Hydrogeology of the Kabul Basin
Part I:
Geology, aquifer characteristics, climate and hydrography

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SUMMARY

The Kabul Basin is a plateau surrounded by mountains located in the eastern central part of the country, and is the site of the Afghan capital. The Kabul Basin covers an area of around 1600 km^2 and is divided up into three sub-basins. Basin fill mainly comprises Tertiary and Quaternary terrestrial and lacustrine sediments, primarily consisting of marls and interbedded sand and gravel horizons.

The climate in Kabul is semi-arid and strongly continental. The data made available for this work covering a period from 1957 to 1977 reveal major fluctuations in the level of precipitation and in the temperatures. The average annual precipitation during the observation period was 330 mm, whilst the annual average temperature varies between 10 °C to 13 °C.

Three rivers flow through the Kabul Basin. The Paghman river enters the Kabul Basin from the west where it becomes a tributary of the Kabul river. The Logar river enters the Kabul Basin from the south where it also discharges into the Kabul river. The Kabul river is part of the Indus catchment. The total catchment area of the Kabul river is around 12,888 km^2.

Almost all of the precipitation in the region occurs during the winter months. This precipitation is stored in the mountains in the form of snow from and recharges the rivers during the snow melts. This water then recharges the aquifers in the Kabul Basin. Rivers run dry when the snow has completely thawed. No continuous water flow is currently observed in the rivers flowing through the Kabul Basin.

The actual evapo-transpiration was determined as part of the project work with the aim of estimating the potential groundwater recharge from precipitation. The evapo-transpiration changes in line with the precipitation. However, the evaporation is always slightly smaller than the amount of precipitation - with a few exceptions. The average difference between precipitation and evapo-transpiration during the observation period was 32 mm/year. Because this figure does not take into consideration either the losses through surface runoff or the precipitation which fell in the form of snow, one can assume that no groundwater recharge occurred directly from precipitation during the observation period, and that this situation probably continues at the present day, particularly because no precipitation has been recorded during the last six years.

The aquifers in the Kabul Basin consist mainly of sand and gravel which becomes slightly cemented, particularly with increasing depth. They extend laterally from both sides of the river courses and can be classified as permeable to very permeable in accordance with DIN 18 130.

The Logar aquifer extends over around 30 km^2 and has an average thickness of 50 m, making it the largest aquifer in the Kabul Basin. It also has the highest permeability coefficients. However, groundwater flow is lower than the other aquifers. This is probably attributable to the interbedded loam layers which are thickest in this aquifer. The groundwater reserves of 70 million m^3 are also smaller than the groundwater reserves in the Paghman aquifer which has a calculated storage volume of 81 million m^3.

Groundwater recharge is at a maximum in the Logar valley at 2.16 m^3/s - it should, however, be borne in mind that the catchment area of the Logar is much larger than the catchment areas of the Kabul and Paghman rivers. Infiltration from the river bed is the predominant means of groundwater recharge for all aquifers. Infiltration from precipitation only accounts for a minor percentage due to the low precipitation and high evapo-transpiration, as well as the clay layer covering the surface.

The Kabul aquifer also has permeability coefficients ranging from permeable to very permeable. This aquifer has the largest amount of groundwater flow, although no figures are available on the groundwater reserves. Groundwater regeneration is given as 0.82 m^3/s in this aquifer, which is much lower than in the Logar aquifer.

The Paghman aquifer is classified as permeable in accordance with DIN 18 130 and has the lowest permeability. The groundwater recharge of 0.48 m^3/s is also the smallest of the three aquifers.

The data used to evaluate the hydrogeology of the Kabul Basin was primarily generated during the 1960s. It is difficult to use these results to assess the present day conditions in the Kabul Basin. Groundwater recharge was very low in the period covered by the available data.

It is assumed that because no precipitation was recorded during the last six years, that there was virtually no regeneration of the groundwater during this period. The groundwater table has also presumably dropped considerably, as clearly demonstrated in the BGR Project house. The depth of the water table here in 1965 was around 2.5 m, but now lies at a depth of 9 m. It is therefore becoming increasingly difficult to provide the inhabitants with adequate supplies of clean drinking water, particularly because the quality of the groundwater is significantly affected by sewage in the vicinity of the build-up areas.

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1. Introduction

1.1 Geography of Afghanistan

Figure 1.1: Political map of Afghanistan (www.nationalgeographic.com)

Figure 1.2: Map of Afghanistan (www.infoplease.com)

Afghanistan is a land-locked country (Figs. 1.1 and 1.2) lying in the south of Asia between Iran and Pakistan. It extends from the 61st to the 74th longitude east and from the 29th to the 38th latitude north. The lowest point in the country is at Amudarja at + 258 m ASL, and the highest point is at Nowshak at + 7485 m ASL.

With an area of 647,500 km^2, Afghanistan is almost twice as large as Germany. It is one of the poorest countries in the world. The borders of the country have a total length of 5529 km, of which 76 km with China, 936 km with Iran, 2430 km with Pakistan, 1206 km with Tajikistan, 744 km with Turkmenistan, and 137 km with Uzbekistan.

Afghanistan is dominated by high ranges of mountains. Several mountain ranges extend eastwards from the Pamir and Hindukusch mountain chains in the south-east. A few plateaux lie on the Amudarja in the north of the country. Some desert-like basins occur in the south-western part of the country along the borders with Iran and Pakistan.

Afghanistan has been divided into 34 provinces since April 13, 2004 and has around 28 million inhabitants according to an estimate made in 2002 (www.bmz.de). It is relatively sparsely populated with around 38 inhabitants per km^2. Around 80 % of the inhabitants live in rural areas. Afghanistan has a relatively high proportion of illiterate inhabitants at 64 % (www.odci.gov). More than a third of the population has fled during recent decades. Around 3 million Afghans found refuge in Pakistan, around 3 million in Iran. It is estimated that 1.4 million Afghans still live in Pakistan and that around 2 million still live in Iran. There is also a major migration within the country to the major cities such as Kabul (Fig. 1.5).

Kabul is the capital of Afghanistan as well as being the largest city in the country with about 3.0 million inhabitants.

The main source of income for the people of Afghanistan is arable farming and livestock farming. However, only 15 % of the land surface is suitable for cereal cultivation and only 6 % is actually used (www.afghanic.de). Another difficulty is the dependence on unreliable water resources which relies amongst other things on the irregular winter and spring rainfall. The gross domestic product of the Afghan population is around 750 US$ per capita per year (www.drmartinus.de).

Afghanistan has many natural resources including large deposits of salt, chrome, iron ore, gold, fluorspar, talc, copper, and lapis lazuli. However, the exploitation of these deposits is rarely worthwhile because of the inhospitable terrain and inadequate transport routes. The most important resource which was exploited for the first time in 1967 is natural gas. Alongside Myanmar, Afghanistan is also the largest grower of opium in the world (www.FAO.org).

1.2 Climate of Afghanistan

Lying as it does in the middle of an arid belt, the Afghan climate is arid to semi-arid with major daytime and night-time temperature fluctuations. The winters are characterised by low temperatures of down to - 10 °C and moderate precipitation. The summers are dominated by high temperatures of up to 50 °C in part combined with drought conditions (Fig. 1.3 and Fig. 1.4). The temperature at the ground surface fluctuates in summer by more than 50 °C during one day whilst temperature fluctuations of up to 30 °C are possible during the winter (DIETMAR 1976). The annual precipitation ranges from less than 50 mm/year in the south-west of Afghanistan to 1000 mm/year in the north-eastern highland.

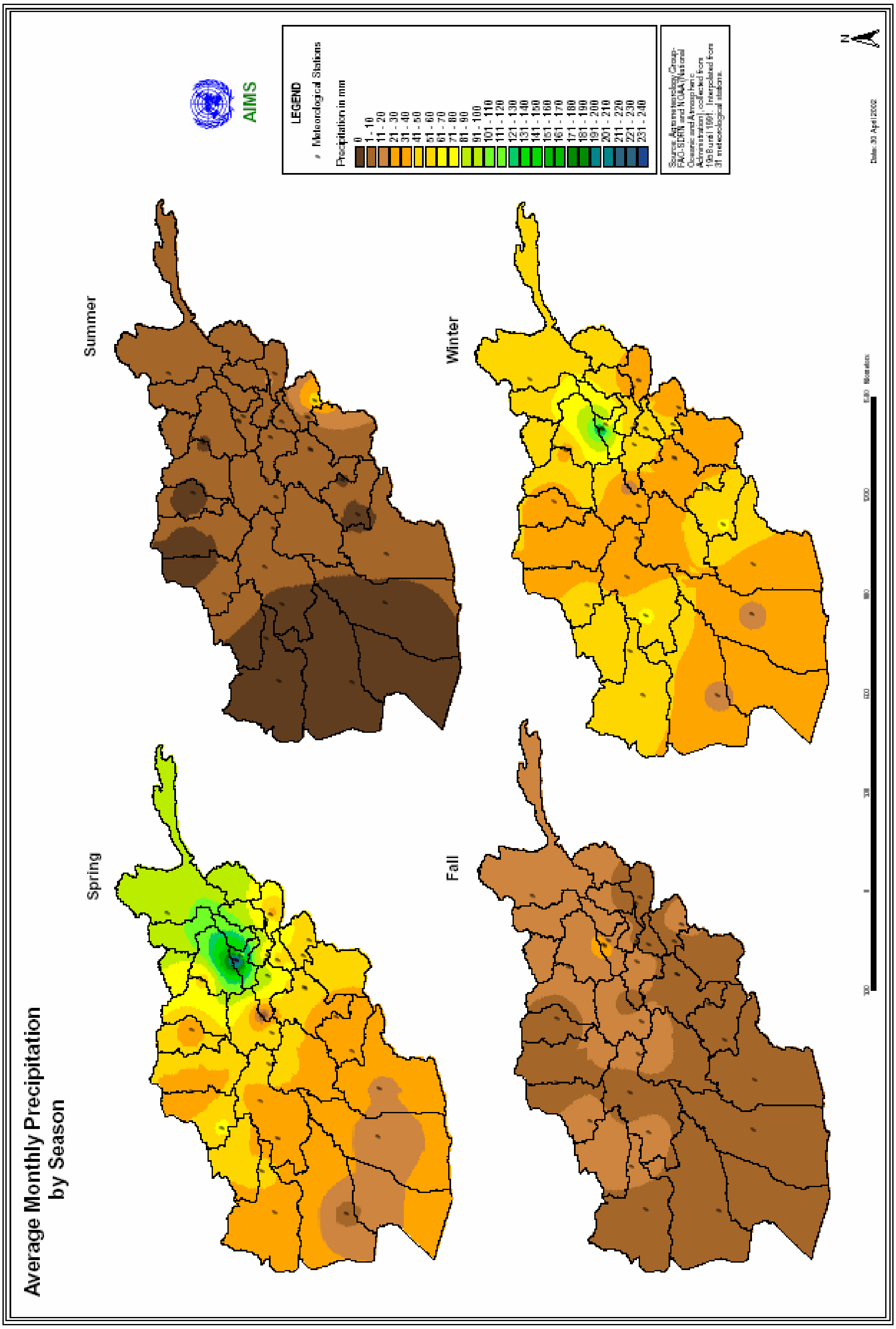


Fig. 1.3: Precipitation in Afghanistan (www.aims.org.af)

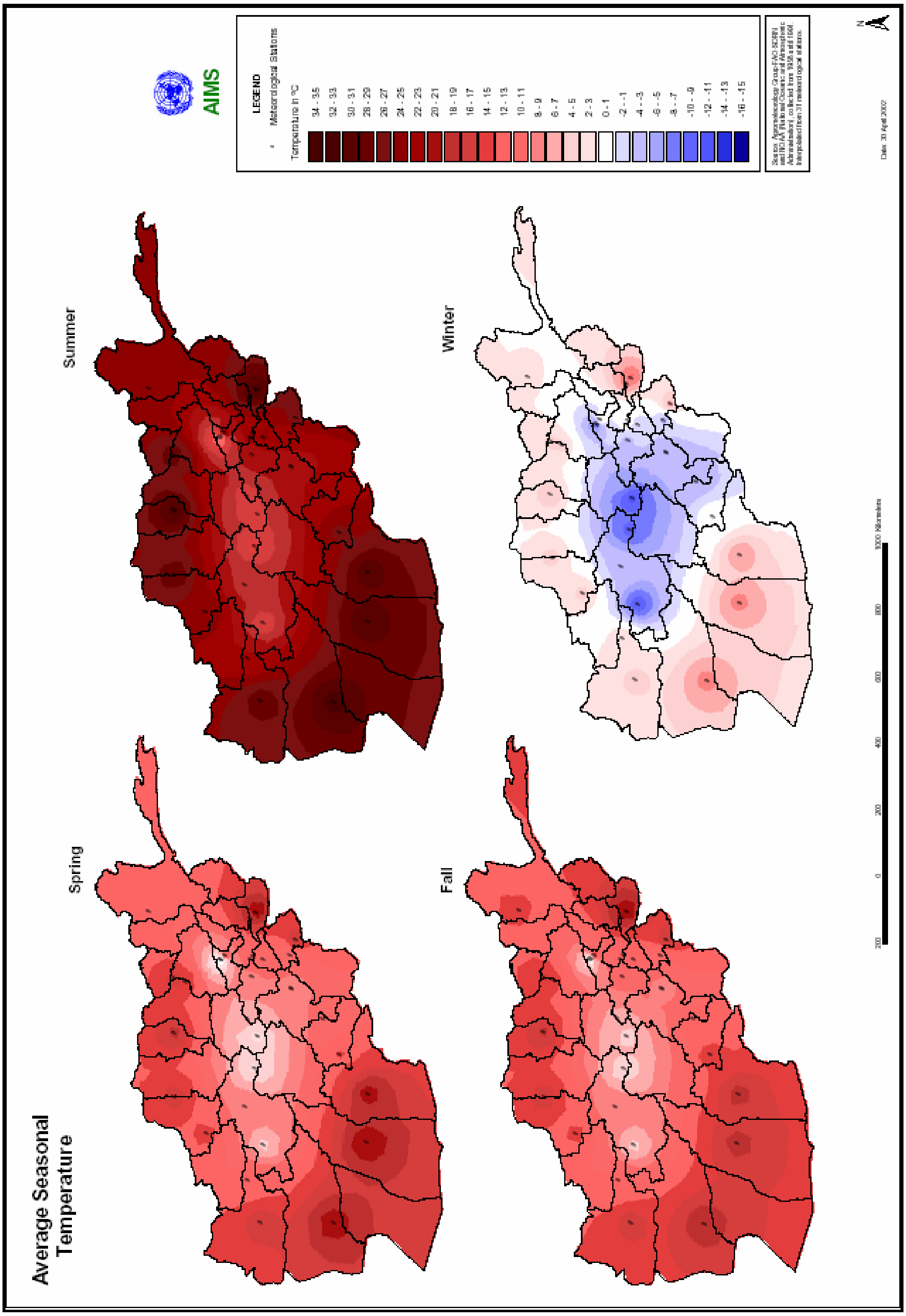


Fig. 1.4: Temperature distribution in Afghanistan (www.aims.org.af)

The vegetation in Afghanistan is directly related to the amount of precipitation and increases from west to north-east. Trees are only found in a few areas as a consequence of the massive deforestation which has taken place in recent decades. There is also no continuous plant cover - areas of relatively dense vegetation are only rarely present in the vicinity of water deposits. Apart from these small localised patches, the country is dominated by steppe and semi-deserts with steppe vegetation such as thistles or camel thorns (Fig. 1.5).

Fig. 1.5: Vegetation in Afghanistan (www.nationalgeographic.com)

1.3 Hydrology of Afghanistan

Afghanistan is covered by a relatively dense network of rivers although most of the smaller rivers only run with water during rainy periods or during the thaw. They are dry in summer. The most important rivers run from the central mountains in all directions. In the south-western part of Afghanistan, the lower courses of the rivers in the area dwindle away, e.g. the Helmand and Farah which die out in terminal lakes and salty swamps as they cross the deserts and steppes (Fig. 1.5).

The most important river in the north of the country is the Amudarja. The most important rivers in the east are the Kabul and Tochi. Although the courses of these two rivers are short, they do have relatively high flow rates. Their river valleys contain many areas of fertile country.

2. Geology

2.1 Geology of the Kabul Basin

The Kabul Basin is a basin structure which arose as a result of plate movements during the Late Palaeocene (Tertiary). It is surrounded and underlain by largely metamorphic rocks. These rocks are part of the Kabul block and are intersected by the faults of the Herat - Bamiyan main fault in the west, the Sorobi fault in the east and the Chaman fault system in the south-east. They are fragmented along the fracture and shear paths and intensely folded - even imbricated in parts.

The western and northern rims of the basin are dominated by precambrian gneisses, mica slates, amphibolites, quartzites and marbles (HOMILIUS 1966). Precambrian phyllites are found in the eastern and southern parts (DIETMAR 1976). The carbonate-dominated Khinghil formation of permo-triassic age transgressed from the south into the area of the recent Kabul basin.

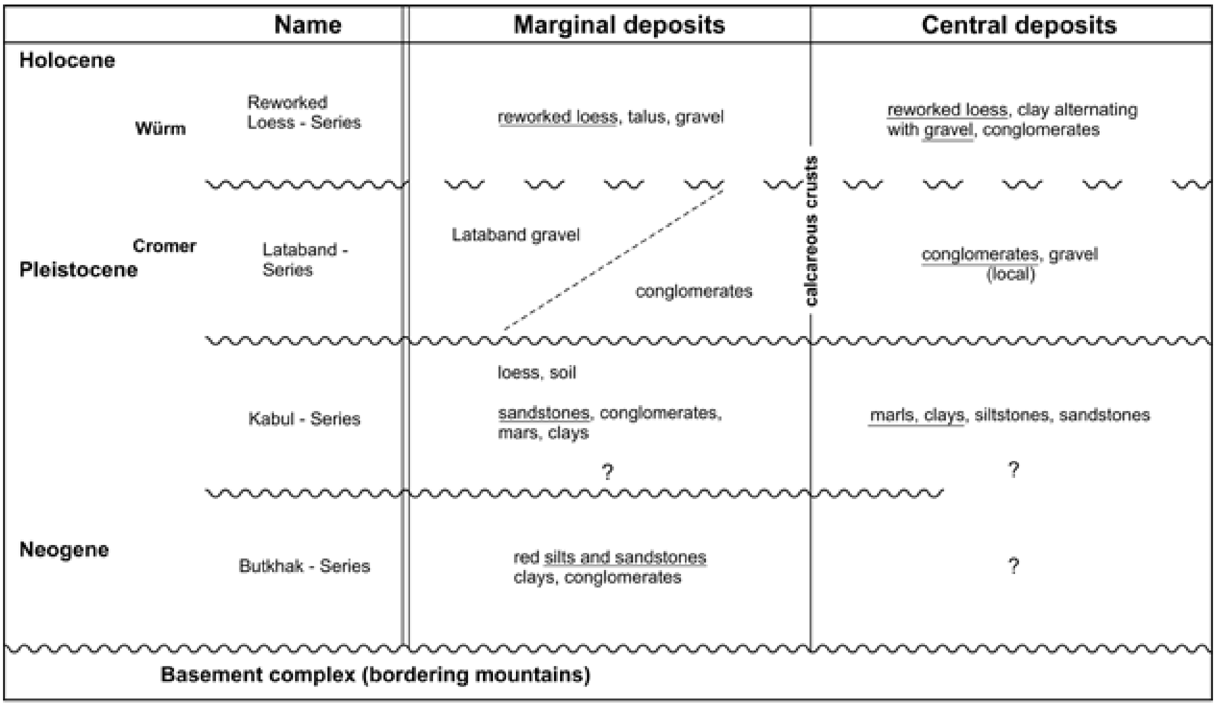
The filling of the Kabul Basin itself consists of an accumulation of terrestrial and lacustrine sediments, mainly of Neogene age. Most of these sediments consist of sand and gravel. Geophysical surveying revealed the total thickness of the sediments as up to 600 m (PROCTOR & REDFERN INT. LTD. 1972). The basin sediments can be subdivided as follows:

a) The molasse-type Butkhak series of the Upper Miocene consist of different beds of clastic material. It mainly comprises red sandstones, gravels, conglomerates and breccias. The Butkhak series were formed after the early Tertiary alpidic uplift of the Hindukusch.

b) The pliocene Kabul series developed in the central part of the Kabul Basin and mainly consist of argillaceous beds, lacustrine silts and fine sand lenses. Greenish colours are common.

c) The Quaternary terrace sediments of middle and younger pleistocene age (Lataband formation) form the main aquifers within the Kabul Basin. Cf. Also Fig. 2.1. Deeper layers have often been affected by cementation leading to the genesis of conglomerates.

d) The youngest formations are loess deposits which reach their highest thicknesses at the rim of the basin. Many loess layers have been reworked one or more times. The oldest loesses are intercalated with the Lataband gravels. In the basin centre, some swamps arose from lakes and depressions without outlet. Frequent evaporation led to the concentration of salts in the soil of these evaporation basins.



Basin deposits in the Kabul area
after GREBE and HOMILIUS 1968 (simplied)

Fig. 2.1: Schematic stratigraphy of the Kabul Basin after GREBE & HOMILIUS (1966).

The following stratigraphic units can be differentiated after HOMILIUS (1966):

Table 2.1: Stratigraphic classification of beds within the Kabul Basin (HOMILIUS 1966).

Stratigraphic group	Description	Rock type
5b	Youngest alluvial deposits	Coarse gravel, gravel, sand, reworked loess
5a	Youngest basin sediments	Reworked loess with locally interbedded sand and gravel banks and lenses
4	Talus slopes, debris fans, from the basin margin	Talus slopes, reworked loess Reworked loess, gravel
3	Basin deposits	Reworked loess with interbedded sand and gravel banks and lenses, gravel and sand, partially hardened to form sandstones and conglomerates
2b	Mainly fluviatile sediments, localised channel-like distribution	Gravel, sand, reworked loess Gravel and sand frequently hardened into sandstones and conglomerates
2a	Basin sediments	Reworked loess with interbedded coarse gravels and sands
1	Older basin sediments	Marl, clay, siltstone, sandstone, conglomerate
Basement	Kabul crystalline	Metamorphites etc.

The high surface temperature fluctuations cause strong physical weathering as identified by the extensive debris fans at some parts of the basin margin.

The low air humidity from June to October combined with the high temperature gives rise to high evaporation rates. This causes the formation of surface crusts and efflorescence from carbonate and gypsum-bearing groundwater in areas with shallow water tables (DIETMAR 1976). This is particularly visible in the salt swamps to the west of Kabul airport.

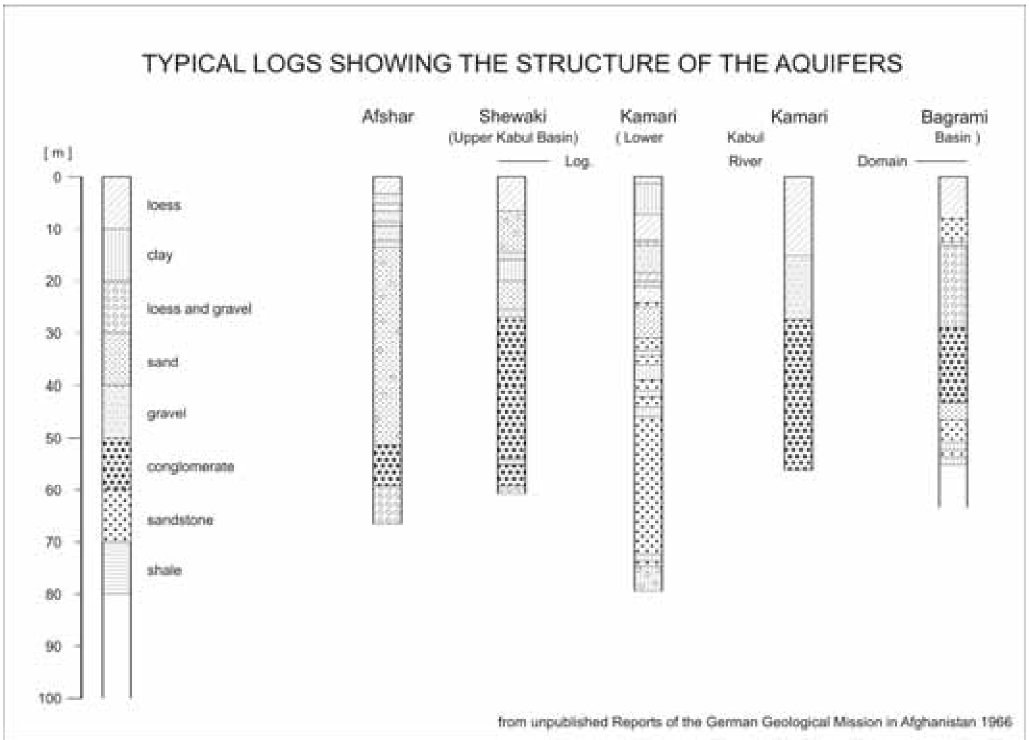
The basin fill can be divided into two facies groups according to DIETMAR (1976): red-coloured coarse molasse marginal facies sediments of Miocene age, and greenish fine-grained lacustrine basin facies sediments of Pliocene age. The boundary between these two facies groups is not only lithological, but also chronological and marked by a hiatus caused by strong erosion. No sediments or morphological structures of younger Pliocene and older Pleistocene have been found. Sediments of middle and younger Pleistocene age are in the form of talus and coarse-gravel deposits on two terraces. These indicate strong phases of erosion which terminated in each case by the deposition of debris and coarse gravels (DIETMAR 1976). The youngest sediments on the surface are glacial loess clays with a thickness of up to several metres (Fig. 2.2). The loess clay may already have been reworked and redeposited several times.

Stratigraphic groups 2b and 3 in Table 2.1 are significant aquifers from which large quantities of groundwater can be extracted. They consist of sand and gravel beds, but are only of localised extent. The aquifers are mostly usable at a depth of 15 to 40 m. The deeper layers have much lower porosity as a result of secondary mineral precipitation (HOMILIUS 1966).

Shallow (perched) groundwater occurs in stratigraphic groups 4, 5a and 5b. However, these usually only have low productivity. They are penetrated and used by many shaft wells (HOMILIUS 1966). Unfortunately, because the water table has dropped as a result of the high water extraction and low recharge, this aquifer is now only of minor importance today.

2.2 Hydrogeology of the Kabul Basin

The Kabul area has four main aquifers. Aquifers generally consist of sandy-gravely deposits formed as river terraces. The Paghman-Darulaman basin has two aquifers lying along the course of the Paghman river and the upper course of the Kabul river. The other two aquifers are located in the Logar basin and the southern part of the Kabul Basin and follow the course of the Logar river and lower Kabul river. The general groundwater flow direction is from the western or south-western basin margin, through the basin centre, to the eastern basin margin. The composition of the aquifers can be interpreted from borehole results (Fig. 2.2). The aquifers mainly consist of gravel and sandy beds covered by loess clay beds with thicknesses of up to a few metres. The pore spaces of the sandy and gravely parts of the aquifers are partially cemented by secondary mineralisation processes. Locally the thickness of the aquifers can be up to 80 metres (BÖCKH 1971). Permeability varies and ranges from $2.3*10^{-5}$ m/s to $1.3*10^{-3}$ m/s. According to DIN 18 130 they are thus classified as permeable to very permeable.



from unpublished Reports of the German Geological Mission in Afghanistan 1966

Fig. 2.2: Lithology of the Kabul Basin aquifers (THIELE & BÖCKH 1971).

Groundwater recharge in the Kabul Basin comprises various components which are listed below according to their importance. The main contribution to the groundwater regeneration in the Kabul Basin comes from surface infiltration at transition zones between consolidated and unconsolidated rocks, and exfiltration along the rivers (at least during the period when the snow thaws).

- Infiltration of surface runoff at the transition between consolidated and unconsolidated rock at the basin margin (foothill infiltration)
- Exfiltration from surface waters
- Exfiltration from irrigation ditches
- Seepage of domestic sewage and industrial effluent
- Direct regeneration from precipitation

The percolation of domestic and industrial sewage does not have any particular effect on the groundwater balance because most of the water is originally extracted from the aquifers. However, this aspect is extremely important when assessing the contamination of the aquifers in the Kabul Basin. The infiltration of precipitation only accounts for a very small part of direct groundwater regeneration. PROCTOR & REDFERN INT. LTD. (1972) assign a figure of 27 % to the regeneration of groundwater from direct precipitation, however, this would mean that of the average annual precipitation of 330 mm/year for the 1957 - 1977 period (Fig. 3.1) almost 90 mm flowed directly into the groundwater every year. However, after deducting real evaporation, but not making allowance for losses and drainage, the maximum possible average groundwater regeneration for this period would be 32 mm/year (Fig. 3), corresponding to around 10 %. However, because this figure does not contain any losses and because the precipitation falling in the form of snow has not been given any special consideration, one can assume that the actual percentage of precipitation which recharges directly into the groundwater will be much smaller than the above figure suggests.

2.2.1 Logar aquifer

The Logar aquifer (Fig. 2.3) extends along both sides of the Logar river over a length of 10 km and a width of around 3 km. It has an average thickness of 30 to 40 m and a maximum thickness of 70 m. The lower parts of this aquifer (table 2.2) consist of coarse-grained deposits mainly conglomerates and coarse-grained sandstones hardened with calcareous sediment. According to reports dating from 1971, the overlying areas contain sand and gravel. In the southern parts in particular, the deposits in the lower zones of the aquifer are interbedded with clay layers with thicknesses of 10 to 15 m and more.

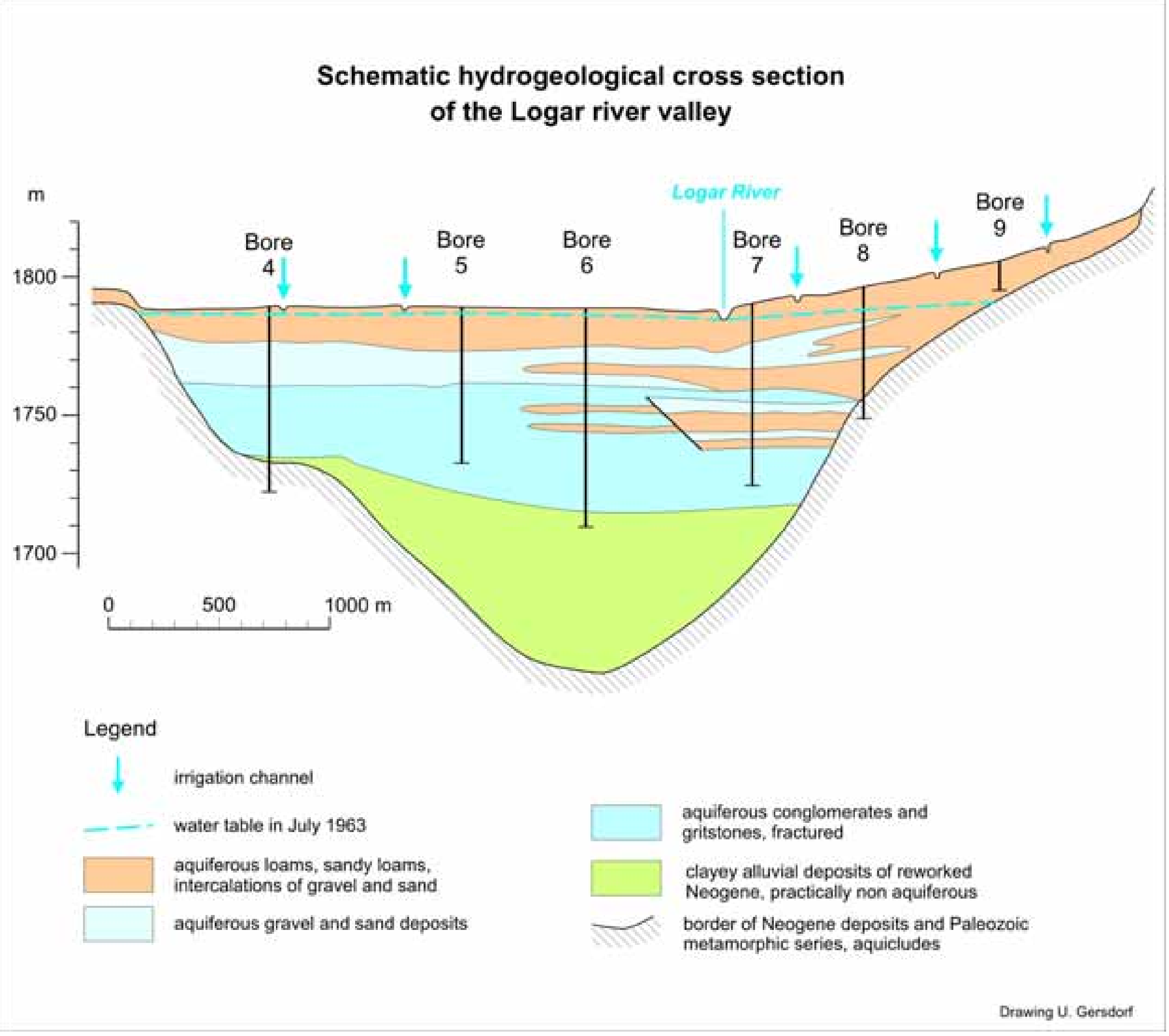


Fig. 2.3: Hydrogeological profile of the Logar basin (BÖCKH 1971)

The different deposits (conglomerates, sandstone and clay marls) act as one aquifer with direct hydraulic contact, i.e. there is no hydraulic separation into separate aquifers.

Table 2.2: Borehole logs in the Logar aquifer (Böckh 1971)

Borehole number	Depth	Aquifer thickness			
		Loam	Sand and gravel	Conglo-merates/ sandstone	Total
	[m]	[m]	[m]	[m]	[m]
2	59.6	3.6	20.0	32.0	55.6
4	63.0	12.5	16.2	23.0	51.7
5	57.0	15.1	11.5	39.8	66.4
6	80.0	12.4	17.3	42.3	72.0
7	66.2	9.8	17.4	46.5*	73.7
11	50.0	12.1	10.5	6.3	28.9

*20 m loam inclusive

The evaluation of the pump tests (Table 2.3) indicates that the permeability coefficients of the Logar aquifer are high but subject t to strong fluctuations (Böckh 1971).

Table 2.3: Pump tests in the Logar aquifer (Böckh 1971)

Borehole number	Duration pumping	Screen intervals from - to		Pumping rate	Drawdown	Specific capacity	Average permeability
	[h]	[m]	[m]	[l/s]	[m]	[l/s/m]	[m/s]
2	120	11.40 26.60	15.40 58.00	58.30	8.40	6.9	$2.3 \cdot 10^{-4}$
4	119	17.80	51.70	93.70	2.25	41.6	$13.3 \cdot 10^{-4}$
5	92	17.90 51.70	46.40 57.00	46.90	3.10	15.1	$4.7 \cdot 10^{-4}$
6	117	14.00 26.10	15.75 72.50	48.40	1.81	26.7	$6.0 \cdot 10^{-4}$
7	68	30.55 52.70	35.70 66.20	41.70	13.80	3.0	$1.4 \cdot 10^{-4}$
11	88	17.90	29.30	24.60	11.80	2.4	$3.2 \cdot 10^{-4}$

The aquifer horizon is classified according to DIN 18 130 as permeable to very permeable because of its permeability coefficients of $1.4*10^{-4}$ m/s to $13*10^{-4}$ m/s. It is also clear that interbedded loam beds reduce the permeability.

Analysis of the overlying loam beds revealed unexpectedly high permeabilities of $5.8*10^{-5}$ m/s to $35*10^{-5}$ m/s in 1961 - 1963. These results are explained by the presence of numerous large and stable pores in these zones (Böckh 1971). In the report by Myslil et al. (1982) the sand and gravel beds within the Logar aquifer to the south of Bagrami (Fig. 2.4) are reported to have transmissivities of $4.1*10^{-2}$ to $9*10^{-2}$ m^2/s and storage coefficients of $1*10^{-2}$ to $1.5*10^{-2}$. The high storage coefficients indicate semi-confined aquifers. With an average thickness of the gravel and sand beds of 15.5 m (table 2.2) the aquifer has permeability coefficients of $2.6*10^{-3}$ to $5.8*10^{-3}$ m/s. These fall within the k_f range of sandy gravel. The sands and gravels are therefore classified as very permeable. The permeabilities are, however, only approximations because the precise thickness of the beds in the logged zones is unknown.

The storage coefficients given for the gravel and sand beds lie between the values for free and confined aquifers which indicates the existence of semi-confined conditions in the investigated areas. Storage coefficients ranging from $1*10^{-4}$ to $1*10^{-3}$ are given for the conglomeratic beds. These values clearly lie within the range for confined aquifers. However, because no additional information is available on the origin of these figures, they cannot be used to make any final conclusions about the whole of the aquifer particularly because the values only apply to a specific bed.

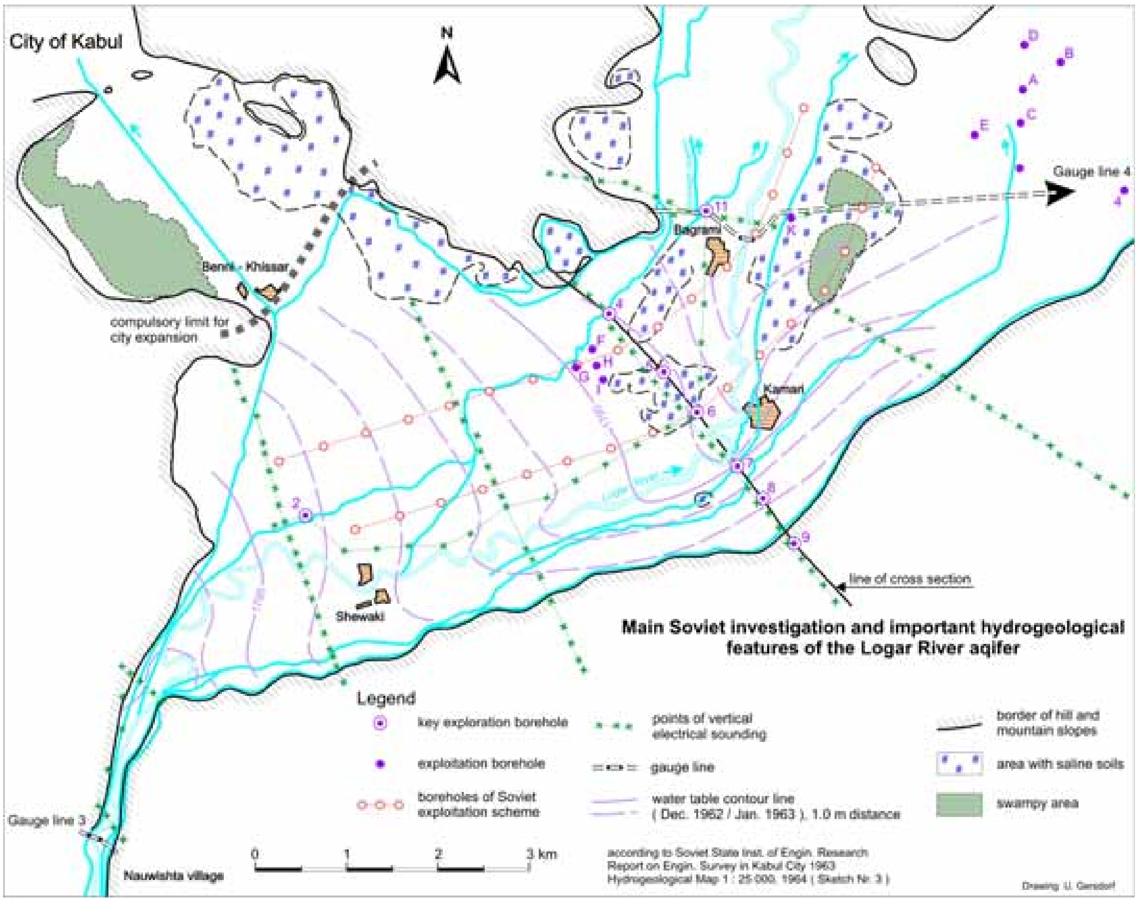


Fig. 2.4: Hydrogeological map of the Logar aquifer (BÖCKH 1971).

The water table of the groundwater on the left bank of the Logar was fairly shallow during the period of investigation, lying at a depth of between 30 to 80 cm in the lower lying flatter areas and between 1.5 and 2 m depth in the higher regions. Seasonal fluctuations cause the depth of the water table to vary by 0.5 to 1 m. On the right bank of the Logar, the water table had a depth of around 5 to 10 m below ground surface according to a 1971 report.

The water table here varies between 1 to 2 m in response to irregular discharge and extraction for irrigation (BÖCKH 1971). The 1971 report does not explain the strong difference between the depth of the water table on the right and left banks of the Logar. The higher terrain elevation on the right bank (fig. 2.4) is probably the explanation.

Analysis of the groundwater contours reveals that groundwater enrichment from the Logar took place in the 1970s in the areas above the 1793 meter isohypse (Fig. 2.4). It is expected that during summer additional enrichment came from exfiltration from irrigation channels. An area of 33,000 hectares was irrigated in the Logar basin with an irrigation volume of 380*10^6 m^3/year (PROCTOR & REDFERN INT. LTD. 1972). Because of the high permeability of the loam, there were high total discharges on the right bank of the Logar calculated as 750 l/s in 1971, and around 200 l/s on the left bank. The discharge from precipitation and underground inflow is low in comparison (BÖCKH 1971). Groundwater flow at the 1790 m groundwater contour was estimated at around 32,000 m^3/day in 1971 (table 2.4).

Table 2.4: Groundwater discharge in the Logar aquifer at the 1790 m water table contour (after Darcy) (BÖCKH 1971).

	Left bank	**Right bank**
Aquifer width [m]	3800	4775
Gradient [-]	0.0014	0.0060
Loam		
Bed thickness [m]	12	50
Permeability [m/s]	$1.16 \cdot 10^{-4}$	$1.38 \cdot 10^{-4}$
Gravel and conglomerate		
Bed thickness [m]	52	-
Permeability [m/s]	$6.00 \cdot 10^{-4}$	-
Discharge rate [m^3/s]	**0.17**	**0.20**
Discharge rate [m^3/day]	**15032**	**17190**

Groundwater infiltrates the river below the 1790 m groundwater contour (Fig. 2.4). The different discharge rates at gauges 3 and 5 (table 2.5) indicate that groundwater outflow is relatively high at certain times. The average inflow of groundwater into the river in the winter of 1962/63 was 1.04 m^3/s (table 2.5). Water losses in the other months can be attributed to the massive extraction for irrigation purposes because the months with negative water balances correspond to the irrigation period. This also explains the fact that losses occur in the total balance between gauges 3 and 4 despite groundwater inflow from November to March (table 2.6). This is also indicated by the fact that during the discharge times when the river loses water between gauges 3 and 4, the channels in the same flow section report increases in discharge (table 2.7).

Table 2.5: Discharge between gauge lines 3 and 4 (Böckh 1971).

Discharge (Rivers and channels)		**Discharge at the gauge line $[m^3/s]$**		**Difference $[m^3/s]$**
		3	4	
1962	October	5.78	4.58	-1.20
	November	12.00	12.50	+0.50
	December	15.80	16.70	+0.90
1963	January	16.00	17.60	+1.60
	February	14.80	16.00	+1.20
	March	12.90	13.90	+1.00
	April	8.40	7.85	-0.55
	May	20.50	21.40	+0.90
	June	2.11	0.57	-1.54
	July	1.89	0.55	-1.34
	August	1.62	0.41	-1.21
	September	1.78	0.39	-1.39
Annual average		9.47	9.37	-0.10

= Discharge diverted from the Kabul river

Table 2.6: Water losses between gauges 3 and 4 from October 1962 - September 1963 (Böckh 1971).

Total discharge	**Discharge at the gauge line $[10^6 m^3]$**		**Water losses $[10^6 m^3]$**	**Water losses [%]**
	3	4		
River	231.80	227.00	4.80	1.60
Channels	67.70	65.50	2.20	0.73
Total discharge	299.50	292.50	7.00	2.34

Table 2.7: Discharge differences between gauges 3 and 4 from October 1962 - September 1963 (Böckh 1971).

Discharge times	**Discharge at the gauge line $[m^3/s]$**				**Discharge difference $[m^3/s]$**	
	3		4			
	River	**Channel**	**River**	**Channel**	**River**	**Channel**
Oct-Nov	5.94	2.95	6.90	1.64	+0.96	-1.31
Dec-Mar	13.30	1.60	12.80	3.30	-0.50	+1.70
April-May	11.80	2.60	11.00	3.60	-0.80	+1.00
June-Sept	0.15	1.70	0.18	0.30	+0.03	-1.40
Annual average	7.43	2.04	7.28	2.09	-0.15	+0.05

The groundwater reserves in the Logar valley are estimated at around 70 million m^3 as part of the investigation. This estimate is based on the following data:

Length of the aquifer	10 km
Average width of the aquifer	3 km
Average porosity of sand, gravel and loam	7.5 %
Average thickness of sand, gravel and loam	28 m
Average effective porosity of conglomerate and sandstone	2.5 %
Average thickness of conglomerate and sandstone	22 m

The effective porosity of sand, gravel and loam treated as a combined layer is around 7.5 %. This lies in the normal range because although sand and gravel have high porosities, and therefore account for a high proportion of the usable pore space, loam only has very low porosities and therefore reduces the porosity of the overall sequence. An effective porosity of 2.5 % is very low for the conglomerate and sandstone sequence. The low porosity of these beds, which lie in the lower part of the aquifer, are a result of the compaction over time caused by the weight of the younger overlying sediments, and hardening as a result of cementation. Compaction and hardening reduce the effective porosity.

Groundwater regeneration in the Logar aquifer involves the following elements according to PROCTOR & REDFERN INT. LTD. (1972):

Table 2.8: Groundwater potential in the Logar aquifer (PROCTOR & REDFERN INT. LTD. 1972).

Source	**Inflow [m^3/s]**	**Inflow [m^3/day]**	**Proportion [%]**
Inflow from basin sides	0.09	8 000	4.17
Recharge from precipitation	0.08	7 000	3.70
Infiltration from rivers and channels	1.99	172 350	92.13
Total	2.16	187 350	100.00

According to PROCTOR & REDFERN INT. LTD. (1972), infiltration from rivers and channels accounts for 92 % of groundwater regeneration (1.99 m^3/s). Inflow from the basin sides and from precipitation only plays a very minor role. The figure quoted here could not be confirmed by modern observations because during the lengthy drought, which had already lasted several years prior to the observation period, no continuous infiltration was observed from the rivers and channels. In addition, hill slope infiltration seems to be just as important for groundwater regeneration. The marginal zones of the Kabul Basin therefore have a different groundwater chemistry to the zones in the centre of the basin (cf. Part II of this study).

2.2.2 Kabul aquifer

A zone of coarse-grained deposits with a length of 9 km and a width of 2.5 km has been confirmed running parallel to the Kabul river. This zone comprises most of the Kabul aquifer. Analogous to the Logar aquifer, the Kabul aquifer consists of three horizons. The main part of the aquifer consists of conglomerates and sandstones covered by a thin layer of sand and gravel. The cover rock consists of loam with large pore spaces. The whole plain is covered by these loams - the only exception being the areas directly adjacent to flowing water. The overlying loam bed is only very thin in the centre of the valley. The overlying layers have a thickness here of 1 - 5 m. Thicknesses of up to 15 m were measured at the edges of the plain in the 1960s. The thickness of the sand and gravel layer in the higher parts of the plain is only 2 to 9 m. In the lower zones it is up to 20 m thick. Because the lower beds consist of older deposits which became consolidated and subsided over time as they became covered by younger deposits, they have become more consolidated and more compact with depth. The lowest conglomerate and sandstone layer has a thickness of 30 to 65 m. The whole aquifer has a total thickness of 40 to 80 m (table 2.9).

Table 2.9: Borehole investigation results in the Kabul aquifer (BÖCKH 1971).

Borehole number	**Depth [m]**	**Aquifer thickness**			
		Loam [m]	**Gravel and sand [m]**	**Conglomerate and sandstone [m]**	**Total [m]**
23	48.7	4.7	-	49.3	54.0
24	76.0	-	2.0	64.5	66.5
25	50.0	-	-	34.0	34.0
26	40.0	12.8	-	5.5	18.3
27	60.0	-	7.0	47.0	54.0

Fig. 2.5 shows the location of the boreholes and the stratigraphic sequence. The permeability of the overlying loam horizon is also relatively high in the Kabul aquifer with coefficients of $1.4*10^{-4}$ m/s to $6.1*10^{-4}$ m/s. The permeabilities in the conglomerate and sandstone bed range from $0.5*10^{-4}$ to $7.5*10^{-4}$ m/s (table 2.5). They can therefore be classified as permeable to very permeable according to DIN 18 130. Because the sand and gravel deposits are thin in the southern part of the aquifer in particular, the permeability is largely dependent on the conglomerates and sandstone. Pump tests in the Kabul aquifer revealed a capacity of 32 to 35.5 l/(s*m) (table 2.10).

The different layers within the Kabul aquifer are considered to be interconnected and forms one aquifer. The aquifer as a whole is phreatic.

Table 2.10: Pump tests in the Kabul aquifer (BÖCKH 1971).

Borehole number	**Duration pumping [h]**	**Screen intervals from - to**		**Pumping rate [l/s]**	**Drawdown [m]**	**Specific capacity [l/s/m]**	**Average permeability [m/s]**
		[m]	**[m]**				
22.0	1.1	40.3	50.0	2.8	5.9	0.5	-
23.0	115.0	7.5	48.7	20.2	13.2	1.5	$0.5 \cdot 10^{-4}$
24.0	92.5	11.8	72.0	34.0	13.1	2.6	$0.7 \cdot 10^{-4}$
25.0	65.0	10.3	40.0	27.7	9.0	3.1	$1.9 \cdot 10^{-4}$
26.0	119.0	10.4	26.3	14.4	8.8	1.6	$3.2 \cdot 10^{-4}$
28.0	68.0	4.4	56.0	75.0	1.9	39.5	$7.5 \cdot 10^{-4}$

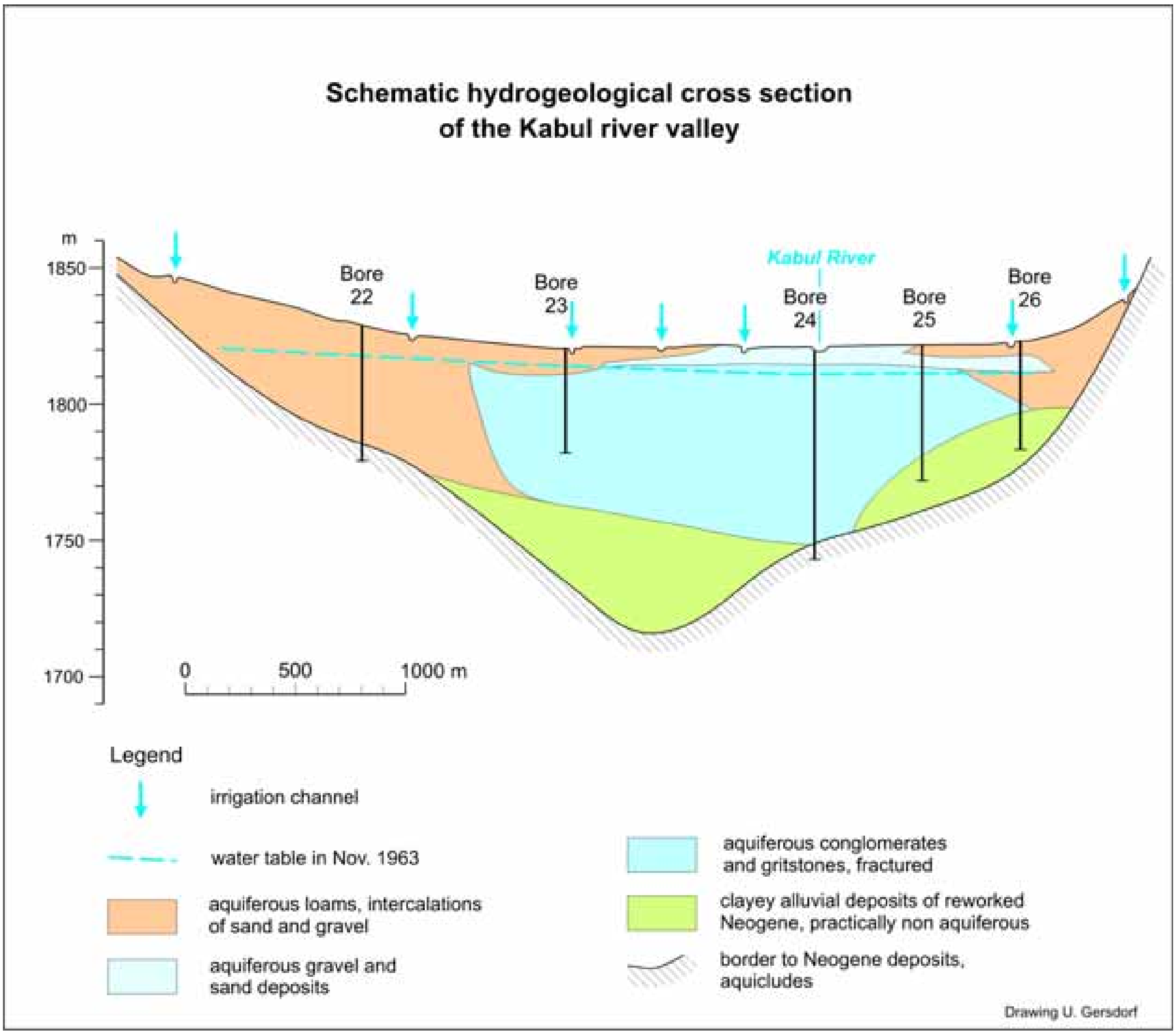


Fig. 2.5: Hydrogeological cross-section of the Kabul Basin (BÖCKH 1971).

The report from MYSLIL ET AL. (1982) contains values for transmissivity of the aquifer determined during pump tests in the Kabul Basin between 1963 - 1982. The transmissivities range from $1.0*10^{-5}$ to $6.8*10^{-2}$ m^2/s - a very large spectrum. The arithmetic average is $1.4*10^{-2}$ m^2/s. Because no information is available on the thickness of the aquifer at the observation well, it is not possible to calculate the permeability of the aquifer.

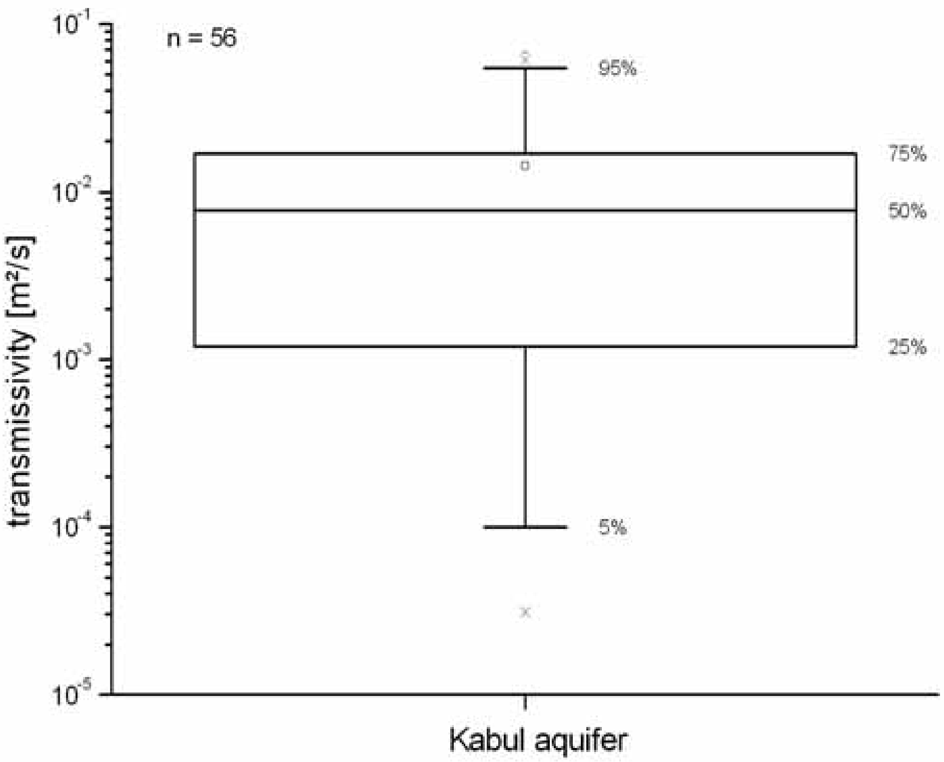


Fig. 2.6: Box-Whisker plot of transmissivities in the Kabul aquifer measured through pump tests 1963 - 1982 (after data from MYSLIL ET AL. 1982).

The depth of the water table in the Kabul aquifer ranges from 2 to 12 m. Fluctuations of up to 5 m and more occur. These fluctuations increase in the vicinity of the river because the water table of the groundwater is directly linked to the discharge behaviour. Information on the water table depth (Fig. 2.7), groundwater hydrographs (Fig. 2.8) and groundwater contours (Fig. 2.9) are available for 1965 for the inner part of Kabul city only.

The water tables within the city of Kabul lay at very shallow depths in 1965 compared to today. At that time, the groundwater table lay very close to the surface at depths of 2 to 5 m. As a result of strong extraction, associated with the population development in the Kabul Basin, and the climatic developments during recent years, the water table of the Kabul aquifer lies at much greater depth today.

In the BGR Project house within the district of Shar-I-Nau, the water table depth in 1965 was around 2 - 3 m. The observation well in the Project house today reveals a depth to the water table of 9.5 m.

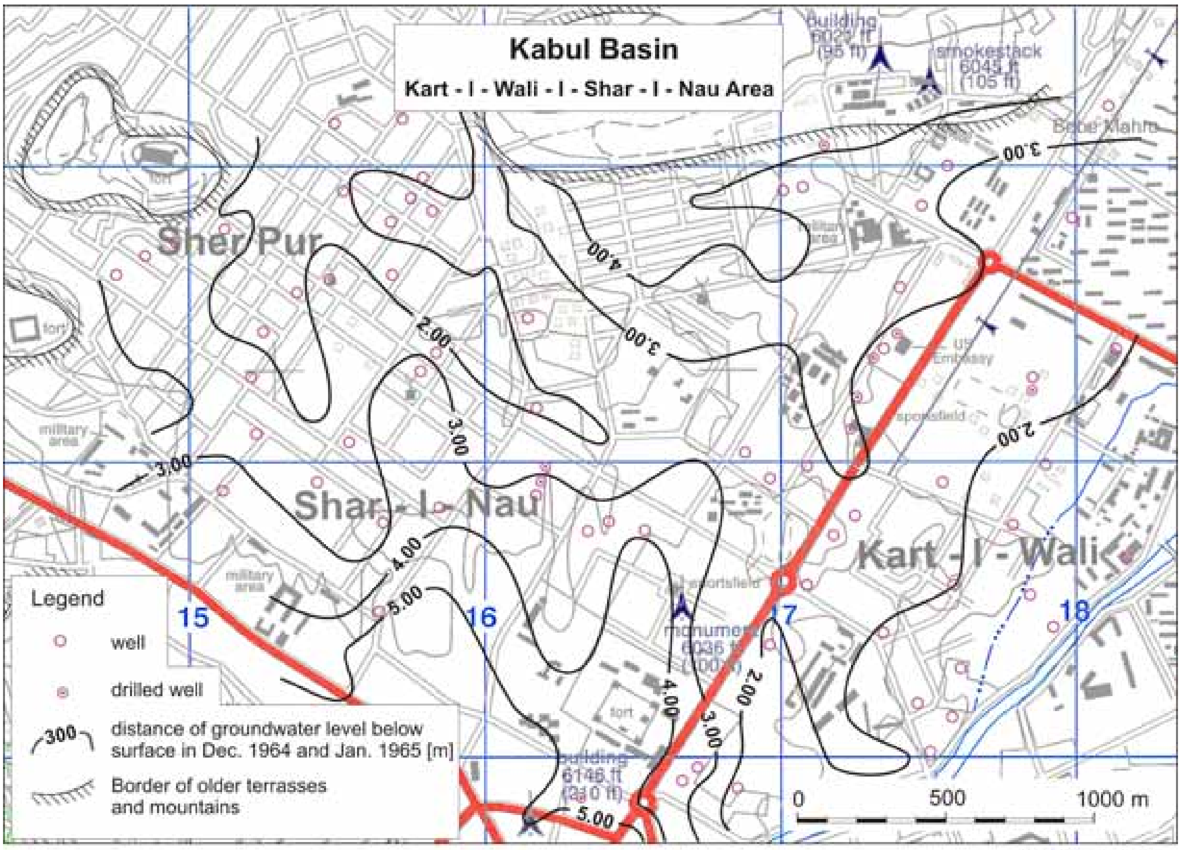


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Fig. 2.7: Depth to groundwater in the urban centre of Kabul, Shar-I-Nau district 1964/65 (GERMAN GEOLOCICAL MISION1965).

This shows that the water table has dropped approx. 6 - 7 m within 40 years. This development is also clearly seen in the many dry shaft wells which are now common within the city.

The analysis of the groundwater hydrographs also shows a clear correlation between the depth of the groundwater table and the precipitation and discharge. Maximum water table heights, i.e. shallowest depths, are recorded in 1963 in May and in 1964 in April. During these periods, the water table lay around 1 m below the surface. In standard years, April is the month with the highest precipitation and the discharge in the Kabul river is also highest during this period as seen from the gauge recordings.

The depth to the water table increases in the other months, and the greatest fluctuations are observed in the wells located closest to the Kabul river. This highlights the dependence of the water table on the discharge situation in the Kabul river. From November through April/May, the water tables in the observation wells and the discharge in the Kabul river lie within the average range and are constant. In the period from June to September, when there is hardly any precipitation, the discharge in the Kabul river is low and the depth to the water table increases to around 3.5 m.

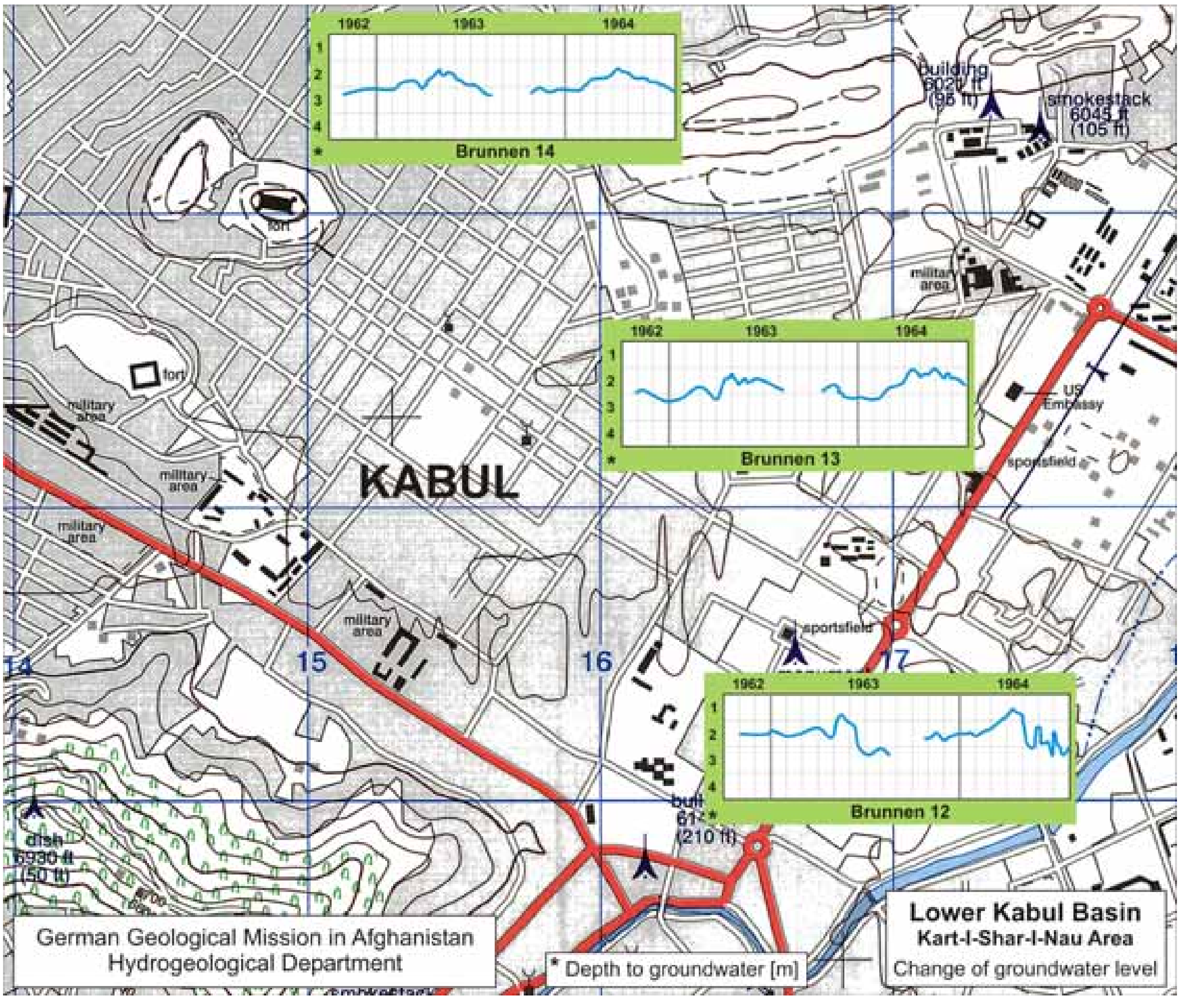

Fig. 2.8: Groundwater level fluctuations in the urban centre of Kabul, Shar-I-Nau district 1962 - 1964 (German Geolocical Mision 1965). (Brunnen = well).

The groundwater contours in the centre of Kabul range between + 1791 m ASL and + 1794 m ASL. Because groundwater flows perpendicular to the potential lines, the groundwater flows from south-west to north-east along the flow direction of the Kabul river. Interaction between groundwater and the Kabul river is observable in the vicinity of the river where groundwater infiltrates the river.

By way of contrast, in the south-western part of the Kabul aquifer, the river infiltrates the groundwater outside of the dry season. The water table rises as a result of the connection to the river. Groundwater regeneration here mainly arises from filtration in the river bed and reaches a maximum when the permeable sands and gravels in the vicinity of the river are flooded.

Because infiltration through the river bed accounts for around 72 % of total groundwater regeneration according to table 2.12 (PROCTOR & REDFERN INT. LTD. 1972), the size of groundwater regeneration can be assessed on the basis of the water losses between gauge 1 at Gulbakh and gauge 2 at Chekhel-Sutun. However, the proportion of the losses due to the extraction of irrigation water is not known. During this period, a total area of 10,500 hectares was irrigated in the Kabul Basin with a total of $12*10^6$ m^3/year (PROCTOR & REDFERN INT. LTD. 1972).

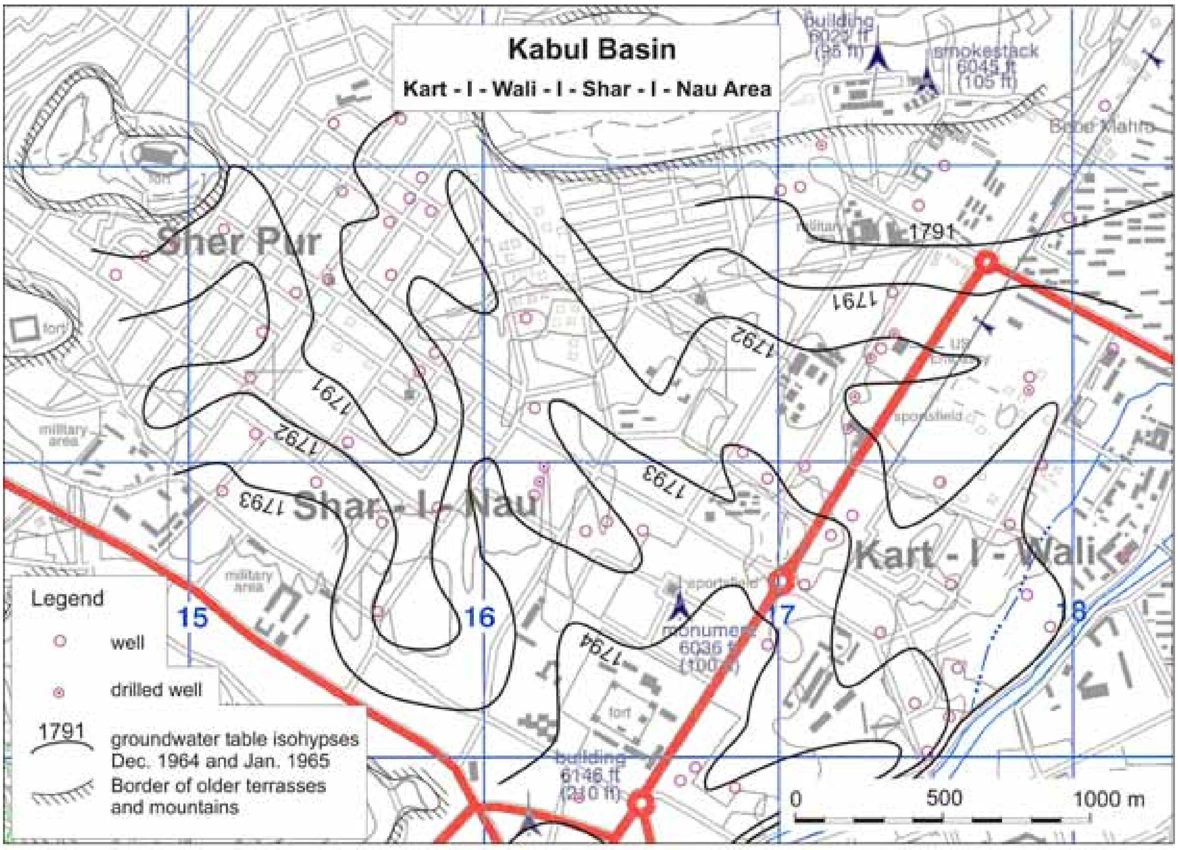

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Fig. 2.9: Groundwater contours in the centre of Kabul, Shar-I-Nau district (GERMAN GEOLOCICAL MISION 1965).

Table 2.11: Water losses between gauge 1 at Gulbakh and gauge 2 at Chekhel-Sutun from October 1962 to September 1963 (BÖCKH 1971).

Total discharge	**Discharge at the gauge line [10^6 m^3]**		**Water losses [10^6 m^3]**	**Water losses [%]**
	1	**2**		
River	96.50	71.10	25.40	20.48
Channels	27.50	14.30	13.20	10.65
Total discharge	124.00	85.40	38.60	31.13

The groundwater potential in the Kabul aquifer comprises the following components:

Infiltration through the river bed also accounts for most of the groundwater regeneration in the Kabul aquifer as well. However, the proportion of inflow from the basin sides is much higher than in the other two aquifers.

Table 2.12: Groundwater potential in the Kabul aquifer (PROCTOR & REDFERN INT. LTD. 1972)

Source	**Inflow [m^3/s]**	**Inflow [m^3/day]**	**Proportion [%]**
Inflow from basin sides	0.20	17,300	21.74
Recharge from precipitation	0.06	5,400	6.52
Infiltration through the river bed	0.66	57,600	71.74
Total	0.92	80,300	100.00

The groundwater flow of the Kabul aquifer is estimated at around 16 million m^3/year at the 1850 m groundwater contour (table 2.13) (BÖCKH 1971).

Table 2.13: Groundwater flow in the Kabul aquifer at the 1850 m groundwater contour (BÖCKH 1971).

	Left bank	**Right bank**
Width of groundwater aquifer [m]	5 850	1 575
Gradient [-]	0.0050	0.0090
Average bed thickness [m]	45	20
Permeability [m/s]	$3.47 \cdot 10^{-4}$	$2.0 \cdot 10^{-4}$
Discharge rate [m^3/s]	0.44	0.07
Discharge rate [m^3/day]	37,900	5,670
Discharge rate [$m^3/year$]	$13.8 \cdot 10^6$	$2.1 \cdot 10^6$

During dry periods (tables 2.14, 2.15) groundwater infiltration mainly takes place in the Kabul river. During these months, the difference in discharge is therefore lower on average than in the remaining months despite extraction for irrigation which usually takes place during the summer months (tables 2.14, 2.15). Because no data was available on the Kabul aquifer for the 1964 discharge year, this work uses the discharge data for October to December from the 1962 hydrological year.

According to the data of a Soviet expert team, there is a permanent groundwater inflow in the Kabul river of 1 m^3/s during dry periods in the south-western part of the Kabul river (BÖCKH 1971). The productivity of the aquifer is estimated at 20 to 75 l/s depending on the properties of the reservoir. From December to June, the Kabul river infiltrates into the groundwater. During this period, the discharge differences in the river between gauge lines 1 and 2 are also higher than during the July to November period (tables 2.14 and 2.15). PROCTOR & REDFERN INT. LTD. (1972) quote an infiltration rate of 0.66 m^3/s.

Table 2.14: Discharge data for the Kabul river between gauge lines 1 and 2 (Böckh 1971).

Discharge (Rivers and channels)		**Discharge at the gauge line [m^3/s]**		**Difference [m^3/s]**
		1	**2**	
1962	October	0.65	0.26	-0.39
	November	1.17	0.35	-0.82
	December	1.94	0.74	-1.10
1963	January	2.81	1.59	-1.22
	February	2.07	1.09	-0.98
	March	1.70	0.75	-0.95
	April	6.55	5.20	-1.35
	May	22.50	17.20	-5.30
	June	6.56	5.05	-1.51
	July	0.64	0.26	-0.38
	August	0.59	0.17	-0.42
	September	0.51	0.18	-0.33
Annual average		3.97	2.74	-1.23

= calculated from discharge at gauge 1

Table 2.15: Discharge differences between gauge lines 1 and 2 (Böckh 1971).

Discharge times	**Discharge at the gauge line [m^3/s]**				**Discharge difference [m^3/s]**	
	1		**2**			
	River	**Channel**	**River**	**Channel**	**River**	**Channel**
April-June	10.70	1.20	8.41	0.73	-2.29	-0.47
July-Nov	0.08	0.63	0.00	0.25	-0.08	-0.38
Dec-March	1.15	0.97	0.42	0.63	-0.73	-0.34
Annual average	3.10	0.87	2.25	0.49	-0.85	-0.38

The extraction of groundwater from the aquifer can be up to 12 million m^3 during a dry year which leads to temporary deepening of the groundwater table. This lowering is a problem for agriculture in the affected areas because their pumping operations for irrigation are dependent on a shallow groundwater table. The groundwater extraction should therefore be limited to max. 0.5 to 0.6 m^3/s to avoid any negative impact on the existing installations (Böckh 1971).

In the north-eastern part of the Kabul aquifer which is located to the east of the mountain range which divides the city of Kabul, a major gravel bed was identified from boreholes and geoelectrical soundings. This is recognised as the fourth most important aquifer in the Kabul Basin. The aquifer which runs north-east along the course of the river from the point where the Kabul river flows into the Paghman-Darulaman basin, has a length of 11 km, a width of up to 2 km, and a thickness of 10 to 30 m. Because the ground to the east of the city of Ut Khel has a high salt concentration, it is not possible to determine the further extent of the aquifer on the basis of soundings. The core of the gravel bed is 6 km long and 1 km wide and consists mainly of gravel and sand. Conglomerates are virtually non-existent. The productivity test produced extraordinarily good values: well production of 40 l/s only gave rise to a 1 m draw-down. However, this aquifer is strongly contaminated by sewage in the immediate vicinity of Kabul where it has much poorer water quality.

2.2.3 Paghman aquifer

The gravel bed located along the Paghman river in the Paghman-Darulaman basin is around 10 km long, 4 km wide and up to 70 m thick. This phreatic aquifer consists mainly of gravel and sand. Conglomerates and sandstones only occur in minor amounts at certain localities (table 2.16) (BÖCKH 1971).

Table 2.16: Borehole exploration results in the Paghman aquifer (BÖCKH 1971).

Borehole number	**Depth [m]**	**Aquifer thickness**				**Normal water table**
		Clay	**Sand and gravel**	**Conglomerates and sandstone**	**Total**	
		[m]	**[m]**	**[m]**	**[m]**	**[m]**
30	64.5	21.0	3.0	24.0	48.0	10.10
31	76.5	22.5	44.5	-	67.0	4.65
32	67.0	-	50.2	7.8	58.0	1.77
33	71.0	13.0	50.0	-	63.0	2.80
34	52.0	14.0	17.7	-	31.7	5.08
36	51.0	10.0	27.0	-	37.0	19.00

The volume of water stored in the western part of the Paghman aquifer is estimated as 81 million m^3. This is based on the following data:

Length of the aquifer	6 km
Average width of the aquifer	4 km
Average porosity of sand, gravel and loam	7.5 %

The effective porosity has an average value of 7.5 %. This indicates that compaction and hardening of the beds has taken place causing reduction of the effective pore space. The permeability of the aquifer ranges from $0.2*10^{-4}$ m/s to $3.0*10^{-4}$ m/s and is therefore permeable according to DIN 18 130. Permeability is uniform throughout the aquifer (table 2.17).

Table 2.17: Pump tests in the Paghman aquifer (Böckh 1971).

Borehole number	Duration pumping [h]	Screen intervals From - to		Extraction [l/s]	Pumping rate [m]	Specific capacity [l/s/m]	Average permeability [m/s]
		[m]	[m]				
30	44.0	39.60	59.00	28.8	12.10	2.20	$1.2 \cdot 10^{-4}$
31	113.5	28.30	34.00	41.4	5.15	8.00	$2.6 \cdot 10^{-4}$
		44.50	72.50				
32	138.0	5.40	60.00	60.0	7.50	8.00	$1.9 \cdot 10^{-4}$
33	71.0	20.25	64.65	44.1	12.50	3.50	$1.2 \cdot 10^{-4}$
34	93.0	18.50	36.00	24.6	7.70	3.20	$3.0 \cdot 10^{-4}$
36	43.5	27.50	50.30	6.6	12.35	0.53	$0.2 \cdot 10^{-4}$

Assuming a permeability of $2.0*10^{-4}$ m/s, groundwater flow is estimated to be 0.5 m^3/s or 15.5 million m^3/year. This estimate is based on the following data:

Average width of the aquifer	4.65 km
Average thickness of sand, gravel and loam	50 m
Average hydraulic gradient	1.08 %

Transmissivities for the Paghman aquifer were determined from pump tests carried out in the Afshar project area - a field of wells in the Paghman-Darulaman basin (Fig. 2.10). Transmissivities range between $1.3*10^{-3}$ to $5.3*10^{-2}$ m^2/s and have a large degree of scatter which indicates that this part of the aquifer is heterogeneous. The arithmetic mean is $1.7*10^{-2}$ m^2/s. Using the thickness of the aquifer given in this report, this gives permeabilities of $4.5*10^{-5}$ to $1.5*10^{-3}$ m/s. This range is larger than the permeabilities determined in the pump tests reported in Böckh (1971) and encloses them. The arithmetic mean at $5.6*10^{-4}$ m/s is higher than the results from the pump tests presented in table 17. According to the results of the pump tests carried out in the Afshar area, the aquifer here would be classified as permeable to very permeable; on the basis of the results of the pump tests according to Böckh (1971), the Paghman aquifer would be classified as permeable according to DIN 18130. Because the Afshar area is only one part of the Paghman aquifer, the permeability evaluation used the figures of Böckh (1971) because the boreholes for his pump tests are spread throughout the aquifer. The storage coefficients for three of the five wells in the Afshar area are given as 0.1; $8.2*10^{-3}$, and 0.02. The storage coefficient of 0.1 given for well 6 lies in the range for free aquifers; the figure for well 6B at 0.02, and $8.2*10^{-3}$ for well 8 lie within the range for free and confined aquifers and therefore indicate semi-confined conditions in the aquifer in the tested area (AUST 1979). However, these results also only reflect the conditions in one part of the aquifer.

The depth to the groundwater table in the centre of the valley is fairly shallow but increases downstream and towards the sides of the valley. In 1962/1963, the groundwater table in the vicinity of the confluence of the Cheltan and Paghman rivers lay at a depth of 19 m.

Groundwater regeneration in the Paghman aquifer area is limited. Groundwater regeneration in May and March from infiltration from the bed of the Paghman river is given as 1.62 m^3/s. The values for the remaining months are much lower and give an average infiltration rate of 0.43 m^3/s (PROCTOR & REDFERN INT. LTD. 1972).

The discharge differences of the Karga and Paghman rivers after flowing through the aquifer zone are only of minor importance. This value only becomes noticeable when the river is in flood, but even during these times, only part of the loss actually benefits regeneration. In spring and during periods of strong precipitation, part of the water from the Paghman aquifer flows into the Karga reservoir which lies around 7 to 10 km outside of Kabul. The effect of this is to further decrease groundwater regeneration (BÖCKH 1971).

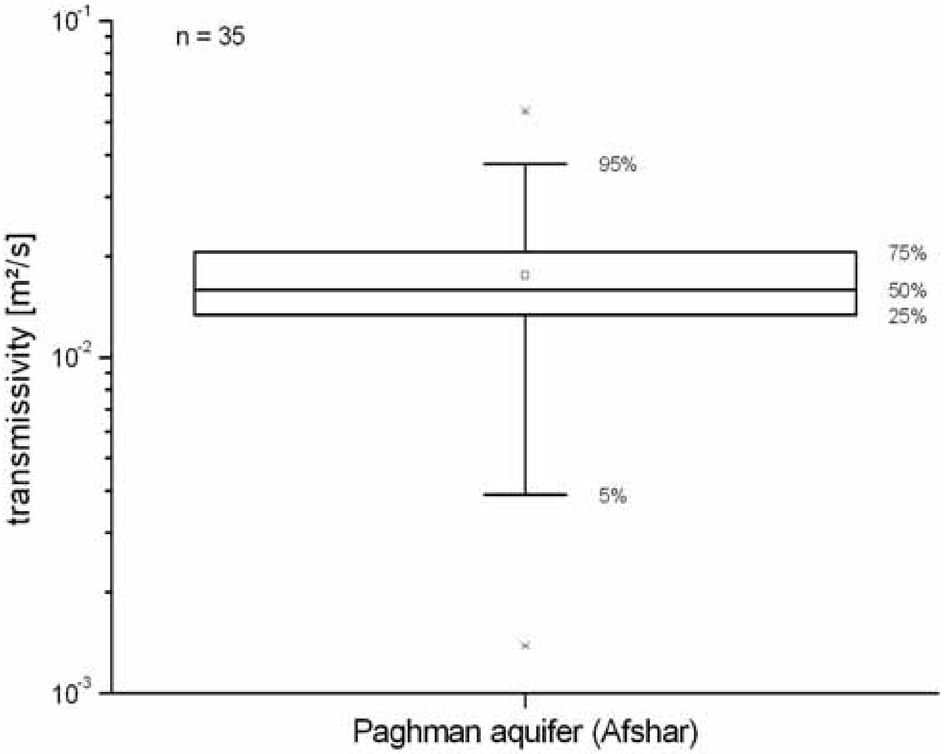


Fig. 2.10: Box-Whisker plot of transmissivities in the Paghman aquifer measured through pumping tests in the Afshar project zone (after data from AUST 1979).

The continuous output of the Paghman aquifer is estimated at around 0.5 m^3/s although neither the groundwater inflow nor the groundwater discharge were recorded during the observation period. 80 % of this continuous extraction is intended to supply drinking water to Kabul. The planned use of the groundwater in the Paghman aquifer during the 1960s resulted in a reduction in groundwater discharge in the deeper lying areas.

During dry periods, the groundwater discharge of the Paghman aquifer and the discharge of the aquifer of the upper Kabul river covers the shallow water demand of the lower part of the city of Kabul, and therefore contributes to the discharge of the lower Kabul aquifer into the Kabul Basin. This inflow is vital because it safeguards the production in the wells and thus the supply of water.

Table 2.18: Discharge differences in the Paghman aquifer area (BÖCKH 1971).

Average monthly discharge (Rivers and canals)		**Paghman gauge 5 (River and canals)**	**Karga gage 7 (River)**	**Cheltan gauge 8 (River and canals)**	**Total gauges 5. 7. 8**	**Paghman gauge 6 (downstream)**	**Discharge difference gauge 6 [m³/s]**
1962	October	0.03	0.00	0.00	0.03	0.00	-0.03
	November	0.03	0.00	0.00	0.03	0.01	-0.02
	December	0.03	0.00	0.00	0.03	0.29	+0.26
1963	January	0.04	0.13	0.00	0.17	0.37	+0.20
	February	0.04	0.11	-	0.15	0.15	0.00
	March	0.02	0.05	0.12	0.19	0.22	+0.03
	April	1.10	0.00	1.06	1.16	0.67	-0.49
	May	1.92	0.26	3.61	5.79	3.77	-2.02
	June	0.37	0.00	0.06	0.43	0.07	-0.36
	July	0.19	0.00	0.05	0.24	0.01	-0.23
	August	0.10	0.00	0.02	0.12	0.01	-0.11
	September	0.06		0.02	0.08	0.00	-0.08
Annual average		0.24	0.05	0.41	0.70	0.46	-0.24

According to PROCTOR & REDFERN INT. LTD. (1972) the groundwater potential comprises the following components:

Table 2.19: Groundwater potential in the Paghman aquifer (PROCTOR & REDFERN INT. LTD. 1972)

Source	**Inflow [m³/s]**	**Inflow [m³/day]**	**Proportion [%]**
Inflow from precipitation	0.05	4 300	10.42
Infiltration through the river bed	0.43	36 800	89.58
Total	0.48	41 100	100.00

Infiltration through the river bed also accounts for easily the largest share of groundwater regeneration in the Paghman aquifer (table 2.19). The proportion of regeneration attributable to the inflow of precipitation is slightly higher than in the Kabul and Logar aquifers even though these basins are larger than the Paghman aquifer. This is probably because the total inflow to the Paghman aquifer is relatively low compared to the data from the other two aquifers. Additionally, in the Paghman the loess cover close to the river is often missing due to erosion, leaving the aquifer gravels exposed.

3 Climate data in the Kabul Basin

3.1 Precipitation

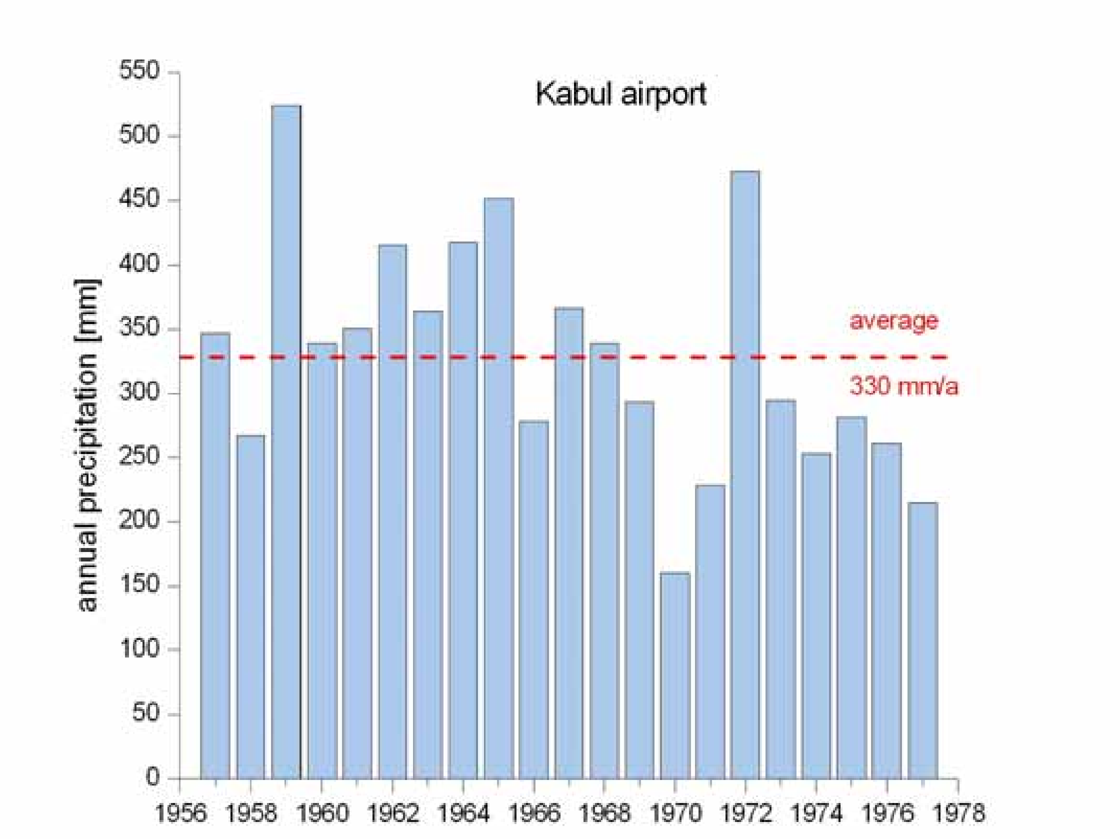


Fig. 3.1: Precipitation in Kabul airport 1957 - 1977 as annual averages

Precipitation data for Kabul recorded at the airport are available as monthly averages for the period from 1957 - 1977 (Fig. 3.2 and Fig. 3.3.) Annual averages have been calculated from this data (Fig. 3.1). The graph clearly shows the major fluctuations from year to year: for instance, the average annual precipitation in 1959 was around 520 mm, whilst precipitation was only slightly over 155 mm in 1970. The average figure for the 21 years covered by this data is 330 mm, and therefore reflects a very dry climate.

The standard year constructed from the monthly average figures for 1957 - 1977 (Figs. 3.2, Fig. 3.3) highlights the change in precipitation during the course of a typical year.

The monthly precipitation in winter and spring changes between 20 to 80 mm. In summer, i.e. the period from June to October, the precipitation is considerably below 3 mm - with one exception.

The scatter of the precipitation figures in the standard year is very irregular during the course of the year (Fig. 3.3). Considerable deviation is seen in the months with relatively high precipitation rates. The figures are relatively constant over the whole of the observation period for the months with very low precipitation.

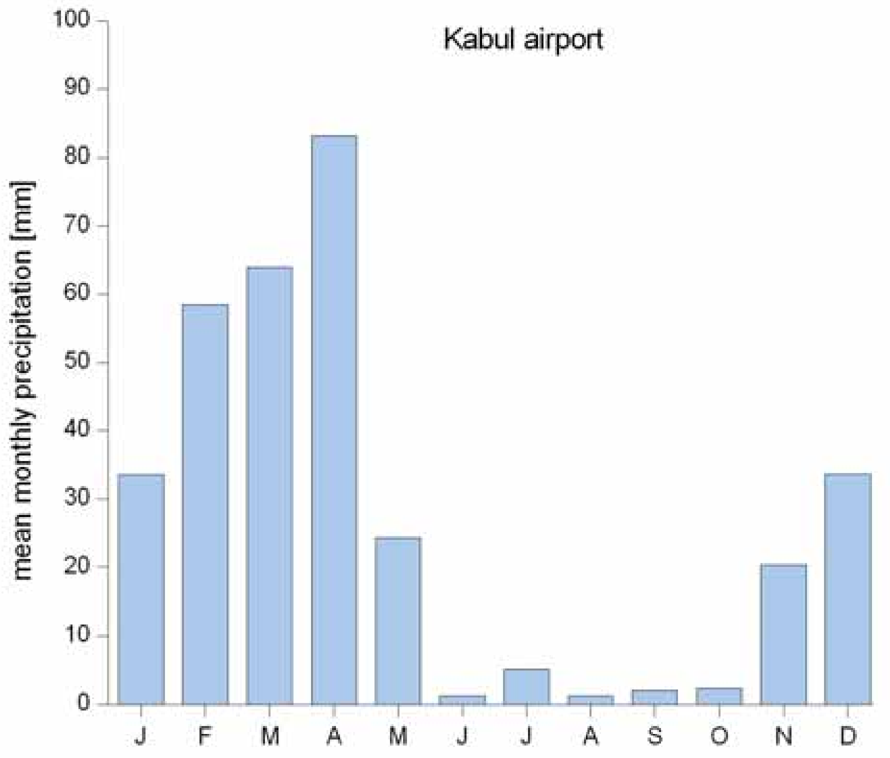


Fig. 3.2: Precipitation in Kabul airport in monthly averages 1957 - 1977

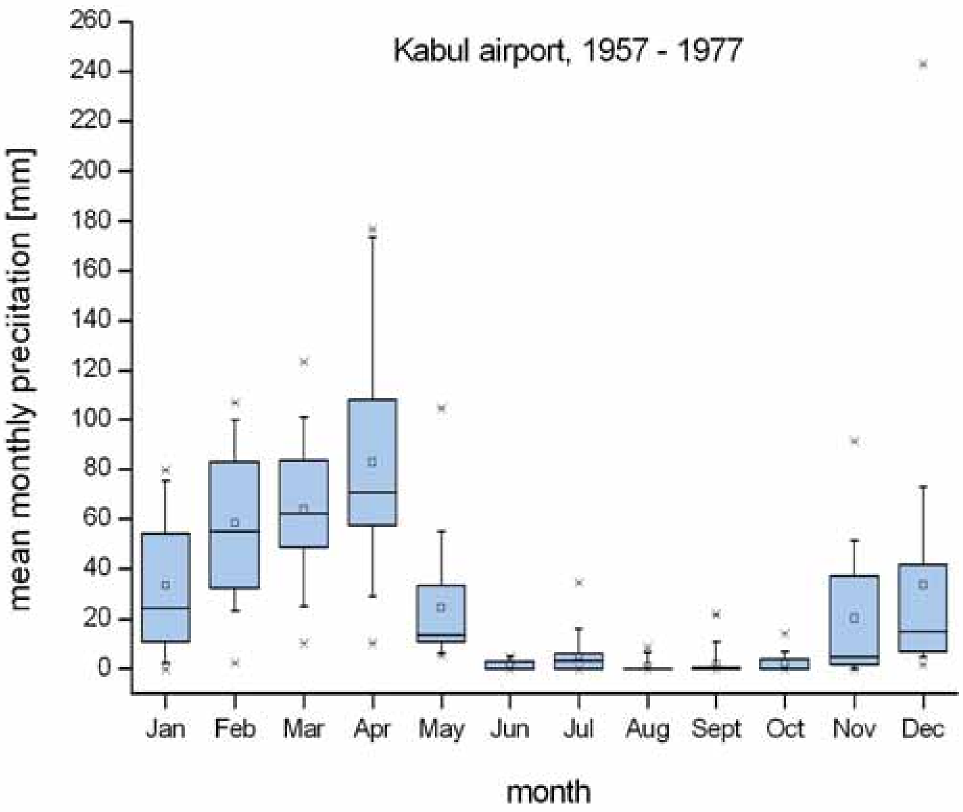


Fig. 3.3: Box-Whisker diagram of average monthly precipitation in Kabul airport measured from 1957 - 1977

Precipitation in winter is mainly in the form of snow. Snow fall data for Kabul is available for 1958 - 1971 (PROCTOR & REDFERN INT. LTD. 1972). The year with the most snow was the winter of 1963/64 with almost a meter of snow. However, it only snowed on 62 days during this winter compared to 81 days of snow altogether for the winter of 1966/67 when only 33 cm of snow fell (table 3.1). The months with the greatest snow fall during the observation period are January and February with an average snow fall of 14.5 and 17 cm respectively. The average number of days with snow fall is approx. 15 days (Fig. 3.4). The month with the longest period of snow fall is December with an average of approx. 23 days. However, only approx. 6.2 cm snow falls in this month on average (PROCTOR & REDFERN INT. LTD. 1972). There is no obvious correlation between the total precipitation and the figures for snow fall over the observation period (Fig. 3.5).

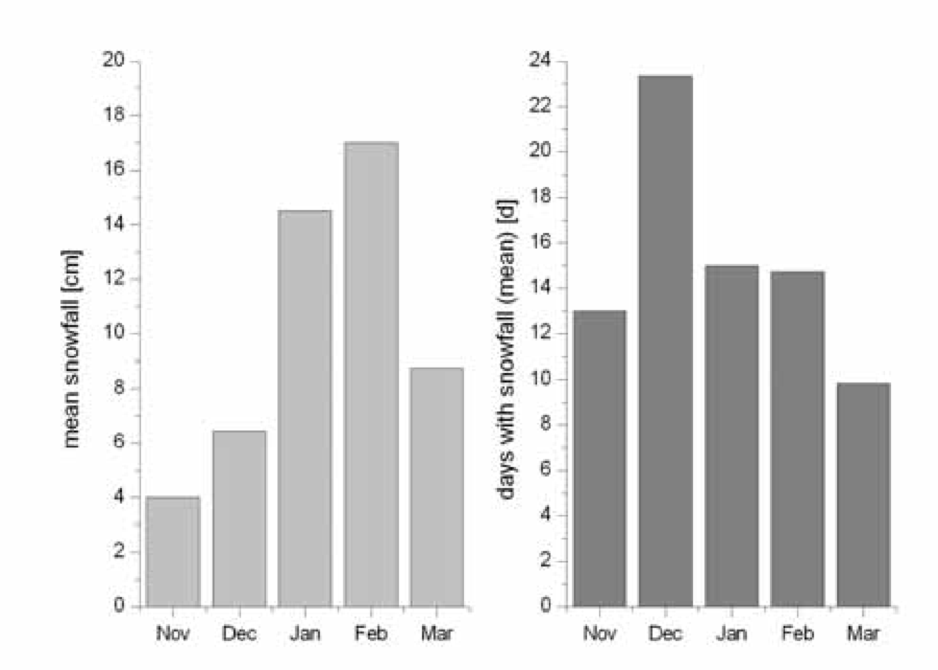


Fig. 3.4: Average monthly snow fall in Kabul from 1957 - 1971 (after data from PROCTOR & REDFERN INT. LTD. 1972)

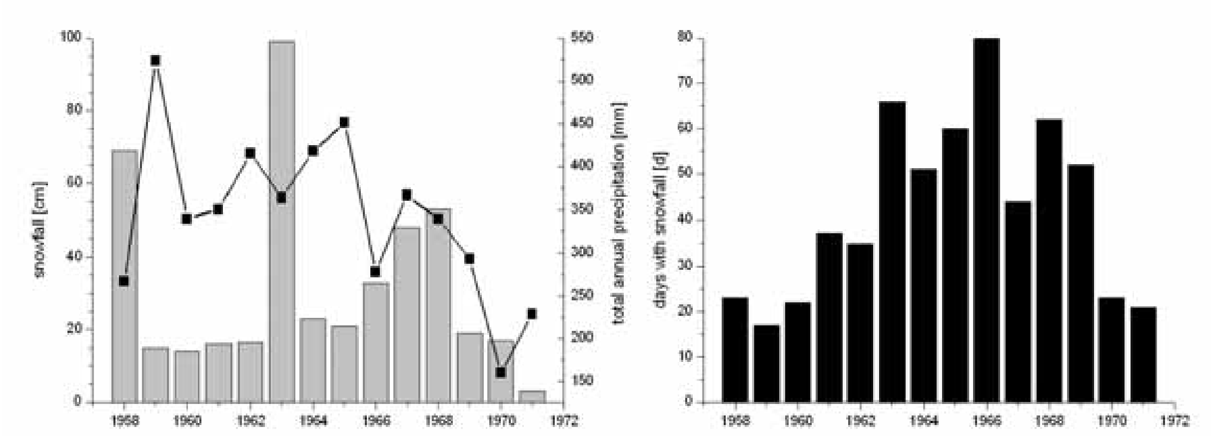


Fig. 3.5: Snow fall (after data from PROCTOR & REDFERN INT. LTD. 1972) and precipitation in Kabul in annual averages from 1958 - 1971

Table 3.1: Snow fall in Kabul 1958-1971 (PROCTOR & REDFERN INT. LTD. 1972).

Winter	**November**		**December**		**January**		**February**		**March**		**Total**	**Total**
	[cm]	**[days]**	**[cm]**	**[days]**	**[cm]**	**[days]**	**[cm]**	**[days]**	**[cm]**	**[days]**	**[cm]**	**[days]**
1958 – 59					4	4	45	18	20	1	69	23
1959 – 60			15	17							15	17
1960 – 61							7	11	7	11	14	22
1961 – 62			4	23	10	4	2	10			16	37
1962 – 63			16	26					0.5	9	16.5	35
1963 – 64	4	13	5	28	44	7	28	15	18	3	99	66
1964 – 65			2	11	7	16	14	24			23	51
1965 – 66			5	24	11	15	5	21			21	60
1966 – 67			2	30	1	6	28	20	2	25	33	81
1967 – 68					19	29	24	5	5	10	48	55
1968 – 69			6	30	26	31	21	1			53	62
1969 – 70					17	24	2	28			19	52
1970 – 71					6	14	11	9			17	23
1971			3	21							3	21
Maximum	**4**	**13**	**16**	**630**	**55**	**31**	**45**	**28**	**20**	**25**	**99**	**81**
Average	**4.00**	**13.00**	**6.44**	**23.33**	**14.50**	**15.00**	**17.00**	**14.73**	**8.75**	**9.83**	**31.89**	**42.43**

3.2 Temperature

The temperature values for Kabul which are also measured at the airport are also present in the form of monthly averages for 1957 - 1977 (Figs. 3.8, Fig. 3.9) and the annual averages calculated from these figures (Fig. 3.6). These plots also show fluctuations. In 1964, the annual average temperature was only slightly over 10 °C whilst the annual average temperature in 1970 was almost 13 °C.
A comparison of the precipitation and temperature plots during the observation period clearly shows that years with high average temperatures also have low precipitation. If the annual average temperature is relatively low, they usually correspond with above average precipitation (Fig. 3.7). These facts highlight the irregular climatic conditions revealed for the 21 year observation period by the precipitation and temperature changes.

A standard temperature distribution for a typical year can be derived from the monthly averages from 1957 - 1977 (Fig. 3.9). The average temperatures during the course of the year vary between - 3 °C in the winter months and 25 °C in the summer.

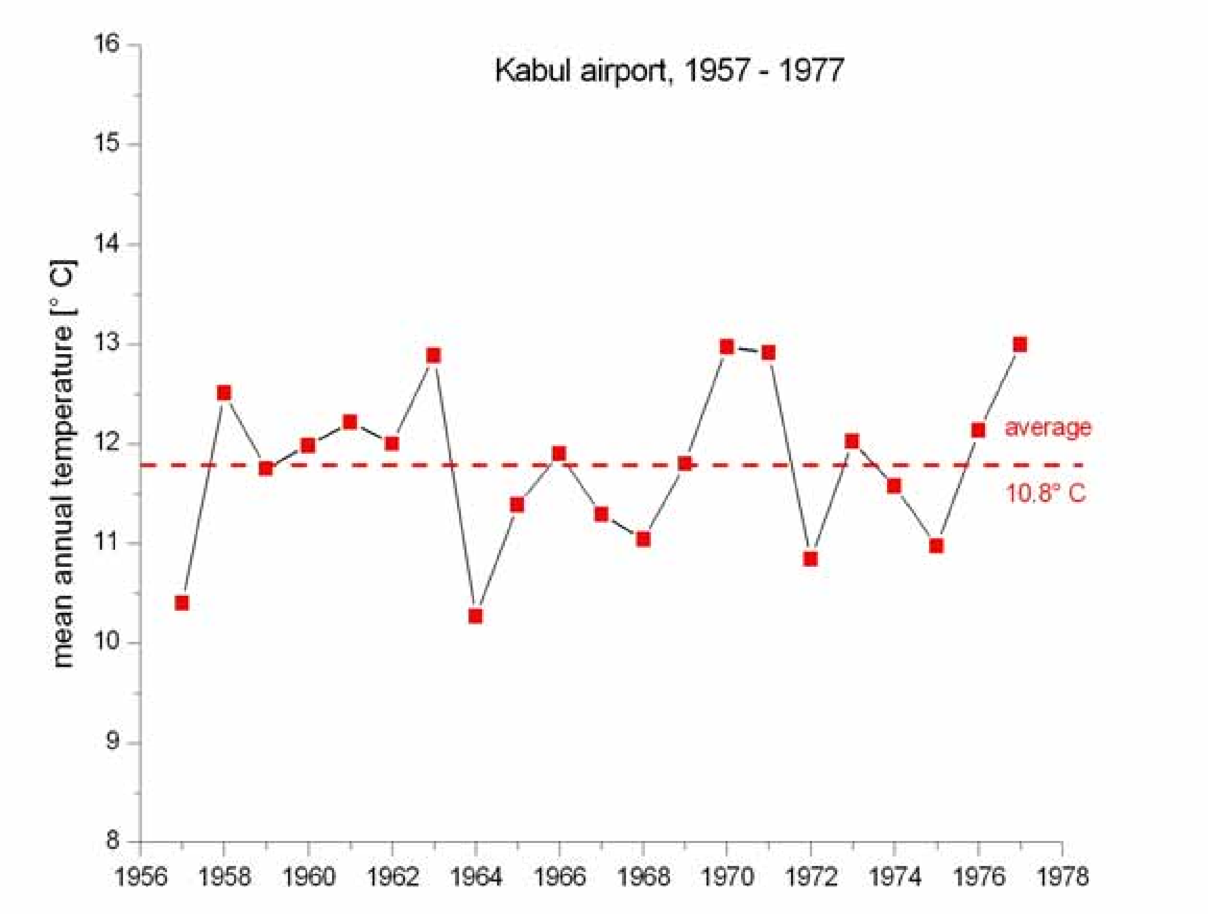


Fig. 3.6: Temperature data from Kabul airport 1957 - 1977 as annual averages.

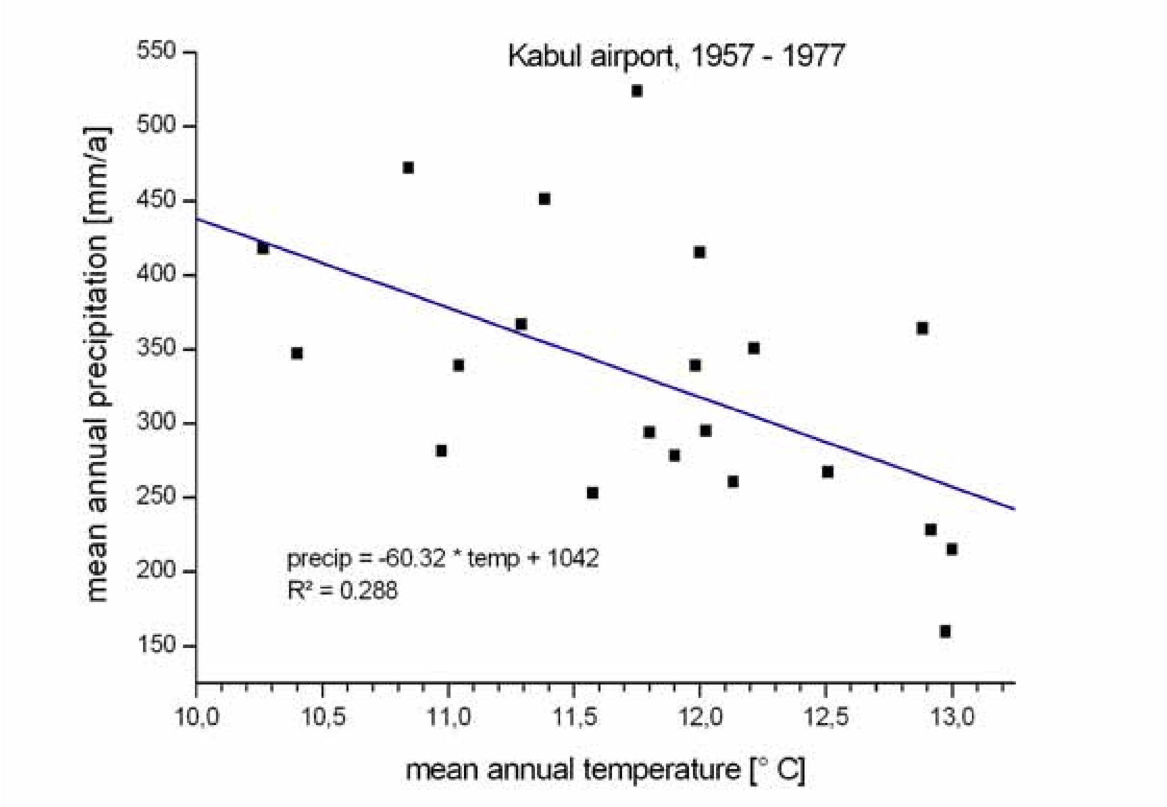


Fig. 3.7: Correlation between annual precipitation / annual average temperature in Kabul 1957 - 1977.

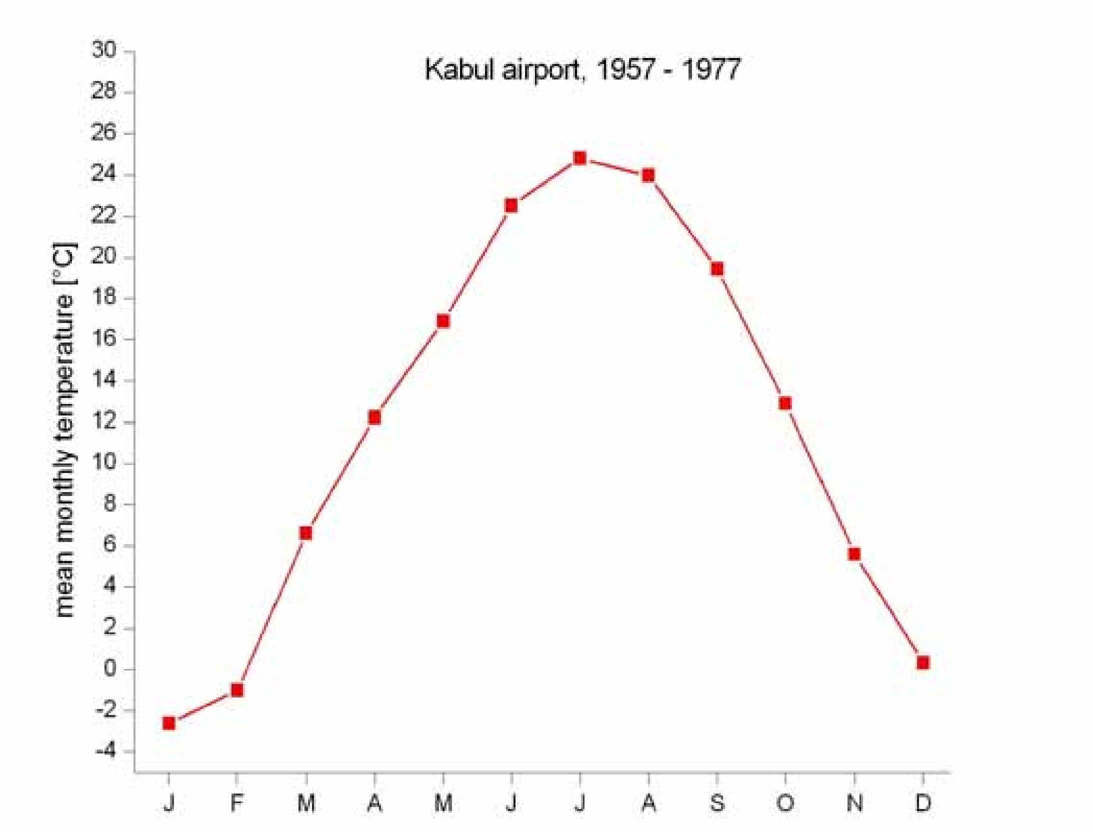


Fig. 3.8: Temperature in Kabul in monthly averages 1957 - 1977.

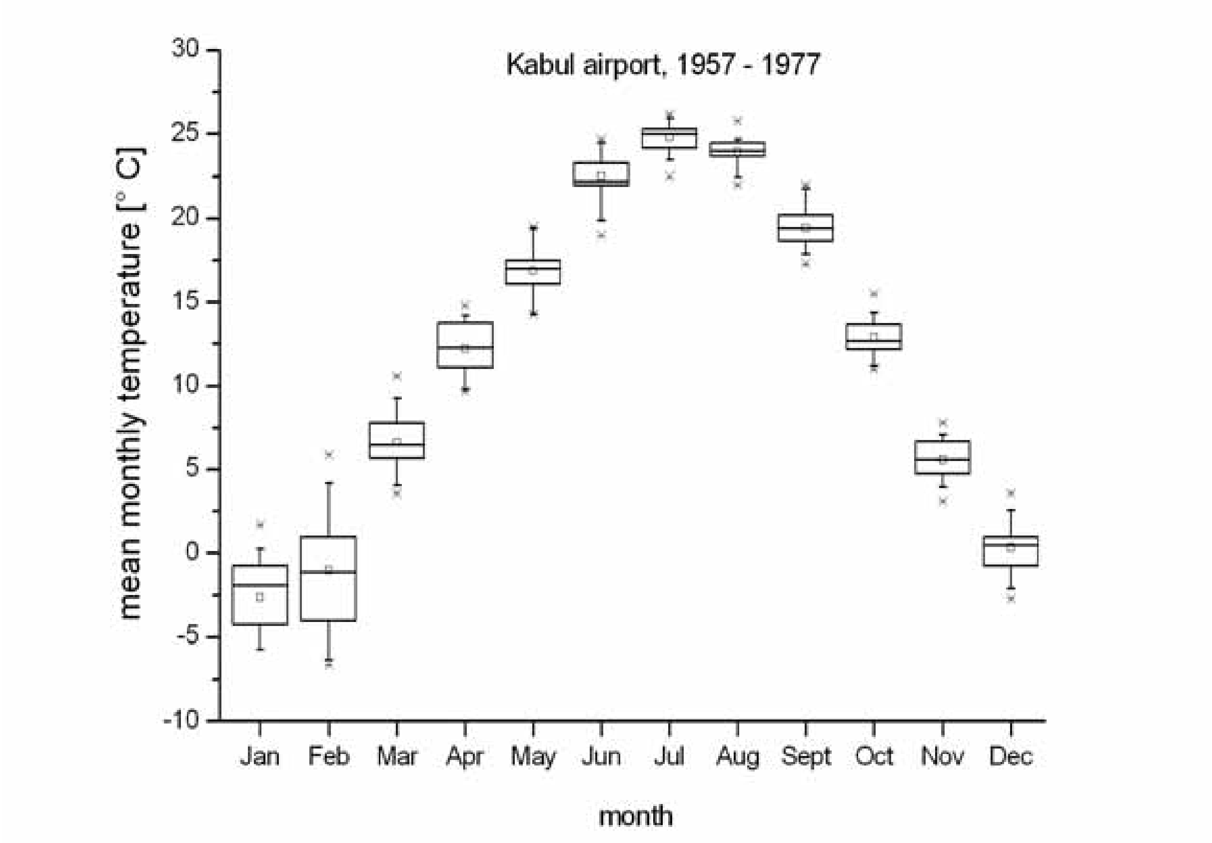


Fig. 3.9: Box-Whisker diagram of average monthly temperatures in Kabul 1957-1977.

The Box-Whisker diagram showing temperature data for a standard year (Fig. 3.9) shows that with the exception of February and August, the average monthly temperature changes are relatively small throughout the year. The deviations in February are above average, whilst the deviations in August are very low.

3.3 Air humidity

The air humidity in Kabul was also measured BÖCKH (1971) but no information was documented how and where exactly the data were taken. The annual average is about 54 % (Fig. 3.10). The months with well below average air humidities coincide with the months with the highest temperatures in the standard year (Fig. 3.10).

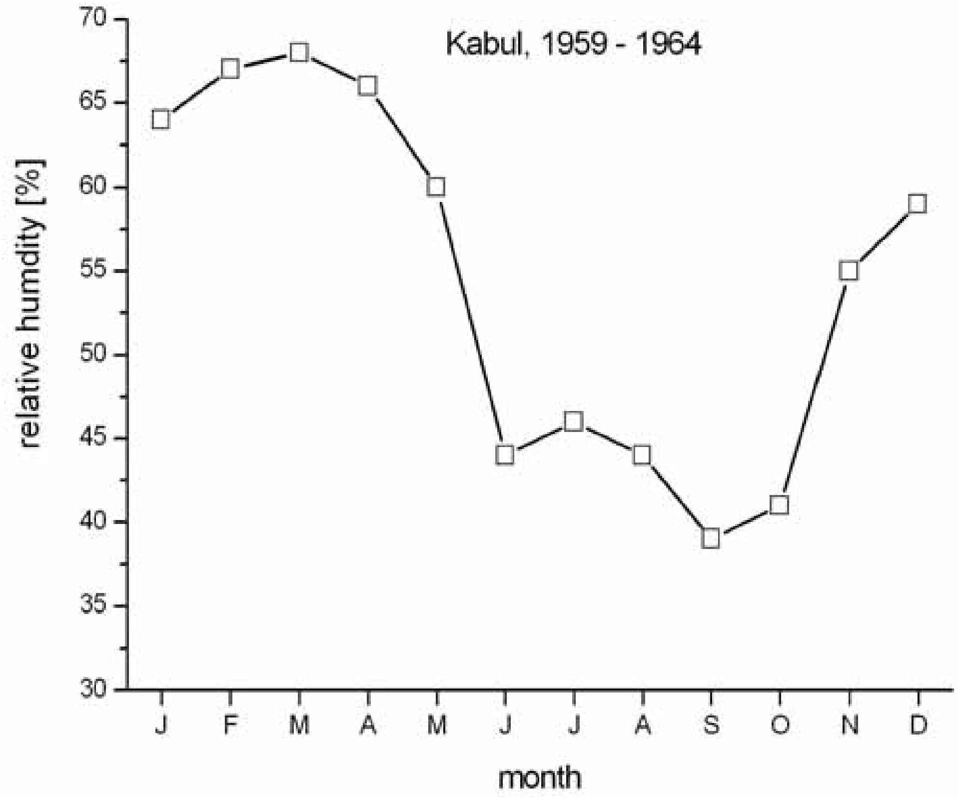


Fig. 3.10: Relative air humidity in Kabul from 1959 - 1964 in average monthly values (after data from BÖCKH 1971).

3.4 Evaporation and evapo-transpiration

3.4.1 Evaporation

Estimated monthly evaporation figures for 1959 - 1964 are also available from BÖCKH (1971) (Fig. 3.11). However, there is again no information available on which method was used to determine these values.

The curve shows that evaporation is naturally at a maximum in the months with the highest average temperatures. Because the evaporation figures exclusively reflect evaporation from an open water body or an open area on the ground and do not represent actual evaporation, they were not used for any other calculations, particularly because the calculation method is unknown.

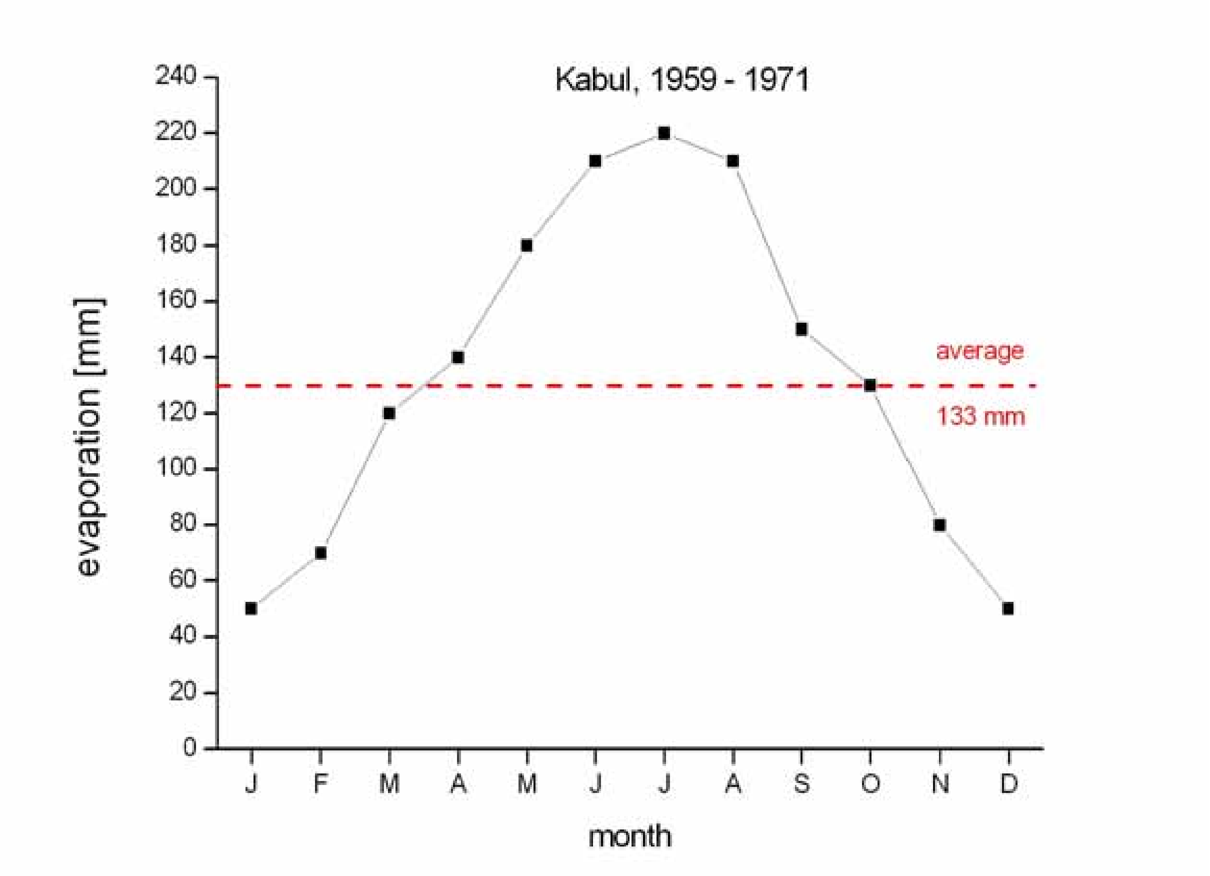


Fig. 3.11: Estimated monthly evaporation figures for Kabul for 1959 - 1971 (after data from BÖCKH 1971)

3.4.2 Evapotranspiration

Evapotranspiration is determined as part of this study using two different formulae: the first with the help of average monthly figures, and the second, taking into consideration the annual averages for temperature, precipitation and air humidity.

A modified IVANOV approach was used to calculate potential evapotranspiration (Eq. 3.1):

$$ET_{p\ Ivanov} = 0.0011 \text{ X } (T + 25)^2 \text{ x } (100 - U) \qquad \text{Eq. 3.1}$$

T = mean monthly temperature [mm], U = relative humidity [%]

This equation can be used to calculate the monthly evapo-transpiration from the average monthly figures for air temperature and air humidity. The advantage of this method is that it can also take negative temperatures into consideration. The input data for the calculation was the temperature data recorded at Kabul airport from 1957 to 1977, and the average monthly air humidity for 1959 - 1964 (Figs. 3.8, Fig. 3.10).

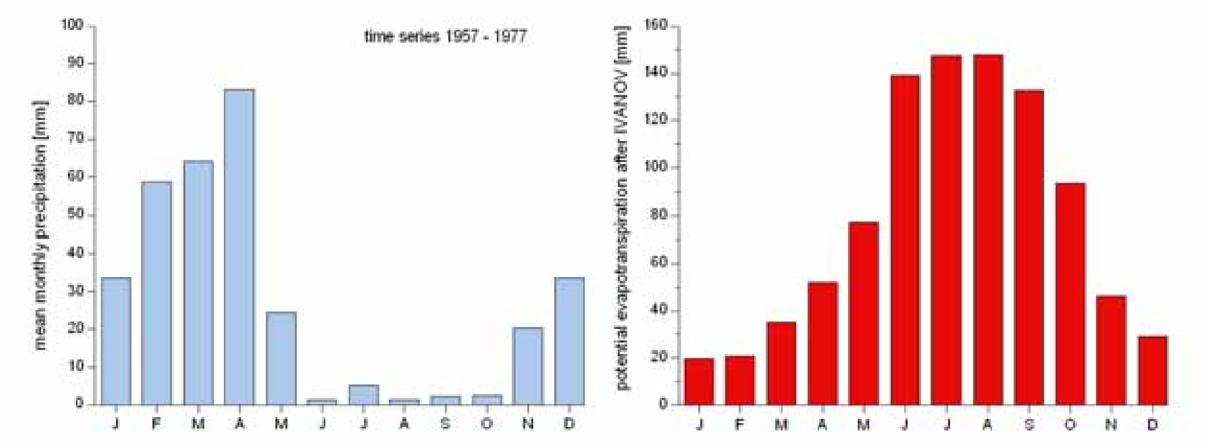


Fig. 3.12: Comparison of monthly averages for precipitation and potential evaporation after IVANOV for 1957 - 1977.

The comparison of precipitation with the potential evapo-transpiration calculated after IVANOV (Fig. 3.12) clearly shows that evaporation from April to November is much higher than the precipitation - usually with a difference of over 120 mm. This situation is also clearly seen in Fig. 3.13 that shows the difference between fallen precipitation and calculated evapo-transpiration. According to this, groundwater regeneration - if at all - only takes place from December to April. However, because precipitation during this period mainly falls in the form of snow and is therefore lost during snow melting, partially also by surface discharge, the volume of precipitation actually available for groundwater regeneration is probably much lower, particularly because part of the assumed excess serves to maintain or re-establish the moisture of the soil (PROCTOR & REDFERN INT. LTD. 1972).

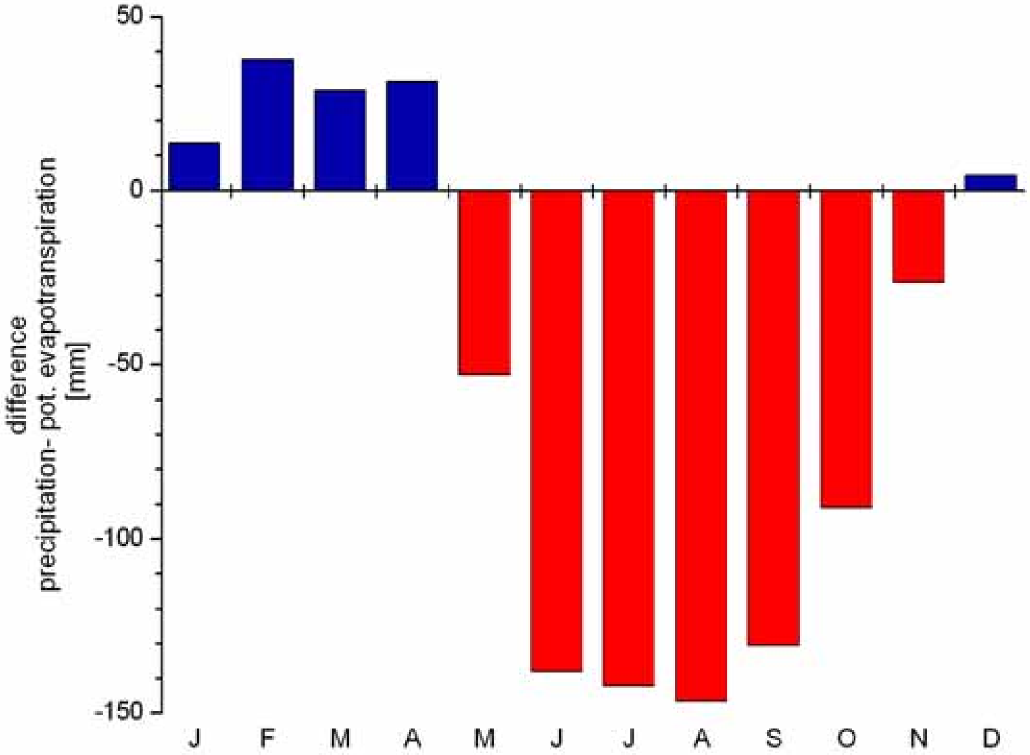


Fig. 3:13: Difference between the average monthly figures for precipitation and evaporation after IVANOV from 1957 - 1977.

Approximate annual averages for real evapo-transpiration can be calculated using the equation after TURC (Eq. 3.2).

$$ET_{real} = \frac{N}{[0.9 + (N/J_t)^2]^{0.5}} \qquad \text{Eq. 3.2}$$

The input values are the precipitation and temperature figures recorded at Kabul airport from 1957 - 1977, or the averages calculated from these data (Fig. 3.1 and Fig. 3.6). Fig. 3.14 clearly shows that the evapo-transpiration largely coincides with the degree of precipitation. If there is more precipitation, more water is available for evaporation. Because the real evapo-transpiration in almost all years is below the figure of fallen precipitation (Fig. 3.14) it is possible in theory that groundwater recharge took place in all years which fulfil this criterion. However, because the discharge or the proportion of precipitation which fell as snow, and other losses are not taken into consideration in this balance, it is only possible to make comments here on the possibilities of groundwater recharge, particularly because the influence of buildings and vegetation is unknown.

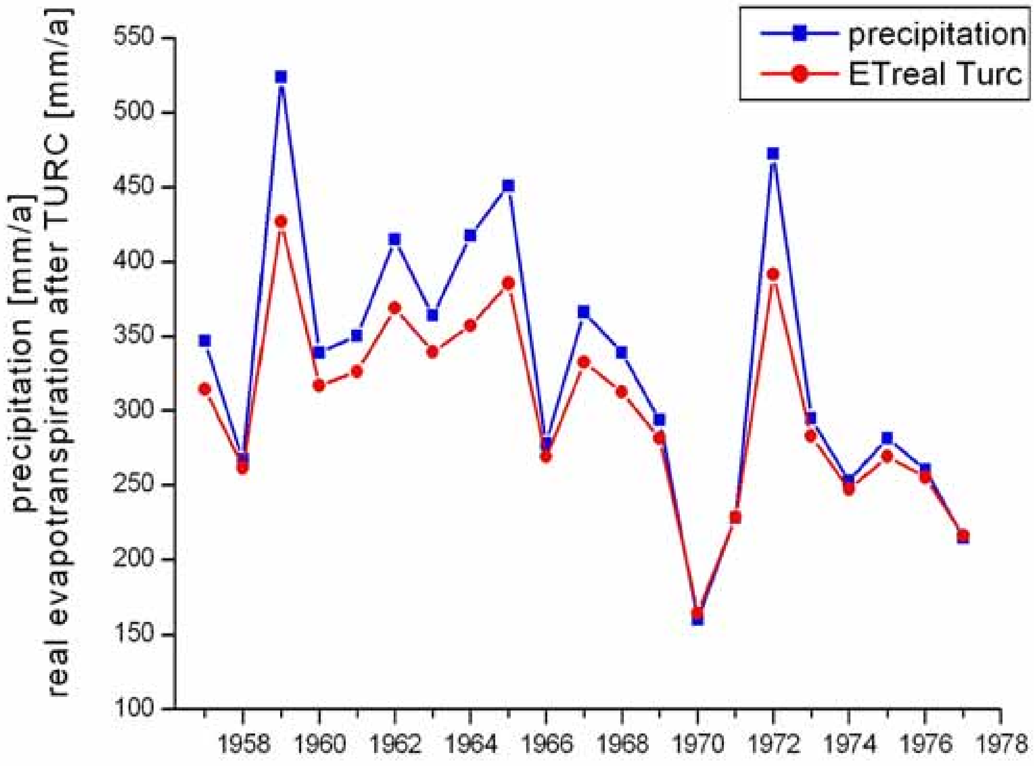


Fig. 3.14: Comparison between precipitation and evapo-transpiration after TURC in Kabul from 1957 - 1977.

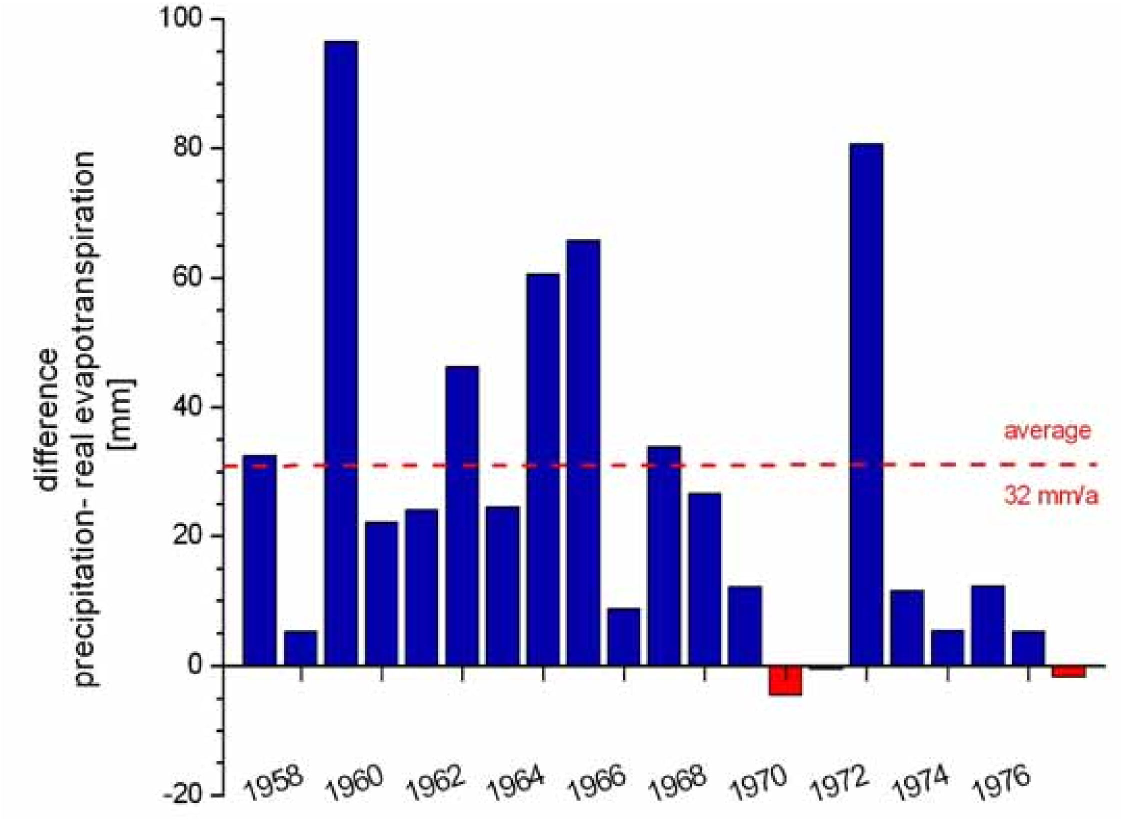


Fig. 3.15: Comparison of the annual averages for precipitation and real evapotranspiration after TURC for 1957 - 1977.

The average possible groundwater regeneration is 32 mm/year ignoring the losses and discharge during the observation period. This figure can therefore be taken as the maximum possible groundwater regeneration rate. The annual groundwater regeneration in Germany is between 100 to 600 mm. On average, 200 mm groundwater are regenerated per year (www.fbw.fh-wiesbaden.de).

Because the figure for Kabul does not include any losses and also because the precipitation falling in the form of snow has not been given special consideration, one can assume that it is unlikely that groundwater regeneration took place from 1957 to 1977 directly from precipitation in the investigation area, and that it is also probably not taking place today.

3.5 Wind direction and speed

The Karizimir weather station recorded wind direction and speed data from 1959 to 1964 (table 3.2). Karizimir lies around 17 km to the north-west of Kabul. Winds which primarily blow from north, south and the north-west, are largely constant throughout the year and have high wind speeds. The average wind speed in the first half of the year is almost twice as high as the second half. Periods of calm occurred on average 67 days a year during the observation period.

Table. 3.2: Wind direction and speed in Karizimir from 1959-1964 (JIDIKOV 1970)

Wind direction	**N**	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**	**Calm**	**Speed [m/s]**	
Month	**[d]**	**[d]**	**[d]**	**[d]**	**[d]**	**[d]**	**[d]**	**[d]**	**[d]**	**max**	**average**
January	2.5	2.7	2	2	8	6	2	1.5	4.3	18	3.4
February	1.8	2	0.8	2.2	10.3	3	3	1	3.5	16	3.2
March	3.3	1.5	1.2	2.8	4.8	3.5	4.3	2.8.	6.8	24	3.1
April	4.5	2.8	1.6	1.8	4	1.5	3.5	3.4	6.9	16	3.3
May	2.7	3.8	2.6	3.7	6.5	1.8.	2.7	3.4	3.7	22	3.8
June	7.2	3.2	0.5	2.6	3	1.8	4.2	3.4	4	16	3
July	7.5	2.7	1.2	1.8	3.6	0.2	2	3.3	8.7	18	1.3
August	6.3	1.5	1.8	2	2.8	0.5	1.2	6.4	8.5	16	1.1
September	5.4	2.4	2.5	2	3.2	0.5	2.2	4.8	7	10	1.1
October	5.2	1.6	2	2.2	4.7	1.8	1.6	6.4	5.5	18	1.3
November	5	2	2.3	1.7	5.6	0.8	3.8	5.6	4.2	14	1.5
December	2.8	2.6	1	3.1	8.5	2.2	3	2.8	5	16	1.9
Days per year	53	30	20	28	64	24	34	45	67		
% of the year	14.5	8.2	5.5	7.7	17.5	6.6	9.3	12.3	18.4		

The current drought in Kabul which has lasted for approx. six years has caused the loss of vegetation cover. This is particularly obvious in the Dhi Shabs region - literally the "green valley" in the north of Kabul, where there is no more vegetation cover on the dry soil (Fig. 3.16). The fine-grained soils in this area, such as the soils formed from loess, are eroded by the wind which causes the loss of agricultural land and generates dust storms (Fig. 3.17).

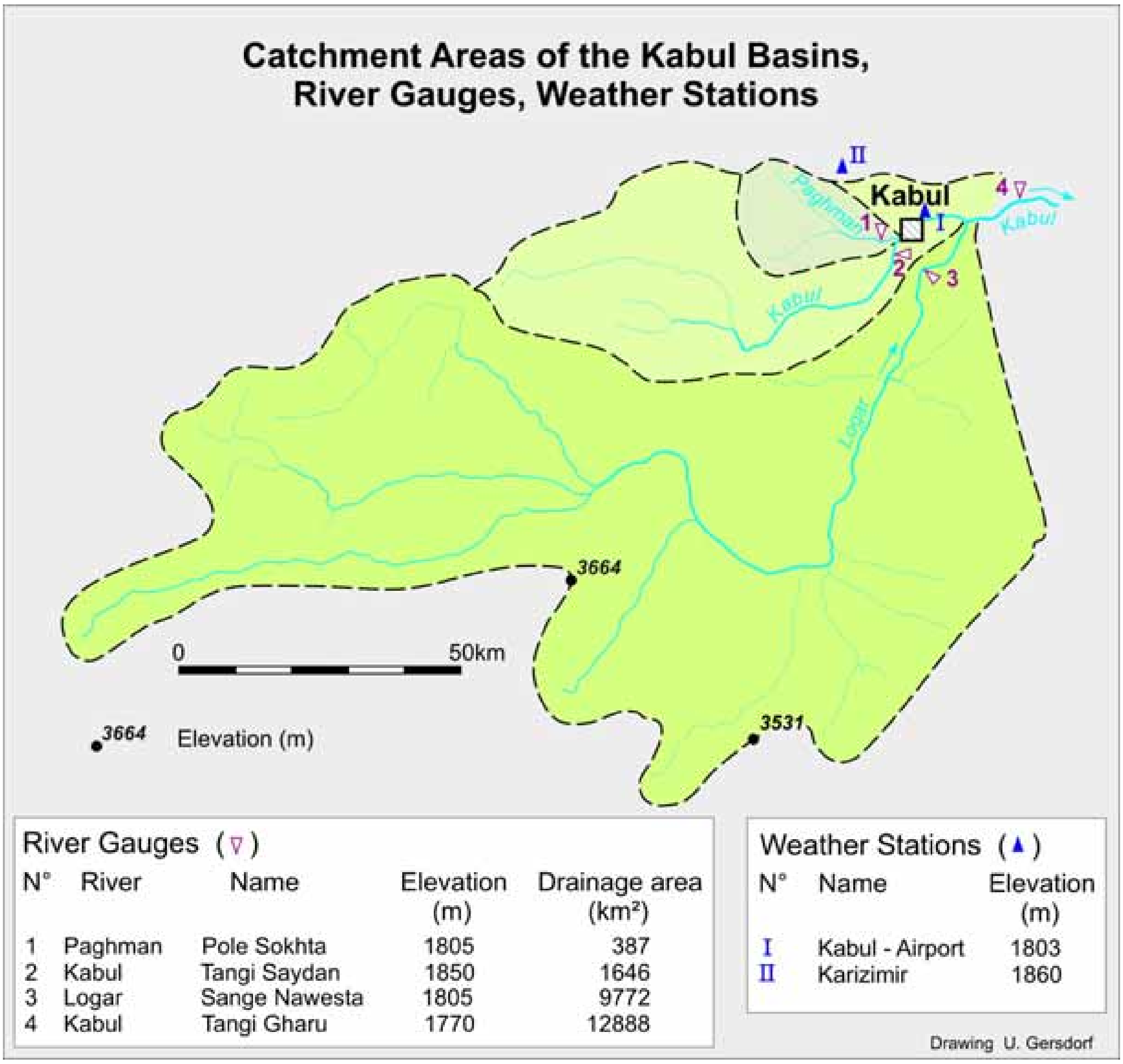
Fig. 3.16: Dhi Shabs region (= green valley) north of Kabul in 2004 (Photo: HOUBEN).

Fig. 3.17: Dust storm approaching Kabul in 2004 (Photo: TÜNNERMEIER).

4. Hydrography

4.1 Rivers of the Kabul basin

There is an enormous range in size of the catchment areas of the Logar, Kabul and Paghman rivers. The discharges of the Logar and the Paghman rivers were each measured at one gauge, whilst the discharge of the Kabul river was measured from two gauges, one upstream of the confluence of the Paghman and Kabul rivers, and one downstream of the confluence of the Logar and the Kabul river (Fig. 4.1).



River Gauges (▽)

N°	River	Name	Elevation (m)	Drainage area (km²)
1	Paghman	Pole Sokhta	1805	387
2	Kabul	Tangi Saydan	1850	1646
3	Logar	Sange Nawesta	1805	9772
4	Kabul	Tangi Gharu	1770	12888

Weather Stations (▲)

N°	Name	Elevation (m)
I	Kabul - Airport	1803
II	Karizimir	1860

Fig. 4.1: Catchment areas and river gauges in the Kabul Basin (BÖCKH 1971)

4.2 Logar river

The Logar river flows into the Kabul Basin from a southerly direction and flows into the Kabul river in the southern part of the basin. The Kabul river flows out of the Kabul Basin in an easterly direction. According to a 1971 report, the Logar drained 78 % of the total catchment area of the Kabul Basin to the point where it flows into the Kabul river (Fig. 4.1). The recorded drainage figures (Fig. 4.2) show that the annual drainage from October 1961 to September 1964 fluctuated between 8.9 m^3/s and

10.8 m^3/s. A base flow of 1 m^3/s was not reached in this time period for four months in 1962 and 1964. In the 1964 hydrological year, the gauges recorded discharges below 50 l/s for a period of 79 days (table 4.1) (BÖCKH 1971).

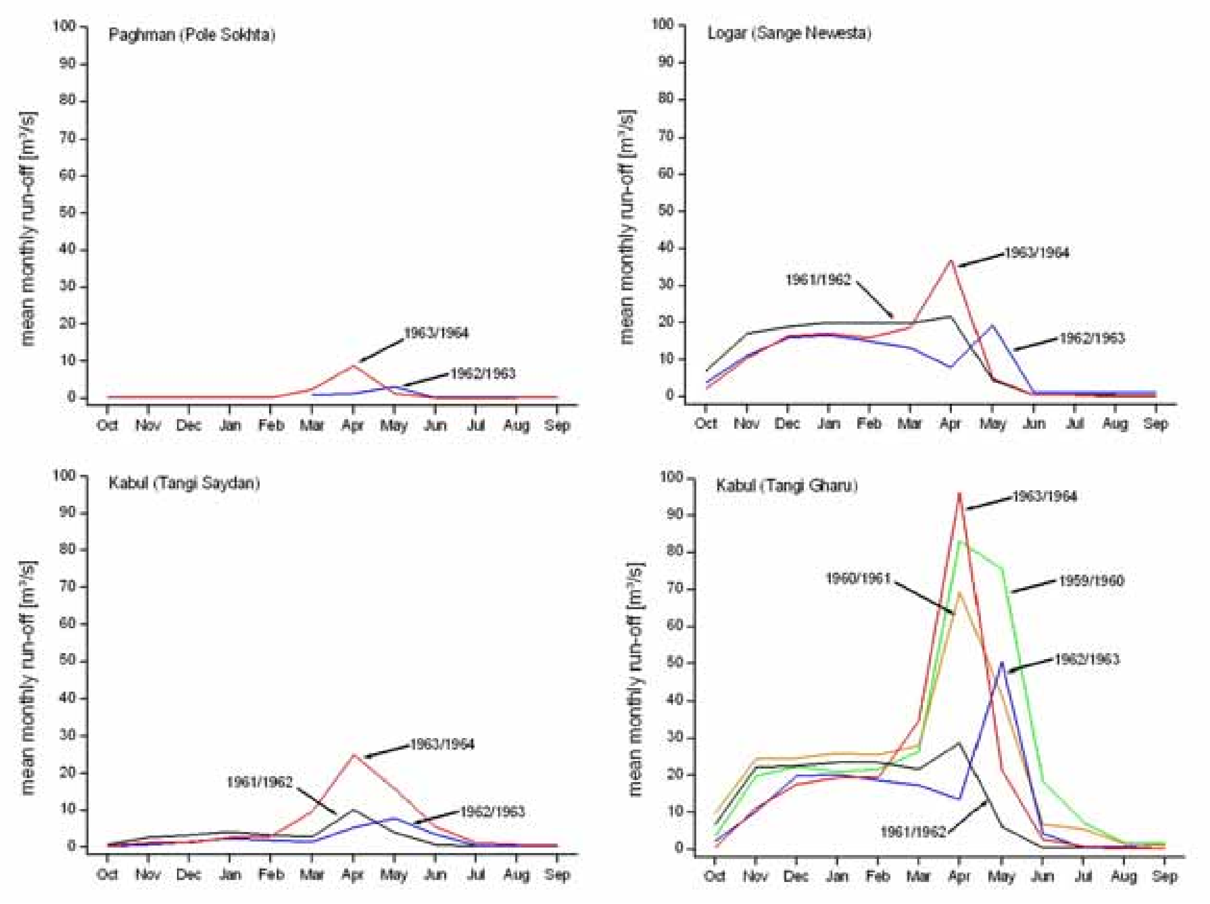


Fig. 4.2: River runoff in the Kabul basin (after data from BÖCKH 1971). Paghman river at Pole Sokhta gauge; Logar river at the Sange Newesta gauge; Kabul river at the Tangi Saydan gauge (upstream of the confluence with the Paghman and the Logar rivers); Kabul river at the Tangi Gharu gauge (after the confluence of the Paghman and Logar rivers).

The drainage hydrographs clearly show a significant correlation between precipitation and drainage. The drainage of the Logar has much higher figures in the period from November to May - the months when most of the annual precipitation falls - than in the months from June to October when hardly any precipitation takes place. The drainage peak is in April or in the case of the 1963 hydrogeological year, May. The standard year constructed from the monthly averages from 1957 to 1977 (Figs. 3.2, 3.3) also has the highest precipitation in April. The peak shift between maximum precipitation and maximum drainage is therefore probably small although no precise calculation of the shift is possible because only monthly figures are available for precipitation and discharge.

4.3 Kabul river

The Kabul river flows into the Paghman-Darulaman basin from the south-west. The Paghman river flows into the Kabul river shortly before the Kabul river enters the Kabul Basin. The Kabul river then flows through the southern part of the Kabul Basin and leaves the basin towards the east shortly after the confluence with the Logar. The Kabul river ultimately flows into the Indus, Pakistan's most important river. According to 1971 reports, part of the flow from the Kabul river was diverted into the Kahirabad basin before the Kabul river enters the Kabul Basin. The river drains around 13 % of the catchment area of the Kabul Basin (Fig. 4.1). Average annual discharge fluctuated from October 1961 to September 1964 between 2.23 m^3/s to 5.62 m^3/s (Fig. 4.2). Discharges below 1 m^3/s were recorded in the 1962 water year for 6 months, in the 1963 water year for 4 months and in the 1964 water year for two months (table 4.1) (BÖCKH 1971).

The discharge of the Kabul river measured at the Tangi Saydan gauge (Fig. 4.1) upstream of the confluence of the Paghman and Logar rivers is much lower than the discharge measured in the Tangy Gharu gauge (Fig. 4.2) after the confluence. The Tangi Gharu gauge has the longest series of recordings covering a period of five years. The discharge hydrographs for the Kabul river also clearly show that the change in discharge in the river is directly related to precipitation. From November to March, the period with the largest proportion of annual precipitation, there is a relatively regular discharge which reaches a maximum in April, or in a similar way to the Logar river, also in May in 1963. The standard year (Fig. 3.2, 3.3) also gives April as the time of maximum recorded precipitation. From June to September, which is the period with the lowest precipitation, there is hardly any water flow in the Kabul river. If one compares the data for April and May, the months with the highest discharge and precipitation rates for 1963 and 1964 (the years for which data is available from all of the gauges), then it is clear that the Kabul river has a higher discharge after the confluence of the Paghman and Logar after leaving the Kabul Basin than calculated from the discharges of the two rivers flowing into the Kabul river and the Kabul river itself upstream of the confluences. This indicates that during periods of higher precipitation, a large proportion of the water flows from the surface directly into the Kabul river, particularly because the discharge of the Kabul river from November to March upon leaving the Kabul Basin only corresponds to the total discharges of the other upstream gauges. However, there is no data on the contribution of the groundwater inflow to the raised discharges of the Kabul river at the Tangi Gharu gauge in May and April.

4.4 Paghman river

The Paghman river, which drained around 3 - 5 % of the Kabul Basin catchment area in 1971, flows into the Kabul river in the Paghman-Darulaman basin. The Kabul river then flows into the Kabul Basin from the south-west. The discharge (Fig. 4.2) is irregular and strongly effected by the extraction of irrigation water. Average discharges of 0.9 m^3/s were recorded in the 1963/64 hydrological year at the Pule Sokhta gauge (Fig. 4.1). The Paghman therefore has the smallest discharge of all the rivers in the Kabul Basin. In the Paghman river a discharge higher than 1 m^3/s was only exceeded in five months during the March 1963 to September 1964 observation period. The daily discharge minimum is 20 l/s (BÖCKH 1971).

The discharge hydrographs of the Paghman also clearly show the relationship between precipitation and discharge. The discharge peaks also occur here in April just as in the gauges reported for the other rivers. This is the month in the standard year with the highest precipitation (with the exception of 1963 when maximum precipitation occured in May).

The fact that the maximum discharges for the 1962/63 hydrological year in all of the recorded gauges occurs in May instead of April (the month with the maximum discharge in all of the other hydrological years) indicates that the distribution of precipitation in 1963 deviates from the precipitation distribution of the standard year constructed from the monthly averages of 21 years.

The discharge minima in the three rivers and the associated periods are shown in table 4.1.

Table 4.1: Discharge minima [m^3/s] and associated periods (BÖCKH 1971)

River	**Minimum 1959/60**	**Time period**	**Minimum 1960/61**	**Time period**	**Minimum 1961/62**	**Time period**
Kabul Tangi Gharu	0.50 m^3/s	2 days (Sept)	0.60 m^3/s	1 day (Sept)	0.15 m^3/s	5 days (Sept)
Kabul Tangi Saydan					0.20 m^3/s	11 days (July. Aug.)
Paghman Pule Sokhta						
Logar Sange Newesta					0.18 m^3/s	23 days (July. Aug. Sept.)

River	**Minimum 1962/63**	**Time period**	**Minimum 1963/64**	**Time period**
Kabul Tangi Gharu	0.13 m^3/s	13 days (July. Aug. Sept)	0.12 m^3/s	2 days (Oct.)
Kabul Tangi Saydan	0.20 m^3/s	4 days (Sept)	0.30 m^3/s	1 day (Oct.)
Paghman Pule Sokhta			0.02 m^3/s	1 day (July)
Logar Sange Newesta	1.00 m^3/s	59 days (June. July. August)	0.05 m^3/s	79 days (July - Sept.)

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