COTE D'IVOIRE

Area: 322,500 km^2

Population: 9.2 million (United Nations estimate, 1983)

I. BACKGROUND

Climate

Côte d'Ivoire is a coastal State on the Gulf of Guinea with a seaboard of about 500 km between Cape Palmas and Cape Three Points. The country is mostly flat with local relief; it is more hilly towards the west, with some points above 500 m, the highest being Mt. Tonkoui (1,189 m) and Mt. Momi.

In the south the terrain is "humpy". It has many low-lying areas and a few isolated or grouped domes, such as Mt. Niénokoué (623 m) in the forest zone and Mt. Niangbo (643 m) in the savannah.

From south to north, at about 600 km from the coast, come the following vegetation zones, with decreasing rainfall: the tropical forest, the wet wooded savannah and the dry wooded savannah. The forest area forms a V in which higher ground towards the west and east encloses an area of savannah in the middle.

The maximum average annual levels of precipitation are in the order of 2,400 mm in the coastal zone, with a minimum of 1,200 mm in the north-east. The rainfall is fairly evenly distributed in time in the south; towards the north it tends to be concentrated in a short rainy season from July to September.

The country has three climatic zones:

- The equatorial type in the coastal zone where the temperature ranges between 21° C and 33° C, with a very high humidity rate of over 80 per cent and abundant rainfall, especially in the west - with 2 m a year at Tabou.

- The tropical type in the forest zone and the south of the savannah zone, with wider temperature ranges (14° C to 39° C), humidity rates of up to 70 per cent and moderate rainfall (1,000 to 1,400 mm). This part of the country has two dry seasons alternating with two wet ones. The "big" rainy season is the longest (beginning in December) and the most intense (with the heaviest rainfall in June); the "small" rainy season lasts about two months, from August to October.

- Lastly, the Sudanese type in the savannah zone - except for the southern part. Here there is a marked contrast between the dry and rainy seasons. The annual rainfall declines from a maximum of 1,000 mm (Odienné, Dimbokro) to 400 mm in the Dabakala region. The monthly temperature range is 7° C in the dry season and 5° C in the rainy season. The north has a single rainy season with the maximum in August and a dry season of six to eight months marked by the Harmattan, a strong wind which reaches its maximum force in January, when the average temperature range is about 18° C.

Monthly rainfall distribution

(mm)

	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL
Transitional equatorial type:													
ABIDJAN	29	42	115	155	355	595	226	30	55	189	187	109	2,087
TABOU	53	48	88	134	416	533	156	83	221	203	195	145	2,275
SASSANDRA	23	24	74	104	295	511	157	23	48	100	142	87	1,588
Moderated transitional equatorial type:													
DIMBOKRO	16	46	123	151	182	184	95	60	138	130	63	19	1,207
BONDOUKOU	15	43	74	131	169	166	80	64	186	177	51	17	1,173
SOURRE	33	56	139	166	173	245	107	100	220	191	120	54	1,604
Transitional tropical type:													
FERKESSEDOUGOU	5	19	47	91	140	158	186	299	251	112	32	110	1,450
ODIENNE	3	14	39	76	118	176	289	383	292	164	54	10	1,618
Mountainous type:													
DANANE	24	68	127	171	180	305	347	347	408	217	75	35	2,304
MAN	16	57	116	159	159	214	207	260	320	170	56	22	1,597

The total annual evaporation, measured in a Colorado pan, increases from the forest zone in the south (1,000 mm) to the savannah in the north (2,000 mm). It is strongly influenced by altitude and vegetation.

II. HYDROLOGY

River system

Côte d'Ivoire has abundant surface water, with four main rivers: Cavally, Sassandra, Bandama and Comoé; several small coastal rivers: Tabou, San-Pédro, Nionniourou, Bonbo, Agnéby, Mé and Bia; and in the north some tributaries of the Niger: Baouié, Bagoé, Kouroukellé, Dégou, Kankélaba; and tributaries of the Black Volta: Koulda and Banlou.

The Cavally rises in Guinea and is almost 700 km long. The Taté station, 60 km above the river's mouth, is downstream of a basin of 28,000 km^2. The Sassandra also comes from Guinea; it is 650 km long and has a basin of 75,000 km^2. The Bandama rises at Boundiali in Côte d'Ivoire; it is 1,050 km long, with a basin of 95,000 km^2.

The Comoé has its source in Burkina Faso. It is 1,160 km long and its basin has an area of 78,000 km^2.

The main rivers flow north to south into the Atlantic Ocean. The coastal rivers do likewise and, with exception of the Bia, they have their sources in Côte d'Ivoire, but some of them discharge into lagoons just before the coast. The tributaries of the Niger, on the other hand, rise in Côte d'Ivoire but flow northwards towards Mali.

The rate of flow of the country's watercourses is determined mainly by the rainfall, the influence of the individual characteristics of the basins, such as relief, vegetation and soil type, being fairly limited.

Hydrological systems

The country has four types of hydrological system:

- The "transitional tropical" system

The influence of this system is felt mainly in the northern part of the country beyond the Ferkessedougou-Touba line, i.e. in a region of savannah which is fairly well wooded - depending on the annual rainfall. In the important watercourses of the Bagoé and the Haut-Bandama this system produces a single crest in August, September and October, followed by a rapid drop in the water level in November and December.

- The "transitional equatorial" system

This system is found in the southern part of the country beyond a line through Abengourou, Toumodi and Soubré, i.e. the forest zone. The double crests of the Agnéby and the Bia are typical, with:

- A first high-water period in June-July;

- A second high-water period in October-November;

- A low-water period in August-September followed by an even lower one from December to March.

- The "moderated/transitional equatorial" system

This system is found in the central part of the country, which is covered by savannah except for a few places in Baoule where the forest predominates.

The Nzi at Ziénoa and the Kan at Tiebissou are fairly typical of this system with average water levels in May and November and two moderate crests a year. This type thus lies between the two previous ones.

- The "mountainous" system

This system is found in the mountainous region in the west of the country (Man, Danané, Toulépleu, Taï). The rainfall is abundant, ranging from 1,600 to 2,500 mm a year. The vegetation is of the forest type.

The high waters occur from April to October with the maximum in September; the low-water period is in January-February. The specific rate of flow is fairly high at this time.

It must finally be noted that most of the big watercourses in Côte d'Ivoire have mixed hydrological systems owing to the large area of their catchment basins.

Hydroelectric potential

Since the average fall of the various watercourses is fairly gentle (less than 1m/km), their hydroelectric potential is generally moderate; but it is of some interest because of the waterfalls which occur. Some sites are fairly suitable for hydroelectric development and a few of them have been exploited: the dams on the Bia (Ayamé I and Ayamé II), on the Bandama (Kossou and Taabo), and on the Sassandra at Buyo.

An important hydroelectric project is to be built on the Sassandra at Soubré. Some other sites are of interest: the section of rapids on the Cavally between Taï and Grabo where the fall is 1m/km; on the Comoé above Malamalasso where there are several kilometres of rapids with a fall of 30 to 40 mm; and between Attakro and Aniassué.

It must be noted that with the construction of the Soubré dam Côte d'Ivoire's electricity requirements will be fully satisfied.

Description of dams in Côte d'Ivoire

	Elevation	Capacity (billions of m^3)	Output (GWH/year)
AYAME I	90.5	1,000	80
AYAME II	69	70	120
KOSSOU	206	28,000	80
TAABO	124	630	960
BUYO	200	8,000	900

III. GEOLOGY

Most of the country lies in the zone of Precambrian crystalline basement rock called the "West African shield". The remaining part is the coastal sedimentary basin which covers about 9,500 km^2, of which 1,700 km^2 is lakes and lagoons.

The oldest basement formations include gneiss, granites and migmatites. This is rock of "Prebirrimian" Lower Precambrian age. These formations of crystalline rocks are most common in the west of the country (migmatites are found everywhere). The metamorphic "Birrimian" formations of Middle and Upper Precambrian age are mostly of sedimentary origin. They are generally schistic rocks with sandstones and conglomerates in places. These metamorphic formations with granite intrusions are accompanied in places by volcano-sedimentary formations of tuffs, breccias, green rocks and schists (Proterozoic). They form bands running north-north-east/south-south-west, heavily folded and sometimes raised to the vertical.

The coastal sediments form a wedge which narrows towards the north where it terminates at the edge of the basement rock less than 35 km from the coast.

The coastal sedimentary basin is crossed from west to east by a fault with a displacement of several thousand metres separating two distinct zones: one to the north where the sedimentary layer is not usually more than 300 m thick, and to the south a deep basin where the bedrock sinks to 4,000 or 5,000 m, vertical to the coast, as has been demonstrated by oil boreholes which penetrated Tertiary and Cretaceous formations (Upper and Middle) of marine facies.

The coastal basin has the following morphological units:

- The lagoons on the site of an ancient hydrographic system, now submerged, with very thick mud deposits on their beds.

- The "high plateaus" north of the lagoons with altitudes of 40 to 100 m. They are composed of detrital continental formations of Miocene-Pliocene and probably Upper Cretaceous age ("terminal continental"). The terimanl continental formation rests directly on the basement rock. In places it overlies a thin stratum of Paleocene (mostly limestone) or Maestrichtian (sand-sandstone) formations. It consists mainly of coarse sands in its lower and sand-sandstone clays in its upper part.

- The "low plateaus" south of the lagoons with altitudes of 8 to 12 m. They consist of Quaternary formations with a series of marine clays interbedded with sands (10 m) overlain by a sand-clay continental formation (20 m).

- Sand bars run along the shore, 2 to 6 m high and a few dozen metres thick.

IV. HYDROGEOLOGY

Aquifers

- Crystalline basement rock

The relatively detailed study of the hydrogeological characteristics of the zone of crystalline basement rock in Côte d'Ivoire began with the launching in 1975 of a programme to install 9,000 village water points (by 1985 there were 11,500). Since the end of 1977 about 2,000 water points have been installed, leading to the following conclusions:

Granitogneiss aquifers

In the quartz-grained granitogneiss rocks the ground water is located in the sands of the alteration zone, 20 to 30m thick on average but sometimes 60 m, and in the fractures of the bedrock. The transmissivity of the sands in the water-bearing part overlying the bedrock is in the order of 10^{-4} to 10^{-5} m^2/s.

Generally speaking, the most sandy, even gravelly, strata, at the level of which are found the largest volumes of water, are located at the base of the alteration, and this depth must be reached by the wells and boreholes.

Sand-clay layers are usually found at the surface. The crystalline bedrock suboutcrops in only a few places: Séguéla, Mankono, Touba.

The annual fluctuations in the piezometric level or "aquifer downdraw" varies from a few metres to 6 to 10 m. The lowest values are found close to depressed areas.

The fissuration of the bedrock is discernible from aerial photographs and by examination of the geological features determined in the field: lines of backwaters and watercourses, configuration of laterite cuirasses, and distribution and type of vegetation. In the schistic rocks of the Birrimian system the alteration zone is mainly argillaceous and barren. The ground water is found in the quartz seams or seams of volcanic matter.

Birrimian aquifers

The Birrimian rocks have been identified mainly from data collected on the sites of the 2,000 boreholes in the "cocoa belt". In these formations there is a danger that the installations may become blocked by fine particles from the alteration stratum, which is mostly argillaceous. There is little ground water available at depths beyond 30 m in the substratum. The incidence of water flows is inversely proportional to the thickness of the argillaceous alteration stratum. They decline rapidly when this thickness exceeds 40 m and are virtually non-existent beyond 60 m.

The thickness of the alteration stratum itself depends on the nature of the underlying Birrimian rocks. It attains an average of 45 m in schists but does not exceed 30 m when the schists are interbedded with sandstone or quartz. These hard strata, which seem to make the formation more resistant to erosion, are the most suitable for ground-water exploitation. Finally, the presence of detrital or volcano-detrital intercalations usually coincides with the most productive sections.

It is agreed that the fissures in the substratum contain a widespread aquifer.

In most cases, wells drilled in sands are between 15-20 m and 35-40 m deep, and the water is usually found at an average depth of 10-20 m below the level of the soil. The yields are usually in the order of 1 to 3 m^3/h per metre of downdraw.

- Coastal basin

This basin covers 6,000 km^2 of terminal continental formations, of which 500 km^2 on the edge of the bedrock in the north is barren ("dry wedge") and 1,700 km^2 consists of coastal Quaternary formations (low plateaus and sand bars). In their upper part these latter formations contain an aquifer which can supply fresh water in amounts ranging from a few to several dozen m^3/h, with very good discharges in places in coarse sands: for example, a borehole at Treichville discharges 310 m^3/h with a downdraw of 3.1 m (the aquifer overlies a clay stratum which protects it from intrusion by the underlying salt water). The salt wedge has been identified at depth in the sands at Vridi.

- Widespread aquifers

The only widespread aquifers are the one in the terminal continental formation which covers no more than three per cent of the territory (most it is divided into small discontinuous aquifers) and the one in the coastal

Quaternary formations (plateaus and sand bars). This ground water is stored in the sands of the upper part and exploited by wells and small boreholes which can deliver considerable amounts of fresh water. The horizons of coarse, very permeable sand found in some places are extremely productive; one of the Treichville boreholes, for example (southern quarter of Abidjan - low plateaus), delivers 210 m^3/h with a drawdown of 3.1 m. At this point the lower clay stratum protects the aquifer against upward intrusion by the underlying salt water.

In contrast, in another borehole in the Vridi peninsula (sand bar) a salt wedge has been identified at depth, with salinity ranging from 100 mg/l to 25 g/l in a homogeneous sand series. This aquifer is recharged by direct infiltration of rainwater and rests in density equilibrium on the salt water or on an impermeable substratum; it is vulnerable to domestic, industrial and saline pollution. This aquifer is exploited at Vridi at present to supplement the supply to certain industries. The terminal continental formation has been more fully studied in the central part of the basin than at its two extremities.

A study of the water resources available to supply the town of Abidjan has provided information about the hydraulic characteristics of the central part of the aquifer. The transmissivity is low to average in the north of the basin: $T = 1$ to 4×10^{-3} m^2/s. It is high to very high in the Abidjan area: $T = 10^{-2}$ to 3×10^{-1} m^2/s. The storage co-efficient 'S' has been determined at two points in the area; the values are S = 14 per cent and S = 9 per cent.

Water quality

The terminal continental water has a low mineral content, with the dry residue usually between 40 and 150 mg/l; it is always very aggressive, with pH close to 4.5, a CO_2 content of 90 mg/l, 1 to 4 mg of Ca + Mg, 3 to 6 mg/l of HCO_3, 7 to 14 mg/l of Cl and 10 mg/l of SiO_2.

The water of the bedrock has a moderate mineral content, with the dry residue of a number of samples analysed ranging between 250 and 500 mg/l, or even up to 650 mg/l; the pH of the fissure water is generally close to 7 (neutral pH).

The recharge conditions are excellent, with effective infiltration of 50 per cent of the rainfall, i.e. 20 m^3/s or a water layer of 0.35 metres or 640 million m^3, an amount close to the drawoff, i.e. 10 million m^3/year.

The boreholes in the catchment area exploited for water supplies have produced the following basic data:

Transmissivity: low in the north: 1 to 4.10^{-3} m^2/s
high at Abidjan: 10^{-2} to 3.10^{-1} m^2/s

Storage co-efficient: 10 to 15 per cent.

V. GROUND-WATER EXPLOITATION

The Village Water Supply Service of the Water Department of the Ministry of Public Works, Construction, Posts and Telecommunications is the government body responsible for drawing up the national water programme. It plans, implements and supervises this programme.

To implement the vast drinking water supply programme adopted by the Government, the technical services concerned have opted for the exploitation of ground water by means of wells and boreholes. The construction of these works has produced a picture of the water-bearing capacities of the main geological units.

The various aquifers of the basement rock are hydrogeologically similar. They are composed of fractures in the granitic or metamorphic rocks which are fed with water contained in the overlying alterites. The fracturation is similar in the crystalline rocks and there is very little variation in the hydraulic behaviour.

In granitogneiss formations 77 per cent of the boreholes have proved positive, with an average thickness of alterites of about 20 m. In the schistic formations, where the average thickness of the alterites is about 30 m, the success rate has been 85 per cent. The air-lift discharge is 2 m^3/h in the granitogneiss formations and 3 m^3/h in the schistic formations. It must be pointed out that the sinking of large-diameter productive wells is difficult in the schistic formations although the alterations are thicker; this is due to the large quantities of clay.

The coastal sedimentary basin has the best aquifer system; the success rate is 100 per cent, except when technical difficulties are encountered. It must be noted, however, that the aquifers are very deep on the Bongua plateau (piezometric level between 70 and 80 m).

Thus more than 12,000 water points were installed between 1975 and 1984. These are mainly wells drilled either by down-the-hole hammer or by rotary drilling, sometimes by auger. The works are undertaken by specialist enterprises after international tender. As stated above, the works are carried out under the supervision of the Water Department, which is also responsible for drilling studies.

Some 11,500 water points were installed between 1975 and 1984 in rural areas. Côte d'Ivoire has a national drilling company - FOREXI. Small-diameter wells are drilled in hard rocks and thick formations and large-diameter (1 m) in unconsolidated formations less than 25 m deep. In this case, excavator rigs of the Calweld type are used.

In the cocoa belt and other "Birrimian" areas small-diameter wells are usually drilled by the down-the-hole hammer method powered by compressed air or by the tricone rotary method. It is accepted that at least three exploration holes must be drilled to produce two exploitable wells; of a series of almost 500 drillings throughout the country, nearly 85 per cent have proved positive.

The terminal continental formation is exploited by many water points in the central part of the country; but in some places the water points are far apart. The thickness of this formation is irregular owing to the fairly contrasted topography of the top of the crystalline substratum.

The water of the terminal continental formation is not very mineralized, with a dry residue ranging from 50 to 150 mg/l. It is aggressive (pH = 4 to 5). The exploitation at Abidjan draws off about 50 million m^3/year (130,000 m^3/day). Almost as much is drawn off from the rest of the basin. As an example, according to some estimates the requirements of the metropolitan area will be in the order of 250 to 300 million m^3 in 2000.

The exploitable reserves are about seven billion m^3. This figure is close to that of the renewable resources and shows that the present rate of drawoff is far lower than the aquifer's capacity; and the aquifer also has a large discharge through springs, especially in the Banco ravine west of Abidjan.

The Abidjan boreholes discharge 150 to 250 m^3/h with a drawdown of 5 to 15 m, the level of the aquifer when stationary being 30 to 50 m, with a well depth of 35 to 65 m.

Some wells in the terminal continental formation are more than 100-400 m deep.

VI. CONCLUSIONS

The drilling of so many wells and boreholes in Côte d'Ivoire since 1974 has provided a better picture of the ground-water potential both in the coastal sedimentary basin and in the areas of crystalline basement rock, where the depth of the base has also been determined, together with the thickness of the alterations in some places and the probable discharges; but much still remains to be done with respect to the hydrology of the ground water. This is particularly true of the recharge of the aquifers in the crystalline bedrock, i.e. the renewal of the resources which determines the life of the installations in terms of the rate of exploitation. Progress must also be made in the determination of the slope of the fractures detected by geophysical methods, with a view to better exploitation of their water.

However, it can be concluded from the present state of knowledge that Côte d'Ivoire as a whole has sufficient ground water, in both quantity and quality, to meet the needs of its rural population and much of the urban population, as well as those of industry.

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