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AGROCLIMATIC CLASSIFICATION OF THE SEMI-ARID TROPICS II. IDENTIFICATION OF CLASSIFICATORY VARIABLES

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ABSTRACT

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Eight agroclimatic variables related to crop production potential in the semi-arid tropics of India are identified. These are used to assess dry-seeding feasibility, water-logging hazard, risk in agricultural production, cropping patterns and their spatial distribution, using data from 80 locations in India. Regression analysis has been used to identify differences between locations at different scales, i.e., local differences caused by orography, regional differences associated with circulation patterns and continental differences associated with general circulation patterns. Using the data of 8 variables from 199 locations in India and two west African countries (Senegal and Upper Volta) three dissimilarity parameters were derived. The basic dissimilarity observed on a continental scale is that for the same amount of mean annual rainfall the growing season is longer in west Africa than in India. Thus, in west Africa the corresponding wet and dry spells within the available effective rainy period are quite different from India. This will have a significant influence on farming systems in general, and on the identification of adopted crop/cropping systems in particular.

INTRODUCTION

Part I of this study (Reddy, 1983a) presents a method for computing agroclimatic variables. Edaphic (soil) factors do play a significant role in the modification of these characteristics, as applied to dry-land agriculture. However, they show wide variations even at microscale (Reddy, 1983a,b). Therefore, this aspect, i.e., the integrated study of soil and weather using soil water-balance models, will be dealt with in a separate study characterizing each zone after grouping locations according to agroclimatic variables. Some of the agroclimatic variables are primarily useful for agricultural planning only, while others are also useful for assessing agricultural production potential. These variables are determined using data obtained at 80 locations in India.

However, for the transfer of location-specific technology, it is also important to understand the dissimilarities between agroclimatic variables associated with local orographic effects, regional effects, such as land—sea contrast and differences in circulation patterns, and the global effects of

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Fig. 1. Locations of the selected stations in India.

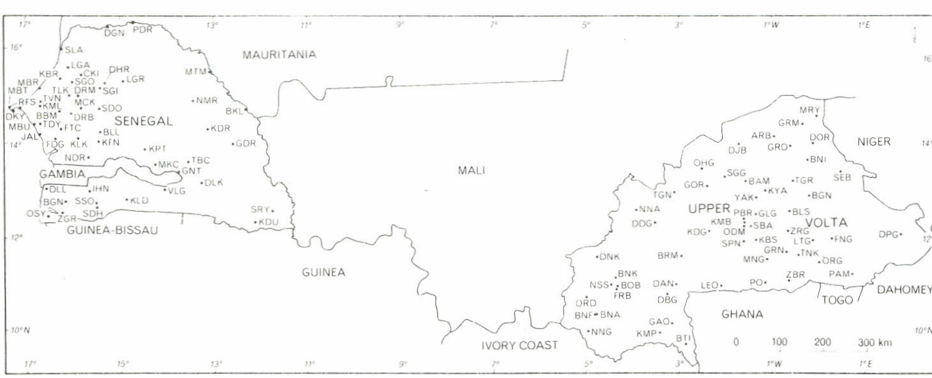

Fig. 2. Locations of the selected stations in Senegal and Upper Volta.

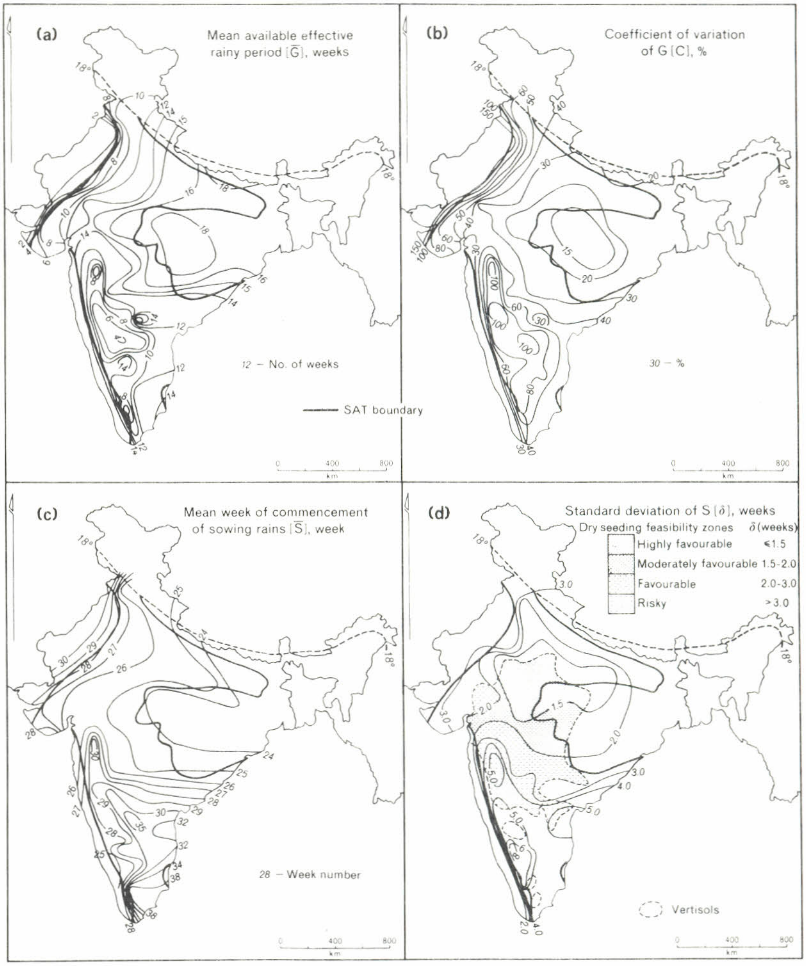

Fig. 3a—d. Spatial distribution of agroclimatic variables.

global circulation patterns. Therefore, for characterization at different scales, data from India and west Africa were used.

To assess the importance of some of these variables for crop production, broad soil types (alfisols and vertisols) were utilized.

DATA AND ANALYSIS

Climatic data represent point observations, but in practice they are treated as representing a region around that point. However, in reality, major variations are evident even at the local or microscale (Reddy, 1980). These are very important in microscale studies, but in macroscale studies the point observations are treated as being representative of a wider region, even with these limitations.

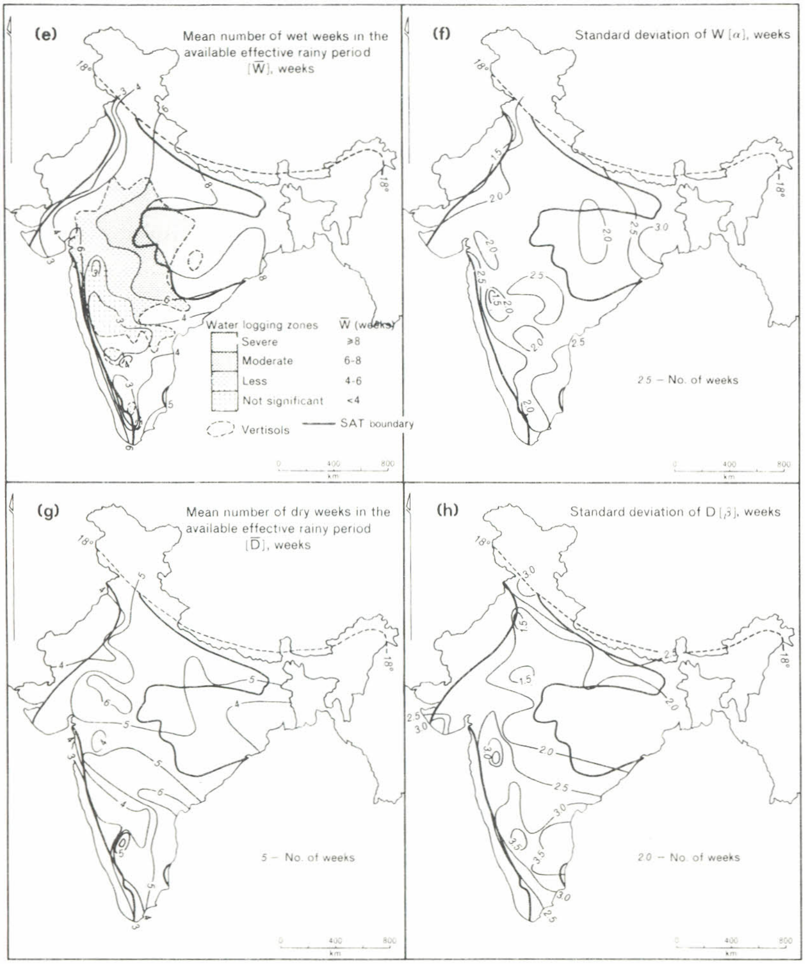

Fig. 3e—h. Spatial distribution of agroclimatic variables.

The basic data consist of observed weekly rainfall (R) and estimated potential evapotranspiration (PE). The rainfall data used in this study are weekly totals, derived ultimately from daily data sets. For India, data from 80 locations (Fig. 1, Appendix I) for the weekly rainfall data sets were obtained from the Indian Meteorological Department (IMD), Poona; and for west Africa (59 locations in Senegal and 60 in Upper Volta) data were obtained from ORSTROM, Paris (Fig. 2, Appendix I). The period of record varies from 15 to 70 years, but most cases exceed 25 years. Data were verified and checked after computerization. Observational errors, if present, are the responsibility of the respective agencies.

The monthly average PE values (primarily derived using Penman's (1948) approach) for India and west Africa were taken from Rao et al. (1971) and Reddy and Virmani (1980), respectively. Weekly average PE values were obtained by graphical interpolation from monthly average values. Individual

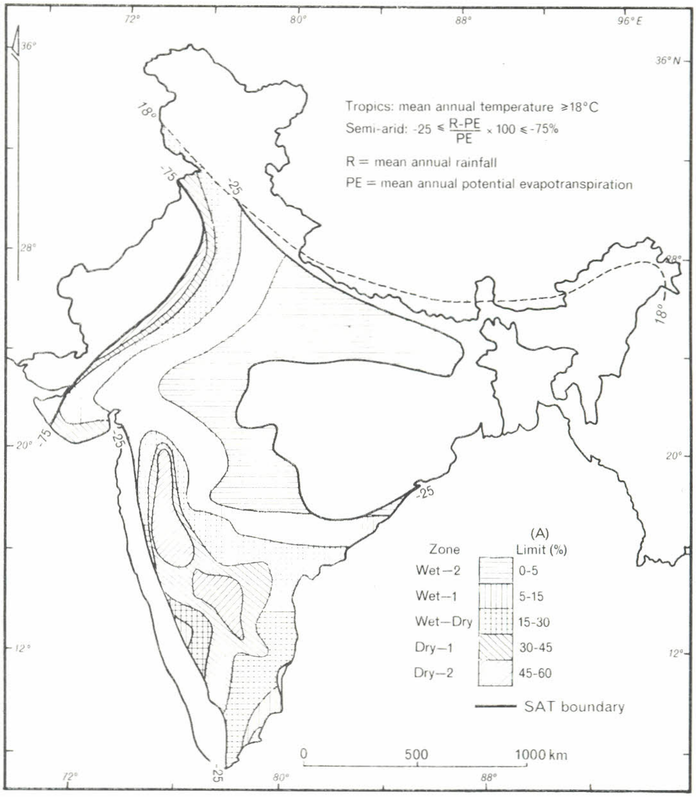

Fig. 4. Spatial distribution of the percentage crop failure years (A) or percentage years with $G \leqslant 5$ weeks.

weekly PE values were computed from average PE, R and individual year R values using the Reddy (1979) method.

Using the methodology suggested by Reddy (1983a) in part I of this study, the mean available effective rainy period ($\bar{G}$) and its coefficient of variation (C); the mean week for time of commencement of sowing rains ($\bar{S}$) and its standard deviation (δ); the mean number of wet ($\bar{W}$) and dry ($\bar{D}$) weeks within the available effective rainy period and their standard deviations (α, β); and the percentage crop failure years (A), were estimated for all 199 locations. Some, particularly those in south central India, show two rainy periods in some years. The first period of <5 weeks comprises pre-monsoon thunderstorms and is less suitable than the second period. Thus, when computing these parameters, the intervening dry period is extended by not considering the first rainy period.

The spatial distribution of $\bar{G}$, C, $\bar{S}$, δ, $\bar{W}$, α, $\bar{D}$, β, and A in India are depicted in Figs. 3 and 4 with the SAT boundary superimposed. In Fig. 3d and e, the vertisols boundary is also superimposed in order to assess some of the important dry-land agricultural problems which are not important in other SAT soils. Crop data for dry-land experimental stations are available at a number of these locations and can be used to assess the relevance of the

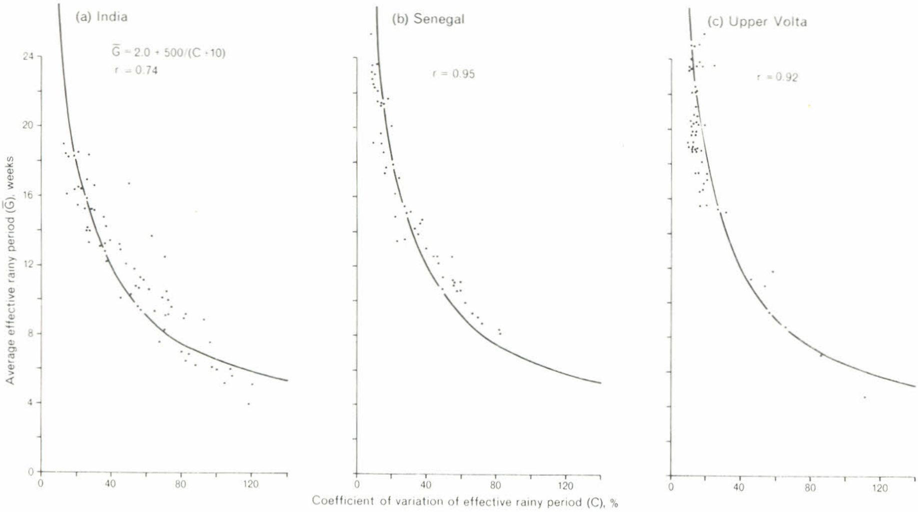

Fig. 5. Variation of the mean effective rainy period ($\bar{G}$) with coefficient of variation of the effective rainy period (C) for India, Senegal and Upper Volta.

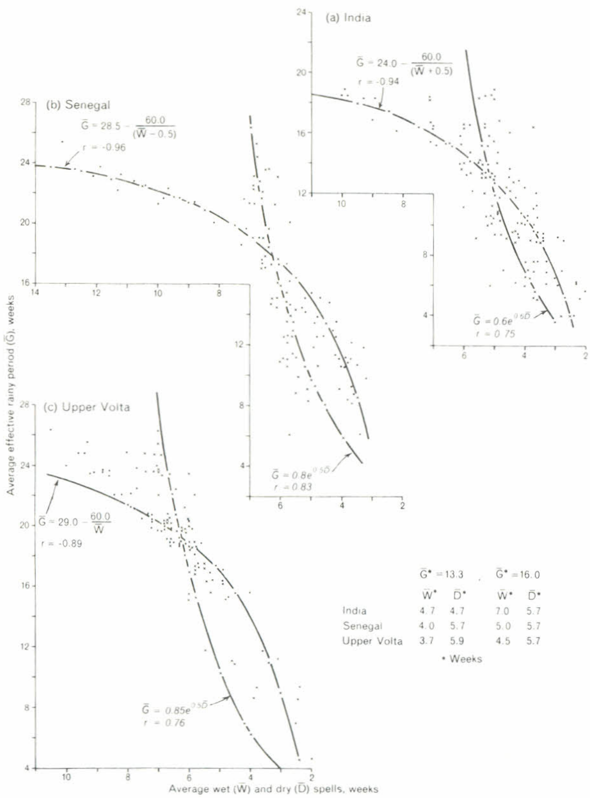

Fig. 6. Variation of the mean effective rainy period ($\bar{G}$) with mean wet ($\bar{W}$) and dry ($\bar{D}$) spells within the effective rainy period in India, Senegal and Upper Volta.

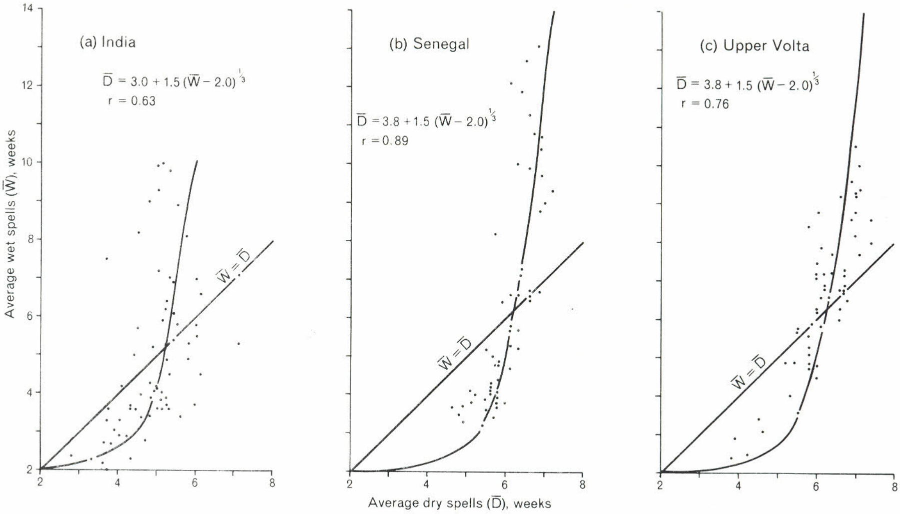

Fig. 7. Variation of mean wet spells ($\bar{W}$) with mean dry spells ($\bar{D}$) within the effective rainy period for India, Senegal and Upper Volta.

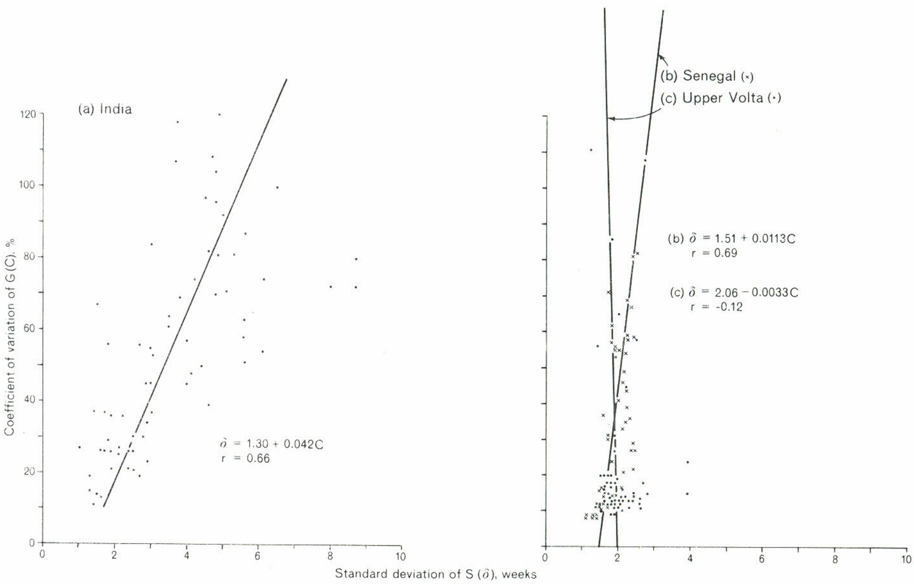

Fig. 8. Variation of coefficient of variation of G (C) with standard deviation of S (δ) for India, Senegal and Upper Volta.

derived variables in terms of potential agricultural production. The results of the comparative analysis are presented in Figs. 5—8 which incorporates both Indian and west African data.

Spatial distribution of agroclimatic variables

The standard deviation of S (δ) is very high over the Deccan plateau and for the extreme north western areas (Fig. 3d). For the former, a bimodal rainfall zone, the high values of δ are due to orography. This causes a high variation in the length of the dry period between the two rainfall peaks, and hence a very low suitability for crop production (Figs. 3b and 4). It is important, therefore, to differentiate between bimodal and unimodal rainfall stations, even if other factors are the same. The bimodal rainfall referred to here is different from that in east Africa (see, e.g., Biodova in Somalia) where the two peaks are separated by a long dry spell and in fact represent two separate cropping seasons. The high value for δ over south India indicates careful planning for sowing operations, with the most appropriate time shown in Fig. 3c. This agrees very well with experimental findings at some of the locations (I.C.A.R., 1982). In south India the available rainy period decreases from the east to the northwest (Fig. 3a) and the associated risk increases in the same direction (Figs. 3b and 4).

In the 500—1250 mm mean annual rainfall zone (SAT) of north India, $\bar{G}$ varies from 4 to 16.5 weeks (Fig. 3a), with C varying from 150 to 15% (Fig. 3b). The reliability of the moist period decreases gradually from east to west in the north, but this pattern is not so systematic in the south. In the north, the wet spells (Figs. 3e and f) gradually decrease from east to west while dry spells (Figs. 3g and h) gradually increase from east to west. Because of this pattern, the western parts of India are more suitable for dry-land agriculture, compared to the eastern parts of north India which fall within the sub-humid zone where upland rice is the major crop in the rainy season. Regions with crop failure years (A) more than 60%, which occur mainly in the arid zone (Fig. 4), are generally unsuitable for food crop production (Singh, 1974; I.C.A.R., 1982).

Dry-seeding feasibility zones

Dry-seeding is feasible only when the onset time of sowing rains is stable over the years, i.e., the variation in the time of commencement of sowing rains, δ, over years must be small. Seed placed in dry soil may not remain viable for long under high soil temperature conditions. An arbitrary limit of 20 days is used here, so that if δ exceeds 20 days then dry-seeding may not be feasible. Regions that are suitable for dry-seeding in India can be delineated using this basic criterion. The spatial distributions of δ were superimposed on the vertisols and are presented in Fig. 3d. The vertisol areas of India are divided into four major zones according to their suitability for dry-seeding and these zones are shown in Fig. 3d. Those regions surrounding Indore are highly favourable for dry-seeding. Akola and its surrounding area is next in order, but at present a major part of this region is kept fallow. These results suggest that these regions have considerable potential for the introduction of dry-seeding techniques (Spratt and Chowdhury, 1978; I.C.A.R., 1982).

Water-logging zones

The length of wet spells ($\bar{W}$) in the available effective rainy period (G), superimposed on vertisol regions in India and four probable zones, are presented in Fig. 3e. The water-logging problem is considered insignificant if $\bar{W} < 4$ weeks. The major part of the area of severe hazard lies in the sub-humid zone, where paddy-rice is the major crop (Reddy, 1983b). Water-logging is not significant in the undependable rainfall zone with longer intermittent dry spells (Fig. 3g). Where α is large, watter-logging is also severe (Fig. 3f) at locations with $\bar{W} < 4$ weeks in some years.

Risk in agricultural production

In agricultural production generally the input level depends upon the associated risk and socio-economic conditions. The aridity index (A, the percentage crop failure years) can be used to assess agricultural risk, although edaphic factors can modify these risk levels. Thus, risk may be relatively high in alfisols but lower in vertisols. In this study, the results present the average risk at a specific location irrespective of soil type. Five zones are identified according to the level of risk (A), as shown in Fig. 4.

In the wet-2 zone, the variations in $\bar{G}$, C and A are small and the variations in δ, $\bar{W}$, and $\bar{D}$ are wide (Fig. 3). The major problems are water-logging and soil erosion (Fig. 3e). At some locations in the wet-1 zone, C and δ (Fig. 3b and d) are highly variable. In the wet—dry zone, crops fail in 16—30% of the years, as the possibility of mid-season droughts occurring is greater ($\bar{D} > \bar{W}$, Figs. 3e and g). In the dry-1 zone crops fail 31—45% of the years. Water-logging is not an important problem (Figs. 3e and g).

In the dry-2 zone crops fail in 46—60% of the years. These regions represent the major drought-prone areas in the Indian semi-arid tropics. Sowing time is critical (Fig. 3d).

Production parameters

The above groups are not at all homogeneous with regard to potential crop production, and these results demonstrate that a single or a few of the variables cannot explain wider variations in the climate, even on a regional scale. Agroclimate may appear similar with regard to some variables, but can differ widely with regard to others such that farming practices are entirely different. The following variables are the most useful in delineating relevant agroclimatic parameters and production potential.

TABLE I

Climatic variables for selected locations in India (dependable and undependable rainfall areas)

Location	Rainfall (mm)	Type[a]	Agroclimatic attributes				
			$\bar{S} \pm \delta$ (week no.) (weeks)	$\bar{G} \pm C$ (weeks) (%)	$\bar{W} \pm \alpha$ (weeks)	$\bar{D} \pm \beta$ (weeks)	A (%)
Low rainfall							
Ajmer	523	1	27.3 ± 1.5	7.6 ± 67	3.6 ± 1.8	3.7 ± 2.1	30
Bijapur	565	2	32.3 ± 3.7	6.0 ± 107	2.9 ± 2.3	4.0 ± 3.0	53
Medium rainfall							
Jalgaon	775	1	25.3 ± 2.2	12.8 ± 36	5.0 ± 2.4	4.4 ± 1.9	7
Cuddapah	752	2	31.0 ± 5.1	10.5 ± 71	3.6 ± 2.5	5.0 ± 3.7	30
Hyderabad	783	1	27.2 ± 2.9	12.9 ± 45	4.2 ± 2.5	5.0 ± 2.5	13
Sholapur	755	2	27.9 ± 4.0	11.3 ± 57	3.6 ± 2.0	5.1 ± 3.0	24
High rainfall							
Agra	824	1	26.3 ± 1.0	13.3 ± 27	5.9 ± 2.0	5.1 ± 1.9	8
Bangalore	827	2	27.4 ± 4.7	11.8 ± 71	3.9 ± 3.1	5.2 ± 3.9	32

[a] 1 = dependable and 2 = undependable.
$\bar{S} \pm \delta$ = Mean week for commencement time of sowing rains ± its standard deviation.
$\bar{G} \pm C$ = Mean available effective rainy period ± its coefficient of variation.
$\bar{W} \pm \alpha$ = Mean number of wet weeks within the effective rainy period ± its standard deviation.
$\bar{D} \pm \beta$ = Mean number of dry weeks within the effective rainy period ± its standard deviation.
A = Percentage crop failure years (% number of years with $G \leqslant 5$ weeks).

$\bar{S}$ and δ: $\bar{S}$ is a time parameter and thus relates more to planning strategy than to production potential; δ, on the other hand, is related to production potential because it gives a measure of suitability for dry-seeding.

$\bar{G}$, C and A: these relate to the possible cropping patterns and associated risks, and in several ways concern production potential.

$\bar{W}$, $\bar{D}$, α and β: these relate to the problems and hazards associated with the particular system of farming, such as water-logging, that concern production potential as well as agricultural planning strategies, e.g., collection and recycling of runoff water, land management, etc.

All 9 variables are significant for delineating agroclimate and 8 (omitting $\bar{S}$) are equally relevant for estimating production potential.

COMPARATIVE ANALYSIS (INDIA, SENEGAL and UPPER VOLTA)

Zones with similar mean annual rainfall

India

Table I presents the data from derived agroclimatic variables for selected locations in India under three groups of mean annual rainfall. Within the first group (low rainfall SAT), the results show wide differences between Ajmer and Bijapur. Bijapur is in a less reliable zone ($\delta = 3.7$ weeks and $C = 107\%$) than Ajmer ($\delta = 1.5$ weeks and $C = 67\%$), and this requires more careful selection of sowing times. The risk is 53% at Bijapur and 30% at Ajmer.

Four stations are included in the next group (medium rainfall SAT), two each from Andhra Pradesh (Hyderabad and Cuddapah) and Maharashtra (Jalgaon and Sholapur). At all these locations most of the deep vertisols are kept fallow during the rainy season and are cropped on residual soil moisture in the post-rainy season (ICRISAT, 1981). This is due to high variability in the time of commencement of sowing rains ($\delta > 4$ weeks) at Sholapur and Cuddapah, and water-logging problems at Jalgaon and Hyderabad ($\overline{W} > 4$ weeks). However, dry-seeding is feasible at Jalgaon and Hyderabad ($\delta <$ 3 weeks). Research station results indicate that with dry-seeding and proper management of soil, it is possible to produce a kharif crop in the vertisols of Hyderabad and Jalgaon, but this is still risky at Sholapur and Cuddapah (Binswanger et al., 1980). At all these stations water-logging is a problem in many years ($\overline{W} > 3.6$ weeks).

Similar problems concern the third group (high rainfall SAT), with Bangalore being located in an undependable rainfall zone ($\delta = 4.7$ weeks and $C = 71\%$) and Agra in a dependable rainfall zone ($\delta = 1.0$ weeks and $C = 27\%$). At Bangalore the high variation between the different variables ($\overline{S} = 27.4 \pm 4.6$ weeks and $\overline{G} = 11.8$ weeks $\pm 71\%$) suggests a widely fluctuating long-term growing season, however, runoff recycling will substantially increase productivity ($\overline{W} = 3.9 \pm 3.1$ weeks) in many years. Studies have indicated that at least 30% of annual rainfall is lost through runoff on lands with 1.5—2.0% slopes. There is a good opportunity for harnessing this surplus (I.C.A.R., 1982). Dry-seeding is feasible at Agra but is risky at Bangalore. Water-logging is a problem in many years at both locations ($\overline{W} >$ 3.6 weeks and $\alpha > 2.0$ weeks).

India, Senegal and Upper Volta

Table II presents results for climatic variables relating to India, Senegal and Upper Volta under four mean annual rainfall groups, varying from ~ 550 to 1350 mm. Table I shows that the variable means, particularly $\overline{G}$, are closely similar within groups, but that the variations of δ and C are considerable. Table II shows that even the mean values can show considerable differences when similar rainfall groups are compared over different continents. The effective rainy period and both wet and dry spells are longer in west Africa than in India under similar rainfall conditions. We would therefore expect that the crops suited to these similar rainfall zones are somewhat different, and indeed this is the case, in west Africa longer duration crops are better suited. In addition, because of the longer dry spells and proportionately shorter wet spells during the effective rainy period in west Africa, compared to India, the crop varieties selected should be more drought tolerant at different stages of growth. Dry-seeding is feasible in almost all zones of west Africa.

TABLE II

Climatic variables for selected locations in India, Senegal and Upper Volta

Location	Country[a]	Rainfall (mm)	Agroclimatic Variables[b]				
			$\bar{S} \pm \delta$ (week no.)	$\bar{G} \pm C$ (weeks) (weeks) (%)	$\bar{W} \pm \alpha$ (weeks)	$\bar{D} \pm \beta$ (weeks)	A (%)
Low rainfall							
Bijapur	1	565	32.3 ± 3.7	6.0 ± 107	2.9 ± 2.3	4.0 ± 3.0	53
Sagata-Louga	2	538	29.2 ± 1.8	12.6 ± 45	4.2 ± 2.0	5.6 ± 1.7	13
Djibo	3	567	28.7 ± 1.9	11.0 ± 53	3.4 ± 1.6	4.5 ± 2.3	14
Medium rainfall							
Cuddapah	1	752	31.0 ± 5.1	10.5 ± 71	3.6 ± 2.5	5.0 ± 3.7	30
Kidira	2	752	26.6 ± 1.7	17.9 ± 20	6.6 ± 2.6	6.6 ± 2.0	0
Boulsa	3	751	24.7 ± 1.5	17.4 ± 20	5.1 ± 2.4	5.8 ± 2.2	0
High rainfall							
Dhar	1	953	25.1 ± 1.4	16.5 ± 21	7.0 ± 2.1	5.3 ± 2.0	0
Dialakoto	2	956	24.4 ± 1.9	21.7 ± 18	9.3 ± 2.9	7.2 ± 2.0	3
Dedougou	3	954	23.2 ± 1.5	20.5 ± 10	7.5 ± 2.3	6.0 ± 1.6	0
Very high rainfall							
Jabalpur	1	1374	23.6 ± 1.5	18.5 ± 14	9.8 ± 2.1	5.3 ± 1.7	0
Diouloulou	2	1388	25.8 ± 1.8	21.3 ± 14	10.0 ± 2.7	6.3 ± 1.2	0
Niangoloko	3	1331	20.5 ± 2.3	26.3 ± 11	10.5 ± 2.6	7.0 ± 1.7	0

[a] 1 = India; 2 = Senegal; 3 = Upper Volta.
[b] See explanation in Table I.

The results presented in Tables I and II reveal dangers in the use of mean annual rainfall as a basis for interpreting agricultural productivity and for grouping locations.

Interrelationships between different variables

In order to understand and characterize the global, regional and local scale dissimilarities associated with both global and regional circulation patterns, land—sea contrast and orography, etc., a regression approach was followed. Figures 5 to 8 depict, respectively, the relationships of C v. $\bar{G}$, $\bar{W}$ and $\bar{D}$ v. $\bar{G}$, $\bar{D}$ v. $\bar{W}$, C v. δ for (a) India, (b) Senegal and (c) Upper Volta. The first four show a non-linear and the last pair a linear relationship. Non-linear functions were fitted to the first four data sets and the best fit is presented in the respective figures for each set of variables. A linear function best fits the last set of variables and this is shown in Fig. 8. All except the last set have solutions significant at $<5\%$ level.

Variation of C *with* $\bar{G}$

The best-fit solution to all data sets presented in Fig. 5 are: $\bar{G} = 2.0 + 500/(C + 10)$. The same equation is found to be valid for all three countries.

The fitted curve from this equation is shown by solid line. In India the dispersion around the predicted curve is large compared with west Africa. The stations to the left of the curve are more dependable, i.e., the crop growing period is stable compared with stations to the right of the curve. The degree of dependability decreases as the station distances increase from left to right of the predicted curve. In the case of India, most of the points on the right of the curve are stations that are in the rain shadow zone of the western Ghats. In west Africa the terrain is uniform and such orographic effects do not occur.

Variation of $\bar{W}$ *and* $\bar{D}$ *with* $\bar{G}$

The best-fit equations for the data presented in Fig. 6 are: $\bar{G} = a + b/(\bar{W} + d)$ and $\bar{G} = a \exp(b\bar{D})$. However, the coefficients for different countries are different in these cases. The predicted curves are depicted by solid lines.

For India, the two curves, i.e., $\bar{W}$ v. $\bar{G}$ and $\bar{D}$ v. $\bar{G}$ intersect at $\bar{G} = 13.3$ weeks and $\bar{W} = \bar{D} = 4.7$ weeks, while for west Africa they intersect at somewhat higher values, i.e., for Senegal $\bar{G} = 17.8$ weeks and for Upper Volta $\bar{G} = 19.4$ weeks with $\bar{W} = \bar{D} = 6.4$ weeks. The large differences in these limits between India and Upper Volta are mainly associated with the global circulation patterns, and the differences between Senegal and Upper Volta are associated with regional factors, such as land—sea contrast.

From these curves it is clear that for higher values of $\bar{W}$, $\bar{W}/\bar{G}$ is large for India, followed by Senegal and then Upper Volta, while at lower values of $\bar{W}$, $\bar{W}/\bar{G}$ is higher for Senegal, followed by India and then Upper Volta. This relationship is similar for $\bar{D}$, where $\bar{D}/\bar{G}$ is large for Senegal, compared with India and Upper Volta (neglecting the lower intersection, this range represents an arid situation only). This means that at stations in India, with the same annual rainfall (Table II), the growing season is shorter, but the proportionate wet spells are larger and dry spells are less at higher values of $\bar{G}$. Because of this, the number of fieldwork days are less and water-logging is a major problem under the same growing season.

Variation of $\bar{D}$ *with* $\bar{W}$

The best-fit equation for the data sets of Fig. 7 is: $\bar{D} = a + b(\bar{W} + d)^{1/3}$. The curves are depicted by solid lines. All other coefficients (b and d) are the same for the three countries (Fig. 7). In these figures a line passing through the origin with $\bar{W} = \bar{D}$ is also depicted. It is seen from these curves that this line meets the predicted curves at 5.4 and 6.4 weeks for India and west Africa, respectively. At stations above the straight line, water-logging is a problem and for the stations below this, mid-season droughts are more common. The latter situation is evident at many locations in India and next in order come Senegal and Upper Volta.

Variation of C *with* δ

The pattern of C v. δ is depicted in Fig. 8. This figure indicates that the pattern of variation of δ with C is quite different for west Africa compared with India. In west Africa, the variation of δ with C is very small even for large values of C (which reflects the regular onset and irregular cessation times of sowing rains.

In India, the plot shows a cone shape with the point near the origin, suggesting wide variation, not only of the onset but also the cessation time of sowing rains. The points on the far left of the best-fit curves (Fig. 8) represent locations with a long-term high variation in the cessation time, and the points to the far right of this line represent locations with a high variation in the onset time of sowing rains. Therefore, the cessation times of sowing rains is highly variable in west Africa, and both cessation and onset times are highly variable in India.

Dissimilarity parameters

The above results show that even when mean annual rainfalls are similar in tropical semi-arid environments, agricultural production potential and the associated risks can be very different for various regions. These differences are associated mainly with orographic effects at local scale, circulation patterns at regional scale and general circulation patterns at continental scale. With the same value of $\bar{G}$, considerable differences in δ and C are seen in India where orographic effects play a major role. When these are compared on continental scale, even $\bar{G}$ itself showed wide variations and the proportion of $\bar{W}$ v. $\bar{G}$ changed substantially for different continents. This inference has a bearing on farming systems in general and the cropping pattern in particular. Comparison of different variables between different continents makes it possible to estimate the continental, regional, or local variation of agroclimatic variables. For example, from C v. $\bar{G}$, the parameters that refer to local or regional effects are defined as

$$G' = G'' - \bar{G}$$

where G'' is the value estimated from the equation

$$G'' = 2.0 + 500/(C + 10)$$

where C is a value corresponding to $\bar{G}$ and G' represents variable 9 of the regional or local effects.

Similarly, from $\bar{W}$ and $\bar{D}$ v. $\bar{G}$, the parameters representing continental dissimilarities are defined as

$$\bar{W}' = \bar{W} - K, \bar{D}' = \bar{D} - K$$

where K is the intersect point shown in Fig. 6, i.e., 4.7 and 6.4, respectively, for India and west Africa. These define the relative water-logging or drought situations in the different continents. W' and D' represent variables 10 and 11 that can be used in the agroclimatic classification (Reddy, 1983c).

The three above-mentioned variables G', W' and D', therefore, indicate the dissimilarities associated with differences at local, regional or continental scale, and are characterized as dissimilarity parameters.

CONCLUSIONS

Of the two climatic variables used to compute the agroclimatic variables, rainfall represents the observed data set and potential evapotranspiration represents an estimate from other climatic data. Both represent point observations.

SAT in India is delimited by 4—16.5 weeks of mean available effective rainy period ($\bar{G}$) and with $\leqslant 60\%$ of crop failure years (A). This analysis identifies some of the important limitations of and feasibilities for agricultural production and planning strategies in SAT India. Some such features are dry-seeding to overcome kharif fallowing in deep vertisol regions; water-logging needing attention in terms of land and water management practices; risk that limits the input levels; cropping patterns that indicate those regions suitable for single, inter- or double cropping and their associated risk; feasibility of runoff recycling and the critical time for sowing.

Some variables have a simple and direct relationship to each other, but this is in appearance only. The deviations of these parameters from an average pattern have different implications in terms of farming system practices in general and cropping patterns in particular. Therefore, it is always better to consider as many variables as possible in the evaluation of climatic data.

The spatial distribution of the 9 agroclimatic variables in India, suggest that 8 of them could be used in connection with production and the remaining one ($\bar{S}$, the mean week of the commencement time of sowing rains) is useful for planning cropping strategies.

The basic contrast between the Indian and west African situations is that for similar mean annual rainfall, the corresponding effective rainy period is longer in west Africa. Accordingly, the other variables relating to the effective rainy period are significantly different. Orographic or local effects are greater in India compared with west Africa, where the terrain is more uniform. However, in west Africa there are regional differences associated with the land—sea contrast. West African stations show wide variations in the cessation times of sowing rains, while in India this is the case for both cessation and onset times. The inter-correlation study among the 8 variables suggest that three dissimilarity parameters related to local, regional and continental scale can be identified. Thus, of the 11 agroclimatic variables for classification of SAT into the relevant agronomically homogeneous zones, 8 can be used in connection with productivity potential and three can be used to identify dissimilarities in scale.

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APPENDIX

Rainfall stations from which data for the analysis were obtained

Station	Code	Lat. °	Lat. '	Long. °	Long. '	Data base (years)	Station	Code	Lat. °	Lat. '	Long. °	Long. '	Data base (years)
INDIA													
Agra	AGR	27	10	78	02	27	Ahmednagar	AHG	19	05	74	55	69
Ajmer	AJM	26	27	74	37	30	Akola	AKL	20	42	77	02	30
Amerali	AMR	21	36	71	13	29	Amritsar	AMT	31	38	74	52	29
Anand	AND	22	34	73	01	30	Anatapur	ANT	14	41	77	37	59
Arogya-varam	ARG	13	32	78	30	17	Aurangabad	ARB	19	53	75	20	70
Banaras	BNR	25	18	83	01	27	Bangalore	BNG	12	58	77	35	70
Banswara	BNW	23	33	74	27	65	Barielly	BRL	15	09	76	51	68
Belgaum	BLG	15	51	74	32	70	Bellary	BLR	15	09	76	51	58
Bhir	BIR	19	00	75	46	70	Bhuj	BHJ	23	15	69	48	66
Bijapur	BJP	16	49	75	43	67	Bikaner	BKR	28	00	73	18	27
Chitra-durga	CHT	14	14	76	26	69	Chittoor	CHR	13	13	79	07	20
Coim-batore	CMB	11	00	76	58	70	Cuddapah	CDP	14	29	78	50	70
Daltonganj	DTG	24	23	84	04	54	Deesa	DSA	24	12	72	12	69
Dhar	DHR	22	36	75	18	64	Dharmpuri	DHP	12	08	78	10	69
Dharwar	DHW	15	27	75	00	70	Dohad	DHD	22	50	74	16	37
Dungarpur	DGP	23	51	73	43	67	Gogha	GGH	21	41	71	17	66
Gorakhpur	GRK	26	45	83	22	66	Gulbarga	GLB	17	21	76	51	70
Hissar	HSR	29	10	75	44	53	Hyderabad	HYD	17	27	78	28	69
Indore	IND	22	43	75	48	30	Jabalpur	JBP	23	10	79	57	69
Jaipur	JPR	26	49	75	48	19	Jalgaon	JLG	21	03	75	34	69
Jhabua	JBA	22	47	74	35	68	Jodhpur	JDP	26	18	73	01	30
Jullunder	JLD	31	20	75	35	24	Kolar	KLR	13	08	78	08	69
Kota	KTA	25	11	75	51	25	Kurnool	KRN	15	50	78	04	70
Lucknow	LKN	26	45	80	53	67	Ludhiana	LDN	30	56	75	52	29
Madhurai	MDH	09	55	78	07	70	Mahboob-nagar	MBN	16	44	77	59	70
Malegaon	MLG	20	33	74	32	70	Mandya	MND	12	32	76	53	70
Mysore	MSR	12	18	76	42	70	Nanded	NND	19	08	77	20	58
Nasik	NSK	20	00	73	47	62	New Delhi	DLH	28	35	77	12	30
Ongole	ONG	15	34	80	03	31	Osmanbad	OSB	18	10	76	03	70
Padegaon	PDG	18	12	74	10	25	Pali	PLI	25	47	73	20	66
Palamau	PLM	24	03	84	04	68	Patan	PTN	24	13	84	11	30
Patiala	PTL	30	20	76	28	16	Phulbani	PHB	30	29	84	14	48
Poona	PNA	18	32	73	51	70	Rajkot	RJK	21	18	70	47	28
Raichur	RCR	16	12	77	21	69	Raipur	RPR	22	14	81	39	69
Ramanth-puram	RMN	09	23	78	50	68	Ranchi	RNC	23	23	85	20	23

APPENDIX (cont.)

Station	Code	Lat. °	Lat. ′	Long. °	Long. ′	Data base (years)	Station	Code	Lat. °	Lat. ′	Long. °	Long. ′	Data base (years)
Rewa	RWA	24	32	81	18	24	Salem	SLM	11	39	78	10	69
Sangly	SGL	16	52	74	34	64	Satara	STR	17	41	73	59	40
Sholapur	SLP	17	40	75	54	30	Sikar	SKR	27	37	75	08	26
Tumkur	TMK	13	21	77	06	70	Udaipur	UDP	24	35	73	42	30
Vishakhapatnam	VIS	17	43	83	14	68	Samalkot	SKT	15	52	81	43	16
UPPER VOLTA													
Aribinda	ARB	14	14	00	52	20	Bam (Tourcoing)	BAM	13	20	01	30	27
Banankeledaga	BNK	10	37	04	46	20	Banfora	BNF	10	37	04	46	48
Banfora Agric.	BNA	10	37	04	46	20	Bani	BNI	13	43	00	10	16
Batie	BTI	09	53	02	55	29	Bobo-Dioulasso	BOB	11	10	04	18	50
Bogande	BGN	12	59	00	08	25	Boromo	BRM	11	44	02	55	47
Boulsa	BLS	12	39	00	34	15	Dano	DAN	11	09	03	04	19
Dedougou	DDG	12	28	03	28	51	Diapaga	DPG	12	04	01	47	43
Diebougou	DBG	10	58	03	15	48	Dionkele	DNK	11	47	04	43	19
Djibo	DJB	14	06	01	37	21	Dori	DOR	14	02	00	02	45
Fada N Gourma	FNG	12	04	00	21	48	Farako Ba (Agro)	FRB	11	06	04	23	18
Gaoua	GAO	10	20	03	11	54	Garango	GRN	11	48	00	38	27
Gorgadji	GRD	14	02	00	31	10	Gorom-Gorom	GRM	14	27	00	14	17
Gourcy	GOR	13	12	02	21	17	Guilongou	GLG	12	37	01	18	15
Kamboince	KMB	12	28	01	33	17	Kampti	KMP	10	08	03	28	19
Kaya	KYA	13	06	01	05	52	Kombissiri	KBS	12	04	01	20	17
Koudougou	KDG	12	16	02	22	50	Koupela	KPL	12	11	00	21	49
Lantaogo	LTG	12	02	00	05	16	Leo	LEO	11	06	02	06	48
Manga	MNG	11	40	01	06	23	Markoye	MRY	14	38	00	04	17
Nasso	NSS	11	12	04	26	20	Niangoloko	NNG	10	16	04	55	22
Nouna	NNA	12	44	03	52	33	Orodara	ORD	10	59	04	55	18
Ouagadougou[a] MSN	ODM	12	22	01	32	60	Ouahigouya	OHG	13	35	02	26	48
Ouargaye	ORG	11	32	00	01	15	Pabre	PBR	12	31	01	34	16
Pama	PAM	11	15	00	42	23	Po	PO	11	10	01	09	30
Saba	SBA	12	03	01	36	16	Sapone	SPN	12	03	01	36	16
Sebba	SEB	13	26	00	31	18	Seguenega	SGG	13	26	01	58	18
Sideradougou	SDR	10	41	04	15	18	Tenkodogo	TNK	11	45	00	23	48
Tougan	TGN	13	05	03	04	39	Tougouri	TGR	13	19	00	30	18
Yako	YAK	12	58	01	16	30							
Zorgho	ZRG	12	15	00	37	18	Zabre	ZBR	11	10	00	39	19

APPENDIX (cont.)

Station	Code	Lat. °	Lat. ′	Long. °	Long. ′	Data base (years)	Station	Code	Lat. °	Lat. ′	Long. °	Long. ′	Data base (years)
SENEGAL													
Bakel	BKL	14	54	12	28	49	Bambey[b] Meteo	BBM	14	42	16	28	46
Bignona	BGN	12	40	16	16	18	Boulel	BLL	14	17	15	32	16
Coki	CKI	15	31	16	00	26	Dagana	DGN	16	31	15	30	52
Dahra	DHR	15	20	15	29	37	Dakar [c]Yoff	DKY	14	44	17	30	27
Darou-mousty	DRM	15	02	16	02	23	Dialokoto	DLK	13	19	13	18	38
Diouloulou	DLL	13	02	16	35	29	Diourbel	DRB	14	39	16	14	52
Fatick	FTC	14	20	16	24	51	Foundiougne	FDG	14	07	16	28	42
Goudiry	GDR	14	11	12	43	30	Guento	GNT	13	33	13	49	34
Inhor	IHN	13	01	15	42	19	Joal	JAL	14	10	16	51	24
Kaffrine	KFN	10	06	15	33	38	Kaolack	KLK	14	08	16	04	53
Kebemer	KBR	15	22	16	27	21	Kedougou	KDU	12	34	12	13	47
Khombole	KML	14	46	16	42	18	Kidira	KDR	14	28	12	13	43
Kolda	KLD	12	53	14	58	48	Koumpen-toum	KPT	13	59	14	33	27
Linguere	LGR	15	23	15	07	40	Louga	LGA	15	37	16	13	37
Maka-Coulibentan	MKC	13	40	14	18	29	Matam	MTM	15	38	13	15	46
M Backe	MCK	14	48	15	55	35	M Bao-Thiaroye	MBT	14	46	17	29	44
M Boro	MBR	14	08	16	53	16	M Bour	MBU	14	25	16	58	37
Namary	NMR	15	02	13	34	19	Nioro du rip	NDR	13	44	15	47	36
Oussouye	OSY	12	29	16	32	32	Podor	PDR	16	38	14	56	48
Rufisque	RFS	14	44	17	18	16	Sadio	SDO	14	48	15	33	16
Sagata-Linguere	SLA	15	13	15	34	17	Sagata-Louga	SGO	15	17	16	11	16
Saint[d] Louis ville	SLV	16	01	16	30	75	Saraya	SRY	12	47	11	47	28
Sedhou	SDO	12	42	15	33	53	Sefa-Sedhiou	SSO	12	47	15	33	24
Tamba-counda	TC	13	46	13	41	48	Thiadiaye	TDY	14	25	16	42	22
Thilmaka	TLK	15	02	16	15	18	Tivaouane	TVN	14	57	16	49	45
Velingara Casa mance	VLG	13	09	14	06	36	Ziguinchor	ZGR	12	33	16	16	50

[a]Ouagadougou (Aero & Ville), Kantachari
[b]Bambey Aero
[c]Dakar (Hospital; Hann; Cap Manual; and Goree)
[d]Saint Louis Aero

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