Hydrological investigations in a small drainage basin of an ephemeral stream in Ngare Ndare / Isiolo District

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Correct citation:
Jürgen Hagmann, (1991) *“Hydrological investigations in a small drainage basin of an ephemeral stream in Ngare Ndare / Isiolo District* ”, in Beiträge zur Hydrologie

Summary - Zusammenfassung

Investigations were carried out on the hydrology of a small drainage basin in the semiarid thornbush savannah near Ngare Ndare. The aim was to evaluate the basic runoff characteristics and the water balance of this catchment area. Infiltration experiments and the examination of the root systems of the plants indicated very shallow wetting of the soil under these climatic conditions. Therefore, seepage is most unlikely.

Measurements of rainfall, runoff, sediment load and infiltration were used to explain the runoff characteristics. All runoff events had extremely low runoff coefficients. The highest loss of surface water was only 2% of the precipitation. A reasonable explanation for this characteristic was obtained by infiltration measurements. Vertic soils in particular, were excessively drained even when the surface was wet. This implicated that only high intensity rainfalls were able to generate runoff. The hydrographs confirmed this assumption. Therefore, the runoff characteristics of the experimental catchment were completely dominated by the excessive infiltration capacity of these soils. Even with seven raingauges within an area of 2.62 km^2 an enormous spatial rainfall variability was assessed.

As a consequence of the low surface runoff, the sediment discharge was also very low. Thus it can be assumed that the catchment is not endangered directly by soil erosion. Low surface runoff and negligible seepage implicate the water balance being dominated by rainfall and evaporation.

Zusammenfassung

Die folgende Untersuchung beschäftigt sich mit dem Wasserhaushalt eines kleinen Einzugsgebietes in der semiariden Dornbuschsavanne im nördlichen Kenia. Ein kleines Testgebiet wurde ausgewählt, um die Wasserressourcen der Trockentäler nördlich des Mt. Kenia und deren Beiträge zum Wasserhaushalt des Ewaso Ngiro, einem der grössten Flüsse in Kenia, zu erfassen. Das Hauptspeisungsgebiet des Ewaso Ngiro liegt im Mt. Kenia-Gebiet, wo jedoch zunehmend Wasser für Bewässerung und Wasserversorgung abgezweigt wird, und somit die Wasserressourcen für die in den nördlichen Tiefländern lebenden Nomaden knapper werden.

Die wesentlichen Charakteristiken des Wasserhaushalts dieses Trockentals wurden mit Niederschlags-, Abfluss- und Infiltrationsmessungen erfasst. Weiterhin wurden Untersuchungen an Wurzelsystemen von Pflanzen als Indikatoren für den Wasserhaushalt, Evaporationsmessungen und Isotopenanalysen des Grundwassers durchgeführt. Hauptmerkmal des Einzugsgebiets war ein extrem

niedriger Abflusskoeffizient (max. 0,02). Dies konnte sehr gut mit Infiltrationsmessungen erklärt werden, welche außerordentlich hohe Infiltrationskapazitäten besonders in den vertischen Böden zeigten. Da keine merkliche Grundwasserneubildung festgestellt werden konnte, stand somit der größte Teil des räumlich sehr variablen Niederschlags dem Pflanzenwachstum zur Verfügung.

Infolge des geringen Oberflächenabflusses konnten nur sehr geringe Bodenverluste verzeichnet werden. Die Erosionsgefahr kann daher zum jetzigen Zeitpunkt als gering bis mässig eingeschätzt werden.

1. Introduction

In remote areas like the arid and semiarid regions of northern Kenya only limited hydrological research has been done to present. The last few years it became obvious that the waterresources of the Ewaso Ngiro, one of the big streams in Kenya, are decreasing. This river has its origin in the north eastern slopes of Mount Kenya, in Laikipia District. Due to high population growth in this district the water consumption has also increased. So the water resources of Mt. Kenya are more and more used for water supply and irrigation whereas the recharge for the Ewaso Ngiro decreases. In particular during droughts consequences are catastrophies for the nomadic pastoralists living in the northern plains. Pasture and water resources reserved for the dry periods are diminishing more and more.

For the upper Ewaso Ngiro basin in the Mt. Kenya area several studys concerning its water resources have been done by DECURTINS (in prep.), LEIBUNDGUT (1983) and LEIBUNDGUT et al. (1986). The discharge of the Ewaso Ngiro, however, is not only depending on Mt. Kenya. All ephemeral streams, called lagga, having a river flow only after heavy rains, contribute to the streamflow of Ewaso Ngiro.

This study assesses the runoff potential of a small lagga located at the beginning of the middle Ewaso Ngiro basin near Ngare Ndare. The runoff potential of such small laggas is also of interest for the dimensioning of small dams as water storage facilities for the Nomads.

The field study was carried out in the rainy season from April to June 1987. Further data were collected until beginning of 1988.

1.1. Objectives

The main objective of this study was to evaluate the hydrological processes in Ngare Ndare area. The main focus was the rainfall - runoff relationship in a small drainage basin of an ephemeral stream. By means of measurements of rainfall, runoff and infiltration the runoff regime was evaluated. Further on, the water balance and the sediment discharge of the area were assessed. Another objective was to develop an appropriate methodology with low technology so that the measurements could be carried on easily by local personnel.

1.2. The Study Area

Within the Ngare Ndare area a small drainage basin of a dry river was chosen. All the experiments were carried out in this catchment area (Fig. 1).

1.2.1. Climate

The semiarid to arid climate is characterised by a mean maximum of the temperature of more than 30°C throughout the year and by two rainy seasons. The first rainy season lasting from March to May has its peak in April and the second one has the maximum rainfall in November (JAETZOLD 1981).

The characteristics of the rainfall were high variability and cyclical occurrence of short rain periods within the rainy seasons (Fig. 2). Between these rain periods often dry periods turned up, lasting even for some weeks. The mean annual rainfall in Ngare Ndare reaches approximately 510 mm. The potential evaporation (PENMAN according to WOODHEAD (1968)) in Isiolo amounts to 2561 mm/year.

1.2.2. Soils

The soils and geomorphology are described by HAGMANN (1988). Therefore, only the distribution of the soils in the catchment is mentioned.

Four different soils exist in the experimental catchment. In the central part of the catchment pellic Vertisol was dominant. Closer to the watersheds vertic Cambisols, calcic Cambisols and calcic Xerosols were following (Fig. 3). A detailed soil survey was carried out to assess the runoff generating processes.

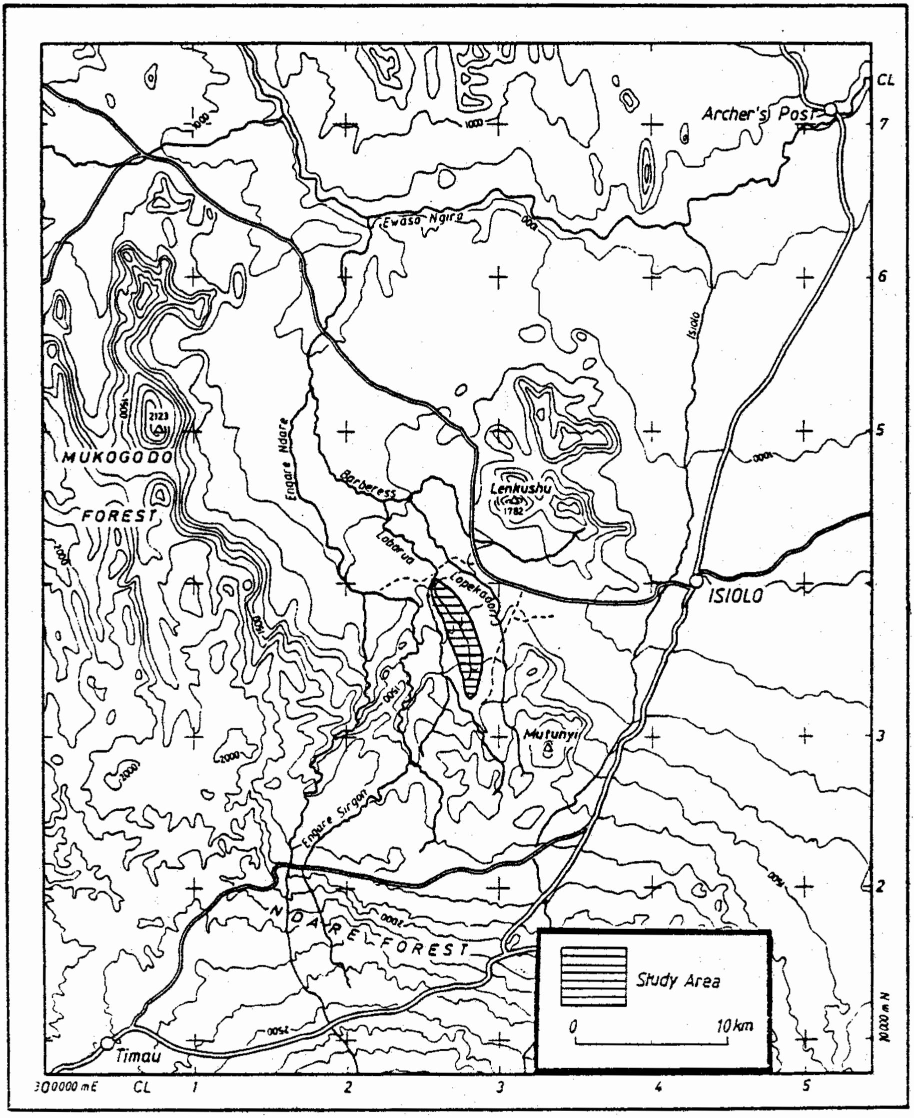

Fig. 1: Location of the Study Area (Drainage Basin)

Abb. 1: Lage desStudiengebietes (Einzugsgebiet)

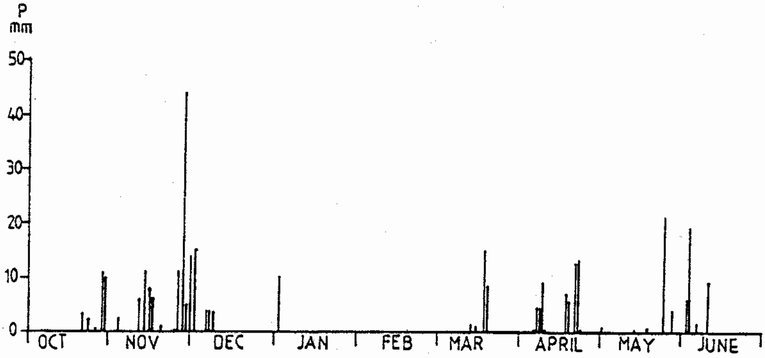

Fig. 2: Rainfall Distribution from Oct. 1986 to June 1987

Abb. 2: Niederschlagsverteilung Oktober 1986 - Juni 1987

1.2.3. Vegetation

The vegetation of the study area could be classified as dwarf shrub bushland. Precise descriptions are found in the literature mentioned above. For this study, however, the vegetational cover was of importance for the runoff generating processes. Therefore, the vegetational cover was mapped (Fig. 4). Density of the vegetation differs extremely as it ranges from almost bare soil to thornbush thicket in the central part of the drainage basin.

2. Physical Characteristics of the Soils

In this chapter emphasis is given to particular physical soil characteristics influencing the runoff processes. The pellic Vertisol dominating in the catchment is mainly characterised by its deepness and by the high clay content. These two features are responsible for deep cracking of the soil. Swelling and shrinkage of the clay are closely related to the change in soil moisture. The resulting peloturbations are bringing about the typical self mulch effect as well as the typical infiltration characteristics. Basaltic material that is found on the soil surface

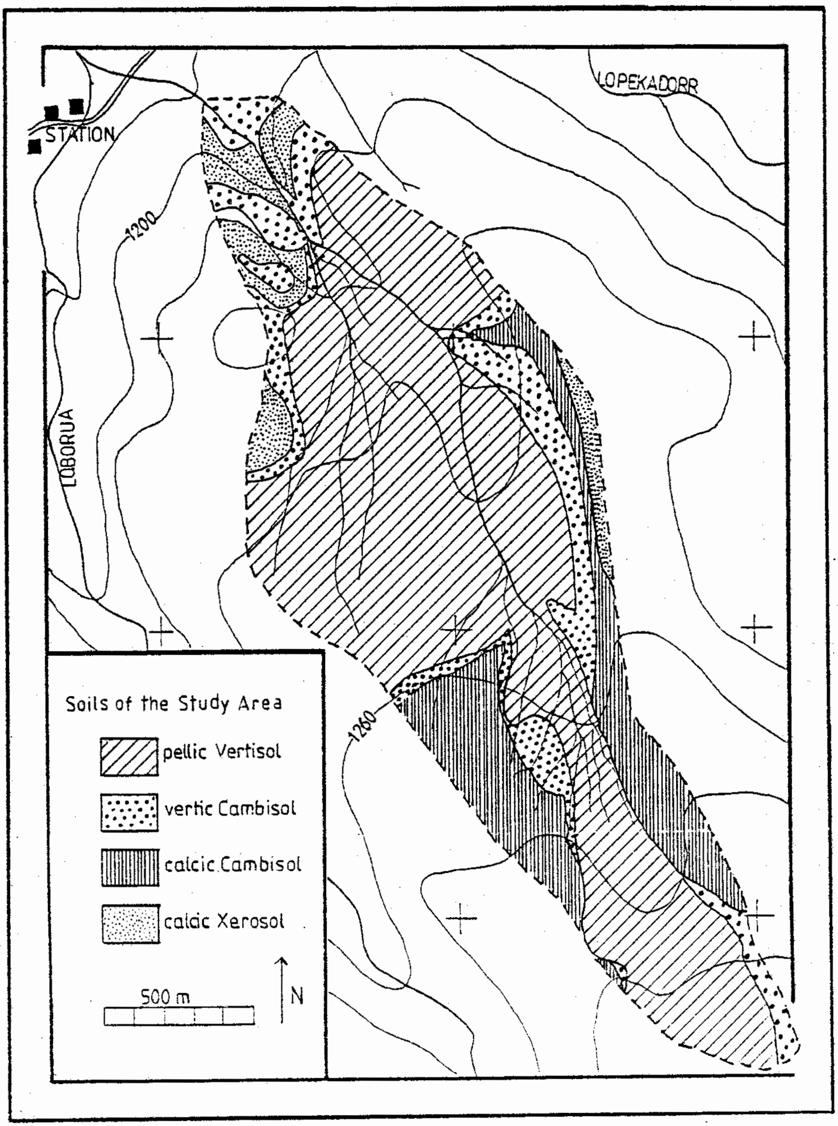

Fig. 3: Soil Map of the Study Area

Abb. 3: Bodenkarte des Einzugsgebiets

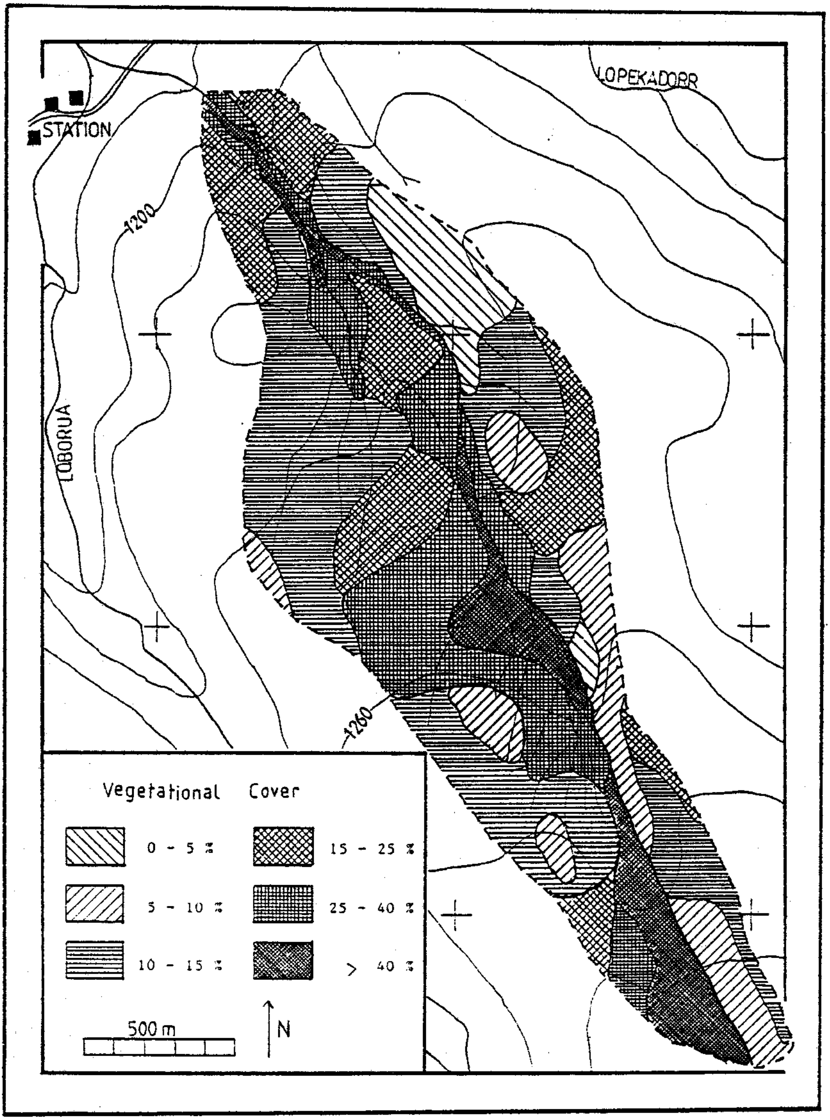

Fig. 4: Density of Vegetational Cover in the Study Area

Abb. 4: Bedeckungsgrad der Vegetation im Einzugsgebiet today was also lifted to the surface by peloturbations.

Deeper horizons had high bulk densities and very hard aggregates when dry. This might even be a mechanical resistance for the rooting of the plants (HEINONEN 1985). In the top soil, however, drying did not cause a hardening but a loosening of the soil structure. Due to the high clay content which implicates a high percentage of unavailable water the available water capacity is restricted. Other soils, in particular the calcic Cambisol and the calcic Xerosol, had lower clay contents and were more compacted and stony. Towards the watersheds the depths of these soils decreased. Drainage characteristics are discussed by means of infiltration experiments.

2.1. Infiltration Experiments

2.1.1. Methodology

In this study infiltration characteristics of the soils were recognized to be an important criteria for the soil water balance as well as for the rainfall - runoff relationship. Therefore, infiltration experiments were carried out in the catchment area.

In semiarid areas where water is precious and not available everywhere the most appropriate method for measuring infiltration capacity is a cylinder infiltrometer with low water consumption. Due to this condition a single ring infiltrometer with a diameter of 15 cm acc. to HILLS (1970, 1971) and TRICKER (1978) was constructed. TRICKER (1978) found that the relation between high water consumption (with bigger diameters) and minimum measurement error reaches its optimum at a diameter of 15 cm. The construction of a specific refilling tank guaranteed a constant hydraulic head of 5 cm upon the soil surface inside the ring. The error due to lateral outflow under a single ring infiltrometer was corrected by an empiric formula according to TRICKER (1978).

The cylinder was vertically driven about 5 cm into the dry soil surface. Measurements were normally carried out for two hours. To eliminate influences of stones and roots a minimum of two measurements were performed at each site.

About one hour after the experiments some of the soils were opened (vertical cross section) to find out how the water had penetrated the soil. The infiltration capacity measured after a two hour run were classified according to ENDLICHER et al. (1987).

2.1.2. Results and Discussion

The experiments showed a close correlation between infiltration characteristics and different soil types. Since distribution and density of the vegetational cover was too scattered (Fig. 4) correlations with the vegetational cover could not be assessed.

Fig. 5 shows the course of infiltration capacities characteristic for different soils in the catchment. An excessive infiltration rate was found in the deep vertisol with an initial infiltration capacity of over 50 cm/h. Due to the high content of swelling clay in the vertisols this fact is striking. Even after an infiltration period of two hours the infiltration capacity was still high (approx. 3 cm/h). This process can be explained by the slow swelling of dry clay which even takes days until the clay minerals are completely swelled. Hence, during the initial phase, water can rapidly penetrate into cracks and macropores of the vertic soil surface (HEINONEN 1985). The characteristic rainfall of this area (see chapter 1.2.1.) implicates that long rain periods which saturate a big soil volume are rare. In addition, high potential evaporation exists. Therefore high infiltration capacity most likely remains throughout the whole rainy season. This means that only during high-intensity rainfalls with a certain duration surface runoff will occur. This makes a high percentage of the precipitation available for plants.

Other soils show distinctly lower infiltration capacity due to their shallowness and their higher bulk density at the surface. Compared to the vertic soils, in particular the initial phase of the Xerosol is very low. Measurements on a cattle track (cX 3 in Fig. 5) give an impression of the effect of soil compaction caused by animals. The soil was so hard that it was even difficult to drive the cylinder into the soil. After two hours of infiltration the wetting front was still not deeper than 15 cm. In particular, the initial infiltration capacity was drastically reduced by compaction, so that these sites are potentially the first to generate runoff during a storm event.

The opening of the vertic soils after this two hour experiment showed wetting of the soil to a maximum of 30 cm, which is considered to be quite shallow. Infiltration experiments of LINIGER (1984) in the Mount Kenya area also proved that the wetting front on pasture land compared to tilled soils was very shallow (about 20 to 30 cm only). This fact supports the assumption that only in very few cases the soils of Ngare Ndare are wetty deeper than 20 to 30 cm.

The conclusion of these experiments considering rainfall on dry soil surface is that, mainly during the first 10 to 20 minutes, a big amount of water can easily infiltrate into the vertic soils, even if the rainfall occurs with high intensity. In the case of a longer duration or if precipitation is occurring on saturated soil surface infiltration capacity is lower and surface runoff might be generated even by lower rainfall intensities. On the soils with the lowest infiltration capacity, the Xerosols,

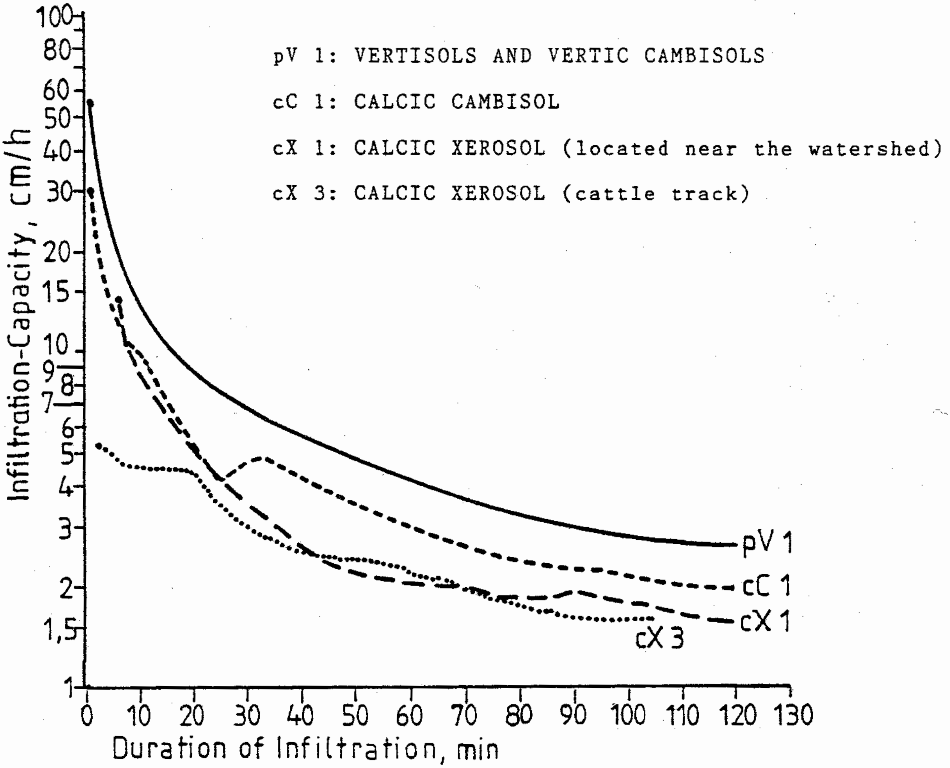

Fig. 5: Characteristic Infiltration Curves of the Soils in the Study Area

Abb. 5: Infiltrationscharakteristiken der Böden im Einzugsgebiet runoff might occur first, in particular in sloped areas.

The main influence of vegetation on infiltration in the catchment is the reduction of the rainfall intensity by leaves, with dense vegetational cover in some locations. This reduction is further affected by plant litter deposited on the soil surface.

3. Root Systems of the Vegetation as an Indicator for the Soil Water Balance

The vegetation of a semi arid thornbush savannah must be adapted to mainly three factors threatening their survival: drought, fire and defoliation (PRATT and GWYNNE 1977). The strongest adaption is directed to the limited rainfall.
The plants have two ways to cope with this problem. Either they survive droughts as seeds in the soil, like annual plants do, or they adapt their physiology to the existing rainfall distribution. Perennial plants survive using the second way. Therefore, water uptake and transpiration must be specialized (PRATT and GWYNNE 1977).

In this study water uptake by roots was focussed. Several root systems of trees, dwarf shrubs and grasses were dug out to gain some basic knowledge about the soil water balance.

The fact that plants in these areas develop highly effective root systems in soil zones where water is available (PRATT and GWYNNE 1977, GLOVER et al. 1962) allows the conclusion of root systems being an indicator for the soil water balance.

Along dry rivers big vertical roots reaching the groundwater could be observed. In areas not within the drainages, however, root systems were completely different. Fig. 6 shows the root system of *Acacia mellifera* growing on Vertisol. This root system has a horizontal and a vertical component. The shallow horizontal system with a diameter of more than 5 meters and with numerous fine roots forms the main water supply of the plant. The vertical root went down to approximately 100 cm below surface. When the roots were examined the soil surface was already dried up below wilting point since two days, but the plant just started wilting that day. In the layer from 80 to 100 cm below surface an increase in water content could be noticed. Water infiltrated here in a deep crack of the Vertisol. Measurements showed that this layer had just reached wilting point.

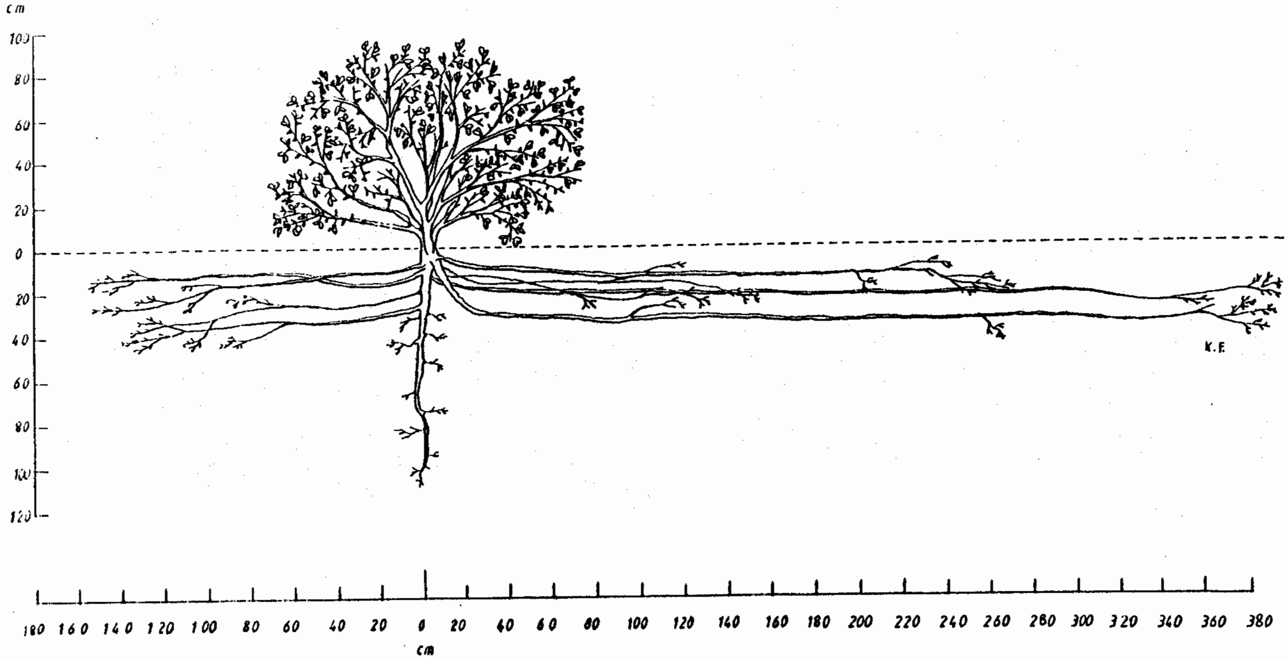

Fig. 6: Root System of an Acacia mellifera (Verisol Site)

Abb. 6: Wurzelsystem einer Acacia mellifers auf einem Vertisol Standort

The relation between the wilting point of the deep layer and the rolling of the leaves at the same time indicated a certain pattern of the water uptake process. First all the water in the top layer was consumed by the horizontal roots. Then, after reaching the wilting point in the top layer, the vertical root took up the water stored in the deep layer. The deep vertical root could therefore be described as an emergency root which is used when water shortage occurs

Due to swelling processes in the Vertisols roots have to withstand pressure and contraction of the soil. A stress situation for the roots results. *Acacia mellifera* is a very dominant species on these deep soils. Therefore, it is obvious that its roots are also well adapted to this factor. The feature of a deep vertical root could only be observed in Vertisol sites.

Again in the root system of *Acacia tortilis* located on a shallow calcic Xerosol (Fig. 7) horizontal roots within 20 cm of the top layer dominated. The vertical root was quite strong and ended abruptly in a depth of 30 cm in a crusty layer. This was a surprising observation, since along dry rivers the roots of the same species reached groundwater levels which were often 10 or even 20 m below surface.

These two examples represent the major feature of all the studied plants. Even dwarf shrubs and grasses showed similar characteristic horizontal root systems. Hence these plants live almost exclusively from water in the top layer. Water in deeper layers must only be available in very few cases. On the Vertisols a small amount of water infiltrated into deep cracks. But even this water was consumed by plants.

The missing of deep root systems indicates that deep wetting of the soil seldom occurs. Therefore, it can be assumed that in normal years in Ngare Ndare the soils beyond the drainages are hardly moistened deeper than about 30 cm below surface. This assumption was supported by investigations on the salt distribution within soil profiles which showed a clear enrichment of soluable salts in this depth (HAGMANN 1988). The observations also correspond to the assumption made by WALTER (1984). He states that with decreasing annual precipitation the root systems of plants are becoming shallow.

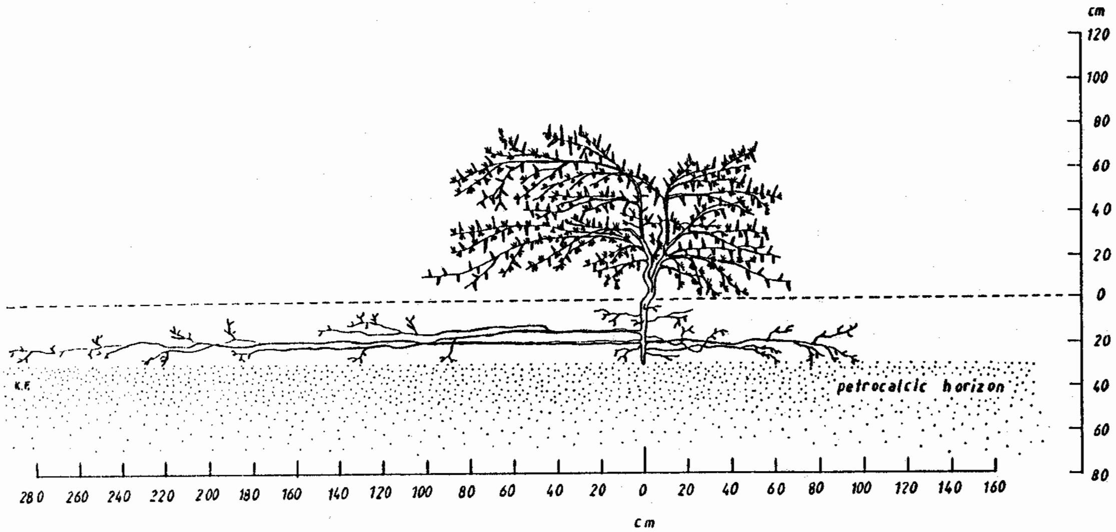

Fig. 7: Root System of an Acacia tortilis (Calcic Xerosol Site)

Abb. 7: Wurzelsystem einer Acacia tortilis auf einem flachgründigen Calcic Xerosol Standort

4. Rainfall - Runoff Relationship

To investigate the rainfall - runoff relationship in Ngare Ndare area a small experimental catchment area was chosen and several installations were made.

4.1. Methodology

Precise mapping of the watersheds was necessary to determine the exact area of the catchment. The flatness of the watersheds required a detailed field survey. In addition, an enlarged topographical map and aerial photographs were used. After mapping the watersheds the catchment area enclosed 2.62 km^2.

4.1.1. Measurement of Rainfall

At the beginning of the study period one pluviometer according to *Hellmann* was installed on the research station, and three other raingauges were placed in the catchment area. After the first storms it became obvious that these three raingauges were not representative for the whole catchment area. Therefore their number was increased to seven (Fig. 8) and guaranteed a high measurement density.

Rainfall intensity was measured at one site located directly near the weir. Continous monitoring during the storm events was guaranteed by reading the scaled raingauge in intervals of three to five minutes.

It happened quite often that several raingauges were destroyed by animals or were stolen. Hence, daily checks to maintain the installations were necessary.

4.1.2. Calculation of Areal Rainfall

In such small catchments precipitation measured at one site is usually used as areal rainfall. Because of high spatial variabilty of the rainfall in Ngare Ndare one raingauge would not have been sufficient for a reliable study. Therefore, a method had to be found to calculate areal rainfall with data of the seven raingauges. A comparison of the *Thiessen* polygon method with the isohyet method showed no significant difference between the two so that the polygony

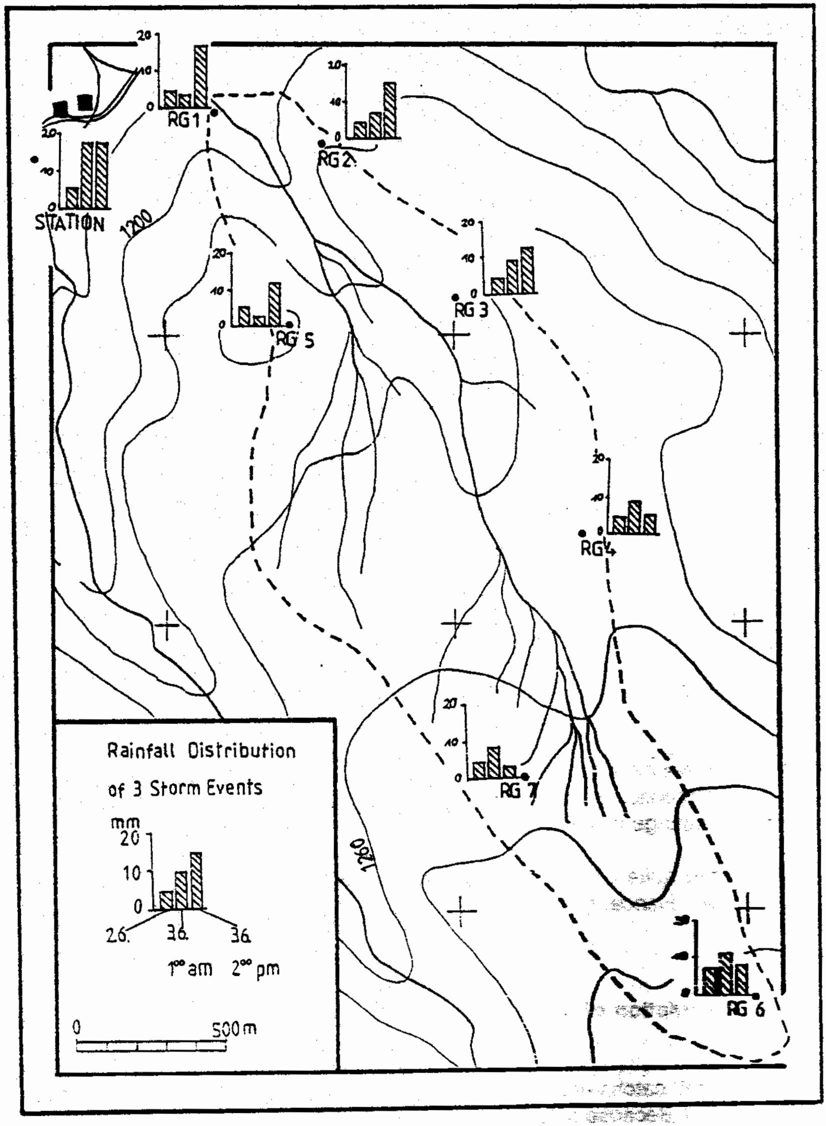

Fig. 8: Spatial Rainfall Variability of three Storm Events

Abb. 8: Räumliche Niederschlagsvariabiltät von drei Niederschlagsereignissen method was arbitrarily chosen.

4.1.3. Measurement of Surface Discharge

On account of the sporadic occurrence of the river flow and the uncertainty about the amount of discharge, river gauging in ephemeral streams is problematic. Therefore, a sharp crested concrete overflow weir was constructed. The water level was read at a staff gauge placed at the edge of the stilling basin upstream of the weir. The water level/discharge relationship was calculated according to the formula of POLENI (DYCK et al. 1983). Flood hydrographs were developed for each of the recorded runoff events.

Discharge measurements and precipitation readings were taken in very short intervals (e.g. 15 sec to 5 min.) during the occurrence of the runoff to guarantee continuous monitoring of the events. Total runoff was related to drainage area and calculated as runoff coefficient and percentage of total precipitation.

4.1.4. Measurement of Sediment Discharge

Parallel to the readings of water levels at the staff gauge and precipitation at the raingauge, water samples were taken to determine the sediment concentration at a specific discharge. This procedure was carried out above the weir by a second person, who collected the samples in one liter bottles. All the readings were recorded in a "runoff schedule". As a result, each sediment sample could be related to a certain waterlevel and discharge. On a rising limb of a hydrograph the sampling frequency was very high. The samples were then filtered, dried and weighted. Sediment concentration of each sample and total sediment discharge at each runoff event were calculated. In addition the electric conductivity throughout one flood event was measured.

4.2. Results and Discussion

4.2.1. Rainfall

Ngare Ndare proved to be in the rain shadow of the nearby mountains. The rains produced by the typical cloudstreams (EDWARDS et al. 1979) drifting from southeast to northwest, often only reached Isiolo whereas in Ngare Ndare no precipitation could be measured. These cloudstreams, and with them the rains, always occurred in short periods of about 3 to 6 days. Then a dry period followed. During the study period no rainstorm provided more than 20 mm (Fig. 2). The rainfall intensities, however, were often high.

The spatial variabilty of the rainfall events in the experimental catchment was enormous. Even with seven raingauges on 2.62 km^2, big differences were recorded in the amount of precipitation among the raingauges (Fig. 8). Due to the topography the southern part of the catchment got often less precipitation than the northern part and the research station (Fig. 8)

4.2.2. Runoff

Since no signs of subsurface flow in this study could be identified "runoff" and "discharge" were restricted to surface flow in this study.

After a dry period the soils were completely dried up. This resulted in a very loose structure of the soil surface and cracks in the vertic soils in particular. Under this condition soils showed very high infiltration capacities (Fig. 5) so that only high rainfall intensities were able to generate surface runoff. After a short time period infiltration capacity decreased, and still assuming medium to high rainfall intensity, surface runoff started. It could be seen that the compacted cattle tracks accelerated this process. Water started to flow on these tracks first. At the end of the storm runoff decreased quickly and increasing evaporation reduced the water quantity stored in depressions and at the vegetation.

4.2.3. Analysis and Interpretation of the Discharge Hydrographs

A runoff event typically occurred in three major waves (Fig. 9). The first very small wave indicated runoff from slopes directly around the gauge which could not be measured. According to the topography and the colour of the sediment runoff of the second and big wave also originated in the northern part of the catchment. Here, slopes reach gradients up to 15% and soils are quite compact and shallow. The runoff generating zone of the third wave were vertisol areas further south in the drainage basin. All the hydrographs showed steep rising limbs and short event durations.

Runoff coefficients of all three events were extremely low: on May, 21st it was 0.0048 (0.4%), on May, 24th it was 0.00175 (0.1%) and on June, 3rd it reached 0.023 (2.3%). According to DYCK (1978), coefficients close to zero are usually bound either to a very low-intensity and low-amount rainfall and/or to a well drained, not saturated soil surface. These processes can be analysed with flood generating storm events (Table 1).

In Table 1 all rainfall events with more than 3 mm of areal rainfall and the runoff events are outlined. Precipitation of less than 3 mm is looked upon as not being runoff generating. With the obtained data it is possible to provide a basic explanation of the runoff generating factors in the drainage basin.

It is obvious that the amount of areal rainfall is not the determining factor for runoff generation. On April, 22nd, areal rainfall was quite high (16 mm) but did not generate any surface runoff, whereas on June, 3rd 8.3 mm were enough to generate relatively high discharge. This can be explained by the infiltration characteristics of the soils and the rainfall intensities.

As pointed out above, in the aridic soil moisture regime only the uppermost soil volume is saturated after storm events and dried up soon afterwards. Therefore, moisture content of the soil surface is the dominating factor for infiltration processes. Since infiltration capacity decreases quickly with increasing water content (Fig. 5) the moisture of the soil surface preceeding a storm event determines the actual infiltration. A saturated soil surface diminishes the initial infiltration capacity considerably. For instance on April 21st, this happened in the northern part of the catchment where runoff originated from. Similar conditions were noticed on June 3rd, where 8.3 mm of a high-intensity rainfall (up to 80 mm/hr) generated discharge of almost 500 m^3.

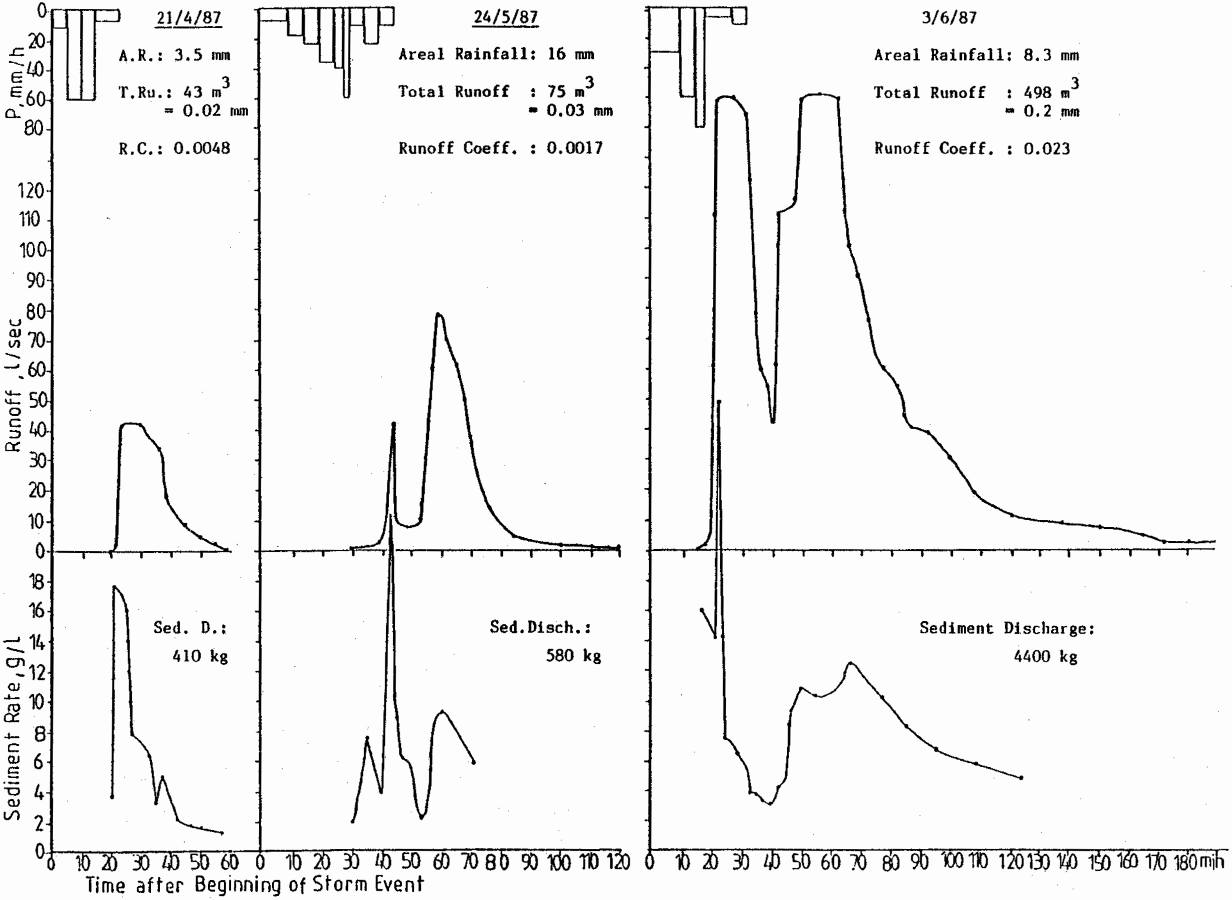

Fig. 9: Hydrographs of three Runoff Events

Abb. 9: Hydrographen von drei Abflußereignissen

Tab. 1: Storm Events exceeding an Areal Rainfall of 3 mm, April-June 1987, measured in the Drainage Basin

Tab. 1: Niederschlagsereignisse im Einzugsgebiet mit mit einem Gebietsniederschlag von mehr als 3 mm (April bis Juni 1987)

DATE 1987	TIME	AREAL-P mm	RUNOFF m^3	MOISTURE ON SURFACE	DURATION OF P min	P-INTENSITY AND DURATION mm/h x min	REMARKS
18.4.	1^{30}pm		0	dry	9	ca. 45	only north. part
19.4.	6^{15}pm	6.3	ca 0.1	low	20	30x10,24x10	
21.4.	6^{00}pm	3.5	43	moist	23	60x10	mainly north.part (up to 12 mm)
22.4.	8^{30}pm	13.5	0	moist	120	Imax ca 10	
24.5.	4^{00}pm	16	75	dry	46	60x2,40x3,36x5, 24x10,18x5	
2.6.	2^{00}am	5.4	0	low		Imax ca 10-20	
3.6.	1^{00}am	7.8	0	low		Imax ca 10-20	mainly north.part
3.6.	2^{15}pm	8.3	498	moist	30	80x3,60x5,30x10	

Although very high storm intensity and reduced infiltration capacity (because of the high moisture level) dominated, the runoff coefficient was extremely low (0.023). On May 24th, the soil surface had been dried up completely resulting in very effective infiltration during of the high-intensity rainfall (16 mm). The runoff coefficient reached only 0.00175. Fig. 10 illustrates well this extremely low coefficient.

Mean infiltration intensities - determined by cylinder infiltrometer - and the course of the rainfall intensity throughout this particular storm were plotted. Before the experiment started the soil was dry. It can be seen that the soil was able to take up all the water during the first 28 minutes of the storm. When the rain intensity exceeded the infiltration capacity of the soil, runoff occurred. The high intensity of the rainfall only lasted some minutes so that the rainfall intensity was below the infiltration capacity soon afterwards again.

The reliability of the infiltration measurements is also supported by the storm event of April, 22nd. A 120-minute low-intensity rainfall with 16 mm fell on a moist soil surface and did not generate any runoff. After 120 minutes the minimum infiltration capacity of all soils was determined to be higher than 10 mm/hr (15 to 30 mm/hr; Fig. 5). This explaines the fact that no runoff occurred during this storm.

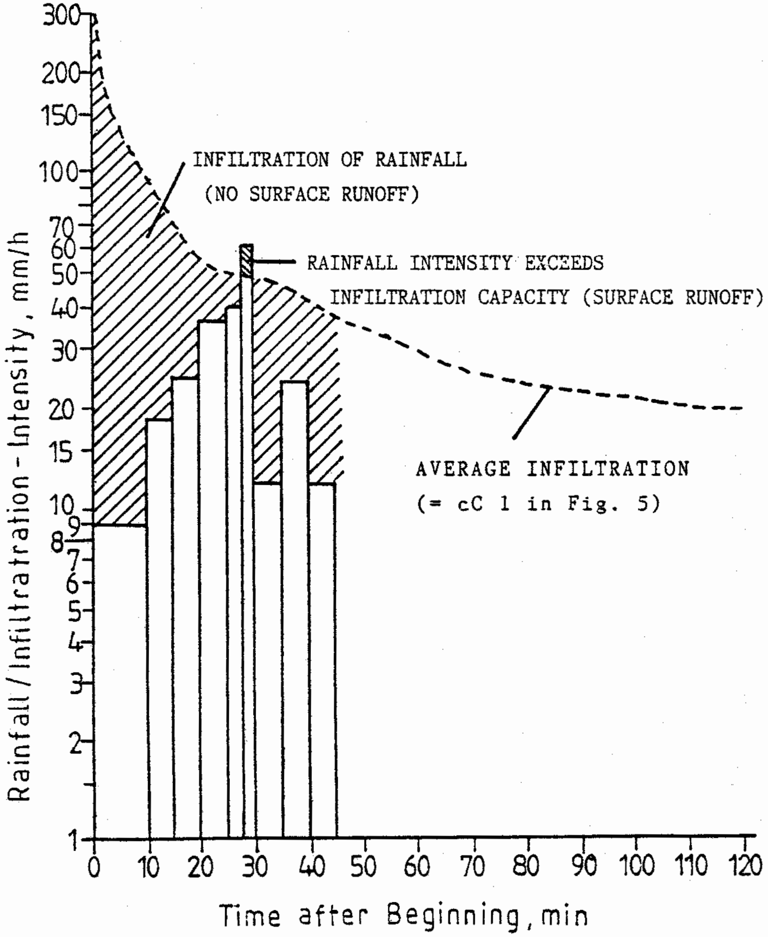

Fig.10: Rainfall Intensity of Storm Event on May, 24th, correlated with averageInfiltration Curve of the Soils

Abb.10: Niederschlagsintensität eines Ereignisses am 24. Mai, in Bezug zu einer mittleren Infiltrationskurve der Böden

The assumption that mainly the rainfall intensities of more than about 50 mm/hr generate runoff is also supported by another fact. On both hydrographs (24.5 and 3.6.) the peak of the second wave at the gauging station (originating from the further southerly sited vertisol areas) occurred almost exactly 30 minutes after the highest rainfall intensity. This was true despite differently skewed precipitation-curves (Fig.9).

4.2.4. Sediment Discharge

The sampling technique made detailed studies of the sediment concentration possible. In Fig. 9 the extreme peaks at the beginning of the first discharge wave were surprising. These peaks included the transport of suspended load up to 30 g/l, whereas in the subsequent waves sediment discharge rates reached only about 8 to 12 g/l. This feature is characteristic for the turbulent front wave which constitues the steep rising limb of the flood wave and acts as a broom in the channel bed. The high sediment load at the beginning of the flood was due to the removal of a big part of sediments deposited during preceeding floods. The low sediment rates in the subsequent waves were caused by the different energy characteristics of the waves themselves, as well as by the lower erodibility of the channel bed.

The rise of the sediment discharge rates in Fig. 9 shows the superposition of discharge waves even better than on the hydrograph. A good example is represented by the event of June, 3rd. 65 minutes after the start only the recession limb of the hydrograph could be recorded. Looking at the sediment curve, however, it is obvious that the recession limb is superimposed by another wave.

Total sediment load was quite low: 410 kg on April 21st, 580 kg on May 24th, and 4400 kg on June 3rd. Sediment load only consisted of suspended matter, mainly clay material. Bed load did not occur in the small catchment. The colour of the sediment load was different in each wave. The good correlation of significantly different colours with various soils allowed a judgement of the origins of the different sediment waves.

Total sediment discharge related to total runoff of each event was proportional. However, the data were not sufficient to conduct a statistical analysis. The total sediment discharge in the rainy season from April to June 1987 was 5.4 tons, which is equivalent to 2.07 tons/km^2. This rate is extremely low and can be explained with low total surface runoff. Calculation of the soil loss in mm is not useful with this data base. Sediment discharge is too low to be sure that the material originates in the plains. Most likely, the major part derives from the channel bed and drainages.

Readings of the electric conductivity of the discharge increased slowly during the runoff event. The discharge on June, 3rd started with a conductivity of 60 μS/cm, then rose slowly to about 80 μS/cm after two hours. After 6 hours the conductivity was 99 μS/cm. This means that the surface runoff contained an extremely low content of soluble salts. This phenomenon is characteristic for sporadic discharges in arid and semiarid areas due to weak chemical weathering.

High infiltration capacities of the soils and low surface runoff resulted in low sediment discharge. Therefore, it can be assumed that the catchment is not directly endangered by soil erosion. The missing of damages due to soil erosion (e.g. gullies) supports this assumption.

5. Groundwater

Considering the groundwater of Ngare Ndare only preliminary results have been obtained. The most importanr result is that the deep groundwater of the Ngare Ndare Borehole obviously is not connected with the surface water. Chemistry and isotope contents of these two waters were rather different. Therefore it must be assumed that the surface runoff of ephemeral flows in Ngare Ndare provides recharge only for the groundwater stored in the alluvial channel beds. Further explanations are found in HAGMANN (1988).

6. Conclusion

The investigations allowed to present a basic evaluation of the hydrological processes in the experimental catchment of Ngare Ndare. By means of infiltration experiments very high infiltration capacities of the soils could be assessed. Wetting of the soils outside of the drainages, however, does not exceed average depths of about 20 to 30 cm within the surface. Root systems of the natural plants, which were highly specialized on water uptake in the top layer, supported this assumption. The consequence for the plants located outside of the drainages is the fact that they live exclusively from the infiltrated rain water in the upper layer. This, on the other hand, makes the occurrence of seepage on the plains most unlikely.

With assessments of the rainfall - runoff relationship and the total sediment load, the basic runoff generating processes in this catchment could be explained.
The general assumption that rainstorms in arid areas produce high surface runoff, in particular when falling on dry soil surface, is not valid for this catchment. The highest water loss caused by surface runoff in the study period was only 2% of

the rainfall. Vertic soils, often described as flood generating areas, proved to have an enormous infiltration capacity even when wet. This is a consequence of the rainfall distribution in this aridic moisture regime. In humid areas where a big soil volume is saturated and clay is completely swelled, infiltration characteristics might be completely different (HEINONEN 1985).

The analysis of the hydrographs clarified that it needs high intensity rainfalls of about 50 to 60 mm/hr to generate surface runoff. As a consequence of the scattered vegetation, a clear impact of the vegetational cover on runoff could not be assessed. The major function of vegetation and plant litter is the reduction of the rainfall intensity. Therefore, infiltration capacities of the soils and storage in depressions are the major runoff determining factors in this catchment area.

The good correlation of the infiltration experiments with the runoff hydrograph shows that these measurements can be used as an indicator to evaluate the runoff generating process. The catchment itself is not directly endangered by soil erosion because of the extremely low surface discharge with these low sediment loads. As surface discharge is extremely low and seepage is not likely to occur, the water balance is dominated by rainfall and evapotranspiration.

The results of this study were obtained during the rainy season from April to June 1987. During the following rainy season from October to November no further runoff occurred. The results are only representative for the conditions in this experimental catchment area. Transferyence of such results to large areas is a general problem in hydrology. It needs further experimental catchments with different drainage characteristics to assess as many different factors of an area as possible. An integration of such a data set into a larger study area could then give detailed information. Results of this study, however, can give essential ideas for the runoff characteristics of areas with similar soil characteristics.

The applied method proved to be very exact and reliable. It is rather labour intensive. In the long run, with good training of local personnel, better results can be obtained that way, than with delicate automatic instruments susceptible to break downs and destruction.

7. Acknowledgements

The field work of this study was financially supported by the GTZ. The author wishes to thank all the persons who assisted him, in particular Dr. Ch. Leibundgut (Institute of Geography, Univ. of Berne) for helpful discussions, Prof. Dr. R. Maeckel (Institut of Physical Geography, Freiburg i.Br.) for assistance in organizing the field work and for discussing many problems, the staff of the Laikipia Research Program in Nanyuki for kind assistance during the study period, K. Fischer, Freiburg, for the preparation of some drawings, and finally the staff of the Ngare Ndare Research Station, particularly the field assistants E. Lekuye, N. Lekoli and H. Learamo.

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