PART I

THE SETTING
CHAPTER I

STRUCTURE AND RELIEF

The State of Uttar Pradesh forms part of the Indo-Gangetic plain, which lies between northern Gondwana land of peninsular India in the south, and the recently built Himalayan chain of mountains in the north. The plain is 400 km. broad at the most, and about 2400 km. long. But the Gangetic trough is only 1920 km. long.

The north Indian plain consists of the alluvium deposited through geological ages by great Himalayan rivers. The nature of the detritus of various sizes from big boulders to silt and clay, the management of the bedding and the general form of the surface is due to sedimentation laid down in generally inclined layers. Which are the principal types of river deposits. The extensive deposits of very young age are the stratified alluvial accumulation. The Gangetic trough, a cylinclorial depression between peninsular India and the southern front of Himalayas is of post-tertiary formation and filled up by Pleistocene alluviation.

The great Austrian geologist Eduard Suess, holds that it is a 'fore-deep formed in front of the resistant mass of the peninsula when the Tethyan sediments were thrust southward and compressed against them.\(^4\) Burra, holds the view, that the north India plains represent a rift valley bounded by parallel faults on either side with a maximum downthrow of twenty miles.\(^5\) The Indian geologists have not accepted this view, on the origin of Indo-Gangetic depression, because it has few geological and geo-physical observations.\(^7\)

A third, and more recent view regards this region as a sag in the crust formed between the northward drifting Indian continent and the comparatively soft sediments accumulated in the Tethyan basin, when the latter were crumpled up and lifted up into a mountain system. The dynamical effect of either the first or the third view would appear to be the same. The depression perhaps, began to form in the upper Eocene and attained its greatest development during the third Himalayan upheaval in middle Miocene. Since then, it has been gradually filled up by sediments to form a levelled

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plain with a very gentle slope.\textsuperscript{8} Geological and geodetic data appear to support the view of the northward drift of the Indian continent and is more acceptable.\textsuperscript{9}

E.H. Pascoe, and G.E. Pilgrim, advocate that the Siwaliks were laid down in the flood plains of a single river, the Indobraham or Siwalik river, which rose in Assam and followed the present line of distribution of these deposits. But, Krishnan and Aiyangar discuss this question and show, that the available evidence points to the basin of deposition being a continuous lagoon or fore-deep formed in front of the Himalayan range. It is almost certain, that Siwaliks extend down for several miles underneath the alluvial cover of the Indus and Ganga valleys.\textsuperscript{10} On the basis of characteristics of Gondwana rocks found on the northern rim of the alluvial belt of the plain, Wadia and Auden, maintain that the Archaean gneiss, and the peninsular rocks are continuous inside the plain. The continued loading of this belt by sedimentation since the first uplift of the Himalayan mountains may have accentuated the sinking of the archean floor, but as the process of sedimentation kept pace with that of depression,

\textsuperscript{8} Krishnan, H.S., \textit{Geology of India and Burma}, op. cit., p.529.
\textsuperscript{9} \textit{idem}, \textit{Introduction to the Geology of India}, (Kadras, 1944), p.19.
\textsuperscript{10} Krishnan, H.S., \textit{Geology of India and Burma}, op. cit., pp.502-3.
there arose the great plain of India. At the same time, there was a great southward shift of the basin with each fresh pulse of the uplift.\textsuperscript{11}

The postulation of de Terra (1933-34), that the successive overlaps of younger over older beds from the Ganga Delta to the northwest of Punjab points to a great tilted syncline along which any master stream originally flowed to the southeast has its own difficulties to be accepted.\textsuperscript{12}

The sunkin basin or the depression in the crust stretching from Sind to Assam of considerable depth is believed to have been created as a complementary depression to the elevation of the Himalaya. There were gulfs, stretching inland far to the north along the present valleys of the Indus and the Ganga, gulfs of Sind and Assam. Its filling up by the sediments, silt clay, sand, and gravel brought down from the newly upheaved Himalayas is most notable event of sub-recent times. The Indo-Gangetic alluvium contains 'a drift soil'.\textsuperscript{13}

Beneath the alluvium of the Gangetic plains, Tertiary strata conceals, what lies below it? However, structural

\textsuperscript{11} ibid., p.502.
\textsuperscript{13} Wadia, D.N., et al., "Introductory Note on Geological Foundation of the Soils of India", Agriculture and Livestock in India, Vol. VI, Part I, Imperial Council of Agricultural Research, Delhi, 1936, p.77.
events determined sedimentation and of course, no solid rock at any depth of drilling in the north Indian plain has been discovered, and the presence of 'only the sand washed down by Himalayan rivers through course of geologic times from the summit of Himalayas' reveals the geological part played by the Himalayan rivers in the formation of the north Indian plains.  

The maximum depth of the alluvium is not ascertained. Some borings have been put down in the alluvial deposits to a depth of around 700 m. for tapping water.  

The bore hole at Lucknow in Uttar Pradesh, is only about 400 m. which has not touched the rock bottom.  

On the basis of geodetic data Oldham, finds the depth of Gangetic trough to be 4,600 to 7,000 m. towards its northern edge. Covle, while criticising the above findings postulated even higher figures from the same data. Recent calculations from geodetic surveys give much lesser thickness for these lighter deposits resting on the dense Archaean bed-rock, and thus, Glennie,

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challenged these figures on the basis of new gravity anamolous readings obtained from different stations in the plain, and calculated the maximum depth of alluvium as 1,980 m. The figures calculated by Glennie, conforms with geodetic data though not with geological facts, it can be regarded as reliable, and may will be higher. The sub‐montane Indo‐Gangetic trough is believed to be 1800–3050 m in depth. 20

All the borings, that have hitherto been made failed to reach the rocky bottom. 21 However, the deepest part is near to the northern edge than the southern. It becomes gradually shallower towards the peninsular margin. The depth of the alluvium is at a maximum between Delhi and Rajmahal hills. 22

The alluvial deposits of Uttar Pradesh are classified under two sub-divisions: old and new deposits, known as bangar and khadar respectively. These deposits, in respect of their geological age correspond with the two main divisions of Quaternary era: the Pleistocene and the Recent.

22. ibid., p.285.
BANGAR

The bangar land occupies the higher ground in Uttar Pradesh, and is not flooded by the rivers during the rains. The bangar alluvium contains the parent material forming the kankar nodules of carbonate of lime. These kankars found in abundance, are the irregular concentration of impure calcareous matter. This older alluvium is distinguished by the nodular segregations of carbonate of lime or calcareous concretions which are abundant in the drier regions. The bangar land is characterised by patches of saline and alkaline efflorescences, which are the result of gentle slope of the land and the composition of the alluvium. The bangar land, above the flood level generally possesses, clay and sodium clay as dominant constituent reacting with kankar (nodul) which liberates sodium carbonate and is turned into calcium clay.

The bangar as a rule occupies higher grounds than the recent khadar. Most of the kankar occurrence consists of irregular small pieces of varying diameters from one

24. ibid., p.160.
26. Spate, O.H.K., op. cit., p.34.
27. Krishnan, H.S., Geology of India and Burma, op. cit., p.34.
centimetre to ten centimetres or more and it is of all shapes and sizes from small grains to big lumps. Banagar of the Ganga valley is rich in nodules of dark colour. The vertical distribution of kankar beds is in well defined layers varying from pure sand beds to those composed of heavy clays of impervious layers, continuous or intermittent within the soil.

The formation of kankar concretions is due to segregation of the calcareous material of the alluvial deposits into lumps or nodules somewhat like the formation of flint in limestone. These kankar nodules, and the calcareous beds are said to have been deposited from water containing a solution of carbonate of lime, derived from the older rocks of various kinds or else from fragments of limestone contained in the alluvium.

In some places of upland banagar alluvium, the kankar concretions outcrops cover wide areas at the surface, while in other places they are found at a depth as great as ten to fifteen metres.

29. Wadia, D.N., Geology of India, op. cit., p.287.
**KHADAR**

The newer alluvium of Gangetic trough, called **khadar**, corresponds with the recent geological age of Quaternary era. The **khadar**, light coloured, sandy and poor in calcareous matter is found generally in the river valleys. The animal remains in the **khadar** are mostly identical with living species. The **khadar** areas in the Gangetic plain are like 'figures' along the main stream and their sub-parallel tributaries such as, the Ramganga and Gomti. The rivers annually refresh the area by bringing down the new silt, particularly in the main flood plains, which they bring from the northern mountains. Nevertheless, the **kankar** areas are of lower ground than those of **bangar**.

The prevailing soil of **khadar** is sandy. It is almost pure (sand) on the banks of river Ganga but, as one proceeds away from the river, sandy character of the soil gradually decreases and is replaced by the fine silt. This fine silt called **panga**, is most fertile and laid down by the river after the flood water is receded. But, the area inundated by it is generally within the range of two km. from each of the banks.

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Khadar lands owe their origin to the bangar lands through the erosive action of the rivers. The remanants of bangar lands are subjected to erosion by the changes in the direction of the meandering river channels.\(^{33}\) The khadar areas contain lenticular beds of sand, gravel and peat beds. But, these contain neither kankar or reh salts. The lenses of sand are gravel, graded imperceptibly into recent alluvium and are good reservoirs of underground water.

There are various names of khadar soils in different parts of the State, although they are sandy with sandy silt of varying consistency. The khapat, patka, bela and kanp are some of the local names of khadar soils. In some places, which are marshy lands and lie some distance from the khadar heavy matiyar clays are found, which are quite suitable for cultivation.

The layers of the sub-soils of the khadar tract are generally uniform in texture unlike those of bangar soils. But, as the sub-soil water level is relatively high, these lands need no irrigation. The amount of nitrogen and organic matter in khadar soil is derived from the silt of the flood water, and needs renewal every year for purposes of cultivation, while in bangar soil they are comparatively more durable.

The **khadar** is deficient in calcareous constituents but is entirely protected from injurious salts of soda and magnesia accumulation and form alkaline or saline efflorescences which reduces fertility and make the soil alkaline, while all of these injurious matters may be present in **bangar** tracts. Unlike the **khadar** areas saline and alkaline soils are found in areas of poor drainage with high evaporation. It is remarkable, that the position of the **khadar** tracts shifts with the shifting of river channels, and those **khadar** tracts which thus become inaccessible to river inundation are converted into **bhur** tracts, as these areas are deprived of annual deposition of fine silt, 'panga', the **bhur** soil then cannot efficiently grow agricultural crops, and are only confined to typical crops like melons and water-melons.

The continued productivity of (khadar) alluvial soils is moreover assured by the deposition during overflows of fresh soil material brought down from the head waters of the stream. Therefore, the **khadar** soils consist a mixture of fine sand and silt which possess usually very favourable physical composition and adequate moisture.
DRAINAGE

The general slope of the land in Uttar Pradesh is from northwest to northeast. With the exception of right-bank tributaries of the Yamuna, almost all other rivers of the State rising in the Himalayas flow from west to east (Fig. 2). The Ganga traverses the State from one end to the other and divide it into two parts. The region which lies to the west and south of the river is much smaller than that which is to the north and east. The western region consists of the tract which lies between the Ganga and Yamuna, while the southern part includes the lower Doab and the area lies to the southwest of the Yamuna. A portion of the southern tract, however, lies to the east of Allahabad and includes the whole of Mirzapur district, and part of Allahabad, Varanasi, and Ghazipur districts. The Hindan river which flows through the northern Doab carries the drainage from the Siwaliks and the plain below, and falls in the Yamuna in the Bulandshahr district. In the northern Doab, the Ganga receives a number of tributaries. While in the south, the Yamuna is joined on its right bank by the Chambal, which drains parts of Madhya Pradesh and Rajasthan. It also receives Kuwari, Sindh, Pahuj, Betwa, Dhasan, Ken, Garara, Baghein, Paisuri and Ohan. These rivers wash the northern slopes of the Vindhyan Mountains and flow through Bundelkhand before
joining the Yamuna. Further east, the Karamnasa River, which forms the boundary between Uttar Pradesh and Bihar, flows through the districts of Mirzapur and Varanasi to join the Ganga in the Ghazipur district. The Son River is another tributary of the Ganga and it traverses the Mirzapur district from west to east.

To the east of the Ganga there are three main rivers, viz., the Ramganga, Gomti and Ghaghara. The Ramganga and the Ghaghara rise in the Himalayas and join the Ganga on its left bank in the district of Farrukhabad and Saran (Bihar) respectively. The Gomti rises in the Tarai and flowing parallel to the Ganga and Ghaghara has a confluence with the Ganga in the Ghazipur district. The Gandak, which rises in the Himalayas, only touches the eastern boundary of Uttar Pradesh. A number of canals have been tapped from these rivers and under the Five Year Plans a number of multipurpose dams have been constructed by which the face of agriculture in Uttar Pradesh is changing day by day.

The Ganga: The Ganga rises in the Gomukhi Glacier of the Himalayas in the Uttar Kashi district of Uttar Pradesh and flows southwards under the name of Bhagirathi till it meets at Devprayag with its first main tributary, Alaknanda, from the east. From here the river is known as the Ganga. After a journey of 288 km. from its source, the river descends to
the plain at Hardwar. Following the general slope of the country, it flows southeastwards across the whole length of Uttar Pradesh leaving it in the extreme east of the Ballia district. The Ganga carries all the drainage not only of Uttar Pradesh but also of the whole of northern India and discharges it into the Bay of Bengal.

The main tributaries of Ganga are the Ramganga, Yamuna, Tons, Gomti and Ghaghara. The Yamuna and Tons join the Ganga on its right bank at Allahabad, and others meet it on its left bank. A number of cities, cultural and educational centres have developed along the course of the Ganga. Some of the more important places are Badrinath, Kedarnath, Joshimath, Karnaprayag, Rudraprayag, Srinagar, Devprayag, Harishikesh, Hardwar, Garhmuktesar, Anupshahr, Farrukhabad, Kannauj, Kanpur, Manipur, Kara, Allahabad, Mirzapur, Chunar, Varanasi, Ghazipur and Ballia.

The Yamuna: Although the Yamuna is a tributary of the Ganga, it is the second most important river of Uttar Pradesh. It rises from the western side of the snow-clad peak of Bandarpunch (6315.46 metres) in the Uttar Kashi district of Uttar Pradesh. It receives waters from the western side of the Tons which forms a part of the northwestern boundary of Uttar Pradesh, the confluence of the two being between Majri and Haripur. The river than passing through the Siwaliks
enters the western plain at Faizabad, and thence flows roughly parallel to the Ganga for 1384 km. to join it at Allahabad. The Yamuna is especially significant because it forms an excellent natural boundary between Uttar Pradesh and Haryana. It enters the Mathura district in the north and passes through the districts of Agra and Etawah. Then, forming the northern boundary of the districts of Jalaun, Hamirpur and Banda, and the southern boundary of the districts of Etawah, Kanpur, Fatehpur, and part of Allahabad it meets the Ganga.

In addition to the Tons, there are a number of other right bank tributaries of the Yamuna. The most important ones are the Chambal, Betwa and Ken. The Hindan is the only important left bank tributary and it joins the Yamuna at Bulandshahr. The more important towns on the Yamuna include Kalshi, Vrindavan, Mathura, Gokul, Sikendra, Agra, Firozabad, Etawah, Kalpi, Hamirpur, Kosan and Allahabad. The city of Delhi, too is situated on its bank.

The Ghaghara: The Ghaghara is the next important tributary of the Ganga in Uttar Pradesh. It rises under the name of Karnali from the upper ranges of the Himalayas which form the northern boundary of Nepal. After traversing Nepal longitudinally, it enters in Uttar Pradesh as two separate streams, viz., Kauriala and Girwa. The Kauriala forms the
boundary between the Bahraich and the Kheri districts for a short distance before meeting the Girwa. It flows towards southeast and then to east, thus separating the districts of Bahraich, Gonda, Basti, Gorakhpur and Deoria from the districts of Kheri, Sitapur, Bara Banki, Faizabad, Azamgarh and Ballia. It joins the Ganga in the Saran district of Bihar. From the extreme southeast of Deoria up to the northeast of Ballia, it forms the boundary between Uttar Pradesh and Bihar. This boundary, however, remains liable to changes on account of the shifting nature of the course of the Ghaghara.

The western most tributary of the Ghaghara is the Kali which (since 1814-16, the date when Kumaon came under the British control), forms the entire western boundary of Nepal with Uttar Pradesh. After leaving Nepal, the Kali is known as the Sarda, and in its latter course as the Chanka, and joins the Ghaghara in the west of Sitapur. The Mohan is another tributary of Kauraila which forms the entire northern boundary of the Kheri district with Nepal. The Saju, which rises in the Dhang Range in southern Nepal, flows across the Siwalik and then through northwestern Bahraich to meet the Ghaghara.

The Gomti: The Gomti River rises in the Pilibhit district of Uttar Pradesh and flows towards southeast between the Ganga and the Ghaghara. After leaving the Pilibhit district it traverses the Shahjahanpur and the Kheri districts. Then, forming the boundary between the Hardoi and Sitapur districts it enters the Lucknow district in the north, passes by the northern and eastern side of Lucknow city, forms for a short distance the boundary between the Lucknow and Bara Banki districts, crosses the western portion of the Bara Banki district, and forms a short boundary between the Bara Banki and Sultanpur districts. It then passes through the Sultanpur district and before leaving it again forms its southeastern boundary with the Pratapgarh district. Further on, it passes through the Jaunpur district and then forming the boundary between the Jaunpur and Varanasi districts, and Varanasi and Ghazipur districts it joins the Ganga on the Varanasi-Ghazipur border. The largest tributary of the Gomti is the Sai, which meets it in the Jaunpur district. Its other tributaries are the smaller streams such as, the Kathna, Sarayan and Kalyan. The first two flowing into the Gomti in the Sitapur district while the third joining it in the Bara Banki district. The most important city on the bank of the Gomti is Lucknow, which is the capital of Uttar Pradesh. Sultanpur and Jaunpur are the other important towns on the banks of this river.
The Ramganga: The Ramganga rises in the Tarai of the Kumaon hills (which lies in the Garhwal district of Uttar Pradesh) and enters the plains in the Bijnor district. It then flows southeastwards through the districts of Bijnor, Moradabad, Rampur and Bareilly. From here it forms boundary between the Bareilly and Budaun districts and also between the Budaun and the Shahjahanpur districts. Then, flowing through the Shahjahanpur and Farrukhabad districts it passes through the Hardoi district. In this way it flows for about 595 km. before it joins the Ganga near Kannauj in the Farrukhabad district. This river very often changes its course, especially during the rainy season. Moradabad is the principal city situated on its bank.

The Sai: It is the most important tributary of the Gomti joining on its right bank. It rises in the Hardoi district and traverses the districts of Rae Bareli and Pratapgarh and forms the boundary between the Lucknow and Unnao districts. Subsequently it flows through Jaunpur district before joining the Gomti about 60 km. upstream of the confluence of the latter with the Ganga. The Sai river has a drainage area of 11,115 sq. km.

The Sarda: It is formed by two streams the Kuthiayankti and the Kalapani near the Indo-Tibetan border at an elevation of 5,250 metres. The river flows in a southwesterly direction
for some distance forming the boundary between Indian and Nepal. In this reach it receives the Dhauli Ganga, the Khoprang, the Sarju and the Ladhiya on its right and the Chumlia on its left bank. It debouches into the plains of Uttar Pradesh after passing through a series of rapids.

Entering the plains, the Sarda continues to form the boundary between India and Nepal for a short distance flowing in a boulder bed. Thereafter, it flows in a southeasterly direction through the district of Pilibhit in a tortuous and constantly changing course. During high floods large areas are inundated by the waters of the Sarda. One of the most important irrigation systems in Uttar Pradesh, irrigating lands in the Gomti-Ghaghara Doab emanates from this river from the Banbassa head works.

The Rapti: It is another tributary of the Ghaghara to join on its left bank. It rises in the lower ranges of Nepal at an elevation of 3600 m. after flowing through Nepalese territory for a distance of about 150 km., it enters the Bahraich district of the State. It then flows in a southeasterly direction through the districts of Gonda, Basti and Gorakhpur before joining the Ghaghara near Barhaj in the last named district. The Rapti also inundates large territory on both the banks. But flooding is beneficial because of the fine silt left behind which makes the land fertile and productive.
PHYSICAL DIVISIONS

The State of Uttar Pradesh is divided into four broad physical divisions: (i) Montane tract; (ii) Sub-Montane tract; (iii) The Gangetic plain; and (iv) Trans-Yamuna tract (portions of Central Indian Plateau).

I. Montane Tract

The montane tract constitutes the extreme northern part of the State, and comprises the districts of Uttar Kashi, Chamoli, Almora, Garhwal, Tehri Garhwal, and Pithoragarh; Dehra Dun and Naini Tal (in part). In respect of area this tract stands fourth and in respect of population fifth in the State.

This region comprises the Inner and the Outer ranges of Himalayas. The outer ranges of hills rise quickly from the sub-montane tract to a height of 2150 to 2450 m. On the western side, there lies the district of Dehra Dun partly between the Himalayas, and the Siwalik hills for 72 km., extending upto the slopes of both ranges. We notice a gradual change in vegetation, climate and physical features moving towards the hills from the plains. In both Inner and Outer Himalayas hill tops, terraced slopes and river valleys are brought for cultivation. The limitations for agricultural
operations seem to be the scarcity of irrigation water, manure and availability of agricultural land. Limited irrigation facilities lead to the cultivation of inferior crop, such as Mandua (small millet) which is grown normally with a great success.

II. Sub-Montane Tract

This region lies between the Ganga and the Sarda rivers and has three distinct portions. First, the tract of Bhabar, which lies immediately below the foot-hills with a strip of land about 32 km. wide in the west and gradually becoming narrower in the east. The word Bhabar means 'porous ground' and in fact during the summer months this tract has little surface drainage. In the rainy season the sub-terranean drainage appears above the boulders and gravel. Secondly, below the Bhabar is a wider strip of land, known as Tarai, a low marshy land infested by tall grasses and scrub and conspicuous by the 'ubiquitous' presence of water. In fact, the bulk of water from the rainfall and small hill-streams loses itself in Bhabar reappears again on the surface in the Tarai. As a result this tract is damp and marshy. The Tarai, particularly in its western part is dotted with springs, marshes, bogs, lakes and 'tals' of varying size and dimensions. The rivers Gandak, the Ghaghara, the Gomti, and the Ramganga are traversing the whole region with a number of tributary
streams of unstable character. In Tarai, the population is sparsely distributed and having migratory character due to unhealthy climate and prevalence of malaria.

Thirdly, the other districts of plain partake of the nature of Tarai, more especially in their northern portions. The rainfall is heavy and the streams are numerous. The whole tract looks like a sloping plain. Such types of lands are found in all the districts, viz., Saharanpur, Bijnor, Rampur, Bareilly, Pilibhit, Khor, Bahraich, Gonda, Basti and Gorakhpur running upto Nepal borders.

III. The Gangetic Plain

More than half of the total area of the State (about 86,041 sq. km.) is included in the great Indo-Gangetic plain. This plain is divided into five sub-regions (Fig.3).

(a) The Ganga-Yamuna Doab

This fertile tract has been enriched by the alluvial deposits of both the rivers, extending nearly upto 832 km. in length and 104 km. in width in the upper part covering an area of about 58,400 km. of the State (Fig.3, III a). It is lying in the form of a trough between Himalayas in the north and the Deccan plateau in the south. The alluvial deposits brought by the Himalayan rivers consist of sediments, silts, and clays with occasional gravel belts.
UTTAR PRADESH
PHYSICAL DIVISIONS

I MONTANE TRACT
II SUB-MONTANE TRACT
III GANGETIC PLAIN
   a Ganga-Yamuna Doab
   b Ganga-Gomti Interfluve
   c Gomti-Ghaghara Doab
   d Trans-Ghaghara Districts
   e Rohilkhand Districts
IV TRANS-YAMUNA TRACT

FIG. 3

SOURCE:
ECONOMIC GEOGRAPHY
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The soils of Doab are alluvial and geologically fall into two divisions: the new alluvium or khadar and the old alluvium or bangar. The khadar soils here are found in the narrow flood plains of the rivers, and the bangar soils varies in accordance with their topographic features and drainage.

This part of the State possesses the highest agricultural productivity. Most of the districts are more advanced and production per hectare and per person is highest as compared to the rest of the State.

(b) Ganga-Gomti Interfluve

The region lying between the Ganga and the Gomti is less fertile compared to that of Ganga-Yamuna Doab. The reason for this is that most of the area is commanded by the Gomti itself and its tributaries which rise from a lake. On account of very gentle gradient of the plain, the Gomti flows in a tortuous course and as a result the command area is dotted with numerous small lakes, which are mostly seasonal in character. During the hot weather season their water is evaporated, but during the wet monsoon months their water overflows and inundates the neighbouring lands resulting in waterlogging. The fertility status of the soil in the Ganga-Gomti Interfluve is generally low because of the fact, that this tract receives less of silt and more of sand during floods.
(c) Gomti-Ghaghara Doab

In the tract between Gomti and Ghaghara the soil deteriorates further, because the Ghaghara brings a huge amount of sand in the wet monsoon, so the commanding areas of this river have a higher percentage of sandy soil. Agricultural practices largely depend on monsoon rainfall. Great variations in agricultural outturns occur due to the variations in the amount of rainfall and the quality of soil.

(d) Trans-Ghaghara Tract

This tract forms the northeastern part of the Gangetic Plain and is a well demarcated physical unit hemmed in between the Himalayas and its Tarai in the north, and the Ganga-Ghaghara Interfluve in the south (Fig.3, III d). The soils of this tract may be grouped under two distinct types, locally known as bhat and bangar. The third type of soil known as dhab occurs nearly on the river banks. The bhat soil which is generally lowlying calcareous, retentive of moisture and does not require much irrigation in the normal years covers the eastern extremity of the tract. Sugarcane is the main crop. These soils are comparatively inferior to those of the Gomti-Ghaghara tract. Irrigation facilities are inadequate and the agricultural operations largely depend on rainfall.
(e) Rohilkhand Tract

The adjoining districts, viz., Bijnor, Moradabad, Rampur, Pilibhit, Budaun, Bareilly and Shajahanpur to Hontane tract, are known as Rohilkhand tract (Fig. 3, III e). This region of the State derives little benefit from the major river and canal systems of the State. The region is not susceptible to floods and therefore, the soil is poor in its nutrient character. The northern portion of these districts possess climate and natural vegetation similar to that of Tarai region.

IV. Trans-Yamuna Tract

On the southwest and south lies two small tracts belonging to natural divisions of India which differ considerably from the main portions of the State. The four districts of Jalaun, Banda, Hamirpur and Jhansi form part of the Central Indian Plateau. The tract is situated on and below the eastern slopes of the great plateau with a gradual fall from southwest to northeast. The soils are largely rocky and infertile with considerable patches of the richer type known as, 'black soil' which differ entirely from the alluvial soils of the great plain.

Mirzapur, the largest district occupying the southeastern part of the State also forms the part of the plateau. The spring level is low, canal system is not well
developed. The tract either suffers from an excess or a deficiency of rainfall, and as a whole ranks agriculturally the poorest and most backward region of the State.
CHAPTER II

CLIMATE

The entire State has tropical monsoon climate, except the Himalayan region where the climate is designated as temperate. It is characterised by a rhythm of seasons which is caused by the south-west and north-east monsoons. The pressure reversal takes place regularly twice in the course of year. At the time of north-east monsoon winds are of continental origin and blow generally from west to east, while during south-west monsoon they are oceanic in origin and blow mostly from east to west. The pressure gradient during the north-east monsoon is quite gentle and the winds are, therefore, weak. During the south-west monsoon the intensive heating of north-west India produces steep gradients owing to which the winds are quite strong. Taking into consideration the nature and directions of winds, they are termed appropriately as dry and wet monsoon respectively.

The two agricultural seasons of kharif and rabi closely follow the dry and the wet monsoons. The dry north-east monsoon extends from November to the middle of June. The first three months record low temperatures, and the last three have high temperatures. The whole period can be divided
into two seasons: (i) Cold weather season, and (ii) Hot weather season. The cold weather season extends from November to February, and the hot weather season lasts from March to mid-June. The cold weather season corresponds with the season of rabi crops, while the hot weather season is generally dry and does not permit cultivation until the onset of the south-west monsoon. Zaid crops consisting of melons, water-melons and cucumbers are grow with the help of irrigation. The wet monsoon months of the year i.e., from mid-June to October correspond with the crops of kharif season. Thus the whole year in the State of Uttar Pradesh is divisible into three separate seasons:

(i) The cold weather season (November to February)
(ii) The hot weather season (March to mid-June)
(iii) The season of rains (mid-June to October)

The Cold Weather Season (November to February)

During the month of November a high pressure belt extends from northwestern India and covers the Indus and

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1. Indian Meteorological Department, has devised a four-fold climatic divisions of the year grouped under the two monsoons as follows:
(a) The season of north-east monsoon:
   (i) January and February; cold weather season,
   (ii) March to mid-June; hot weather season.
(b) The season of south-west monsoon:
   (i) Mid-June to mid-September; season of general rains,
   (ii) Mid-September to December; season of retreating monsoon. These divisions are purely based on the meteorological conditions and do not consider the agricultural seasons of the year. In appreciation of the climatic influence on the agriculture of the area, the writer has followed the common classification of the three seasons correspond with the three agricultural seasons of the year.
Ganga valley and passes through the Bundelkhand tract of the State from northwest to southeast. The prevailing direction of the winds from west to east is usually determined partly by pressure distribution and partly by stretches of the Himalayan relief. The pressure gradients are not steep to produce strong winds, therefore, the breezes are very light in November and December with a velocity of 2.7 km. per hour. But, as the pressure increases in the month of January and February the gradient becomes a little steep, the velocity increases to 3.5 and 4.3 km. per hour in the each respective month.

It will be seen from Figs. 4 & 5 that the mean minimum temperature in the month of November at Roorkee, Aligarh, Bareilly, Jhansi, Allahabad, Gorakhpur and Bahraich ranges between 5°C and 10°C, but the mean maximum temperatures at the above stations ranges between 29°C and 33°C. The month of December records a further decrease both in the mean minimum and maximum temperature. The mean minimum temperature ranges between 2.5°C and 6.5°C. While the mean maximum shows range between 25°C and 27°C. The days in December are less warm, and the nights are cooler than November.

3. Seven stations covering different parts of the State have been selected to present the temperature condition of the State. Calculations are based on the sixty years record collected from Indian Meteorological Department, New Delhi.
MEAN MONTHLY TEMPERATURES

**FIG. 5**

**ALIGARH**

**GORAKHPUR**
The month of January is the coldest of the whole year and records lowest temperature conditions. The mean minimum temperature in this month at the above mentioned stations ranges between $2.0^\circ C$ and $5.4^\circ C$. While mean maximum temperature ranges between $24^\circ C$ and $26^\circ C$. The occurrence of frost is quite rare, but during December and January, fog is often formed owing to temperature inversion in the three hours before or after sunrise. In February, the temperature begins to rise but the mean monthly minimum and maximum temperature still remains relatively low compared to that of November. The days are warm but the nights are cool in this month.

During this season, the velocity of the wind is least in November, but gradually increases with the advance of the season. During the months of November to February, the velocity ranges between 3 and 5 km. per hour\textsuperscript{4} at the above mentioned stations.

A significant climatic feature of this season is the occurrence of frost which adversely affects certain crops like, arhar (pigeon pea), peas and gram are most susceptible to its adverse influence. Both, fog and frost\textsuperscript{5} are liable to

\textsuperscript{4} Climatological Tables of Observatories in India, op.cit., p.121.
\textsuperscript{5} The fog is locally known as 'kohra' while frost as 'pala', which is cooler than the kohra.
occur mostly in the coldest months i.e., December and January. The fog usually occurs after a winter precipitation and lasts for one or two nights.

During the season, the relative humidity\(^6\) remains low in November being 79 per cent at Roorkee 53 per cent, at Aligarh 77 per cent, at Bareilly 70 per cent, at Allahabad 54 per cent, at Jhansi and 76 per cent in Gorakhpur and Bahraich. In January it generally increases but again decreases in February.

During the months of December, January and February a few depressions bring some rainfall. Most of these depressions are supposed to originate in the Mediterranean Sea, and few coming as distant as North Atlantic and passing over Iran move towards the east and come as far as the mid-Gangotic valley.\(^7\) Other believe, that a fragment of the polar front is to be found in northwestern Indo-Pakistan, where northwesterly continental air invades the realm of the Indian Trades. Not frequently, those westerlies and their front extend well down the Ganga valley. Weak depressions develop along the front in northern India, providing a modest amount of winter rainfall.\(^8\)

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Some believe, that the Indian monsoon is closely connected with the trade winds of the northern hemisphere and say, that the high pressure zones formed in the northern part of India play an important role in the origin of the winter monsoon in India.9

The precipitation from these western disturbances is usually fairly widespread and light to moderate.10 The winter rains are important for rabi crops. But the failure or deficiency of winter rainfall affects seriously the yield of the rabi crops in northern India.

The stations in the vicinity of Himalayas receive greater precipitation than those lying far away. Fig. 6 shows that some northern stations like, Dehra Dun, Naini Tal, Pauri and Almora receive greater rainfall than the central stations namely, Farrukhabad, Kanpur, Lucknow and Bara Banki. Southern stations of the State also receive less rainfall, viz., Jalaun, Jhansi, Allahabad and Kirzapur. The total rainfall varies from 180 mm. at Naini Tal to 157.2 mm. at Dehra Dun in the north to 50 mm. and 42.8 mm. at Lucknow and Sultanpur respectively in the centre, and 52.4 mm. and 54 mm. at Jhansi.

and Allahabad respectively in the south, 56.61 mm, 46.3 mm, and 38.2 mm at Bahraich, Basti and Deoria respectively in the east and northeast. Stations situated in the west receive rainfall less than the range of 35-45 mm.

The number of rainy days ranges on an average from 1 to 1.5 in a month, and in the whole season from November to January from 2.5 to 4.5. The number of total rainy days in the season is, however, greater at the northern stations of Naini Tal and Dehra Dun than the southern stations.

The Hot Weather Season (March to mid-June)

The second half of the dry monsoon period includes the months of March, April, May and the first half of June. From the beginning of March, the temperature rises abruptly and there is a continuous fall of pressure. In this month the mean monthly temperatures at Roorkee, Aligarh, Bareilly, Jhansi, Allahabad, Gorakhpur and Bahraich ranges between 21.0°C and 25.8°C. The mean minimum temperatures at these stations between 7.5°C and 12.5°C and the mean maximum between 34.5°C and 39.2°C. The days are thus warm and the nights are cool and pleasant.

A further increase in temperature takes place in the month of April. The mean minimum temperatures of the above mentioned stations ranges between 12.6°C and 19.1°C, and
the mean maximum between 40.1°C and 43.2°C. The mean monthly temperature of this month ranges between 26.3°C and 31.1°C.

The temperature reaches its climax in the month of May. The mean minimum temperature at the above stations varies between 18.3°C and 23.4°C, and the mean maximum ranges between 42.6°C and 45.6°C. While the mean monthly temperatures are between 30.4°C and 34.5°C (Fig. 4). The excessive temperature conditions often continue and have a desiccating influence on the vegetation up to mid-June till the advent of the summer monsoon. The months before the outbreak of the monsoon namely, May and June are the hottest in Uttar Pradesh.

The relative humidity during this season remains always less than any other season. At Roorkee, it is 64 per cent in March but this percentage is reduced to 44 per cent in April and 42 per cent in May. Similarly, at other stations of the State, at Aligarh it is 50 per cent in March and is reduced to 32 per cent in April, at Allahabad it is recorded as 47 per cent in March and goes down to 35 per cent in April.

The prevalence of hot dry westerly winds, locally known as lfoo throughout the hot season which contain little moisture. The strength of these winds is subject to considerable diurnal variations. The lfoo blows during the
day with a normal speed of 8 to 9 km. per hour at Aligarh, 7.5 to 8.5 km. per hour at Allahabad, 6.8 to 8.0 km. per hour at Jhansi. The velocity of these winds increases from 9 a.m. till noon and whenever, the conditions favour the winds below almost with a gale force until 2 or 3 p.m. and during the evening hours they end. Occasionally when these winds are most vigorous, the humidity to as low as 2 or 3 per cent.

The occurrence of dust storms locally known as 'andhi' also form an important feature of this season particularly in the closing hours of hot day. The andhi produces a huge cloud of dust which prevail over the surface and within few minutes it obstructs the visibility in the atmosphere. These storms occur due to abnormal high temperature and least air pressure with a hot calm atmosphere. They originate generally in the afternoon or in the evening, and occasionally at night. Their velocity abnormally remain 30 to 50 km. per hour. These storms are short-lived and frequently end up in light showers of rain; sometimes they are accompanied by hail and thunder storms which modify the weather for a short period.

The rainfall during the hot weather season is associated with the storms that often form violent squalls

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11. The wind speed is based on the records climatological tables for different stations, Climatological Tables of Observatories in India (New Delhi, 1953).
during the heat of day. These squalls are formed owing to conventional over-turning of dry cool north-westerly wind blowing at some height above the surface of earth and hot moist wind from the sea blowing at ground level underneath the dry and cool wind. These squalls are formed in the excessive heat of the day but the downward moving cool air of the upper strata causes sufficient cooling of the air before the approach of the squalls. These squalls are accompanied with condensation in the upper air but there is rarely any rain as owing to excessive heat in the lower layer, it is again evaporated before reaching the ground or is soon evaporated after its fall. The total rainfall received from the squalls during the three months March to May ranges above 100 mm. at the northern stations of the State and from 22 to 50 mm. at the remaining stations (Fig. 7). Since the rainfall is associated with the occurrence of squalls, it is very much irregular in its incidence. The characteristics of rainfall of this season may be summarized as being sporadic, short-lived, subject to great local variations, and frequently repeated day after day for many days in succession about the same hours.

The high temperature, low humidity and cloudless skies of March and April favour the ripening of rabi crops.

UTTAR PRADESH
RAINFALL IN SUMMER MONTHS
(IN MILLIMETRES)
MARCH–MAY

FIG. 7

SOURCE
MEMBERS OF THE INDIAN METEOROLOGICAL DEPARTMENT
VOL XXIII PART II
and are helpful in the process of winnowing. The increased wind speed in April and early May helps much in winnowing the cereal grains. After harvesting, the fields remain barren and ceases, till the advent of the monsoon rainfall, as the vegetative growth in the latter half of the season is hindered due to dessicating effect of excessive dry weather conditions.

The Season of Rainy (Mid-June to October)

In June the features of hot weather season become more intensified and the continuous heat and dryness of the air causes unbearable conditions. With the 'burst' of monsoon, it brings a complete change in the weather. Its major effect is a great fall in the temperature, the mean minimum temperature at Roorkee, Aligarh, Barcolly, Jhansi, Allahabad, Gorakhpur and Bahraich ranges between 20.9°C and 24.0°C, and the mean maximum temperature varies between 41.4°C and 44.2°C. The mean monthly temperature of this month ranges from 32.2°C to 34.5°C.

Each of the mean minimum, mean maximum and mean monthly temperatures (Figs.4 & 5) has gradually a continuous fall from June to the end of August at all stations. The mean maximum temperature in September shows a little increase from August, but the mean minimum temperature records a decrease.
During this season, the hailstorms, fog or frost are commonly absent. The relative humidity increases from June to August. A comparison of relative humidity at different stations shows, that in each of the months from July to October it remains generally high. In the northwest at Roorkee it is about 80 per cent, at Gorakhpur in the northeast about 85 per cent and at Allahabad in the south about 82 per cent. It is highest at all stations in the months of July and August - the period of growth of the kharif crops.

The jet monsoon stream, characterised by heavy and prolonged rainfall is a large scale inflow of moist maritime air. It gives widespread rains over most of the area (Fig. 8). The setting of monsoon rainfall is not equal in all parts of the State. The time of its occurrence at various places may also vary. The average rainfall during the monsoon months varies from west to east the areas being below 700 mm. are in the west (695 mm. at Meerut, 577 mm. at Bulandshahr, 693 mm. at Aligarh and 488 mm. and 619 mm. at Mathura and Agra respectively), and more than 1000 mm. in the east (at Basti 1200 mm, Gorakhpur 1260 mm, Dooria 1050 mm, Ghazipur and Ballia 1070, and 1100 mm. respectively).

A comparison of Fig. 9 shows that 80 to 90 per cent of the annual rainfall is received during the five months -
UTTAR PRADESH
AVERAGE ANNUAL RAINFALL

IN MILLIMETRES

- Over 2000
- 1100 - 1200
- 1000 - 1100
- 900 - 1000
- 800 - 900
- 700 - 800
- 600 - 700
- Less than 600

SOURCE
Averages are based on monthly and annual rainfall data recorded in Uttar Pradesh 1935 to 1971. Data of U.P. Lucknow

FIG 8
June to October, 5 to 10 per cent is received from November to February and 2.5 to 5 per cent is received in March to May. Rainfall distribution has the same pattern in the wet monsoon as that of the annual rainfall and decreases from east to west as well as from north to south. The period of wet monsoon does not constitute a continuation in rainy days, but the outbursts of rain are alternated with the spells of fine and pleasant weather, which are very much advantageous to the crops of that season. These spells of fine weather are produced by 'a shoulder of high pressure' and short-lived covering the whole of Uttar Pradesh by pushing the axis of the low pressure trough of North India towards the foothills of Himalayas. Due to such conditions the easterly winds fail to cross the Ganga Valley and this causes a break in the monsoon. Therefore, the stations located in the upper Ganga valley receive less rainfall.

VARIABILITY OF RAINFALL

Annual Variability

The annual variability, of rainfall in Uttar Pradesh ranges from 8 per cent at Allahabad to about 20 per cent

15. The variability of annual as well as in the wet monsoon rainfall has been calculated by the writer on the method evolved by F.R. Crowe. The rainfall contd.....
at Mathura (Fig. 10). A comparison of average annual rainfall and the mean annual variability (Figs. 8 & 10) shows, that in the northwestern and western parts of the State where the distribution of rainfall is less, has proportionately higher data for 37 years (1935-71) obtained from the records of Monthly and Annual Rainfall in Uttar Pradesh were arranged in ascending order for separate stations. Upper quartile, median and lower quartile were marked in the series and the variability of rainfall in interquartile range as percentage to the median was computed. The method would be read as follows:

\[
\text{Upper Quartile} - \text{Lower Quartile} \times \frac{100}{\text{Median} \times 2}
\]

Normal rainfall obtained for a number months or year by arithmetic mean is quite erroneous owing to its obvious shortcoming of being sensitive to occasional heavy rainfall. The variability computed from these normals is also liable to serious errors. The method evolved by Crowe is based on quantitative foundations, and the values derived by this method are more expressive of the sequence of rainfall and its variation in each months.

For a detailed knowledge of the method evolved by Crowe, and its application to rainfall studies of different regions see:


UTTAR PRADESH
MEAN ANNUAL VARIABILITY
(IN PERCENTAGE)

SOURCE
The percentages have been computed on the basis of
monthly and annual rainfall table recorded in
Uttar Pradesh 1925 to 1971, Govt of U P Lucknow

FIG. 10
tendency of deviation from the mean than the southern and northeastern parts where rainfall is relatively high. The area of the largest percentage of mean annual variability corresponds to the area of the least rainfall in the summer monsoon months i.e., mid-June to October as well as to that of least annual rainfall (Fig. 10). Here the variability of rainfall both at Roorkee and Hathura is 20 per cent and Meerut 19 per cent. The other area of high variability extends in the eastern part of the State, the variability being 19.2 per cent at Jaunpur, 14.2 per cent at Sultanpur, and 13.5 per cent at Ghazipur. Besides these, there are certain pockets where variability is high, such as Hardoi in the centre where it is 14.2 per cent and in the Naini Tal a mountainous area where it is 17.5 per cent.

It is assumed, that any place with a rainfall variability of 12 per cent or is liable to the occurrence of famine and in this respect most of the areas of Uttar Pradesh with the exception of a small pockets in the south and northeast are susceptible to famine. The total rainfall at different stations has generally large variations from the average from place to place as well as from year to year, which is particularly a common feature due to fluctuating

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nature of rainfall makes agriculture in certain regions of Uttar Pradesh precarious and artificial arrangements for irrigation have been made to irrigate the cultivated land in those areas. For instance, the annual rainfall at Roorkee in 1935 was 500.2 mm, which is below the average, while in the same year, it was above the average at Muzaffarnagar, Jhansi and Gorakhpur being 707.7, 1021.4 and 1230.7 mm, respectively. Similarly, in 1940 the rainfall was 1115.4 mm at Bareilly, being above the average, when it was 537.5 and 819.0 mm at Muzaffarnagar and Jhansi respectively, which is below the average. It was below the average in 1960 at Bareilly and Gorakhpur stations. The year 1971 shows a variation above the average at Muzaffarnagar, Sultanpur, Mirzapur, and Gorakhpur (Figs. 11, 15, 16 & 17).

The variability in the distribution of rainfall also exists from one year to another at a certain place. If the rainfall in one year is on the average, it is liable next year to be below or above the average. The annual rainfall for example, at Roorkee was below the average in 1964, whereas, in its preceding year it was recorded far above the average (Fig.14). The rainfall at Muzaffarnagar received in 1942 was more than the double what it was recorded in the preceding year (Fig.11). This type of climatic phenomena can be observed at any station. The monsoon activities and the distribution of rainfall are liable to considerable variations.
ANNUAL RAINFALL
1935-71

MUZAFFARNAGAR

FIG. 11

BAREILLY

FIG. 12

JHANSI

FIG. 13
It can be seen from the Figs. 12 to 19, that the rainfall in a given year is more than enough at a place causing conditions of floods while at another place it may be lesser than the average or equal to the average in the same year. For instance, during 1940 the rainfall was below the average at all stations excluding Sultanpur and Ghazipur, where it was recorded more than the average (Figs. 15 & 18).

Variability in the Wet Monsoon Months

About 90 per cent of the total rainfall in Uttar Pradesh is received during the wet monsoon months. From agricultural point of view, the distribution and variation of rainfall in these months is quite significant owing to its effect on the crops of both kharif and rabi seasons. Whenever, the rainfall is excessive during the month of June the sowing date of early kharif crops is delayed leading to low yield of the crops. September is the most critical month for the farmers as any excess or deficiency of rainfall in this month has large-scale repercussion on the crops of kharif and rabi season. Rainfall in this month is necessary to mature kharif crops and to soften the ground for rabi ploughing. But, heavy falls lead to water-logged conditions, while premature condition of the rains may cause postponement of restriction of rabi sowing.\(^\text{17}\) On the other hand, if the

monsoon rain comes in light but in regular showers and lasts till the end of September, the outturn of kharif crops is good, and apparently there is a large extension of the area under plough for sowing rabi crops. In this way, the agricultural operations are largely controlled by the rainfall of this month. The timely distribution of rainfall is rather more important than the total rainfall of the year. The extent of variability to which these months are liable is given in the Table I. The range of monthly variability is shown in the rainfall dispersion diagrams (Figs. 19 to 28).

It will be seen from Table I, that the variability in the month of June is sufficiently high at Bulandshahr and Jhansi being 40.90 and 40.76 per cent respectively and varies between 46 to 50 per cent at Aligarh and Ballia. Among other places, it is 35 per cent at Roorkee, 37.5 per cent at Jaunpur, 45 per cent at Mathura and 41 per cent at Allahabad. The months of July and August have the least variability, below 35 per cent throughout the State. And at certain stations, it is as low as 5.5 per cent at Jalaun and 10 per cent at Kheri. The value of variability in the month of September ranges from 52 and 62 per cent respectively at Ballia and Meerut. In this month too, we notice a high variability. In the month of October, the variability figures further go up to a maximum level as 80.5 per cent at Bulandshahr and 60.5 per cent at Etah.
RAINFALL DISPERSION DIAGRAMS
JUNE-OCTOBER
1935-71

MILLIMETRES
000

ROORKEE

MEERUT

ALIGARH

BALLIA

JEHRA DUN

FIG. 19

FIG. 20

FIG. 21

FIG. 22

FIG. 23
TABLE I

Mean monthly and annual variability at selected stations in Uttar Pradesh

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</tr>
<tr>
<td>Gonda</td>
<td>28.57</td>
<td>24.71</td>
<td>19.09</td>
<td>17.44</td>
<td>46.87</td>
<td>20.00</td>
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</tr>
<tr>
<td>Bahraich</td>
<td>23.37</td>
<td>26.61</td>
<td>24.32</td>
<td>24.38</td>
<td>45.00</td>
<td>23.91</td>
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</tr>
<tr>
<td>Sultanpur</td>
<td>31.35</td>
<td>17.07</td>
<td>15.76</td>
<td>26.78</td>
<td>47.61</td>
<td>29.13</td>
<td></td>
</tr>
<tr>
<td>Bara Banki</td>
<td>23.07</td>
<td>23.97</td>
<td>17.79</td>
<td>15.86</td>
<td>36.48</td>
<td>30.45</td>
<td></td>
</tr>
</tbody>
</table>

Variability from the Median

The variability of rainfall from month to month i.e., June to October is shown on Figs.19 to 28 drawn after the method of Crowe for a monthly data of 37 continuous years. He points out, that the ordinary average rainfall at a certain place is sometimes insufficiently sensitive and at other times over-sensitive leading to extreme variations. In order to analyse the variability of rainfall from June to October by the Crowe's method the distribution of monthly rainfall covering a period of 37 years (1935-71) for ten selected stations has been shown on Figs.19 to 28. It should

18. Crowe, P.R., op. cit., p.73.
be pointed out at first, that among the selected stations Roorke, Meerut and Aligarh (Figs. 19 to 21) represent the northwestern part of the State, Ballia and Ghazipur are selected to represent the extreme eastern part, Dehra Dun and Naini Tal are representatives of sub-Montane tract, the Gorakhpur station represent the Trans-Ghaghara plain i.e., northeastern part, and the remaining two stations Hardol and Sultanpur are selected to represent the central part of the State.

The rainfall dispersion diagrams of the three northwestern stations (Figs. 19 to 21) show a considerable similarities. Here both the months July and August enjoy the highest rainfall and similar patterns in dispersion of rainfall and do not possess any difference which may be encountered as an important aspect for agriculture. Both Ballia and Ghazipur eastern most stations follow the same pattern of dispersion as that of northwestern stations. The picture at two northern stations is rather critical. The four months here starting from June to September show a pronounced variability (Figs. 23 & 24). Therefore, the sowing periods are liable to be affected very seriously. The variability at Gorakhpur is quite significant for the three months July to September as compared to other stations (Fig. 25). The dispersion pattern at both the central stations, viz., Hardoi and Sultanpur is to some extent identical, in the sense, that
both of them show no significant difference (Figs. 26 & 27). Rainfall dispersion in the months of July and August at both of them is largely variable. And at Hardoi station too, shows little variability in the months of June and October.

During the month of October the inter-quartile range at the three northwestern stations (Figs. 19 to 21) is very small and there were six years in which this month received not a single drop of rain, and about four years in which rainfall was insignificant. The rainfall received in the month of September shows a higher range of variability at eight out of ten stations except, Dehra Dun and Naini Tal, where it is significant also in the month of June. Consequently, the agricultural operations depend out on variability of those months.

It may thus be seen at all stations more or less during three months i.e., July to September dispersions of rainfall are fairly significant as indicated by inter-quartile ranges. But this variability during these months is of less significance in view of heavy amounts of rainfall received. But, for the month of June, much smaller variability may hinder the agricultural operations because monthly median remains low and further any reduction in this amount can compel the farmers to postpone the agricultural operations.
Thus, the variability study of rainfall in the State of Uttar Pradesh leads one to conclude, that two months of October and June are most critical from the point of view of variability, and this may be followed by the month of September. It is also significant to note, that rainfall in both the months is liable to be deficient.
CHAPTER III

SOILS

Adequate scientific records are not available covering detailed informations about the soils of Uttar Pradesh. The oldest sources of information are, the Settlement Reports, District Gazetteers, Assessment Reports, and the Revenue Records which provide a textural classification of soils. The soil surveys of some scattered areas have been carried in recent years, which provide a generalised information and do not show accurately the soil sub-divisions of the area. A wide range of soils, both of residual and alluvial origin are found, and the major area is occupied by the alluvial soil (Fig. 29).

The residual soils occupy the Hilly, Bundelkhand and Vindhayan regions comprising the northern and the southern parts of the State. The alluvial soils are spread of the central part covering the whole of the region commanded by Ganga and Yamuna rivers, flanked in the west and east by well defined productive soils.

Based on geological and pedogenic characteristics, differing from one another seven well defined groups of soils have been recognised in the State. The detailed or even

reconnaissance soil map of the State has so far not been completed. A tentative map showing the distribution of soil groups prepared by the State Survey Organization is available (Fig. 30). The area occupied and the distribution pattern of each group of soil is given in Table II.

### TABLE II

<table>
<thead>
<tr>
<th>Soil groups</th>
<th>Area in hectare</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Hill soils</td>
<td>4,217,440</td>
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</tr>
<tr>
<td>Bhabar soils</td>
<td>590,510</td>
<td>2.00</td>
</tr>
<tr>
<td>Tarai soils</td>
<td>1,686,740</td>
<td>5.73</td>
</tr>
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<td>Alluvial soils</td>
<td>18,185,300</td>
<td>61.78</td>
</tr>
<tr>
<td>Vindhayan soils</td>
<td>1,501,290</td>
<td>5.10</td>
</tr>
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<td>Bundelkhand soils</td>
<td>3,192,440</td>
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</tr>
<tr>
<td>Aravali soils</td>
<td>63,290</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Source: Melhotra, C.L., Soils of Uttar Pradesh their Broad Distribution and Management, op. cit., p. 79.

**Hill Soils**

This group of soils is found in the northern portion of the State and accounts for 14.33 per cent of the area of the State, comprising the hills of Kumaon and Garhwal
and part of the southern outer spur of Himalayas belonging to extra peninsular region of immense thickness and represents all systems from Tertiary or Quaternary sediments of fluviatile nature. The spa-in of hill soils is extended into the eight hilly districts, viz., Almora, Chamoli, Garhwal (Pauri and Tehri), Naini Tal, Pithoragarh, Uttar Kashi and Dehra Dun. The parent rock materials are mostly biotite-schists and granite-gneiss. Regarding the fertility status the districts of Uttar Kashi, Chamoli and Pauri Garhwal have a fair preponderance of acidic soils, while those of Tehri Garhwal, Almora and Dehra Dun have small patches of acidic soils. The soils of Pithoragarh and Naini Tal passes very little acidic character. In this group of soils normal reaction predominate between the range of 59 to 66 per cent in the former three districts, and 81, 89 and 92 per cent the latter districts respectively. Practically, no alkaline soils are reported in this group, except for the district of Pithoragarh. The availability of phosphorus falls in medium category in the districts of Chamoli, Pauri Garhwal, Almora and Pithoragarh, the remaining districts show low phosphorus distribution. Potash distribution has been found to be high in Tehri Garhwal, Dehra Dun and Uttar Kashi, but

medium in the districts of Almora, Pithoragarh and Pauri Garhwal. The concentration of potash is low only in the districts of Chamoli and Naini Tal. Organic carbon is high in the soils of Uttar Kashi, Tehri Garhwal, Pithoragarh and Dehra Dun districts. The values of organic carbon are moderate in the soil of Chamoli, Pauri Garhwal, Almora and Naini Tal districts. The problem of high soluble salt contents is not found in this region.

The natural vegetations of the area are the forests of Oak and Pine, with luxuriant undergrowth of grasses, weeds and herbs.

Bhabar Soils

This group of soils occur only in the form of a narrow strip (Fig. 30) in the foothill region of the outer spurs of Himalayas throughout its east-west expanse in the districts of Dehra Dun, Saharanpur, Bijnor, Garhwal and Naini Tal. These soils have developed under a sub-humid and moist climate which becomes dry during summer months. These soils have been formed by the mechanically transported alluvium from the adjoining Siwalik and Himalayan ranges comprising sandstones in rapid state of weathering and conglomerates interstratified with boulders along with purple shales and clays.
The soils of the area are underlain by large or small sized pebbles and coarse gravel detritus, mechanically transported from adjoining hills. The soils are of dark grey to black colour and are moderately alkaline in reaction. They are rich in plant nutrients, but despite of this they fail to support normal cultivation, specially due to the acute scarcity of moisture resulting from the disappearance of streams coming from the adjacent Sivalik owing to rapid percolation. This excessive percolation results presence of the boulders made of sub-stratum below the surface which drains out all the water under ground and which ultimately emerges again in the adjoining Tarai tract.

These soils support only inferior crops of shorter maturity which require less water. Shifting cultivation is the usual practice in this area.

**Tarai Soils**

This group of soils occur immediately adjacent to the strip of Bhabar soils in the form of a narrow belt below the Himalayas extending from Dehra Dun in the northwest to the extreme northeastern district of Deoria in the State. The expanse of this type of soil is 5.73 per cent of the total area of the State (Table II). The Tarai tract can be
divided into two distinctly different systems: (i) northwestern Tarai extending from Dehra Dun to Kheri, and (ii) northeastern Tarai extending from Bahraich to Deoria district, up to its border with the State of Bihar. The climate in Tarai area is generally damp and unhealthy, and is categorised as sub-humid with annual precipitation ranging from 1000 to 1500 mm, maximum rainfall coming in the months of July to September. These soils remain saturated during the monsoon months and bear fairly moist nature during the succeeding winter due to the very high level of underground water. It is on this account, that these soils have received the nomenclature of Tarai, meaning the moist humid area. Ground water aquifers are very common in northwestern Tarai and artisan wells are frequently met within the region.

In Tarai tract, the soils have generally a normal reaction and normal salt content, except for the Tarai areas of Gorakhpur, which comprises the well known 'bhat' soil. These soils are deficient in available phosphorus in the districts of Saharanpur, Kheri and Gonda. In the remaining districts of this tract, viz., Bijnor, Bahraich, Basti, Gorakhpur and Deoria these soils have medium phosphorus status. Available potash content in the Saharanpur soils is high, but the soils in Bijnor, Gonda, Basti and Deoria districts are low to medium in available potash content.
Organic carbon status in this tract is generally medium except for Deoria and to some extent in Gorakhpur and Bahraich districts.

Soils of both western and eastern Tarai are productive and possessing initial reserves of plant nutrient specially the nitrogen which gets depleted within few years of intensive cultivation. They are ideally suited for relay or multiple farming. Balanced doses of fertilizers are most responsive in these areas.

**Bundelkhand Soils**

Bundelkhand lies on the southwest of the river Yamuna. The soils of the tract are entirely different from those of the State as a whole, since these differ geologically from the rest is being non-alluvial in nature. This tract constitutes about 10.85 per cent of the total area of the State and comprises the districts of Jhansi, Jalaun, Hamirpur and Banda. The soils have developed from the Vindhyan rocks abounding in gneiss and granites of the Deccan trap with highly ferruginous beds and often soft limestone.

Four broad soil associations have been recognized in this area, differing from each other in respect of colour, texture, parent material, depth and crop adoptability. These have been named as: (i) Bundelkhand coarse grained reddish
brown soils, (ii) Bundelkhand coarse grained grey to greyish brown, (iii) Bundelkhand clayey loam black, and (iv) Bundelkhand clayey black soils which are distinguishable in local parlance by the names of raker, parwa, kabar and mar.

In general, the agriculture of this tract is of a very low status. This is due to the poor nature of the soil and scarcity of water, these two important factors are responsible for this condition. Most of the cultivation is done during the kharif, while rabi cultivation is insignificant, except on good black soil. Jowar, small millets, and til are the principal kharif crops, and wheat, gram, and linseed are the principal rabi crops. Wheat and jowar are generally grown on better soils, and gram and smaller millets on the soils of lesser fertility.

The soils of Bundelkhand region have generally normal reaction and soluble salt contents. The soils of Jhansi and Banda districts can be classed in low category with respect to available phosphorus content, while that of Jalaun and Hamirpur in the medium category. All the four districts in Bundelkhand have low to medium available potash.

contents. Organic carbon status in this area is predominately of moderate category.

The natural vegetations of the area are shrubs and grasses, both tall and small ones. The soils are shallow and the parent rock is met within a depth of half to two metres. Balanced manurings are the most effective practices for optimum growth of crops.

**Vindhyan Soils**

These soils are residual in origin and occur in the State south of the river Ganga as to comprise the districts of Mirzapur, Varanasi and Allahabad, and cover an area not exceeding more than 5 per cent of the State's total area. These soils have developed on the decomposition products of the sub-adjacent rocks of the Vindhayan system. The soils of the region are broadly classified on the basis of their topography into three categories: (i) Vindhayan uplands, (ii) Vindhayan flats, and (iii) Vindhayan lowlands.

The Vindhayan uplands occupy high-level sites and are basically alluvial in nature being formed under excessive drainage. These soils are coarse grained, red and very shallow, poor in nutrients, resulting in sparse cultivation.
The Vindhayan flats soils have developed on flats having relatively poor drainage conditions. These soils contain more finer-grained material, the profiles are deeper and exhibit better moisture conditions than those of uplands.

The Vindhayan lowlands soils are associated with low-level sites and are consequently alluvial in character. These tracts constitute the most fertile portion of the districts which excessively grow rice.

Aravali Soils

This type of soils occur only to an insignificant proportion in southwestern corner of Agra district in Khairharh and Kirolie tehsils, adjoining outer spurs of Central Indian Hills at Bharatpur and Dholpur in the State of Rajasthan. The area under this type of soil in Uttar Pradesh is only 0.21 per cent of the total area (Table II).

These soils have been developed from various formations of Vindhayan sandstones including Kaimur group as the lowest member and Bhandar group as the highest. They are found in an advanced stage of disintegration having a thick soil material, but intermixed with undecomposed fragments of sandstones. These soils are coarse gravelly sands or even loamy sands depending on their location and
topography. They are gravelly and are known in local parlance as 'Bhur'. The soils support scanty cultivation and where inferior grains are grown.

**Alluvial Soils**

Alluvial soils constitute the most extensive soil formation of the State, accounting for 61.78 per cent of its total area. They occur in the central, eastern, western and the southern portions of the State with river Yamuna as its western and southwestern boundary for most of its expanse with the exception of a portion of Agra and Mathura districts, and river Gandak as its eastern boundary separating it from the State of Bihar. These soils have developed from the alluvium deposited by the two rivers Ganga and Yamuna, and their tributaries including Ghaghara, Gandak, Gomti and Ramganga.

Although the nature of the soils in alluvial areas differs widely from district to district, they have been broadly classified into a number of soil associations, named on the basis of the river family which has contributed to the deposition and development of soils in various districts. The soil associations recognised in each district in a particular river system comprise (i) riverine soils or the *khadars*, (ii) soils of flat lands, (iii) soils of uplands,
and (iv) soils of low lands. Although variations in soil characters from district to district are very wide, but the broad zonal features of these associations remain more or less the same. Soils comprising the recent alluviums are accordingly grey to ash grey in colour, light textured and of calcareous nature. The flat land soils are accordingly neutral to moderately alkaline and calcareous with accumulation of lime in the form of lime concretions at varying depths and sizes in lower layers of the soil profile. Soils of uplands exhibit most of the zonal characters, and the profile shows all the evidence of maturity. Low land soils are found in numerous pockets within the upland regions and have been formed from the washing of the finer material transported from the upland areas. The soils are grey to dark grey in colour, and clay loam to clay in texture.

The soils of Gangetic family differ from those of Yamuna family in morphological features of the soil profile as well as agricultural behaviour resulting primarily in the difference of parent material in the two formations. These differences have originated from the regions where the two rivers flow. Ganga covering a wide range of Himalayan rocks while the Yamuna flows for a considerable distance in the region predominating in basaltic rocks in Central Indian
Hills, through the outer spurs of which Yamuna flows in southwest Uttar Pradesh. The recent alluviums of this family are accordingly black coloured, and are of very fine texture, the soil profile shows a marked uniformity at all depths.

Alluvium found in the northeastern tract of Uttar Pradesh is laid down by the rivers Gandak and Ghaghara, the tributaries of Ganga, though following the same pattern of soil development in bottom lands, flats and uplands genetically differ from the soils of the Ganga plains, specially in respect of parent materials which is generally very highly calcareous and in an advanced stage of mechanical disintigration.

The alluvia on the left banks of the Ganga owe their origin to the alluvial material laid down by its tributary Gomti. The soil formation in this family is more or less similar in nature to that of Ganga, differing only in the degree of maturity.

In view of the fertility status, the soils of the alluvial tract almost in all the districts of northern region has normal pH values except, in Bijnor district where slightly acidic soils are also met with. The salt content in the soil in all these districts is normal with no problem of soil salinity. Available phosphorus and potash contents are low in all the districts except, in Bijnor where soils
are moderate containing phosphorus and potash. Organic carbon is low in all the districts with the exception of Bareilly and Rampur where it is moderate. With the exception of Aligarh district, the soil reaction of more than 80 per cent soils is in normal range. A very significant proportion of soils in Aligarh district are alkaline in reaction and are fraught with danger of soil salinity. All the districts except of Muzaffarnagar, have low concentration of available phosphorus and potash content. Organic carbon levels are universally low in this region, the least being in the soils of Agra district. In the central region the soils have normal reaction except in the districts of Farrukhabad, Lucknow, Kanpur and Unnao. Alkaline soils are more common in the districts of Farrukhabad, Lucknow, Kanpur and Unnao. Soluble salt contents are normal in all districts except, Unnao, Hardoi and Rae Bareli where 10 to 26 per cent soils have shown critical levels of salt concentration. Potassium status in these soils is medium and all the districts have shown lower concentration of organic carbon. Soils of eastern districts have generally a normal reaction, but the soils in Allahabad, Azamgarh, Ballia and Pratapgarh districts exhibit moderate alkalinity. The salt concentration in the soils of these districts is found to be normal. The soils are deficient in available phosphorus status in all the districts except, in Deoria, Gonda, Basti and Gorakhpur
districts. The soils in these districts have moderate available potash status. Soils of these districts are poor in organic matter except, the district of Gonda where the soils have medium level of organic carbon. Soils of Pratapgarh district are on the border line between low and medium categories of organic carbon.

Agriculturally the alluvial soils of Uttar Pradesh are highly productive and constitute one of the most fertile formation of the country. They have immense potentials for increasing crop productions and it is from these soils that the agricultural production levels have lately be achieved by adopting high yielding varieties of seeds and improved practices of cultivation.

**Intrazonal Soils**

Within the zonal group of alluvial soils two important intrazonal categories of soils have been recognized in Uttar Pradesh. These include: (i) saline alkaline soils, and (ii) karail soils. These two types of soils have been developed due to local influences, mainly hydrological, climatic and halomorphic.

1. **Saline Alkali Soils**

These soils are found all along the alluvial region but mainly in central and northwestern portion of Ganga-Yamuna
Doab including a very significant concentration on the left side of Ganga. The greatest concentration of such soils are found in the districts of Meerut, Bulandshahr, Mainpuri, Aligarh, Etah, Farrukhabad, Etawah, Kanpur, Unnao, Fatehpur, Allahabad, Rae Bareli, Lucknow, Pratapgarh, Sultanpur and Hardoi. Even the districts of Azamgarh and Varanasi which are located under relatively less arid climate could not escape the hazards of soil salinization. The factors which have contributed to the formations of this group of soils are the parent material, climate, topography and the drainage. The parent material of this group of soil comprises the alluvial deposits in riverine areas forming saline soils and finely washed material accumulated in the depressions within the zonal tract or innumerable low lying pockets within the landscape of the alluvial regions.

The soils have been commonly categorized into saline soils, saline alkali and non-saline alkali soils. More common category of intrazonal soils in this state is of saline alkali type which occurs in large or small blocks with extensive deposition of salts on the surface during dry months.

(ii) Karail Soils

The black coloured and very fine textured Karail soils occur in the Ganga valley below the point of confluence of Yamuna with Ganga in southeastern part in the district of
Allahabad, Mirzapur, Varanasi, Ghazipur and Ballia. Extensive patches of such tracts are usually found in the deep interior of the region where the river forms circular loop like bends in its course. Closely related black soils are also found in the higher reaches of the alluvial plains principally in the water sheds of Yamuna, even in the districts of Aligarh, Etawah, Kanpur and Fatehpur from the alluvial material transported by the river Yamuna.

Three groups of soils have been recognised in this formation; light shallow Karail soils, deep medium Karail soils, and deep heavy karail soils, which occur respectively in khadar, trans-khadar and lowland tracts of the region adjacent to the course of Ganga below the point of its confluence with Yamuna.

These soils are composed of black heavy clays of considerable depths underlain by coarser alluvial material. The soils have cloddy or prismatic structure, cracking on the surface in dry months and occasionally forming big fissures through the vertical column of the soil profile. They swell on getting wet and become extremely sticky. Ploughing of these soils present colossal problems to the farmers, principally due to their physical characteristics in which they dry or swell during summer months and any delay or
advanced handling makes the tillage operations in these areas almost impossible. The problems get worsen during kharif season when the soils become extremely plastic in nature and cannot be tilled.