PART I. GENERAL PHYSICAL FEATURES.

CHAPTER I.—PHYSICAL FEATURES.

This report deals with the occurrence of floods in the delta of Orissa which comprises the three administrative districts of Cuttack, Puri and Balasore. It lies approximately between 19° 28′ and 21° 57′ N., and 85° and 87° 29′ E., and is a narrow strip of alluvial soil formed by the deposit of silt brought down by the rivers. The width of the delta never exceeds 60 or 70 miles and is at places only from 15 to 20 miles wide. It is bounded on the east by the Bay of Bengal. In the north-east the river Subarnarekha very nearly forms the boundary between Orissa and the province of Bengal. In the north and the west the delta is overhung by the uplands of the Orissa Tributary Mahals, which form a southerly projection of the hills and rivers of Chota Nagpur. Some of the smaller rivers of Orissa take their origin from these hills, others draw their main supply from huge tracts of undulating uplands on the further side of these ranges. In the south the delta is bounded by the lake Chilka and the Presidency of Madras. The area of the delta is about 8,000 square miles, and the population in the three districts of Puri, Cuttack and Balasore according to the Census of 1921, was 4,202,461.

From the point of view of floods the area in the centre and in the south consisting of about 3,300 square miles is the most important. The greater part of this area (about 2,300 square miles) consists of the Mahanadi delta watered by the innumerable branches of that river. The north central area (about 800 square miles) is the Brahmini-Baitarani delta watered by the different distributaries of the rivers Brahmini and Baitarani. In the extreme north is the Subarnarekha delta drained by the Subarnarekha and some minor rivers. All the rivers run directly into the Bay of Bengal, except a few branches of the Mahanadi in the district of Puri which run into the Chilka lake.

The delta can be divided into three distinct zones, each of which runs roughly parallel to the sea coast.

The salt tract.—Along the coast line lies a narrow strip of salt tract from one to six miles broad, traversed by innumerable sluggish streams with coarse jungly growths of canes, brushwood, and reedy grass on either side, and full of swamps and morasses. The tract is purely alluvial, and subject to inundations from the sea which renders it unfit for cultivation; towards the sea the soil has a distinct saline taste. Near the beach rise sandy ridges from 50 to 80 feet high, sloping inland and covered with scrubby vegetation, as also sand-hills covered with creepers which the rivers find difficult to pierce. Further inland lies a prairie land of long grass and scrubby jungle practically uninhabited and uncultivated, although here and there some of the low lands are used for grazing purposes. On the western boundary of the marshy woodland lie long lines of villages.

The arable belt.—The second belt is a level plain about 40 or 50 miles broad lying between the maritime salt lands on the sea coast and the hilly country on the west. It is a dead level of rice fields with a light friable soil, sparsely wooded except round the villages where it is dotted with magnificent groves of mango, banyan, pipal, tamarind and bamboo trees.

The Balasore-Cuttack-Ganjam Trunk road, the Bengal Nagpur Railway line from Cuttack to Waltair, and the High Level Canal Ranges I, II, and III, all run roughly parallel to the coast on the western boundary of this tract. It is intersected by several large rivers which, emerging from the western mountains, throw a net-work of branches in every direction, and is also traversed by the Orissa Canals.

This is the most fertile and densely populated area of Orissa, and the aim of all schemes of flood control developed so far has been to protect this patch of land. The problem of flood regulation in this division, however, is one of peculiar difficulty owing to the fact that the land is extremely flat and practically without any slope throughout its breadth. Consequently the speed of the water coming down the rivers decreases rapidly. This leads to a tremendous amount of deposit of silt and sand every year in the drainage channels.

In the absence of any systematic scheme of river training a continual deterioration of the rivers is inevitable. It is estimated that the deltaic rivers in spite of their great number, are unable to carry away even 50 per cent of the water brought down by the main streams from the western mountains. Therefore, as we shall see later on, the delta suffers badly from even moderate floods in the main rivers. It is only when a very heavy flood occurs (for example such as those in 1872, 1896, 1911, etc.) that a part of the sand is cleared away by the rush of water. and in consequence the effects of very heavy floods are indirectly beneficial to some extent even from a flood point of view.

The Sub-montane Tract.—The third belt is the sub-montane tract of land lying between the Tributary States and the level plain on the east. It is an undulating country with a red soil, in which masses of laterite buried in hard ferruginous clay crop up here and there. The land is broken up into ravines clothed with prickly thorns and stunted shrubs. The hill ranges which are irregularly scattered are for the most part covered with vegetation. None of them is more than 2,500 feet high, and from their rounded form it is evident that they were at one time subject to marine action. Large tracts of this area are covered with *sal* trees, and the country is broken up by the hills into narrow fertile valleys intersected by small hill streams.

There is a great diversity of level in this area, but on an average it may be said to lie between the 500 feet, and 250 feet contour lines. The drainage slope is therefore quite satisfactory, and the country is practically immune from river floods, although it is liable to occasional damage from abnormally heavy local rain.

The western hills belonging to the Archaean crystalline group consists of excessively hard granite rock. To the west and south-west, the structure alters considerably, becoming a hard tough indistinctly crystallized horn-blendic rock, and further south-west quartz schist comes in, well foliated and sharply cleavable.

Between the hills and the sea the land is composed of alluvium, being a perfect plain to the east, while to the west the surface is much more irregular and undulating, most of the deposit in the river valleys is of recent origin, while portions of the delta which belong to an older alluvial deposit are distinguished by being more sandy, and the country covered by it being more undulating, and more modified by denudation, also being more frequently accompanied by laterite. This laterite is evidently of detrital origin and consists of small pisolitic nodules of haematitic iron and coarse quartz sand.

It is probable that the clusters of isolated hills, which dot the whole of Orissa, were once islands, and are the end products of ancient denudation. The fact that the whole country resembles an upraised archipelago suggests that the Bay of Bengal washed the western cliffs at a comparatively recent geological period*.

A general description of the chief rivers flowing into Orissa is compiled below from the Imperial Gazetteers.

SUBARNAREKHA ('The stream of gold').—Rising in Ranchi district, 10 miles south-west of Ranchi town, it flows towards the north-east, leaving the Chota Nagpur plateau in a picturesque waterfall called Hundrughat. From

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* Blown sand from the sea has formed sand-hills which cover a considerable area. There can be little doubt that each range of sandhills marks an old sea coast, and it seems probable that the sea has retired gradually, and the land has been raised, not continuously and uniformly but at intervals and by interrupted movements.

this point it forms the boundary with Hazaribagh district, its course being eastwards to the tri-junction point with Manbhum district. From there the river bends southwards into Singhbhum, then passes into the State of Mayurbhanj, and afterwards enters Midnapore district from the north-west. It traverses the jungle in the western tract of this district till it reaches Balasore, through which it flows in a tortuous southern channel, with gigantic windings east and west, until it finally falls into the Bay of Bengal, after a course of about 300 miles, having drained an area of about 8,000 square miles. The chief tributaries of the Subarnarekha in Chota Nagpur are the Kanchi and Karkari, both joining it from the west. The river is navigable by country craft for about 16 miles from its mouth, up to which point it is also tidal, and the bed is studded with islands. During the rains rice boats of two tons burden make their way into Mayurbhanj. The bordering country is cultivated to within a few miles of the sea in the cold season. The Subarnarekha is fordable only at places within Balasore district; it is embanked here in its lower reaches.

BAITARANI.*—Rising among the hills in the north-west of Keonjhar State in 21° 28′ N., and 85° 33′ E., it flows first in a south-westerly and then in an easterly direction, forming successively the boundary between Keonjhar and Mayurbhanj States, between Keonjhar and the district of Cuttack, and between Cuttack and Balasore. In the latter district the Brahmani joins it after the Baitarani has had a course of 224 miles, and the united stream falls, under the name of the Dhamra, into the Bay of Bengal. The river is navigable as high as Olokh, 15 miles from its mouth; beyond this point it is not affected by the tide, and is fordable during the hot season. The chief tributaries are the Salindi and Matai in the Balasore district. The river is crossed by the Orissa High-level Canal, which derives from it a portion of its water-supply.

BRAHMINI.—Formed by the junction of the south Koel and Sankh rivers in Gangpur State, Orissa, the united stream, assuming the name of Brahmini, passes through the Orissa Tributary States of Bonai, Talcher, and Dhenkanal, and enters Cuttack district near Garh Balarampur. It then follows a very winding easterly course, and reaches the Bay of Bengal by two mouths, the Dhamra estuary and the Maipara river, after a length of about 260 miles. At the southern end of Sukhinda just below the railway bridge, the Brahmini gives off the Pattia branch on its left which changing its name to Kharsua further down, rejoins the Brahmini below Aul. The other principal branch of the Brahmini is the Kimiria, which takes off on its right bank opposite Rajendrapur village in Cuttack district, and, after mixing its waters with the Ganguti, Kelo, and Birupa (the last an offshoot of the Mahanadi), falls again into the stream at Indpur under the name of the Birupa. As it approaches the sea the Brahmini receives on its left bank the Kharsua, and a short distance below this point its waters unite with those of the Baitarani, forming the Dhamra. The Brahmini is crossed by the Orissa High-level Canal, which derives from it a portion of its water-supply, and is spanned by a fine bridge on the Bengal Nagpur Railway.

DHAMRA.—River and estuary formed by the Brahmani and Baitarani and their tributaries, which meet at 20° 45′ N., 86° 49′ E., and enter the Bay of Bengal at 20° 47′ N., 86° 58′ E. The Dhamra is navigable, but is rendered dangerous by a bar across its mouth. It forms the boundary between the districts of Cuttack and Balasore, but its waters lie within the jurisdiction of Balasore.

MAHANADI ('the great river').—A large river with a total course of 533 miles, about half of which lies within the Central Provinces. The drainage area of the Mahanadi is estimated at about 51,000 square miles with about 27,000 square miles in the Central Provinces. Its maximum discharge in flood time is calculated to be about 1·6 million cubic feet a second, or nearly as great as that of the Ganges; in the dry season, however, the

* This river is mentioned in the Markanda Purana, chapter 57, as flowing right through the Kalinga country (R. C. Majumdar, "Orissa in the Making," *Calcutta University Press*, 1925, page 15.)

discharge dwindles to about 1,000 cubic feet a second, and has been known to fall to so low a value as 200 cusecs, while the least discharge of the Ganges is 45,000 cubic feet per second. During eight months of the year the river is nothing more than a narrow and shallow channel winding through a vast expanse of sand.

The Mahanadi[1] rises in an insignificant pool, a few miles from Sihawa in the extreme south-east of Raipur district. In the first part of its course it flows to the north, and drains the eastern portion of Raipur, its valley during the first 50 miles being not more than 500 or 600 yards broad. A little above Seorinarayan, on entering Bilaspur district, it receives the waters of its first great affluent, the Seonath, which in Raipur district is a more important river than the Mahanadi itself. It flows in an easterly direction through Bilaspur, its principal tributaries being the Jonk and the Hasdo. It then enters Sambalpur, and turning south at the town of Padampur flows south and south-east through that district. Its affluents here are the Ib, the Ong, and the Tel,[2] and numerous minor streams. In Sambalpur it has already become a river of the first magnitude with a width of more than a mile in flood time when it pours down a sheet of muddy water overflowing its submerged banks, carrying with it the boughs and trunks of trees, and occasionally the corpses of men and animals which it has swept away. The Mahanadi subsequently forms a series of rapids, until it reaches Dholpur. During the rainy season the water covers the rocks and suffices to float down huge rafts of timber. At Dholpur the rapids end, and the river rolls its unrestrained waters straight towards the outermost line of the Eastern Ghats. This mountain line is pierced by a gorge 40 miles in length, overlooked by hills and shaded by forests on either side. The Mahanadi finally leaves the Tributary States, and pours down upon the Orissa delta from between two hills a mile apart at Naraj, about 7 miles west of the city of Cuttack. It traverses Cuttack district from west to east, and throwing off numerous branches falls into the Bay of Bengal, by several channels, near False Point, in 20° 18′ N., 86° 43′ E.

On the right or south bank, soon after entering Cuttack district, it gives off a large stream, the Katjuri[3], the city of Cuttack being built upon the spit which separates the two channels. The Katjuri immediately divides into two, of which the southern branch, under the name of the Koakhye[4] passes into Puri district, and shortly afterwards throws off the Surua, which reunites with the parent stream after a course of a few miles. The offshoots from the left or north bank of the Mahanadi are the Birupa and the Chitratala. The Birupa takes off opposite the city of Cuttack, and afterwards joins the Brahmini, and its waters ultimately find their way into the Bay of Bengal by the Dhamra estuary.

The total length of the course from the source of the Seonath to Naraj is about 493 miles, and from the source of the Mahanadi to Naraj is about 466 miles. The distance to the sea would be about 67 miles more.

In the upper parts of its course the bed of the Mahanadi is open and sandy, with banks usually low, bare, and unattractive. After entering Sambalpur its course is broken in several places by rocks through which the river forms rapids, dangerous to navigation. Boats can, however, ascend the Mahanadi as far as Arang in Raipur district, about 120 miles from its source, but owing to the Mahanadi Anicut through passage is not possible

(1) It has been identified by competent scholars with "Manada" mentioned by Ptolemy in the second century A.D. The name was probably an old one of aboriginal or tribal origin. The settlement of Hindus and Hinduized people in the Sambalpur tract began from the seventh century A. D. from which period the names probably began to be Sanskritised. [B. C. Majumdar, "Orissa in the making." page 79.]

(2) That the river Tel lay on the western border of Andhradesa has been mentioned in Jataka stories and has been pointed out by Mr. K. P. Jayaswal.

(3) Mr. B. C. Majumdar points out that here 'Jari' represents the name "Jorri" (rivers) of the Kandaha tribes ("Orissa in the Making" p. 81).

(4) Mr. Majumdar also states (p. 10) that Koakhye is but a slightly altered form of the real name *Kayyakkai*, from '*Kayya*' meaning 'deep', and '*Khai*' meaning 'hand' or 'arm' in Tamil speech which was the language of the rulers of Orissa so late as the thirteenth century A. D. Mr. J. Shaw (Special Flood Officer, Orissa) points out, however, that the word "Khai" means a hollow or channel in modern Oriya. He thinks that *Koya-khai* is 'crow-channel', and cites *Bilua-khai* or fox-channel, *Dahi-khai* or curd-channel, *Khaja-khai* or Sweetmeat-channel for comparison.

Before the construction of the Bengal Nagpur Railway the Mahanadi was the main outlet for the produce of Sambalpur district, which was carried in boats to Cuttack, salt, cloth, and other commodities being brought back in exchange. The through traffic has now, however, been superseded by the railway, and there remains only a small amount of local trade between Sambalpur and Sonepur.

CHILKA LAKE.—A shallow gulf, situated between 19° 28′ and 19° 56′ N. and 85° 6′ and 85° 36′ E. in the south-east corner of Puri district. A long sandy ridge, in places little more than 200 yards wide, separates it from the Bay of Bengal, with which its only connection is by a single narrow mouth intersecting this ridge towards its centre. On the west and south the lake is walled in by lofty hills, while to the north it loses itself in endless shallows, sedgy banks, and islands just peeping above the surface, formed year by year from the silt which the rivers bring down. The lake spreads out into a pear-shaped expanse of water 44 miles long, of which the northern half has a mean breadth of about 20 miles, while the south tapers into an irregularly curved point, barely averaging 5 miles wide. Its smallest area is 344 square miles in the dry season, increasing to about 450 during the rainy season; and the average depth is from 3 to 5 feet, scarcely anywhere exceeding 6 feet excepting at the north-west end where the depth is reported to be 10 to 12 feet. The bed is generally below the high-water level of the sea, although in some parts it is slightly below low-water mark. The narrow tidal stream, which rushes through the neck connecting the lake with the sea, suffices to keep the water distinctly salt during the dry months from December to June. But once the rains have set in, and the Bhargovi and Daya rivers come pouring down upon its northern extremity, the sea-water is gradually driven out and the Chilka becomes a fresh-water lake.

The Chilka may be regarded as a gulf of the original Bay of Bengal. On the south, a bold, barren spur of hills runs down to the coast; on the north the land-making rivers have pushed out their rounded mouths and flat deltas into the ocean. Nor has the sea been idle. Meeting and overmastering the languid river-discharge that enters the Chilka, it has joined the two extremities with a bar of sand, and thus formed a lake. The delicate process of land-making from the river silt at the north-east end of the lake is slowly but steadily going on, while the bar-building sea is still busily at work. Old documents show that in the early years of the 19th century the neck of land dividing the lake from the sea was from half a mile to a mile broad; the average sand spit separating the lake from the sea is at present about half a mile broad, but was reported to be two miles wide at certain places some time ago; and the opening in the bar, which was a mile wide in 1780 A. D. and had to be crossed in large boats, was described forty years later as choked up. Shortly before 1825 an artificial mouth had to be cut; and although this also rapidly began to silt up, it remained as late as 1837, more than three times its present breadth. The present mouth is about one mile wide, and opens and closes according to the severity of floods. The difficulty in maintaining an outlet from the Chilka forms one of the chief obstacles to utilizing the lake as an escape for the floods that desolate the delta. Engineers report that, although it would be easy and cheap to cut a channel, it would be very costly and difficult to keep it open; and that each newly opened mouth would speedily choke up and share the fate of its predecessors.

CHAPTER 2.—GENERAL METEOROLOGICAL CHARACTERISTICS.

It will be useful to give a brief summary of the seasonal changes of weather conditions with special reference to rainfall in Orissa and adjoining districts.

The seasonal distribution of rainfall in the administrative districts concerned is shown in Table 1. The figures have been compiled from the table of monthly and annual rainfall figures published by the Indian Meteorological Department (1924). It will be noticed that the greater part of the rainfall occurs in June, July, August and September, i.e., during the prevalence of the south-west monsoon.

The Meteorological characteristics for certain selected stations in the area under consideration are also shown in Tables 2—9.

Table 2 gives the average monthly and annual means of the barometric pressure at 8·0 A.M. reduced to 32°F., constant gravity and sea-level. Table 3 gives the corresponding monthly and annual means of the barometric pressure for the whole day.

Tables 4 and 5 show the average monthly and annual mean direction of wind at 8-0 A.M. and for the whole day respectively; Table 6 the average monthly and annual mean velocity of the wind (in miles per hour); Table 7 the average monthly and annual means of relative humidities corrected to true diurnal means; Table 8 the average monthly and annual means of cloud proportions corrected to true diurnal means; and finally Table 9 gives the monthly and annual means of air temperatures corrected to true diurnal means. (These tables have been compiled from *Ind. Met. Mem.*, Vol. XVII, 1904.)

Table 1.—Normal Rainfall in each District.

District.	No. of stations.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1. Midnapur	28	·33	1·10	1·67	1·72	5·29	11·83	11·54	11·42	8·71	5·31	1·07	·13	60·12
2. Balasore	10	·44	1·32	1·41	2·13	4·81	9·35	11·18	11·51	9·96	5·52	1·44	·18	59·24
3. Cuttack	15	·43	1·20	1·16	1·36	4·43	9·80	12·20	12·08	8·90	5·90	2·26	·19	59·97
4. Puri	12	·38	1·09	·81	·79	3·08	9·00	11·40	13·38	9·34	6·71	3·04	·20	59·34
5. Angul	6	·48	1·06	1·05	1·19	2·32	9·01	13·02	13·38	8·66	3·82	·83	·28	56·90
6. Orissa Feudatory States ..	30	·49	1·21	1·03	1·30	2·68	10·29	14·01	13·46	8·60	3·56	·66	·22	58·06
7. Sambalpur	7	·47	·84	·86	·85	1·07	9·77	16·20	15·68	8·12	2·16	·32	·19	56·42
8. Ranchi	15	1·01	1·25	1·16	·82	2·13	10·31	14·75	15·54	8·54	3·20	·31	·16	59·17
9. Hazaribagh	12	·64	1·08	·88	·39	2·03	8·49	12·01	13·03	8·25	3·01	·36	·14	50·31
10. Palamau	20	·85	1·20	·76	·38	1·06	7·58	12·65	14·85	7·49	2·20	·42	·14	49·67
11. Manbhum	14	·59	·87	1·03	·90	2·84	9·36	11·96	11·96	8·20	3·03	·36	·07	51·77
12. Singhbhum	10	·70	1·31	·94	1·23	3·25	9·97	13·32	12·80	8·41	2·37	·50	21	55·51
13. Drug	8	·30	1·24	·44	·86	·73	8·91	12·33	13·62	7·27	2·03	·41	·33	48·37
14. Raipur	19	·33	·98	·51	·93	·82	9·54	13·92	15·13	7·16	[illegible]	·27	·28	52·06
15. Bilaspur	9	·75	1·16	·75	·57	·84	8·47	14·76	15·01	7·23	2·23	·38	·18	52·32
16. Feudatory States ..	15	·56	1·36	·73	·83	·97	8·97	14·98	15·18	7·81	2·77	·39	·27	54·82
17. Mandla	8	1·04	1·43	1·00	·57	·69	8·88	15·96	17·62	7·76	2·39	·63	·20	58·17
18. Chanda	15	·35	·83	·65	·65	·68	8·78	16·56	13·43	8·12	1·93	·49	·33	52·80
19. Bhandara	7	·52	1·26	·56	·42	·63	10·32	15·88	15·96	7·30	2·19	·41	·33	55·78
20. Balaghat	8	·51	1·10	·52	·54	·65	10·08	19·11	17·04	7·01	2·23	·55	·29	60·53
21. Ganjam	16	·26	·67	·69	1·11	2·51	5·51	7·22	8·03	8·09	7·45	2·70	·84	45·08
22. Ganjam (agency) ..	6	·30	·86	1·00	2·25	3·93	8·92	12·06	12·41	9·08	5·62	1·52	·42	58·97
23. Vizagapatam	18	·28	·54	·61	4·07	2·63	4·91	5·41	6·51	7·63	6·90	2·70	·83	40·02
24. Vizagapatam (agency) ..	11	·16	·40	·80	2·06	3·06	8·42	13·98	14·85	10·00	4·09	1·31	·33	59·46

Table 2.—Average Monthly and Annual Means of 8 A.M. Pressure reduced to 32°F., constant gravity and sea-level.

Stations.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1. Raipur ..	30·048	29·980	29·884	29·761	29·643	29·558	29·560	29·611	29·703	29·876	29·997	30·070	29·806
2. Sambalpur..	30·060	29·982	29·886	29·772	29·658	29·558	29·554	29·605	29·709	29·874	30·001	30·072	29·810
3. Ranchi ..	30·059	29·992	29·875	29·757	29·646	29·548	29·535	29·588	29·705	29·883	30·002	30·082	29·806
4. Chaibassa ..	30·045	29·973	29·868	29·749	29·639	29·533	29·517	29·568	29·658	29·864	29·985	30·065	29·791
5. Balasore ..	30·042	29·975	29·875	29·772	29·666	29·555	29·532	29·586	29·699	29·870	29·986	30·063	29·802
6. False Point	30·025	29·964	29·879	29·785	29·678	29·564	29·560	29·597	29·689	29·849	29·963	30·036	29·798
7. Cuttack ..	30·028	29·962	29·876	29·776	29·668	29·564	29·544	29·592	29·683	29·849	29·967	30·038	29·795

Table 3.—Average Monthly Mean of Daily Pressure reduced to 32°F., constant gravity and sea-level.

Stations.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Raipur ..	29·984	29·923	20·812	29·686	29·575	29·508	29·516	29·566	29·650	29·824	29·937	30·013	29·749
Sambalpur ..	·998	·935	·821	·697	·587	·508	·524	·562	·659	·822	·945	30·013	·756
False Point ..	·980	·923	·836	·738	·649	·536	·523	·574	·657	·809	·926	29·993	·762
Cuttack ..	·980	·919	·822	·720	·627	·523	·519	·564	·657	·810	·931	·994	·756

Table 4.—Average Monthly and Annual Mean Direction of Wind at 8-0 A.M.

Stations.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Raipur ..	N 13°E	N [illegible]°W	N 69°W	S 56°W	S 76°W	S 56°W	S 49°W	S 56°W	S 63°W	N 27°E	N 40°E	S 14°W	S 69°W
Sambalpur ..	N 32°E	N 27°W	N 46°E	S 87°E	S 76°E	S 23°W	S 34°W	S 30°W	" S "	N 33°E	N 21°E	N 10°E	N 33°E
Ranchi ..	N 73°W	N 68°W	N 80°W	S 61°W	S 43°W	S 42°W	S 63°W	S 66°W	S 79°W	N 80°W	N 63°W	S 68°W	S 78°W
Chaibassa ..	S 68°W	S 66°W	S 60°W	S 62°W	S 68°W	S 82°W	S 66°W	S 61°W	S 63°W	S 63°W	S 77°W	S 64°W	S 66°W
Balasore ..	N 27°W	N 42°W	S 81°W	S 29°W	S 29°W	S 32°W	S 37°W	S 40°W	S 69°W	N 41°W	N 21°W	S 25°W	S 81°W
False Point ..	N 25°W	N 57°W	S 70°W	S 38°W	S 27°W	S 43°W	S 69°W	S 67°W	S 68°W	N 45°W	N 19°W	N 17°W	
Cuttack ..	N 8°W	N 36°E	S 50°W	S 39°W	S 46°W	S 47°W	S 00°W	S 66°W	S 81°W	N 61°W	N 45°W	S 49°W	S 61°W

Table 5.—Average Monthly and Annual Means (daily averages) of Direction of Wind.

Stations.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Raipur ..	N 12°W	N 48°W	N 75°W	N 89°W	N 81°W	S 72°W	S 69°W	S 72°W	S 84°W	N 33°E	N 33°E	N 33°E	N 75°W
Sambalpur ..	N 48°W	N 52°W	N 88°W	S 80°W	S 62°W	S 59°W	S 50°W	S 54°W	S 49°W	N 7°E	N 1°W	N 13°W	N 85°W
False Point ..	N 57°E	S 11°E	S 54°W	S 30°W	S 21°W	S 36°W	S 54°W	S 48°W	S 18°W	N 61°E	N 30°E	N 30°E	S 33°W
Cuttack ..	N 25°E	S 12°W	S 18°W	S 30°W	S 12°W	S 39°W	S 61°W	S 42°W	S 23°W	N 33°E	N 12°E	N 21°E	N 43°W

Table 6.—Average Monthly and Annual Mean Hourly Velocities of Wind.

Stations.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Raipur ..	2·7	4·0	4·9	6·3	8·0	9·7	11·1	8·4	5·0	3·8	3·2	2·5	5·9
Sambalpur..	2·6	2·9	3·1	3·9	4·3	5·2	4·8	4·4	3·9	2·0	2·7	2·5	3·6
Ranchi ..	5·2	5·8	6·6	7·4	7·6	8·7	7·9	7·8	6·9	4·5	3·7	4·3	6·3
Chaibassa ..	1·2	1·5	1·7	2·6	2·8	2·9	2·7	1·6	1·4	0·9	0·9	1·0	1·8
Balasore ..	2·8	3·8	5·8	8·6	8·8	7·2	6·0	4·3	3·5	2·6	2·1	2·1	4·8
False Point	5·9	7·8	10·8	13·8	13·7	12·5	11·2	9·8	8·5	6·0	6·0	5·8	9·2
Cuttack ..	1·4	2·1	3·3	5·0	5·1	4·0	3·3	2·7	2·4	1·8	1·6	1·2	2·8

Table 7.—Average Monthly and Annual Means of Relative Humidity corrected to true Diurnal Means.

Stations.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Raipur ..	53·0	44·9	36·3	31·7	31·1	62·2	84·1	86·1	82·6	69·8	61·0	65·5	58·2
Sambalpur..	68·3	58·9	51·8	43·9	47·8	66·9	86·4	87·9	83·0	78·0	70·4	70·4	68·2
False Point	78·6	79·5	82·0	84·8	82·8	81·0	85·7	86·8	80·2	60·2	76·7	75·7	81·5
Cuttack .	65·5	61·9	60·8	62·2	68·4	71·4	79·8	80·9	78·6	74·0	69·5	69·5	69·7

Table 8.—Average Monthly and Annual Mean Proportion of Cloud corrected to true Diurnal Means.

Stations.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Raipur ..	1·2	1·3	1·8	2·4	3·2	6·8	8·6	8·2	6·5	3·4	2·1	1·4	4·0
Sambalpur..	1·0	1·1	1·6	2·3	3·3	6·2	7·9	7·3	5·7	2·8	1·9	1·4	3·6
False Point	1·4	2·9	2·9	3·5	5·1	7·2	8·4	8·2	7·3	4·3	3·0	2·3	4·7
Cuttack ..	1·1	1·6	2·3	2·9	4·3	6·2	7·5	7·1	5·6	3·7	2·1	1·3	3·9

Table 9.—Average Monthly and Annual Means of Air Temperature corrected to true Diurnal Means.

Stations.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Raipur ..	67·7	73·6	81·9	90·3	93·6	86·0	79·6	79·0	80·3	78·1	71·5	66·0	79·0
Sambalpur..	67·7	72·6	80·7	88·6	92·9	87·3	81·1	80·9	82·1	79·4	71·9	65·4	79·2
Ranchi ..	61·8	66·0	75·1	84·5	86·6	81·7	77·4	76·7	77·0	73·5	66·9	61·3	74·0
Chaibassa ..	65·6	70·5	79·6	88·4	90·8	86·0	82·4	81·5	81·8	78·5	70·0	64·7	78·4
Balasore ..	67·3	72·4	79·3	86·1	87·1	84·2	81·9	82·0	82·4	79·4	72·3	66·6	78·4
False Point	67·6	72·5	77·8	82·1	84·3	84·1	81·8	81·8	81·8	79·8	73·0	66·7	77·8
Cuttack ..	70·2	75·8	82·5	87·3	88·6	86·4	83·0	82·4	83·0	81·1	74·2	65·6	80·3

Winter Conditions.

Weather is dry throughout the winter months of December, January and February. Barometric pressure decreases towards the south, from a belt of high pressure lying over the north-west of the Punjab to a belt of low pressure situated to the south of the equator.

This is the period of the so-called "North-East Monsoon", which is associated with a pressure gradient from south to north in the upper air in a direction opposed to that of the surface gradient. Eliot concluded from cloud observations (*Ind. Met. Mem.*, Vol. IV, Part 8, and Volume XV, Part 1) that the winter air movement in north India was comparatively shallow. W. A. Harwood, in his study of Pilot Balloon data, (*Ind. Met. Mem.*, Volume XXII, Part 5) found that the north-east monsoon current strengthened with increasing distance from its source in north-west India. He concluded that "the north-east monsoon system is the same, with slight modifications, as the trade wind system of the Atlantic".

The monsoon starts at about Lat. 30° N. as a surface current, 1 Kilometre to 2 Kilometre thick, and its depth increases steadily towards lower latitudes, reaching 7 Km. to 10 Km. in Lat. 13° N., ... the current diminishes in thickness with the southward movements of the doldrums. Above the monsoon is an anti-monsoon which as far as our land observations can tell us is exactly like the anti-trade, nearing and approaching the surface with increase of latitude and finally joining the general west to east circulation at about Lat. 30° N. [*Ind. Met. Mem.*, Volume XII, Parts 7 and 8, pages 254—255].

The air movement is generally from the north and the wind is usually light as can be easily seen from Tables 4 and 6 which give the average monthly mean direction and the mean hourly velocity of wind. The sky is practically free from cloud (Table 8) and the humidity is moderate throughout the winter season (Table 7).

Rainfall.—In the south of the Orissa Delta some of the winter rainfall is given by the north-east monsoon and occasionally by late storms in the Bay. But over the greater part of the region the light falls of rain in winter are usually given by western depressions. Sir Gilbert Walker has given the following description of these depressions :—

"After entering India they generally travel eastwards and take three to five days to reach Bengal; but they sometimes extend into North Burma. Those disturbances which take a northerly course give rain in Kashmir and usually after travelling for three days in Tibet, reappear in Assam, the time taken may sometimes be so long as five days. But generally it is less. Those that take a southerly tract give rain in the central parts of the country and Orissa. There are also disturbances which give areas of rain both in north-west India and in the central parts of the country. When the latter rainfall occurs it is usually associated with a feebly marked depression travelling eastwards through Southern Rajputana." [*Ind. Met. Mem.* Volume XXIV, Part XI (1925) pp. 348-349.]

Rainfall, however, is extremely scanty and lies between 1·50" and 2·0" practically throughout the region under consideration.

It will be noticed that winter rainfall is slightly heavier in the north-west and decreases towards the south-east. This is of course easily explained by the fact that almost all the winter rain is brought down by depressions from the north-west.

Weather of the Hot Season.

During March, April and May there is a rapid rise of the temperature (Table 9) accompanied by the heating up of the land surface, and a continuous decrease of pressure over North India, which gradually becomes a low pressure area relative to the Indian Ocean. This low pressure trough is very slight at first, gradually deepens in intensity, and causes an increasing indraught from the Bay of Bengal. Over the greater part of the area the wind now changes from a northerly to a southerly direction and attains greater velocities. Relative humidity still remains low (Table 7), but there is a slight increase in the average cloud proportions (Table 8).

During day time strong hot winds continue to blow from the north-west into the interior of the country, while near the sea-coast damp sea-winds blow in from the south-east. The inter-action between these two currents, supplemented by the action of the Nilgiri hills and the hills of the Orissa Feudatory states in causing a vigorous forced ascent, gives rise to local thunderstorms. A glance at the Rainfall Map no. 1 will show that the rainfall rapidly increases as the hills are approached, reaching the maximum value of 9" to 10" in two particular regions near the Nilgiri and the Udaigiri hills. Further inland there is a gradual decrease of rainfall until it becomes less than 2 inches in the western portions of the Mahanadi catchment area. Table 13 also shows that the deltaic area, and the catchment basin of the Baitarani and the Subarnarekha, receive comparatively a much greater proportion of the rainfall (over 10 per cent) during the summer months. The rainfall during these months is however extremely local in character, and although important from an agricultural standpoint, has no bearing on floods.

THE SOUTH-WEST MONSOON.

The months of June, July, August and September comprise the period of the south-west monsoon. For our present investigation this is the most important season, from 75 per cent to nearly 90 per cent of the annual rainfall being concentrated in these months. In years of normal rainfall the distribution of the rainfall controls the crop-yield, in years of drought the failure of the rains causes scarcity or famine, and finally in years of excessive rainfall the amount and distribution of the precipitation determine the nature and intensity of the floods.

The rapid increase of temperature during the months of March, April and May reduces the surface pressure over northern India, so that by the beginning of June, the winter high pressure area is replaced by a deep low-pressure area extending in India from Sind and Western Rajputana to Bengal.

The lower monsoon current may be considered to be a part of the large circulation round the Asiatic low pressure area (*Ind. Met. Mem.*, Volume XXIV., Part VIII, page 268). A steady indraught of moisture-laden winds from the oceanic area blowing roughly from the south-west in the Arabian Sea and the Bay of Bengal constitutes the south-west monsoon in the lower levels. The Arabian sea branch of the monsoon usually sets in Bombay in the first week of June, a few days before the Bay current reaches Bengal.

Although a certain amount of rainfall occurs in Orissa and the catchment areas without being associated with any large change in the barometric pressure the heavier and more concentrated falls occur at intervals along the tracks of depressions and cyclonic storms which originate in the Bay of Bengal and usually travel in a north-westerly direction.

The monsoon is not an uninterrupted current, but usually comes in pulses of various durations. Periods of heavy rainfall alternate with periods when the rain is confined to the coast districts and to scattered local thunderstorms. The front of an advancing current of monsoon in the Bay of Bengal is usually an area of disturbed weather, strong winds, and rain squalls. A characteristic feature is the formation of cyclonic storms and depressions.

The intimate connexion between the occurrence of maximum discharge in the Mahanadi and the occurrence of storms and depressions in the Bay has been fully brought out in the analysis, given later, of Bay storms and depressions which affected the area under discussion during the years 1891-1928.

TRANSITION STAGE.

Towards the end of September the transition from monsoon to cold weather condition begins, but is not usually completed until the middle of December. Barometric pressure begins to rise rapidly, and with the disappearance of the monsoon trough, winds change to a northerly direction. The sky gradually becomes dry, and there is a rapid drop of the air-temperature. [Tables 2—9.]

October and November are, however, characterized by the occurrence of occasional storms of a very severe intensity. Fortunately they are comparatively rare, only 17 entered the area under discussion during the 38 years 1891—1928. These storms are often accompanied by very heavy local rain and high winds. They usually cause damage along their own tracks, and do not give rise to widespread river floods.

CHAPTER 3.—RAINFALL NORMALS.

The rainfall records of 156 stations have been used in the discussion of floods in Orissa. Out of these, 112 are situated in the catchment area of the Orissa rivers, 12 in the Orissa delta, and 30 near the boundaries of the catchment areas, data for which have been used for drawing lines of equal rainfall. The rainfall stations have been grouped under respective catchment areas, which have been described in detail in Chapters 5—8 and are shown in accompanying maps (1)—(4).

Unfortunately, in earlier years, most of the stations were not in existence. A complete list of all the stations with the latitude and longitude, district, and year from which records are available in each case, is given in Table 10. The number of stations available in different years is shown in Table 11. It will be seen that almost all the stations were started after 1865, and only 10 are available from 1868. (This is why I decided to begin the detailed analysis of floods from the great flood of 1868.)

Records from 1891 are available in printed form in the Annual Rainfall volumes published by the Indian Meteorological Department. Records for the period 1868—1890 were collected from manuscript data in the Meteorological Offices in Calcutta and Poona.

The daily rainfall records are compiled from two sources. In the case of a few important stations the rainfall data are recorded under the direct supervision of the Meteorological Department. These stations are periodically inspected, and as the observer is usually a person of some scientific training the records are reliable. In the case of a majority of stations, however, the records are kept and published under the supervision of the Agricultural Department; owing to the lack of any systematic inspection the data are often faulty. Considerable care had to be exercised therefore in scrutinizing the primary data. It is not uncommon to find the same identical rainfall repeated every day at the same station for 7, 10, or 12 days consecutively. I have even found instances when the rainfall have been carefully recorded for the 31st day of June for several years.

Table 10.—List of Rainfall Stations with their Latitudes and Longitudes.*

Rainfall station.	Year of starting.	Latitude.	Longitude.	Administrative District.
Mahanadi I—				
1. Udaigiri ..	1870	20° 8′	84° 22′	Ganjam, Orissa.
2. Phulbani ..	1881	20° 30′	84° 14′	Angul, Orissa.
3. Banki ..	1883	20° 22′	85°31·5′	Cuttack, Orissa.
4. Kunjabangarh ..	1883	20° 2′	84° 5′	Tributary Mahals.
5. Narsingpur ..	1887	20° 28′	85° 4′	Ditto.
6. Baramba ..	1890	20° 26′	85° 20′	Ditto.
7. Nayagarh ..	1894	20° 8′	85° 6′	Ditto.
8. Tickerpara ..	1901	20° 36′	80° 47′	Angul, Orissa.
9. Rampur ..	1902	21° 4′	84° 20′	Feudatory States.
10. Baud ..	1903	20° 50′	84° 19′	Tributary Mahals.
11. Balandapara ..	1905	20° 46′	84° 4′	Angul, Orissa.
12. Athgarh ..	1906	20° 32′	85° 37′	Feudatory Mahals.
13. Bolgarh ..	1915	20° 11′	85° 16′	Puri.
Mahanadi II—				
1. Bargarh ..	1867	20° 20′	83° 36′	Sambalpur, Orissa.
2. Padampur ..	1902	21° 0′	83° 5′	Ditto.
3. Bhawanipatna ..	1902	19° 55′	83° 10′	Feudatory States.

*The rainfall stations have been grouped under catchment areas as defined in Part II of the Report.

Table 10.—List of Rainfall Stations with their Latitudes and Longitudes—*contd.*

Rainfall station.	Year of starting.	Latitude.	Longitude.	Administrative District.
Mahanadi II—concld.				
4. Bolangir ..	1902	20° 43′	83° 30′	Feudatory States.
5. Sonepur ..	1902	20° 51′	83° 55′	Ditto.
6. Saraipali ..	1902	21° 20′	82° 52′	Raipur, Central Provinces.
7. Deobhag ..	1906	19° 53′	82° 40′	Ditto.
8. Khariar ..	1906	20° 17′	82° 46′	Ditto.
9. Binka ..	1915	21° 2′	83° 48′	Feudatory States.
10. Dhama ..	1920	21° 16′	83° 55′	Sambalpur, Orissa.
11. Bijapur ..	1920	20° 12′	83° 27′	Ditto
Mahanadi III—				
1. Sambalpur ..	1865	21° 28′	83° 59′	Sambalpur, Orissa.
2. Janjgir ..	1866	22° 1′	82° 39′	Bilaspur, Central Provinces.
3. Korba ..	1880	20° 21′	82° 42′	Ditto.
4. Raigarh ..	1880	21° 53′	83° 23′	Feudatory States.
5. Sarangarh ..	1880	21° 35′	83° 51′	Ditto.
6. Gangpur ..	1883	22° 78′	84° 2′	Ditto.
7. Sakti ..	1902	20° 2′	82° 57′	Feudatory States.
8. Dharmajaigarh ..	1906	22° 28′	83° 16′	Ditto.
9. Pasan ..	1912	22° 51′	82° 6′	Bilaspur, Central Provinces.
10. Baikanthapur ..	1913	23° 12′	82° 38′	Feudatory States.
11. Katghora ..	1916	22° 31′	82° 33′	Bilaspur, Central Provinces.
12. Jharsuguda ..	1920	21° 50′	84° 31′	Sambalpur, Orissa.
13. Ambabhona ..	1920	21° 35′	83° 28′	Ditto.
Mahanadi IV—				
1. Dhamtari ..	1866	20° 42′	81° 33′	Raipur, Central Provinces.
2. Kankar ..	1902	20° 16′	81° 29′	Feudatory States.
3. Gariband ..	1903	20° 37′	82° 4′	Raipur, Central Provinces.
4. Arang ..	1905	21° 13′	81° 31′	Ditto
5. Rajim ..	1905	20° 58′	81° 7′	Ditto.
6. Mehesamund ..	1906	21° 7′	82° 5′	Ditto.
7. Kurid ..	1906	20° 5′	81° 43′	Ditto.
8. Pithora ..	1917	21° 15′	82° 31′	Ditto.
9. Nowapara ..	1918	20° 16′	81° 50′	Ditto.
Mahanadi V—				
1. Bilaspur ..	1866	22° 5′	82° 9′	Bilaspur, Central Provinces.
2. Drug ..	1866	21° 11′	81° 16′	Drug, ditto.
3. Raipur ..	1866	21° 14′	81° 38′	Raipur, ditto.
4. Simga ..	1866	21° 38′	81° 42′	Ditto.
5. Mungeli ..	1866	22° 03′	81° 40′	Bilaspur, Central Provinces.
6. Pendra ..	1880	22° 47′	81° 56′	Ditto.
7. Pondaria ..	1897	22° 13′	81° 24′	Ditto.
8. Kawardha ..	1902	22° 00′	81° 14′	Feudatory States.
9. Chhuikhadan ..	1902	21° 32′	81° 0′	Ditto.
10. Khairagarh ..	1902	21° 25′	80° 58′	Ditto.
11. Dongargarh ..	1902	21° 12′	80° 45′	Ditto.
12. Nandagoan ..	1902	21° 6′	81° 2′	Ditto.
13. Baladabazar ..	1903	21° 39′	82° 10′	Raipur, Central Provinces.

Table 10.—List of Rainfall Stations with their Latitudes and Longitudes—*contd.*

Rainfall station.		Year of starting.	Latitude.	Longitude.	Administrative District.
Mahanadi V—concld.					
14. Ambachowki	..	1905	20° 45′	80° 23′	Drug, Central Provinces.
15. Sanjari	..	1906	20° 52′	81° 01′	Ditto.
16. Bametara	..	1906	21° 43′	81° 32′	Ditto.
17. Gondai	..	1906	21° 40′	81° 06′	Ditto.
18. Pondilafa	..	1906	22° 8′	81° 15′	Bilaspur, Central Provinces.
19. Kusrang	..	1906	21° 22′	82° 1′	Raipur, ditto.
Baitarani—					
1. Keonjhar	..	1883	21° 37′	85° 34′	Tributary Mahals.
2. Akhoyapada	..	1885	20° 56′	86° 16′	Balasore, Orissa.
3. Anandapur	..	1893	21° 13′	86° 7′	Tributary Mahals.
4. Karanjia	..	1905	21° 53′	85° 59′	Ditto.
5. Bonth	..	1905	21° 7′	86° 19′	Balasore, Orissa.
6. Korai	..	1912	20° 59′	86° 8′	Cuttack, Orissa.
7. Champan	..	1922	22° 4′	85° 39′	Tributary Mahals.
Nilgiri—					
1. Baripada	..	1870	21° 56′	86° 43′	Tributary Mahals.
2. Nilgiri	..	1905	21° 28′	86° 46′	Ditto.
3. Turigaria	..	1908	21° 17′	86° 36′	Balasore, Orissa.
Brahmini I—					
1. Angul	..	1881	20° 48′	85° 0′	Angul, Orissa.
2. Dhenkanal	..	1881	20° 40′	85° 36′	Tributary Mahals.
3. Talcher	..	1881	20° 57′	85° 14′	Ditto.
4. Pallahara	..	1892	21° 36′	85° 11′	Ditto.
5. Chhandipara	..	1901	21° 5′	84° 53′	Angul, Orissa.
6. Deoghar	..	1903	21° 32′	84° 44′	Feudatory States.
7. Hindol	..	1903	20° 37′	85° 12′	Tributary Mahals.
8. Sukinda	..	1915	20° 57′	85° 57′	Cuttack, Orissa.
9. Barchana	..	1915	20° 40′	86° 6′	Ditto.
10. Tarpara	..	1917	20° 54′	84° 52′	Angul, Orissa.
Brahmini II—					
1. Tashpur	..	1883	22° 53′	84° 6′	Feudatory States.
2. Lohardaga	..	1884	23° 26′	84° 40′	Ranchi, Bihar.
3. Chainpur	..	1894	23° 7′	84° 14′	Ditto.
4. Palkot	..	1894	22° 52′	84° 38′	Ditto.
5. Gailkura	..	1896	22° 31′	85° 21′	Singhbhum, Bihar.
6. Manoharpur	..	1896	22° 23′	85° 13′	Ditto.
7. Kurdeg	..	1900	22° 33′	84° 8′	Ranchi, Bihar.
8. Bano	..	1900	22° 40′	84° 5′	Ditto.
9. Gumla	..	1903	23° 2′	84° 32′	Ditto.
10. Jagannathpur	..	1904	22° 13′	85° 38′	Singhbhum, Bihar.
11. Bonaigarh	..	1906	21° 49′	84° 57′	Feudatory States.
12. Simdega	..	1910	20° 36′	84° 29′	Ranchi, Bihar.
Subarnarekha I—					
1. Jellasore	..	1873	21° 48′	87° 13′	Balasore, Orissa.
2. Bharogora	..	1887	22° 17′	86° 43′	Singhbhum, Bihar.

Table 10.—List of Rainfall Stations with their Latitudes and Longitudes—*contd*.

Rainfall station.	Year of starting.	Latitude.	Longitude.	Administrative District.
3. Silda ..	1909	22° 37′	86° 48′	Midnapur, Bengal.
4. Kultikri ..	1910	20° 7′	87° 8′	Ditto.
Subarnarekha II—				
1. Ranchi ..	1864	23° 22′	85° 19′	Ranchi, Bihar.
2. Chaibassa ..	1870	22° 33′	85° 48′	Singhbhum, Bihar.
3. Ghatsila ..	1886	22° 35′	86° 28′	Ditto.
4. Jhalda ..	1886	23° 22′	85° 58′	Manbhum, Bihar.
5. Silli ..	1887	23° 21′	85° 49′	Ranchi, Bihar.
6. Chakradharpur ..	1887	22° 40′	85° 37′	Singhbhum, Bihar.
7. Kalikapur ..	1893	22° 36′	86° 27′	Ditto.
8. Tamur ..	1895	23° 3′	85° 38′	Ranchi, Bihar.
9. Seraikella ..	1901	22° 42′	85° 55′	Tributary Mahals.
10. Kharswan ..	1901	22° 47′	85° 49′	Ditto.
11. Khunti ..	1907	23° 5′	85° 16′	Ranchi, Bihar.
12. Piska ..	1922	23° 20′	85° 12′	Ditto.
13. Sonahatu ..	1922	23° 11′	85° 42′	Ditto.
Delta—				
1. Cuttack ..	1870	20° 29′	85° 53′	Cuttack, Orissa.
2. Hukitola ..	1870	20° 25′	86° 48′	Ditto.
3. Bhadrak ..	1870	21° 4′	86° 31′	Balasore, Orissa.
4. Balasore ..	1870	21° 30′	86° 56′	Ditto.
5. Puri ..	1870	19° 48′	85° 49′	Puri, Orissa.
6. Kendrapara ..	1871	20° 3′	86° 25′	Cuttack, Orissa.
7. Tajpur ..	1871	26° 51′	86° 21′	Ditto.
8. Khurda ..	1871	20° 11′	85° 47′	Puri, Orissa.
9. Jagatsingpur ..	1872	20° 11′	86° 10′	Cuttack, Orissa.
10. Chandbally ..	1873	20° 46′	86° 45′	Balasore, Orissa.
11. Banpur ..	1879	19° 47′	85° 10′	Puri, Orissa.
12. Ranpur ..	1893	20° 4′	85° 21′	Tributary Mahals.
Border—				
1. Ramgarh ..	1888	23° 41′	85° 31′	Hazaribagh, Bihar.
2. Gola ..	1911	23° 34′	85° 43′	Ditto.
3. Barakatha ..	1922	23° 33′	85° 27′	Ditto.
4. Mahuadanar ..	1900	23° 24′	84° 8′	Palamau, Bihar.
5. Chandwa ..	1910	23° 40′	84° 42′	Ditto.
6. Purulia ..	1870	23° 21′	86° 21′	Manbhum, Bihar.
7. Manbazar ..	1905	23° 4′	86° 41′	Ditto.
8. Bandwan ..	1915	22° 57′	86° 28′	Ditto.
9. Midnapur ..	1859	22° 24′	87° 19′	Midnapur, Bengal.
10. Bankura ..	1886	23° 14′	87° 7′	Bankura, Bengal.
11. Jagadalpur ..	1902	21° 8′	82° 55′	Feudatory States.
12. Sirguja ..	1882	23° 7′	83° 13′	Ditto.
13. Mandla ..	1867	22° 37′	80° 21′	Mandla, Central Provinces.
14. Dindoria ..	1886	22° 58′	81° 4′	Ditto.
15. Bajag ..	1916	22° 41′	81° 19′	Ditto.
16. Mul ..	1867	20° 5′	79° 39′	Chanda, Central Provinces.
17. Armoria ..	1882	20° 28′	79° 58′	Ditto.
18. Ghot ..	1908	19° 48′	79° 59′	Ditto.
19. Dhanora ..	1921	20° 18′	80° 17′	Ditto.
20. Sakoli ..	1867	21° 5′	79° 56′	Bhandra, Central Provinces.
21. Baihar ..	1870	22° 5′	80° 31′	Balaghat, Central Provinces.
22. Lanji ..	1870	21° 30′	80° 35′	Ditto.

Table 11.—Number of stations in each catchment available in different years.

Years.	Mahanadi.						Brahmini.		Subarnarekha.		Baitarani.	Grand Total.
	M—I.	M—II.	M—III.	M—IV.	M—V.	Total Mahanadi.	Br. I.	Br. II	Sb. I.	Sb. II.		
1864	..	..	..	..	..	..	..	..	..	1	..	1
1865	..	..	1	..	..	1	..	..	..	1	..	2
1866	..	..	2	1	5	8	..	..	..	1	..	9
1867	..	1	2	1	5	9	..	..	..	1	..	10
1868	..	1	2	1	5	9	..	..	..	1	..	10
1869	..	1	2	1	5	9	..	..	..	1	..	10
1870	..	1	2	1	5	9	..	..	..	2	..	11
1871	..	1	2	1	5	9	..	..	..	2	..	11
1872	..	1	2	1	5	9	..	..	..	2	..	11
1873	..	1	2	1	5	9	..	..	1	2	..	12
1874	..	1	2	1	5	9	..	..	1	2	..	12
1875	..	1	2	1	5	9	..	..	1	2	..	12
1876	1	1	2	1	5	10	..	..	1	2	..	13
1877	1	1	2	1	5	10	..	..	1	2	..	13
1878	1	1	2	1	5	10	..	..	1	2	..	13
1879	1	1	2	1	5	10	..	..	1	2	..	13
1880	1	1	5	1	6	14	..	..	1	2	..	17
1881	2	1	5	1	6	15	3	..	1	2	..	21
1882	2	1	5	1	6	15	3	..	1	2	..	21
1883	4	1	6	1	6	18	3	1	1	2	1	26
1884	4	1	6	1	6	18	3	2	1	2	1	27
1885	4	1	6	1	6	18	3	2	1	2	2	28
1886	4	1	6	1	6	18	3	2	1	4	2	30
1887	5	1	6	1	6	19	3	2	2	6	2	34
1888	5	1	6	1	6	19	3	2	2	6	2	34
1889	5	1	6	1	6	19	3	2	2	6	2	34
1890	6	1	6	1	6	20	3	2	2	6	2	35
1891	2	1	5	1	6	15	3	2	2	6	2	30
1892	6	1	5	1	6	19	4	2	2	6	2	35
1893	7	1	6	1	6	21	4	2	2	7	3	39
1894	7	1	6	1	6	21	4	2	2	7	3	39
1895	7	1	6	1	6	21	4	4	2	8	3	42
1896	7	1	6	1	6	21	4	6	2	8	3	44
1897	7	1	6	1	7	22	4	6	2	8	3	45
1898	7	1	6	1	7	22	4	6	2	8	3	45
1899	7	1	6	1	7	22	4	6	2	8	3	45
1900	8	1	5	1	7	22	4	8	2	8	3	47
1901	9	1	6	1	7	24	5	8	2	10	3	52
1902	8	6	7	2	12	35	5	8	2	10	3	63
1903	10	6	7	2	12	37	7	9	2	10	3	68
1904	11	6	7	4	13	41	7	9	2	10	3	72

Table 11.—Number of stations in each catchment available in different years—*concld.*

Years.	Mahanadi.						Brahmini.		Subarnarekha.		Baitarani.	Grand Total.
	M—I.	M—II.	M—III.	M—IV.	M—V.	Total Mahanadi.	Br. I.	Br. II.	Sb. I.	Sb. II.		
1905	12	6	7	5	14	44	7	9	2	10	5	77
1906	12	8	7	7	19	53	7	9	2	10	5	86
1907	12	8	7	7	19	53	7	9	2	11	5	87
1908	12	8	7	6	19	52	7	9	2	11	5	86
1909	12	8	7	7	19	53	7	9	3	11	5	88
1910	12	8	7	7	19	53	7	9	4	11	5	89
1911	12	8	8	7	19	54	7	9	4	11	5	90
1912	12	8	9	7	19	55	7	9	4	12	6	93
1913	11	8	10	7	19	55	7	9	4	12	6	93
1914	10	8	10	7	19	54	7	9	4	12	6	92
1915	11	9	10	7	19	56	9	9	4	12	6	96
1916	13	9	11	7	19	59	9	9	4	12	6	99
1917	13	9	11	8	19	60	10	9	4	12	6	101
1918	13	9	11	9	19	61	10	9	4	12	6	102
1919	12	10	11	9	19	61	10	9	4	12	6	102
1920	12	11	13	9	19	64	10	9	4	12	6	105
1921	13	11	13	9	19	65	10	9	4	12	6	106
1922	13	11	13	9	19	65	10	9	4	13	7	108
1923	13	11	13	9	19	65	10	9	4	13	7	108
1924	13	11	13	9	19	65	10	9	4	13	7	108
1925	13	11	13	9	19	65	10	9	4	13	7	108
1926	13	11	13	9	19	65	10	9	4	13	7	108
1927	13	11	13	9	19	65	10	9	4	13	7	108
1928	13	11	13	9	19	65	10	9	4	13	7	108

Monthly Normal Rainfall.

The normal rainfall figures for each station for each month are given in Table 12.

The totals for the different seasons :—

(1) Hot weather ... ... March, April, May.
(2) Monsoon ... ... June, July, August, September.
(3) Autumn ... ... October, November.
(4) Winter ... ... December, January, February.

and for the whole year are given in Table 13, and are shown on Rainfall Map nos. (1)—(4).

Table 12.—Monthly Normal Rainfall in inches corrected up to 1920.

Rainfall stations.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Mahanadi I—												
1. G. Udaigiri ..	·31	·86	1·34	2·73	4·44	8·56	11·34	10·67	9·80	5·93	2·08	0·67
2. Phulbani ..	·41	·82	·93	1·54	2·27	9·37	13·48	11·96	9·09	4·03	·84	·33
3. Banki ..	·29	1·10	1·17	·99	2·63	9·26	11·86	11·77	9·30	4·83	1·36	·36
4. Kunjabangar ..	·41	·87	1·52	1·64	2·62	9·25	11·85	10·58	9·37	4·87	1·24	·21

Table 12.—Monthly Normal Rainfall in inches corrected up to 1920—*contd.*

Rainfall stations.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
5. Narsingpur ..	·39	·87	·84	1·07	2·47	9·47	11·74	10·41	7·65	4·01	1·20	·17
6. Baramba ..	·33	1·14	1·14	1·75	2·86	9·21	11·90	11·90	9·29	5·05	1·10	·23
7. Nayagarh ..	·37	1·12	1·21	1·92	2·74	8·92	12·10	10·93	9·31	4·79	1·29	·32
8. Tikerpara ..	·75	1·50	·96	·99	3·23	8·92	11·40	10·73	7·85	2·48	·54	·19
9. Rampur ..	·60	·94	·78	·96	1·58	11·74	17·63	16·77	8·00	3·09	·37	·21
10. Baud ..	·24	1·03	1·00	·89	2·00	9·82	14·26	12·59	7·09	3·63	·34	·14
11. Balandapara ..	·54	1·26	1·13	1·11	2·00	13·16	10·30	21·23	10·55	4·01	·71	·29
12. Athgarh ..	·50	1·25	·73	1·09	2·06	9·45	12·62	12·78	8·26	4·46	1·45	·28
13. Bolgarh ..	·85	1·32	·74	·86	2·57	9·52	11·75	10·78	7·21	6·65	3·22	·02
Mahanadi II—												
1. Bargarh ..	·42	·61	·96	·54	·99	9·04	16·14	15·01	7·67	1·74	0·34	0·21
2. Padampur ..	·43	1·18	·77	1·41	·96	9·14	13·52	14·13	8·19	2·46	·24	·14
3. Bhawanipatna ..	·31	·80	·80	1·56	1·70	10·25	13·58	15·83	8·07	3·07	·47	·22
4. Bolangir ..	·38	·98	·78	1·27	1·54	10·34	14·31	14·72	8·09	2·92	·35	·17
5. Sonapur ..	·34	·98	·53	1·10	·73	11·91	13·91	16·21	7·22	2·70	·27	·20
6. Saraipali ..	·40	·95	·58	1·13	1·00	8·96	14·16	16·10	7·99	1·84	·36	·16
7. Deobhog ..	·33	·82	·63	1·77	2·22	9·61	13·09	14·13	8·18	2·28	·38	·40
8. Khariar ..	·49	1·03	·51	1·77	1·59	10·15	12·40	13·77	7·56	3·22	·37	·41
9. Binka ..	·33	1·34	·75	·64	1·05	15·07	18·70	19·67	7·93	3·01	1·57	·00
Mahanadi III—												
1. Sambalpur ..	·56	·74	·85	·60	1·25	11·12	18·93	17·59	15·74	2·25	0·38	0·21
2. Janjgir ..	·46	·78	·67	·49	·67	8·56	14·95	15·11	7·39	1·73	·34	·34
3. Korba ..	·74	1·11	·62	·45	·76	7·81	17·72	17·40	7·48	2·26	·40	·20
4. Raigarh ..	·41	·99	·69	·48	·52	9·62	19·24	18·88	8·71	2·12	·38	·19
5. Sarangarh ..	·36	·91	·68	·65	·76	8·53	15·67	14·87	7·99	2·29	·38	·15
6. Gangpur ..	·68	1·48	·77	·73	1·32	13·17	17·25	17·04	8·29	2·51	·46	·27
7. Sakti ..	·62	1·29	·80	·55	·74	10·65	17·02	17·08	9·25	2·26	·21	·17
8. Dharmajaigarh. ..	·90	1·74	·96	·62	·54	11·07	20·14	18·78	7·33	2·24	·36	·26
9. Pasan ..	1·26	1·51	1·21	·43	1·00	7·83	13·59	14·41	6·21	2·41	·37	·05
10. Baikunthapur ..	·89	1·86	1·23	·37	1·09	8·95	17·62	18·53	7·31	2·86	·31	·13
11. Katghora ..	1·08	1·08	·69	·23	1·38	12·22	15·80	20·31	7·73	3·49	·49	·01
Mahanadi IV—												
1. Dhamtari ..	·25	·71	·44	·70	·99	9·33	14·72	13·26	7·82	1·97	0·35	0·19
2. Kanker ..	·45	1·33	·33	·98	1·52	8·02	11·93	11·41	8·60	3·06	·34	·31
3. Gariaband ..	·27	1·08	·37	1·42	1·11	10·00	14·48	15·75	8·14	3·11	·40	·36
4. Arang ..	·45	1·09	·49	·77	·75	11·24	14·02	14·89	7·81	2·10	·46	·24
5 Rajim ..	·38	1·28	·43	·92	·84	10·18	15·25	15·64	7·71	2·88	·24	·20
6. Mahasamund ..	·33	1·04	·55	1·13	1·05	13·47	16·37	17·86	7·73	2·63	·47	·22
7. Kurud ..	·29	·85	·45	·39	·61	9·26	12·65	15·77	5·93	2·08	·30	·31

Table 12.—Monthly Normal Rainfall in inches corrected up to 1920—*contd.*

Rainfall station.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Mahanadi V—												
1. Bilaspur ..	·62	·77	·60	·72	·84	8·05	14·57	13·00	7·74	1·92	0·44	0·26
2. Drug ..	·36	·74	·55	·61	·58	8·61	13·82	12·89	7·48	1·04	·45	·20
3. Raipur ..	·56	·70	·67	·69	·08	9·47	14·28	13·31	7·80	2·00	·38	·23
4. Singa ..	·34	·03	·43	·63	·65	7·68	13·26	12·44	6·84	1·32	·25	·17
5. Mungeli ..	·67	·88	·05	·66	·65	7·77	12·82	11·92	7·14	1·65	·31	·22
6. Pendra ..	·72	1·30	·97	·73	·98	7·55	15·11	13·47	7·30	2·60	·42	·28
7. Pandaria ..	·71	1·31	·61	·89	·75	6·32	12·41	11·35	6·09	1·95	·45	·21
8. Kawardha ..	·60	1·51	·75	·95	·98	6·23	11·12	9·57	5·98	2·32	·44	·37
9. Chhukikhaidhan. ..	·87	1·53	·54	·96	·53	7·20	11·08	10·34	6·63	2·80	·48	·33
10. Kheragarh ..	·48	1·34	·64	·75	·59	8·05	12·24	11·10	6·75	3·09	·40	·27
11. Dongargarh ..	·43	1·40	·63	·81	·59	9·06	13·03	13·37	7·63	3·11	·47	·32
12. Nandgaon ..	·37	1·62	·50	1·19	·96	9·30	13·61	14·45	6·71	2·96	·27	·39
13. Boladabazar ..	·49	1·20	·63	·76	·64	9·25	13·71	16·73	7·03	2·03	·11	·31
14. Ambachouki ..	·85	1·18	·41	·88	1·00	9·28	14·63	15·22	8·80	2·28	·67	·40
15. Sanjari ..	·50	1·13	·51	1·23	1·11	10·07	12·32	14·13	8·81	2·66	·53	·41
16. Bemetara ..	·39	1·42	·39	1·03	·55	9·57	13·37	12·73	6·99	1·70	·37	·28
17. Gondai ..	·48	1·68	·40	·89	·64	7·19	10·67	12·08	5·83	1·92	·40	·37
18. Pondi'ala ..	·60	1·53	·50	·54	·57	10·15	15·85	18·07	7·36	2·04	·11	·23
19. Kusrangi ..	·21	1·19	·52	·72	·48	10·98	14·27	14·31	9·23	1·97	·08	·20
Baitarani—												
1. Keonjhar ..	·66	1·11	·91	1·67	3·00	7·65	11·80	9·61	7·41	3·27	0·73	0·26
2. Akhayapada ..	·39	0·93	1·17	2·06	4·56	9·45	11·34	12·22	9·82	4·73	1·35	·21
3. Anandapur ..	·51	1·34	1·39	2·20	4·13	9·34	10·70	10·65	9·33	4·24	0·85	·12
4. Karanjia ..	·73	1·88	1·22	1·93	3·81	10·62	15·57	12·90	7·61	3·52	0·86	·40
5. Bonth ..	·61	1·45	1·60	1·73	3·77	8·87	10·02	11·54	8·12	4·10	2·20	·12
6. Korai ..	·56	1·15	1·25	1·45	4·43	9·39	12·44	10·59	7·08	5·98	1·78	·05
Nilgiri—												
1. Baripada ..	·13	1·21	1·46	2·04	4·99	10·51	13·00	12·08	11·15	6·00	0·87	0·19
2. Nilgiri ..	·02	1·86	1·70	3·12	5·72	10·84	12·00	12·54	10·80	7·05	1·78	·12
3. Turiagaria ..	·24	1·53	·93	2·07	5·44	10·63	10·81	11·31	9·54	6·40	1·18	·12
Brahmini I—												
1. Angul ..	·39	1·06	1·04	1·19	2·39	8·76	11·15	10·18	7·54	3·86	1·07	0·29
2. Dhenkanal ..	·34	·97	1·19	1·05	3·43	9·69	12·74	12·51	9·83	4·35	1·21	·27
3. Talcher ..	·40	1·08	1·07	1·19	2·64	9·10	13·22	11·43	7·49	2·93	·87	·19
4. Pal-Lohara ..	·52	1·26	1·15	1·62	2·87	11·28	19·48	17·66	8·34	3·08	·49	·23
5. Chhendipara ..	·55	1·04	1·02	1·04	2·21	9·06	13·05	11·64	7·60	2·95	·61	·33
6. Deoghar ..	·47	·86	·82	·74	2·15	11·26	17·85	18·74	9·25	4·21	·45	·42
7. Hindol ..	·54	1·16	1·29	1·51	2·79	9·61	12·47	10·87	6·82	4·64	1·26	·24
8. Sukinda ..	·64	1·51	1·79	1·00	4·91	12·53	13·51	12·74	8·53	6·20	1·82	..
9. Barchana ..	·48	1·76	1·20	1·22	4·74	11·30	15·69	12·35	7·70	5·91	2·31	..

Table 12.—Monthly Normal Rainfall in inches corrected up to 1920—*contd.*

Rainfall stations.	Jan.	Feb.	Mar.	April.	May	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Brahmini II—												
1. Jashpur ..	·89	1·13	1·36	·81	1·89	11·26	16·57	17·01	9·54	3·86	0·38	0·30
2 Lohardaga ..	·93	1·32	1·00	·60	1·71	7·86	12·50	13·09	8·15	2·93	·40	·27
3. Chainpur ..	1·06	1·80	1·00	·68	1·54	8·22	14·70	14·74	7·01	2·01	·56	·24
4. Palkot ..	·88	1·11	·83	1·08	1·70	9·70	15·20	16·62	8·48	3·48	·30	·12
5. Gailkura ..	·73	1·26	·78	1·13	2·27	10·05	15·89	16·51	7·99	4·00	·29	·22
6. Manoharpur ..	·76	1·50	·85	1·08	2·05	10·89	18·72	12·14	9·76	2·90	·56	·21
7. Kurdeg ..	1·05	1·43	·70	·59	1·14	9·50	17·54	18·24	8·07	1·58	·20	·32
8. Bano ..	1·04	1·16	·70	·59	1·61	9·03	17·09	17·33	7·72	2·36	·26	·23
9. Gumla ..	·68	1·87	1·41	·67	1·93	8·81	13·88	14·69	6·74	2·95	·42	·16
10. Jagannathpur ..	·86	1·23	1·15	·90	2·81	9·75	12·84	12·05	7·35	2·83	·30	·15
11. Bonaigarh ..	·49	1·22	1·06	·96	2·13	13·16	18·40	17·73	7·85	2·40	·60	·25
Subarnarekha I—												
1. Jellasore ..	·56	1·02	1·43	1·84	4·40	9·04	12·31	11·16	10·32	4·81	·02	·08
2. Baharogora ..	·38	1·16	1·19	1·91	4·19	10·23	12·87	11·70	9·60	3·47	·40	·28
3. Silda ..	·39	1·05	1·15	3·21	4·66	10·67	10·60	11·09	8·02	3·88	·67	·10
4. Kultikri ..	·29	1·17	2·03	1·69	4·82	10·64	10·28	10·68	7·87	5·86	1·10	·05
Subarnarekha II—												
1. Ranchi ..	·63	1·24	1·10	·80	2·33	9·00	14·46	13·01	8·23	2·79	0·37	0·10
2. Chaibassa ..	·67	1·25	1·07	1·03	3·46	8·16	12·00	12·40	8·07	2·88	·52	·24
3. Ghatsila ..	·67	1·27	1·06	1·37	3·73	10·20	12·97	13·14	9·32	3·04	·56	·23
4. Jhalda ..	·69	1·19	1·21	1·12	2·49	9·55	12·77	13·91	8·59	2·92	·42	·12
5. Silli ..	·60	·86	·94	·87	2·46	8·71	12·76	13·42	7·89	2·47	·28	·12
6. Chakradharpur ..	·77	1·23	·72	1·00	3·17	9·25	12·62	12·03	8·01	2·53	·59	·17
7. Kalikapur ..	·44	1·16	·92	1·60	3·85	11·64	13·03	10·51	7·99	4·00	·29	·22
8. Tamar ..	·58	1·34	·68	·84	2·35	10·07	12·10	12·00	8·19	2·53	·27	·12
9. Seraikela ..	·75	1·50	·96	·99	3·23	8·92	11·40	10·73	7·85	2·48	·64	·19
10. Kharswan ..	·93	1·50	·90	1·04	3·06	10·81	12·99	12·77	8·55	2·84	·49	·19
11. Khunti ..	·71	1·51	1·33	·92	2·30	12·18	15·09	19·13	9·19	3·30	·52	·25
Delta—												
1. Cuttack ..	·32	·90	1·18	1·30	3·86	10·60	12·18	13·08	10·07	5·40	1·43	0·25
2. Hukitola ..	·47	1·06	·99	1·35	3·98	8·82	12·69	13·31	9·98	8·64	3·46	·51
3. Bhadrak ..	·44	1·42	1·48	2·35	5·34	9·53	11·72	11·72	9·89	[illegible]	1·27	·30
4. Balasore ..	·51	1·34	1·80	2·30	4·79	9·31	11·99	11·85	12·07	6·38	1·28	·22
5. Puri ..	·28	·86	·52	·64	2·71	7·44	9·07	11·27	9·21	7·45	3·26	·30
6. Kendrapara ..	·37	·97	·95	1·39	4·29	9·34	11·75	12·38	9·77	5·87	2·09	·32
7. Jajpur ..	·37	1·11	1·16	1·62	4·50	9·87	12·11	12·29	9·71	5·17	1·31	·38
8. Khurda ..	·40	0·74	·90	·61	3·35	9·04	12·80	12·84	10·14	6·05	1·76	·37
9. Jagatsingpur ..	·35	·97	·97	1·03	3·50	8·54	11·88	13·32	10·61	6·85	2·37	·23
10. Chandbali ..	·39	1·01	1·28	1·44	4·98	8·82	11·85	11·61	10·68	6·23	2·38	·31
11. Banpur ..	·33	1·22	·81	1·22	2·12	7·84	10·08	12·06	9·09	6·31	2·14	·61
12. Ranpur ..	·40	1·21	·90	1·54	2·47	9·28	11·01	11·21	10·22	6·11	1·49	·32

Table 13.—Seasonal Normal Rainfall in inches.

Rainfall stations.		Number of years up to 1920.	Winter (Dec.—Feb.).	Summer (March—May).	Monsoon (June—Sept.).	Autumn (Oct.—Nov.)	Total. (whole year)
Mahanadi I—							
1. G. Udaigiri	..	51	1·54	4·44	40·46	8·01	54·45
2. Phulbani	..	46	1·56	2·27	43·88	4·87	52·58
3. Banki ..	..	44	1·75	2·63	42·25	6·19	52·82
4. Kunjabangarh	..	44	1·49	2·62	41·05	6·11	51·27
5. Narsingpur	..	40	1·43	2·47	39·27	5·21	48·38
6. Baramba	..	37	1·70	2·86	42·30	6·15	53·01
7. Nayagarh	..	33	1·81	2·74	41·26	6·08	51·89
8. Tikerpara	..	26	2·44	3·23	38·90	3·02	47·59
9. Rampur	..	25	1·75	1·58	54·14	3·46	60·93
10. Baud ..	..	24	1·41	2·09	43·76	3·97	51·23
11. Balandapara	..	22	2·09	2·00	64·33	5·32	73·74
12. Athgarh	..	21	2·03	2·66	43·11	5·91	53·71
13. Bolgarh ..	..	12	2·19	2·57	39·26	9·87	53·89
Mahanadi II—							
1. Bargarh	..	60	1·24	2·49	47·86	2·08	53·67
2. Padampur	..	25	1·75	3·14	44·98	2·70	52·57
3. Bhowanipatna	..	25	1·42	4·06	48·63	3·54	57·65
4. Bolangir..	..	25	1·53	3·59	48·06	3·27	56·45
5. Sonepur	..	25	1·52	2·36	48·25	2·97	55·10
6. Saraipali	..	25	1·51	2·71	47·21	2·20	53·63
7. Deobhag	..	21	1·55	4·02	45·01	2·66	53·84
8. Khariar ..	..	21	1·93	3·87	43·88	3·59	53·27
9. Binka ..	..	12	1·67	2·44	61·97	5·48	71·56
10. Dhama ..	..	7	..	..	..	..	..
11. Bijepur ..	..	7	..	..	..	..	..
Mahanadi III—							
1. Sambalpur	..	62	1·51	2·70	63·38	2·63	70·22
2. Janjgir ..	..	61	1·58	1·83	46·01	2·07	51·49
3. Korba ..	..	47	2·05	1·83	50·47	2·75	57·10
4. Raigarh	..	47	1·59	1·69	56·45	2·50	62·23
5. Sarangarh	..	47	1·42	2·09	47·06	2·67	53·24
6. Gangpur	..	44	2·43	2·82	53·35	2·97	61·57
7. Sakti ..	..	25	2·08	2·09	54·00	2·47	60·64
8. Dharmajaigarh	..	21	2·90	2·12	57·32	2·60	64·94
9. Pasan ..	..	15	2·82	2·46	42·04	2·78	50·10
10. Baikunthapur	..	14	2·88	2·69	52·71	3·17	61·45
1. Katghora	..	11	2·17	2·30	56·06	3·98	64·51
12. Jharsuguda	..	7	..	..	..	..	..
13. Ambabhona	..	7	..	..	..	..	..
Mahanadi IV—							
1. Dhamtari	..	61	1·15	2·13	45·13	2·31	50·72
2. Kanker ..	..	25	2·09	2·83	42·96	3·40	51·28
3. Gariabund	..	24	1·71	2·90	49·27	3·57	57·45
4. Arang ..	..	23	1·78	2·01	48·86	2·56	55·21
5. Rajim ..	..	22	1·95	2·19	48·78	3·12	56·04
6. Mahasamund	..	21	1·59	2·73	55·43	3·10	62·85
7. Kurid ..	..	21	1·45	1·45	43·63	2·38	48·91
8. Pithora ..	..	10	..	..	..	..	..
9. Nowapara	..	9	..	..	..	..	..

Table 13.—Seasonal Normal Rainfall in inches—*contd.*

Rainfall stations.		Number of years up to 1926.	Winter (Dec.—Feb.).	Summer March—May).	Monsoon (June—Sept.).	Autumn (Oct.—Nov.).	Total (whole year).
Mahanadi V—							
1. Bilaspur	..	61	1·65	2·36	43·36	2·36	49·63
2. Drug ..	..	61	1·30	1·74	42·80	2·39	48·23
3. Raipur ..	..	61	1·29	2·34	44·42	2·38	50·43
4. Simga	..	61	1·14	1·71	40·22	1·57	44·64
5. Mungeli ..	..	61	1·77	1·05	39·65	1·06	45·33
6. Pondra ..	..	47	2·30	2·08	43·43	3·08	51·58
7. Pandaria	..	30	2·23	2·25	36·77	2·40	43·65
8. Kawardha	..	25	2·38	2·68	32·90	2·76	40·72
9. Chhuikhadan	..	25	2·23	2·03	35·25	3·28	42·79
10. Khairagarh	..	25	2·09	1·98	38·14	3·49	45·70
11. Dongargarh	..	25	2·15	2·03	43·09	3·58	50·85
12. Nandgaon	..	25	2·38	2·71	44·07	3·23	52·39
13. Balodabazar	..	24	2·00	2·03	46·72	2·14	52·89
14. Ambachouki	..	22	1·93	2·38	47·99	2·95	55·25
15. Sanjari ..	..	21	1·84	2·85	45·33	3·19	53·21
16. Bemetara	..	21	2·09	1·97	41·66	2·07	47·79
17. Gondai ..	..	21	2·53	1·93	35·82	2·32	42·60
18. Pondi Lafa	..	21	2·36	1·61	51·43	2·15	57·55
19. Kusrangi	..	21	1·63	1·72	45·85	2·05	51·25
Baitarani—							
1. Keonjhar	..	44	1·93	5·58	36·47	4·00	47·98
2. Akhoyapada	..	42	1·53	7·79	42·83	6·08	58·23
3. Anandapur	..	34	1·97	7·78	40·02	5·09	54·86
4. Karanjia	..	22	3·10	6·96	46·70	4·38	61·14
5. Bonth ..	..	22	2·18	7·10	38·55	6·30	54·13
6. Korai ..	..	15	1·76	7·13	39·50	7·76	56·15
7. Chanoua	..	5	..	..	..	..	..
Nilgiri—							
1. Baripada	..	48	1·83	8·49	46·74	5·87	62·93
2. Nilgiri ..	..	21	2·60	10·54	46·18	8·83	68·15
3. Turigaria	..	10	1·89	8·44	42·29	7·58	60·20
Brahmini I—							
1. Angul ..	..	46	1·74	4·62	37·63	4·93	48·92
2. Dhenkanal	..	46	1·58	5·67	44·77	5·56	57·58
3. Talcher ..	..	46	1·67	4·90	41·24	3·80	51·61
4. Pal-Lahara	..	35	2·01	5·64	56·76	3·57	67·98
5. Chhendipara	..	26	1·92	4·27	41·35	3·56	51·10
6. Deogarh	..	24	1·75	3·78	57·10	4·66	67·29
7. Hindol ..	..	24	1·94	5·65	41·77	5·90	55·26
8. Sukinda	..	12	2·15	7·70	47·31	8·02	65·18
9. Barchana	..	12	2·24	7·16	47·04	8·22	64·66
10. Jarpara ..	..	10	..	..	..	..	..
Brahmini II—							
1. Jashpur	..	44	2·32	4·06	51·38	4·24	63·00
2. Lohardaga	..	43	2·52	3·31	42·20	3·33	51·36
3. Chainpur	..	33	3·10	3·22	44·67	3·47	54·46
4. Paikot ..	..	33	2·11	3·61	50·09	3·87	59·68
5. Gailkura	..	31	2·21	4·18	50·44	4·29	61·12
6. Manoharpur	..	31	2·47	3·98	51·51	3·46	61·42
7. Kurdeg ..	..	27	2·80	2·43	53·35	1·78	60·36
8. Bano ..	..	26	2·43	2·00	51·16	2·62	59·11
9. Gumla ..	..	24	2·72	4·01	44·12	3·37	54·22
10. Jagannathpur	..	23	2·24	4·95	43·30	3·19	53·77
11. Bonaigarh	..	21	1·96	4·15	57·14	3·06	66·31
12. Simdega	..	8	..	..	..	..	..

Table 13.—Seasonal Normal Rainfall in inches—*contd.*

Rainfall stations.		Number of years up to 1926.	Winter (Dec.—Feb.).	Summer (March—May).	Monsoon (June—Sept.).	Autumn (Oct.—Nov.).	Total (whole year.).
Subarnarekha I—							
1. Jellasore	..	54	1·86	7·76	43·43	5·73	58·78
2. Baharogora	..	40	1·82	7·29	44·40	3·87	57·38
3. Silda ..	..	18	1·54	9·02	41·07	4·55	56·18
4. Kultikri	..	17	1·51	8·54	39·27	6·96	56·28
Subarnarekha II—							
1. Ranchi ..	..	63	2·03	4·23	45·30	3·16	54·72
2. Chaibassa	..	57	2·16	5·50	41·83	3·40	52·95
3. Ghatsila	..	41	2·17	6·16	45·63	3·60	57·56
4. Jhalda ..	..	41	2·00	4·82	44·82	3·34	54·98
5. Silli ..	..	40	1·58	4·27	42·78	2·75	51·38
6. Chakradharpur	..	40	2·17	4·89	41·91	3·02	51·99
7. Kalikapur	..	34	1·82	6·46	49·77	4·29	62·34
8. Tamar ..	..	32	2·04	3·87	42·36	2·80	51·07
9. Seraikella	..	26	2·44	5·18	38·90	3·02	49·54
10. Kharswan	..	26	2·62	5·00	45·12	3·33	56·07
11. Khunti ..	..	21	2·47	4·64	55·59	3·88	66·58
12. Piska ..	..	5	..	..	..	..	..
13. Sonahatu	..	5	..	..	..	..	..
Delta—							
1. Cuttack ..	..	57	1·47	6·34	45·93	6·92	60·66
2. Hukitola	..	57	2·04	6·32	44·80	12·10	65·26
3. Bhadrak	..	57	2·16	9·17	42·86	6·95	61·14
4. Balasore ..	..	57	2·07	8·89	45·20	7·66	63·82
5. Puri ..	..	57	1·50	3·87	37·89	10·73	53·99
6. Kendrapara	..	56	1·66	6·63	43·22	7·96	59·47
7. Jajpur ..	..	56	1·86	7·58	43·08	6·48	59·90
8. Khurda ..	..	56	1·51	5·06	44·91	7·81	59·29
9. Jagatsingpur	..	55	1·55	5·59	44·35	9·22	60·71
10. Chandbally	..	54	1·71	7·70	42·96	8·61	60·98
11. Banpur ..	..	48	2·16	4·15	39·07	8·45	53·83
12. Ranpur ..	..	34	1·93	4·91	42·62	7·60	57·06
Border area—							
1. Ramgarh	..	39	2·00	2·87	42·74	4·04	51·65
2. Gola ..	..	16	2·09	5·19	47·99	4·97	60·24
3. Barakatha	..	5	..	..	..	..	..
4. Mahuadanar	..	27	2·39	3·09	43·26	3·23	51·97
5. Chandwa ..	..	17	1·52	3·10	42·78	4·90	52·30
6. Purulia ..	..	57	1·89	5·24	43·69	3·40	54·22
7. Manbazar	..	22	1·67	5·78	38·65	4·27	50·37
8. Bandwan	..	12	1·19	5·72	40·55	4·13	51·59
9. Midnapur ..	..	68	1·91	8·60	42·46	4·70	57·67
10. Bankura ..	..	41	1·67	7·41	44·12	3·55	56·75
11. Jagdalpur ..	..	25	1·35	4·68	48·80	4·45	59·28
12. Sirguja	..	45	2·71	1·99	56·61	3·12	64·43
13. Mandla	..	60	2·05	2·40	48·71	2·20	55·26
14. Dindoria	..	41	2·60	2·14	46·21	2·96	53·91
15. Bajag	..	11	3·20	3·19	47·20	4·95	58·54
16. Mul	..	60	1·18	2·12	48·74	2·43	54·47
17. Armari	..	45	1·15	1·87	41·77	2·75	47·54
18. Ghot	..	10	1·78	1·28	53·77	2·96	59·79
19. Dhanora	..	6	..	..	..	..	..

Table 13.—Seasonal Normal Rainfall in inches—*concld.*

Rainfall stations.	Number of years up to 1926.	Winter (Dec.—Feb.).	Summer (March—May).	Monsoon (June—Sept.).	Autumn (Oct.—Nov.).	Total (whole year).
20. Sakoli ..	60	1·50	1·63	48·89	2·16	54·18
21. Baihar ..	57	2·02	1·92	52·81	2·64	59·39
22. Lanji ..	57	1·67	1·45	57·36	2·50	62·98
23. Russelkunda ..	..	1·93	6·37	36·44	6·94	51·68
24. Surada ..	..	2·02	6·99	36·08	8·01	53·10
25. Dorringabad ..	..	1·52	8·11	41·73	6·95	58·31
26. Nowrangpur ..	..	·97	4·50	56·05	3·94	65·46
27. Bissemkatak ..	..	1·34	6·88	38·34	4·67	51·23
28. Royagadha ..	..	1·25	5·94	33·79	4·89	45·87
29. Suri ..	...	1·33	5·88	45·93	3·82	56·96
30. Hazaribagh ..	..	2·01	3·66	43·56	3·50	52·73
31. Balumath ..	..	2·19	2·49	44·69	3·04	52·41
32. Latehar ..	..	2·55	2·71	48·30	2·89	56·45
33. Daltonganj ..	..	1·87	1·96	38·17	2·57	44·57
34. Sohagpur ..	..	1·15	·69	44·81	1·73	48·38
35. Ranka ..	..	2·95	2·53	46·53	2·55	54·56

CHAPTER 4.—STORMS AND DEPRESSIONS.

The heaviest rainfall in the catchment area of the Orissa rivers are given by storms and depressions which move inland from the Bay of Bengal during the monsoon season.

The actual track of all storms* which entered the land area lying between 19° and 24°N, and between 81° and 88°E have been indexed in Tables 14—20 for the months of May, June, July, August, September, October, and November, for the period 1891—1928 from "Storm Tracks in the Bay of Bengal" (published by the Indian Meteorological Department, 1925) and the Daily Weather Report.

In calculating the mean track of storms,* I have not taken "depressions" into consideration. The distinction between "storms" and "depressions" is, of course, conventional. The India Meteorological Department tries to limit the use of the word "depression" to those "cyclonic circulations in which the wind does not reach gale force, i.e., of force 7 or less on the Beaufort scale" (which corresponds to 28—33 miles per hour). A "depression" becomes a "storm" when the wind in a part of the cyclonic area reaches gale force, Beaufort scale 8 (34—40 miles per hour), and is called severe when the wind rises to force 10 (49—56 miles per hour).

In these track tables the latitude position of the centre of the storm has been given for each degree of longitude. For example in Table 18, storm of September 21—26, 1893, the centre was lying at latitude 19°0′N. on longitude 88°E, and at latitude 19·8°N. on longitude 87°E., etc.

The origin of the storm (where determinate) is shown by a star (*) mark. Thus in the case of the present storm, the origin was located at 16·4°N. and 89·4°E. The direction of the storm is usually from left to right in the tables, that is, from east to west, or from higher to lower longitudes. In a few cases, the storms curved back, moving from west to east. In such cases the approximate region where the storm turned back is indicated by a reversed arrow. For example, the present storm turned back at 23·0°N. and 83·3°E. The direction of motion is indicated by an arrow mark in all cases, and the position of the storm on the reverse track is written in the second line. Thus, the present storm moved from 87° to 86°, 85° and 84°E at 19·8°, 20·4°, 21·0°, and 21·6°N. latitude, respectively on its direct track, and had the latitude position of 25·3°, 26·4°, 27·1°, and 27·5°N corresponding to 84°, 85°, 86°, and 87°E. respectively on the reverse track. The position of disappearance of the storm or depression is indicated by the sign †. The present storm is marked with this sign indicating that it disappeared near the region 27°·5N. and 86°·7E.

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* In earlier years the Meteorologists were very cautious in asserting the existence of a storm or depression and in several cases I have noted the fact of a depression having formed in the light of later developments.

Table 14.—Storm Tracks for the month of May.

Year	Date.	98°	97°	96°	95°	94°	93°	92°	91°	90°	89°	88°	87°	86°	85°	84°	83°	82°	81°	80°	79°	78°	77°	76°	75°	74°	73°	72°	71°
1893	(23—26)—28 ..	..	..	..	..	..	..	..	..	..	..	→ *87·3 *19·3*																	
						†25·6 ←	25·0	24·7	24·0	24·1	23·5	22·5 ←																	
1904	25·(26—28) ..	..	..	..	...	..	..	..	..	..	..	..	..	..	..	*83·5 → *13·4*	14·3	→ 16·4											
											†25·0 ←	24·4	23·7	23·0	22·3	21·4	20·0	17·4 ←											
1914	13—(16·17) ..	..	..	..	..	..	..	..	→ **13·2*	13·9	14·0	15·2	16·0	17·0	→ 18·5														
												†23·4 ←	22·9	22·0	20·6 ←														
1917	1—(3)·4 ..	..	..	..	..	..	..	..	..	..	†22·8 ←	21·3	20·0	16·4	16·9	*14·8** ←													

Year.	Date.	93°	92°	91°	90°	89°	88°	87°	86°	85°	84°	83°	82°	81°	80°	79°	78°	77°	76°	75°	74°	73°	72°	71°	70°	—
1892	8-(9-•-12)-13 ..	..	..	..	..	→ *19·0*	20·0	21·0	22·0	22·6	23·0	23·6	24·2	→ 24·7												
													†27·5 ←	25·7 ←												
1894	(21—23)-24 ..	..	..	..	..	..	→ *•87·3* *20·0*	21·0	22·3	23·0	23·6	24·2	25·0	→ 26·0†												
	13-(14—16)—18 ..	..	→ *•91·3* *23·0*	23·0	23·0	23·1	23·2	23·3	23·4	23·5	23·6	23·6	23·7	23·8	24·0	24·0	24·1	24·3	24·4	25·0	→ 26·0					
																				†30·7 ←	29·4 ←					
1895	(19-20)-21 ..	..	..	..	..	..	→ 20·6	21·0	21·3	21·5	21·7	22·0	22·5	23·0	23·3	24·3	25·0	→ 26·5								
	(28-29)—1st July ..	..	..	..	..	..	→ 20·4	21·0	21·2	21·6	21·8	22·0	22·5	23·0	23·5	24·0	25·0	→ 26·0†								
1896	18-(19—21)—23 ..	..	..	..	→ *89·1* *20·4*	21·0	22·4	22·7	22·9	22·9	23·0	23·1	23·3	23·6	24·1	24·7	25·1	..	..	..	..	..	..	..	..	→ *67·6†* *28·1*
	26—(28·29)—1st July	..	..	..	→ 20·4	22·3	23·2	23·4	23·6	23·4	24·0	24·3	24·6	24·8	25·3	..	... †30·7 ←									
1897	(15—19)—20 ..	..	..	..	..	→ 19·6	20·4	21·0	21·6	22·4	23·2	23·7	24·2	24·4	24·4	24·4	→ 24·4†									
1898	13-(14—18)—20 ..	..	..	..	†26·2 ←	25·7	22·4	21·0	•18·4 ←																	
1900	(11—14)—15 ..	..	..	..	..	→ *•88·4* *·18·8*	19·2	19·7	20·2	20·6	→ 22·0															
					†25·6 ←	25·3	24·7	24·4	24·0	23·4	22·0 ←															
	(22—24) ..	..	..	..	..	..	→ *•21·0*																			
						†23·4 ←	22·6 ←																			

Table 15.—Storm Tracks for the month of June—*contd.*

Year.	Date.	91°	90°	89°	88°	87°	86°	85°	84°	83°	82°	81°	80°	79°	78°	77°	76°	75°	74°	73°	72°	71°	70°
1903	(25—26)	..	..	..	→21·8	22·0	22·5	→23·0†															
1905	(30—2)-3 July ..	..	..	..	..	→20·5	20·8	21·0	21·3	21·6	22·1	→23·0											
												†28·0 ←											
1906	(18—20)—23	..	..	..	..	..	→19·0	19·4	19·8	20·3	20·8	21·6	22·4	23·0	→23·6†								
1907	13—(16—20)	..	..	..	..	..	..	→**15·6*															
					20·3	19·6	19·0	18·0															
					←22·7→	23·3	23·6	←23·9†→															
	23—(25-26)	..	→*20·5*	22·2	23·2	23·3	23·2	22·9	→22·3†														
1911	9-(10—13)—15	..	..	→**18·0*	18·5	18·8	19·5	20·1	20·8	→22·0													
			†24·0 ←	23·3	23·2	23·4	23·8	24·1	24·2	24·0 ←													
1914	(24-26)-28	..	..	..	..	..	→*19·2*	19·3	19·4	19·6	19·8	20·0	20·2	20·4	20·6	21·0	21·5	22·0	22·4	22·8	→23·4†		
1915	23-(24-25)-26 ..	..	..	..	..	→*16·9*	17·0	17·5	17·8	18·4	19·2	20·7	→21·8†										
1927	16-(17-18)—20..	..	..	..	..	→**86·7* *15·2*	20·0	21·0	21·9	22·4	22·6	23·0	23·4	→24·4									
													†30·7 ←	29·0 ←									

Table 16.—Storm Tracks for the month of July.

Year.	Date.	92°	91°	90°	89°	88°	87°	86°	85°	84°	83°	82°	81°	80°	79°	78°	77°	76°	75°	74°	73°	72°	71°	—	..	—
1891	24·(25—27)—30..	..	..	..	→ •88·2 22·2	22·2	22·3	22·6	22·8	23·0	23·3	23·5	23·7	24·1	→ 24·4†	..	..	..	..	..	..	..	→ 70·2† 28·0			
1892	(9—13) ..	..	..	..	→ 19·0	•20·7	21·3	21·7	22·1	22·6	23·4	→ 82·3† 25·4														
	(22—24)—26 ..	..	..	..	..	→ 87·8 23·0	23·1	23·3	23·4	23·5	23·5	23·7	24·1	24·4	24·7	25·3	→ 25·6†	..	..	..	..	..	..	→ 69·4† 29·0		
1894	(11—12)—14 ..	..	..	..	..	→ •87·4 19·4	19·8	20·6	21·0	21·2	21·3	21·3	21·4	21·5	21·6	21·7	22·0	22·2	22·5	22·9	..	..	..	..	..	→ 65·5† 25·5
	(16—19)—24 ..	..	..	..	→ •88·5 20·0	20·7	21·3	21·4	21·6	21·7	21·8	21·9	22·0	22·1	22·2	22·3	22·6	22·7	23·2	..	..	..	..	..	..	→ 65·5† 25·5
	(24—27) ..	..	→ •90·3 21·6	22·0	22·4	22·5	22·6	22·7	23·1	23·5	23·7	24·2	→ 24·5†													
1895	18·(19)·20 ..	..	..	..	..	→ •20·0	21·7	23·0 †28·0 ←																		
	(30·31)—2nd July	..	..	..	..	..	→ •21·2	21·6	22·1	22·6	23·2	24·2	25·5	→ 28·0†												
1896	(22—24)—26 ..	..	..	..	→ •21·3	21·3	21·3	21·3	21·3	21·3	21·3	21·3	21·3	21·4	21·6	21·8	→ 22·0†									
	26·(27—29)·30 ..	..	..	..	→ •21·4	21·4	21·5	21·5	21·5	21·5	21·5	21·5	21·5	21·6	22·4	→ 23·7†										
1897	(9·10) ..	..	..	..	..	→ •20·7	21·0	21·2	21·4	21·7	22·0	22·3	22·8	23·4	24·2	→ 24·8†										
1898	(2—5)—7 ..	..	..	..	→ •88·4 21·6	21·7	22·4	22·8	23·1	23·4	23·6	23·6	23·9	24·1	24·2	24·3	..	..	..	..	..	..	..	..	..	→ 67·0†
1900	(13·14)·15 ..	..	..	..	..	→ 21·6	22·0	22·5	23·0	23·4	23·8	24·5	26·0	..	..	..	→ 27·7†									
	29—(31st—2nd Aug.). ..	..	..	..	→ •88·5 18·5	18·8	19·4	20·2	21·0	21·7	22·4	23·0	23·7	24·5	25·3	→ 26·0†										

Table 16.—Storm Tracks for the month of July—*contd.*

Year.	Date.	93°	92°	91°	90°	89°	88°	87°	86°	85°	84°	83°	82°	81°	80°	79°	78°	77°	76°	75°	74°	73°	72°	71°	—	..
1902	15-(16-17)—19 ..	..	..	..	..	← 20·6	21·3	21·7	22·3	22·7	23·2	23·6	24·0	24·5	25·0	→ 27·0†										
	(27—29)—2nd Aug.	..	..	..	..	→ •88·5 21·5	22·0	22·8	23·4	23·7	24·0	24·3	24·4	24·6	24·7	25·0	→ 26·5									
															← †29·4	28·6	27·5 ←									
1903	12-(13-14) ..	..	..	..	..	..	..	→ 18·4	18·6	→ 85·5† 20·5																
	(23-24) ..	..	..	..	..	..	..	→ 20·8	20·8	20·8	20·8	20·9	20·9	→ 21·0†												
1904	(1—3)—5 ..	..	..	..	..	→ •88·4 21·0	21·1	21·3	21·4	21·6	21·6	21·7	21·7	21·8	22·0	22·1	22·3	22·5	22·6	22·8	23·1	23·4	→ 27·6†			
	(7—9)—11 ..	..	..	..	..	→ •85·4 23·0	23·0	23·0	23·3	23·7	24·3	24·4	24·5	24·6	24·7	25·2	25·7	→ 77·5† 26·0								
1905	(5—7)-8 ..	..	..	..	→ •89·4 21·9	22·0	22·2	22·4	22·6	22·9	23·0	23·1	23·3	23·4	23·5	23·6	23·6	→ 23·6†								
	11-(12-13)-14 ..	..	..	..	→ •89·5 21·0	21·5	22·1	23·5	24·2	24·6	25·0															
	(19—21)—24 ..	..	..	..	..	→ 21·2	21·1	21·0	21·0	21·0	21·1	21·4	21·6	21·6	21·7	21·7	21·8	..	..	..	..	..	..	..	→†	
1906	(21—23) ..	..	..	..	..	..	..	→ •20·0	20·3	20·5	20·8	21·3	21·7	22·1	→ 22·7†											
	25-(26-27) ..	..	..	→ •90·6 21·4	22·0	22·7	23·2	23·4	→ 23·6†																	
1910	1—(3—5)—7 ...	..	..	..	→ •20·1	20·8	21·0	21·2	21·4	21·6	21·8	21·9	22·1	22·2	22·4	22·5	22·7	22·8	23·0	23·2	23·4	23·7	23·8	..	..	→†
1912	27-(28-29)-30 ..	..	..	..	..	..	→ •20·3	20·4	20·8	20·9	21·2	21·7	22·0	22·2	22·8	23·0	23·4	23·8	24·0	24·0	24·1	24·2	24·3	..	..	→†

Table 16.—Storm Tracks for the month of July—*concld*

Year.	Date.	93°	92°	91°	90°	89°	88°	87°	86°	85°	84°	83°	82°	81°	80°	79°	78°	77°	76°	75°	74°	73°	72°	71°	—
1913	16-(17-18)—21 ..	..	..	..	..	..	..	→19·5	20·0	20·3	20·5	20·8	21·0	21·4	21·8	22·0	22·5	22·9	23·3	23·6	24·0	24·1	24·4	..	→†
	23-(24—26)—28..	..	..	..	→21·0	21·3	21·7	22·2	21·8	22·4	23·0	23·1	23·3	23·4	23·5	23·6	23·7	23·9	24·0	24·1	24·1	24·2	24·3	..	→†
1914	(10—12)-13 ..	..	..	..	..	..	..	→19·0	21·4	21·9	22·1	22·6	23·0	23·4	24·0	→24·7†									
1920	21—(23-24)—26..	..	..	..	..	..	→21·0	20·1	20·0	20·0	20·0	20·3	20·9	21·9	23·1	→23·7†									
1921	24—(27—29)—1st Aug.	..	..	..	..	→21·8	22·5	22·9	23·2	23·4	23·5	23·8	23·9	24·2	24·3	24·5	24·7	24·8	25·0	25·0	25·0	25·0	25·1	..	→†
1922	7-(8-9)-10 ..	..	..	..	..	→19·7	20·5	21·4	22·3	23·1	24·0	→24·6†													
	27-(28-29)-30 ..	..	..	..	..	→88·6 20·7	21·0	21·3	21·8	22·0	22·2	22·6	23·1	23·6	→80·3† 24·2										
1925	9—(12-13)-14 ..	..	..	..	*→89·4 19·0	20·0	21·0	20·9	20·9	21·0	21·2	21·7	22·4	23·5	24·7	25·4	→25·6†								
	25-(26—28) ..	..	..	..	..	→22·3	21·4	21·6	22·0	22·4	22·6	22·7	23·0	23·0	23·0	→23·0†									
1926	5—(7)—9 ..	..	..	→22·2	23·6	23·6	23·4	23·0	22·7	22·4	22·4	22·4	22·6	22·8	23·2	23·6	24·0	24·5	25·0	→25·6†					
1927	27—(29-30)-31 ..	..	..	→19·7	21·0	22·3	22·6	23·0	23·3	→84·7† 25·3															
1928	17—(19-20)—23.	..	→19·2	19·7	20·3	21·0	22·0	22·8	23·0	23·1	23·0	23·0	22·9	22·7	22·7	22·8	23·0	23·6	24·3	25·0	25·7	26·7	28·0	29·0	→70·3† 30·3
	23—(26-27)-28 ..	..	→18·5	18·7	19·5	20·1	21·5	21·8	22·0	22·1	22·7	23·3	23·8	24·7	25·7	→26·8†									

Table 17.—Storm Tracks for the month of August.

Year.	Date.	93°	92°	91°	90°	89°	88°	87°	86°	85°	84°	83°	82°	81°	80°	79°	78°	77°	76°	75°	74°	73°	72°	71°	..	..	—	—
1891	1—(3·4)	..	→ *91·2 20·4	20·6	20·8	21·0	21·2	21·3	21·5	21·7	22·0	22·7	23·8	→ 81·5† 24·5														
	12-(13·14)—16	..	..	..	→ *89·4 23·0	23·0	23·0	23·0	23·0	23·2	23·5	24·0	25·0	26·2	→ 27·6†													
1892	29-(30—3rd Sept.)—6th ..	..	..	..	..	..	→ *87·3 17·5	17·7	18·8	19·9	21·0	21·9	22·5	22·9	23·0	23·0	23·1	23·2	23·2	23·5	24·0	25·5	→ 72·4† 27·5					
1893	(31st July—4th Aug.) ..	..	..	..	..	→ *88·4 19·7	20·4	21·6	22·0	22·6	22·7	23·0	23·3	23·6	24·0	24·7	→ 78·3† 26·0											
1894	(13—15)—18	..	..	..	..	→ *88·5 22·5	22·7	23·0	23·4	23·7	24·0	24·3	24·4	24·6	24·8	25·2	→ 78·9† 25·5											
1895	(6—8)-9	..	..	..	..	..	..	21·0	22·0	22·5	23·0	23·3	23·6	24·0	24·2	24·3	24·4	24·4	24·4	24·4	24·4	24·4	24·5					
1896	1-(2·3)-4	..	..	..	→ *89·5 20·6	21·0	21·6	21·7	21·9	22·0	22·3	22·3	22·6	22·9	23·2	23·4	23·7	..	..	..	..	..	..	..	..	..	..	→ 68·0† 27·0
	(13·14)—16	..	..	..	..	→ *88·6 20·5	20·8	21·3	21·6	21·6	21·9	22·0	22·0	22·1	22·2	22·3	22·3	22·5	22·7	..	..	..	..	..	..	..	..	→ 68·0† 27·0
	20-(21)-22	..	..	..	→ *89·4 21·4	21·7	22·5	23·4	24·4	25·3	26·5	→ 83·3† 27·4																
1897	(13—15)—19	..	..	..	..	..	→ 21·0	21·2	21·3	21·5	21·8	22·1	22·4	23·0	23·7	24·7	25·7	26·6	..	..	..	..	..	→				
1898	(9—11)-12	..	..	..	..	→ *88·6 21·5	22·2	23·2	24·0	→ 25·5†																		
	(21—28)	..	..	..	→ *90·4 22·0	22·0	22·0	22·0	22·0	22·1	22·3	22·5	22·7	23·0	23·4	→ 79·3† 23·5												

Table 17.—Storm Tracks for the month of August—*contd.*

Year.	Date.	94°	93°	92°	91°	90°	89°	88°	87°	86°	85°	84°	83°	82°	81°	80°	79°	78°	77°	76°	75°	74°	73°	72°	71°	..	..	..
1899	8—(10—12)	→ *94·1 15·6	..	..	..	..	..	..	..	19·0	19·7	20·7	22·0	23·3	→24·5†													
	(27—29)—31	..	..	..	..	..	..	..	→ 86·7 19·2	19·6	20·4	21·5	→24·0															
								←†25·5	..	25·6	25·4	25·3 ←																
1900	(9—13)-14	..	..	..	..	..	→ *88·2 20·2	20·3	20·6	20·7	21·0	21·3	21·5	21·7	21·9	22·2	22·4	22·7	23·2	23·7	24·6	→25·0†						
	15—(17—20)-21.. ..	..	..	..	→19·6	20·3	20·7	21·1	21·4	20·0	22·6	23·1	23·5	23·9	24·3	24·5	24·7	25·0	25·3	→25·5†								
	25-(26-27)—30	..	..	..	..	→ *89·7 20·5	21·2	21·8	22·5	23·0	23·6	24·2	24·7	25·3	25·7	→20·6†												
1902	19-(20)—23	..	..	..	..	..	..	..	→ *86·5 17·0	17·4	18·0	18·6	19·4	20·0	20·0	21·6	22·0	22·4	22·6	22·7	23·0	23·8	23·5	→24·0	..	..	..	→
	(24—26)—29	..	..	..	..	..	..	→20·3	21·0	21·5	22·0	22·5	23·0	23·4	23·7	24·3	24·6	24·8	25·0	25·1	→25·8							
1903	(1—3)	..	..	..	..	..	..	→ *87·3 20·3	20·4	20·7	21·3	21·7	22·4	23·0	23·5	→24·3†												
	29-(30)	..	..	..	..	..	..	..	..	→ *85·3 16·6	17·0	18·4	→19·6†															
1904	12-(13-14)—16	..	..	..	..	..	→ *20·0	21·4	21·8	22·3	22·7	23·4	24·0	24·6	25·2	25·8	→79·2† 20·5											
	20-(21-22)—24	..	..	..	..	..	→ *88·6 20·6	22·0	22·3	22·5	22·0	23·5	23·8	24·3	24·7	25·3	26·0	→27·0†										
1907	(12—16)—18	..	..	..	..	..	..	→ *20·6	21·4	21·9	22·1	22·3	22·9	23·4	24·0	25·0	25·8	→26·3	..	..	..	..	..	..	→			
	18-(19—21)-22	..	..	..	..	..	→ *88·3 22·7	22·4	22·1	22·4	23·0	23·6	24·3	→25·0†														
	(26-27)	..	..	..	..	..	..	→ *20·6																				
								†21·7 ←																				
1908	(7-8)	..	..	..	..	..	..	→ *20·6	22·0	23·3	→85·5† 23·8																	
	(28—31)—5th Sept. ..	..	..	..	..	..	..	→ *87·2 19·0	19·8	20·4	21·0	21·4	22·0	22·6	23·0	23·7	24·3	25·0	25·5	26·3 †32·5 ←								
1910	1—(3—5)-6	..	..	..	..	..	..	..	→ *20·0	21·3	21·9	22·1	22·3	22·6	22·8	23·2	23·5	→27·0†										

Table 17.—Storm Tracks for the month of August—*concld.*

Year.	Date.	91°	90°	89°	88°	87°	86°	85°	84°	83°	82°	81°	80°	79°	78°	77°	76°	75°	74°	73°	72°	71°
1912	1·(2—4)·5	..	..	..	..	..	→ *18·8	20·6	21·8	22·6	23·3	→ 23·7†										
1913	30th July, 31st July—2nd Aug. ..	..	..	→ *21·8	22·0	22·0	22·2	22·3	22·6	22·8	23·0	→ 23·8	..	→								
1915	1·(2—4)—6	..	..	..	→ *20·0	21·1	21·7	21·9	22·0	22·5	23·0	23·6	24·3	25·2	→ 26·5†							
	26·(27—29)—1st Sept.	..	..	..	..	← *17·7 20·5 →	20·9	21·3	22·0	22·9	→ 23·9 †20·4 ←											
1919	28th July—(1·2)—4	..	→ *18·3	19·4	20·2	20·8	21·1	21·5	21·8	22·0	22·3	22·6	23·0	23·5	24·1	24·6	25·2	→ 25·7				
1924	2—(5)—11	..	..	..	→ 20·7	21·2	21·6	22·0	22·4	23·0	23·7	24·7	25·4	..	..	..	→ 26·5					
1925	(20—23)	..	..	→ *88·5 21·2	21·2	21·4	21·6	21·8	22·0	22·3	22·6	23·0	23·4	→ 79·5† 24·0								
1926	13—(16—18)—21	..	..	→ *88·3 25·0	23·0	21·1	21·0	21·2	21·5	21·8	22·2	22·5	23·0	23·4	24·0	25·0	26·3	→ 28·0†				

Table 18.—Storm Tracks for the month of September.

Year.	Date.	93°	92°	91°	90°	89°	88°	87°	86°	85°	84°	83°	82°	81°	80°	79°	78°	77°	76°	75°	74°	73°	72°	71°
1891	(1—3)-4	..	..	..	..	→ *88·5 20·5	20·7	21·3	22·0	22·7	23·4	24·0	24·5	24·8	25·6	→ 79·6† 26·0								
	(5—7)—10	..	..	..	→ *89·6 21·0	21·0	21·3	21·4	21·6	22·0	22·7	23·7	24·3	24·3	24·4	24·8	25·5	26·4	→ 76·6† 26·5					
	(11—13)—16	..	..	..	→ *89·5 20·3	20·4	20·5	20·8	21·2	21·4	21·7	22·3	23·2	20·7	→ 80·2† 28·7									
	17·(18-19)	..	..	..	..	..	→ 87·5 18·3	18·4	18·8	19·2	19·7	20·2	20·6	20·9	21·2	21·6	21·9	22·3	22·6	23·0	23·4	→ 73·6† 23·6		
	20—(22—24)	..	..	..	→ *18·5	19·5	20·4	21·2	21·7	21·9	22·0	22·0	21·8	21·7	21·5	→ 21·0								
													†25·8 ←	26·4	24·0	23·2 ←								
1892	7·(8—11)-12	..	→ *17·7	18·0	18·4	18·8	19·3	19·6	20·1	20·6	20·8	21·4	21·8	22·4	23·0	23·7	24·7	25·7	→ 26·4†					
1893	(2—4·5)	..	..	..	..	→ *88·7 19·4	20·6	21·2	21·7	22·3	22·7	23·0	23·2	23·6	24·0	24·8	→ 78·3† 26·0							
	9·(10—13)	..	..	→ *90·3 17·7	18·4	20·3	21·1	21·7	22·0	22·4	22·6	23·0	23·4	→ 24·0†										
	21·(22—24)—26.. ..	..	..	..	→ *89·4 16·4	17·6	19·0	19·8	20·4	21·0	21·6	← 83·3												
								†27·5 ←	27·1	26·4	25·3	23·0 ←												
1894	(24—30)—1st Oct. ..	..	..	..	..	→ *88·5 19·3	19·4	19·7	20·3	20·6	20·8	21·1	21·3	21·6	→ 22·3									
													†25·3 ←	24·7	23·7 ←									
1895	16—(18—19)·20 ..	..	..	..	→ *18·0	20·0	21·0	22·0	23·4	24·5	25·3	26·0	→ 27·0†											
	(30—1st Oct.)—2nd Oct. ..	..	→ *24·8	23·7	22·8	21·5	→ 20·5†																	

Table 18.—Storm Tracks for the month of September—*contd.*

Year.	Date.	93°	92°	91°	90°	89°	88°	87°	86°	85°	84°	83°	82°	81°	80°	79°	78°	77°	76°	75°	74°	73°	72°	71°
1896	13—(15·16)—19..	..	..	→ *90·6 *19·9*	20·0	20·3	20·7	→ 22·0																
						†25·1 ←	24·7	23·8 ←																
1897	23·(24·25)·26	..	..	→ ..	..	..	..	..	..	..	→ 18·6	19·0	19·6	20·4	21·6	23·0	⟶	towards the north.						
1898	11—(13—15)·16.. ..	..	..	..	..	..	..	→ *86·6 *18·2*	22·6	→ 24·4														
										†25·7 ←														
	(20·21)—23	..	..	..	..	→ *88·5 *21·1*	21·7	23·0	23·7	24·4	24·9	25·4	20·0	20·4	→ 80·3† 26·6									

Table 18.—Storm Tracks for the month of September—*contd.*

Year.	Date.	94°	93°	92°	91°	90°	89°	88°	87°	80°	85°	84°	83°	82°	81°	80°	79°	78°	77°	76°	75°	74°	73°	72°	71°
1899	9—(12·13)—16 ..	..	..	→ *18·3	..	..	..	..	..	..	18·0	18·3	18·7	19·3	20·1	21·3	→ 23·0								
											†25·6 ←	25·7	26·0	26·2	26·1	25·5 ←									
1900	15·(16—24)—27 ..	..	..	..	..	..	→ *88·6 *20·6*	20·7	20·9	21·0	21·0	20·0	20·9	20·8	20·8	21·0	→ 22·0								
													†26·3 ←	25·5	24·7	24·0 ←									
1901	20—(23·24) ..	..	..	..	..	..	..	..	..	→ *85·4 *16·7*	17·0	17·6	18·5	19·3	20·3	→ 22·2									
														†27·8 ←	26·2	24·6 ←									
1902	(1·2)·3	..	..	..	..	..	..	→ *21·0	21·3	21·6	21·9	22·3	22·6	22·9	23·2	23·3	23·3	23·3	23·2	23·1	→ 23·0	..	..	..	→
	23·(24·25)·26	..	..	..	..	→ *89·6 *17·3*	20·3	21·0	22·0	23·7	26·0	→ 84·8† 27·0													
1905	(7—9)—11 ..	..	..	..	..	..	..	..	→ *86·5 *19·0*	20·6	20·7	21·0	21·0	21·3	21·5	21·7	22·0	22·5	→ 23·0						
	22—(24—26) ..	..	..	..	..	..	..	..	→ *86·5 *16·0*	16·1	16·5	17·6	19·4	20·6	21·5	22·3	→ 22·7								
	(28·29)·30 ..	..	..	..	..	..	→ *22·0	22·0	22·5	23·4	→ 85·6† 26·5														
1907	(2·3) ..	..	..	..	..	..	→ *23·0	23·6	→ 24·6†																
1911	20—(25)—28 ..	..	→ *15·4	16·0	16·4	16·9	17·3	17·6	17·8	17·9	18·0	18·3	18·7	19·1	20·3	22·8	24·0	25·0	→ 28·0†						

Table 18.—Storm Tracks for the month of September—*concld.*

Year.	Date.	92°	91°	90°	89°	88°	87°	86°	85°	84°	83°	82°	81°	80°	79°	78°	77°	76°	75°	74°	73°	72°	71°
1912	5-(6)-7	..	..	..	..	→ *22·0	22·2	22·5	22·8	23·0	23·4	23·9	24·3	25·0	→ 25·7†								
1913	30th Aug.—(1)—4 ..	..	..	..	..	..	→ **19·7*	19·8	19·9	20·0	20·1	20·3	20·4	20·8	21·1	21·7	22·0	22·4	22·8	23·0	23·4	23·9	→†
1916	19—(21—23)—28 ..	..	→ *18·0	18·7	20·2	22·6	23·0	23·0	22·9	22·9	23·0	23·0	23·0	22·9	23·0	23·8	24·5	25·2	→ 25·9†				
1921	2—(4—6)-7	..	..	..	→ **88·7* *17·8*	18·1	18·8	19·4	20·0	20·6	21·2	21·8	22·3	23·0	23·7	24·3	→ 77·7† 24·6						
1925	30th Aug.—(1-2)—4 ..	..	..	..	..	→ *18·4	19·2	20·2	22·0	→ 24·4													
							†25·4 ←	25·7	26·0	26·0 ←													
	6-(7)—9	..	..	..	→ **88·6* *19·6*	21·0	22·1	23·2	24·2	24·7	25·2	25·4	→ 25·5†										
1926	14—(16—18)—24 ..	..	..	→ **89·7* *15·6*	16·0	17·0	18·4	21·1	21·7	21·8	21·7 †27·5 ←	→ 21·7 25·5 ←	→ 22·0 ←										

Table 19.—Storm Tracks for the month of October.

Year.	Date.	93°	92°	91°	90°	89°	88°	87°	86°	85°	84°	83°	82°	81°	80°	79°	78°	77°	76°	75°	74°	73°	72°	71°
1892	26—(31) ..	..	..	..	..	..	..	→ *86·8 10·2	..	..	..	..	13·8	14·3	14·6	15·0	→ 16·0							
													†19·3 ←	19·3	19·3	19·0	18·0 ←							
1894	(2—4)·5	..	..	..	..	..	→ *20·6	21·8	22·8	23·5	24·2	24·7	25·3	25·7	26·3	→ 26·7†								
1897	——	..	..	..	..	..	..	..	†27·4 ←	25·6 ←	from South to North 17°—25° lat.													
1898	——	..	..	..	..	..	..	..	..	→ *13·2	→ 13·5													
					†25·0 ←	24·6	23·7	22·8	21·6	20·4	19·2 ←													
1899	12—(14·15)·16 ..	..	†25·4 ←	24·4	23·2	22·3	21·4	20·6	19·6	18·6	17·3	15·5	11·0* ←											
1900	4—(6—10) ..	..	..	..	..	..	→ *87·2 14·5	15·0	19·5	20·4	20·6	20·6	→ 21·3	→ 22·0 ←										
											†24·0 ←	23·6	22·7 ←											
1903	(5—8)—11 ..	..	..	..	..	..	..	..	→ *19·0	21·0	22·0	22·6	23·2	23·6	24·0	→ 24·4								
														†25·0 ←	25·6	25·7 ←								
	28—(30·31) ..	..	..	..	..	..	..	..	..	..	→ *13·2	→ 14·2	→ 18·0 ←											
								†21·7 ←	21·6	21·5	21·3	20·5 ←												

Table 19.—Storm Tracks for the month of October.—*concld.*

Year.	Date.	94°	93°	92°	91°	90°	89°	88°	87°	86°	85°	84°	83°	82°	81°	80°	79°	78°	77°	76°	75°	74°	73°	72°	71°
1904	14—(16·17) ..	..	..	..	..	..	..	..	.. †26·2 ←	→ *85·4 12·3 25·6	12·6 25·2	13·7 24·5	15·0 23·7	10·4 22·6	→ 18·0 22·0 ←										
1912	28—1st Nov.-2nd ..	..	..	..	..	..	→ *8·8	9·1 †24·0 ←	9·6 22·0	10·8 20·0	→ 11·3 18·2 ←														
1913	13—16	..	..	..	..	..	..	.. †24·5 ←	.. 23·8	→ *17·8 23·0	18·3 22·0 ←	→ 20·4													
1915	30th Sept.—(3—5)—7	..	..	..	..	..	..	→ *17·4	17·8	17·9	17·7	17·2	16·3 †26·2 ←	16·3 25·0	→ 18·0 23·6 ←										
1928	1—(3—6) ..	..	→ *15·0	16·0	16·7	17·5	18·0	18·6	19·3	20·0	20·4	21·0 †23·6 ←	21·5 23·4	→ 22·0 23·0 ←											

Table 20.—Storm Tracks for the month of November.

Year.	Date.	97°	96°	95°	94°	93°	92°	91°	90°	89°	88°	87°	86°	85°	84°	83°	82°	81°	80°	79°	78°	77°	76°	75°	74°	73°	72°	71°
1891	1—(5-6)-7 ..	..	..	..	→ *11·2	11·7	12·0	12·4	12·7	13·0	13·5	14·0	→ 15·0															
					†24·8 ←	24·3	23·8	23·3	22·7	22·0	21·5	20·7	20·0 ←															
1916	7—(9-10)-11 ..	..	..	→ *15·1	..	16·0	16·7	17·6	18·3	19·1	← 20·5																	
								†24·6 ←	24·2	23·9	23·1 ←																	
1923	10—(19-20) ..	..	→ *9·6	9·5	9·6	9·7	9·8	9·9	10·0	10·1	10·3	10·5	10·7	11·0	11·6	→ 12·5												
						†22·1 ←	†21·9	21·6	21·4	20·1	20·8	20·3	19·9	19·3	18·6	17·3 ←												
1924	14—(19) ..	..	..	..	..	..	..	..	→ *10·6	10·7	11·2	11·8	13·0	17·0	→ 84·6† 19·7													

Taking the average of these latitude positions we can find the mean latitude position of the storm track corresponding to each longitude. These mean tracks with corresponding probable errors are shown in Tables 21-22 separately for the three months of July, August and September, and also for the combined monsoon period.

Table 21. Storm Tracks 1891—1928 : Mean latitude with probable error and Standard Deviation—July, August and September.

Longitude Degrees.	July.			August.			September.		
	Number of storms.	Mean ± P.E.	S. D.	Number of storms.	Mean. ± P.E.	S. D.	Number of storms.	Mean. ± P.E.	S D.
90°	..	..	..	8	20·86 ± ·31	1·20	20	18·43 ± ·31	2·04
89°	..	..	..	10	21·36 ± ·20	1·29	22	19·81 ± ·23	1·62
88°	34	21·47 ± ·15	1·30	30	21·26 ± ·17	1·42	26	20·44 ± ·19	1·43
87°	40	21·51 ± ·13	1·23	34	21·11 ± ·17	1·46	29	20·61 ± ·23	1·87
86°	41	22·04 ± ·15	1·45	30	21·30 ± ·21	1·00	33	21·13 ± ·27	2·32
85°	38	22·15 ± ·13	1·20	37	21·97 ± ·19	1·71	30	21·74 ± ·30	2·47
84°	30	22·35 ± ·13	1·18	35	22·31 ± ·17	1·49	28	21·69 ± ·30	2·34
83°	35	22·58 ± ·13	1·11	34	22·79 ± ·13	1·15	26	21·87 ± ·27	2·07
82°	34	22·84 ± ·14	1·10	32	23·31 ± ·14	1·20	25	22·24 ± ·28	2·10
81°	33	23·12 ± ·15	1·29	29	23·62 ± ·14	1·13	24	22·77 ± ·25	1·81
80°	31	23·69 ± ·21	1·75	25	24·07 ± ·18	1·36	22	23·02 ± ·28	1·96
79°	28	23·89 ± ·21	1·68	21	24·14 ± ·18	1·19	17	23·44 ± ·22	1·35
78°	22	23·90 ± ·22	1·55	19	24·40 ± ·32	2·08	10	23·87 ± ·30	1·42
77°	16	23·80 ± ·27	1·55	12	23·83 ± ·41	2·13	9	24·11 ± ·42	1·89
76°	11	24·01 ± ·32	1·55	11	23·94 ± ·40	2·27	6	24·38 ± ·47	1·70
75°	11	24·36 ± ·35	1·74	8	24·06 ± ·64	2·70			
74°	8	23·40 ± ·68	2·84	4	24·18 ± ·21	·62			

Table 22. Mean storm Tracks for combined period : July—September, 1891—1928.

Longitude Degrees.	Number of storms.	Mean latitude with P.E.	Standard Deviation.
90°	28	19·13 ± ·28	1·46
89°	41	20·52 ± ·18	1·13
88°	90	19·79 ± ·21	1·95
87°	103	21·12 ± ·10	·96
86°	113	21·52 ± ·12	1·30
85°	105	21·97 ± ·12	1·23
84°	99	22·15 ± ·12	1·15
83°	95	22·46 ± ·10	1·00
82°	91	22·84 ± ·11	1·06
81°	86	23·19 ± ·12	1·08
80°	78	23·62 ± ·11	·93
79°	66	23·85 ± ·12	1·00
78°	51	23·08 ± ·28	2·01
77°	36	24·00 ± ·21	1·25
76°	28	24·06 ± ·24	1·28
75°	19	24·24 ± ·34	1·48
74°	12	23·66 ± ·45	1·51

The actual position of the mean storm track for the combined period is shown in red line in the accompanying Map No. (2). The two broken lines in red on either side indicate the margin of error of the track.

It will be noticed that the region of heaviest rainfall is, naturally enough, determined to a great extent by the position of the mean track of storms entering the area under consideration.

It is interesting to observe in this connexion that the tracks of the storms and depressions "show a marked relation with the winds at Cirrus level" (*Ind. Met. Mem.* Volume 24, 7 and 8, page 270). Storms at the head of the Bay in May and June follow the direction of the prevailing southerly winds at the Cirrus level observed over Akyab, Calcutta and (less clearly) Darjeeling. Further in the middle of the monsoon, storms from the Bay in general follow the easterly winds at the Cirrus level across the head of the peninsula, and curve round towards north and north-east in the region of the south-west upper winds over north-west India. And finally, in late October and November the storms of the retreating monsoon period move from east to west in the same direction as the prevailing winds at the Cirrus level over the south Indian stations. It may also be recalled that the winter depressions of north India move from west to east in the same direction as the prevailing upper wind in that area. There is, therefore, a strong presumption that storms and depressions in India move in the same general direction as the winds at the high cloud level.

PART II. CATCHMENT BASINS OF THE ORISSA RIVERS.

CHAPTER V.—THE CATCHMENT OF THE MAHANADI.

In Orissa an enormous volume of water is brought into the delta by the river channels, and most of the inundations are caused by high floods in the rivers. In fact the total precipitation in the catchment areas is nearly 30 times as large as the rainfall in the delta. A knowledge of the rainfall in each catchment is, therefore, of far greater importance in connexion with floods than the rainfall at individual stations or in each administrative district.

I, therefore, decided to study the catchments separately. For this purpose I used the Survey Maps, Carte Internationale du Monde, 1 : 1,000,000 (1 inch = 15·78 miles), 2nd edition, 1926, published by the Survey of India.

I first of all separated the main catchments of the Mahanadi, the Brahmini, the Baitarani, the Subarnarekha, and the Mayurbhanj and Nilgiri rivers taken together (the Salindi, the Matai, the Kansbans, the Burabalong, and the Panchpara) by carefully marking watershed lines on the Survey map.

THE MAHANADI CATCHMENT.

The Mahanadi river rises in the administrative district of Raipur in the Central Provinces. Its catchment area measures about 51,000 square miles and lies approximately between 80° 30′ E. (at 20° 45′ N.) and 84° 50′ E.(at 20° 30′ N.), and between 19° 20′ N. (at 82° 50′ E.) and 23° 35′ N. (at 82° 25′ E.). It includes practically the whole of the administrative districts of Drug, Raipur, Bilaspur, Raigarh, Jashpur, and portions of Kanker, Korea, Surguja, and a few smaller states of the Central Provinces, and the whole of Sambalpur, Sonepur, Patna, Baud, and portions of Gangpur, Bonai, Bamra, Rairakhol, Athmalik, Angul, Kalahandi, and a small portion of Cuttack and Puri districts in the province of Bihar and Orissa, with small pieces of Vizagapatam and Ganjam in the provinces of Madras and Orissa.

The whole catchment was subdivided into 5 sections—M-I, M-II, M-III, M-IV and M-V, to bring out the peculiar rainfall characteristics of each region. The catchments are shown separately in red dotted lines in the accompanying maps.

MAHANADI SECTION V.

Section V (M-V) lies between 80° 26′ E. (at 20° 42′ N.) and 82° 33′ (at 22° 19′ N.) and between 22° 49′ N. (at 81° 55′ E.) and 20° 29′ N. (at 81° 1′ E).

Section V is the area drained by the Seonath before its junction with the Mahanadi at Changori 21° 44′ N., 82° 26′ E. The Seonath has its source in a region in the neighbourhood of 20° 45′ N., 88° 25′ E., and during its course is joined by a large number of tributaries which drain the area covered by the rainfall stations Ambachowki (20° 45′ N., 80° 23′ E.), Sanjori (20° 52′ N., 81° 1′ E.), Dongargarh (21° 12′ N., 80° 45′ E.), Nåndangaon (21° 6′ N., 80° 2′ E.). The Tendula and the Pathra join it a little above Drug (21° 11′ N., 81° 16′ E.). Further down it receives the Sambarsa, the Amner which drains Khairgarh (21° 25′ N., 80° 58′ E.), and Chuikhadan (21° 32′ N., 81° E.), another tributary draining Gondai (21° 40′ N., 81° 6′ E.), the Kanrooah draining Bemetara (21° 43′ N., 81° 32′ E.), the Kharum draining Raipur (21° 14′ N., 81° 38′ E.), and the Kulhan above Simga (21° 38′ N., 81° 42′ E.). It is next joined by the Hamp draining Kawardha (22° N., 81° 14′ E.), Pandaria (22° 13′ N., 81° 24′ E.), Pondi-Lapha (22° 8′ N., 81° 15′ E.) ; the Agar draining Mungeli (22° 3′ N., 81° 40′ E.) ; the Maniari ; the Arpa draining Pendra (22° 47′ N., 81° 56′ E.), Bilaspur (22° 5′ N., 82° 9′ E.) ; and finally the Lilagar just before its confluence with the Mahanadi.

MAHANADI SECTION IV.

Section IV lies between 81° 1′ E., (20° 29′ N.), and 82° 48′ E., (21° 25′ N.), and between 21° 44′ N., (82° 32′ E.), and 19° 56′ N., (82° 5′ E). It comprises the area on the right of the Mahanadi, the drainage water of which falls into the river between Changori (21° 44′ N., 80° 46′ E.), and Seorinarayan (21° 44′ N., 82° 35′ E.).

The Mahanadi is formed by a large number of small streams one of which drains Nawapara (20° 16′ N., 81° 50′ E.), and another Kanker (20° 16′ N., 81° 29′ E.). It then passes through the area covered by Dhamtari (20° 42′ N., 81° 33′ E.), Kurid (20° 50′ N., 81° 43′ E.), and Rajim (20° 58′ N., 81° 71′ E.), where the Pairi which drains Gariabund (20° 37′ N., 82° 4′ E.) falls into it. Passing the region of Mahasamund (21° 7′ N., 82° 5′ E.), Arang (21° 18′ N., 81° 3′ E.), and Kusrangi (21° 22′ N., 82° 1′ E.), the Mahanadi unites with the Seonath at Changori, and the united river assumes the name of Mahanadi. About 10 miles further down it is joined by a large stream, the Jonke which drains Pithora (21° 15′ N., 82° 3′ E.).

Mahanadi Section III.

Section III lies between 82° 4′ E., (22° 40′ N.), and 84° 48′ E., (21° 40′ N.), and between 23° 35′ N., (82° 28′ E.) and 21° 17′ N., (83° 8′ E.). It is a large area on the left (north) of the river, the drainage water from which reaches the Mahanadi between Seorinarayan (21° 41′ N., 82° 35′ E.) and Sambalpur (21° 28′ N., 83° 59′ E). Important tributaries are the Hasdo which drains Janjgir (22° N., 82° 39′ E.), Korba (22° 1′ N., 82° 30′ E.), Katghora (22° 31′ N., 82° 33′ E.) and Pasan (22° 51′ N., 82° 61′ E.), the Sone draining Sakti (22° 21′ N., 82° 57′ E.) ; a tributary from the south from near Sarangarh (21° 53′ N., 83° 23, E) ; the Mand on the north from the region of Dharmajaygarh (22° 28′ N., 83° 13′ E.) and Baikunthapur (23° 12′ N., 82° 38′ E.) ; the Kelo draining Raigarh 21° 53′ N., 83° 23′ E.) ; a small tributary near Ambabhona (21° 35′ N., 83° 28′ E.), and another draining the area on the north-east near Gangpur (22° 71′ N., 84° 2′ E.), and Jharsuguda (21° 50′ N., 84° 3′ E.).

Mahanadi Section II.

Section II lies between 82° 3′ E., (19° 45′ N.), and 84° 23′ E., (21° 29′ N.) and between 21° 34′ N., (83° 30′ E), and 19° 18′ N, (82° 44′ E.). It is the area lying practically wholly on the right (south) of the river and sending its water into the Mahanadi between Sambalpur (21° 28′ N., 83° . 9′ E.) and Sonepur 20° 51′ N., 83° 55′ E.). A small stream draining Bargarh (21° 20′ N., 82° 30′ E.) joins a little below Sambalpur, and the Ong which drains the region covered by Sartaipali (21° 20′ N., 82° 52′ E.), Padampur (21°N., 83° 51′ E.) and Bijepur (21° 12′ N., 83° 27′ E.), joins it a little later. The river next passes Dhama (21° 16′ N., 83° 55′ E.) on the left, and Binka (21°2′ N., 83° 48′ E.) on the right and is joined by its largest tributary, the Tel, at Sonepur. The Tel is formed by the confluence of a number of small streams two of which drain the region of Deoblog (19° 53′ N., 82° 40′ E.), and Bhawanipatna (19° 55′ N., 83° 10′ E.), and is fed by the Barabhailat, and the Suktel which drains Bolangir (20° 43′ N., 83° 30′ E.), and a number of other streams.

Mahanadi Section I.

Section I lies between 83° 48′ E. (20° 34′ N.), and 85° 42′ E., (20° 23′ N.) and between 21° 19′ N., (84° 13′ E.), and 19° 54′ N., (85° 3′ E.). It is the area drained by the Mahanadi between Sonepur (20° 5. ′ N., 83° 55′ E.), and Naraj (20° 31′ N., 35° 48′ E.), 7 miles above Cuttack. Balandapara (20°46′ N., 84° 4′ E.) stands on a south tributary ; Udaigiri (20° 81′ N, 84° 22′ E.) and Phulbani (20° 30′ N., 84° 14′ E.) are drained by the Salki which joins the Mahanadi from the right ; Rampur (21° 4′ N., 84° 20′E.) stands on a left tributary ; Kunjabangarh (20° 2′ N., 84° 50′ E), Nayagarh (20° 81′ N., 85° 6′ E.) and Bolgarh (20° 11′ N., 85° 16′ E.) are drained by the Kauria on the south. The rainfall stations Boud (20°50′ N., 85°19′ E.) and Banki (20°22′ N., 85°31′E.) stand on the right (south) bank of the river, and Tikarpara (20° 36′ N., 84° 47′ E.), Narsingpur (20° 28′ N, 85° 1′ E.), Baramba (20° 26′ N., 85° 20′ E) and Athgarh (20° 32′ N., 85° 37′ E.) on the left.

The above division into sections is convenient in many ways. Water from the nearer sections M-I or M-II reach Naraj practically within a short time, but there is an appreciable lag for the other sections, so that heavy rainfall in M-IV or M-V produce their maximum effect at Naraj after a considerable time. For a detailed study of the floods it is necessary to take this lag into consideration.*

It is, therefore, desirable to obtain some idea regarding the average distance from Naraj of the different sections. For flood purposes, we must of course take the distance along the river channels. A complication arises, however, from the fact that in any given section, we have not one but many different channels. It is, therefore, necessary to find out the average effective length of the channels within each section.

Using a disc type of distance meter (supplied by the Mathematical Instruments Department) the total length of river channels within each section was directly determined from the International map. Minor drainage channels not marked on the map were perforce neglected. But such channels must necessarily be small and extremely local in character, so that the excess run-off most probably reach one or other of the printed channels within a very short time, possibly within a few hours. (I am not considering here that portion of the water which enters the sub-soil, or is held up in local retarding basins. That is I am considering only the free excess flow under monsoon conditions.)

Table 23.—Mahanadi Catchment—Average Length of River Channels in miles.

Section.	End station.	Distance from Naraj (in miles).	Within section.		Average effective length from Naraj (in miles).
			Number of channels.	Average path (in miles).	
1	2	3	4	5	6
M—I	Naraj	...	87	96	96
M—II	Sonepur	131	83	69	200
M—III	Sambalpur	180	143	128	308
M—IV	Seorinarayan ...	282	43	36	318
M—V	Changori	296	81	112	408
	Whole Catchment ...	...	437	...	265

In Table 23, column (2) gives the name of the station situated at the extreme end of each section (i.e. nearest to Naraj), column (3) the distance of each of these stations from Naraj, column (4) the number of channels measured within each section, column (5) the average distance up to the extreme point (nearest to Naraj) within each section, and column (6) the average effective length of the drainage channel from each section up to Naraj.

An example may make the position clear. In section V, Changori is the end station nearest to Naraj, and its distance from Naraj is 296 miles. The number of channels within section V was 81, and the total length of all these 81 channels, each measured up to Changori, was found to be 9,072 miles. The average length of drainage channels in this section up to Changori is, therefore, 112 miles. To this we must add 296 miles—the distance between Changori and Naraj. The effective average distance of the equivalent drainage channel from section V to Naraj is, therefore, 408 miles.

From the above figures we can easily find the length of the effective equivalent channel for the Mahanadi catchment as a whole measured up to Naraj. This will be clearly given by the weighted average, i.e., by $[(87\times96)+(83\times200)+(143\times308)+(43\times318)+(81\times408)]/437=265$ miles.

*Mr. J. Shaw, Special Officer, Floods, in his type-written note, dated the 8th March 1938 states: "As 38 hours (at 5 miles per hour) is the quickest for the Sambalpur gauge water to reach Cuttack and the longest period is about 58 hours (depending on the state of river between these points) I should say it would take about 30 hours for water from M—II to reach Cuttack. From Sonepur at the rate of 5 miles per hour it would take 26 hours"

The physical conditions in the different sections are not, of course, identical. The flood velocity in different sections must, therefore, be also different. Still the above table may be used to give a rough idea of the time lag for different sections.

Information regarding the gradient is rather meagre. We know that the datum for the Sambalpur gauge is 449·20 ft. above mean sea level. The Cuttack river survey datum is the zero point of a gauge on the Katjuri revetment at the Lalbagh House, Cuttack. This zero point is 55·50 ft.† above mean sea level at False Point and is the datum for the gauge at Naraj. We also know that average height of 27 ft. at Sambalpur, that is, 476·26 ft. above M. S. L. corresponds to 88·40 ft. at Naraj. This gives a fall of 388 feet in 180 miles (distance between Sambalpur and Naraj) or an average gradient of about 26 inches per mile.

In order to calculate the total volume of precipitation it is necessary to know the actual area of each catchment. These were determined by direct planimetric measurements on the International Map. A large number of readings were taken for each section, and mean values based on independent measurements on the same map were found to be in agreement within less than half of one per cent.

The real uncertainty lies in marking the catchment areas on the map. To form a rough estimate of the magnitude of the error involved I tried measuring the sectional areas on the different maps, using different planimeters.* I found that the discrepancies varied from 1·4 per cent to 3·1 per cent for different sections. It would appear, therefore, that the size of the catchment area can be determined with an accuracy of about 2 or 3 per cent which is amply sufficient for our present purposes. For convenience of arithmetic calculation I have adopted for the size of the Mahanadi catchment the round figure 51,000 square miles (against 49,800 square miles given by Mr. Shaw). In the same way slightly adjusting the values for each section (the maximum adjustment being less than 2 per cent in every case), the size of the different sections are taken to be as in Table 24 :—

Table 24.—Mahanadi Catchment—Size of Sections.

Section.	Symbol.	Area in square miles.	Proportion.
Section I	M-I ...	6,400	12·55
" II	M-II ...	12,400	24·31
" III	M-III ...	14,300	28·04
" IV	M-IV ...	6,600	12·94
" V	M-V ...	11,300	22·16
Whole Catchment ...	M ...	51,000	100·00

Mahanadi Delta.—This area is defined in these investigations as the areas in the districts of Cuttack and Puri bounded by the Bay of Bengal, the Chilka, the Ganjam metalled road between Tangi in Puri and Barchana in Cuttack, the river Ganguti and the Patamundai Canal. The total area of the delta as defined above was found by direct planimetric measurement to be about 3,100 square miles of which about 1,400 square miles lie in the Puri district and 1,700 square miles in Cuttack. In the "Report of the Contour Survey of the Flooded Tract of Orissa, 1924" published by the Bihar and Orissa Secretariat the area of the Mahanadi delta is given as 2,525 square miles. Unfortunately in the above report the boundaries of the delta were not mentioned. We have used our own estimate directly measured by a planimeter on survey maps.

The normal rate of rainfall in the above area during the flood months June, July, August and September is about 30,000 cubic feet per second.

* In letter no. 6018, dated Calcutta, the 20th September 1931, from W. Connan, Superintending Engineer, the datum for Sambalpur was given as 403·04 feet above mean sea level. But Mr. J. Shaw, Special Officer, Floods, in his letter no. 130, dated the 8th March 1938, gave the Smbalpur datum level as 449·26 feet above mean sea level.

† A. S. Thomson, Rivers of Orissa, 1905, page 1.

CHAPTER VI.—THE CATCHMENT OF THE BRAHMINI.

The Brahmini catchment lies between 83° 55′ E. at 23° 13′ N. and 86° 4′ E. at 20° 51′ N. and between 23° 37′ N. at 84° 41′ E. and 20° 35′ N. at 85° 3′ E. and consists of an irregular rectangular area of about 14,000 square miles with its longer axis lying roughly in a north-north-westerly to west-north-westerly direction. It covers portions of the administrative districts of Ranchi, Jashpur (Central Provinces Feudatory States), Orissa Feudatory States and Tributary Mahals, Singhbhum, Angul and Cuttack.

The Sankh and the South Koel have their origin in the Ranchi plateau, and lie wholly in hilly country. They unite at 22° 15′ N., 84° 48′ E. a little above Bonaigarh (21° 22′ N., 84° 57′ E.), and the united river is known as the Brahmini. Below Bonaigarh it is joined by the Tikkira and a number of other hill streams which have their source in the Feudatory States and Tributary Mahals.

Brahmini Section II.

Section II lies between 83° 55′ E. (23° 13′ N.) and 85° 44′ E. (22° 16′ N.), and between 23° 37′ N., (84° 41′ E.), 21° 40′ N., (84° 48′ E.), and comprises the upper reaches, i.e., the drainage area of the Sankh represented by the rainfall stations Chainpur (23° 7′ N., 84° 14′ E.), Jashpur (22° 53′ N., 84° 8 E.), Kurdeg (22° 33′ N., 84° 8′ E.) and Simdega (22° 30′ N., 84° 29′ E.), and the South Koel represented by Lohardaga (23° 26′ N., 84° 40′ E.), Gumla (23° 2′ N., 84° 32′ E.), Palkot (22° 52′ N., 84° 38′ E.), Bano (22° 40 N., 84° 5′ E.), Gailkura (22° 31′ N., 85° 2′ E.), Manoharpur (22° 23′ N., 85° 13′ E.) and Jagannathpur (22° 13′ N., 85° 38′ E.). This area extends to just below Bonaigarh.

Brahmini Section I.

Section I lies between 84° 17′ E. (21° 12′ N.) and 86° 4′ E. (20° 51′ N.), and between 21° 50′ N. (85° 10′ E.) and 20° 35′ N. (85° 3′ E.) and includes the whole of the lower reaches of the river covered by the rainfall stations Deogarh (21° 32′ N., 84° 44′ E.), Pal Lahara (21° 26′ N., 85° 11′ E.), Chhendipara (21° 5′ N., 84° 53′ E.). Jerpara (20° 54′ N., 84° 52′ E.), Angul (20° 54′ N., 84° 52′ E.), Talcher (20° 51′ N., 85° 14′ E.), Sukinda (20° 57′ N., 85° 57′ E.), Hindol (20° 37′ N., 85° 12° E.), Dhenkanal (20° 40′ N., 85° 36′ E.) and Barchana (20° 40′ N., 86° 6′ E.).

I have adopted 14,000 square miles as the adjusted area as compared with Shaw's estimate of 13,700 square miles. The discrepancy is about 2 2 per cent. The areas of the two sections are shown in the following table :—

Table 25.– Brahmini Catchment.

Section.	Symbol.	Area in square miles.	Proportion.
Section I	Br.-I	5,600	0·4
Section II	Br.-II	8,400	0·6
Whole catchment ...	Br.	14,000	1·0

The length of the longest channel of the Brahmini from the source of the South Koel to Jenapore is about 305 miles. The effective equivalent length of the channels were also determined in the same way as in the case of the Mahanadi and are given below :

Table 26.—Effective Length of Brahmini Channels.

Section.	End station.	Distance from Jenapore.	Within sections.		Equivalent distance from Jenapore.
			Number of channels.	Equivalent length.	
Br.-I ...	Jenapore	0	90	104 miles	104 miles.
Br.-II ...	Bonaigarh	150 miles	118	125 „	275 „
Total Brahmini...	Jenapore	...	208	...	196 „

CHAPTER VII.—THE CATCHMENT OF THE BAITARANI AND THE OTHER RIVERS OF ORISSA.

The Baitarani catchment is a compact roughly oval shaped area of 4,000 square miles lying between 85° 10′ E. (at 21° 50′ N.) and 86° 22′ E. (at 21° 4′ N.) and between 22° 12′ N. (at 85° 48′ E.) and 20° 54′ N. (at 86° 16′ E.). It rises in the Mayurbhanj hills, and its drainage area comprises portions of Mayurbhanj and Keonjhar States, and in the lower reaches portions of district Balasore.

I have adopted 4,000 square miles as the size of this catchment against 3,700 square miles estimated by Shaw. In view of the uncertainty introduced by the hilly character of the catchment, the adjustment made is not unreasonable. *

The Baitarani catchment is represented by the following rainfall stations: Chanoua (22° 4′ N., 85° 39′ E.); Karanjia (21° 53′ N., 85° 59′ E.); Keonjhar (21° 37′ N., 85° 34′ E.); Anandapur (21° 13′ N., 86° 7′ E.); Korai (20° 55′ N. 86° 8′ E.) and Akhoyapada (20° 51′ N., 86° 16′ E.) while Boudh (21° 7′ N. 86° 19′ E.) lies just on the border line.

The course of the Baitarani is comparatively small and is about 142 miles up to Akhoyapada. There are 63 channels in the map, and the effective equivalent distance to Akhoyapada is about 100 miles.

The Subarnarekha Catchment.

The Subarnarekha rises in the Ranchi plateau and receives a large number of hill streams such as the Kanchi, the Karkari, the Sanjai, the Kharkai, etc. on its right bank. It drains large portions of the districts of Ranchi, Manbhum, Singhbhum and in its lower reaches, Midnapore.

The Subarnarekha catchment is a long strip of land wide in its upper (Section II) and very narrow in the lower (Section I) reaches of the river. It lies between 85° 9′ E. (at 23° 27′ N.) and 87° 30′ E. (at 21° 38′ N.) and between 23° 30′ N. (at 85° 25′ E.) and 21° 34′ N. (at 87° 10′ E.).

Subarnarekha Section I

Section I is represented by the rainfall stations Silda (22° 37′ N., 86° 48′ E), Baharagora (22° 17′ N., 86° 43′ E.), Kultikri 22° 7′ N., 87° 51′ E.) and Jallesore (21° 48′ N., 87° 13′ E.).

Subarnarekha Section II.

Section II lies between 85° 9′ E. (23° 27′ N.) and 86° 33′ E. (22° 43′ N.) and between 23° 32′ N. (85° 26′ E.) and 21° 57′ N. (86° 15′ E.). It has a very large number of rainfall stations :—

Piska (23° 20′ N., 85° 12′ E.); Ranchi (23° 22′ N., 85° 13′ E.); Silli (23° 2′ N., 85° 49′ E.); Jhalda (23° 22′ N, 85° 48′ E.); Sonahatu (23° 11′ N. 85° 42′ E.); Khunti (23° 5′ N., 85° 16′ E.); Tamar (23° 3′ N., 85° 38′ E.); Kharswan (22° 47′ N., 85° 49′ E.); Chakradharpur (22° 40′ N., 85° 37′ E.); Seraikela (22° 42′ N., 85° 55′ E.); Chaibassa (22° 33′ N., 85° 48′ E.); Kalikapur (22° 36′ N., 86° 27′ E.) and Ghatsila (22° 35′ N., 86° 28′ E.).

Section II represents roughly the hilly portion of the course and end just below Ghatsila, while Section I runs through more or less flat alluvial plains.

The adjusted areas for the Subarnarekha catchments are :—

Table 27.—Subarnarekha catchment.

Section.			Square miles.	Proportion.
Section I	...	...	2,000	0·267
Section II	...	...	5,500	0·733
	Total	...	7,500	1·000

* In an old manuscript note by Rhind, I find that Odling had given the area of the Baitarani catchment as 3,970 square miles.

Shaw's estimate of the total area is 7,400 square miles which agrees with the adopted estimate of 7,500 square miles within 1·33 per cent.

The Minor Rivers of the Mayurbhanj Hills.

The Mayurbhanj catchment consists of the area drained by the Salindi, the Kansbans, the Burrabalong and the Panchpara all of which have their sources in the Mayurbhanj and Nilgiri hills. It is a small compact area lying between 86° 9′ E. (at 21° 15′ N.) and 87° 9′ E. (at 21° 57′ N.) and between 22° 17′ N. (at 86° 28′ E.) and 21° 55′ N. (86° 19′ E.). The adopted size of this catchment is 3,600 square miles, and it is represented by 3 rainfall stations, Baripada (21° 56′ N., 86° 43′ E.); Nilgiri (21° 28′ N., 86° 46′ E.) and Turigaria (21° 17′ N., 86° 36′ E.).

CHAPTER VIII.—NORMAL PRECIPITATION IN THE CATCHMENT BASINS IN THE MONSOON SEASON.

I have already pointed out that for purposes of flood study, the total precipitation over each catchment area as a whole is more important than the rainfall at individual stations. It will be convenient to explain here the method adopted for calculating such normals, and the nature of the material used for this purpose.

The analysis is in each case based on the records for individual stations for the period July to September (92 days) given in the printed Annual Rainfall Volumes from 1891—1928 (38 years).

The year 1891 was taken as the starting point for two reasons. The data were available in a compact and convenient printed form. And more important, the records prior to 1891 were comparatively meagre in character. Especially the number of stations available for the different sections were extremely variable, which rendered the averages for different sections unequal in reliability. A glance at Table 11 will show, for example, that in 1890 we had only one station for Mahanadi Section II against six stations for Mahanadi Section V.

The procedure followed was identical in each case and was absolutely straight-forward. The stations situated within a particular section were grouped together, and the daily rainfall records were entered from the printed Rainfall Volumes. All cases of missing records were specially noted, and were omitted in taking the average. Suspicious readings of rainfall were specially scrutinized. In certain cases the figures could be corrected with safety. For example, shifts in the decimal places, or obvious misprints 7 for 1, or 8 for 0, etc., could be easily detected and corrected. Doubtful figures were, however, rejected in every case. The daily totals were then struck for all available stations, and the average calculated by dividing by the number of stations available. In taking the average, zero or nil rainfalls were, of course, taken into consideration, but missing or rejected records were neglected.

The secondary data, that is, the daily normal rainfall for each catchment for the period July to September (92 days) 1891—1928 (38 years) will be found in Tables 71—75.

The values for the Mahanadi catchment as a whole were obtained by adding together the sub-totals for each section and dividing by the total number of records available for all the sections taken together. These represent, therefore, the weighted average for the catchment as a whole.

Even the data available in 1891 and for a few succeeding years cannot be considered quite satisfactory. I could, of course, have equalized to some extent the effect of unequal numbers of rainfall stations in different catchments or sections by using the isohyetal method. But this would have involved a tremendous amount of additional work. I have given the analysis separately for 5 sections in the Mahanadi, 2 in the Brahmini and 1 in the Baitarani, or 8 sections altogether. (The total for the Mahanadi or the Brahmini basins as a whole were of course derived from the sectional figures, and need not be considered here.) In order to prepare the daily average for each section 92 individual maps (one for each day during the period July—September) would be required for each year, or 92×38=3,496 maps altogether. These would then have to be planimetered for each of the 8 sections separately.

We know from our experience of a comparison of the isohyetal and the numerical average method in the case of normal rainfall, that the discrepancy between the results reached by these two methods was of the order of five per cent. Even assuming that the isohyetal method always gave the more reliable estimate, the net gain in accuracy would be about five per cent. It was clear, therefore, that in the case of daily averages, the gain in accuracy would be altogether incommensurate with the stupendous amount of labour required for the task.

I decided, however, to test this point a little further. Estimates of rainfall for the Mahanadi catchment as a whole were prepared by the isohyetal and numerical average methods for short periods of heavy rainfall extending over 3, 4, and 5, 6 and 10 consecutive days immediately before the occurrence of floods in the river. These two estimates are given in Tables 29—33. It will be noticed that in individual cases the difference may amount to as much as 1·85" or 29 per cent, neglecting the difference of 4·18 in Table 33 as an abnormal value. The average discrepancies are, of course much less, and are shown in the following table :—

Table 28. Mahanadi catchment.

Comparison of Isohyetal and Numerical Methods of Estimating Amount of Rainfall.

Number of days (period of rainfall).	Average difference between two methods.
3	9·05%
4	10·70 ,,
5	7·40 ,,
6	6·60 ,,
10	9·60 ,,

The average discrepancy may, therefore, be taken to be of the order of 10 per cent in the case of short periods of rainfall (3, 4, 5, 6 and 10 days) as against about 3·5 per cent in the case of monthly normals.

It is clear from the above discussion, that the uncertainty in the estimate of short period precipitation data (i.e. the number of rainfall stations being fixed) is about 10 per cent. This is the margin of error arising in the coursel of calculation, i.e. during the process of estimation.

But there is an altogether different kind of deficiency inherent in the primary data. We know that in the case of very heavy rainfall, the actual amount often fluctuates irregularly within short distances. Our primary data (rainfall records at a finite, usually small number of stations) represent merely small samples of the total rainfall. The reliability of the final estimate would, therefore, depend on the actual variability of the rainfall from one station to another and on the total number of stations available. I regret I have not had the opportunity of investigating this point in detail.

Table 29.—Comparison of (a) Isohyetal and (b) Numerical Methods for estimating amount of rainfall in the Mahanadi catchment :—Period of 3 days preceding Floods.

Years of flood.	Total rainfall in inches. (a)	(b)	Difference in inches.	Percentage Difference.
1872	5·38	5·13	+·25	4·8%
1874	4·08	3·99	+·09	2·3%
1876	3·09	3·12	—·03	1·0%
1877	2·96	2·85	+·11	3·8%
1879	6·68	6·81	—·13	1·9%
1880	6·24	5·31	+·93	1·7%
1881	3·44	2·81	+·63	2·2%
1885	6·80	5·61	+1·19	21·2%
1891	7·15	7·89	—·74	9·2%

Years of flood.	Total rainfall in inches.		Difference in inches.	Percentage Difference.
1892	6·60	6·12	+·48	7·8
1894	4·41	4·83	—·42	8·3
1895	5·70	5·19	+·51	9·8
1896 (*i*)	6·02	6·03	—·01	0·2
1896(*ii*)	3·56	3·75	—·19	5·1
1900	4·11	4·68	—·57	12·2
1904	3·68	3·21	+·47	14·6
1907	3·29	4·26	—·97	22·7
1908	2·78	3·66	—·88	24·0
1910	6·19	5·58	+·61	10·9
1911	4·51	6·36	—1·85	29·1
1912	1·90	2·01	—·11	5·4
1913	5·36	5·52	—·16	2·8
1914	3·71	3·08	+·63	20·4
1915	4·65	5·31	—·66	12·4
1917	3·22	3·54	—·32	9·1
1918	7·65	8·25	—·60	7·3
1920	7·25	7·38	—·13	1·8
1923	2·47	2·91	—·44	15·1
1925	5·46	5·61	—·15	2·7
1926	7·63	7·76	—·13	1·7

Table 30.—Comparison of (*a*) Isohyetal and (*b*) Numerical methods for estimating amount of rainfall in the Mahanadi catchment:—Period of 4 days preceding Floods.

Years of flood.	Total rainfall in inches.		Difference in inches.	Percentage Difference.
	(*a*)	(*b*)		
1872	6·38	6·64	— 0·26	3·9
1874	4·57	5·08	— ·51	10·0
1876	4·10	4·04	+ ·06	1·4
1877	3·83	3·88	— ·05	1·3
1879	7·42	7·24	+ ·18	2·5
1880	7·72	6·76	+ ·96	14·2
1881	4·12	4·28	— ·16	3·7
1885	8·91	7·24	+1·67	23·0
1891	7·87	7·72	+ ·15	1·9
1892	7·26	7·36	— ·10	1·3
1894	4·90	5·24	— ·34	6·4
1895	6·47	7·36	— ·89	12·0
1896 (*i*)	6·70	7·16	— ·46	6·4
1896(*ii*)	3·91	3·84	+ ·07	1·8
1900	4·91	5·28	— ·37	7·0
1904	4·83	4·28	+ ·55	13·0
1907	4·12	4·84	— ·72	14·9
1908	3·53	4·32	— ·79	18·3
1910	6·89	5·48	+1·41	25·7
1911	5·12	6·36	—1·24	19·5
1912	2·49	2·72	— ·23	8·4
1913	6·04	6·68	— ·64	9·5
1914	4·85	5·68	— ·83	14·6
1915	5·06	5·28	— ·22	4·1
1917	4·00	4·88	— ·88	18·0
1918	9·20	10·80	—1·60	14·8
1920	8·23	8·72	— ·49	5·6
1923	3·00	4·08	—1·08	26·4
1925	6·98	6·36	+ ·62	9·7
1926	8·62	11·04	—2·42	21·9

Table 31.—Comparison of (a) Isohyetal and (b) Numerical Methods for estimating amount of rainfall in the Mahanadi catchment :—Period of 5 days preceding Floods.

Years of flood.	Total rainfall in inches.		Difference in inches.	Percentage Difference.
	(a)	(b)		
1872	6·50	6·80	—0·30	4·4
1874	4·78	4·80	—·02	0·4
1876	5·06	4·65	+·41	8·8
1877	4·21	4·45	—·24	5·3
1879	7·79	7·35	+·44	5·9
1880	9·50	8·55	+·95	11·1
1881	4·76	4·40	+·36	6·8
1885	10·25	9·35	+·90	9·6
1891	8·43	7·95	+·48	6·0
1892	7·74	7·40	+·34	4·5
1894	5·25	5·55	—·30	5·4
1895	6·88	7·90	—1·02	0·2
1896 (*i*)	7·41	7·35	+·06	0·8
1896(*ii*)	4·83	4·55	+·28	6·1
1900	5·33	5·50	—·17	3·0
1907	4·58	4·35	+·23	3·0
1908	4·11	4·70	—·59	12·5
1910	7·42	6·85	+·57	8·3
1911	5·62	7·05	—1·43	20·2
1912	2·75	3·25	—·50	15·3
1913	6·23	6·85	—·62	9·0
1914	5·37	6·35	—·98	15·4
1915	5·17	5·05	+·12	2·3
1917	4·39	4·65	—·26	5·5
1918	10·12	11·80	—1·68	14·2
1919	4·39	4·50	—·11	2·4
1920 (*i*)	9·02	10·55	—1·53	14·5
1920(*ii*)	4·88	4·70	+.18	2·1
1925	7·76	7·05	+·71	10·0
1926	8·88	10·10	—1·22	12·0

Table 32.—Comparison of (a) Isohyetal and (b) Numerical Methods for estimating amount of rainfall in Mahanadi catchment.—Period of 6 days preceding Floods.

Years of flood.	Total rainfall in inches.		Difference in inches.	Percentage Difference.
	(a)	(b)		
1872	6·97	6·06	+0·91	15·0
1874	4·84	5·04	—·20	3·8
1876	5·88	5·76	+·12	2·0
1877	4·86	4·32	+·54	12·5
1879	7·65	7·68	—·03	0·3
1880	10·06	9·18	+·88	9·5
1885	10·87	9·84	+1·03	10·4
1892	7·61	7·26	+·35	4·8
1894	5·62	5·64	—·02	0·3
1895	6·98	7·86	—·88	11·0
1896 (*i*)	7·78	7·38	+·40	5·4
1896(*ii*)	5·51	5·76	—·25	4·3
1900	5·90	5·70	+·20	3·5
1907	4·95	4·98	—·03	0·6

Years of floods.	Total rainfall in inches.		Difference in inches.	Pecentage Difference.
1908	4·09	5·10	—1·01	19·8
1910	7·36	6·24	+1·12	17·9
1911	6·00	7·80	—1·80	23·0
1912	2·88	3·36	—·48	14·2
1913	6·17	6·12	+·05	0·7
1914	5·62	6·60	—·98	14·7
1915	5·26	5·16	+·10	1·8
1917	4·24	4·80	—·56	11·6
1918	9·21	9·24	—·03	0·3
1919	4·32	4·26	+·06	1·4
1920 (*i*)	10·72	10·80	—·08	0·7
1920(*ii*)	5·03	5·10	—·07	1·3
1925	7·95	7·32	+·63	8·6
1926	9·05	10·02	—·97	9·6

Table 33.—Comparison of (*a*) Isohyetal and (*b*) Numerical Methods for estimating amount of rainfall in Mahanadi catchment:—Period of 10 days preceding Floods.

Years of floods.	Total rainfall in inches.		Difference in inches.	Percentage Difference.
	(*a*)	(*b*)		
1872	13·28	9·1	+4·18	46·0
1874	7·05	7·8	—·75	9·6
1876	7·21	7·1	+·11	1·5
1877	5·95	6·5	—·55	8·5
1879	9·70	10·2	—·50	4·8
1880	12·66	12·0	+·66	5·5
1885	13·25	10·8	+2·45	22·6
1892	11·18	9·7	+1·48	15·2
1894	7·24	7·2	+·04	0·5
1895	10·77	12·4	—1·63	13·1
1896 (*i*)	9·89	9·1	+·79	8·6
1896(*ii*)	8·67	8·6	+·07	0·8
1900	6·66	5·9	+·76	12·8
1907	5·60	6·0	—·40	6·6
1908	7·25	8·4	—1·15	13·6
1910	8·57	7·5	+1·07	14·2
1911	8·03	9·4	—1·37	14·5
1912	4·37	5·3	—·93	17·5
1913	7·59	7·0	+·59	8·4
1914	7·60	8·0	—·40	4·4-
1915	7·79	7·7	+·09	1·1
1917	7·85	7·8	+·05	0·6
1918	13·02	14·0	—·98	7·0
1919	6·03	6·5	—·47	7·2
1920	12·48	12·3	+·18	1·4
1925	10·74	10·7	+·04	0·3
1926	10·93	13·2	—2·27	17·2

Normal Rainfall in the Catchment Basins.

The average rainfall for each catchment area (based on stations of not less than 24 years' standing) for each season and the whole year is shown in Table 34, and similar figures for each river basin as a whole are given in Table 35. The corresponding percentages are given in Tables 36 and 37.

It will be seen from accompanying rainfall Map no. (5) that the actual rainfall in the different catchment areas is considerably greater than the rainfall in the delta. This is mainly due to the effect of the western hills. There is first a slight rise near the hills on the western edge of the Orissa Delta, and a much sharper and more pronounced increase in the rainfall near the mountainous region of the Feudatory States and Tributary Mahals. The isohyets jump from about 42″ near Phulbani, Chhendipara, or Chakradharpur to over 56″ at Pal-Lahera or Deoghar within a distance of about 20 miles. The maximum rainfall occurs over the northern portions of the Brahmini catchment (Section I) and the south-eastern portions of the Mahanadi catchment (Section III). Further west the rainfall decreases gradually with a closed minimum in Mahanadi Section M-V near Kawardha, Gondai and Chuikhadan.

Tables 36 and 37 give the seasonal falls expressed as percentages of the total annual precipitation. It will be seen that not only the gross rainfall but the percentage rainfall is considerably greater over the catchment area during the monsoon period. In the delta only about 72 per cent of the total annual precipitation occurs during the monsoon; while the corresponding percentage is 82·66 in the Brahmini basin, and 85·06 in the Mahanadi catchment area (varying between 77·71 and 89·01 in the different sections). Roughly speaking we may say that about four-fifths of the total annual precipitation occurs during the four monsoon months in the river basins.

Table 34.—Seasonal Normal Rainfall in Sectional Areas.

Section.	Number of stations.	Winter. December to February.	Summer. March to May.	Monsoon. June to Sept.	Autumn. October and November.	Annual. January to December
Mahanadi I ..	10	1·72	5·23	42·73	5·31	54·99
Mahanadi II ..	6	1·49	3·06	47·49	2·78	54·82
Mahanadi III ..	7	1·81	2·15	52·96	2·58	59·50
Mahanadi IV ..	3	1·65	2·62	45·78	3·09	53·14
Mahanadi V ..	13	1·91	2·19	40·83	2·66	47·59
Brahmini I ..	7	1·80	4·93	45·80	4·56	57·09
Brahmini II ..	9	2·52	3·52	49·10	3·38	58·52
Baitarani ..	6	2·08	7·06	38·84	5·60	53·58
Nilgiri ..	1	1·83	8·49	46·74	5·87	62·93
Subarnarekha I	4	1·68	8·15	42·04	5·27	57·14
Subarnarekha II	11	2·13	5·01	44·91	3·33	55·38
Delta ..	12	1·80	6·35	43·15	8·37	59·67

Table 35.—Seasonal Normal Rainfall in Catchment Areas.

Catchment.	Number of stations.	Winter.	Summer.	Monsoon.	Autumn.	Total.
Mahanadi ..	39	1·76	3·13	44·90	3·38	53·17
Brahmani ..	16	2·21	4·14	47·66	3·90	57·91
Baitarani ..	6	2·08	7·06	38·84	5·60	53·58
Nilgiri ..	1	1·83	8·49	46·74	5·87	62·93
Subarnarekha ..	14	1·98	5·93	44·30	4·12	56·33
Delta ..	31	1·80	6·35	43·15	8·37	59·67
Brahmini and Baitarani.	22	2·17	4·93	45·25	4·36	56·71

Table 36.—Seasonal percentage of rainfall in Sectional Areas.

Section.	Winter.	Summer.	Monsoon.	Autumn.	Total.
Mahanadi I ..	3·13	9·51	77·71	9·65	100·00
„ II ..	2·72	5·58	86·63	5·07	100·00
„ III ..	3·04	3·61	89·01	4·34	100·00
„ IV ..	3·11	4·93	86·15	5·81	100·00
„ V ..	4·01	4·60	85·80	5·59	100·00
Brahmini I	3·15	8·64	80·22	7·99	100·00
„ II	4·31	6·02	83·90	5·77	100·00
Baitarani	3·88	13·18	72·49	10·45	100·00
Nilgiri	2·91	13·49	74·27	9·33	100·00
Subarnarekha I ..	2·95	14·26	73·57	9·22	100·00
„ II ..	3·85	9·05	81·09	6·01	100·00
Delta	3·02	10·64	72·31	14·03	100·00

Table 37.—Seasonal percentage of rainfall in Catchment Areas.

Catchment.	Winter.	Summer.	Monsoon.	Autumn.	Total.
Mahanadi	3·31	5·89	84·45	6·35	100·00
Brahmini	3·81	7·15	82·31	6·73	100·00
Baitarani ..	3·88	13·18	72·49	10·45	100·00
Subarnarekha	3·34	10·00	79·71	6·95	100·00
Delta	3·02	10·64	72·31	14·03	100·00
Brahmini and Baitarani ..	3·83	8·70	79·78	7·69	100·00

Isohyetal lines.

Two different methods were used for calculating the normal precipitation in the catchment basins. In Tables 34 and 35 the arithmetic average of the normal precipitation for a number of rainfall stations scattered over the catchment area has been adopted as the average normal rainfall in the whole basin. In the second method a number of isohyets (lines of equal rainfall) were drawn on the map, and the actual area, lying within two isohyets was measured by a planimeter. If X_1 is the average rainfall in area A_1, X_2 in area A_2 and X_3 in area A_3 then the average precipitation in the whole catchment area (or in any particular section) is given by

$$\bar{X} = \frac{X_1 A_1 + X_2 A_2 + X_3 A_3}{A_1 + A_2 + A_3}$$

This isohyet method is theoretically superior for two reasons. It makes some allowance for the irregular distribution on the rainfall stations. In the numerical method, in taking an arithmetic average equal weight is given to all stations inspite of the fact that the distribution of rainfall stations is not uniform. Secondly as the stations were started in different years, the arithmetical average refers to widely varying assemblages and cannot be considered to be strictly comparable.

Even in the isohyet method a certain amount of variation would be introduced by the manner in which the isohyets are drawn. Table 38 shows the normal monsoon rainfall as calculated by the isohyet and the arithmetic average methods respectively. The agreement though far from brilliant, is not altogether unsatisfactory. The residual uncertainty varies from—6·2 to+8·9 per cent, and neglecting signs may on the whole be taken to be of the order of 3·5 per cent.

Table 38.—Normal Rainfall, June—September.

Sections.	Isohyet.	Arithmetic average.	Number of station.	Difference between Isohyet and Arithmetic Averages.	
				Actual.	Percentage.
M— I ..	44·277	42·73	10	+1·547	+3·5
M— II ..	47·553	47·49	6	+0·063	+0·1
M—III ..	52·914	52·96	7	—0·016	—0·03
M— IV ..	46·237	45·78	3	+0·457	+1·0
M— V ..	42·478	40·83	13	+1·648	+3·9
Mahanadi ..	47·427	44·90	39	+2·527	+5·3
Br.— I ..	43·143	45·80	7	—2·657	—6·2
Br.—II ..	47·589	49·10	9	—1·511	—3·2
Brahmini ..	45·862	47·66	16	—1·798	—3·9
Baitarani ..	42·627	38·84	6	+3·787	+8·9
Sb.—I ..	45·314	42·04	4	+3·274	+7·2
Sb.—II ..	43·879	44·91	11	—1·031	—2·3
Subarnarekha ..	44·137	44·15	15	—0·013	—0·03

So far we have worked with the normal rainfall for the whole monsoon season of 122 days (June-September). It is, however, more convenient to use the daily normal rainfall which is given in Table 39.

For flood purposes it is still more convenient to convert these figures into rates of precipitation. One inch of rainfall in one day represents 26·8 cubic feet per second (cusec) per square mile. Multiplying the area of each catchment by 26·8 we obtain the cusec rate corresponding to one inch of rainfall in one day given in column (3) of Table 39. Multiplying these factors by the corresponding daily normal rainfall given in columns (4), (5) and (6) of Table 39, we obtain the daily normal rate of precipitation given in columns (7), (8) and (9) of Table 39 respectively for the isohyet and the arithmetic average methods.

In view of the discrepancy of the order of 3·5 per cent, we are justified in slightly adjusting the data for convenience of arithmetic calculations. We, therefore, finally adopt the daily normal rate of precipitation given in column (10) of Table 39 for the different catchments for use in connexion with flood analysis.

Table 39.—Daily Normal Rainfall for the period June—September.

Section.	Adjusted area in sq. miles.	Cusecs per inch of rainfall.	Normal rainfall in inch per day.			Normal rainfall in cusecs per day.			Adopted normal rainfall in Kilo-cusecs per day for calculation of excess rainfall.
			June—Sept.		July—Aug.	June—Sept.		July—Aug.	
			Numerical.	Isohyet.	Numerical.	Numerical.	Isohyet.	Numerical.	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Mahanadi I ..	6,400	172,089	0·3502	·3629	·3964	60,266	62,451	68,216	65
Mahanadi II ..	12,400	333,422	·3893	·3898	·4748	129,801	129,968	158,309	150
Mahanadi III ..	14,300	384,511	·4341	·4340	·5516	166,916	166,916	212,098	210
Mahanadi IV ..	6,600	177,467	·3752	·3790	·4545	66,586	67,260	73,755	70
Mahanadi V ..	11,300	303,844	·3347	·3482	·4156	101,697	105,798	126,278	125
Brahmini I ..	5,000	150,578	·3754	·3536	·4447	56,527	53,244	66,962	60
Brahmini II ..	8,400	225,867	·4025	·3901	·5074	90,911	88,111	114,604	100
Baitarani ..	4,000	107,556	·3184	·3494	·3244	34,246	37,580	34,891	35
Subarnarekha I	2,000	53,778	·3446	·3714	·3874	18,532	19,973	20,834	20
Subarnarekha II	5,500	147,888	·3681	·3925	·4346	54,438	58,046	64,273	60
Mahanadi ..	51,000	1,371,333	·3680	·3887	·4585	504,654	533,037	628,756	600
Brahmini ..	14,000	376,444	·3907	·3759	·4761	147,077	141,505	179,225	160
Baitarani ..	4,000	107,556	·3184	·3494	·3566	34,246	37,580	34,891	35
Subarnarekha	7,500	201,667	·3631	·3618	·4175	73,225	72,963	84,195	80
Delta ..	3,100	83,356	·3537	..	·3856	29,483	..	32,142	30

I should note here that in Table 39 we have taken the daily normal as averaged over the whole period of 122 days (June—September). In actual fact the daily normals for different days are different. These have been analysed in detail in later chapters of the Report. But for flood study the average normals are quite sufficient, for the uncertainty in making estimates of the actual flood rainfall is much too great to allow of the variation in daily normals being taken into consideration to any useful purpose.

The July and August normals, however, have a special importance, in view of the fact that the heaviest rainfall occurs in these two months. The daily normals in inches, and the corresponding rate of precipitation for the different catchments are given in Table 39.

PART III. DRAINAGE CHANNELS OF THE ORISSA RIVERS.

CHAPTER IX.—THE DRAINAGE CHANNELS OF ORISSA.

The Orissa Delta is traversed by a network of distributaries arising chiefly from the three rivers:—the Mahanadi, the Brahmini and the Baitarani. Compared with the main rivers of India the above three are of a medium class. The length of the course, drainage area, and discharge capacities are given below:—

Table 40.—Orissa Rivers.

River.	Length in miles.†	Area in square miles.		Discharge in cubic feet per second.		
		Catchment.	Delta.	Maximum.	Monsoon Normal.	Minimum.
Mahanadi	533	51,000	2,500	1,670,000	300,000	204
Brahmini	438	14,000	700	650,000	90,000	130
Baitarani	215	4,000		400,000	25,000	small
Total ...	...	69,000	3,200	2,620,000	415,000	...

N. B.—The estimates of discharge are very approximate.

It will be seen that the catchment basin is about 20 times larger than the deltaic area in the case of the Mahanadi, and about 25 times larger in the case of the other two rivers. The total normal precipitation in the catchment basins during the monsoon is 415,000 cusecs,* while the normal rainfall intensity in the delta is only 30,000 cusecs. The overwhelming importance of the water brought down from the catchment area can be easily appreciated.

All three rivers resemble one another in many ways. They all run roughly parallel, and all have their origin in the hilly countries of the Central Provinces or the Tributary Mahals. Each river enters the Orissa delta in one simple stream, and almost immediately divides into a great number of branches owing to deltaic action. During the monsoon season the rivers emerge from the hilly country with high velocities and laden with large volumes of silt. The velocity is suddenly reduced on reaching the plains, and the silt is deposited on the river beds. In this way the bed of the river rises, and gradually a shallow ridge is built up, on the summit of which the river flows. But the gradient along the river channel decreases at the same time, which causes a further reduction of the velocity and consequently a greater deposit of silt, until the bed of the river is raised so high that the river bursts its banks and sends out branches into the valleys lying between two successive river ridges. Fresh ridges are formed by the deposit of silt along the channels of the new branches, and the whole process is repeated with the formation of more new branches. During heavy floods, water is spilled over either bank and silt is deposited over the surrounding country which slowly raises the general level of the deltaic land. This action is, however, much slower than the raising of the river beds, so that the formation of new branches is a characteristic feature of all deltaic countries. Such deltaic action is very marked in Orissa, and we find that the Mahanadi, the Brahmini, and the Baitarani have divided into about 15 main branches with innumerable minor streams about half way between the gorges and the sea. These branches are interlaced in a very intricate manner so that waters from the different rivers become inextricably mixed on their way to the sea as can be seen from the accompanying map of the Delta.

*Or about 430,000 cusecs if we include the Subarnarekha and the minor catchments.

† The lengths of the rivers as directly measured on the maps came to 526, 424 and 203 miles respectively for Mahanadi, Brahmini and Baitarani; but were adjusted to agree with the values given by Mr. J. Shaw in Appendix VI to the *Interim Report of Orissa Flood Advisory Committee, 1939-40* in consideration of loops and turns which could not be measured accurately on the maps.

The detailed analysis of gauge readings at Naraj, Jenapore, and Akhoyapada (given in later chapters) shows that the average height of the Mahanadi, the Brahmini and the Baitarani at these three places, respectively, have remained practically steady during the last 50 or 60 years. Deltaic action, therefore, appears to have practically ceased at the head of the delta.

Deltaic action is, however, still at work in the plains which causes considerable fluctuations in the relative discharge through different channels from time to time. For example, the main Mahanadi channel appears to have been considerably silted, but the Pyka is taking the increased discharge thrown on it. Or again, the Daib and Daya are improving while the Kushbhadra and Bhargobi are becoming silted up at present. (O. F. C., 1928, page 38.)*

Along the sea-coast of Orissa there exists a steady northward littoral sand drift. "This drift tends to form bars across the mouths of the rivers from south to north ; a bar of this nature is often raised in the hot weather by the prevalent wind so as to form an unbroken sand dune across the mouth some 25 or 30 feet high above sea level. It is not uncommon to find a river pursuing a fairly straight course to the sea, there to be diverted parallel to the coast for several miles before it can succeed in obtaining an outlet. The Sonamuhi for instance, rising in the Samaung Pat behind Puri runs parallel with the coast behind the dunes for about thirteen miles and in some years has a common mouth with the Chilka Lake though independent mouths have been opened on occasion as high up as Harachandi". (O. F. C. 1928, pages 8-9.) During heavy floods direct mouths are sometimes opened across the sand dunes, but such openings are again soon closed by the littoral drift. The Orissa Flood Committee of 1928 was of opinion that the shortness of the Orissa delta was very possibly due to this drift :—"Whereas the heads of the deltas of such rivers as the Ganges and Indus are situated about 400 miles from the sea, the deltas of the Mahanadi, Brahmini and Baitarani are little more than fifty miles long. It is probable that these rivers are continually striving, by deposit of silt, to form new land on the sea edge but that this silt is continually being forced towards the north by the littoral drift. We consider it likely that to this drift is due, on the one hand, the long shallow shelf which is shown on the charts as stretching into the Bay of Bengal in front of the Orissa rivers, and, on the other, the progressive filling in of the Balasore Roads. This raising of the sea-bed in the north-west angle of the Bay has affected the estuaries of the rivers flowing into the Balasore Roads, the Subarnarekha bed has deteriorated, and the Dhamra estuary and its outer bar have several feet less water now than they had in 1885." (O. F. C. 1928, page 9.)

Tidal action extends to a considerable distance inland and causes marked variation in the level of all the rivers. During the monsoon season, water in the Bay of Bengal is headed up which raises the level of the water at the mouths of the rivers by some 2 or 3 feet or considerably more during storms. (O. F. C. 1928, page 8.) Owing to the very small width of the Orissa delta (from 30 to 50 miles), this monsoon heading up to tidal action offers considerable obstruction to the flood discharge by appreciably reducing the slope of the water flowing down the rivers.

Finally, the natural situation has been very seriously complicated by the erection of embankments for the protection of the arable tract from flooding and by the construction of canals for irrigation and navigation. A valuable "Narrative of the Principal Events connected with the Flood Embankments in Orissa and of the Origin and Development of the Orissa Canals extending over the period from 1840 to 1880" was prepared by Mr. W. A. Inglis, Superintending Engineer, in 1900. I shall give a brief description of the development of the Orissa canals and embankments in a later section. But a few salient points may be mentioned here.

In Balasore district the Orissa Coast Canals up to Charbatia runs parallel to and a few miles from the sea coast. It constitutes a barrier 60 miles long which prevents the free flow to the sea of the spill water from the numerous channels which cut it almost at right angles. The Coast Canal thus heads up

*O. F. C. : *Report of the Orissa Flood Committee, 1928.*

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the water during floods and causes great harm. Free flow of drainage is also obstructed by the Salt Embankment which runs parallel to the Coast Canal and between it and the sea.

The High Level Canal from Bhadrak to Cuttack, the Orissa Trunk Road, and more recently the Bengal-Nagpur Railway line, all cut the main drainage channel practically at right angles, and thus complicate the flood situation.

In the Brahmini delta a number of embankments (Uttikhan, Gajaria, Raj Kanika, Aul, etc.) seriously obstruct the flow of water, and causes excessive flooding in the tract lying between the Khursua and the Brahmini.

In the area drained by the main channel of the Mahanadi and its branches in the Cuttack district a more stable regime has been reached by practically fully protecting the land from inundations by a system of embankments connected with the Pattamundi, Kendrapara, Taldanda, Machgaon and other canals which run roughly parallel to the river channels.

The situation, however, is very bad in the Puri district which is drained by the southern branches of the Mahanadi. These rivers are unable to carry even half the volume of water received during moderate floods from the main channel.

Flooding is, therefore, inevitable in this part of the country. And it is not surprising that an intricate and most haphazard system of embankments has arisen in the course of years through the efforts of the people to protect themselves from floods. These embankments have in their turn further obstructed the flow of water to the sea, and have aggravated greatly both the duration as well as the intensity of the floods.

In the Puri district another important factor is the premature reclamation of land along the sea face. There are large areas only a few feet above the mean sea level which are protected from tides by salt embankments. Once they are flooded, rapid drainage is practically impossible. The premature reclamation also affects adversely the deterioration of estuaries which appears to be still in progress in this region.

A general idea of the protection from floods given by the embankments may be obtained from the following summary table which has been prepared from the data given by A. S. Thomson (" Rivers of Orissa, " 1905, pages 40—52).

Table 41.—Embankments of Orissa Rivers.

River.	Deltaic Area (Sq. miles).		Embankment (miles).
	Total.	Protected.	
Mahanadi	2,525	1,327	540
Brahmini	855	263	131
Baitarani		289	75
Other rivers		156	58
Total ...	3,380	2,035	804

Thomson mentioned that out of these 804 miles of embankments 294 miles were connected with the Canal system, while 510 miles were classified as agricultural works. Fuller details of the embankments for each important channel are given in Tables (43—45).

Mr. H. A. Gubbay, Superintending Engineer, in his note of the 3rd July 1923, gave the following figures for the area dealt with under Orissa Canals and Embankments in Puri, Cuttack and Balasore districts in 1920.

Table 42.—Embankments.

Description.	Area in sq. miles.
Protected from all floods but not irrigated	580
Protected from all floods and irrigated	450
Total fully protected ...	1,030
Total protected from low floods ...	1,020
Total protected ...	2,050
Open to all floods ...	1,254
Total ...	3,304

It will be noticed that out of about 3,300 sq. miles, roughly one-third is fully protected, one-third has partial protection, while one-third is open to all floods.

Table 43.—Length of Embankments in Orissa with Protected Areas.

Embankments.	Miles.	Feet.	Protected area in sq. miles.
Mahanadi.			
Mahanadi	61	859	172·78
Suk Pyka	22	2,511	27·80
Chittratola	64	3,962	259·82
Nuna	8	40	13·47
Pattia	3	1,740	6·56
Bhimdaria	1	2,425	3·58
Pyka	22	1,531	23·38
Gobri	..	3,600	2·25
Patuali	1	2,090	0·90
Beropa	25	672	50·05
Katjuri	27	2,251	52·53
Surua	17	4,460	36·00
Debi	32	3,701	194·62
Kundal	4	412	2·19
Madrung	..	1,800	0·25
Tangra	1	2,750	1.69
Bindhum	4	2,050	4·25
Koakhye	20	3,960	22·18
Kushbhadra	18	5,195	61·57
Daya	33	2,310	72·44
Managuni	9	1,540	21·07
Bhargovi	65	2,086	252·98
Kanjhariadhar	3	3,790	1·25
Kanchi	8	3,534	2·18
Sur Lake	15	4,620	9·67
Atharnala	5	2,640	0·79
Dhanuria	5	3,045	1·62
Sonamuhi	7	4,680	4·66
East Kania	4	2,770	4·84
Nayanadi	9	2,970	10·81
South Kania	7	4,790	8·10
Chilka Lake	4	1,320	1·68
Total ..	560	1,624	1327·96

Table 44.—Length of Embankments in Orissa.

Embankments.	Miles.	Feet.	Protected area in sq. miles.
Brahmini.			
Brahmini	101	1,065	244·75
Saukra	4	2,039	3·66
Kimiria	3	1,592	2·51
Kharsua	21	3,971	11·98
Total ..	130	3,387	262·90
Baitarani	51	2,516	271·02
Burha	20	2,323	17·50
Ganguti	3	1,834	0·77
Total ..	75	1,393	289·29
Salindi	8	3,395	13·27
Kopali	2	2,735	5·03
Subarnarekha	23	3,995	99·50
Sea (Salt Embankment)	13	1,605	37·00

Table 45.—Length of Embankments and Protected Areas.

——	Embankments. Miles.	Protected area in sq. miles.
Mahanadi	550·308	1327·96
Brahmini	130·641	262·90
Baitarani	75·245	289·29
Salindi	8·643	13·27
Kopali	2·518	5·03
Subarnarekha	23·757	99·50
Sea (Salt)	13·304	37·00
Total ..	804·416	2034·95

NOTE.—Mr. J. Shaw, Executive Engineer, Floods and Drainage Division, gives the following latest figures in Appendix VI to the *Interim Report of the Orissa Flood Advisory Committee, 1939-40.*

——	Mahanadi.	Brahmini.	Baitarani.
1. Total area of Delta (square miles)	2,940	854	659
2. Protected Area served by Canals (square miles)	641	62	190
3. Area protected by embankment but not irrigated (square miles)	456	166	103
4. Semi-protected areas affected by high floods " "	725	192	177
5. Area frequently flooded " "	475	230	140
6. High ground, jungles, etc., not ordinarily flooded " "	278	124	90
7. Total length of embankments in miles	761	178	100
" " " (Government)	584	105	77
" " " (Private)	187	73	23

CHAPTER X.—THE MAHANADI.

After reaching Sonepur the Mahanadi runs for about 150 miles in a south-easterly direction through the Feudatory States and Tributary Mahals of Orissa and enters the delta through a narrow gorge at Sydessur hill immediately above Naraj, 7 miles from the town of Cuttack.

At Naraj the river divides, the main stream called the Mahanadi flowing east towards the sea through the district of Cuttack, and a large branch called the Katjuri turning off towards the south partly through the district of Puri. The Mahanadi next gives out a large branch on the left a little below Cuttack, while 4 miles below Naraj, opposite Cuttack, the Katjuri sends out a big channel, the Koakhye on the right.

The channels of the Mahanadi are very old. We know that during the last 60 years the level of the river at Naraj has remained practically steady showing that deltaic action at the head of the river has practically ceased.

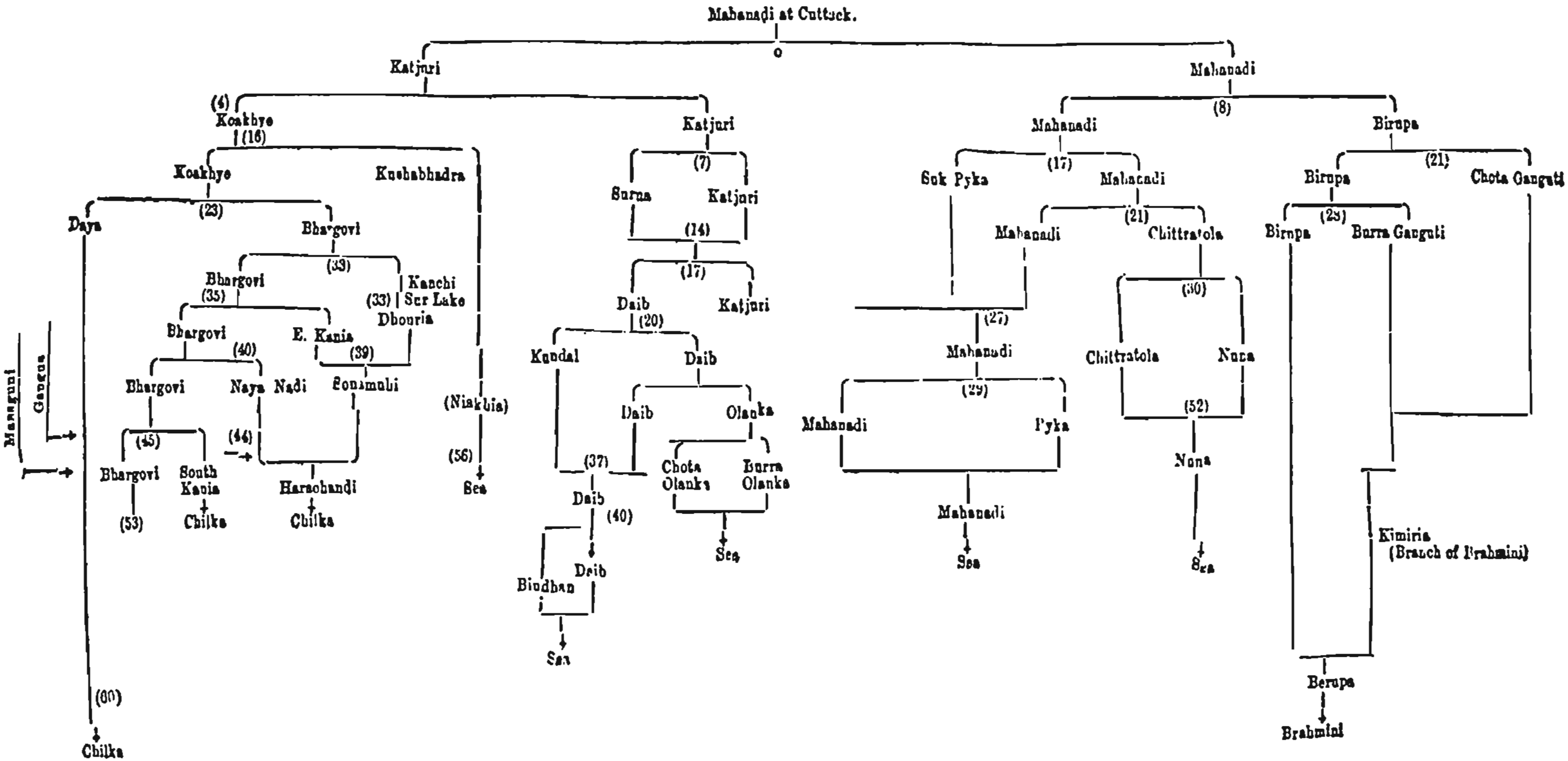
Inglis in his "Narrative" has given sections of the channels of the Mahanadi which were taken at the time of the construction of the Bengal-Nagpur Railway bridge. He pointed out that "in the case of the Mahanadi main channel it will be noticed that for the greater part of the channel only sand has been found. This may be taken as confirming the view that this is the oldest channel of the river.

"In the case of the Katjuri, clay is met at 25 to 35 feet below mean sea level, and this, I think, is sufficient to show that this channel is also of great age. In the case of the Koakhye the clay is met with just about mean sea level, indicating doubtless a somewhat later origin, but still one far from recent in the ordinary sense of the term. The Beropa is the only one of the channels which appears to be of comparatively recent development."

A stone spur was constructed at Naraj in 1858, at the suggestion of Lieutenant Harris, with a view to reducing the discharge into the Katjuri and the Koakhye. This spur was further extended in 1859, and was subsequently developed by the East India Irrigation and Land Company into the Naraj anicut which today regulates the flood discharges into the two branches.

We shall now consider the branches of the Mahanadi, a schematic diagram of which is given in Figure 1.

Figure 1. Schematic Diagram of the Branches of the Mahanadi below Cuttack.



N. B.—The figures within brackets give the approximate distance from Cuttack in miles along river channels.

CHAPTER XI.—THE KOAKHYE AND THE PURI RIVERS.

About 4 miles from Naraj, opposite Lalbagh (Cuttack), the Katjuri is a mile and a half wide, and here the Koakhye, its largest branch starts from the right bank at the village Kajipatna. The Koakhye after flowing in a south-south-easterly direction for 12 miles throws off a branch called the Kushbhadra, and then travels nearly due south for 7 miles until it reaches the village of Sardaipur, where it forks into two big branches : the Daya to the west and the Bhargovi to the east. The Koakhye is embanked for its whole length on the left bank, and is fed on the right bank by a small tributary, the Bulbhadra.

The Kushbhadra leaves the Koakhye at Balihanta about 12 miles from the head, and flows in a south-easterly direction for some 40 miles till it enters the Bay of Bengal near the shrine of Ramchandi, 15 miles east of Puri. The Kushbhadra has no branches and for the last few miles of its course it is called the Niakhia.

The mouth of the Kushbhadra below Ramchandi is free from silt, but the river bed between the Niakhia ferry crossing and the mouth is shallow, and there are many mounds of sand in the bed which obstruct the free passage of the water to the sea. During the cold and hot weather months the tide is felt as far as village Padampada, but during the rainy season, only as far as Katkutpatna, somewhat below Takna village. Mr. Arnott noted (Thomson, page 15) :—

" After the first three miles of its course the Kushbhadra narrows considerably, and the pressure of the floods is greatly felt, so that breaches may occur anywhere in the embankments situated on either bank between the 2nd and the 10th mile. "

As already mentioned the Koakhye divides at Sardaipur, about 19 miles from its head, into the Daya on the west and the Bhargovi on the east. The head of the Bhargovi is silted up to a great extent, and the Daya carries more than its fair share of the water. The course of the Daya runs due south for 8 miles, and then it makes a sharp turn westward for 4 miles, and after that continues its course southward for the rest of its length, emptying itself into the Chilka Lake at the north-eastern corner, some 37 miles from its off-take. Two small rivers enter the Daya, the Gangua Nadi just above the village of Kanti, and the Monaguni river, a mile or two below Kanas. Although these streams are small, they drain a hilly country, and during rainfall they add a considerable volume of water to the Daya. The Daya is tidal as far as Bhutpara, opposite the 24th mile of the left embankment, but the action of the tide is inappreciable in the flood season.

The Bhargovi which is about 53 miles in length " is the last branch of the Koakhye and begins its course, as stated before, at Sardaipur, travelling for the first 4 miles in a south-easterly direction. It then trends to the west for another 4 miles, turning again to the south-east and keeping this course until the village of Tornia is reached, 14 miles away. Here its direction is south-west for 23 miles, when it shoots to the north for 5 miles, travels in a direction due west for another 5 miles and then empties itself into the outfall of the Daya, breaking up into numerous branches in the last 2½ miles of its course." (Thomson, p. 19.) The Bhargovi is embanked for its whole length but as the channel is extremely constricted, breaches occur frequently on both sides during floods of any intensity.

Between the off-take of the Bhargovi and the 28th mile the only tributary is the Kanjhariadhar river, which rises opposite the 24th mile of the Puri road and after running for about 3 miles enters the Bhargovi in the 8th mile. It is embanked on both sides for practically 2 miles from its junction with the Bhargovi, but as it has a drainage area of only about 1½ square miles is of no importance.

The Bhargovi at its lower end branches into a most complicated system of drainage channels. The Kanchi, the first branch of the Bhargovi, takes off at Jankadaipur village and travels south-east, having its outfall in the

Sur Lake about a mile below village Panchumoni. During a flood in the Bhargovi, the Kanchi relieves the pressure lower down, the spill water entering the Sur Lake, and when the flood subsides, this spill returns and escapes again by the Bhargovi. At its lower end the Kanchi meets the Athara Nala, and also throws off a branch, the Dhouria, which takes off a good deal of the excess water of the Bhargovi. The Dhouria runs in a westerly direction, falls into Samang Pat and is absorbed there.

The East Kania which is the second branch of the Bhargovi, takes off in the 35th mile, and runs in a south-easterly course for four miles when it joins the Sonamuhi at its head at south-west corner of the Samang Pat. The flood water flows up and down this river during the monsoon months, flowing towards the Sonamuhi when the Bhargovi is rising, and towards the Bhargovi when it is falling The Nayanadi, the third branch of the Bhargovi, is an artificial channel taking off from the 40th mile, and running in a south-easterly direction for a distance of 3½ miles, it joins the Sonamuhi and merges with the latter into the Harchandi river. It was meant to pass the excess flood water of the Bhargovi into the Harchandi, but it has become so silted up that it is of little use. The South Kania, the fourth and last of the branches of the Bhargovi, starts at 45th mile and travelling in a south-westerly direction enters the Chilka Lake 10 miles from its off-take. It is a narrow and winding stream with its head much silted up, and is not of much use in escaping the Bhargovi flood water. In high spring tides and during the prevalence of the southerly winds, the brackish water of the Chilka Lake is forced up the South Kania, doing a certain amount of damage to the soil.

The Harchandi is not a branch of the Bhargovi, but all the branches of the latter eventually drain into it. From its junction with the Nayanadi and the Sonamuhi it runs for 10 miles south-west until it empties itself into the Bay of Bengal by the Chilka Lake mouth. Its whole course is through sand and consequently its bed is considerably silted up and the river has become very shallow. Owing to the prevailing south-west wind that blows steadily from February to June, carrying sand with it, the keeping of the bed clear for any length of time without yearly excavation would be next to impossible. The tides reach village Jagannathpatna, about half a mile above the Temple.

The Sur Lake, the Samang Pat, and the Chilka Lake act as balancing reservoirs during the time of floods. Formerly the Sur Lake and the Samang Pat had no connection with the sea, but recently a cut has been made joining the Sur Lake to the sea at the time of flooding.* The area of the Sur Lake during the rains is 20 square miles, which is reduced to 4 square miles in December owing to seasonal reclamation of land for cultivation. The Samang Pat is about 6 square miles.

It is worth while noting at this place that "at the highest tides the sea will always be running into the Chilka Lake in every month for a few days both before and after the conjunction of the moon". This was established by a comparison of the gauge readings at Satpara in the Chilka Lake with the extrapolated sea levels at Puri, which were taken roughly 6" (six inches) higher than the levels at Vizagapatam given in the Tide Tables of the Indian Ports published by the Survey of India. (Letter of the Superintending Engineer, Orissa Circle, No. 2255, dated Cuttack, the 20th May 1926.) The Superintending Engineer concluded, therefore, that if a fresh cut is made at the mouth of the Chilka there was "danger of the sea water entering and causing still further damage to the villages in the Chilka".

The general arrangement of these southern branches of the Mahanadi has been described as not unlike the spokes of a fan, the Daya running south-west by south, the Bhargovi south, the Kushbhadra south-east by south, and the Daib south-east, The beds of the rivers are only from 5 to 8 feet lower than the corresponding ground level on either sides of the rivers. In fact all these rivers run on ridges with three valleys between them which are drained by internal drainage channels. The Daya-Bhargovi basin is drained by the Nuna

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*Mr. J. Shaw's letter of 8th March 1938.

and Ratanchira, and the Bhargovi-Kushbhadra basin by the Dhanua, while between the Kushbhadra and the Debi lies the Prachi. Deltaic action is more backward and hence more marked in this region. Almost all the rivers contract near the sea, and the effect of the littoral drift is also most marked in this area. The maximum combined capacity of these four rivers is only a fraction of the volume which they receive from the Katjuri.

We have already seen that the Koakhye cannot be regarded as of recent origin. It must, therefore, be considered how it is that the channels of the Puri district, viz., the Kushbhadra, the Bhargovi and the Daya, can only take such a small part of the discharge which the Koakhye brings to them. Mr. Inglis wrote :—" I think the explanation must be sought for in the previous existence of another channel flowing to the sea which has been filled up, while the channels of the Puri district have not had time to develop. There is at present a drainage course, known by the name of Prachee, which very nearly follows the boundary between the Cuttack and the Puri district, and which has the following peculiarity; along the northern side of this drainage there is a sand ridge, which resembles the ridges and mounds of blown sand that are found at places on the northern banks of most of the present channels of the river, and which can hardly be accounted for in any other manner. These sand ridges occur in the northern banks because of the strong south winds which blow during the hot weather and which cause the origin of sand. I think then that at some period, more or less remote, there must have been a large river where the Prachee now flows, and that by this course the greater part of the water which now passes through and over the Puri district must have then found its way to the sea."

In any case it has been proved by experience that the rivers Kushbhadra, Bhargovi and Daya cannot pass on to the sea, within their embanked channels, the whole volume of flood which is poured into them. Regarding the nature and extent of the protection from floods given by the embankments on the Koakhye and its branches, Mr. Arnott remarked in 1904 :—

" It will be readily gathered that the protection from floods is on quite a different footing to that given by the embankments that protect the Taldanda and Machgong Canals. The embankments on the Koakhye and its branches, that is, in fact all the embankments in the Puri district, are devoted simply to the protection of land and village sites. It will be seen at once that the protection given by the embankments of the Koakhye and its branches is only very partial, and that the Puri district will always be liable to be badly inundated when a flood of any considerable magnitude comes down the Mahanadi while things remain as they exist at this present time."

The drainage of the Daya is also becoming seriously obstructed by the silting up of its outfall into the Chilka Lake through which the flood of the greater part of the Puri district has to pass to the sea.

It is worth while noting that the southern portion of the Puri district is liable to fairly heavy flooding due to a moderate excess of local rainfall even without high floods in the Mahanadi. For example, it has been estimated (O. F. C. 1923, pp. 21-22) that locally heavy rainfall of 9" in 6 days together with a low flood in the Mahanadi would cause almost as great a flood as a local fall of 3" with a high flood in the Mahanadi in an area of 272 sq. miles lying east of a line through Puri town in the Kushbhadra-Bhargovi drainage area.

On the subject of the injury or benefit resulting from inundation, Mr. Arnott noted (Thomson, 1905, p. 25) :—

" On the whole I am inclined to the belief that in the Puri district the injury to inundation outweighs the benefit. Except on the land to the right of the Daya, and that land must be some distance away from it, or land at the outfalls of the Bhargovi and Daya, all inundation is the result of breaches in embankments. This means that there has been a ponding-up of water whose pressure at last overcomes the resisting capacity of the embankment, the water rushes through the breached embankment with great force, bringing in sand, uprooting the rice and, if not uprooting it, killing it by submersion for a greater number of days than the rice plant can survive in, namely, seven. Any way during my ten years' experience of the Orissa rivers, I have never known a breach in any of the embankments accompanied but with loss. It may be argued that though the areas near the breach may suffer, areas further away will receive benefit, but even then the result is 'nil' for the benefit and injury cancel, and it is no satisfaction to a cultivator to know that crops at the further end of the village have received benefit while his own are lost. Take the land over which the Bhargovi water spills through the Adlabad breach, and given a year of three or four moderate floods in the rivers, and inspection of the land will bring conviction home to one that the inundation is injurious. When inundation comes as a backwater gently and without a rush and remains for a short time, I have no doubt that this is beneficial, but such a state of things does not obtain as a rule with inundations in the Puri district."

CHAPTER XII.—THE KATJURI AND ITS BRANCHES.

We have seen that the Katjuri leaves the Mahanadi at Naraj and sends off a branch, the Koakhye, about 4 miles below Naraj. About a couple of miles below Lalbagh is the bridge carrying the Bengal Nagpur Railway, and about a mile further down, the river divides at Jhinkiria village, the main stream running to the east and the branch, Surua, running to the south. These two reunite a few miles further down. The river then runs straight for about 3 miles and sends off the branch Debi (or the Daib as it is sometimes called) at Gobindapur. The Katjuri at one time used to flow north-east and re-enter the Mahanadi at Jaipur, but at the time of construction of the Canals it was closed firstly by the left embankment of the Debi, secondly by the Machgong canal which crosses the old stream further down, and lastly by the Taldanda Canal which crosses it at Jaipur. Therefore the old bed of the Katjuri which is now called the "Cross Katjuri" has ceased to be of any use except as a local drainage channel. The Katjuri used to have another branch, the Olanka. This was also closed along with the Katjuri but it still has some sort of an outlet into the sea through the Chota and Burra Olanka.

The Barang, the first branch of the Katjuri, used to take off from the right bank a little below Naraj, and entered the Koakhye opposite Telengapenth at the 8th mile of the Puri road. Its head was, however, closed and it no longer takes its supply from the Katjuri, but it still acts as a spill channel of some importance.

The Surua takes off from the Katjuri at the village of Jhinkiria and running for a distance of 10 miles from west to east, joins the Katjuri again at Barera in a somewhat northerly direction. Its bed is about 10 feet lower than that of the Katjuri and being confined on both banks the flood rushes down with considerable velocity, carrying more water than the Katjuri.

The Daib which branches off from the Katjuri about three and a half miles below the point where the Surua re-unites with the latter, breaks up into a complicated system of branches such as the Kundal, the Doikhai, the Madrung, the Tangra, the Boraikhama, the Pota, etc. Mr. Arnott thus described the river in 1904 :—

"It is seen that the Katjuri at Gobindpur splits into the Katjuri and Daib, the latter being the southerly portion. The Daib runs south, south-east for about three miles and then taking a more easterly course branches into the Kundal river, which is the southerly portion, the off-take being at village Karmonga. It then runs in an easterly direction until it meets the Bilua Khai and flows south-easterly until reaching Debidole in the 15th mile of the embankment no. 87A, when it is joined by the Tangra. Continuing a south-easterly course from here for seven miles, it is met by the Kundal at village Sikhar, opposite the 22nd mile of the embankment, at which place there is a ghat. Then the Daib flowing for three miles forks again at village Bundesahi into the Daib to the north and the Bindhun to the south. The bed of the Daib has here been raised by sand deposit so that most of the water flows down the Bindhun. The Daib and the Bindhun unite again at village Patsunderpur, and they flow as the Daib, into the Bay of Bengal. The Bindhun, the Daib, and the Kundal are all tidal; the Daib up to the 14th mile of the Daib left embankment, and the Kundal to two miles above Sikhar.

"The Kundal, after taking off from the Daib at Karmonga village, proceeds in an easterly course for two miles to its junction with the Tangra and then flows due south for another three miles, when after running south-east by east for 5 miles it joins the Daib. The Madrung is a small river taking off from the Daib half a mile below Karmonga flowing south-easterly and joining the Doikhai, a tributary of the Kundal, which starts a mile below the off-take of the latter and also flowing south-easterly joins the Kundal again seven miles lower down. The Tangra is a junction between the Kundal and Daib coming out opposite Debidole. The 'old Daib' is the former channel of the Daib, but it has now become considerably silted up and its junction with the Daib is the Kajakhai, into which no water flows except in times of high flood. The Baraikhama and Pota are channels between the Doikhai and the Daib at its junction with Biluakhai." (Quoted by Thomson, 1905, p. 11.)

As regards embankments Mr. M. H. Arnott wrote:—

"Owing to the Machgong canal and its distributaries, complete protection is afforded to the land lying to the north of the Katjuri, the east of the Biluakhai, and the north-east of the Daib. Cuttack, of course, has to be protected, and the country lying to the south of the Surua might receive complete protection, except in the untoward event of a breach happening. With regard to the embankments on the different islands of the Daib and its sub-branches, the case is different; they are only intended to give very partial protection. The reason is that this area must be kept open for the Katjuri spill, and the erection of any embankments in the islands would be fatal to the security of the canal protective embankments. In ordinary floods these which do exist on the Kundal, Daib and Bindhun serve their purpose well, but in high floods of any duration they are liable to be breached." (Thomson, 1905, p. 13.)

Regarding the effect of inundations he remarked:—

"The villages in the islands formed by the Katjuri, Daib and the Kundal have wisely recognized the position and no longer grow autumn rice to any large extent. They devote their energies to the cultivation of *biali* and *rabi*. The inundation under any circumstances would be an unmixed blessing except for two drawbacks: (*a*) if it occurs too early and lasts for any length of time it kills the young *biali*, (*b*) it always brings in a lot of sand which deteriorates the land near the banks, (*a*) is partly discounted by the fact that if the inundation last long and do kill the *biali*, the *rabi* crop is a marvellous one. Again, this must be qualified by the fact that more sand will be deposited."........... On the whole Arnott was of opinion:—"If a villager can be got to really tell the truth he will say that the inundation is beneficial to him on the whole, never mind its drawbacks." (Thomson, 1905, p. 13.)

CHAPTER XIII.—THE MAHANADI AND ITS BRANCHES.

After throwing off the Katjuri on the right, the Mahanadi gives out a big channel, the Birupa, on the left. A little further on is the head sluice of the Taldanda Canal at Jobra. The weir is nearly 1½ miles long, with undersluices in the centre, and at the south end, and folding shutters three feet high along the crest. The crest of the weir is at R. L. 65·00, and the arrangements admit of the water in the river being ordinarily maintained at a level of 67·60. About a quarter of a mile below the weir is the bridge carrying the Bengal Nagpur Railway.

The Taldanda canal which is a navigable channel 51¾ miles in length, carrying a full discharge, at its head, of 1,150 cusecs, and capable of irrigating together with its branch the Machgong canal, an area of 63,250 acres, falls into the Mahanadi at Paradip. The Machgong Canal which is for irrigation only, leaves the main canal at Birbati, 7 miles from the head, and has a length of 32 miles.

Following the Mahanadi from Jobra, it divides 9 miles down at Aitpur village, the main stream continuing in a north-easterly direction, and a branch called the Suk Pyka, running south-east. A little further down the Mahanadi, another important branch, the Chittratola takes off towards the north. From Jobra to Aitpur the Mahanadi is embanked on the right by embankment no. 78A and this is continued, with portions of the Taldanda Canal bank, along the right bank of the Suk Pyka down to the 27th mile at Kulsai where the Suk Pyka rejoins the Mahanadi. In fact there is a continuous flood embankment from Jobra to Paradip, the outfall of the Taldanda Canal; the last 25¾ miles, from Tarpur being canal bank. A short distance below Kulsai, the Pyka branches off to the north, and this branch reunites with the main river at Taldanda in the 44th mile of the canal.

From Taldanda the Mahanadi flows eastward, and enters the Bay of Bengal below False Point. The river is navigable up to Kothiasahi, opposite the 45th mile of the Taldanda canal, at all seasons for the largest cargo boats carrying 1,750 maunds and drawing 3 feet of water. At high tide similar boats can go up to Taldanda opposite 43½ miles of the canal.

As regards the protection from floods afforded by the Mahanadi embankments, the country on the right bank of the river, and its branches the Suk Pyka is entirely protected by strong embankments, 4 feet above maximum flood level. On the left bank and on the Pyka branch the embankments are not continuous nor are they maintained to resist extraordinary floods; they protect certain cultivated areas and village sites during ordinary floods. Mr. M. H. Arnott, Executive Engineer, made the following remarks (Thomson, 1905, pp. 3-4) concerning the injury or benefit due to inundation :—

"On the whole, it may be said that the inundation on the islands formed by the Pyka, Suk Pyka and Mahanadi are beneficial. This could not be asserted with any degree of accuracy did such inundations take place yearly, for it is undoubtedly true that the land on the margin of the rivers suffers considerably from the influx of sand which is pushed on to it from their beds This water, however, if the inundation take place in July, which it usually does, is heavily silt-laden and the deposit fertilises the land for some years. Although in the particular year of inundation the villagers may lose a greater portion of their autumn rice, still they will be compensated by a bumper *rabi* crop, such as mustard, *biri*, *kulthi*, etc. This was seen in 1897 after the great flood of 1896."

The Chittratola leaves the Mahanadi, to the left, opposite the 9th mile of the Kendrapara canal. About 9 miles further down the Nuna branch takes off, and, flowing along close to the Kendrapara canal, rejoins the Chittratola at Marsaghai in the 40th mile of the canal. From this place the river is called the Nuna, and it falls into the Mahanadi near Paradip. There are small branches from the Nuna, which are of little importance. The Bhandaria Nadi takes off opposite the 25th mile Kendrapara canal and joins the Bagni. The Potti Nadi takes off opposite the 27th mile and meets the Bara Nadi, which joins the Nuna nearly opposite Kulpara. The Pyka takes off from the Mahanadi, to the left, opposite about two miles above Narendrapur, and joins the Mahanadi again nearly opposite Marsaghai.

The Gobri river is not actually a branch of the Mahanadi, though probably it was at one time connected with the Mahanadi, and possibly also with the Beropa, by spill channels now closed by the Kendrapara and Pattamundi canals. Some 20 miles below the head of the delta between these canals two small channels, the Suknadi, and the Kundinadi combine to form the Gobri which then flows eastwards to Gandakia. There it joins the Chota Brahmini (the head of which has been closed by the Pattamundi canal, at Pattamundi) and becomes the Gandakia river. The latter is a tidal river which joins the Jumboo river near the tail lock of the Kendrapara Extension canal, and flows thence into False Point harbour. (Thomson, p. 6.)

THE BEROPA.

The Beropa leaves the Mahanadi opposite the town of Cuttack. A mile and a half from its off-take is the masonry weir impounding the water for the supply of the High Level Canal, Range I, and the Kendrapara Canal.

The weir is 1,980 feet long and has a set of sluices at either end, the crest of the weir being fitted with folding shutters four feet high. The weir crest is at R. L. 63·50 and the water can ordinarily be maintained at R. L. 67·00.

On the left, or north side of the weir, at Chowdwar, is the head lock of the High Level Canal, Range I. This canal is navigable, it is 33 miles long and ends at the Brahmini river at Jenapur. The supply available at the head is 500 cusecs, and the area commanded is 47,737 acres, of which 24,568 acres are suitable for irrigation.

The Kendrapara canal starts from the south end of the weir at Jagatpur. It is navigable, and extends to Jambu, 54 miles from the head. The outfall lock admits boat traffic to the Jambu tidal river, which runs into the harbour of False Point a few miles from the lock. The latter half of this canal has, however, been abandoned.* In the 28th mile of the Kendrapara canal the Gobri canal branches off. This is also a navigable channel which runs for 15½ miles to the Gandakia river, a tidal stream 200 yards wide. The Gobri Extension canal starts from the opposite side of the Gandakia river and with a length of 6 miles, falls into the Brahmini river at Alba. From Alba steamers and boats proceed by the tidal reaches of the Brahmini and Baitarani rivers to Chandbali, a distance of 36½ miles. Chandbali is the chief port of Orissa, and a regular service of steamers connects it with Calcutta. At one time the Calcutta steamers used to run right up to Alba lock, but this has been discontinued. There is another branch of the Kendrapara canal, called the Pattamundi canal, which takes off about half a mile below the head of the main canal. The Pattamundi canal is intended for irrigation only and is not navigable. It has a length of 47 miles, and from the Escape Fall at its end a feeder channel, over 3 miles long, supplies fresh water to the Gobri Extension Canal.

The Bengal Nagpur Railway crosses the Beropa a quarter of a mile below the Chowdwar weir. Some 10 miles down a branch called the Chota Ganguti takes off towards the north, and 7 miles further down is another branch, the Bara Ganguti. The head of the former has been permanently closed by the construction of embankment no. 29A, which is over 12 miles long. The channel now serves for local drainage and receives the back water of the Bara Ganguti, which joins it at about 6 miles from its source. The two Gangutis then flow together for about 12 miles to join the Kimiria, and about 2 miles further down rejoin the parent stream, Beropa. Here a portion of their water goes into the Kaloonadi to meet the main branch of the Beropa again about 2 miles above Indpur bungalow. The Beropa taking together all the divided waters and the Kimiria branch of the Brahmini, joins the main stream of the Brahmini near Indpur bungalow.

* Mr. J. Shaw's letter of 8th March 1938.

CHAPTER XIV.—THE MINOR RIVERS IN THE MAHANADI DELTA.

There are a number of small rivers near the sea coast in the Mahanadi Delta which do not derive their origin from the Mahanadi itself. Thomson described these rivers in their order from the north-east to south-west.

The Samolia river starts from the village of Haripa, and is tidal as far as Haripa, but the tidal action in the rainy season is not felt beyond Panchpalli, a village 6 miles below Haripa. Its course is from west to east, which is much silted up from Haripa to Panchpalli.

The Gobri river which drains the tract of country between the closed up Olunka and the Daib, starts near Devidole and flows in a south-easterly direction, joining the Daib near Bandasahi, 10 miles from its source. It is now connected with the Tampua Drainage cut of which it forms the outfall.

The Prachi river starting from about 2 miles north-west of village Kantapara travels for 30 miles in a due south-westerly course and drains the country between the Kundal and the Kusbhadra rivers. It has a small embankment on its left bank, commencing about 7 miles down from its head and just a little over 2 miles in length.

At the village of Charaigao in *pargaṇa* Antardha two small streams meet and below their junction the river is known as the Kadua; above, as far as village Naruson, one of the streams, is known as the Sylow Jore. The Kadua travels due south for the first 5 miles of its course, then turns in an easterly direction for 3 miles, and for the rest of its course to the Bay of Bengal, a distance of some 14 miles, it meanders in a south-easterly direction. It drains the country between the Prachi and Kusbhadra, and during high floods it receives a good deal of the spill water of the latter river, which overtops its left bank at Nimapara. In the rainy months the Kadua is tidal as far as Tecorpa, but in the dry season the tide reaches to Kantugram, 15 miles above the junction.

The Dhanua river has its rise between Balkati on the Bhargovi and Balipatna on the Kusbhadra about one and a half miles east of the former village. Its course is south-south-east for 16 miles, and then it turns due east and enters the Kusbhadra 8 miles further on, about 3 miles below the village of Gope. It drains the country between the above-mentioned rivers, and, since the keeping open of the Adlabad breach, it has a great deal more drainage to carry off than, in the silted up state of its bed, it is capable of.

The Rattanchira has its origin between Mokundpur village on the Trunk Road and Sainso on the Bhargovi. It travels due south practically for 13 miles, and then for another 13 miles runs south-westerly, when it joins the Bhargovi in the 49th mile. It drains the country between the Trunk Road and the Bhargovi crossing the road near Satyabadi It is embanked on its right bank for the last 8 miles of its course, but this embankment has long since been abandoned, and is full of breaches and in places obliterated. It is rather an important drainage channel, but its bed is silted up in many places and this obstruction requires removal. The Rattanchira has a branch called the Chingiria; it is about 3 miles in length and enters the former river 2 miles above its junction with the Bhargovi.

The Nuna rises about 2 miles north of the Gurudia Hills, and after skirting them runs a southerly course for 20 miles, when it turns due west at Sahupara, and falls into the Dya, 2 miles further on. It has a small branch connecting it with the Bhargovi. The mouth of the Nuna is free from silt and so is its bed for nearly its entire course.

CHAPTER XV.—DISCHARGE OF FLOOD WATER THROUGH THE CHANNELS OF THE MAHANADI.

In the present section I shall give a general summary of the available information regarding the maximum discharge capacities of the various river systems.

We may start with the undivided channel of the Mahanadi at Naraj. The first estimate of flood discharge was made by Lieutenant Harris after the great flood of 1855. His calculations were made before the construction of the Naraj weir, and the formula used was the Eytelwin formula :—

Velocity $= 0{\cdot}9\sqrt{(2\ f.\ d)}$, where "f" is the fall in feet per mile, and 'd is discharge.

Lieutenant Harris estimated the maximum discharge of the Mahanadi during the flood of 1855 to be 1,800,000 cubic feet per second, and during the great "Dusserah" flood of 1834 to be 1,850,000 cusecs. In 1855 the Lalbagh gauge reached 127·13 on the 29th July. Subtracting 44·5 (the correction for the zero of the gauge), the reduced height was 82·63 feet above mean sea level*. Applying the calibration correction, the corrected level at Lalbagh was 82·23 feet above mean sea level.

He had also calculated the maximum discharge at Banki (about 37 miles above Naraj), and believed it to be 2,117,385 cusecs.

In 1871, Col. Rundell, Chief Engineer, noted that "the volume of maximum flood assigned to the Mahanadi by Major Harris, viz., 1,800,000 feet per second, was too large, and that it was in all probability more nearly 1,500,000 cubic feet per second." (Inglis, page 23.)

After the great flood of 1872, Mr. R. H. Rhind made a detailed study of the discharging capacity of the Mahanadi and its branches. He was of opinion that Harris's calculations were unreliable for two reasons :—

(*a*) Harris had considered the fall per mile to be uniform at different gauge readings, and

(*b*) Harris did not make any allowances for spill water. Rhind himself came to the conclusion that the maximum volume of the 1872 flood was 1,503,367 cusecs, of the 1855 flood was 1,543,431 cusecs, while the flood of 1834 was slightly greater, so that the maximum flood volume at Naraj to be reckoned with should be taken as 1,571,000 cusecs.

Throughout his work, Rhind used the Missisipi formula given below in Table 46 :—

Table 46.—Missisipi formula.

If f = fall in feet per mile,

$$R = \frac{\text{area}}{\text{wetted perimeter} + \text{surface width}},$$

$$\text{Mean velocity} = \{(3{\cdot}0965\ R\sqrt{(f)})^{\frac{1}{2}} - 0{\cdot}0388\}^2.$$

3% was deducted when R is less than 5,

5% was deducted when R is less than 2.

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*The datum used in these surveys and in all subsequent surveys connected with the embankments and canals in Orissa Circle is the zero point of the gauge which had been for a considerable period established on the Katjuri revetment at the Lalbagh House. The value of this point was taken as 100. Subsequently levels were taken from the point to sea at False Point, and it was determined that the point (zero of the gauge) was 55·5 feet above mean sea level.

I found the following note in a handwritten Flood Report no. 844 of the 23rd October 1896, submitted by Mr. J. H. Clewes, Executive Engineer, Mahanadi Division :—

"In checking levels between the Bellevue gauge and Lalbagh gauge it is found that 126·00 on Bellevue which is R. L. 81·50 corresponds to 81·90 of Lalbagh—and therefore the latter is 0·40 too low and in the same way the Ghoosery Ghat gauge 0·10 too low."

Evidently the "zero" of Lalbagh gauge was placed 0·4 feet lower than that of the Bellevue gauge; hence the readings are 0·4 feet too high.

Mr. J. Shaw, Special Flood Officer, Orissa, in his letter of the 8th March, 1939, informs me that "actually the Lalbagh gauge has settled and the graduations are not exact and hence not reliable at present."

The fall 'f' between two points was taken as parabolic. The difficulty of determining 'f' with sufficient accuracy was recognised by Rhind. But as Rhind used this formula throughout his calculations, his figures may be taken as giving accurately at least the proportionate discharges through the various channels in the delta of Orissa.

Rhind used an approximate formula for dealing with the discharges through breaches. (For a fuller discussion a note by Mr. J. Shaw, Assistant Executive Engineer, dated 4th April, 1929, may be consulted.)

From his observations Rhind deduced a table showing the discharges for various gauge readings at Naraj above weir ranging between 65·00 feet and 93·36 feet. This table named after him, which has been used throughout the present volume, is reproduced here with interpolated values* for every 0·1 ft. from 85 feet to 91 feet (Tables 47-48).

It will be noticed that Harris's estimate for the 1855 flood was about 16% greater than that of Rhind.

Table 47.—Rhind's Table for the Discharge of the Mahanadi at Naraj.

Naraj gauge reading.	Discharge in cubic feet per second.	Naraj gauge reading.	Discharge in cubic feet per second.
Not known	1,570,622	79·00	279,659
93·36	1,543,431	78·00	239,854
92·10	1,503,637	77·00	196,723
92·00	1,498,615	76·00	154,582
91·00	1,349,310	75·00	113,241
90·00	1,212,396	74·00	86,315
89·00	1,140,975	73·00	59,094
88·00	1,016,102	72·00	38,845
87·00	898,591	71·00	30,582
86·00	788,319	70·00	21,599
85·00	685,270	69·00	15,101
84·00	591,312	68·00	6,559
83·00	502,782	67·00	3,291
82·00	399,186	66·00	2,146
81·00	337,148	65·00	1,670
80·00	322,901		

* These values were calculated in our laboratory by linear interpolation.

Table 48—Interplated values for the Discharge of the Mahanadi at Naraj.

Gauge heights at Naraj.	Discharge in cubic feet per second.	Gauge heights at Naraj.	Discharge in cubic feet per second.	Gauge heights at Naraj.	Discharge in cubic feet per second.
85·0	685,270	87·6	969,098	90·2	1,239,778
·1	695,575	·7	980,848	·3	1,253,469
·2	705,879	·8	992,600	·4	1,267,160
·3	716,185	·9	1,004,351	·5	1,280,851
·4	726,490	88·0	1,016,102	·6	1,294,542
·5	736,795	·1	1,028,589	·7	1,308,233
·6	747,099	·2	1,041,076	·8	1,321,924
·7	757,404	·3	1,053,563	·9	1,335,615
·8	767,709	·4	1,066,050	91·0	1,349,310
·9	778,014	·5	1,078,537	91·1	1,364,240
86·0	788,319	·6	1,091,024	·2	1,379,170
·1	799,346	·7	1,103,511	·3	1,394,100
·2	810,373	·8	1,115,998	·4	1,409,030
·3	821,401	·9	1,128,485	·5	1,423,960
·4	832,428	89·0	1,140,975	·6	1,438,890
·5	843,455	·1	1,148,117	·7	1,453,820
·6	854,482	·2	1,155,259	·8	1,468,750
·7	865,509	·3	1,162,401	·9	1,483,680
·8	876,537	·4	1,169,543	92·0	1,498,615
·9	887,564	·5	1,176,685	92·1	1,503,637
87·0	898,591	·6	1,183,827	93·36	1,543,431
·1	910,342	·7	1,190,969	Not known	1,570,622
·2	922,093	·8	1,198,111		
·3	933,844	·9	1,205,253		
87·4	945,595	90·0	1,212,396		
87·5	957,346	90·1	1,226,087		

Two subsequent estimates of the discharge at Naraj are available, that of Mr. G. Stevenson in 1921, and of Rai Sahib Nibaran Chandra Ganguli in 1923. We have the following figures.

Table 49.—Discharge of Mahanadi.

Naraj Gauge Reading in feet.	Discharge in cusecs.		
	Rhind.	Stevenson.	Ganguli.
87·8	992,089	...	980,531
87·0	898,591	977,293	...
86·0	788,319	776,087	...

At 86·0 feet Stevenson's estimate falls short by 12,232 cusecs or by about 1·5 per cent. At 87 feet the discrepancy is much greater.[*] Rhind's figure was obtained approximately. Moreover, it is known that Stevenson was unsuccessful in obtaining correct values for his velocities.

At 87·8 feet the difference between Rhind's and Ganguli's estimates is 11,558 cusecs or less than 1·2 per cent.

We find, therefore, that two recent independent estimates of the discharge agree with Rhind's estimates within about 1 per cent or 1·5 per cent. This cannot be called unsatisfactory. We conclude that Rhind's estimate of about 1,570,000 cusecs as the maximum discharge at Naraj may be accepted as fairly reliable.

* Mr. J Shaw, Special Flood Office r, in his letter of the 8th March 1938 informed me that Stevenson's estimate of discharge at 87·0 feet was obtained "by collection of branch discharges."

It is worth noting here that the Mahanadi shows a great contrast between its monsoon and hot weather discharges. In May, the discharge in the Mahanadi has been known to fall to a few hundred cusecs, for example in 1892 it fell to 204 cusecs at a time.

The Relative Discharge in the Mahanadi and the Katjuri.

As the most important factor in connexion with floods in the Puri district is the volume of water passing down the Katjuri and the Koakhye, it has engaged the attention of all engineers since very early times.

Col. Rundall, Chief Engineer, in his note dated 28th January, 1871, stated (Inglis, page 23) :—" In 1856, when Col. Harris made his first report, the proportion (of the volumes in Mahanadi and Katjuri respectively) was 5 : 4. In 1870, after Naraj weir and dividing embankments were constructed by the late East India Irrigation and Canal Company, the proportion was 5 : 2·3, vide Chief Engineer's progress report for 1869-70 ". Mr. Inglis who looked up this progress report commented that there was nothing to show how the figures were arrived at, and was of opinion that there was " no doubt but that they were incorrect as applied to high floods. They were probably based on some observation of low floods, as regards which the weir has a greater effect. "

In a printed note of Mr. R. H. Rhind, dated the 3rd October, 1881, I find it stated that the following figures were obtained for the flood of 1855 with Captain Harris's data but using the Missisipi formula.

Table 50.—Flood Discharge in 1855.

Name of river.	Value of f.	Total area of cross section.	Perimeter including surface width.	Value of R in feet.	Mean velocity in feet per second.	Discharge cusecs.	Number.
1	2	3	4	5	6	7	8
Mahanadi at Cuttack ...	1·84	145,687	17,030	8·554	5·8024	845,334	g—h
Katjuri at Lalbagh ...	1·76	106,356	11,253	9·451	3·0388	642,263	c—d
Katjuri at Khannuggur	2·20	61,131	5,945	10·282	6·6703	407,761	i—k
Koakhye at head ...	1·70	39,500	4,806	8·218	5·5753	220,224	e—f

Adding the discharges for the Mahanadi at Cuttack and the Katjuri at Lalbagh, we get a total volume of 1,487,597 cusecs at Naraj, which gives about 57 per cent for Mahanadi and 43 per cent for Katjuri.

Rhind mentioned, however, that section (c—d) was not complete as this did not include the spill. After making a correction for the spill, he came to the conclusion " that at the time when the great flood of 1855 occurred, the discharges of the Katjuri and Mahanadi were to one another as 0·802 to 1", or in the proportion of 4 : 5 which is the figure quoted by Col. Rundall.

For the flood of 1872, Rhind had estimated that the total volume passing over the Mahanadi and Beropa weirs was 721,875 cusecs and the volume entering Katjuri was 781,702. The actual proportions were, therefore, 52 per cent and 48 per cent for Katjuri and Mahanadi respectively. In the volume entering the Katjuri is included, however, the discharge estimated at 59,010 cusecs which passed through breaches at Moondilow which were situated above Naraj. Further, about 63,951 cusecs were estimated to have passed from the Katjuri to the Mahanadi through gaps in the dividing embankments. Allowing for these two quantities, the actual volumes would be 722,752 and 721,875 cusecs for the Katjuri and the Mahanadi respectively, which gives practically equal proportions (1·098 : 1).

The Naraj weir was, however, seriously injured in 1872. Rhind tried to make allowances for the damage to the weir, and finally came to the conclusion that if the weir had been uninjured the volumes in the Katjuri and the

Mahanadi would have been in the proportion of 1·001 to 1. He was, therefore of opinion that, at the time of writing his note (i.e., in 1881), "the effect of the Naraj weir would be to divide the flood, as nearly as possible, equally between the Mahanadi and Katjuri rivers".

By a comparison of the discharge in the Mahanadi, Rhind also concluded that "in the period that elapsed between the occurrence of the floods of 1855 and 1872, the carrying capacity of the Mahanadi branch had deteriorated to the extent of 79,814 cubic feet per second, or nearly 10 per cent of its total volume." He pointed out that "any deterioration of carrying capacity of the Mahanadi branch must be detrimental to the Puri district, as it leads to an increase in the quantity of water thrown into the Katjuri and its branches, so that, as the construction of the Naraj weir and the dividing embankment have now permanently fixed the width of the head of the Katjuri, and thus prevented any further diminution in the discharge of the Mahanadi branch, the Puri district, must be benefited by these works, even although their construction has not affected any reduction in the total quantity of water which enters the Katjuri river".

According to Shaw, Stevenson found the volumes in the Mahanadi and the Katjuri to be in the proportion 56 per cent and 44 per cent with the gauge at 86 feet, and 54 per cent and 46 per cent with the gauge at 87 feet. Ganguli in 1923 found the proportions to be 52 per cent and 48 per cent with the gauge at 87·8 feet.

Unfortunately no recent observations are available for high floods, of about 90 feet or above. But we can approach the problem indirectly in the following way. Table 51 shows the average difference of gauge readings at Bellevue on the Katjuri and Jobra (above weir) on the Mahanadi for three different periods, namely 1866—76, 1877—96 and 1897—1920. We know that the river beds near Naraj did not change appreciably during the last 60 years. The average difference in level will, therefore, give an approximate measure of the relative proportion of the flood water carried off by the two branches. If the average difference remained constant we would be justified in inferring that the relative flood discharges were also steady.

Table 51.—Comparison of Gauge Heights.

Years of flood.	Approximate reading at Naraj.	Difference in gauge readings : Bellevue-Jobra.		
		Average difference.	Highest difference.	Lowest difference.
1	2	3	4	5
1866, 1870, 1872, 1874, 1876 ...	75 ft.	—4·95	—6·53	—3·30
	80 "	3·16	—7·02	2·50
	85 "	4·21	5·05	3·20
	90 "	6·59	7·38	5·75
1877, 1878, 1879, 1880, 1889, 1892, 1895, 1896.	75 ft.	—6·09	—8·20	—0·90
	80 "	2·73	4·35	0·90
	85 "	4·83	6·00	3·95
	90 "	6·73	7·90	5·90
1900, 1910, 1912, 1914; 1916, 1918, 1920.	75 ft.	—6·00	—8·10	—2·70
	80 "	0·30	2·15	—3·50
	85 "	5·03	7·10	2·20
	90 "	6·39	6·96	5·20