentine is deposited around such material and forms what is traditionally referred to as elephant pearls (Gajamuthu).

The life of the elephant can last only as long as its molar teeth. During its life time an elephant produces 6 sets of massive molars in horizontal succession. At any one time there are only two molars in each jaw. Thus, the elephant chews its food with 4 teeth. As the animal grows the molars produced becomes larger and larger. The number of lophs of ridges on each tooth increase. Therefore, it is possible to estimate the age of an elephant by counting the number of lophs on the teeth currently in use. Once the last of the molars is worn or lost, the animal can no longer grind sufficient food to support life and must gradually die of starvation. Humans are fortunate because they can use dentures.

One consequence of the large size of the animal is the need for very large amounts of food. It is often stated that the life of the elephant is one long meal. Usually, it has to spend up to 20 hrs a day feeding, consuming about 150 kg in the process. Which is about 6-8% of its own body weight. (This may seem an enormous amount, but when we compare elephants with other animals it turns out that elephants eat less food in relation to their body weight than other animals do. For example, a rat may consume 40% of its body weight as food in a day).

Finding this quantity of food is possible only by ranging over large areas with appropriate vegetal cover. The Sri Lankan female elephant requires about 10 square kilo meters of range in wet season and 17 square kilo meters in dry season. The male requires about 25 square kilo meters in wet season and 60 square kilo meters in dry season. Each herd has its own traditional home range. As seasons change the herds move along regular paths of migration which are traditional.

FIGURE 2: FAMILY UNIT



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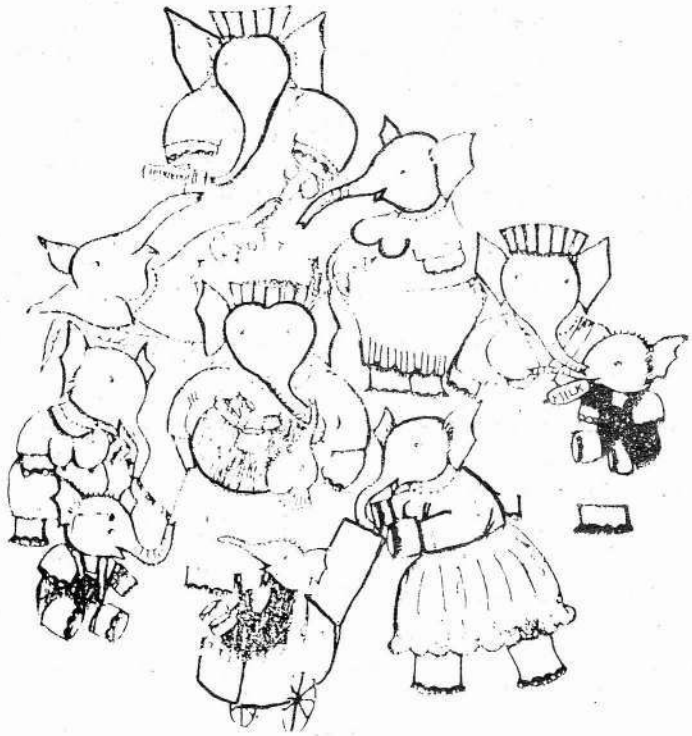
Unlike the other specialized herbivorous mammals such as cattle which have bacteria that help in digestion in the chambers of their stomach, bacteria are present only in the caecum of elephants. Therefore, much of the food intake is wasted. The time taken for food to pass through the gut of an elephant may be any where from 11-46 hours, but an average time of 24 hours seems usual. Large amounts of faeces are voided with undigested matter. About 15 boluses are voided for a day each weighing about 3 kgs. Rabbits too have bacteria only in the caecum, but they are coprophagus (they eat their own faeces) and thus increase the efficiency of digestion. The elephants are mainly grazers (African over 80% and Asian over 50% on grasses), but they also browse, feeding on any green matter that they can lay their trunks on. The Sri Lankan elephant is known to consume about 88 plant species. They are able to detoxify toxic materials such as alkaloids, and cyanogenic glucosides that are found in their food by using special liver enzymes. It is of interest to note that elephants have no gall bladder. They avoid eating certain young plants which contain HCN, but will eat the mature plants in which this poisonous materials are absent. It is known that their habit of consuming the barks of trees is related to their great need for calcium both to support their tusks and teeth and also to support pregnancy. The fibre of the bark, in addition, prevents abdominal colics to which the elephants are prone and is a source of essential fatty acids. High fibrous diet may also contribute to the extremely low level of cholesterol in the blood of elephants.

In the life of an elephant water is a critical factor. They drink up to 225 liters of water per day and urinates about 10 times per day. Usually, the quality of the water is assessed before drinking by using the trunk. They can smell water at a distance. When a herd is drinking, animals stand in line according to hierarchy. In the dry season, when the water sources dry up, they dig into the river or tank bed for locating water if it is available. However, studies of the African elephant have shown quite clearly that the animals are able to be without water for up to 2 weeks at a time.

Another consequence of size is that, the surface area of the skin is relatively small compared to the volume of the body. Therefore, there is a problem of over heating. An elephant produces about as much heat as 30 men. Moreover, the skin is thick and without sweat glands. They cannot tolerate high temperatures. Special methods have been developed to cool their bodies. The normal body temperature of Sri Lankan elephant is 36.5^{0}C. The development of large ears having high surface to volume ratio is one method. The surface area of the ear is about 20% the total skin surface and is well supplied with a network of

FIGURE 3: NURSING UNIT



Lactating females and their young (< 2 yrs) Expectant mothers Older, experienced, lactating females-Midwives helping at birth and cleaning up the new born babies.
Allomothers to babies of yound mothers and of orphaned babies by cleaning them, helping to take solid food and even allowing them to suckle.

blood vessels. Excess heat of the body is radiated at the ear surface and assisted by constant fanning of the ears (at a rate of 690 flapping/hr). The efficiency of this mechanism is reflected by the fact that the temperature of blood leaving the ear is 16-18 F lower than that entering the ear. Other methods frequently used to cool themselves are: squirting water on to the body; bathing or wallowing in rivers; plastering body with mud packs; powdering body with sand or dust; and in extreme drought conditions spraying their own saliva over their ears.

The lungs of elephants, unlike those of other mammals, are attached to the chest wall. Therefore, they cannot lie on one side for long periods. This could be the reason why elephants rarely lie down to rest or sleep. Rib movements contribute little to breathing which is diaphragmatic. The heart of elephants are unique in having twin apexes in the ventricle.

Generally, in tall animals venous return to the heart is difficult against gravitational pull. Elephants move their limbs continuously to facilitate venous return. But according to some views such movements are thought to be stress behaviour. There are some special features in the blood profile of elephants. Red blood counts are the lowest among mammals (2-3x10/ cu mm vs 5-6x10 cu mm in man). On the other hand, they have the largest red blood cells (diameter greater than 9.2 um vs 7.2 um man and mean corpuscular volume of 138 um vs 110 um in man). Also Elephant haemoglobin has greater affinity for oxygen than human haemoglobin. As a result elephants could function well even at high altitudes where partial pressure of oxygen is low. A considerable Bohr shift is also seen in elephant haemoglobin. This would restrict them working continuously for long periods. Elephants are also peculiar for showing a platlet serge during early pregnancy.

There is peculiarity in the myoglobin of elephants. This is also an oxygen carrier, but in elephant it also has extremely high affinity to carbon monoxide. This property makes it dangerous to keep elephants for long near garages and other sources of carbon monoxide.

It is noteworthy, that in the elephant society the sole function of the male seems to be that of mating. Beyond that they bear no responsi

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There are many interesting aspects of the social life of elephants. They live in groups or herds which vary in size. In Sri Lanka herds usually consists of 15-40 individuals each. The herd is materiachal and led by the oldest, largest reproducing female, contrary to the popular belief that the male is the leader. The herd is a complex unit, subdivided into functional groups. These parallel in structure and function to human social units. (Figure 1).

A Family Unit consists of a number of related adult females and their daughters of all ages and sons of prepubertal age. (Figure 2).

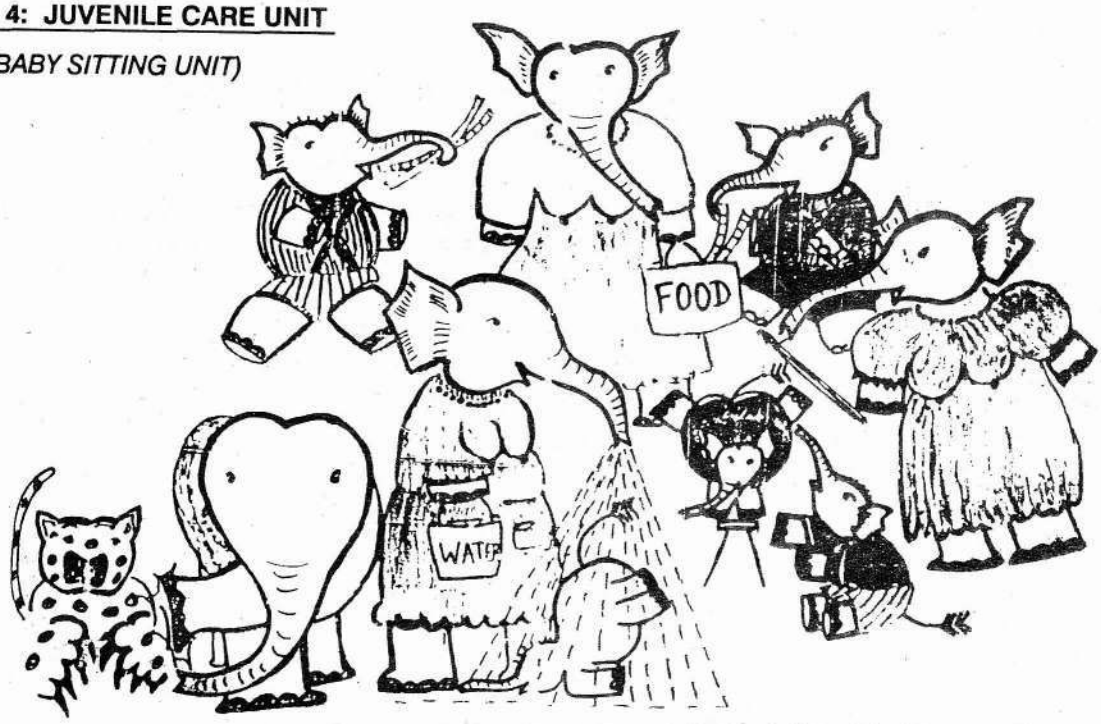
B Nursing Unit of lactating females and their young (under age of 1 year) and expectant mothers. Within this unit the older, experienced, lactating females are midwives, helping at birth and cleaning up the new born baby. They may act as allomothers to babies of young mothers and of orphaned babies by cleaning them, helping to take solid food and even allowing them to suckle. (Figure 3).

C Juvanile Care Unit or (baby sitting unit) of non lactating females. They look after the playful juvaniles (1-5 years) from chewing their food for them and bathing them as well as ensuring that they come to no harm. (Figure 4).

In the elephant society males have a hard time. When they reach puberty (about 12 years) they are chased away from the family unit. Such males usually form bachelor groups. They still live near the main herd, moving in advance of the main herd. The leader of the bachelor group, is usually a large male. Sometimes a bull does not enter a bachelors group but leads a solitary life (Thany aliya). These solitary animals can become aggressive and dangerous. (Figure 5).

FIGURE 4: JUVENILE CARE UNIT

(BABY SITTING UNIT)



Non-lactating females Playful juveniles (1-5 years) finding their food, bathing, ensuring that they come to no harm protection from predators such as leopard.

bility for raising their offspring. They probably do not even know them. In this respect, they are similar in behaviour to some human males.

In Sri Lanka, during the past 200 years the elephant population has declined by over 67%. At the turn of the century, about 12,000 individuals were distributed over most part of the island from the coastal plains to the hill country (up to 2500 meters). Today, we have a captive population of about 550 elephants and a wild population of about 2500. The wild population is found mainly in the low country dry zone in 15 scattered, protected areas constituting about 9.3% of the total land area of the island. Why has the elephant population declined? Human population has increased. There is pressure on land for human settlement, agriculture and development activities. The habitat that elephants have enjoyed for millenia are being transformed by man. Elephants need a home range of 40 - 400 square kilometers. They roam back and forth into their traditional home grounds, as they have done for millenia. Now where there were forests and grasslands they find, instead, paddy, sorgham, kurakkan, sugarcane and banana. From the elephants point of view, these are highly palatable, easily digestable, succulant and nutritious. They turn to these new foods readily leading to human/elephant conflicts.

Elephants destroy crops, homes and may even kill poor farmers and villages. On the other hand, the farmer resorts to protective measures especially to shooting elephants. Individuals of reproductive age may be lost and the elephant population goes into decline. In this process potential breeders are lost.

Elephants reproduce extremely slowly. Reproductive period of females begins at between 10 - 20 years. A calf is produced every 5 years. Males mate effectively at around 24 - 30 years and reach prime breeding state around 40 years.

Secondly, when adult animals die the social structure of the herd is affected. This is known to lead to increase in calf mortality. These are factors that threatened the elephant population.

Survival of the elephants is also threatened by their existance as small isolated populations. The optimum size for a herd is 125 - 150 individuals. However, in more than half of our protected areas the herds have much fewer members. In small isolated populations, such as ours inbreeding depression, lowered fertility, increased juvenile mortality and impaired growth rate results.

Intensification of competition for food is becoming another factor that can affect elephant survival. Populations of water buffalo, axis deer, sambur are large and they all share the same food resource with elephants. As these other animals increase in numbers the pressure on the elephant herds will increase. The problem is compounded by the well known fact that small islands cannot really support large numbers of large mammals and the elephant is the largest of them all.

The life of the elephant can last only as long as its molar teeth. During its life time an elephant produces 6 sets of massive molars in horizontal succession. At any one time there are only two molars in each jaw. Thus, the elephant chews its food with 4 teeth. As the animal grows the molars produced becomes larger and larger. The number of lophs of ridges on each tooth increase. Therefore, it is possible to estimate the age of an elephant by counting the number of lophs on the teeth currently in use.

Hindu mythology relates how an elephant in distress was saved by Lord Vishnu. Today, the elephant is in grave danger but this time there is no guarantee of divine intervention. We ourselves have to act to save them. Can they be bred in captivity? Captive elephants do mate but rarely give birth to babies. It is now understood that herd structure and free ranging are important factors associated with successful breeding. In the captive breeding programme at Pinnawala Elephant Orphanage we simulated wild conditions in a 25 acre coconut plantation. Herd structure was established and animals were allowed to range free. We used the opportunity to study, important aspects of reproduction in the elephant. We were also able to make a systematic study of the musth cycle.

The elephants are allowed to range free and interact as a herd during the daytime at Pinnawala. They are bathe for 2 hours in the morning and 2 hours in the afternoon every day. However, at night they are chained and given additional foliage. The experiment commenced in 1981 with only 5 elephants. At present, the number has grown to 42 by influx of animals.

In a coordinated and continuing study we observed bahaviour patterns of the herd, monitored and sampled blood weekly to establish reproductive hormonal profiles and looked for physical changes in females through the oestrous cycle.

Our breeding programme commensed in 1982 and is continuing. The first birth occurred in 1984 and since then seven calves have been born, 3 males and 4 females. Two births were expected in 1991. This is a remarkable success story by any standard and is not paralleled by in any other country.

Valuable information regarding oestrous cycle has been collected, at the same time. The length of the cycle has been a matter of controversy. However, recent work on African elephant has indicated a period of 16 weeks in those animals. We have established behavioural and hormonal data that indicate the oestrous cycle in our elephants to vary from 12 - 16 weeks. The period when females are sexually receptive lasts for 2 - 3 days. During these days the female will stand and allow the male to mount.

We observed various external signs associated with oestrous (Some of these may be mentioned). The female become more excitable and shows interest in males, rubbing herself on males and even on trees. A white gummy discharge apppears from the urinogenital opening. The veginal folds become swollen and the clitoris becomes visible. The vagina itself becomes reddish in colour. Males introduce the tips of their trunks into the urinogenital sinus of females in oestrous, frequently testing the urine. Usully this behaviour is seen at a rate of 12.0 times/hr but at oestrous it increases to 120 times/hr. We observed a very interesting feature in that some pregnant females showed signs of oestrous, as well.

Intense urine testing, by the male is indicative of attaining full receptive condition in the female. This is followed by precopulatory behaviour. Male and female engage in reciprocal touching behaviour of various parts of the body, especially of the mouth and genital regions. The penis then become fully erected. The male stands on his hind legs with fore limbs and trunk extended on the back of the female. The penis becomes s-shaped and about 1/3rd is inserted into the vagina. About 4 - 9 pelvic thrusts have been observed. However, other workers, working in the wild have not reported pelvic movements. Ejaculation usually occurs about 30 seconds after intromission. Copulation lasts for 1 - 2 minutes. The male dismounts, but the couple remain in close proximity from a few hours upto 3 days, a pattern referred to as consort bahaviour. Two-to four copulatory episodes have been observed by us in a single oestrous day. A single female has been observed to mate with two males. Copulation was also observed in the river during bathing. Some females vocalize during mating. The reactions to copulation from other group members range from absence of any reaction to intense excitement including vocalization, flapping of ears, urination and defection. Our work also suggests that males are selective in their choice of mates. For instance, at Pinnawala, it has been observed that Wijaya prefers to mate with Kumari than with Anusha.



Sometimes a bull does not enter a bachelors group but Leads a solitary life

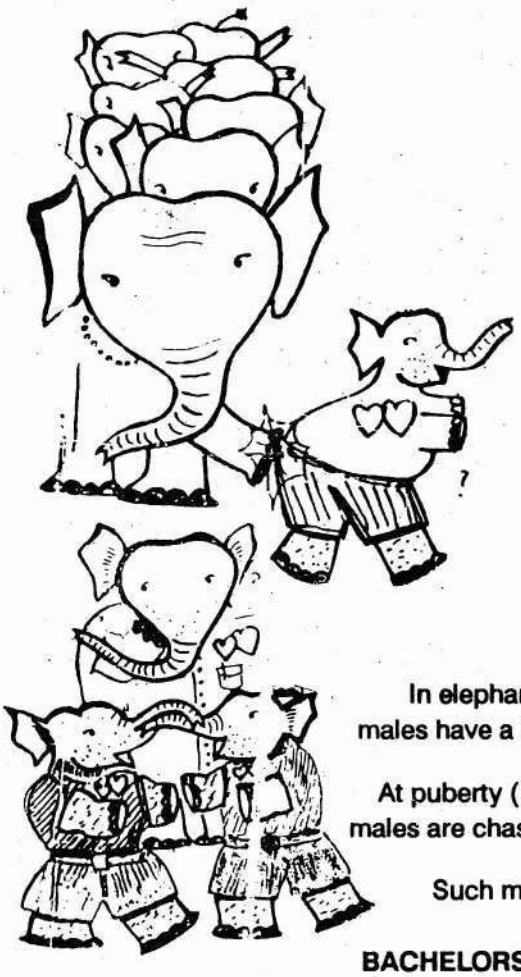
THANY ALIYA

Can become agressive and dangerous

The duration of pregnancy of the Sri Lankan elephant is about 20.8 months, yet another consequence of large sized body. As in other mammals, a rise in progesterone levels was observed but this was lower than in other mammals. A peculiarity noted was that the prolactin levels were elevated during pregnancy (300 - 700 ng/ml). The corresponding levels in non pregnant animals and during lactation were less than 2 ng/ml and 13 - 15 ng/ml respectively. No similar results are known for other mammals and the significance of the differences remain to be understood. Breast enlargement begins from 7 - 9 months into pregnancy. We also noted mating occuring during pregnancy in some females. Except in humans, mating does not occur during pregnancy in other mammals.

All births observed at Pinnawala occured at night. Pregnant animals, approaching delivery become restless. The female constantly touches the vaginal area with her trunk and vocalises frequently. When this behaviour is observed the female is brought to the shed. As time progresses, irregular contractions of the abdominal region and vaginal folds occur every 4 - 6 minutes followed by discharge of blood and amniotic fluid. Three of the females observed lay on their sides during birth while one female assumed a squatting position. At birth the head of the baby emerged first in all cases and the baby when born was covered fully in the amniotic bag. The process of birth was invariably accompanied by vocalisation by the female. In some instances the water bag burst as it hit the ground. Otherwise the mother removes the bag. The placenta weighing about 12 kg was ejected between 30 minutes to 5.0 hours after birth. The baby was able to stand, between 5 - 15 minutes of birth, but limb coordination was imperfect. The weight of the babies was between 50 - 61 kg height, at shoulder 2'7" to 3' - body length measured from head to anus between 2'4" to 3'7".

Figure 5



In elephant society
males have a hard time

At puberty (~ 12 yrs)
males are chased away.

Such males form

BACHELORS GROUP

Babies began breast feeding between 8 min to 1 hour, of birth. Each sucking bout lasted 1 - 2 min occurring at bout 1/2hr intervals. Alternation of breast sucked usually takes place with each successive sucking. Mothers breast feed their babies upto the age of about 4 years, but time period between feeding intervals increase progressively. Calves were observed to suck from thir own mothers and other lactating females. Orphaned babies introduced into Pinnawala are also allowed to suck by lactating mothers but their own baby seems to dislike it. Some workers have reported that certain females in a herd though without babies sometimes lactate and feed calves born to other females. Such females are described as 'aunts'.

Most people have heard of elephants in musth and of the problems they create when in that condition. Musth is a complex of physical and behavioural features displayed periodically by adult males of the Asian elephant and by both males and females of African elephants.

The most commonly occurring signs of musth observed in captivity are : enlargement of the temporal gland, which are modified sweat lands located midway between the eye and the ear, on both sides, secretion of a sticky smelling liquid containing Phenols and m and p-cresols, dribbling of urine without the penis being extended, as is usual, during urination. The penile sheath showing the "green penis syndrome" (the penile sheath become greenish in colour).

Behaviourally, there is: a decrease in responsiveness to commands of their keepers (especially to the head keeper); deliberate destruction of objects, frequent touching of top of head (4/hr) and temporal gland (4/hr); production of a special kind of infra sound known as musth rumbler (low pulsating, low frequency sounds of 14 Hz).

A sharp rise in serum testosterone levels is reported to occur during musth. We have estimated the blood testosterone levels, weekly for about 3 years and observed the smae trend but testosterone levels were comparatively low. None of the males at Pinnawala exhibited musth but in the Zoo, 2 males showed musth. Our work also suggests that the threshold level to induce musth appears to be different for different individuals and females who do not show musth, have nearly low levels of testosterone throughout. Most people believe that male elephants can mate only at musth. This is not true. At Pinnawala non of the males exhibited musth but they have mated and fathered young.

Since testosterone levels are implicated with musth, it may be possible to suppress musth by the use of anti-androgens such as cyproterone acetate or GnRH agonist/antogonist. We hope o investigate this possibility and that is why we are monitoring testosterone levels over a long period of time. Currently in captivity, feeding with Una Bada, Ehatu and Budeliya and frequent prodding of a nerve centre in the analfold with an ankus or burning with hot ankus are used to suppress musth. When tested on rats, Una Bada has been shown by us to possess potent sedative action, thus may be able to calm down the elephants at musth.

In Sri Lanka, musth never appears in males below age of 10 years, appears sporadically between 14 - 20 years and periodically after 20 - 30 years of age upto old age. In contrast, only about 4 - 5% of male African elephants around 30 years show musth. For a given individual, onset of musth is fairly consistant from one year to next. It appears that onset in captive elephants can occur by expose to large number of females, as during peraheras.

In the wild however, presence of receptive females does not appear to induce musth. Some claim that high ranking males can suppress musth in low ranking males.

What is the significance of musth? It is claimed to increase an individual's reproductive success because musth helps to achieve dominance status in a herd which helps to overcome other males and aggressive older females thereby enhancing the chance of access to a oestrous female. Furthermore, in African forms, female elephants prefer to mate with a musth male.

The captive breeding programmes if developed further will help to ensure that, elephants will always be a part of the Sri Lankan scene. However, we need to ensure the continued existance of elephants in the wild, as well. In order to achieve this objective the central issue is the resolution of man elephant conflicts. The problem is the extension of agriculture into traditional ranges and migration routes of the elephant.

Agricultural expansion has the effect of fragmenting herds, and I have already pointed out the adverse biological effects of reduction in herd size. Further, they become trapped in small pockets of jungle, surrounded by extensive farm lands with monoculture. Of course, the animals will move into the cropland and inevitably the farmer has to act to protect his own livelihood. Guns are used and often injure the intruders. Wounds fester and the wounded animal undergoes intense suffering. As a result, a normally docile animal becomes an aggressive and dangerous rouge (Hora Aliya). Rouges are usually loners whose behaviour is very different from that of normal elephants. They attack human beings with out provocation. Some rouges even go in search of humans to attack them. Others wait patiently hidden in jungles adjoining pathways for humans to pass by and attack them. Such animals should be captured and treated for wounds, transferred to protected areas, or tamed. Otherwise, they should be eleminated.

A long term approach, is the translocation of pocketed animals by elephant drives. They have to be shifted from critical areas into protected areas where their demand for food, water and range are adequately met. There have been successful drives in the past. For instance, 3 small pocketed herds were successfully driven to Wilpattu National Park from the catchment areas of Kalawewa reservoir. Similar operations were done successfully in other countries like Sumatra.

Another important long term strategy is the establishment of 'jungle corridors'. These function as migration routes hold in forest cover which interconnect the protected areas. Their location and extent must take into account traditional migration patterns as well as the optimum needs of space and food for migrating herds.

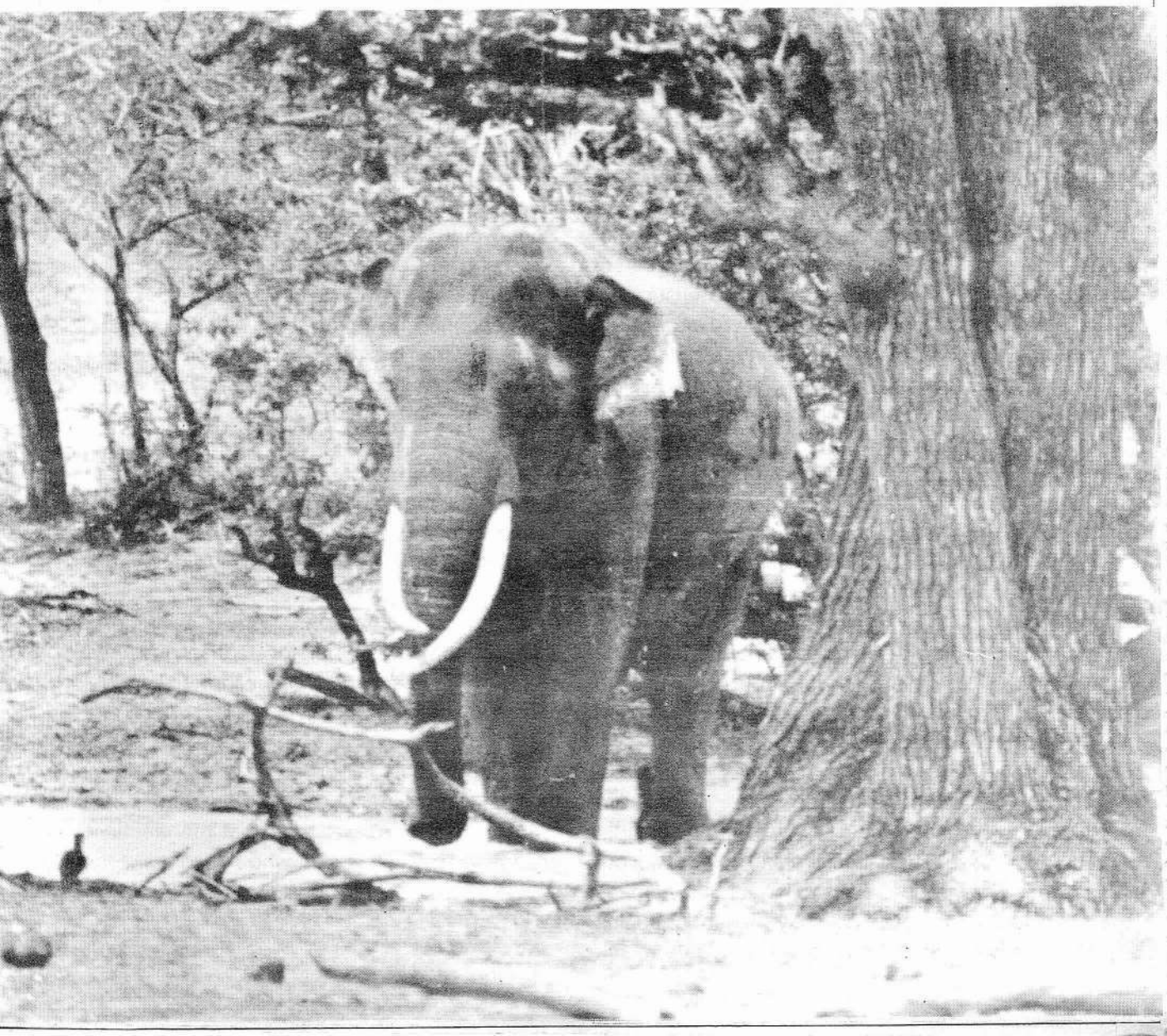
Currently, there are two corridors, one connecting Somawathi National Park and Wasgamuwa National park, and the other connecting Wasgamuwa National Park and Maduruoya National park. Another one is proposed connecting Maduruoya National park and Galoya National Park. It is necessary to monitor the use of the herds in existing corridors as a basis for further management of the elephant population.

Finally, there are other methods used for protection of human holdings and are experimentally investigated. These include use of trenches, building of high voltage electric fences, creation of buffer zones, use of high frequency sound beepers use of repellents or attractants (common salt), promotion of public awareness and soliciting community support for elephant conservation and crop and life insurance schemes for settlers at low premium.

Unlike in the past, all development planning, hereafter, must take into account ecological and conservation factors. It must be understood that the elephant cannot change its ways. It is man who has to make the adjustment - Man the Agriculturist, Man the Planner, Man the Politician.

Acknowledgements

I wish to express my thanks to Prof. K.D. Arudpragasam (Chairman, Central Environmental Authority), Mr. Bradly Fernando (Director, National Zoological Gardens of Sri Lanka), Mr. A.M.V.R. Manatunga (National Zoological Gardens of Sri Lanka),Dr.(Mrs.) Y.N.A. Jayatunga (Department of Zoology, University of Colombo), Mr. Nihal Dayawansa (Department of Zoology, University of Colombo), Dr. T.B. Poole (Universities Federation for Animal Welfare, U.K.), Elephant Keepers at Pinnawala and at National Zoological Gardens and Medical Research Council (Edinburgh, U.K.).



IMPACT OF THE WEATHER ON LANDSLIDES IN SRI LANKA

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A landslide is a kind of earth movement which is due to the instability of slopes. Excessive precipitation due to monsoonal, depressional or cyclonic activity has been identified as the main cause for slope instability which gives rise to Landslides. Main causes for Landslide can be listed as follows (Dhanayake, K., 1986).

1. **Rainfall - Unusually high**

   Continuous rain results in increasing pore pressure in the debris material and expansion of clays within the joint planes of underlying rocks.

2. **Nature of the Rock**

   Internal properties of earth materials. Failure of weak rocks characterized by multiple fracture systems and feldspar-rich composition.

The geomorphic setting and environment, different topographic relief, steepness and shape of land surface, characteristics of vegetation, climate etc. can be determining factors of slope stability.

3. **Man-made Activities - Land use**

   Destabilization of ancient landslides (which are in equilibrium,), by man-made activities such as road construction, drain construction, etc.

   Slope stability is reduced by artificially filling the up-slope area or cutting of the down-slope area. This, coupled with heavy rainfall, causes the most disastrous landslides.

   Mining operations by man also modifies the terrain and severely affects the stability of hill slopes.

In this article the Landslide problem is viewed as a natural hazard which is promoted by man-made activities and the weather pattern of Sri Lanka is discussed since this natural disaster is mainly triggered by excessive precipitation. This facilitates to identify the Landslide prone areas and also the season which is favourable for Landslides.

Seasons are identified by the meteorologists by studying the wind pattern, both at the surface and at upper levels, intensity and spatial distribution of rainfall.
The monsoon is now defined as a flow pattern of general atmospheric circulation over a wide geographical area in which there is a clearly dominant wind in one direction in every part of the region concerned.

General Weather Pattern in Sri Lanka

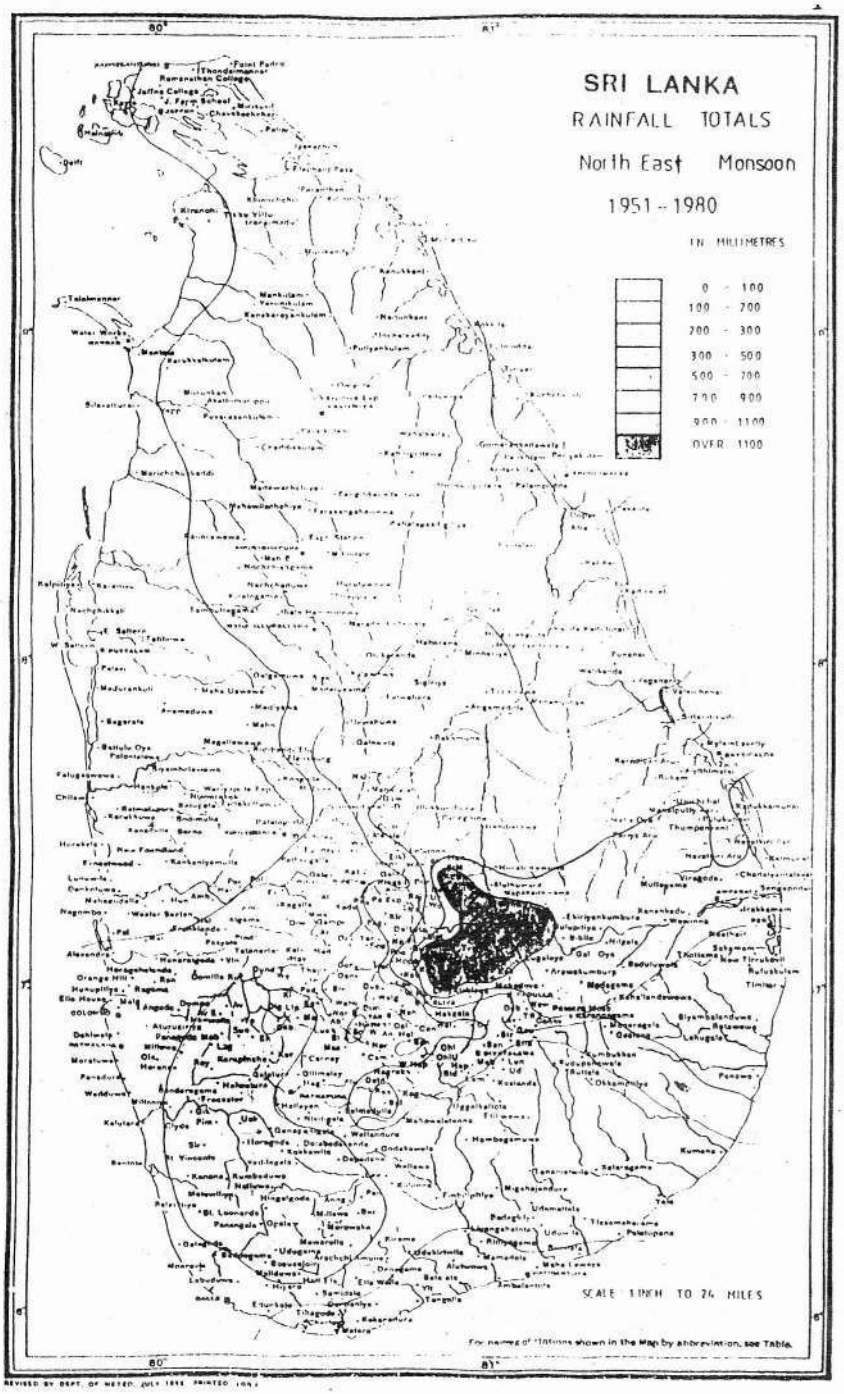
Our island Sri Lanka is in the Indian ocean located to the south of the Indian sub continent. The features of the island consist of a mountainous mass comewhat south of the centre, with heights exceeding 2500 meters, surrounded by broad plains. Sri Lanka lies in the tropical belt.

The tropics is defined as a zone between the semi-permeant anticyclonic belts in the Northern and Southern hemispheres. According to this definition and the generalized wind flow, the Island Sri Lanka should

be in a region which is under the influence of easterly winds. But we experience two wind regimes namely the Southwesterlies and Northeasterlies throughout the year. The tilt (23 1/2) of the earth axis, land/sea distribution and topography govern the wind pattern over our region.

By studying the long term behaviour of meteorological parameters, it is possible to identify four climatic seasons for Sri Lanka.

1. Southwest monsoon (May to September)
2. Second Inter-monsoon (October to November)
3. Notheast monsoon (December to February of the following year)
4. First Inter-monsoon (March to April).



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Monsoonal rainfall is very important for Sri Lanka since the nature of the rain specially the intensity and temporal distribution is very much favourable to the crops. The spatial distribution of the northeast monsoon rainfall is shown in the Figure 1.

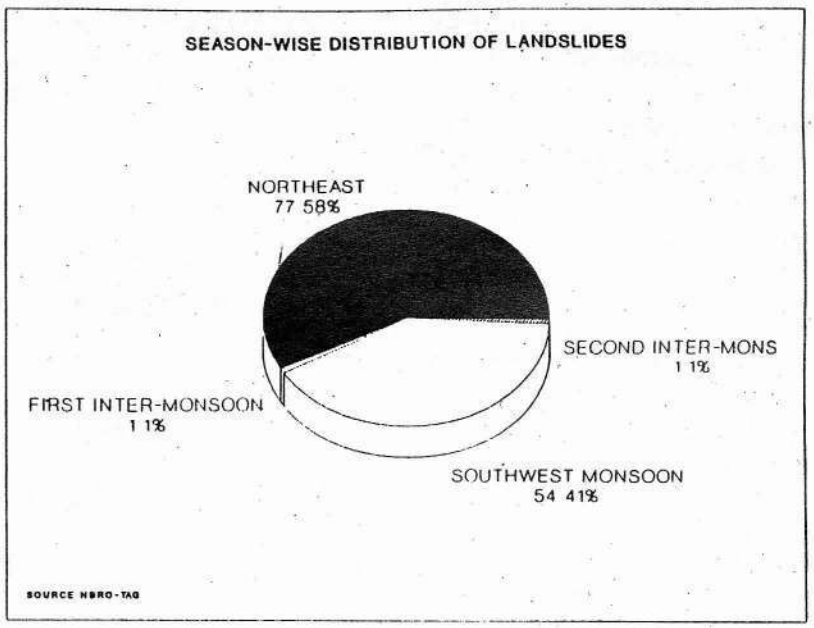
Climatologically the months from May to September are defined as the southwest monsoon months. But the onset of the southwest monsoon varies from year to year. Onset date is somewhere around mid May. The onset of the southwest monsoon is declared when the wind flow at Colombo (Observatory) becomes southwest to west up to or above 3 km. and when a sharp increase in the 5 day means of rainfall are observed. The monsoon rains are sometimes not easy to distinguish from the inter-monsoon thundershowers. There-

fore Meteorologists find it difficult to fix the date of the onset of the monsoon, uniquely.

Cross equatorial wind flow originates from the Madagascar area bringing moisture to our area during the southwest monsoon periods. Moisture convergence which produces monsoonal rain occurs due to various factors. The spatial distribution of rainfall over Sri Lanka is mainly controlled by its characteristic topography.

Intermonsoons are the periods between the two monsoons when there is usually no wind. The months, from March to April and from October to November are defined as the First and Second Inter-monsoons respectively. During these inter-monsoon seasons, particulary during the first inter-monsoon, local convection asoociated with sea/land breeze circulations are dominant. Thunderstorms develop particularly during the afternoon or evening. When there is no synoptic forcing (regional scale influence on the weather pattern) morning peaks of rainfall can be observed. These falls are associated with the Land breeze (Land breeze convection usually occurs off the coast) and shift towards the land due to the influence of the characteristic topography of Sri Lanka. The spatial or temporal distribution of rainfall during the inter-monsoon periods are not so favourable to the crops, though this rainfall contributes largely to the annual total rainfall.

The second inter-monsoon, the months October to November are usually considered as cyclone prone months. During this season most of the depressions that form in the



southeast bay of Bengal further develop into tropical cylones. Fortunately, the frequency of cyclones having a direct effect on Sri Lanka is low. The last experience was in November 1992.

The change-over of the prevailing wind direction over the island occurs in mid-November and the seasonal wind flow goes on till mid-March. The wind stream over the island is predominantly northeasterly in direction from December to February and as such this period is reckoned as the period of the North-east monsoon in Sri Lanka. During this period the low pressure systems are to the south of the island.

Sri Lanka receives its rain during the North-east monsoon from two air streams, namely, the outflow from the Siberian High and the west Pacific High. The former air stream is cold and dry when it flows into the warm Bay of Bengal but becomes moisture laden after passing over the Bay and reaches the north-eastern coast of the island as a moist air stream. The latter air stream also passes over the warm Bay of Bengal before it reaches Sri Lanka and thus it will be moisture laden by the time it reaches the north-east coast of the island.

By referring to the spatial distribution of the seasonal and the annual total rainfall, the central part of Sri Lanka which is mountainous can be identified as a Landslide prone area. This identification takes into account the Geological factors as well.

However, the heavy rainfall during the period of the north-east monsoon is mainly due to:

i. a series of upper air low pressure systems which form over or near the island or cross the island from east to west, and
ii. tropical depressions that move across the island or form off the east coast of the island.

(Fernando, T.K., 1985).

Occurrences of Landslides

By referring to the spatial distribution of the seasonal and the annual total rainfall, the central part of Sri Lanka which is mountainous can be identified as a Landslide prone area. This identification takes into account the Geological factors as well. Figure 2 shows the seasonal-wise distribution of landslides. Maximum occurrences of landslides were recorded during the Northeast monsoon period.

Priyasekera, G.D. (1987) documented a landslide which was triggered by excessive precipitation caused by a depression. This was positionaed approximately 200 km. off the southeastern coast of Sri Lanka by the 7th of January 1986 and moved across the island in a Northwesterly direction and weakened by the 10th of January.

There was almost continuous and widespread rain over Badulla and Nuwara eliya districts during the period from the 6th to the 9th January 1986. Three rain gauge stations in Badulla district had recorded an aggregate of over 1000 mm of rainfall for the 5 day period. The areas of the districts, North of Nuwara Eliya town adjacent and to the west of the Badulla district received the heaviest rainfall.

Nuwara Eliya district areas bordering and to the west of the Badulla district were affected by Landslides. At these locations landslides had taken place during the early part of January (Northeast monsoon period) on the 7th in 1986. There had been continuous rain during the previous two days on the 5th and on the 6th January; very heavy at some places. By using a contour analysis of cumulative rainfall, it was concluded that a threshold figure of 350 to 400 mm of rainfall during two consecutive days could cause Landslides to occur in areas prone to such natural events.

In this case data availability in the vicinity of the area was favoured to study the Impact of the excessive precipitation on Landslides.

The threshold figure of cumulative rainfall is definitely lower than the value obtained in 1986 due to the mismanagement of land use and other man-made activities.

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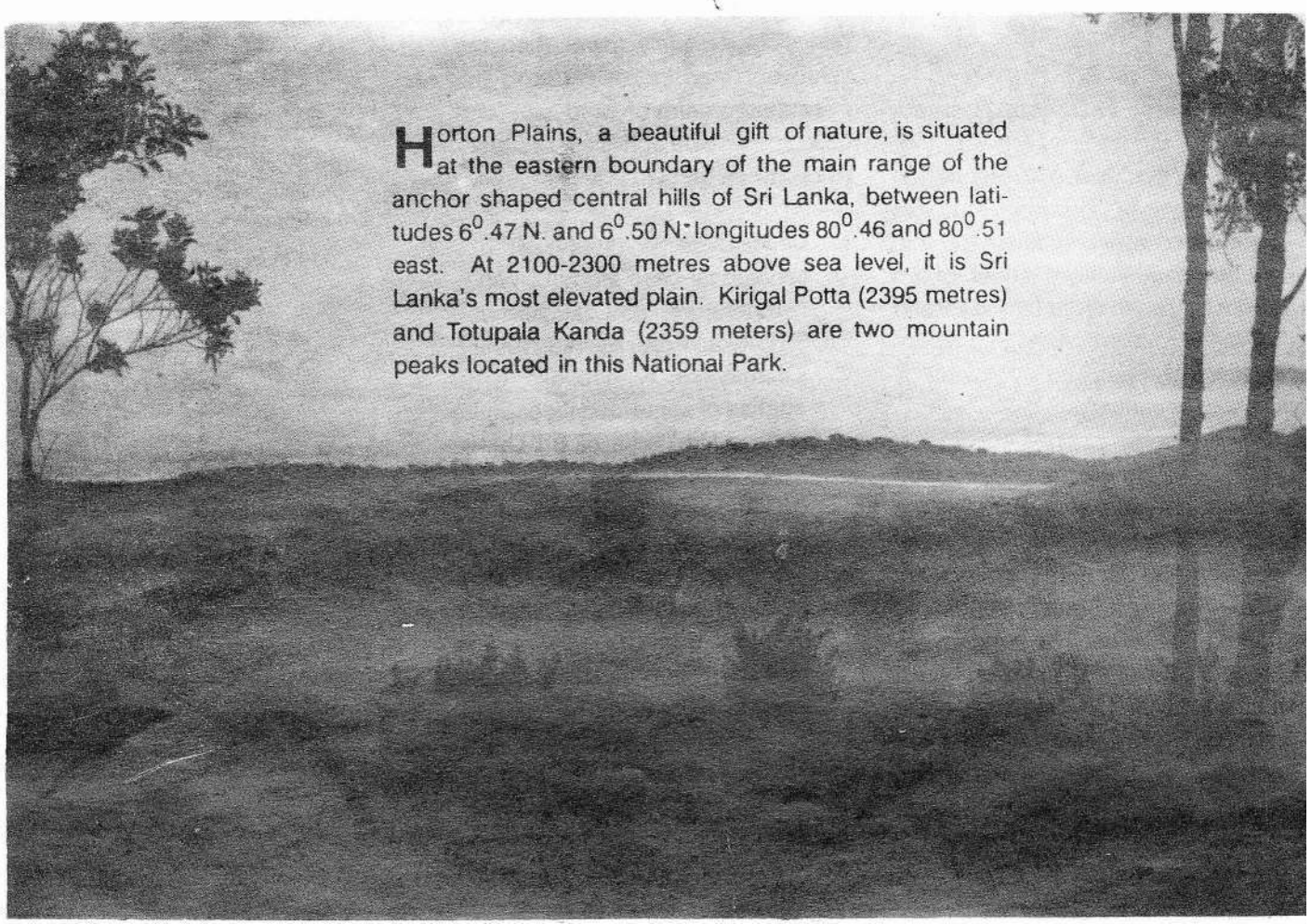
HORTON PLAINS

-A NATIONAL HERITAGE AT A HIGH ALTITUDE



Horton Plains, a beautiful gift of nature, is situated at the eastern boundary of the main range of the anchor shaped central hills of Sri Lanka, between latitudes $6^0.47$ N. and $6^0.50$ N. longitudes $80^0.46$ and $80^0.51$ east. At 2100-2300 metres above sea level, it is Sri Lanka's most elevated plain. Kirigal Potta (2395 metres) and Totupala Kanda (2359 meters) are two mountain peaks located in this National Park.

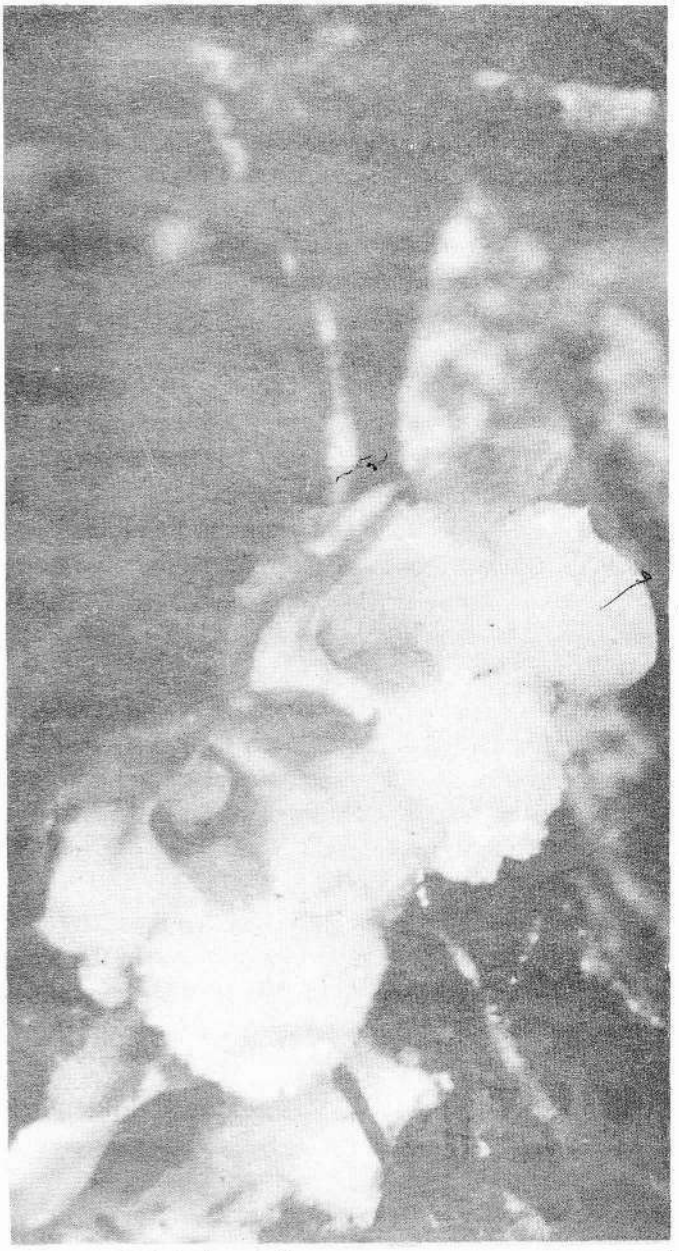
History does not record any information about the Horton Plains other than that it served as a hunting-ground. It is believed that Sir Robert Horton named the plains after him in 1836 during the British occupation. In January that year he had made arrangements to tour Nuwara-Eliya and meet his friend the Rate Mahattaya of Sabaragamuwa. They decided to meet each other in some place between Nuwara-Eliya and Ratnapura. This place was Mahaweli or Mahatenne (Great Plain). River Mahaweli originates in the Horton National Park. Therefore it is possible to presume that the river took its name from the place 'Mahaweli'.

In 1969 Horton Plains National Park was declared a natural reserve for the first time. This plain which is 31600 hectares in extent is bounded on the east by the Samanala Kanda Peak Widerness Sanctuary. When the necessity to protect this area arose it was raised to the status of a National Park in 1988.

Records of weather or climatic conditions of the plains have not been kept for any considerable length of time. Although there is a regular incedence of rainfall throughout the year. During this season midday temperature is about 27^0C, and the night temperature 5^0C or less. In 1971 Muller Dombis and Perera have recorded an average February temperature of 12^0C. Annual rainfall in the region is about 2540 mm (Wijewansa, 1983) but for Horton Plains, may exeed 5000 mm (Ratnayake & Balasubramaniam, 1989). Rain occurs throughout most of the year but there is a dry season from January to March. In February and March dew forms on the grass in the early mornings. In the rainy season there is mist throughout the day. The strong winds and the ceaseless drizzle which fall during the South-West Monsoons is a climatic condition not experienced in most other parts of the country.

In 1961 seed potato was cultivated in parts of the Horton Plains. But due to the efforts of environmentalists it was possible to put a stop to this. However the environmental destruction caused during the 9 years have created many problems within the National Park.

A recent study reveals that 7 major habitat types can be observed within the National Park (Wijesundara, MFC, 1992), namely:



Flower of *Christisonia* Sp.

- Upper Montane Rain Forest (including the pigmy or cloud forest).
- Wet Patana Grasslands.
- Marshy and aquatic areas.
- Forest-grassland Ecotone.
- Open areas (gaps) in the forest.
- Disturbed areas in the grasslands.
- Roadsides and around buildings.

The upper Montane Rain Forest is the most dominant habitat type in Horton Plains National Park. Forests are present as continuous ranges as well as isolated patches in the grasslands. The dominant families of flora in the National Park are Lauraceae, Myrtaceae, Rubiaceae, Symplocaceae and Euphorbiaceae.

Among the large trees of the rain forests can be identifies 101 different species of trees. Of these 49 are endemic to Sri Lanka. Hence in the Horton Plains National Park's Upper Montain rain forests about 48.54% of these varieties can be seen. Only in Sri Lanka and no where else is this possible. The dominant plants in this forest are, Kurundu *(Cinnamoum ovalifolim)*, Karan damba *(Syzgium revolutum)*, Keena *(Calophyllum walkeri)*, Maharatmal *(Rhadodendron arboreum)* etc.

The beauty of this forest is enhanced by a kind of lichens *(Usenea barbara)* that hangs from their branches like beards of old men. Numerous varieties of orchids grow on these trees. A special feature of the environment here is the total absence of palms.

The lower parts of the grassland is marshy. Small streams and springs flow slowly over this portion. In the slow moving rivulets many kinds of Kekatiyas *(Aponogetova jacobseuii)* Diya Pasi, Beraliya Pasi *(Ntricularia* sp.) grow.

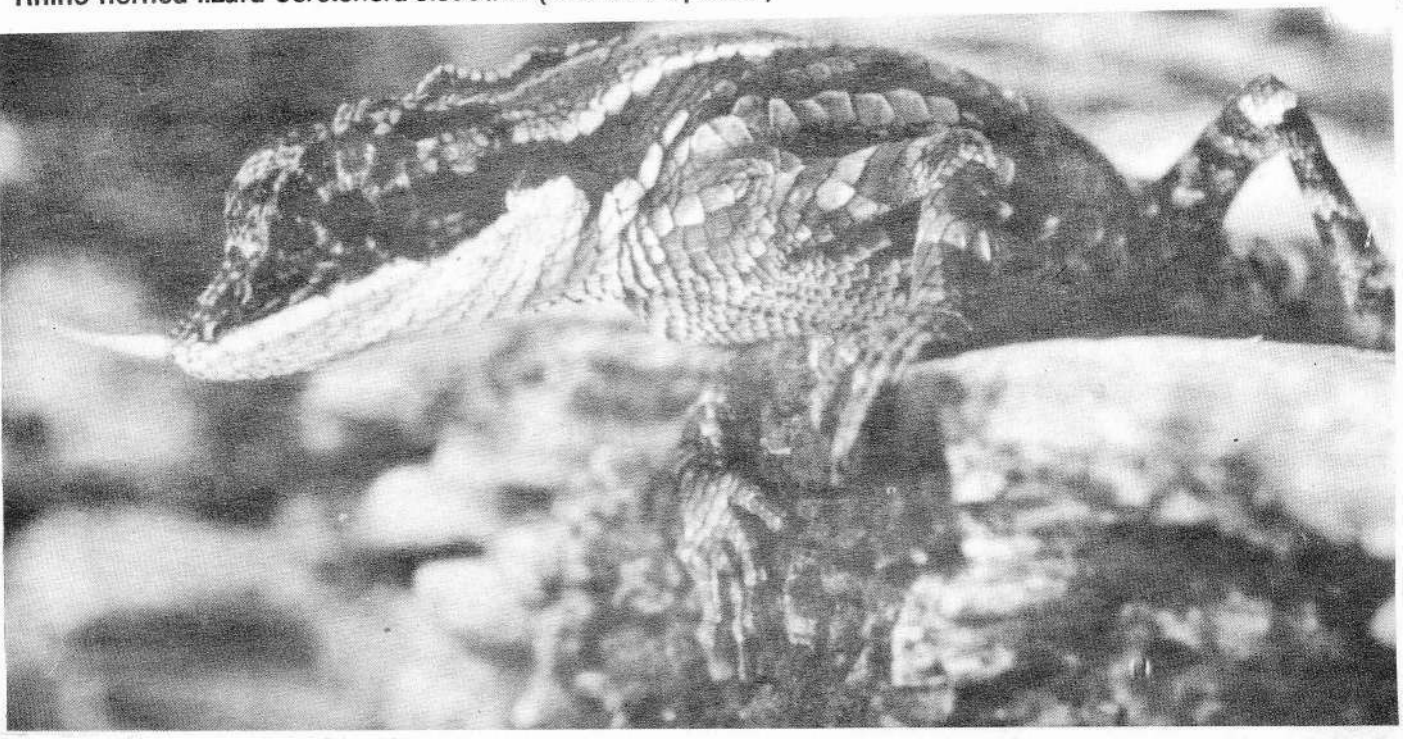
On the bands of the rivulets and brooks grow thick bushes of bamboo *(Chimanobamusa devisifolia)*. Near the marshes grow different kinds of grass. The more prominent are *Gavnotia mutica Denmistaedtia seabva, Ericanlon* sp., *Exacume maeravithum* grasses.

The dominant species of grasses that grow in the main grasslands are *Arundinella villose,* and *Chysopogon zeylanicus.* Fire resistant Maha Ratmal trees *(Rhododendron arboreum)* grow interspersed on the grasslands. Hence these grasslands resemble the Savannas. Various kinds of shrubs grow on the road clearings. Among them are kinds of Bovitiya (*Osbeckia* sp.).

Large mammals except the elephant inhabit the Horton Plains. Nowhere in Sri Lanka could one see so many sambur *(Cervus unicolor)* roaming about as on the Horton Plains National Park. There are herds comprising more than 50 animals at times. The spotted deer is absent here, but the Barking deer *(Muntiacus muntjak)* and Mouse deer *(Tragulus meminna)* are a common sight.

A large number of endemic fauna of Sri Lanka could easily be seen here. Of the 23 endemic Sri Lankan birds 17 could be found on the Horton Plains.

Rhino-horned lizard *Ceretohora stoddartii* **(Endemic Species)**



The special identy of its environment is exhibited by the presence of Rhino-horned lizard *(Ceratophora stoddartii)*, Purple-faced leaf monkey *(Presbytis senex)*. Several species of insects and animals have been discovered in this National Park. Its zoological phenomena may be treated under a different heading.

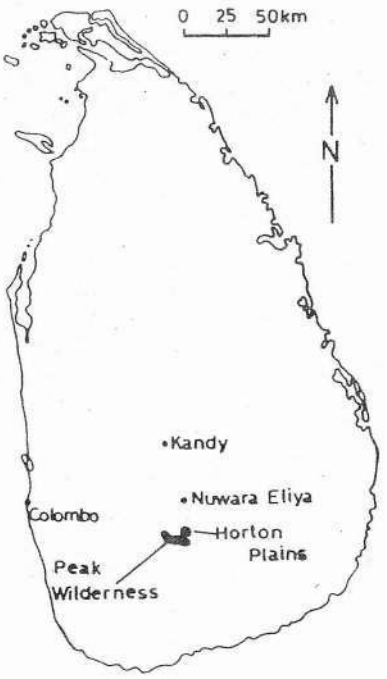
Today the Horton Plains National Park is a reserve which protects our wildlife and plants. Large water resources like the Mahaweli and the fate of our hydro electric power plants depend on the catchment area of the Park.

The catchment of rivers Mahaweli, Walawe, Kelani, Belihul Oya, Uma Oya and Bagawantalawa Oya which joins the Castlereigh reservoir is based in this National Park. Hence is should be protected not only for wildlife but also as a catchment.

At present there are environmental problems in the National Park. On some parts there is a forest die back. This phenomenon was first observed in 1978 (Perera), is the dying of the cloud forest on all peripheral aspects of the plateau (Ratnayake and Balasubramanium, 1989). This has reached serious proportions, with a 50% reduction of forest cover in some places. Water deficit is believed to be the main cause of the die-back, droughts having become noticeably more frequent during the last few decades. Regeneration of cloud forest is impeded by forest, which may be becoming increasingly more severe (Werner, 1988; Ratnayake and Balasubramanium, 1989).

Other problems include increasing disturbance from visitors, poaching for meat, gemming around the park, annual fires caused by miscreants, localised spread of introduced exotics and the great increase of the number of sambur.

The scarcity of pure drinking water is a major worldwide environmental problem now and is one of Sri Lanka's foremost problems in the protection of this National Park.



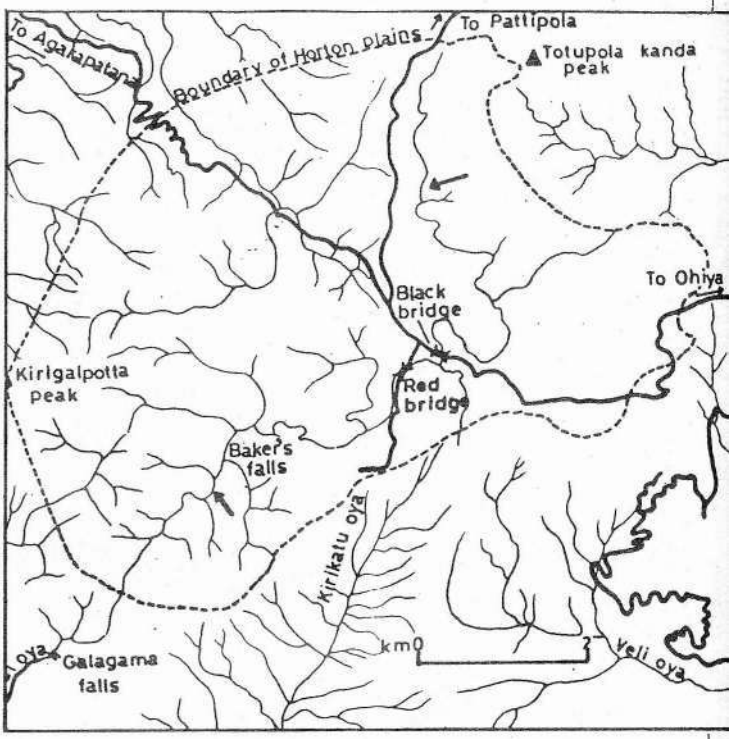


Plate 2: **Debris and rock slides during excessive rains in 1989 damage to the Kandy - Mahiyangana road at Hunnasgiriya. (B) Landslide in a rubber estate at Pantiya (Matugama) in the Kalutara district.**



LANDSLIDES IN SRI LANKA : SOME ASPECTS

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A landslide is a downslope gravitational movement of rock, earth, debris or artificial fill. The movement may be a slide, flow or fall, acting singly or together (Simonett, 1968). Landslide may be induced by natural agencies such as heavy rain, earthquake or it may be caused by human interference with the slope stability (Whittow, 1984). Among the natural hazards such as earthquakes, seismic sea waves, volcanic eruptions, tropical cyclones, monsoon storms, tornadoes, thunderstorms, sea fogs, sea ice and ice burg drift, landslides are least documented and researched. This could be because landslides are restricted to small areas or because no adequate statistics are available (WMNH, 1988; Figure 1). However, the extreme rainfall intensities, thunder and lightning, the downslope gravitational movement of rocks, debris and earth associated with landslides can damage the natural environment as well as destroy life and property within a short period of time.

Landslides in Sri Lanka

Physical Conditions of Landslide Prone Areas

The incidence of landslides in Sri Lanka has increased over the past ten years in the districts of Kegalle, Ratnapura, Kalutara, Kandy, Matale, Nuwara Eliya and Badulla. The hilly areas of these districts include Central Highlands, the Sabaragamuwa ranges, the Rakwana and the Knucles Massifs. Physiographically, the whole area ranges between 300 m and 2200 m altitude and is broadly divide into (a) uplands, and (b) highlands.

The Central Hill Country, the Knuckles Massif, the Sabaragamuwa Ranges and the Rakwana Massif are

characterized by Rolling and hilly terrain (Upland I, 150 - 460 m); dissected rolling and hilly terrain (Upland II, 460 - 930 m); steeply dissected rolling and hilly terrain (Upland III, 915 - 1830 m); and Mountainous terrain (1830 m or more). The convex creep slopes, free faces of these terrains (Figure 2) are highly dissected by 1st and 2nd order streams. The slopes in the Uplands & Mountainous have gradients between 1 to 5 and 1 to 1 (Katupotha, 1992).

Rolling and hilly topography comprises dissected ridges and valleys. It is a distinctive feature developed due to the transverse valleys. Parallel drainage pettern has been developed along the tributaries in the western Sabaragamuwa Ranges and the Rakwana Massif. The dendritic drainage pattern is developed in the moderately steep, rolling and hilly terrain laid on the Highlands planation and intermediate planation surfaces of the western flanks of the Central Hill Country. Locally this drainage pattern is responsible for the formation of dissected features by 1st and 2nd order streams. According to the observations made by Cooray (1984) the highest part of the Sabaragamuwa ridges consist of a series of high plains such as Handapan Ella and Tangamale at a general elevation of 1,000 m to 1,225 m; they are surrounded by escarpments and several peaks. The more prominent peaks in the area are Beralagala (1,385 m), Gongala (1,346 m), Suriyakanda (1,310 m) and Abbey Rock (1,300 m). The Bulutota escarpment and much of the massif are made up largely of gently - dipping resistant charnockites. The other high plains can be seen between the upper Highland planation surface and the middle Highland planation surface (from Palabaddala to Balangoda). The common features of the mountain terrain are the ranges and peaks (e.g. Samanala, Pidurutalagala, Namunukula, Lunugala and Knuckles); relict plateaus, platforms and rocklands (Hatton, Kandy, Koslanda, Haputale and Eastern Platform). This Highland planation surface is strongly dissected by the upper reaches of the rivers.

Due to regional variations, the rainfall figures of the landslide districts show different maximum seasons. Ratnapura, Kegalle, Kalutara, Kandy, Kurunegala and Matale receive rainfall mainly during the southwest monsoon (May - August) and convectional-cyclonic-depression at rainfall in the inter-monsoon period (October to November). Diyatalawa, Baddula and Nuwara Eliya receive rainfalll mainly from northeast monsoon (November - February) and from the convectional - cyclonic - depressional rainfall of the inter-monsoon period (March - April).

Indicators for Identification of Landslide Areas

Several visible indicators can be applied for the identification of slide, fall and flow of rocks, earths and debris in steep slopes. Formation of cracks and fractures, especially as horizontal lines on Convex Creep Slopes and free Faces, encourage seep age of rain-water down to the weathered bedrock layer. If there are iron-rich clay materials between bedrock and the top soil layer, lubrication of the weathered material is possible, and rock blocks, so that the debris and blocks of rock move downwards by the force of gravity.

Muddy water springs are another indicator of landslides. Some times, seep or saturated water flows through bedrock and the top soil, outwards from valley bottoms, road intersects of the roads and foundations. The iron-rich clay materials present in muddy waters indicate that the bond between bedrock and the top soil is broken. These features appear on steep slopes, sometimes even on 15^0 slopes subject to downward movement.

When the soils of the steep slopes are saturated, the bond between bedrock and weathered top soil is broken. Consequently, the vegetation cover would wither due to putrefication of the root-system. This indicates that there is a sign of a slope failure during the heavy rains. Furthermore, gradually inclining wire poles, telephone and electric wire poles, masonary walls, cracked rocks (Plate 1.A), and cracks of the houses on fair to moderate and steep slopes also indicate future landslides.

Causes of Landslides

The island of Sri Lanka, which is situated in the Australia-Indian Plate, is considered as tectonically stable. This land mass is made up of highly weathered metamorphosed rocks of Precambrian age (2000 m.y., Rb/Sr) and is similar to other Gondwana masses of the Indian Ocean (Crawford and Oliver, 1969). Several researchers have indicated the occurrence of high seismicity conditions between Sri Lanka and the Cocos Islands, Sri Lanka and the Carlsberg Ridge and along the Calrsberg Ridge in the Indian Ocean with earthquakes of magnitude 7 or larger as the Ritcher scale (Stover, 1966; Bangar

and Sykes, 1969; Sykes, 1970). There have had an impact on the movement of landmasses in Sri Lanka. Vitanage (1990) has reported that 53 earthquakes have occurred in Sri Lanka during the period between 1823 and 1976. This indicates how deeply weathered parent materials of high slopes can be shaken and moved downwards during periods of excessive rainfall.

Highly weathered metamorphosed rocks in the hill country contain a high proportion of feldspar and they are sometimes well jointed. These rocks weather into reddish brown clayey meterial known as lithomarge in which are embedded boulders of varying size (Cooray, 1984). When this weathered material is saturated with rain water, the iron-rich clayey material acts as a lubricant, causing the mass of earth and rock to move rapidly down the slope under the force of gravity. When there is no vegetation cover to bind and hold these material together the lubrication of the rocks, debris and earth can be intensified. During heavy rains, the fall or topple of rock material may be further intensified due to shaking of weathered rocks and debris by thunder and lighting. Infiltration of water along joints and natural tunnels in dolomitic areas could also led to landslides in steep slopes.

Human Influences on Landslide Probability

The land polices in Sri Lanka adopted by the Colonial government and later by National governments since Independence can be cited as a major reason for acceleration of landslide (Madduma Bandara, 1988). Under the Land Ordinance Act of 1840, the Colonial administration forcibly acquired the land used by the peasants for plantation agriculture and extraction of timber. Prior to this, the villages were largely concentrated in the valleys and lower slopes of the hills had been cultivated from natural streams. The gentle hill slopes had been used for chena (shifting) cultivation. The absence of human settlements and other activities on steep slopes of the head streams often minimized the damage to life and kept the balance of nature during the pre-colonial times. The forest cover on the ridges, upper slopes and hilltops remained undisturbed under a canopy of tropical mountain forest.

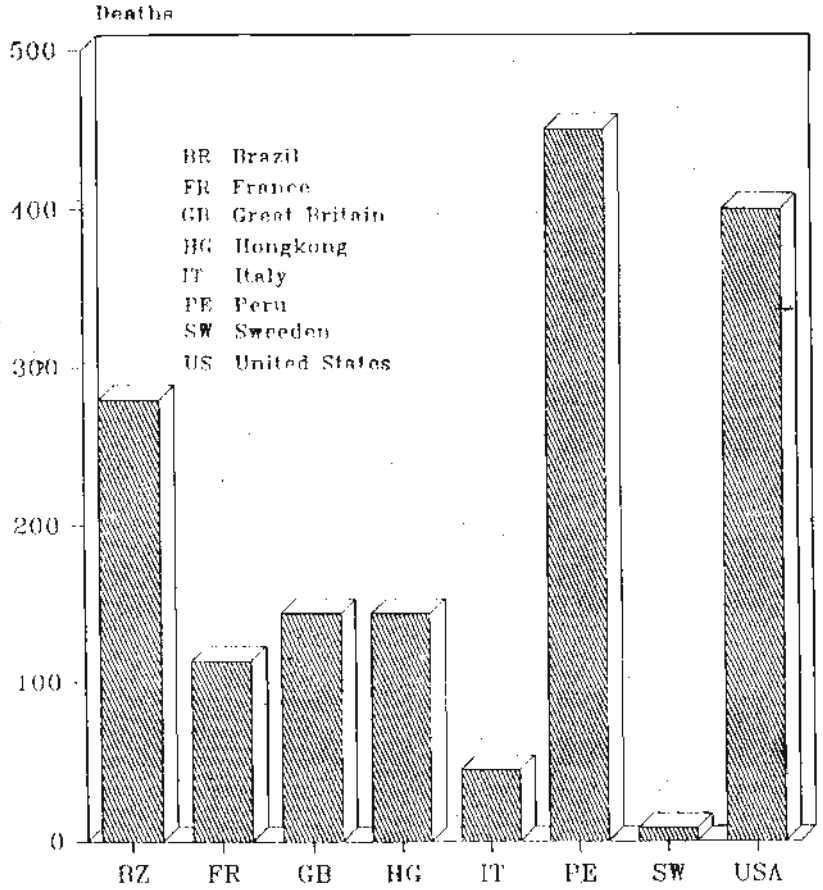


Figure 1: Mortality figures due to mass movements from 1966 to 1987.

During the time of the British colonial government, the exploitation of natural forest for timber and clearing of forest for coffee, tea and rubber plantations increased sharply. Tropical mountain forests were cleared and set on fire which broke the structural bond between natural vegetation cover and earth material. Since then , the occurrence of landslide has accelerated in proportion to the rate of clearance of forest cover. Legislation for the control and management of forest, land, soil, water and air were passed during the times of the Colonial government and later by National governments, but it has not been possible to enforce the regula-

tions successfully (Kurunanayake and Katupotha, 1990).

Proportionate to the increase of population in the villages of the Hill Country the demand for land for settlements and agriculture has increased. The imbalance in the man/land ratio, due to the pressure of population on land has caused the dense forest, reservations and patches of grasslands *(Patana)* in the steeper slopes and peak areas to be utilized for chena cultivation (for subsidiary food crops), plantation crops (tea and rubber) and commercial crops (tobacco and potato) as well as for illicit felling for timber by small holders and landless people. As a result, the natural forest cover has been further reduced (from 44 percent in 1961 to 24 percent in 1989). Wanton utilization of land in the upper slopes, where the slopes are moderate to fair (6^0 - 8^0 in Upland I); fair to steep (11^0 - 25^0 in Upland II); steep (18^0 - $25^{0)}$ and steep to extremely steep (18^0 - 45^0) in Mountainous terrains have been used for housing schemes and cultivation.

Man-made causes such as construction of reservoirs (Plate 1.B), forest felling on an extensive scale, periodic uprooting of tea and rubber trees, tunneling and pumping out of water from gem pits in the valley bottoms have all led to slope failures and subsidence of the lands, creating slope instability. Therefore, inefficient drainage of steep slopes along bare rock slopes and those under plantations may also contribute to slope failure.

Table 1: Occurence of Lasndslides in Sri Lanka 1930 - 1993.

Year	District	Location	Major/ Minor	Deaths	Houses damaged
1930	Kegalle	Thalawela	Major	Not known	Not known
1947	Kegalle	Kadugannawa	Major	40	Not known
1947	Kegalle	Aranayake-Sela-wakanda	Minor	Not known	Not known
1952	Nuwara-Eliya (NE)	Udahewaheta	Minor	Not known	Not known
1957	Kegalle	Pahala-Gadugannwa	Major	05	15
1964	NE	Walapane	Minor	(17 families affected)	
1970	NE	Walapane	Major	19	Not known
1973	NE	Walapane	Major	13	Not known
1978	Kegalle	Bulath-Kohupitiya Wegalla	Major	03	10
1979	Ratnapura	Kuruwita Akurana	Major	05	10
1979	Kalutara	Bulathsinhala	Minor	Not known	Not known
1981	Kegalle	Yatiyantota Polpetiya	Major	02	20
1981	Kegalle	Aranayale- Berawala	Major	Not known	30
1982	Kegalle	Mawanella Heenalipana Kanda	Major	Not known	Not known
1982	Kandy	Pathahewaheta Paginiwela Kanda	Minor	Not known	Not known
1982	Ratnapura	Pelmadulla Pathulpana	Major	08	15
1982	Matale	Pitakanda Pansalatenna Palindagama	Major	23	Not known
1983*	Kalutara	Welkandala	Major	13	03
1983	Kegalle	Mawanella Elangapitiya Kanda	Minor	Not known	15
1983*	Matale	Rattota Pitakanda	Major	13	08
1984	Kalutara	Bulathsinhala Agalawatta Matugama	Major	42	Not known
1984	Badulla	Haliela- Baddegama	Minor	Not known	02

Table 1 Contd.

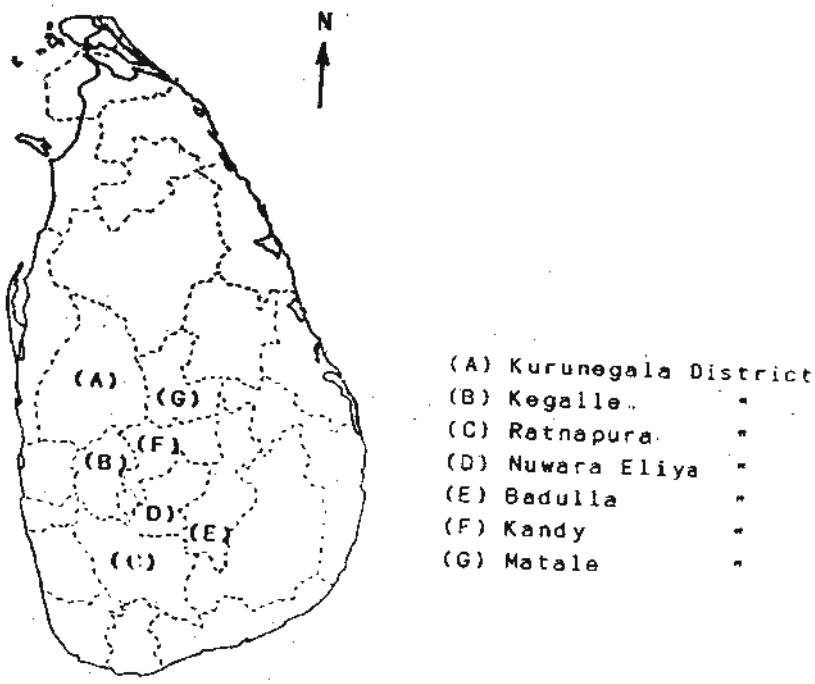
Year	District	Location	Major/ Minor	Deaths	Houses damaged
1984	Badulla	Bandarawela - Liyanagahawela	Minor	Not known	21
1984	Ratnapura	Embilipitiya Ihala Anduliwewa	Minor	Not known	21
1984	Ratnapura	Kolonna-Bulutota	Minor	02	05
1984	Ratnapura	Kuruwita Ratnapura Eheliyagoda Balangoda	(40 threats of minor earth slips reported)		
1985	NE	Noton Bridge	Minor	05	Not known
1985	NE	Town Division	Major	Not known	40
1985	Kalutara	Matugama Uduwala	Minor	Not known	Not known
1985	Kegalle	Warakapola Thiyambarahena Kanda	Minor	10	03
1985	Kandy	Galagedara Bodikulawa	Minor	Not known	Not known
1985	Kandy	Nawalapitiya Pemross Est.	Major	04	10
1985	Ratnapura	Elapata Kohombakanda	Major	Not known	46
1986*	NE	Hanguranketa Maturata	Major	06	01
1989*	Kegalle	Bambaragala Ataluganka nda Panawala	Major Major Minor	24 12 01	Not known Not known 03
1989*	Kurunegala	Ridigama Katiyawa Walimunukanda	Major	03	05
1989*	Ratnapura	Hinidunkanda	Major	01	03
1990*	Badulla	Welimada Gawammana	Major	05	Not known
1990*	Matale	Ukuwela Elkaduwa	Major	03	Not Known
1992*	Kalutara	Bulathsinhala	Major	05	03
1993*	Ratnapura	Kalawana Town Division	Minor	03	-

*Source: NARESA 1990; * Katupotha 1992 and Field observations.*

Impact of Landslides

Landslide prone areas in Sri Lanka are shown in Figure 3. The incidence of landslide which had increased in 1983, 1986, 1989 and 1992 caused 323 deaths and the loss of property and livelihood of 1327 families (Table 1).

Excessive rains between 29 May and 5 June in 1989 caused damage to 56 villages in the Ratnapura district (Karunanayake and Katupotha 1990) and 40 villages in the Kegalle district (Katupotha, 1992). During this period, 280 deaths were reported and 346 families (nearly 2100 persons) were rendered destitute in the Kegalle district alone. The intensity of damage to houses and properties, is related to the landslide types and to their magnitude. This includes bedrock-related materials (rock fall, rock topple, rock slump, rock block slide and rock slide), debris movement (debris fall, debris slump, debris slide and debris flow) and earth movement (earth slump, earth slide and earth flow) where they occur. Bedrock-related materials (debris and boulder) have been toppled at Hettikands (Hinidunkanda) in the Ratnapura district and at Berannewa in the Kegalle district. As a consequence, 24 deaths occurred and paddy fields were covered by boulder-rock slide with earth flow at Bambaragala (Kegalle district) during the same period. Debris and earth movements have occurred at Ataluganka nda, Punugala, Minimaruwa, Gatemulla, Warawela, Malmaduwa, Makura (Kegalle district), Wewalgama and Dodamgahaela (Kurunegala district). The excessive rains



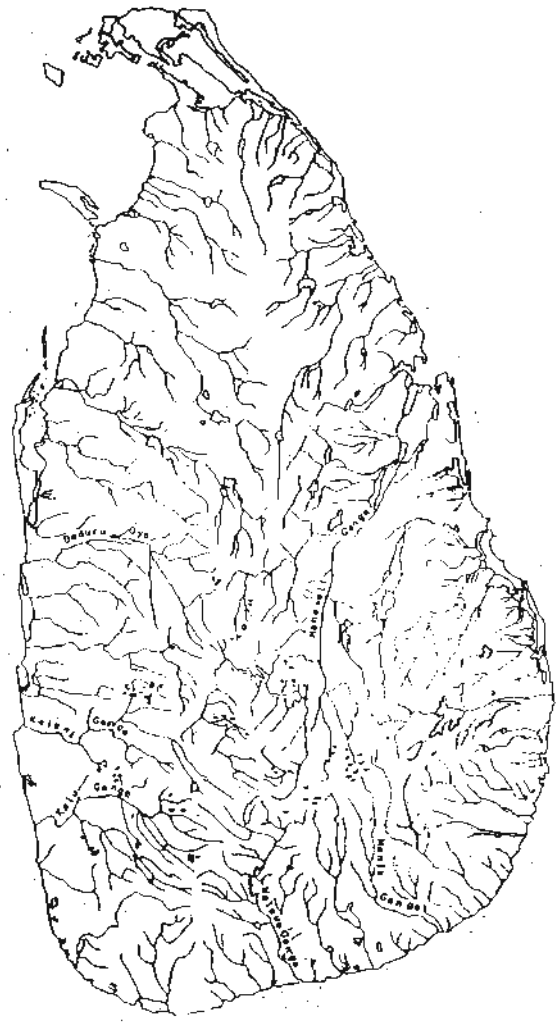


Figure 2: Landslide prone areas of the Central Hill Country, Sabaragamuwa Ranges, Rakwana and Knuckles Massives.

in 1989 also caused damage to the Kandy - Mahiyangana road (at Hunnasgiriya) by displaced debris and boulders (Plate 2.A). Slope slumping in several places of these areas appeared singly or as a combination of two or more types (Katupotha, 1991). Due to excessive rainfall between 25 and 30 May in 1992, a catastrophic slide of debris and rock blocks caused five deaths, and three families were rendered destitute at Bulatsinhala in the Kalutara district (Plates 3 and 4). Based on a recent study, Katupotha (1992) indicated that the occurrence of landslides has increased in areas of the Provincial Secretariat Divisions at Ridigama and Ibbagamuwa in the Deduru Oya basin; Bulatsinhala, Matugama (Plate 2.B), Agalawatta, Ayagama, Elapata, Kalawana, Ratnapura, Kahawatta, Kuruwita, Pelmadulla in the Kalu Ganga basin; and Weligepola, Haputale, Godakawela, and Kolonna in the Walawe River basin. Landslides in these areas have altered the micro relief and causing changes in the flow pattern of streams either through damming or diversion and deposition of rock, debris and earth.

Similar occurrences frequently take place around newly constructed reservoirs such as Victoria, Kotmale, Rantambe, Randenigala and Samanalawewa, and in tunneled areas. Slope slumping in those areas is due to wanton and unplanned investigations of local geologic parameters. Blasting of highly weathered metamorphosed rock for road building (e.g. the Kandy - Mahiyangana road), mining of graphite using heavy explosives

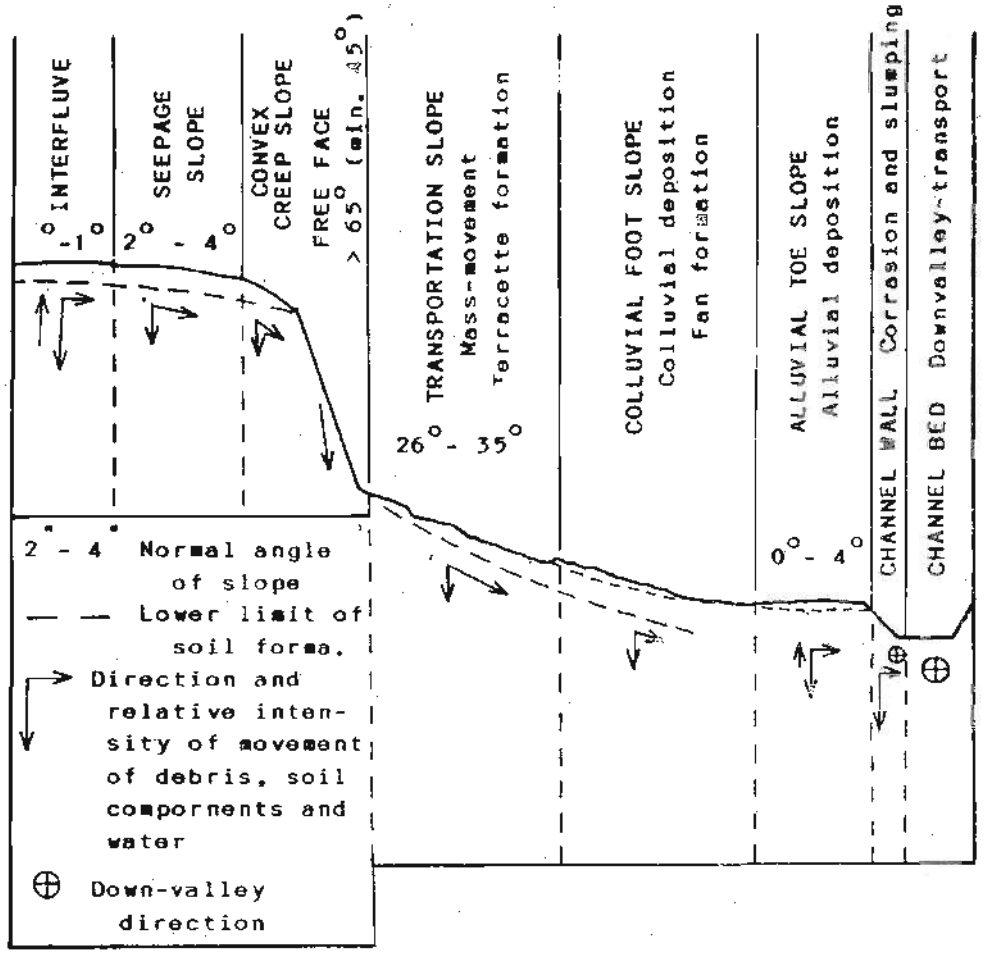


Figure 3: Slope units on a hypothetical land surface (Whittow 1984). Convex creep slope and free face are mainly subjected to landslide.

(Kurunegala and Kegalle district), gemmining (Ratnapura district), and forest or grassland fires on steep slopes (Kegalle, Ratnapura and Badulla districts) have increased the occurrence of landslides as well as of land subsidence on steeper slopes.

Recommended Preventive Measures

The intensity of environmental damage caused by landlides has increased as a result of inadequate investigations of geological structure, increased constructional activities, short-sighted land policies of the government and over-exploitation of natural forest resources in the uplands and mountainous areas. Therefore, several measures are urgently needed in order to protect the environment. Karunanayake and Katupotha (1990) recommended following conservation measures for the Ratnapura district, either singly or in combination; (a) reaforestration; (b) preventing haphazard forest clearance; (c) monitoring of 'suspect' areas; (d) grading of steep slopes according to the gradient and provision providing of contour drains; (e) terracing and nonutilization of landslide affected slopes either for human settlement or agriculture.

They have further pointed out that the adoptation of long-term strategies for hazard management is constiained by several factors. Example, a basic drawback is the absence of a landslide preparedness plan within the context of an overall district natural disaster preparedness strategy. Other contiants are that technical advice on the conservation of landslide-prone areas is inadequate and, given the paucity of funds, the implementation of conservation measures is made extremely difficult; and lack of inter-agency (district administration, JEDB, line departments and NGO's) coordination.

For the settlement of evacuees the following options have to be considered: (a) resettle the evacuees in the areas around their homeland where suitable land is available; (b) the evacuees could be absorbed into surrounding estates as employees; (c) relocating them in

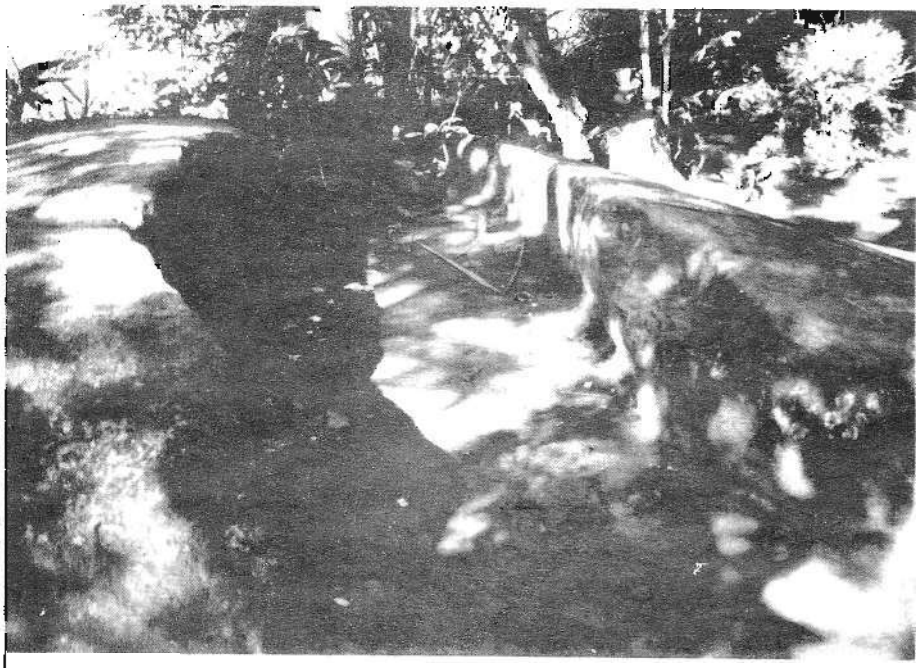


Plate 1:

(A) Cracked rock at Palankanda (Openayaka) indicates the gradual movement of the landmass. (B) Newly constructed reservoir (part of a Victoria reservoir) and road intersects (Kandy - Mahiyangana road) of the Central Hill Country will be subjected to future landslides.



Plate 4: (A) Damaged rooms in one of the houses shown in Plate 3(B). (B) rock and other debris of the same landslide of Plate 3.

downstreame areas of the Mahaweli Development project and absorbing them for present agriculture. For this purpose, it is necessary to provide reasonable quantity of land, e.g., about 2.0 ha. for a family to grow seasonal crops (chillies, onion and leguminous crops), annual crops (sugar cane) and animal husbandry. Moreover, the imbalance in the man/land ration due to the increase of population, the poverty of the people, vocational and educational background of the younger generation should be taken into consideration.

Katupotha (1992) has also recommended the following measures that might minimize occurence of the landslides in Sri Lanka.

a Grading of slopes into moderate (6^0 - 11^0), fair to steep (11^0 - 25^0) and steep and extremely steep (18^0 - $45^{0)}$ or over for the management of landslides and soil erosion. However, and steep to extremely steep or over slopes should not be used at all for human settlements and agriculture.

b Minimize the use of moderate slopes for human settlements and agriculture.

c Continue reforestation and forbid the unplanned and illicit forest fellings in graded slopes.

d Monitoring haphazard quarrying of rocks and other mining activities in fair to steep or over slopes.

e Forbid or manage the use of explosives in the mining activities, e.g., graphite, rocks, gems, in moderate to extremely steep or over slopes.

f Provide contour drains and terracing to protect the high slopes from soil erosion.

g Systematic and careful uprooting methods of plantation crops are needed to protect high slopes from landslides and soil erosion.

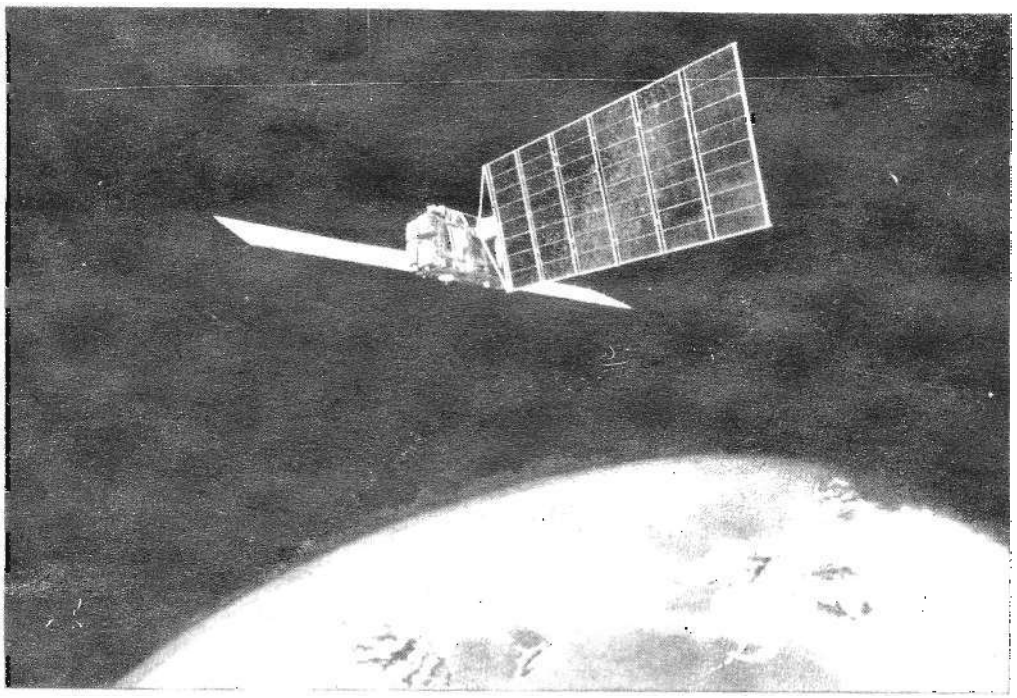
h Enforcement of existing Laws pertaining to the protection and management of natural resources.

The above mentioned recommendations can be implemented as short-term, medium-term and long-term strategies to prevent landslide hazards.



Plate 3: **(A and B) Deposition of rocks, debris and earth by landslide in 1992 caused the damage of three houses and five deaths at Bulatsinhala (Kalutara district).**





METEOROLOGY AND HYDROLOGY FOR SUSTAINABLE DEVELOPMENT

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"OUR COMMON FUTURE", the report of the World Commission on Environment and Development, which was described as the most important document of the decade on the future of our planet, set in motion in virtually every country, a series of initiatives whose ultimate goal is the achievement of **sustainable development** - development that meets the need of the present without compromising the ability of future generations to meet their own needs.

This concept of sustainable development does imply limits - not absolute limits, but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the human activities. There have been many definitions of sustainable development before and after the release of Our Common Future in 1987. But all such definitions imply the need for forms of development that are sustainable in three senses. First, development must not damage or destroy the basic life support systems of planet Earth; the air, the water and the soil and biological systems. Nor should development serious degrade natural resources, such as water, soil and the vegetation on which human economic and social activities depend. The second aspect of the sustainability of development is economic, to provide for a continuous flow of goods and services derived from the Earth's natural resources. Much more careful and efficient use of these resources, our water, our soil, our forests is required than in past decades. The third implication of most definitions of sustainable development is the need for sustainable social systems, at international, national local and family levels, to ensure the equitable distribution of the benefits of the goods and services produced, and of sustained life support systems.

The last two aspects of sustainability, the need for economic and social systems, are human-centred, whereas the first aspect concerns all forms of life on the planet. It is for this first aspect of sustainable development, the sustaining of natural systems and resource, at weather, climate and hydrological services have a vital role to play. For many years these services have been routinely observing, recording, analyzing and forecasting weather and climate events and their repercussions. They have contributed to our understanding of the behaviour of the atmosphere, including the vagaries of its gaseous constituents, as well as of the movement and storage of the water on and below the land surface. It is this knowledge and the ability to acquire and update it which have assigned a primary responsibility to the sciences of meteorology and hydrology in the quest for sustainable development.

The atmosphere of our planet is an essential environment and resource. It has developed in harmony with the biosphere of Earth, and is essential for life of all creatures. It produces the climates which determine the natural endowments of regions and the way we live. For development to be truly sustainable, the character of the atmosphere must not be significantly degraded or altered.

One of the earliest signs of adverse large-scale impacts of humans on the atmosphere was acid rain. A particular problem for North America and Europe, it is the result of the discharge of gaseous sulphur and nitrogen oxides into the atmosphere from the burning of coal and oil, during the operation of electricity generating and smelting industries and from transportation. In the atmosphere, these gases combine with water vapour to form acids. Falling as rain or snow these lead to acidification and degradation of sensitive lake and river systems and damage to forests and to metal and limestone structures.

Until the latter half of this century it was generally considered that the envelope of air around us was so vast, and the energy involved in the restless weather systems so enormous, that human activities would have but temporary and local impacts. But measurements and documentation of global contamination of the atmosphere which disprove this idea are now only too well known. Such documentation includes the increasing acidity of the rain over extensive regions, the startling reductions in the stratospheric ozone over Antarctica during the southern hemisphere spring, the rapid rate of increase of the greenhouse gases throughout the global atmosphere giving rise to projections of global climate warming, and the inter continental transport by sea and air ofoxic chemicals from the Arctic to the Antactic in detectable, even dangerous amounts, and far away from industrial and agricultural sources.

One of the earliest signs of adverse large-scale impacts of humans on the atmosphere was acid rain. A particular problem for North America and Europe, it is the result of the discharge of gaseous sulphur and nitrogen oxides Into the atmosphere from the burning of coal and oil, during the operation of electricity generating and smelting industries and from transportation. In the atmosphere, these gases combine with water vapour to form acids. Falling as rain or snow these lead to acidification and degradation of sensitive lake and river systems and damage to forests and to metal and limestone structures.

If human uses of water are to be on a renewable, sustainable, basis they should be at a rate that does not exceed the minimum flows of the accessible rivers and in the case of ground water, the rate at which it is recharged through precipitation. In many locations these sustainable rates are being exceeded. In addition, pollution of water bodies by human activities is effectively reducing even more the available safe supply, especially for domestic use. It is estimated that human water use has grown 35 times in the past three centuries, and is now growing at between 4 to 8% per year due to rapid increases in both per capita use and the total population. It is clear that such rated of growth would not be sustainable for long in many parts of the world.

Perhaps the most serious threat to sustainable use of the Earth's renewable natural resources lies in the rapidly increasing contamination of the atmosphere by the greenhouse gases, and the changes in the climate expected as a result. It is a pervasive issue whlch provides the most obvious reasons as to why more sustainable development practices must be adopted.

The energy that drives and shapes the constantly changing atmosphere-ocean-biological system, comes from the Sun. About on-half of the incoming solar energy is absorbed and reflected by the atmosphere with its clouds and dust, and other half absorbed and reflected by the surface of the Earth. The incoming energy is balanced by the outgoing radiation at longer, infra-red wavelengths from the Earth and the atmosphere. A number of gases occurring naturally in the atmosphere, especially water vapour, carbon dioxide and methane radiate much of this long wave radiation energy back to Earth, warming the air masses near the Earth's surface.

Without this natural "greenhouse effect", the global climate would be some 33^0C colder, an uninhabitable environment for most present life forms. However since the beginning of the Industrial Revolution, human economic activities have emitted pollutants to the atmosphere that have increased the natural greenhouse effect, mostly by adding to the existing concentration of carbon dioxide, methane, nitrous oxide and low level ozone, but also by the introduction of the wholly artificial greenhouse gases, especially chlorofluorocarbon (CFC_5).

Scientists are not yet able to predict with confidence what changes will take place in regional and local climates or what the impacts of those changes on society and the environment will be. However, In spite of the present uncertainties a number of impacts of a warmer Earth can be reasonably predicted. First, sea level is projected to rise from 30 cm to 100 cm by the end of the next century. Heavily populated low-lying coastal zones would be inundated or seriously affected by increasingly damaging storm surges, by salt water intrusion into coastal aquifers, and changes in shorelines. A sea level rise of the order of one metre would threaten the very existence of some of the smaller islands.

A second major impact of the global warming is that Arctic and sub-Arctic areas would be 6-12^{0}C warmer in winter than at present, which would mean that the surface layers of permafrost would melt, the stability of buildings, roads and other structures in those areas would be threatened, and Arctic sea ice would be reduced. In the snow melt season, greater floods due to both a more rapid melt and greater accumulation of snow would occur.

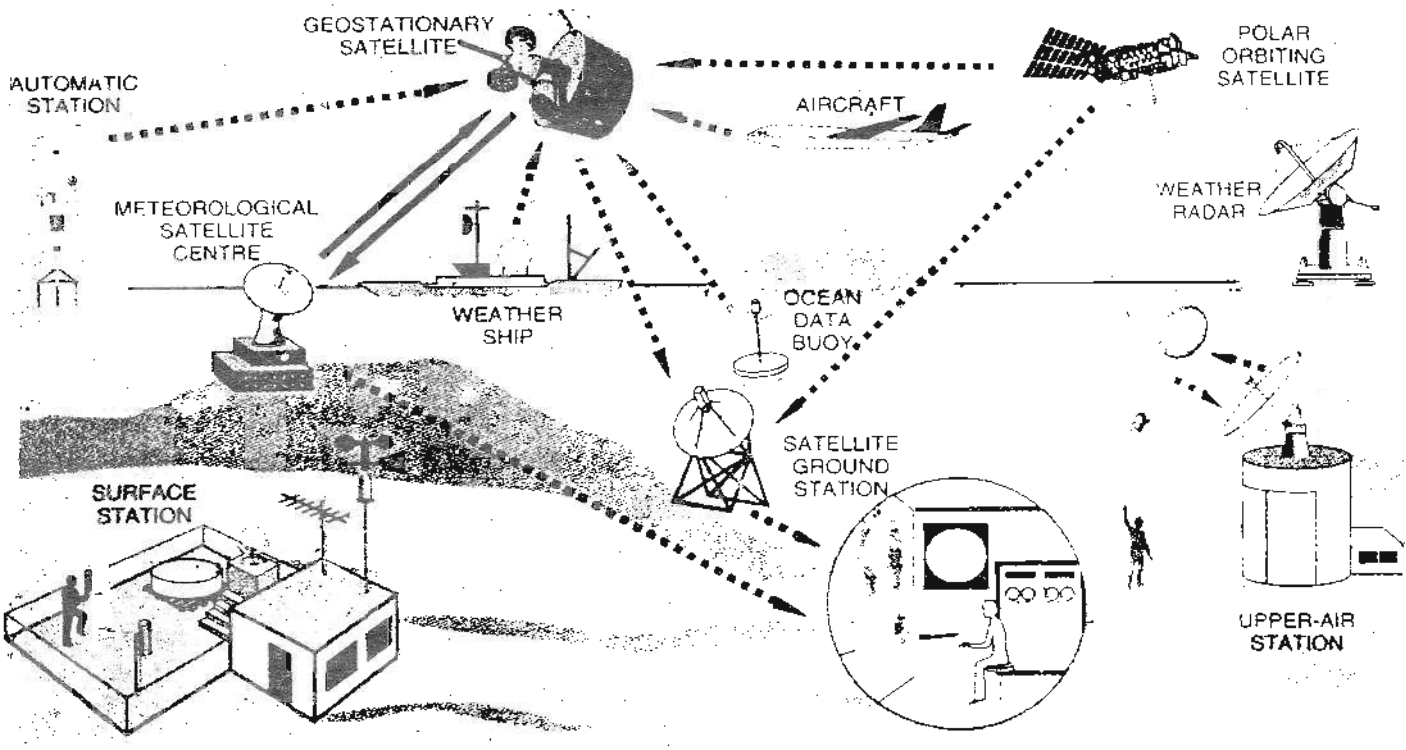
Changes in agricultural production are less predictable because of uncertainties as to the distribution of rainfall. However, most models suggest a drying of the southern portions of the great grain-growing areas of North America and Eurasia that would seriously reduce world cereal production and change the balance of agricultural exports and imports for a number of countries. There would, as well, where adequate water is available. be direct stimulation of plant growth rates because of the increased concentrations of carbon dioxide in the atmosphere.

Another impact, not often emphasized is the possibility of the spread of tropical diseases. In many cases the agents that transmit the diseases, mosquitoes, anails, bacteria, are markedly limited in their range by the water and air temperatures-they cannot thrive at temperatures lower than certain thresholds-often about 26^{0}C. With gradual warming the areas would expand in which favourable conditions for these agents persist, resulting in a spread poleward of these tropical diseases.

The world's surface water resources are already under great stress. Only two percent of the 1.41 billion cubic kilometres of water of Earth is fresh water of which eighty-seven per cent is estimated to lie in ice caps and glaciers and the rest in deep ground water. Only about 2,000 Km^3 is at any instant readily available in lakes, rivers and shallow ground water for numerous human uses.

If human uses of water are to be on a renewable, sustainable, basis they should be at a rate that does not exceed the minimum flows of the accessible rivers and in the case of ground water, the rate at which it is recharged through precipitation. In many locations these sustainable rates are being exceeded. In addition, pollution of water bodies by human activities is effectively reducing even more the available safe supply, especially for domestic use. It is estimated that human water use has grown 35 times in the past three centuries, and is now growing at between 4 to 8% per year due to rapid increases in both per capita use and the total population. It is clear that such rated of growth would not be sustainable for long in many parts of the world.

In no other economic activity are the dilemmas of sustainable development so clearly evident as in the production and distribution of energy. Energy use has increased eighty fold since the middle of the 19th century, with profound effects on carbon, sulphur and nitrogen flows on the planet. The wealthy industrial economies of the world have developed on the basis of abundant cheap energy mainly through the burning of fossil fuels, i.e coal, oil and natural gas. These are non-renewable resources, dug from the earth. It is estimated that each year's current consumption of fossil fuels represents a million years of accumulated fossil deposits. Known oil reserves will be exhausted over the next century with, at current consumption rates, the most readily accessible and cheapest reserves being depleted in 30 to 40 years. Natural gas reserves and coal will last longer but will be consumed over the next centuries at present rates of use. In short, burning of fossil fuels is inherently a non-sustainable activity-fossil fuel resources are being exhausted, and their burning is rapidly changing the composition of the atmosphere. On the other hand, renewable energy sources, solar, wind, wave, tidal power and biomass energy represent a small proportion of the current global energy mix. Hydro-Electricity is the only renewable energy source with a significant share (6.6%) of global commercial power production. Nuclear power occupies an im-



portant niche in some developed countries, but represents only five per cent of the commercial energy production.

The knowledge so far acquired on environmental issues is based largely on the data collected through meteorology, hydrological oceanographic services. Through the assessment and evaluation of these data, information can be derived on changes in atmospheric composition radiation budget, water balance and concentrations of dissolved and suspended materials ; future scenarios can also be predicted. These can then be considered by governments so that environmental management policies may be adjusted to changing situations. In this manner meteorology and hydrology can be used to test whether or not existing development is sustainable and what future development may be most propitious in the context of sustainability. Well-established meteorological, climatological, and hydrological services provide the essential assurance that the environment is managed to the advantage of all.

Recent development in environmental and resource issues related to the global atmosphere and to fresh water, have clearly demonstrated the urgent need for better measurements and understanding of these components of our Earthly inheritance. To preserve this inheritance for future generations and to use it for the benefit of all people, will require an unprecedented level of understanding of the atmosphere and of water systems, and wise use of that understanding in public policies.



CYCLONES, STORM SURGES AND THE ENVIRONMENT

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Tropical cyclones are storms with winds of over about 120 kph (or about 73 mph). Many can have sustained speeds of 200 kph (120 mph) and gusts upto 400 kph (240 mph). The word " cyclone " is derived from the Greek " Kyklos" for the coil of a snake.

Similar meteorological phenomena are called by other names in different parts of the world. In the Western Hemisphere regions of the Caribbean and North Atlantic they are known as "hurricanes" (from Huracan, the name of a Carib god of evil) while the term "typhoon" is applied to those forming in the Pacific.

The biggest of these storms are those of the Western Pacific. Other names applied to these storms are baguios near the Philippines, papagallos in the eastern North Pacific, trovadoes around Madagascar and willy - willies by Australia.

The approximately 80 to 100 tropical cyclones each year mostly arise between about 5 and 30 degrees on each side of the equator. However, "Arctic cyclones" are also known, although the conditions leading to their formation are somewhat different from those resulting in tropical cyclones.

Associated with cyclonic storms are the storm surges or coastal floods of meterological origin. These have also been called tidal waves but the latter term has also been used in connection with the tides related to the gravitational attraction of (principally) the sun and moon as well as for seismic sea waves (or "tsunamis").

The latter are usually a result of under sea vertical land movements, as in earthquakes, but also by other geological events, such as volcanic eruptions.

The greatest damage caused by a cyclone is usually attributable to that caused by the storm surge and the flooding which takes place on land. Since these are closely interrelated it is of interest to examine how they arise and develop.

Origins and development

A. Tropical Cyclones: A Tropical cyclone may commence after moist air is warmed by the sun and rises upward from a warm sea. On reaching a certain height the moisture condenses into droplets of water. This condensation results in the release of energy which warms the surrounding air - thus providing further force to its upward movement.

The reduction of atmospheric pressure which results causes more moist air to rush in. In the cases of storms which become cyclones north of the equator, the earth's rotation causes the air to take an anticlockwise movement.

In the case of cyclones south of the equator, a clockwise movement takes place. The centrifugal force caused by the spinning wind system tends to expel air and cause a drop in pressure within.

The spiral of winds, thus, has at its center an "eye" or region of calm with only light rain. This eye may often be only a few kilometres in diameter. The actual cyclone could, however, be one to two hundred kilometres across with a height of around eleven to nineteen kilometres. The effective region of disturbance could reach upto 500 km in diameter.

The cyclone may move at around 15 to 30 kph over tropical seas and over thrice these speeds at other latitudes before exhausting itself. Over land it exhausts itself more rapidly but the rainfall shed by it usually causes serious floods and loss of life.

B. Artic cyclones: Artic cyclones are different from tropical cyclones in several characteristics. For instance, a) the diameter of the storm may be much more compact although that of the 'eye' may be more similar, b) they may develop in under 24 hours rather than taking up to around a week, c) they are most frequent from October to April, d) their height may be only around 8 Kilometres and, e) While their speed of travel may be twice that of a tropical cyclone the wind speed may be only 80 to 160 kph.

Their identification as being cyclones has been confirmed by satellite photographs using infra red cameras.

C. Storm surges: Storm surges may sometimes account for upto ninety percent of the casualties of the impact of a cyclone. They are most prevalent along coasts of the Bay of Bengal, the Gulf of Mexico, the eastern seaboard of the USA, Japan and some other Western Pacific Islands. Some coastal areas of the North Sea may also be affected.

Storm surges are however, mostly associated with tropical cyclones. Two factors contribute to their



Coastal erosion due to destroying mangroves for timber.

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generation. The first is the drop in atmospheric pressure which causes the sea water below to be raised by a small amount.

The other factor is the effect of the strong wind component along the surface of the water. The height of the surge depends partly on the strength of the wind and may reach over 25 feet and last for some hours.

Some of the factors which can modify a storm surge are, a) the cyclone characteristics, b) the depth of the water, c) the shape of a bay, d) low-lying islands, e) the normal tide action and f) inlets and estuaries.

Depending on the drainage area of a river, the flood and storm surge associated with a cyclone may occur together or separately. In the case of a river with a large drainage area the two may be quite distinct while in that with a small drainage area, the two may occur together. In intermediate cases (eg. of drainage area between 1000 and 3000 sq. km.) the two could meet partway up the river.

D. Requirements for formation of a cyclone: Several factors have been described as being necessary for cyclone formation. However, it has also been noted that such factors or conditions are frequently present in tropical oceans without cyclones necessarily developing. work therefore needs to be done to establish definitively why cyclones are relatively rare even when conditions are apparently suitable for their formation.

An important condition for the development of a tropical cyclone appears to be a column of water of a depth of 60 metres or more at a temperature of 26 centigrade or more.

The temperature difference between the surface water and the atmosphere should be sufficient to ensure the smooth rise of warm moist air while the depth of the column appears likely to be necessary for the prevention of mixing with cold water from the lower strata.



Coral reefs are being mined to manufacture lime.

Other requirements appear to include minimal vertical wind shear through the tropospheric layer and that the coriolis parameter should not be below a minimum figure. However as stated above, even when these and other described empirical conditions are met, tropical cyclones do not necessarily occur.

Arctic cyclones which may reach the intensity of those of the tropics arise, as mentioned earlier, under somewhat different conditions. Here the conditions for them to develop appear to be met by the great differences in temperatures between the seas and the atmosphere above.

For instance, the ocean currents may have temperatures as much as around 18 centigrade, while that of the air cooled down by the polar ice may have fallen down to around -29^0 centigrade. While other factors, such as the earth's rotational force, have influences on artic cyclones different from those occurring in the tropics, the answers to many of the questions relating to them may lie in the interactive effects of relatively warm ocean currents and warm and cold air currents above.

E. Cyclones in the Bay of Bengal: Our main interest, however, is in the destructive cyclones that occur in the Bay of Bengal. These are most frequent in the pre-monsoonal period of April-May and the post-monsoonal period of September/ October to December. Violent cyclones have not generally been a significant problem from January to March while the phenomena that occur during the southwest monsoon of June to September have been rather classed as being monsoonal depressions.

Among the numerous records of violent cyclones in the Bay of Bengal are:

a) that of the furious hurricane (together with a violent earthquake) which took place on October 7, 1737 at the estuary of the Ganges causing 300,000 deaths.

b) that on the Coromandel coast on April 13, 1749,

c) that in November 1797 in the northern part of the Bay and

d) that between Trincomalee and Madras around December 4, 1803. Records of violent cyclones occurring in the Bay of Bengal and affecting littoral states exist from those years to the present.

Anwar Ali has noted that 25% of the 19 most severe cyclones disasters experienced in the world in 1960 to 1970 affected Bangladesh. That of 12 November 1970 led to some 500,000. deaths and $ 63 million crop loss in addition to other severe losses and damage.

Other cyclone disasters to have affected Bangladesh include those of

1822,1876 and 1897 causing 40,000, 100,000 and 175,000 deaths respectively. Flooding of the plains are a primary cause of the terrible tragedies wrought by cyclones to this region.

The environmental aspects

Considerable damage is caused by tropical cyclones and the associated storm surges. The damage can include short-,medium-and long-term effects and it could affect natural physical features and living organisms, as well as human life and activities. These aspects are, however, interrelated and it is not practical to discuss them under defined headings. However, mention could be made initially of factors which may modify the damaging effects of cyclones and storm surges.

First, it will be recalled that one of the factors predisposing to the development of a tropical cyclone is a temperature of at least 26^0 centigrade from the surface to a depth of 60 metres or more. While the influence of other factors are necessary to ensure or "kick" the development of a tropical cyclone, it has been suggested that if the hypothesized global warming due to the "greenhouse effect" does occur it may well lead to the increased frequency of violent cyclones.

This hazard would be in addition to the possibility of inundation of low-lying land and islands should the levels of the ocean rise due, at least in part, to the melting of some of the polar ice caps.

Secondly, mention should be made that some protection against cyclone -related damage is afforded by the living natural barriers of coral reefs and trees. These could be included among the first lines of defence, particularly when the trees include belts of mangroves.

However, unfortunately coral reefs are being mined to manufacture lime for construction purposes while the mangroves are being felled for timber and other purposes. Similarly, coastal marshes which provided a valuable "sink" for flood waters are often filled in for housing developments (which may be exposed and in the path of an advancing storm).

Some of the many factors which can modify a storm surge have been given earlier. Once a cyclonic storm moves onto dry land it may exhaust itself fairly soon, particularly when it expends its energy against obstructions such as mountain ranges, hills and inselbergs.

The damage which is, however caused by cyclones and storm surges on land can be considerable and, as has been noted above, include damage to structures and living organisms and disruption of human life and activities. It may also, however, be said that not all effects are damaging but that a few may in fact be beneficial.

One cyclone in Sri Lanka, for instance, washed away some long-standing pollution from a pulp and paper factory on the east coast and also increased the salinity of some lagoons to the benefit of the breeding of prawns and crabs.

However, the most widespread effects of tropical cyclones and their storm surges in the loss of life and extreme property damage they cause . We shall next consider some of these questions although the discussion cannot claim to be comprehensive of all the problems which may arise.

For instance, the economic cost to a nation of diverting funds, administrators and technologists during the period of reconstruction will not be discussed nor, for example, the possible environmental consequences of a nuclear power plant being damaged by a severe cyclonic storm.

One of the earliest effects of a cyclone may be on fishing boats out at sea. Loss of life and destruction of fishing vessels, whether out at sea or on inland waters has been a feature of many cyclones, whether in the tropics or in Arctic waters. For instance, around 9000 marine fishing boats and 90,000 inland water fishing boats were lost in the Bangladesh cyclone on 12 November 1970.

When approaching land the cyclone (ie. together with its storm surge) may change the topography of the sea bed and change the pattern of waves and currents. Next loose sand may be pushed up the beach and later drawn back, together with sediment and topsoil, into the sea.

If there is reef of live coral in the area the particulate matter may be deposited in the pores and cause the death of the coral animalcules. The death and eventual degradation of the reef would leave the beach and coast more exposed to subsequent wave action and erosion.

The destruction of the coral reef would also lead to that of a complete specialised ecosystem. The coral reef habitat, as is well known, supports a large number of fish and other living organisms, such as anemones, which are directly or indirectly, interdependent on each other.

The export of ornamental aquarium fish and shellfish taken from the coral reef habitat is as well, a useful earner of foreign exchange for some of the countries of the region in addition to the attraction of coral reefs for tourism. These too may be affected in the aftermath of a cyclone.

The movement of the cyclone onto land causes widespread uprooting of trees and other vegetation. If a belt of mangroves is present, they will reduce some of the force of the cyclone and storm surge. However, it must be recognised that the mangrove habitat is a location of choice for the breeding of fish, shellfish and other aquatic organisms in addition to supporting populations of amphibians, reptiles and birds. The passage of a cyclone through such a specialised habitat inevitably wreaks havoc on the communities it harbours as well as, eventually, on the adult forms which spent their larval or juvenile stages in mangrove areas but later migrated elsewhere.

Similar considerations apply following the passage of a cyclone through other specialised habitats such as seagrass beds.

The cyclone which hit the east coast of Sri Lanka near Batticaloa on 24 November 1978 caused the destruction of a large number of coconut palms (and an additional hazard was caused due to the blowing of debris such as coconut husks found abundantly on such plantations.)

Other crops, such as rice, may also be affected during a cyclone. The damage to crops may be physical due to the wind. However, additional degradation or agricultural land may be caused by movement of topsoil (sometimes into the sea) and due to salinization of soil and ground water due to passage of the storm surge.

The salt and the soil may get washed out by the heavy rain deposited during the monsoon. However, in some cases, additional leaching with fresh water may be necessary.

The salinization of wells and surface water may present a problem in obtaining adequate drinking water supplies for people and animals immediately after a cyclone. This is indeed a major factor in the widespread destruction of surviving wildlife, animal and plant, immediately after a cyclone.

Related problems of starvation and disease occur among wild animals, livestock and people following a cyclone.

The maintenance of population of wild animals takes on lower priority, particularly when the numbers of people and livestock affected are of any significance.

In addition to the question of availability of resources at short notice, the provision of emergency relief is hampered by the damage to hospitals, Water supply schemes, roads, railways and telecommunications and disruption of community services. In cases of widespread damage, it may be of a higher priority to replant rice crops than to attempt to set about reconstruction of houses, schools and other buildings.

Outbreak of looting and theft is another social environmental problem which may occur under these conditions.

Pre-storm policies

Considerable work has been done worldwide regarding policies and procedures in relation to coping with natural disasters. It is not proposed to discuss in any detail the work of relevance to cyclones and storm surges here, but a fairly quick review of some principal noteworthy points may be helpful in connection with certain environmental questions and preliminary to the later discussion.

One of the first pre-requisites to coping with cyclones and storm surges is to identify the cyclone-prone areas and list the problems which may occur.

Some problems which may arise may be serious enough to justify the preparation of a special contingency plan to follow should an unlikely event take place. An example could be serious damage being caused to nuclear power installation.

An estimation of whether an area is cyclone-prone would initially require an examination of historical records of cyclones and storm surges in the region and available meteorological data. However, this can, at best only help to assess the probability of a cyclone of "typical" severity affecting

the area at a given frequency.. In addition, it cannot exclude the possibility of occurrence of a cyclone of unusual severity.

Again, the available data may be inadequate to prepare more than general estimation of maximum wind velocities which could be experienced. This would be relevant to arriving at building design and construction criteria keeping in mind the reasonable use of available resources. It must, also, be noted that the estimates and decisions based on these would need to be reviewed regularly as an ongoing process.

Even the risk assessments themselves may change over time, for example, if, as mentioned above, global warming due to the "greenhouse effect" proves to influence the frequency and characteristics of tropical cyclones.

With the help of orbiting satellites and cloud imagery, the task of accurately locating the centre of the cyclone is much facilitated.

However, predicting a cyclone's future path poses greater problems and regions at possible risk are alerted by means of **Cyclone watch bulletins** and **Cyclone Warning Bulletins.**

Issuance of such or similar bulletins, as distinct from Bad Weather Warnings, should serve to activate responses at different levels in the nation down to that of the community.

The media (news papers, radio, and television) should collaborate closely with the Meteorological Department or Ministry of Information to provide and disseminate actual information of relevance to the actual situation.

One cyclone in Sri Lanka, for instance, washed away some long-standing pollution from a pulp and paper factory on the east coast and also increased the salinity of some lagoons to the benefit of the breeding of prawns and crabs.

Mitigating measures to reduce the adverse effects on the environment of the impact of cyclones and storm surges include actions to ensure that natural barriers are provided and remain intact. These will include planting of trees, such as mangroves, and taking steps for the protection and preservation of coral reefs and sand bars.

Particular care should be taken to minimise the exploitation of these natural features for construction materials during the repair and rebuilding period following a storm. Preservation of such natural features also help to maintain the attractiveness of a region for tourism as well as helping to protect coastal roads and railways.

Regional co-operation between South Asian countries as regards environmental effects of cyclones and storm surges could take many forms.

One important aspect is improvement in early warning activities. This function is greatly assisted today by information obtained from orbiting satellites but much still remains to be developed as regards diffusing this information at community level.

Systems need also to be improved for transmitting this information to boats at sea.

Detailed surveys should be performed by littoral states of the shoreline and under water seaslope. This data would be invaluable for helping in the identification for vulnerable areas, as well.

Another invaluable aspect is detailed land use planning and its implementation for cyclone-prone areas.

This should include all r elevant aspects such as retention of marshes to act as "sinks" for flood waters, location of hotels and other vulnerable buildings behind belts of trees and other natural barriers etc. Hazardous industries should, as far as practicable, be located outside "cyclone-prone" areas.

The countries of the region should co-ordinate programs to identify alternatives to the use of sand and coral for providing materials for construction purposes. Information on these questions should be circulated among member states and tested to ascertain its usefulness under the conditions obtaining in each state.

The member state should co-operate in programs of research on the development and early detection of cyclones. It has been noted already that the development of a cyclone depends on many factors and in fact, cyclones are relatively rare considering the fact that conditions such as sufficiently warm sea surface temperatures are fairly frequently available.

It is possible that more research on cyclones will help reveal some hitherto unappreciated condition which can be deliberately disturbed in the case of necessity in order to impede the further development of the storm.

tion should be directed to developing a beneficial use of the energy source, which may prove inexpensive, renewable and free of chemical pollution.

Developing a novel technology for tapping solar energy based on the phenomena on which cyclones develop may well take even fifty years of unremitting effort but would be of utmost benefit to the region when perfected.

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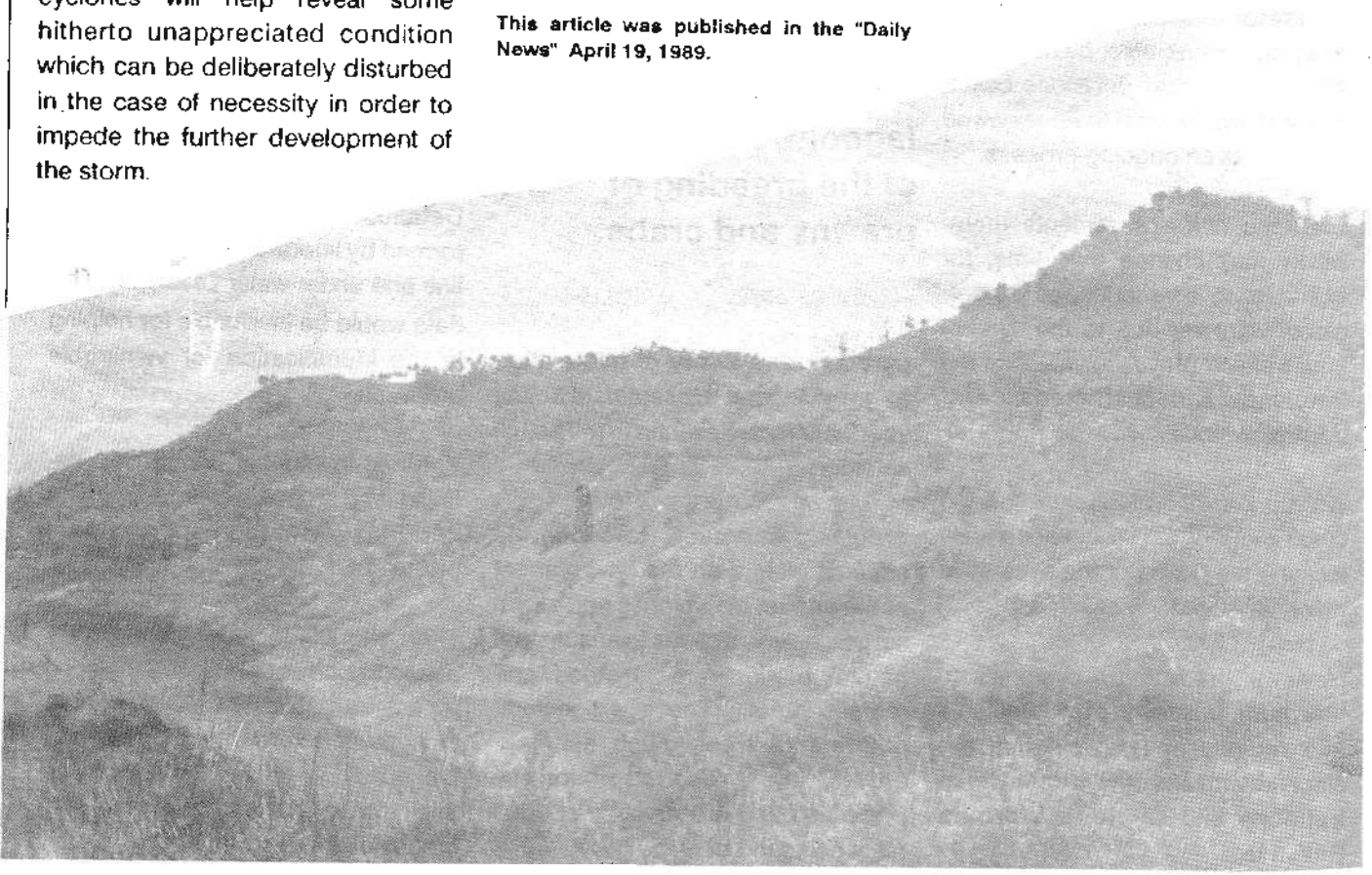

Finally, a more distant goal towards which the combined research skills of member states could be directed is to develop a means of harnessing or "tapping" the tremendous energy found within a cyclone to serve man. In view of our fortunate position in a region where cyclones form, atten-