QUANTITATIVE AND QUALITATIVE ANALYSES OF THE SUSPENDED SEDIMENT FROM RIVERS OF NWFP

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DEDICATED TO THE SOUL OF MY DECEASED FATHER **Mr. GHULAM SABIR** WITHOUT WHOSE DEEP CONCERN TOWARDS MY STUDIES THIS WORK WOULD NOT EVEN HAVE STARTED

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ABSTRACT

Ten rivers of NWFP were studied for the quantitative and qualitative analysis of their suspended load. All rivers sampled for examining temporal variations in their suspended load but Indus and Kabul rivers were also studied for spatial variation along their course. The results of the study revealed that the Kunhar River is the most turbid river of this area whereas water of the Swat River is very clear with a uniform load round the year. The peak water discharge of these rivers occurs during summer (July/August) as a result of maximum snow melting and monsoon rains but the highest suspended load in most rivers is observed in Spring and early summer. This anomalous behavior can be attributed to a major role played by glacial erosion as compared to fluvial or wind erosion. Higher suspended load ratio is noticed in most of these rivers which causes severe problem of silting in reservoirs and canals. Indus River shows great decrease in the suspended load downstream of Tarbela as its water comes out of the Tarbela Lake. The Kabul River data shows inconsistent behavior. Temporally Warsak follows the same pattern of decrease in sediment load highest during spring followed by summer and winter. Other two stations, however, show no relation other than increase of suspended sediment load from Noshera to Kund because of industrial effluents. Mineralogical study of representative samples show that minerals of clay, mica, zeolite and chlorite groups (formed as a result of chemical weathering) are mostly found in the suspended load. Water chemistry however shows a great variation amongst the physico chemical parameters like pH, TDS, conductivity, Na^+, K^+, Li^+, PO_4^- and So_4^- Whereas Zn, Ag, Ni, Mn, and Cu were below detection limits.

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CHAPTER- 1

INTRODUCTION

The northern part of the Indian Ocean is landlocked by the great Eurasian landmass in the north and by Africa in the west containing some of the world's largest deserts surrounding the ocean. The close proximity of arid land such as deserts of China, Arabia and India to the Bay of Bengal and Arabian Sea has a pronounced affect on the atmospheric circulation of this region. North of 10° S a peculiar meteorological regime - the alternative seasonal system of monsoon winds - predominate the scene (Tchernia, 1980). During summers, when low pressure zone develops over Eurasia in response to quick heating of land as compared to the adjacent ocean, a clockwise circulation pattern, called SW monsoon, sets in. Strong onshore wind currents ($\sim$30 knots/hours) having a high moisture content are experienced from May through September. During winters, however, atmospheric pressure is high over the Asian continent as a result of which wind direction reverses itself from November to March and mild ($\sim$10 knots/hours), offshore (anticlockwise), dry air currents constitute the NE monsoon.

The 2500 km long and 200-400 km wide Himalayan mountain range borders the northern part of Indo-Pakistan subcontinent with other high relief mountains such as Karakoram in the north and the Hindukush in the west (IUCN, 1989). Together these ranges set up a series of lofty peaks including 5 summits in excess of 8000 meters and 68 having more than 7000 m height in a relatively small area (Survey of Pakistan, 1985). These orogenic belts have a remarkable influence on the climate an orographic barrier to the monsoon winds and causing rainfall during summer, these ranges also receive and accumulate snow during winters which leads to the formation of a large number of valley glaciers. There are reportedly some 1214 glaciers in this region of which 202 positively contribute to the hydrology of the Indus and its tributaries (Khan, 1994).

The Himalayas have formed as a result of continental collision between India and Eurasia subsequent to the northward migration of Indian Plate and the closure of the Tethys Sea ~45-50 Ma (Kearey & Vine, 1990). Since then the Himalayas have undergone a rapid uplift ranging between 0.5 - 4 mm a^{-1}. In Pakistan the Himalayas are divisible into three distinct domains. The Lower (or lesser) Himalayas, Sub-Himalayas and the Higher Himalayas. The Lesser Himalayan domain has a relief of 1500-3000 m and are thrust over the sub-Himalayan domain along the Main Boundary Thrust (MBT). The sub-Himalayan domian comprises a thick terrigenous Siwalik sequence of molasse sediments of Miocene-Pliocene age. The Higher Himalayas reach altitudes over 8000 m and consist of Precambrian basement gneisses overlain by Paleozoic Tethyan sediments (Kearey & Vine, 1990).

Precipitation

The diversity in geographical conditions cause likewise climatic conditions in north Pakistan including NWFP. Dera Ismail Khan is one of the hottest regions in Pakistan, with maximum tempreatures of 46-50° C, whereas, in the mountainous north winter is often extremely cold and summer temperate. The air remains mostly dry througout the year except for rainy season. In NWFP precipitation varies widely, both temporally and spatially. The rainfall mainly occurs in two distinct periods corresponding to the frontal system from west and southwest monsoons i.e., December-March and July-Septemer, respectively. The quantity of rainfall gradually decreases towards the southern part of the country. The average winter-spring rainfall ranges from 1100 to 100 mm in the mountainous north to plain south, whereas, the summer average is 900 to 100 mm for the same region (Dijk & Hussein, 1994). The annual average rainfall ranges from 150 mm a^{-1} to 1000 mm a^{-1}. In Kohistan the average annual rainfall is between 250 to 500 mm. Peshawar, Kohat and Bannu enjoy an average of 500 to 750 mm annually, whereas, Dir and Swat get an average of 750 mm. In the mountains, the north of Mansehra district the annual precipitation exceeds 1000 mm, while in the arid regions of north of Chitral and in Dera Ismail Khan it is less than 150 mm (Djik & Hussein, 1994).

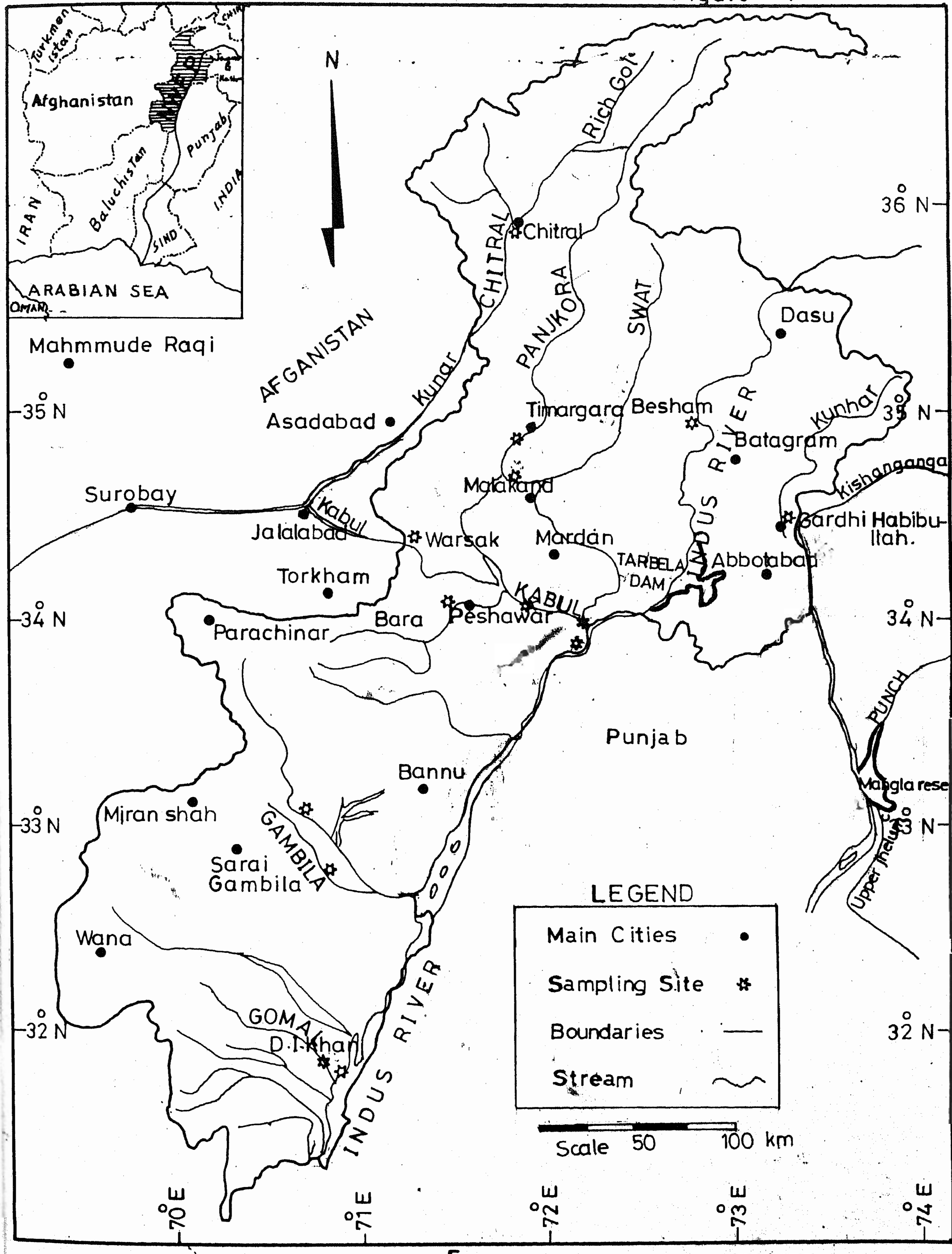
Frozen precipitation over the north Pakistan is also notable and contributes significantly to the hydrology of the region. There are more than 10 glaciers of over 10 km length in northern Pakistan. The source of this huge glaciological complex lies at a height of 4500 m a.s.l. while their snouts extend down to the semi-arid valley floors at a height of 2700 m a.s.l. Annual precipitation totals have been found to be in excess of 2000 mm. Most of the glaciers are alpine type with maximum ablation during summers i.e July/August (Khan, 1994). Winter snowfall in the districts of Chitral, Dir, Swat, Abbottabad, Mansehra and tribal areas such as Kurram and Orakzai agencies is also significant. The amount of snow varies from a centimeter to a height of several meters. This ensures the prominent and more physical weathering than chemical weathering; which effects the sediment influx in various streams of the area.

The northern Pakistan is drained by a network of major streams all of which eventually join the Indus River at some point (Fig.1.1). Besides Indus, the other notable rivers of NWFP (the study area) include Chitral, Panjkora, Swat, Kunhar, Kabul, Bara, Kurram, Gambila and Gomal. Due to a general aridity of the climate in this region and a large difference between summer and winter temperatures, these rivers owe their discharge primarily (70-80 %) to the glacial melt-water from snow covered peaks and valleys in the surrounding mountains. Glacial ablation is at its peak from May to August which also coinsides with the monsoon rains. Hence, the peak discharge during this season which often leads to flooding in the lower Indus basin. These streams also transport a large quantity of glacially derived sediment as their bedload and suspended load, which is a major concern in the context of reservoir silting. The increased sediment load during summers adversely affects the carrying capacity of these rivers and leads to flooding. The detritus transported as bedload becomes trapped in the channels or reservoirs, whereas, the suspended load is deposited on various floodplains, reservoirs and finally on the sea shelf. A brief introduction of the rivers studied during this project is given below.

Indus River

Indus is the principal river of Pakistan with a total length of ~2900 km from its head in the Mansarowar Lake in Tibet (4875 m) to the Arabian Sea (Khan, 1991). It is one of the largest rivers of the world in terms of discharge, sediment load and catchment area. The present day deltaic complex, typically triangular in shape, occupies an area of about 1600 km^2 extending from Thatta to Keti Bunder (Kazmi, 1984). Pakistan lies in an arid to semi-arid climatic zone

Figure 1·1



Turkmenistan
CHINA
Afghanistan
Punjab
Baluchistan
INDIA
IRAN
SIND
ARABIAN SEA
OMAN
N
Rich Gol
36° N
35° N
34° N
33° N
32° N
Chitral
CHITRAL
PANJKORA
SWAT
AFGANISTAN
Kunar
Mahmmude Raqi
Dasu
Timargara
Besham
INDUS RIVER
Kunhar
Asadabad
Batagram
Malakand
Kishanganga
Surobay
Kabul
Jalalabad
Warsak
Mardan
Gardhi Habibullah.
TARBELA DAM
Abbotabad
Torkham
KABUL
Parachinar
Bara
Peshawar
PUNCH
Punjab
Bannu
Mangla reser
Miran shah
GAMBILA
Sarai Gambila
Upper Jhelum
LEGEND
Main Cities
Sampling Site
Boundaries
Stream
Wana
GOMAL
D.I.Khan
INDUS RIVER
Scale 50 100 km
70° E
71° E
72° E
73° E
74° E

and receives 75% of its total annual rainfall during July and August. Despite these climatic constraints the Indus River flows round the year and owes ~80% of its total discharge (142 MAF) to the glacial melt from the Himalayas, Karakoram and Hindukush mountains. During the last 40 years the construction of upstream barrages, reservoirs, and a huge network of canals etc., has drastically reduced the discharge and sediment load of the Indus River. Subsequently, the present sediment load of the Indus is estimated as 50 million tonnes a^{-1} as opposed to 100 mt 20 years ago and 250 mt about 40 years ago (Qureshi, 1992). The sediment load of the Indus river is amongst the highest in world (Kirmani, 1959), as evident in Tab. 1.1.

TABLE 1.1 Comparison of sediment loads in different world rivers

NAME OF RIVER	COUNTRY	SEDIMENT CONTENT % BY WT
Indus	Pakistan	0.531
Damodar	India	0.285
Irrawaddy	Burmah	0.057
Mekong	Indochina	0.016
Red	China	0.1070
Yangtze	China	0.096
Mississippi	U.S.A	0.028

Source (Attaullah, 1970)

The river Indus enters into NWFP at Sazin - the boundary of Kohistan and Gilgit, and after traversing through NWFP it enters Punjab near D.I. Khan. On its way from north to south of the province it swings out to Punjab at places but re-enters NWFP. This huge body of moving water is known as Abasindh in NWFP (the father of rivers).

By the time the Indus River enters into NWFP it has already travelled several hundred km through a host of lithologies including unconsolidated materials, glacial moraines, fragile sandstone and shale sequences, and tectonically active zones. Subsequently, it has already been joined by some very important tributaries such as the Shyok, Shigar, Zaskar, Gilgit, Hunza, Astor and Tangir rivers. On its way through the Kashmir Himalayas, Ladakh, Zanskar and Karakoram mountains, the Indus River not only, incorporates glacial melt-water from major glaciers of the region such as the Siachen, Biafo, Hispar, Baltoro and Chogo Lungma but a large amount of glacially derived detritus as well. The highest recorded erosion rate amongst these is for the Hunza River whose suspended sediment concentrations indicate an annual erosion rate of about 5000 tonnes km^{-2} (Khan, 1994). The sediment load flux further shoots up during the flood season and the entire sediment discharge enters the Tarbela Reservoir.

Kabul River

Kabul is a 700 km long ancient Greak cophes river in eastern Afghanistan out of which 275 km are in Pakistan. The Kabul River rises in the Sanglakh Range about 70km west of Kabul city, it flows east and past Kabul and Jalalabad, enters into Pakistan north of the Khyber Pass. The Kabul River joins the Indus River near Khairabad (Kund). It has four major Tributaries in Afghanistan, the Lowgar, the Kunar, the Panjsher and the Alingar (Encyclopaedia Britanica, 1990). In Pakistan the Bara and the Swat rivers join the Kabul River, which is extensively used for irrigation both in Afghanistan and Pakistan. The Warsak Dam was constructed on this river just near the Pak-Afghan border. Kabul is a snow fed river mostly draining the dry western mountains where geological erosion continues with varying degrees of severity .

Chitral River

The Chitral River is a left bank tributary of the Kabul River. This river drains a seismic region of lofty ranges including the Trichmir (7690 m) and after rising in Hindukush flows southward into Afghanistan near Arandu in the Chitral district. In Afghanistan this river is known as the Kunar River. After traversing a course of 480 km, the Chitral/Kunar River joins the Kabul River some 75 km upstream of the Pak-Afghan border, east of Jalalabad (Ecyclopaedia Britanica, 1990). In wiew of its potential for locally generating hydro electricity, the Sarhad Hydel Development Orgnization (SHYDO) and WAPDA have proposed a number of small to medium (up to 20 MW) hydro power projects on the various tributaries of the Chitral River including Reshun, Shishi, Ojhor, Buni and Golen Gols.

Panjkora River

This snow fed tributary of Swat River originates from the mountains of Dir Kohistan near Thal and drains Dir Distt. and part of Mlakand Agency. The catchment area of this river is mostly forested . The confluence of Panjkora and Swat Rivers lies northwest of Kalangal Village near the border of Malakand and Bajaur agencies. This river is important for its high head and great discharge even in winters. There are a number of sites selected on this river and its tributaries for high head power production by SHYDO - Sarhad Hydel Development

Orgnization, Government of NWFP: This river follows a roughly 200 km long north-south traverse from its head to the confluence with Swat River. Pankora River is also famous for fishing (specially Trout).

Swat River

The Swat River is formed by the union of Ushu and Gabral rivers. It owes its flow primarily to glacial/snow melt and runoff from several thousand meters high peaks of the outer Himalayas and the rest of the Swat valley. Its catchment includes a part of Mohmand Agency, Malakand Agency and the districts of Swat and Dir. The river flows in southward direction up to Saidu and then turns westward, untill joined by the Panjkora River. The united stream then follows a southwest ward course, enters the Peshawar plain and joins the Kabul River at Nisatta near Noshera Town, after travelling about 320 km. The Swat River is important for its support to agriculture (the Upper and Lower Swat canals) by irrigating ~65000 ha in Mardan and Charsadda districts. According to Kruseman & Naqvi (1988), WAPDA has constructed two power stations on the Upper Swat Canal at Dargai and Jabban which produce 20000 KW, which are being upgraded now. A number of other hydro electric power projects are proposed on this river and its tributaries. This river is also famous for the Trout fish. A number of public and private hatchries have been established in the upper Swat area.

Kunhar River

The Kunhar River starts from the legendary Saiful Maluk Lake at Naran. It drains the Kaghan Valley and joins the Jhelum River (one of the major left bank tributaries of Indus) near

Dulai in Azad Kashmir. The Mangla Dam, which is of vital importance in electricity production of Pakistan is situated on the Jhelum River. This snow fed river was famous for its clear blue water but due to recent floods and increased soil erosion in the area it has become the most turbid river of NWFP, raisining the amount of silting in Mangla reservoir. Trout is very famous and found in abundance in the Kunhar River. A number of hydroelectric power projects are proposed on the Kunhar River and its tributaries.

Bara River

Being a small right bank tributary of the Kabul River in Pakistan (Peshawar), the Bara River originates in eastern Afghanistan and owes its flow primarily to seasonal rains. It enters Pakistan in Khyber Agency west of Tirah and joins the Kabul River near Peshawar. The water of Bara River has been extensively used for drinking and domestic consumption by the inhabitants of Peshawar city and its surroundings areas for a long time. Althogh this region now receives most of its water supply from tubewells, yet people prefer the water from Bara River over the ground water for its good quality.

Gomal River

Gomal River rises in eastern Afghanistan in Khumbur Khule Range and enters Pakistan near Domandi, southwest of Wana (South Waziristan). Beyond this point it is joined by the Kandar River, Wana Toi and the Zhob rivers . It falls into the Indus River just south of D.I. Khan after a course of nearly 240 Km. The proposed dam on the Gomal River at Mian Noor and Khajuri Kach, below the confluence of Gomal and Zhob rivers will serve as a multipurpose scheme to control the hill torrents during monsoons, irrigation of ~66400 ha of cropland in D.I. Khan region and the production of hydroelectric power. The discharge of the Gomal River depends more on the surface runoff from rainfall and groundwater than on the snow melt which is restricted to the months of March through May.

Kurram River

Like most other rivers of NWFP, the Kurram River also starts in Afghanistan and after traversing through the hilly Parachinar - Tal - Bannu region it enters Bannu basin through the Kurram Garhi gorge. Near Bannu city the water of Kurram River is used only for irrigation and not for drinking because of its high mud content. Upstream of Bannu, however, its water is suitable for domestic consumption as well and people use it for drinking. The irrigation system of Kurram River dates back to 16th century when the Kurram-Gambila Doab was irrigated by private "Zamindari" canals, which diverted water from the river by temporary dams. This irrigation system was improved in 1954 by constructing a weir accros the river at Kurram Garhi gorge extending irrigation facilities for 53820 ha. In 1962 a reservoir and a hydroelectric power plant of 4000 KW was constructed on the Barran Nullah which receives water not only from the nullah but also surplus water from the Kurram River. This new facility was designed to irrigate about 60690 ha of the Marwat plain. The high sediment load of the Kurram River, however, quickly silted up the reservoir, thereby reducing its storage capacity (Kruseman & Naqvi, 1988). This mainly snowfed river debouches into the Indus River east of Lakki Marwat.

Gambila River

The Gambila River is a tributary of the Kurram River having its source in eastern Afghanistan . This river is rain fed as well as snow fed and joins Kurram river near Bannu. This river is mainly used for irrigation purpose as its water is too muddy to be drunk. The Gambila river can become a good source of hydroelectricity.

Purpose and Scope of Study

Pakistan has been facing acute energy crisis since independence which is considered a major hurdle in the way of her industrial progress. Years of research have shown that our hydrocarbon resources are insufficient to support rapid industrial progress. Thus hydro electric power remains the most economically viable and environmentally safe method of overcoming the energy crisis. The estimated potential of hydel power in Pakistan is eighty thousand mega watts out of which only five percent is being utilized (Gul,1994). Warsak, Mangla and Tarbela dams were, therefore, built in sixties and seventies as multipurpose reservoirs but each of them was imperilled by silting and lost a substantial part of their storage capacity. The Warsak reservoir is now almost full of sediment whereas Tarbela lake has lost about a quarter of its storage capacity during the last 20 years (PNCS,1992). Our dependence on hydel power continues to grow, hence the need to build more such dams and resevoirs to meet our future demands. It is therefore imperative to investigate the runoff and sediment discharge data of meltstreams coming out of major glaciers in the upper Indus basin and examine their temporal and spatial variations before the construction of major structures is undertaken.

The North West Frontier Province (NWFP) is the most suitable area for hydroelectric power generation. The hydroelectric power potential is determined by two factors, the head and the discharge of a stream. In this part of Pakistan we have appreciable discharge with admireable head per unit area, hence it is very easy to get good amount of electricity, specially in the northern part of the province. A number of sites have been proposed for small to medium and even large size hydel power projects in upper and lower Chitral, Dir, upper Swat, Hazara and Indus Kohistan areas, by the SHYDO (working under provincial power ministry) and WAPDA. Some very important proposed schemes are Reshun in Upper Chitral, Golen Gol in Lower Chitral, Matiltan and Swat System in Upper Swat, Kunhar River System in Hazara, and Kundian System and Allai Khwar in Indus Kohistan.

This study was carried out for qualitative and quantitative analysis of the suspended load of notable rivers of NWFP to identify areas of maximum sediment input (high soil erosion) and seasons/months of maximum suspended load. The mineralogical composition and textural characteristics of the sediment provide basic information regarding the erosional history of a region. Knowledge about the erosional history of northern Pakistan is of great significance for planning dam sites, hydel power stations, watershed management and for other geotechnical matters. About 16% of our population lives in NWFP and FATA (16.3 million; BOS, 1986). Many of the amenities of modern life such as safe water supply, gas and electricity are available to only a part of the population. This study can be helpful in managing clear water supply and electric power to most inhabitants of the province.

CHAPTER- 2

PREVIOUS WORK

Despite their tremendous importance in our economy, rivers in Pakistan have ironically been the least studied subjects for their discharge and sediment load during the last nearly fifty years. The latest available work on this topic dates back to 1970 in the context of Pakistan, however, no such study has ever been undertaken on the provincial (NWFP) level. The paucity of literature can be attributed to the applied nature of this subject. This is the first study in the context of this province. The available literature is cited below.

The materials transported by streams are brought to them by groundwater, rainwash, creep, landslide, wedge work of ice and roots, expansion of rocks/soils beyond their position of stability, and animals particularly man (Twenhofel, 1932). The material transported by rivers is divided into two groups i.e., the bed load and the suspended load. Bed load comprises coarse particles and is transported along the substrate, whereas fine grained material is carried by the currents in suspension (Bagnold, 1973). The relative abundance and quality of total load varies from river to river and is dependant on several factors such as nature of rocks in the catchment area, topographic features, rate of uplift, climate, vegetational cover of the region and river discharge (Leeder, 1982). Maximum grain size of sediment that may be held in suspension depends primarily on the turbulance energy of the transporting medium (Lane, 1938). Reineck & Singh (1980) proposed that a sediment grain is moved in suspension when the shear velocity is equal to or more than the settling velocity of the currents. According to Friedman and Sanders (1978), the basic driving force for transport of the suspended load is turbulent flow. Turbulance can be maintained within a current of water up to the point where the density of water becomes ± 2.0 g cm^{-3}. According to them the speed of a current required to maintain fine sand in supension must be about 50 cm s^{-1}. They divided suspension in two groups, (a) Graded suspension - the turbulent suspension that exchanges sediment with its substrate and within which the quality and particle-size distribution of the suspended load decreases upwards and, (b) Uniform suspension - which travells independently of their substrate.

Visher (1969), also gave the idea about interchanging suspended load with the bed load. He gave a range of population of the particles that can be transported either as bed load or as suspended load. According to him 2 to 35% of the total population can be held in suspension in a fluvial environment. Reineck & Singh (1980), divided suspended load into two without proposing any names for them, (a) the suspended load which is transported either as suspended load or as bed load intermittently, this transport is either free moving in suspension or by saltation and, (b) the fine grained suspended load which once lifted remains in suspension untill deposited by decellerated flows. Middleton (1977), had already named these two groups as intermittent suspension load and wash load, respectively and described the latter as comprising silt and clay size particles.

The use and development of rivers throguh a system of storage at reservoirs changes their hydraulic regime and problems caused thereby can be categorized as follows: (Kirmani, 1959),

a. Sedimentation in reservoirs

b. Sedimentation in river channels and

c. Sedimentation in canals

After studying the total sediment load of Indus, Jhelum, Sutlej, Chenab and Bias rivers he concluded that the total sediment of the Indus River is greater than many foreign rivers. Hence the acute problem of siltation in the Indus River and its tributaries. According to Kirmani (1959), there are two main sources of sediment in the Indus River basin - the igneous and metamorphic mountains of great Himalayan region and the younger, lower and still unconsolidated sedimentary rocks of Siwaliks.

Ataullah (1970), carried out a study for the Water and Power Division, Planning Commission, Government of Pakistan to determine the origin and quality of sediment entering the Indus River, its main tributaries and desert/coastal streams of Baluchistan. The study included collecting and analyzing hydrological and meteorological data (already available in Pakistan at that time) with a view to assess the suspended and bed loads to make recommendations for minimizing sediment loads in the rivers of west Pakistan. The catchment of Indus River was divided into three major areas - above Kalabagh (upper Indus), between Kalabagh and Guddu Barrage and the Lower Indus. This study delineated broad areas of excessive erosion and made recommendations for overcoming the problem. Along with Indus River, Chitral, Swat, Kunhar, Bara, Kabul Kurram and Gomal rivers were also studied (from NWFP) during this study. The following conclusions were reported:

- The sediment problems exist for the Tarbela dam because of the high ratio of annual flow to the storage volume.

- The main source of sediment input for the Indus lies in alluvial deposits found near the upper reaches of the river around Skardu.
- Soil conservation, reforestation and sediment control measures will not appreciably prolong the life of Tarbela Reservoir.
- The short life of Tarbela Reservoir can be extended by such measures as: developing off-channel storage, constructing a series of dams on the main Indus upstream of Tarbela, and installing a sediment by-pass around or through the reservoir.
- Acceptable grazing intensities should be determined for individual subcatchments, and vigorously applied to maintain soil stability and optimum forage production on damaged and rehabilitated rangelands.
- Soil conservation reforestation, reseeding, controlled grazing, animal improvement etc; should be implemented in the upland drainage

In order to collect surface water data required for its various projects and general investigations, WAPDA established its surface water circle in 1960 which was designated as Surface Water Hydrology Project (SWH) in 1966. The SWH has been publishing its data in the form of annual reports for the last several years, the latest being for the year 1990. The volume-1 of this three-volume report shows river discharge, suspended sediment concentration, chemical analysis and water temperatures regarding several important rivers of Pakistan (WAPDA, 1990). The physicochemical parameters like sodium, sulfate, dissolved solid, electric conductivity and pH of water are also described. The reports of 1989-90 include data on the Indus, Kabul, Chitral, Swat, Kunhar, Bara and Gomal rivers in NWFP. Recent data are also available in raw form at their Lahore office and has not been analyzed for any scientific purpose.

IUCN - The world conservation union has carried out a study of the Kabul River, the principal objectives of which were to determine the locations where polluted effluents were being discharged into the Kabul River along with types of pollution. This work is of great importance because it throws light on some important aspects of the Kabul River and its tributaries - the Swat, Chitral and Bara rivers. According to this study the Bara River needs urgent attention due to the high levels of human use (IUCN, 1994). This study gives us some very important information regarding the utility of these river. Besides comparing discharge of the Kabul River with those of Bara, Chitral and Swat rivers, it also describes suspended solids and conductivity at different stations along the course of Bara River. The study concludes that the Kabul is a very turbid river (10 - 800 and 340 - 1310 mg l^{-1} under low and high flow conditions, respectively). The source of much of the material is erosion of rocks and soils, rather than pollution, because of which the conductivity values are also high. The toxicity of heavy metals such as zinc, chromium and copper would have made the Kabul River water lethal if it was not balanced by matching values of hardness, alkalinity and suspended solids (IUCN, 1994).

A World Bank Appraisal report for 1992 on environmental Protection and resource conservation described that "policy makers and farmers have focused almost exclusively on questions related to agricultural production and have given insufficient consideration to develope sustainable resource use system which has led to the indiscriminate deforestation of mountains and hillsides (Dijk & Hussein, 1994). According to the Environmental Profile of NWFP, overgrazing of rangelands and over watering of crops on the irrigated plains of Peshawar and Mardan region, over tapping of groundwater in Kohat and Bannu and inadequate drainage system have resulted in severe soil erosion and silting of reservoirs (Dijk & Hussein, 1994). They further added that the denuded mountain slopes are also a cause of massive soil erosion and siltation of dams, reservoirs and river beds. They divided the soils of NWFP into three categories;

a. Residual - colluvial soil of mountain slopes, fans and terraces

b. Alluvial plains

c. Loess plains

According to them the highest rates of erosion are in the Indus catchment between Tarbela reservoir and 90 km upstream where estimated soil loss is 150-165 tonnes ha^{-1} a^{-1} most of which is transported by the rivers during monsoon period.

Collins and Hasnain (1994), have carried out a study of the discharge and sediment content of melt-water draining from the Batura glacier in Krakoram mountains. They have obtained data at hourly intervals and provide a detailed pattern of temporal variations during an ablation season compared with other glaciers in Himalayan heawater basins of the Indus and Ganga rivers. According to their findings, the total annual sediment flux from the Batura glacier was 3.950 Mt, which can be translated to a yield of 6.086 Kt km^{-2} a^{-1}, considerably higher than in comparable period for Chhota-Shigri and Dokriani glaciers. They also claim that the glacierised upper Indus basin which comprises 17% of the total area, accounts for an estimated 60% of the sediment load and 35% of the runoff of rivers in the Karakoram region.

Kruseman & Naqvi (1989), have divided NWFP into four broad geological units (Fig. 2.1).

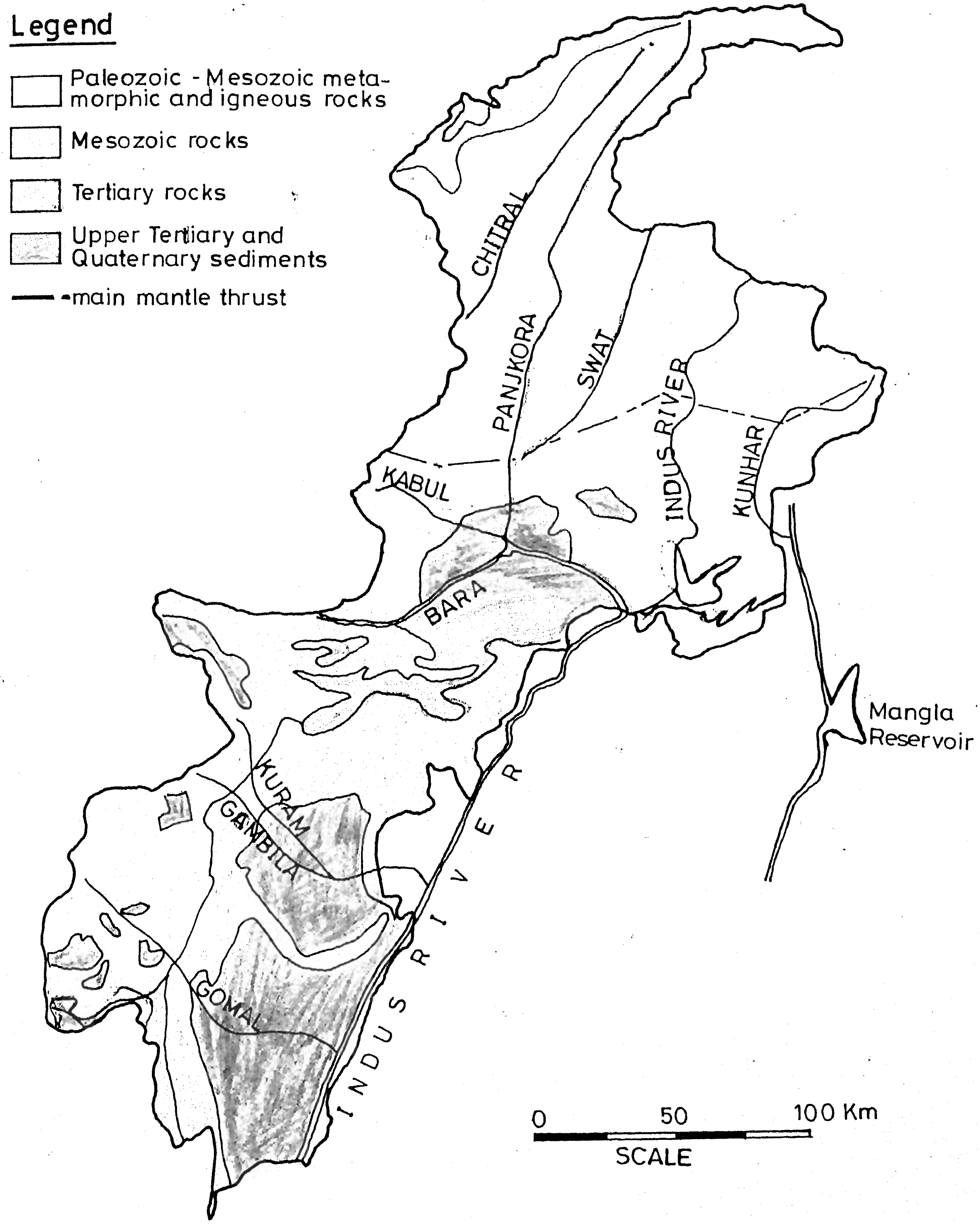
1. The metamorphic and igneous rocks of the northern mountains
2. The Mesozoic rocks of the southern and southeastern part
3. The Tertiary rocks of central and southern part and
4. The upper Tertiary and Quarternary fill of the intermotane basins

The most important of these units is the upper Tertiary and Quarternary fill of the intermotane basins because of two reasons (i) eight out of ten rivers studied during the project drain this unit just near their confluence with the Indus River (direct or through its major tributary) and, (ii) this unit is impotant in bringing sediment load to rivers because of being unconsolidated and more susseptable to erosion.

The intermontane basins are filled with deposits mainly alluvium, consisting of sand, gravel, boulder, silt, and clay. These are weathering/erosion products of the surrounding mountains and have been transported by streams and rivers both from the hills and from more distant source areas. Not only river water but wind also is an active medium of sediment transport in this region. Thick layers of well sorted fine wind blown loess are found at many places. The coarse alluvial deposits are found along the mountains where each river has deposited its own alluvial load loosing its coarse material upon entry into the plain. Many basins

Figure 3·1

GEOLOGICAL MAP OF NWFP



may have lakes at some time in their "recent" history. Consequently, the central parts of large basins such as Peshawar and Bannu are filled with clayey lacustrine deposits having sandy intercalation and overlain by very young alluvial deposits. Flood plain deposits, present along the course of rivers can be found in the central parts of many basins. These deposits consist of sandy stream bed material that interfingers with clayey sediments spread out by rivers overflowing their banks during high floods. Away from the floodplain the surface is covered with sheet flood deposits consisting of fine erosion material transported by overland runoff after rain storm. In larger basins such as Peshawar vale, Bannu and D.I. Khan basins, which are related to the Indogangetic plain, upper Pliocene deposists are found as well. The character of sediments is strongly related to the nature of surrounding mountains.

Burbank and Tahirkhelli (1985), have concluded that the Peshawar intemontane basin has a ~300m thick sediment fill unconformably overlying the folded and faulted Murree Fomation. Sedimets from the Attock Cherat Range in south of Peshawar valley, metasediments of Khyber and granites of Warsak in the west and northwest and metasediments of the Malakand range in the north are the chief sources of this sediemnt fill. It appears that braided rivers have invaded the basin in geological past which left behind coarse grained gravel fining upward into silt. In the centre of the basin the gravel deposits thin out and are eventually replaced by 1acustrine sediments. These deposits show alternating sandy and silty strata. At some places loess is found between different lacustrine layers. These deposits and the present day detritus of the surrounding mountains (alluvial fans) are the primary source of sediment input into the Indus, Kabul, and Bara rivers from this region.

The Bannu basin, drained by the Kurram and Gambila rivers, is relatively younger than the Peshawar vale. Partially consolidated Late Tertiary mollase deposits of the Bhittanni, Marwat and Shinghar ranges also form the bedrock of the Bannu basin which was gradually filled with younger alluvial sediments. These ranges separate the younger Bannu basin from the older Indogangetic plain. Large amount of sediment is contributed to the Indus River from these deposits, particularly during rainy seasons.

The Dera Ismail Khan plain belongs to the western fringes of the Indogangetic plain, bordered on the west by mountains that largely consist of consolidated or semiconsolidated sand with thick clay or shale beds (mollasse deposits) of Tertiary Siwalik Group. The fault zone mostly burried under young sediments separates the mountains from basin. The basement of unconsolidated Quarternary sediment, is formed by a hard clay layer 200m below the surface. The alluvial fill found in the basin is of two types (a) peidmont deposits, and (b) flood plain deposits (Kruseman & Naqvi, 1989). Both of these types are important in bringing sediments to the Indus river directly and also through the Gomal River.

CHAPTER- 3

METHODOLOGY

The present study was designed to examine qualitative and quantitative variation in the suspended sediment of major rivers of NWFP. Such variations can occur both spatially and temporally along the course of each river in response to changing climate/weather and man's interference with a river system. Not only the river discharge but its sediment load also increases in response to rains when runoff is incorporated in the rivers. Similarly, significant changes take place in discharge when glacial/snow melt is at its peak during summer months.

Though the original plan included frequent samplings from several stations along the course of each river but due to logistic and financial limitations the sampling strategy/frequency was modified and it was decided to collect one season-representative sample (for summer, winter and spring) from each river per station.

Indus is the principal river of Pakistan and is considered very important because a large number of agriculture and hydro power projects are supported by it. In keeping with its importance, it was decided to sample the Indus River from three different stations along its course in NWFP such that any spatial variation caused by the Tarbela reservoir may be readily noticed. The selected stations were at Besham Qilla, Khairabad (about 1 km downstream of the old Attock Bridge) and D.I. Khan (Fig. 3.1). The criteria for site selection was that Besham is the first major easily approachable station after the Indus River enters NWFP, whereas Khairabad is situated downstream of the Tarela Dam and most sediment settles out in the reservoir. D.I. Khan is the last station in NWFP and by this time the river has been joined by other smaller tributaries along its course as a result of which the sediment load should increase.

The other major river of NWFP is the Kabul River which not only supports the hydro power station at Warsak but also supplies water for agriculture through a major canal network. Kabul River was also sampled from three different location i.e.(i) Warsak (upstream the dam), (ii) Nowshehra where it has reunited into a single channel and received all of its major tributaries and, (iii) Kund, before its union with the Indus River.

All the remaining rivers were, however, sampled from only one station each, keeping in view the easy approach to the localities. Details of the sampling strategy are given in Table 3.1 (Fig. 1.1).

In order to study the suspended load of these rivers, samples were collected from near surface running water in 4-5 l quantity through clean polyethylene plastic bottles. During the sampling it was made sure that the bottle was withdrawn as soon as it was filled to avoid extra sediment from entering the bottle. It was also emphasized that water samples were collected from the running water, instead of pools usually found along the river banks. In order to avoid bed load from being incorporated into the sample, water was collected significantly higher from the substrate.

Table-3.1 Details of sampling site locations and time.

Name Of River	Sampling Site	Catchment Area km^2 *	Sampling Date
Kunhar River	Garhi Habibullah	2383	29-4-93, 7-8-93 & 28-1-94
Chitral River	Chitral Town	11396	27-4-93, 16-8-93 & 23-1-94
Kurram River	Bannu	-	6-5-93, 8-8-93 & 1-2-94
Bara River	Peshawar	1847	9-5-93, 8-8-93 & 2-2-94
Gambila River	Sarai Gambila	-	6-5-93, 8-8-93 & 2-2-94
Swat River	Chakdara	5776	20-4-93, 6-8-93 & 27-1-94
Gomal River	D. I. Khan	-	6-5-93,8-8-93 & 2-2-94
Panjkora River	10 km down stream Timargara	-	20-4-93, 6-8-93 & 27-1-94
Indus River	Besham	162393	29-4-93, 6-8-93, & 27-1-93
Indus River	Khairabad	252525	20-4-93, 7-8-93 & 28-1-94
Indus River	D. I. Khan	-	6-5-93, 8-8-93 & 2-2-94
Kabul River	Warsak	-	10-5-93, 15-8-93 & 30-5-94
Kabul River	Noshera	88578	20-5-93, 7-8-93 & 28-1-94
Kabul River	Kund	-	20-5-93, 7-8-93 & 28-1-94

* Source: WAPDA, 1990.

After the first phase of sampling (Spring 93) it was realized that the amount of sediment obtained from most of the samples was not sufficient for qualitative studies (XRD analyses). It was subsequntly decided to increase the sample size from 4-5 l to ~25 l during the summer sampling phase.

Quantitative Analyses

In order to determine the amount of sediment, each water sample was sifted through a filter paper of pre-determined weight and volume of the filtrate measured with a graduated beaker. The filter paper and the residue thereon were dried at room temperature and weighed on an electronic balance. The difference in the weight was then calculated and divided by the volume of the sample to get average sediment concentration (grams per liter). This procedure was repeated for all the samples collected during this study. The results thus obtained showed a comparison of the sediment concentration from season to season for each river.

Qualitative Analyses

The qualitative analysis of the suspended load was performed by analysing the gravimetrically separated sediment through X-Ray diffraction technique. For this purpose sediment obtained from summer sampling phase (25 l volume) was analyzed on XRD by the Rigaku XRD d/max-2 (Japan made), for 2θ angle 2-75°. The graphic results of XRD were interpreted through Henawalt method and minerals identified tentatively.

Water Analysis

The 25 l water samples collected during summer were also analyzed for following physico-chemical properties: pH of water; total dissolved solids; conductivity; cations such as Sodium (Na^+), Potassium (K^+) and Lithium (Li^+); anions including Phosphates (PO_4^{--}) and Sulfates (SO_4^{--}); and trace elements like Nickel (Ni), Copper (Cu), Zinc (Zn), Manganese (Mn) and Silver (Ag).

pH

The pH of these samples was determined by HI-8417 (Hanna, Italy) micro-processor bench pH meter in the laboratory and nitrogen gas was passed through the samples during this process to avoid any differance of pH if measured in field. The instrument was first standardized with the buffer solution of pH 4.01 and 6.86 supplied with the instrument. The two-in-one electrode (glass) properly connected to the instrument, was dipped in the sample and the pH was noted directly from the pH meter. Prior to each measurement the instrument was checked for its standardization. After every measurement the electrode was rinsed with distilled water and dried with a tissue paper.

Electrical Conductivity and Total Dissolved Solids

The Electrical Conductivity and Total Dissolved Solids were measured by digital conductivity meter type AGB 1000 CSI (England). The instrument was first standardized with 0.01N potassium chloride solution and then the reading recorded.

Li, K, Na

Lithium, Potassium and Sodium were determined with the help of digital flame photometer - model 410 (made of Corning, UK), with the following method. The stock and working standards were prepared for each of these elements to standardize the machine. After proper stadardization and optimization of machine, the unknown samples were run for the actual concentration of element of interest.

Stock Solution

1000 ppm stock solution was prepared by dissolving 2.54 g of NaCl for sodium, 6.04 g LiOH for lithium and 1.907 g of KCl for potassium in double deionized water (D.D.W) and made to the volume with D.D.W in one liter volumetric flask.

Standard Solution

Working standards in the range 10-100 ppm were prepared from 1000 ppm stock solution by using formula $c_1v_1 = c_2v_2$

Procedure

Zero and hundred of the instrument were set with distilled water and 100 ppm standard solution repectively. Emission intensity was noted for each concentration of standard solution after aspirating it into the flame. The emission intensity of all the collected samples were noted in the same way as for the standards. A plot of emission intensity Vs concentration was prepared for the standards and the concentration of Na, K, and Li was calculated.

Determination Of Trace Elements

Nickel (Ni), Copper (Cu), Zinc (Zn), Manganese (Mn) and Silver (Ag) were determined by using Atomic Absorption Spectrophotometer (Pye - Unicon model SP 190/191) in the geochemistry laboratory of the National Center of Excellence in Geology, University of Peshawar.

Nickel

1.273 g of Nickel oxide was dissolved in 10% v/v HCl and diluted to 1000 ml with deionized water. The standard solution contained 1000 ppm Nickel . Working standards of 0.5, 1,2 4 and 8 ppm were prepared from this standard solution.

Copper

One gram of Copper metal was dissolved in "1:1" HNO_3 and was diluted to 1000 ml with deionized water in a volummetric flask. This standard stock solution contained 1000 ppm Cu. Working standard of 0.5,1,2,4 and 8 ppm were prepared from this stock solution.

Manganese

Accurately weighed 4.418 g Manganese sulphate ($MnSO_4 . 4H_2O$) was dissolved in 200 ml of deionized water. The solution was diluted to 1000 ml in a volumetric flask with deionized water. This standard stock solution contained 1000 ppm of Mn. From this solution, working standards of 0.5,1,2,4 and 8 ppm were prepared.

ZINC

Zinc metal 1.0 g was dissolved in 20 ml (1:1) HCl and was diluted to 1000 ml with deionized water in a volummetric flask. The standard solution contained 1000 ppm zinc. Working standards of 1,2,4 and 8 ppm were prepared from this standard solution.

Silver

1.57g of $AgNO_3$ was dissolved in deionized water and made to volume in a 1000 ml volumetric flask. 0.5, 1, 2, 4, and 8 ppm working standards were prepared

Procedure

The instrument was set to the best operation conditions for each element by using appropriate cathode lamp, wavelength burner light and gas flow as given in the table 3.2. The machine was then standby using working standards prepared for specific element. After making sure that the machine is set for its maximum accuracy and precision the unknown water samples were aspirated for the determination of element of interest.

Table 3.2

S.NO	ELEMENT	WAVE LENGTH	FLAME	AIR FLOW
1.	Zinc	213.9 nm	Acetylene	50 PSF
2.	Copper	324.8 nm	acetylene	50 PSF
3.	Nickel	323.0 nm	Acetylene	50 PSF
4.	Manganese	279.8 nm	Acetylene	50 PSF
5.	Silver	382.0	Acetylene	50 PSF

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Phosphate and sulfate were determined on Spectonic-20 (Bausch and Lamb USA).

Determination of Sulfate

Reagents

a) Hydrochloric acid (1:1) : 50 ml of HCl was mixed with 50 ml of double distilled water in 100 ml volummetric flask.

b) Barium chloride crystals.

c) Standard Sulphate Solution

A 1000 ppm stock solution was prepared by dissolving 0.4535 g of K_2SO_4 in DDW to make 250 ml of the solution. The standard working solutions of sulphate were then prepared by dilution from this solution.

Procedure

50 ml of the sulphate solution was mixed with one ml of HCl (1:1) and 0.1 g $BaCl_2$ in 100 ml volummetric flask. After 5 minutes, the optical density of this solution was measured at 335 nm by Spectonic -20 Spectrophotometer.

A standard curve showing absorbance VS concentration was prepared using working sulphate standard solution. Concentration of the unknown solutions were read from the standard curve.

Determination of phosphate

Reagents

a) Sulfuric acid (5N): 70 ml H_2SO_4 was diluted to 500 ml .

b) Ammonium molybdate: 20 g of Ammonium molybdate was dissolved in DDW and diluted to 500ml.

c) Potassium Antimonyl tartrate (1 mg sb/ml): 0.2743 g of potassium antimonyl tartrate was dissolved in DDW and diluted to 100 ml.

d) Ascorbic acid (0.1M): 1.32 g of ascorbic acid was dissolved in 75 ml of DDW. This solution was prepared at the time of analysis.

e) Mixed reagent: 125 ml of 5NH_2SO_4 and 37.5 ml of ammonium molybdate were thoroughly mixed. 75 ml of ascorbic acid solution and 12.5 ml of potassium antimonyl tartrate solutions were added to it.

f) Standard phosphate solution: Stock solution of 100 ppm of KH_2PO_4 was prepared by dissolving 0.438 g of KH_2PO_4 in DDW and the volume was made upto the mark, then by dilution method concentrations of 1 ppm up to 12 ppm were prepared from the stock solution.

The maximum wavelength was determined by using these solutions which was 882 nm. At this wavelength the reading was taken photometerically.

Procedure.

20 ml of solution was taken in to 25 ml flask, 4 ml of the mixed reagent was added to it, diluted to the mark with DDW and then mixed well. After allowing the solution for ten

minutes settle, optical density of the solution was measured at 882 nm by spectrophotometer Spectonic -20. A standard curve showing absorbance VS Concentration was prepared by using the working phosphate standard solutions 1-12 ppm. Concentration in the unknown solution were read from the standard curve.

CHAPTER- 4

RESULTS AND DISCUSSION

Suspended Sediment

Out of the 10 rivers studied during this project it has been observed that the Kunhar River - a tributary of the Jehlum River which drains Kaghan Valley in northern Hazara - transports maximum load during all seasons, whereas, the Swat River was found to be most clear round the year. The results also show that Gomal and Bara rivers remain almost dry during winter months but the latter becomes very turbid during spring and summer (1.15 g l^{-1} in Spring). Contrary to the expected maximum suspended load during summer and minimum during winters (in line with river discharge), the temporal variation in suspended load of various rivers of NWFP indicates a peak flux during the spring/early summer (Apr-May) to a minimum during winter (Dec-Feb) while summer values mostly fall in between those for spring and winter. This anomaly can be explained if we know the sources of sediment input into the fluvial system. There are three main sources of the suspended sediment namely glacial, meteoric and substrate of the channel.

As a result of heavy snow accumulation during winters the glaciers advance and move down their valleys to reach a certain level. At the turn of the season (spring) high ablation rates force these glaciers to recede, leaving behind their terminal and ground moraines immediately in front of them which can be readily picked up by the meltstreams. Though the ablation rates steadily increase during spring and reach a maximum during summer but by this time almost all the available fine particles have alredy been removed from there and transported downstream. When the stream-flow and current velocity increase during summers coarser particles may also start moving in appreciable quantities which comprises bed-load. This is why snow-fed streams usually show maximum suspended sediment during spring time.

Rivers and streams receive their water (runoff) from the entire catchment during rains as opposed to a localized input from headwater during dry periods. Therefore, the amount of sediment entering a river substantially increases during rainy periods. The finer fraction of this rain washed sediments is transported as suspended load whereas, coarser particles as bedload. Some perennial streams of the study area show little change in the suspended load from spring to summer which may be attributed to extra sediment input during monsoon rains.

During winters the river/stream discharge and current velocity are very small. This leads to the deposition (within the channel) of relatively coarse grained material which is normally transported through saltation. At the end of winters when current velocity starts increasing again it resuspends/erodes material from the substrate and transports it as its suspended load.

It has already been mentioned that samples of the Indus River were collected from Besham, Khairabad and D.I. Khan. The significance of the first two stations is that they are located upstream and downstream of the Tarbela Reservior and variations in the suspended load flux of these two stations will indicate amount of silting in the Tarbela lake. It must, however, be emphasized here that the Khairabad sampling station of the Indus River is located downstream of its confluence with the Kabul River. It , therefore, implies that the suspended load flux of the Indus River at Khairabad also includes input from the Kabul River which joins it downstream Tarbela. Therefore, the difference between suspended load flux at Besham and Khairabad stations would not be a direct measure of the silting rate at Tarbela.

The three season data of the Indus River (Fig.4.1, 4.2 and 4.3) shows that the quantity of suspended load is maximum at Besham, minimum at Khairabad and intermediate at the D.I. Khan stations. This anomally is due to silting at Tarbela Reservoir where most of the suspended load of Indus River settles out during the residence time of water. Hence highest and lowest suspended sediment flux immediately upstream and downstream of the reservoir, respectively. It is also evident from the figure (4.4) that the concentration of suspended sediment at Besham climaxed some times between April and August as an increase of about 700 mg l^{-1} was observed from winter to spring but the summer concentration was 150 mg l^{-1} less than that of the spring months. Whereas, at Khairabad (Fig. 4.5) the increase in concentration was 400 mg l^{-1} from winer to spring which reduced by ~250 mg l^{-1} in August. It is to be noted here that there is no significant rain in the catchment of Indus River upstream Besham during April and August 1993 (Fig.4.7), so the suspended load at this stage of the river is primarily of glacial origin.

A comparative analysis of the suspended load data for stations immediately upstream and downstream Tarbela Reservior shows a decrease of 1365 mg l^{-1} (~90%) in summer, 1261 mg

l^{-1} (75%) in spring and 963 mg l-1 (96%) in winter from Besham to Khairabad. It must be noted that the river discharge is usually minimum during winters which starts appreciably increasing from spring and reaches its climax during July/August (WAPDA, 1993). In order to maintain the required water level in the Tarbela Reservior, the outflow is regulated accordingly which determines the length of residence time of water in this lake from season to season. Thus during winters, when the inflow and outflow are minimum and subsequently residence time greatest, there is relatively more silting. From the same token it was expected that the percentage of reduction during spring should have been intermediate between summer and winter values because the residence time of water is less relative to winters but still greater than summer. The observed values of reduction in spring are, however, anamolous which may be attributed to increased sediment input into the Indus River beyond Tarbela from other local sources including the Kabul River. This assumption is supported by the meteorological data which indicates heavy rains (~550 mm during April, 1993) in the catchment of the Kabul River and its tributaries viz. Bara, Chitral, Panjkora and Swat rivers (Fig. 4.10a).

In between Khairabad and D.I. Khan sampling stations, however, the Indus River acquires more sediment from other tributaries such as Kurram and Gambila rivers which gradually increases its load further downstream. As we shall see later that both these tributaries of Indus are very turbid and their sediment input is relatively much higher than the Indus' load at D.I. Khan. Here also the observed sediment load follows the same pattern of maximum load during spring followed by summer and minimum during winter. The observed suspended load of the Indus at D.I. Khan (Fig 4.6) reaches a maximum of ~550 mg l^{-1} during spring which seems a much lower value as compared to its other local tributaries. The reason for this lower concentration may be the reduced current velocity which forces some of the coarser suspended particles to be deposited in the channel. This reduction in the current velocity can be attributed to the fact that the channel suddenly widens several kilometers as the river divides itself into many distributaries upon entry into the plain area.

TABLE 4.1 SPATIAL AND TEMPORAL SUSPENDED SEDIMENT LOAD

Name of river	spring load mg l^{-1}	Summer load mg l^{-1}	Winter load mg l^{-1}
Chitral	1112	646	106
Panjkora	443	333	8
Swat	57	57	51
Indus(Besham)	1692	1542	1002
Indus(Khairabad)	431	177	39
Indus(D.I.Khan	545	313	87
Kunhar	5214	2750	1920
Kabul(Kund)	742	753	622
Kabul(Noshera)	684	710	26
Kabul(Warsak)	1095	337	312
Bara	1152	682	Dry
Kurram	1454	1306	87
Gambila	1037	1120	333
Gomal	439	18	Dry

The Kabul River is another major right bank tributary of the Indus River in central NWFP. It enters Pakistan through the tribal territory of Khyber Agency and joins the Indus River near Khairabad. In the Peshawar valley the Kabul River is divided into several major distributaries and also joined by the Swat and Bara rivers before it re-unites into a single channel near Noshera. The size of catchment is very large at this locality and during the monsoon rains the river overflows its banks and inundates certain low lying areas along its course. This is the last major tributary of Indus before it reaches the proposed site for the controversial Kalabagh dam. The opponents of the dam argue that damming the Indus at Kalabagh will retard the flow of Kabul River which will not only lead to more frequent summer flooding of the channel but also cause water logging and salinity problems in the Peshawar - Nowshera - Khairabad basin.

The spatial comparison between various stations of the Kabul River, however, does not reveal any consistent trend (Fig. 4.8, 4.9, 4.10) apart from the fact that suspended load always increases from Noshera to Kund. Because of continuous silting for the last thirty years or so, the Warsak reservior has become full of sediment and its storage capacity has almost finished. Subsequently, the hydroelectric power project designed to generate 240 MW from a reservoir is now working as a runoff river project and producing only about 65 MW at its peak (Pers. Comm.). Because of the loss of storage capacity, the inflow and outflow from the Warsak Reservior are equal and the residence time of water in the lake is negligible, therefore, no significant decrease in the suspended load was expected at Noshera. The temporal difference in the suspended load follows the same pattern i.e., highest in spring (1095 mg l^{-1}) and lowest in winter (312 mg l^{-1}) for Warsak (Fig 4.11) but for the other two stations (Fig 4.12, 4.13) the maxium load was observed during summer (Table 4.1). This may be due to the fact that eight significant industrial premises and important urban centres of the province discharge their waste directly into the main Kabul River and its tributaries. In addition to that numerous small industries are discharging effluents to channels and drains which eventually end up in the Kabul River (IUCN, 1994). These effluents also include suspended solids and thus become a major controlling factor of the suspended load concentration, particularly, downstream Noshera. Besides, the Bara River and Swat River both join the Kabul River downstream Warsak near Peshawar and Charsadda, respectively and complicate the situation. Whereas the Swat River may dilute the Kabul River sediment concentration, the Bara River sediment load (Fig 4.22) may increase its load, particularly, during spring.

The northern most part of NWFP - the Chitral District - is drained by several smaller streams including Yarkhun, Mastuj, Lutkho and Chitral rivers. The Yarkhun River is a tributary of the Mastuj River, whereas, Mastuj and Lutkho rivers eventually become tributaries of the Chitral River at Chitral city. The Chitral River then crosses the Pak-Afghan border and continues into Afghanistan where it is known as the Kunnar River. The water of Chitral/Kunnar River re-enters Pakistan after it becomes a tributary of the Kabul River somewhere east of Jalalabad. Water samples for this study were collected from Chitral city to represent the Chitral River. The results show (Fig 4.14) that again the maximum suspended sediment (1112 mg l^{-1}) was transported during spring time, which is about twice as much of the summer load (646 mg l^{-1}). The peak water discharge of the Chitral River, however, is usually recorded during July (WAPDA, 1992) which does not correspond with the highest suspended load flux. The meteorological data for Chitral and Drosh towns exhibit heavy rainfall (about 250 mm in April, 1993 at Chitral) during spring as opposed to almost no rain during August. The sediment input from surface runoff can, thus, be considered as an additional source for higher spring time load. The Chitral River acquires about 70% of its sediment load from the Mastuj River between Chitral and Buni towns. This area is characterized by unconsolidated Quarternary sediment, weak rock zones (exposing slate, shale, schist and marble), two well known faults (Reshun and Ayun faults), scarcity of vegetation, landsliding/rock fall and man-induced processes such as blasting for road construction. A combination of the above mentioned factors is responsible for contributing sediment input into the Mastuj River between Chitral and Buni towns. Lutkho and Mastuj rivers upstream Buni town are otherwise famous for their clear water.

The Panjkora River drains the area situated between Swat and Chitral valleys. The catchment area of the Panjkora River is characterized by a thick coniferous forest, little unconsolidated material and steep gradient. Lithologically the area exposes black amphibolites and associated diorites and peridotites of the Upper Swat Hornblendic Group and Tertiary volcanics (Kazmi et al., 1984). Water samples of the Panjkora River were collected from a site located between Talash and Temargara where the rocks are tectonically disturbed due to the suturing of Indian plate with the Kohistan Island Arc along the Main Mantle Thrust (MMT - Tahirkheli, 1979). The suspended load flux of the Panjkora River (Fig 4.15) also follows the pattern - highest during spring (443 mg l^{-1}) and lowest during winters (8 mg l^{-1}). The rainfall data shows that maximum rainfall takes place in March (437 mm during March, 1993), whereas, during the remaining part of the year (1993) it never exceeded 200 mm.

The Swat River is a snow fed perennial stream, which drains a fairly large catchment area (5776 km^2, at Chakdara) of the Swat valley. It is an important river from the point of view of hydropower production and irrigation. The Swat River records its peak mean monthly discharge during the month of June - a period of very small rainfall but maximum glacial ablation. Unlike most other rivers studied in this project, the suspended sediment flux of the Swat River (Fig 4.16) was found to be the same (57 mg l^{-1}) for August and April and even the winter load (51 mg l^{-1}) was not much less. This suggests that the peak sediment flux may also have climaxed sometimes between April and August in line with the maximum discharge. The meteorological data of Saidu Sharif indicates that the catchment of Swat River receives its maximum rainfall during Feburary and March (~440 mm), whereas the maximum discharge takes place during June. It can, therefore, be inferred that the main source of Swat River water is the glacial/snow ablation which reaches its peak during June. The absence of any significant temporal variation in the suspended load of Swat River can also be due to the stability of its catchment area which is not undergoing any notable physical weathering, soil erosion and landsliding.

The S.L. flux of the Kunhar River (Fig 4.17) was found to be highest among all rivers of NWFP. This result stands out more prominently when catchment areas of various rivers included in this study are compared. Samples of the Kunhar River were collected from Garhi Habibullah which has a considerbly smaller catchment (2383 km^2) than other stations in the study area. The quantity of sediment measured here varies from 5200 to 2750 and 1920 mg l^{-1} during April, August and January, respectively. Traditionally, the maximum water discharge of this station takes place during May/June (WAPDA, 1993). The Kunhar River can, thus, be regarded as the most turbid river in this part of the country which remains heavy round the year. The Kaghan Valley is characterized by heavy winter snow cover/small valley glaciers; rugged topogarphy; tectonic unstability; soft rocks such as unconsolidated Quaternary material and extensive alluvial fans/cones, shale of Murree Formation and phyllite/schist of the Salkhala Formation (Calkins, 1975); intense runoff and landsliding, etc. Glacially derived detritus from the upper reaches of the Kaghan valley (Naran) constitutes a major part of the sediment load in Kunhar River which becomes a tributary of the Jehlum near Dulai (Azad Kashmir) and eventually enters the Mangla Reservoir near Mirpur. With a mean annual discharge rate of ~3 g l^{-1}, a total of approximately 100,000 tonnes of suspended sediment is entering the Mangla Reservoir through the Kunhar River alone. Approximately, 60-65% of this seston is silt size, whereas about 30% is clay fraction (WAPDA, 1993). The majority of silt and sand size grains are deposited in the reservoir during their stay period which are fast reducing its storage capacity. Even though the Forest Department is actively involved in protecting its trees in Hazara and Kashmir area, excessive consumption of fuelwood through deforestation has resulted in the faster soil erosion rates making the area prone to land sliding. Such landslides and snow avalanches always serve as important sources of sediment input into the rivers and streams.

The southern part of NWFP (Bannu & D.I. Khan Divisions) is characterized by very hot and arid climate. The mean annual rainfall is less than 250 mm with around 75% of it concentrating in July-August (Dijk & Hussein, 1994). Three important tributaries of the Indus - the Kurram, Gambila and Gomal rivers drain large catchment areas and transport significant amounts of suspended load. These perennial streams drain the Sufed Koh mountains of Parachinar, intermontane Bannu basin and, the plains of Dera Ismail Khan including North and south Waziristan agencies, respectively. Apart from the summer the water discharge of these rivers is not very significant yet they are considered as an important water source for municipal and irrigation uses in an otherwise arid region. In order to protect the torrential runoff from being wasted, small reservoirs have been constructed on the Kurram and Gomal rivers which store the water during summer rains for drinking and irrigation in the remaining part of the year.

The quantitative analysis of the Kurram River S.L. flux (Fig 4.18) shows that the peak sediment discharge (1454 mg l^{-1}) during spring is only marginally greater than summer (1306 mg l^{-1}). For Gambila River (Fig 4.19), however, maximum sediment is found during summer (1120 mg l^{-1}) followed by spring (1037 mg l^{-1}) and winter (333 mg l^{-1}). During summers, when the area receives maximum rainfall (Fig 4.20), the surface runoff brings in significant quantities of sediment from the entire catchment into the river channel and hence relatively high suspended load in summer as compared to spring when the sediment is primarily of glacial origin. This shows the importance of rains in bringing sediments to the rivers. The Gomal River is dry during winters at the sampling site and the difference between spring (439 mg l^{-1}) and summer (18 mg l^{-1}) is sizable (Fig 4.21). This is because of the fact that river flow does not remain confined to the channel but spreads over a wide floodplain during summers. Subsequently, the currents become sluggish and form stagnant pools where suspended sediment starts depositing on the floodplain.

Mineralogy of the sediment

The qualitative analysis (mineral identification) of the suspended load of various rivers of NWFP was performed by analyzing the sediment through XRD. For this purpose water was separately sampled during summer in larger quantity (25 litres) so that a sizeable amount of sediment could be obtained. The resulting peaks were then compared manually with data files and mineral identified provisionally. The results of the qualitative analysis are given below with a note of caution that identification of unknown minerals is not alway 100% reliable when matching is performed manually. It was, therefore, decided to select only those minerals for description which are either common rock forming minerals or otherwise there is a logical likelihood of their occurrence in the area.

From the mineralogical study of the suspended sediment it is evident that illite is the most widely occuring mineral in rivers of the study area as it has been identified at 8 out of 14 sites. Illite developes by the altration of mica and alkali feldspar under alkline conditions and it is described as the most common clay mineral which is also supported by our data. The presence of illite in the fluvial system of the entire province is pretty much in line with the alkaline nature of the rocks exposed in various catchments areas of the study area (granites, granitic gneisses, schists, acidic volcanics and sandstone etc.). It should be emphasized here that the primary source of sediment for these rivers is the glacially derived detritus which does not promote chemical weathering, however, the frequent occurrence of illite indicates that a significant amount of chemical weathering also takes place in the region. The next abundantly occuring mineral is lepidolite (mica), showing 6 out of 14 occurances. It is especially characteristic of

TABLE 4.2 RIVERWISE MINERALOGY OF THE SUSPENDED LOAD

Name of Rivers	Identified Minerals
Chitral	illite, halloysite, lepidolite, clinochlore
Swat	quartz, clinochlore, anorthite, albite, muscovite, illite, depsujolsite
Panjkora	illite, roscoilite, gismondine
Bara	tridymite, depsujolsite, illite, lepidolite, gismondine, low albite, rustumite
Kabul (at Warsak)	nil
Kabul (at Noshera)	low quartz, lepidolite, illite, albite
Kabul (at Kund)	tarasovite, lepidolite
Indus (at Besham)	muscovite, depsujolsite, phlogopite, low quartz, illite
Indus (at Attock)	clinochlore
Indus (at DI Khan)	illite, gismondine, low quartz
Gomal	stellerite, fenaksite, rustumite, nitratite, calcite
Kurram	low quartz, lepidolite, gismondine, depsujolsite, rustumite, tosudite, illite, muscovite
Gambila	nitratine
Kunhar	darapskite, muscovite, lepidolite, wardite, masutomilite

TABLE 4.3 GROUP, HARDNESS, DENSITY AND CHEMISTRY OF MINERALS

Name of mineral	Chemcal formula	Group	Hardness **	Specific gravity**
Albite	$NaAl(Si,Al)Si_2O_8$	Feldspar	6.0 - 6.5	2.60 -2.62
Anorthite	$CaAl(Si,Al)Si_2O_8$	Feldspar	6.0 - 6.5	2.74 - 2.76
Calcite	$CaCO_3$	Carbonate	3.0	2.71
Clinochlore	$(MgFe)_4Al_2(Al_2Si_2)O_{18}(OH)_8$	Chlorite	2.0 - 2.5	2.65 - 2.78
Darapskite	$Na_3NO_3SO_4H_2O$	Nitrate	2.0 - 3.0	2.2
Depsujolsite	$Ca_3Mn^{4+}(SO4)_2(OH)_4$	Sulfate		
Fenaksite	$(K,Na,Ca)_4$ $(Fe^{+2}Fe^{+3}MgMn)_2$ $(Si_4O_{10})_2$ (OH,F)			
Gismondine	$CaAl_2Si_2O_8.4H_2O$	Zeolite	4.5	2.265
Halloysite	$Al_2Si_2O_5(OH)_5$	Clay	2.25	2.469
Illite	$KAl_4(ALSi_7O_{20})(OH)_4$	Clay	1.0 - 2.0	2.6 - 2.9
Lepidolite	$K_2(Li,Al)_{5-6}[Si_{6-7}Al_{2-1}O_{20}](OH,F)_4$	Mica	2.5 - 4.0	2.8 - 3.3
Masutomelite	$K(Li,Mn)_3(Si,Al)_4$ $O_{10}F_2$	Mica		
Muscovite	$KAl_2(AlSi_8)_{10}O$ OH_4	Mica	2.2 - 2.5	2.76 - 3.0
Nitratine	$NaNO_3$	Nitrate	1.5 - 2.0	2.24 - 2.29
Phlogopite	$K(Mg,Fe^{-2})_8(AlSi_8)O_{10}(F,OH)_2$	Mica	2.5 - 3.0	2.78 - 2.85
Quartz	SiO_2	Silicate	7	2.65
Roscoilite	$K(V,Al)_2(AlSi_5O_{10})(OH)_2$	Mica	2.5	2.97
Rustumite	$Ca_4Si_2O_{10}(OH)_2$			
Stellerite	$Ca_4Si_{28}O_{72}$ $28H_2O$	Zeolite	3.5 - 4.0	2.12
Tarasovite	Interlayered mica/clay			
Tosudite	Interlayered chlorite/smectite			
Tridymite	SiO_2	Silicate	7	2.26
Wardite	$NaAl_3(PO_4)(OH)$ $2H_2O$	Phosphate	5.0	2.81

** Source Mason & Berry, (1968)

granite pegmatite, but often occurs associated with lithia-bearing tourmaline, amblygonite and spodumene. Some times grown in parallel position with muscovite more rarely in granites and gneieses (Dana & Ford, 1932).

Depsujolsite (sulfate), gismondine (zeolite), muscovite and quartz were found at four sites each. Gismondine is a mineral of the secondary origin formed at comparatively low temperatures (during diagenesis) by the alteration of plagioclase. Its presence in the Panjkora River may be attributed to calcareous pelites exposed in the catchment, whereas its source in Bara River may be the metasediments of Tirah and rocks of Attock-Cherat Range. Gismondine found in the Indus (at D.I. Khan) and Kurram rivers seems to have been incorporated locally from Bannu - D.I. Khan basin. Muscovite is the most common mica, commonly found in pegmatitic facies. It is an essential constituent of mica schists, phyllites and related rocks, often associated with biotite. It also occurs in some syenites, nepheline-syenite, gneises, crystalline limestone and unaltered sedimentary rocks. The presence of muscovite in Kunhar, Swat, Indus (at Besham) and Kurram rivers is understandable because the catchment rocks include granites, schists, gneisses and other possible sources.

Abite, clinochlore and rustumite were identified in three samples each. Albite is a well known member of the plagioclase series and is a constituent of many igneous rocks specially those of the alkline type such as granite, syenite, diorite and also in corresponding feldspathic lavas and more acidic rock types. In the present study albite was identified in Bara, Kabul (at Noshera) and Swat rivers. Clinochlore is probably the most common of the chlorite minerals. It occurs in concentration with chlorite and talcose rocks or schists. It is sometimes found in parallel position with biotite or phlogopite. It is usually of secondary origin formed from the alteration of some other aluminous ferromagnesian minerals (Dana & Ford, 1932). Clinochlore was identified in samples collected from Chitral, Swat and Indus (at Khairabad) rivers.

Nitratine is a soluble mineral and was found at two localities (Gambila and Gomal rivers) in the southern part of the NWFP. Nitratine is a soda niter homoeomorphous with calcite. It usually occurs in masive forms, as an incrustation or in beds. Besides nitratinne, darapskite is another soluble nitrate and was found once (in Kunhar R.). Like nitrates, calcite is also soluble in water and was identified once (Gomal R.). The presence of these minerals in undissolved (suspended) form in the rivers indicates a local source of the minerals near the sampling sites. Such minerals could have been brought into the river channel by some local springs. All other minerals shown in Table 4.2 and 4.3 were identified for only one sampling site.

Anorthite is characteristically found in the basic igneous rocks both volcanic and plutonic as in anorthite basalt, doirite, gabbro and norites etc., also in amphibolites and in granular limestone of contact deposits. Halloysite occurs in viens, beds or ores as a secondary product. It can also be found in granites and other rocks being drived from the decomposition of some aluminous minerals. Phlogopite is especially characteristic of crystalline limestone or dolomite and is also found in serpentine. It is a product of both contact and regional metamorphism.It is often assocated with pyroxene, amphibole and serpentine etc. Rarely occurs in igneous rocks. Roscoelite is essentially a muscovite in which vanadium has partly replased the aluminum. Stellerite is found in cavities diabtse tuff in copper island. Occurs in basalt, Granites and greises.

Wardite is a basic hydrous phosphate. The properties and paragenesis of some of the minerals identified in this study could not be ascertained from the literature review.

From the above discussion it is assumed that most commonly occurring group of minearls are being transported altered and unaltered from the catchments of the rivers of this part of the country. These minerals are mostly clays, micas, chlorites, zeolites and some very hard minerals like quartz and feldspar. it is also evident that the process of soil formation is considerable which indicates the importance of chemical weathering in the area.

Water Chemistry

pH

pH is the logrithm in base 10 of the reciprocal of hydrogen ions activity given in moles per litre. The pH value extends from 0 (very acidic) to 14 (very alkline) with the middle value (pH=7) corresponding to exact neutrality at 25°C (Zuane, 1992). pH has no immediate direct effect on human health but plays an important role in the corrocivity, solubility, alkalinity, chlorination, hardness, acidity, coagulation, and carbondioxide stability, all of which have their individual effects. The range of pH allowed by WHO (1984) for potability is 6.5-8.5. The pH of water samples studied during this project ranges between 5.3-7.6. Eleven out of fourteen samples lie well within the range recommended by WHO. The remaining three, Swat, Kurram and Kabul rivers (at Noshera) are below the required limits. The water of Bara River shows a neutral nature.

Total dissolved solids

The Total Dissolved Solids (TDS) is a measure of solid carried by water in suspension. High content of solids in water has been inversely correlated with increased morbidity and mortality rates (possibility of potential danger of soft water mainly on cardiovascular diseases). The maximum limit for TDS is 1500 mg l^{-1} by WHO (1984). All samples lie well within the permitted limits. The highest value is exhibited by the Gambila river.

Conductivity

Coductivity or specific conductance is the measure of electric current a water sample carries by the ionized substances; therefore the dissolved solids are basically related to this measure. Hence no limits have ever been fixed by any agency.

Sodium

Sodium is a natural constituent of raw water, but its cocentration increases by pollutional sources. It is a requirement of our life. According to USEPA (1984) a daily level of sodium in foods is 1600-9600 mg in adults and 69-92 mg kg^{-1} day^{-1} for infants. But its high cocentration in drinking water is considered harmful to persons suffering from cardiac, renal and circulatory diseases. WHO has published no sodium maximum contaminant level for water but United States Environmental Protection Agency (Zuane, 1992) has allowed a maximum level of 20 mg l^{-1} of sodium in drinking water. The sodium present in the samples studied varies greatly - 1 to 137.91 mg l^{-1}. Swat River shows the smallest of all whereas, the Kabul River shows greatest amount of sodium content (1.0 and 137.91 mg l^{-1} respectively). Eight of fourteen samples lie within the desired limit and one is slightly higher.

Potassium

Potassium is an essential nutritional element for humans, animals and plants; nontoxic but acts as a cathartic excessive concentrations (1-2 g). Major biological functions are influenced by poassium. It is a substitute of sodium in foods for those who suffer from cardial, renal and circulatory diseases. WHO and USEPA have no recommended limits for potassium while Europian Community has issued a guide number of 10-12 mg l^{-1} in 1980 (Zuane, 1992). Potassium content of water varies from 0.00 for the Kabul River at Noshera to 21.53 mg l^{-1} for the Kunhar River. None of the samples lies within the required limits. Twelve samples are below and two are above the limits.

Lithium

The biological function of lithium is not known so it is not concidered in Primary Drinking Water Standards. Suggested lithium maximum limit is 5 mg l^{-1} (Zuane, 1992). The lithium content varies from 0.00 for Gambila River to 1.00 for Indus River both at Attock and D.I. Khan. All the samples are below the maximum contamination limit allowed.

Sulfate

Sulfates are found in natural waters as a product of sources related to mining or industrial wastes. Sulfate also occurs in rainfall in or near metropolitan areas where it is produced as a fossil fuel combustion byproduct. High level of sulfate can cause diarrhea and gastroantritis.

WHO recommends a maximum sulfate level of 400 mg l^{-1} in drinking waters but the USEPA recommends a much lower level (250 mg l^{-1}). The sulfate content in the different samples varies from 0.00 for the Kabul River at Warsak to 342.67 mg l^{-1} for the Gomal River. These values are within the limits set by WHO but two values are greater than the maximum limit allowed by USEPA.

Phosphate

Water supplies may contain phosphate derived from natural contacts with minerals or through pollution from application of fertilizers, sewage and industrial wastes. Ground waters are, therefore, more likely to have higher phosphate cocentrations than surface waters. Polyphosphates have been used to prevent scale formation and inhibit corrosion. Their discharges are considered as nutrients with consequent growth of plants and organisms. The New York State, therefore, (1989) designated that "concentration should be limited to the extent necessary to prevent nuisance growths of algae, weeds, and slimes that are or may become injurious to any beneficial water use. Newjersey adopted a maximum of 50 micro gram l^{-1} as a total phophorus for designated public water supplies (Zuane, 1992). There is no level defined by either WHO or USEPA but Europian Community has issued a guide number of 0.400 - 5.0 mg l^{-1}. The phosphate values range from 0.00 mg l^{-1} for Indus at Attock and Kabul at Warsak, to 29.31 mg l^{-1} for Kabul at Kund.

Besides, all water samples were also analysed for trace elements such as Zinc, Nickle, Silver, Copper and Manganese contents but they were found below detection limits. The detection limit of Atomic Absorption Spectrophotometer is >1 ppm. This instrument cannot detect presence of such elements below this limit.

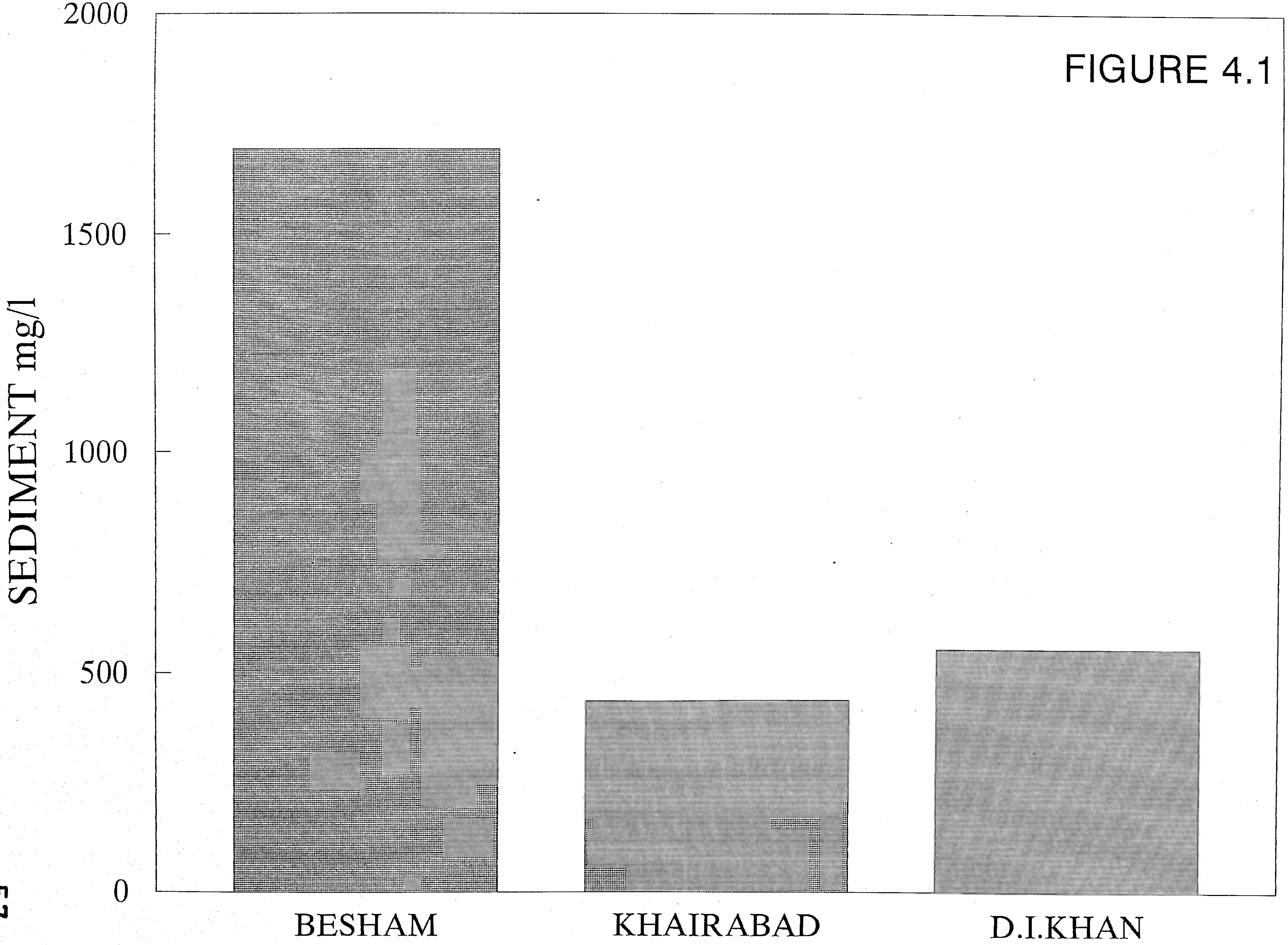
TABLE 4.4 pH, TDS, AND C ODUCTIVITY OF WATER SAMPLES

Name of river	pH	TDS mg l^{-1}	conductivity ms\cm
Chitral	7.3	291.00	0.458
Panjkora	6.6	19.70	0.027
Swat	5.3	99.50	0.153
Indus (Besham)	7.6	191.10	0.337
Indus (Attock)	7.3	193.10	0.337
Indus (D I Khan)	6.5	20.09	0.029
Kunhar	7.4	291.00	0.455
Kabul (Kund)	7.1	314.00	0.438
Kabul (Noshera)	6.0	95.10	0.343
Kabul (Warsak)	7.4	249.00	0.395
Bara	7.0	486.00	0.757
Kurram	5.7	371.00	0.923
Gambila	7.3	1251.00	1.971
Gomal	6.7	193.00	0.027

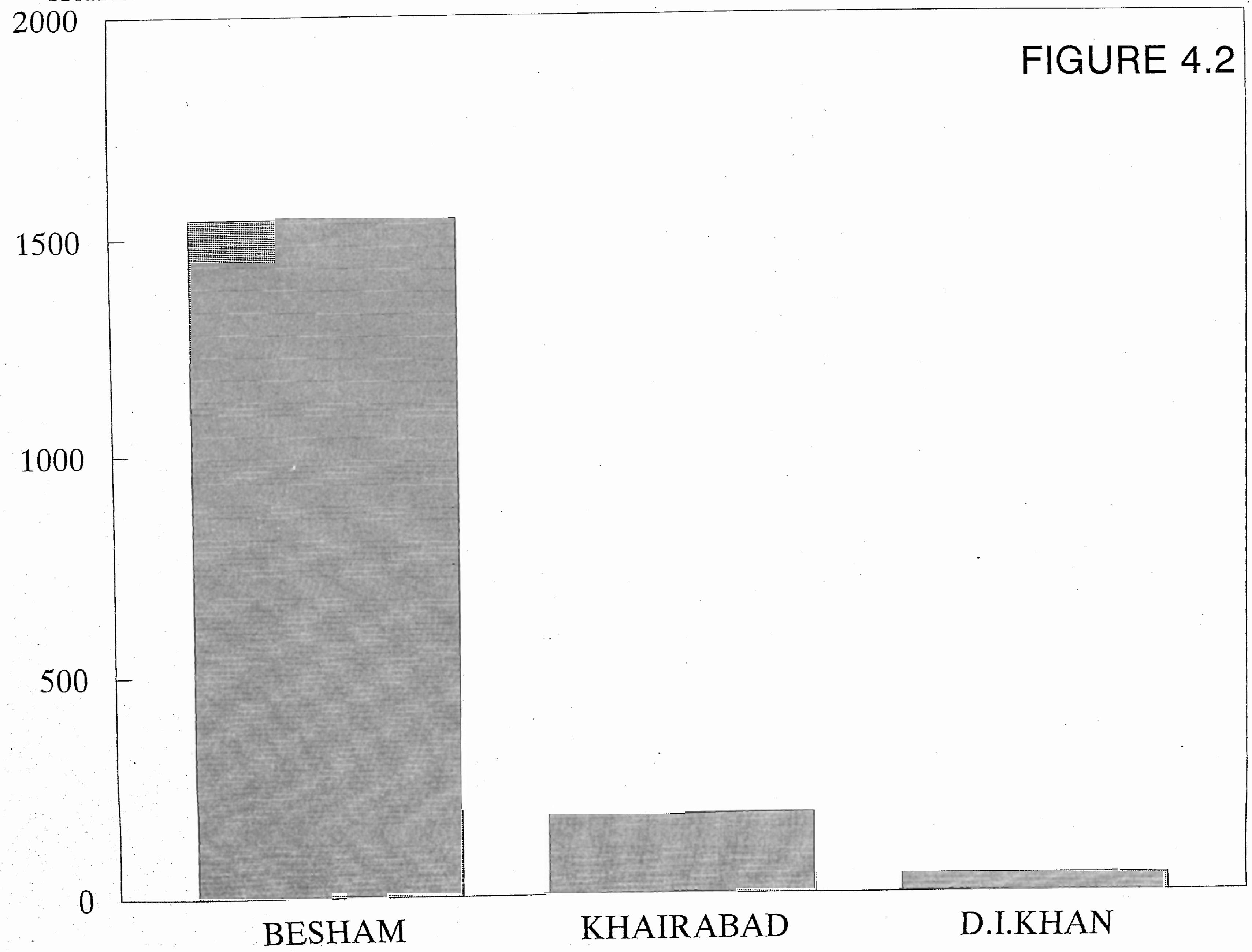
TABLE 4.5 Na^+, K^+, Li^+, SO_4^{--} AND PO_4^{---} CONTENT OF WATER SAMPLES

Name of river	Na^+ ppm	K^+ ppm	Li^+ ppm	PO_4^{---} ppm	SO_4^{--} ppm
Chitral	34.70	6.51	0.07	0.90	0.93
Panjkora	4.39	1.37	0.63	1.97	29.00
Swat	1.00	2.00	0.98	1.31	113.00
Indus (Besham)	72.40	4.05	0.61	0.03	0.09
Indus (Attock)	38.00	1.02	1.00	0.00	298.73
Indus (D I Khan)	4.06	2.90	1.00	2.13	123.60
Kunhar	90.32	21.53	0.02	18.93	80.67
Kabul (Kund)	6.87	1.67	0.71	29.31	11.93
Kabul (Noshera)	2.07	0.00	0.75	2.67	1.90
Kabul (Warsak)	137.91	8.39	0.25	0.00	0.00
Bara	10.11	19.37	0.69	10.50	5.67
Kurram	9.32	0.39	0.89	0.92	110.13
Gambila	20.50	0.80	0.00	12.62	59.30
Gomal	6.75	0.48	0.31	5.63	342.67

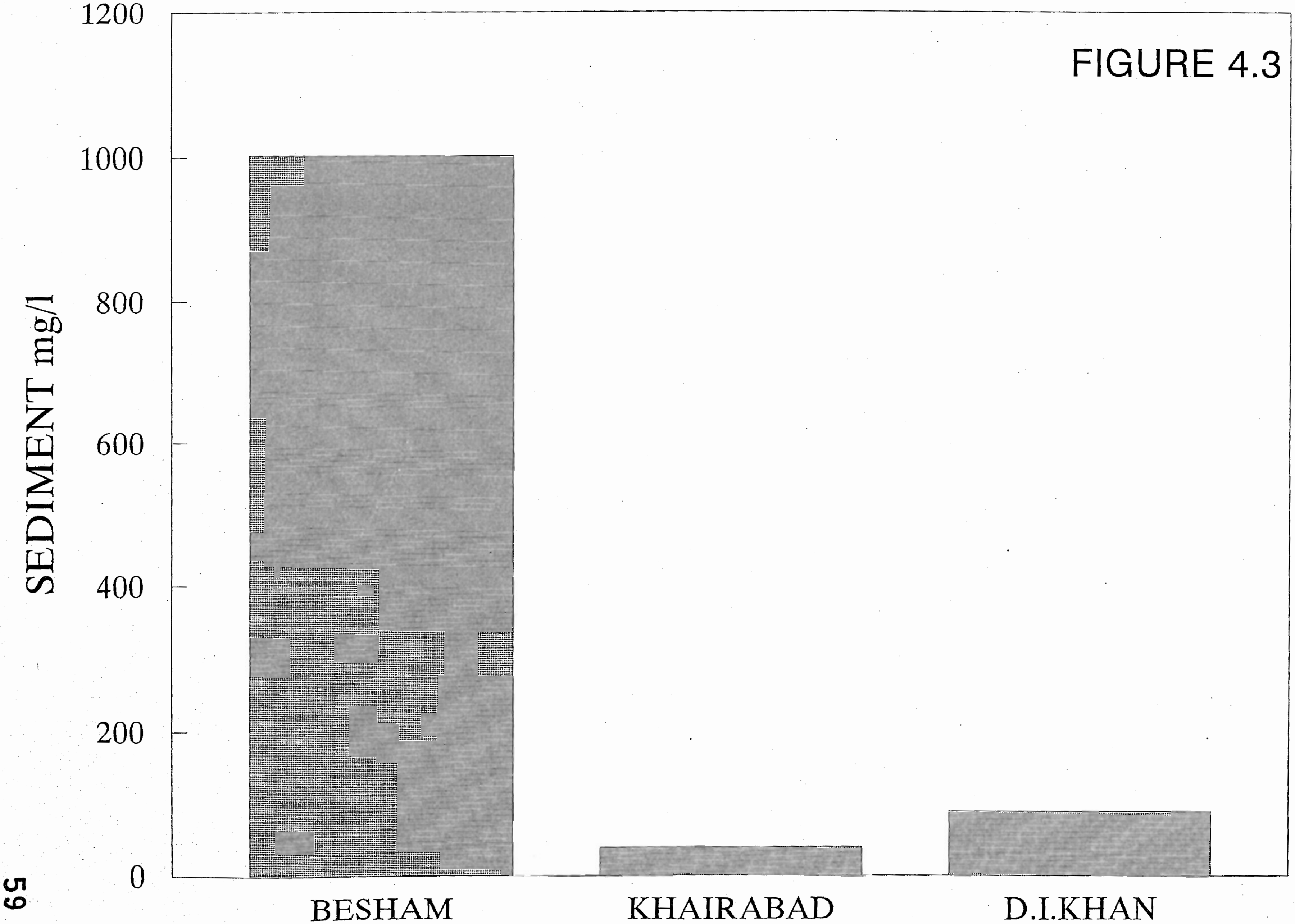
SPATIAL VARIATIONS IN SUSPENDED LOAD OF THE INDUS RIVER AT DIFFERENT STATIONS DURING SPRING



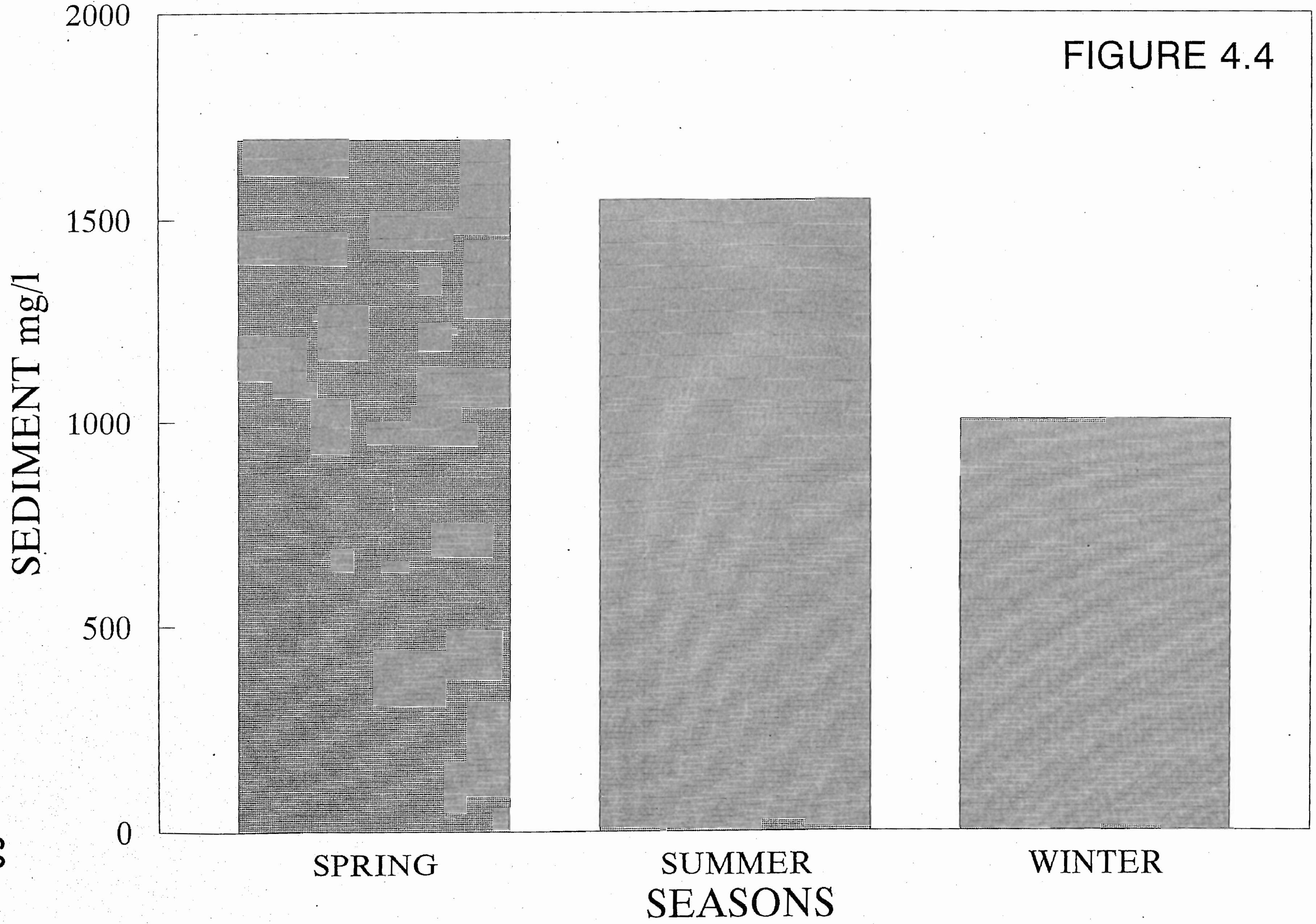
SPATIAL VARIATIONS IN S.L FLUX OF THE INDUS RIVER AT DIFFERENT STATIONS DURING SUMMER



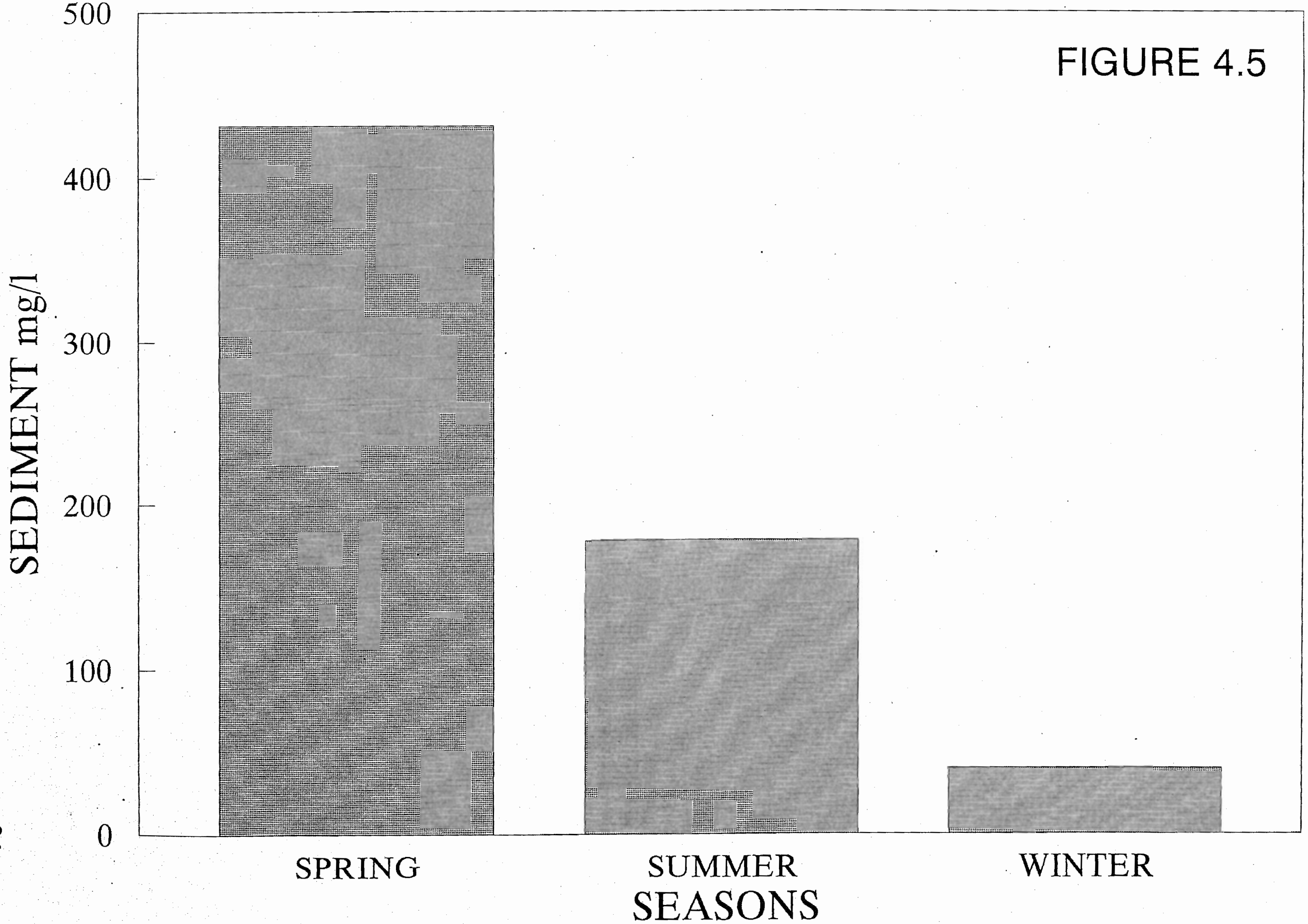
SPATIAL VARIATIONS IN S.L FLUX OF THE INDUS RIVER AT DIFFERENT STATIONS DURING WINTER



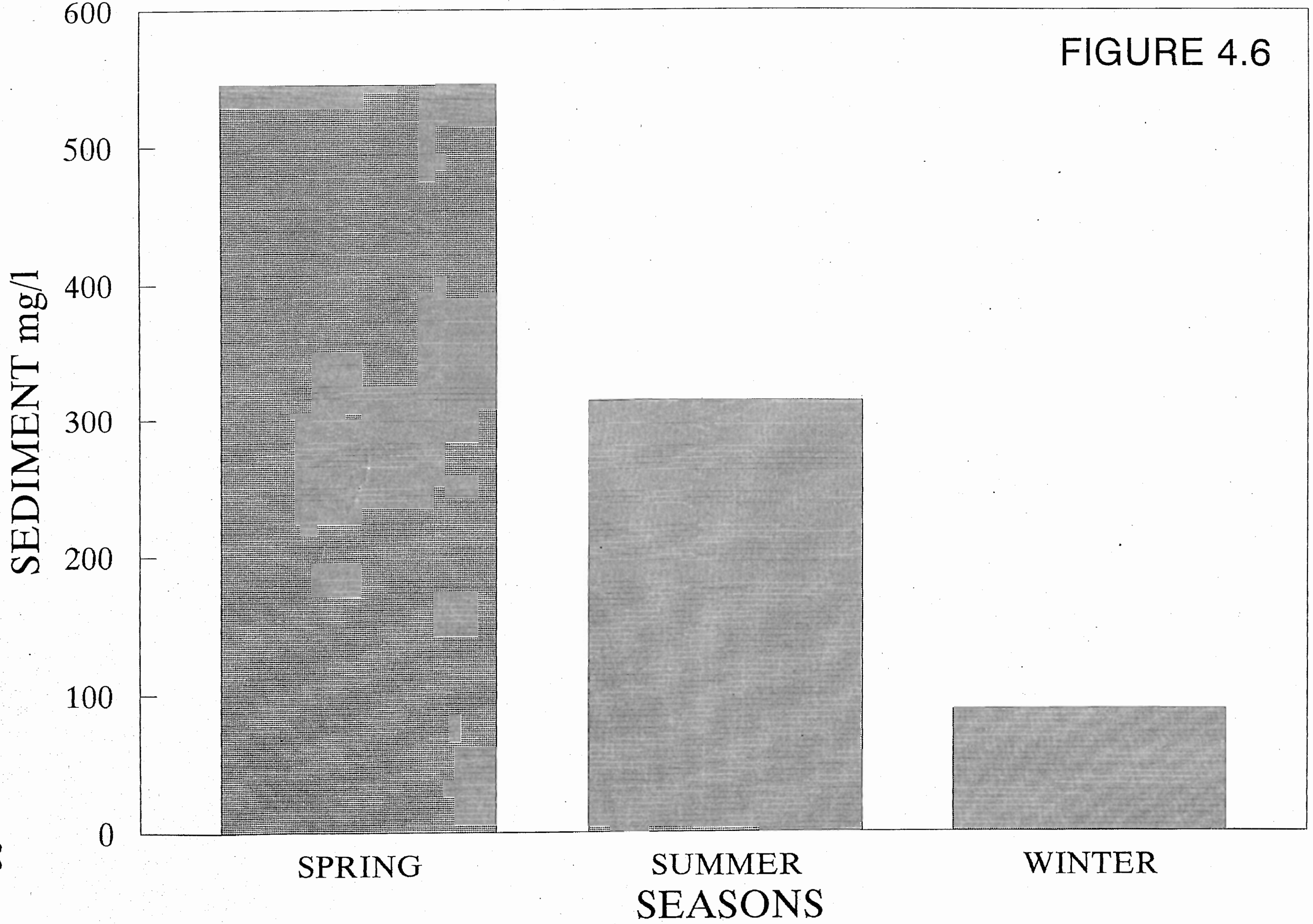
TEMPORAL VARIATIONS IN SUSPENDED LOAD OF THE INDUS RIVER AT BESHAM



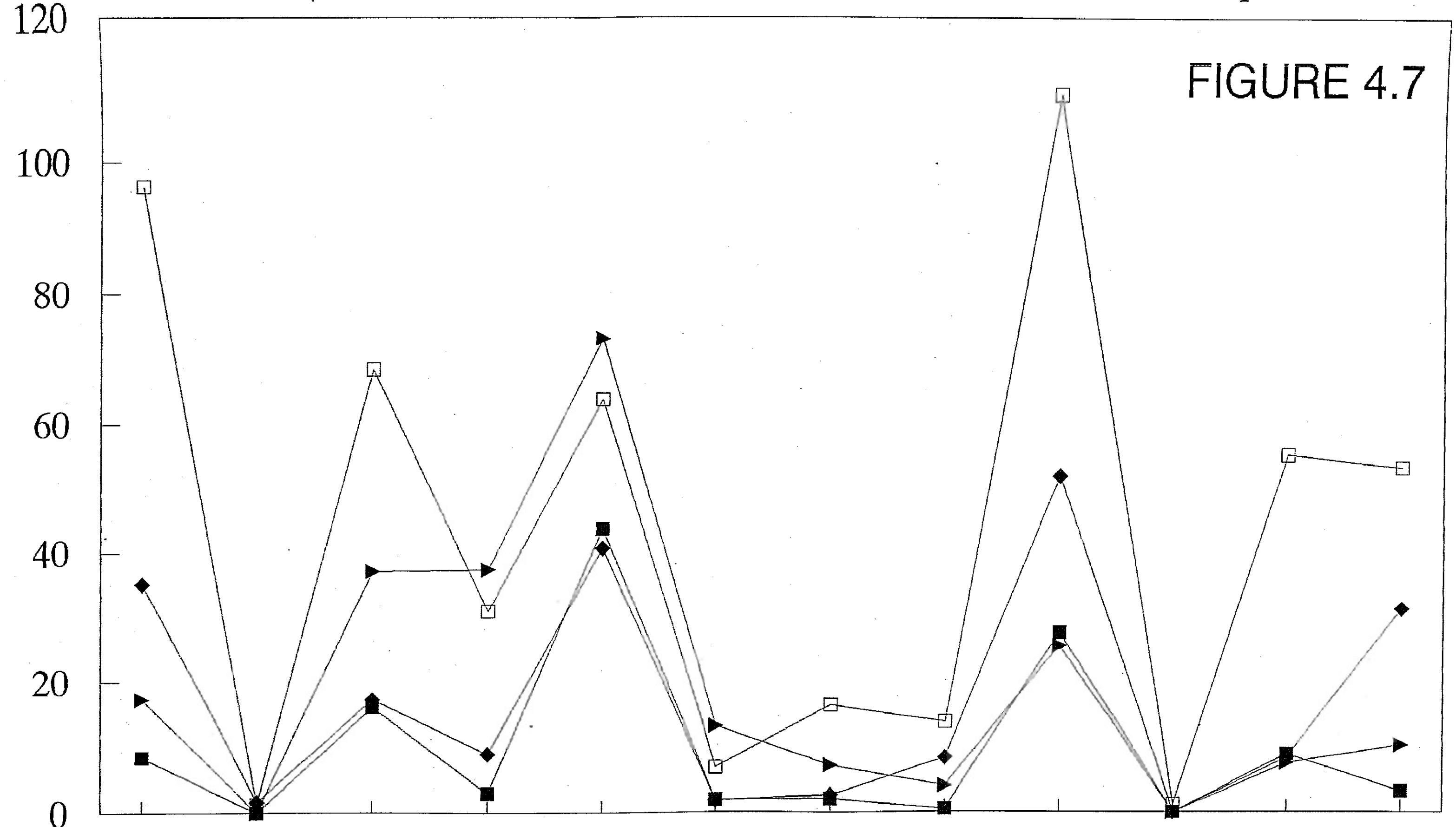
TEMPORAL VARIATIONS IN SUSPENDED LOAD OF THE INDUS RIVER AT KHAIRABAD



TEMPORAL VARIATIONS IN SUSPENDED LOAD OF THE INDUS RIVER AT D.I.KHAN

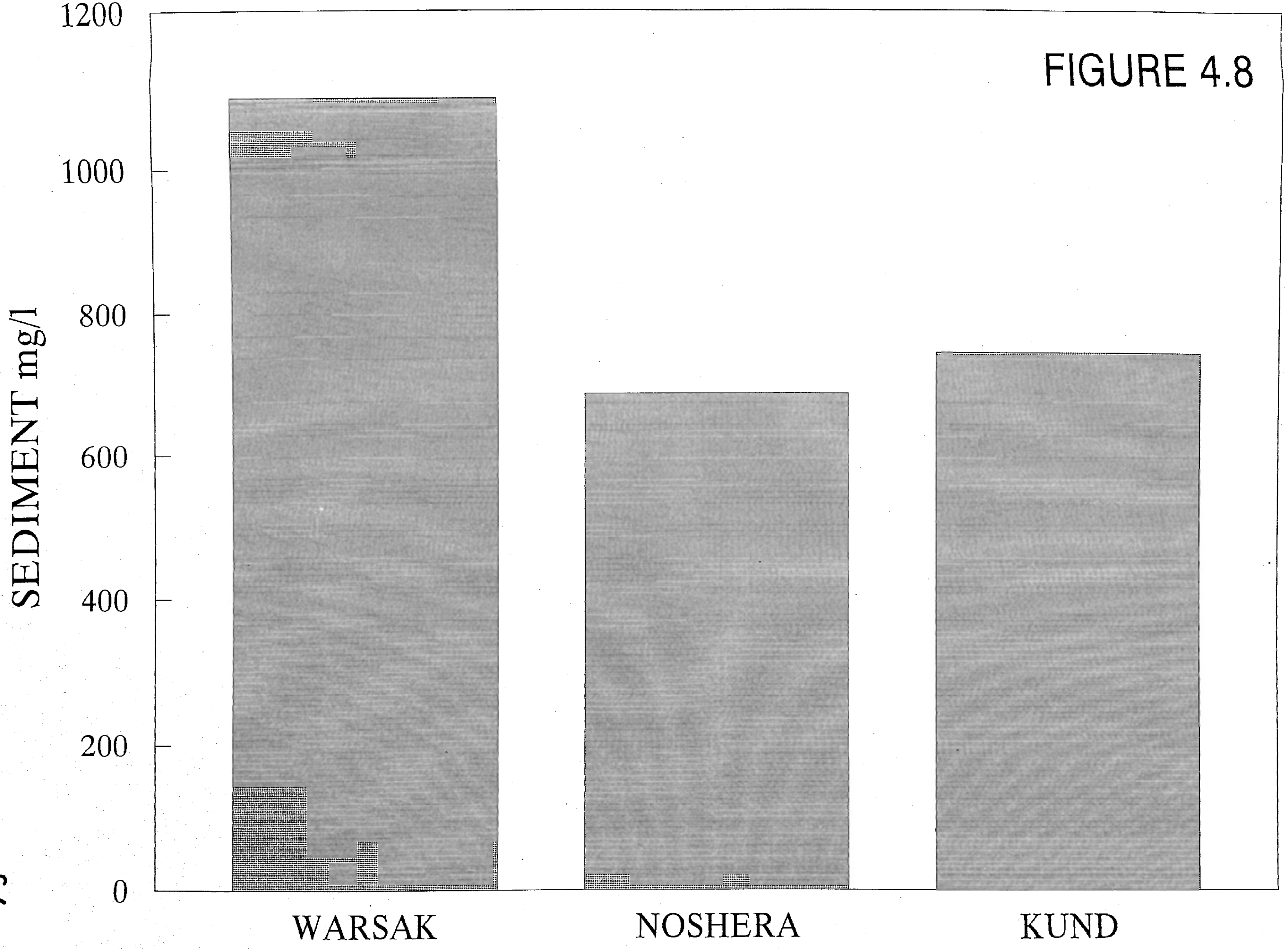


Monthly rain fall (from Mar. 93 to Feb. 94) in catchment of the Indus River upstream Besham



MONTHS	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
GILGIT	8.5	0	16.1	3	43.5	1.9	2.1	0.4	27.4	0	8.8	3.2
CHILAS	35.2	1.6	17.3	9	40.5	1.8	2.6	8.3	51.7	0	8.3	31.1
BUNJI	17.3	0	37.1	37.4	72.9	13.1	7.2	4	25.4	0	7.5	10.2
ASTORE	96.3	1.3	68.4	30.9	63.5	6.8	16.4	13.7	110	1.2	54.9	53

SPATIAL VARIATIONS IN SUSPENDED LOAD OF THE KABUL RIVER AT DIFFERENT STATIONS DURING SPRING



SPATIAL VARIATIONS IN S.L. FLUX OF THE KABUL RIVER AT DIFFERENT STATIONS DURING SUMMER

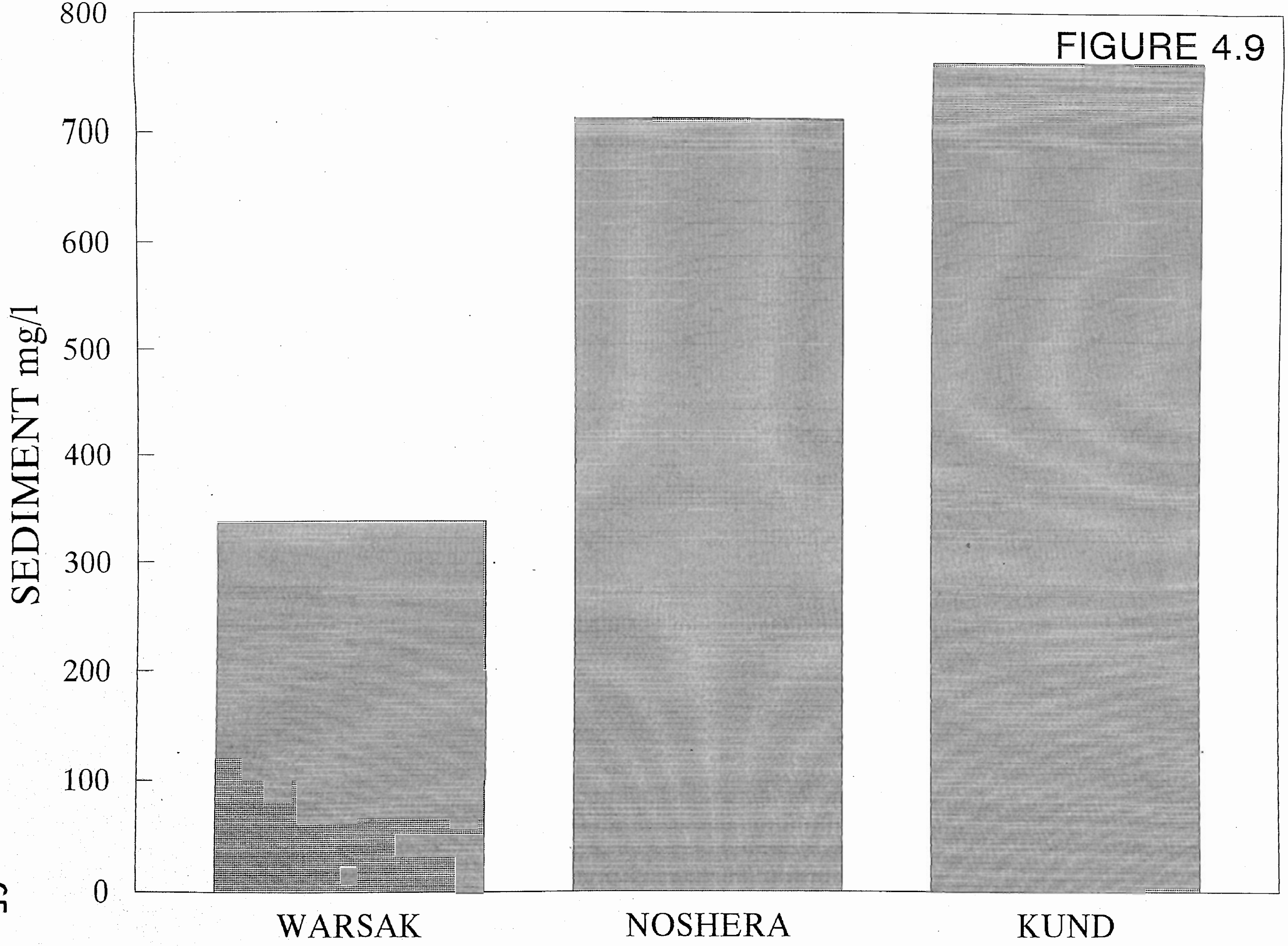
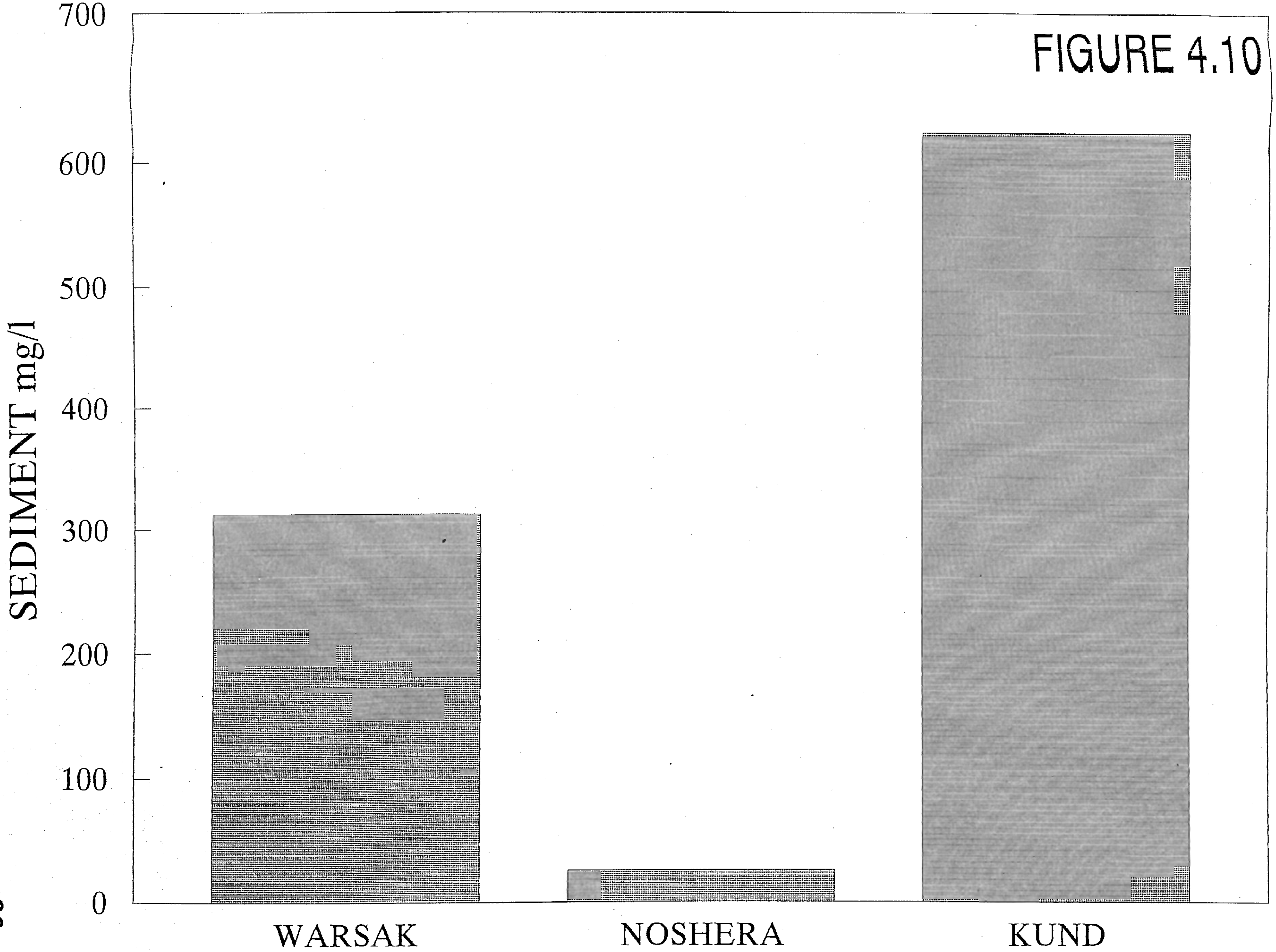
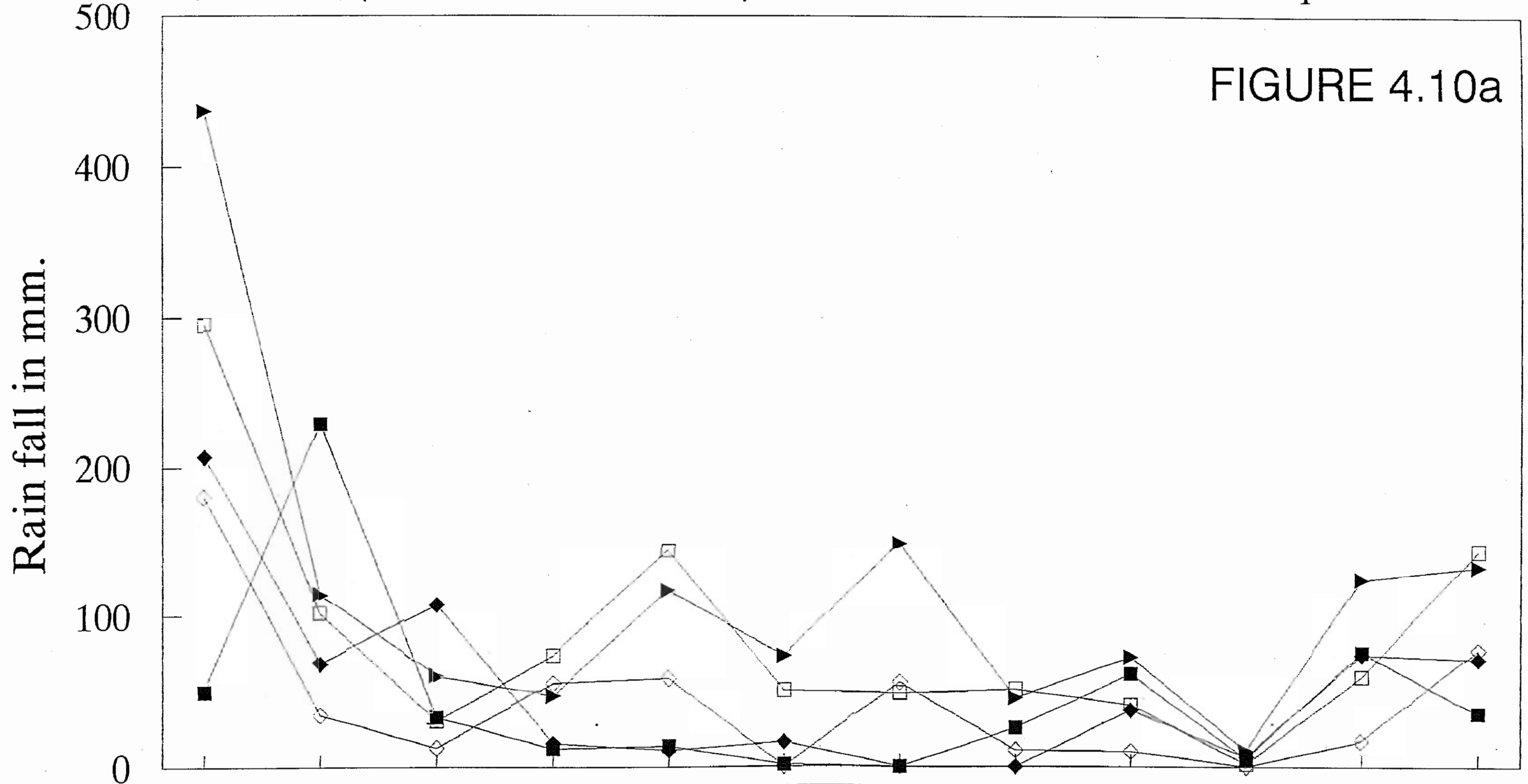


FIGURE 4.9

SPATIAL VARIATIONS IN S.L. FLUX OF THE KABUL RIVER AT DIFFERENT STATIONS DURING WINTER



Monthly rain fall (from Mar. 93 to Feb. 94) in catchment of the Kabul River upstream Noshera



MONTHS	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
CHTRL	49.7	228.8	32.6	12.1	13.9	1.1	0	25.9	61.6	5.1	76.1	35.5
DROSH	206.6	68.5	107.3	15.6	10.9	16.1	0	0	37.6	6.2	74.6	71.7
DIR	437	114	60	47.4	116	73	147.7	46	72.6	10.5	124.8	132.9
SAIDU	295.2	101.2	30.4	74.1	142.2	50.1	49.2	51.4	41	1.6	60.1	143.5
PESH.	178.5	34.4	12.3	55.4	58.4	0	56	11	10.2	0	17	77.5

TEMPORAL VARIATIONS IN SUSPENDED LOAD OF THE KABUL RIVER AT WARSAK

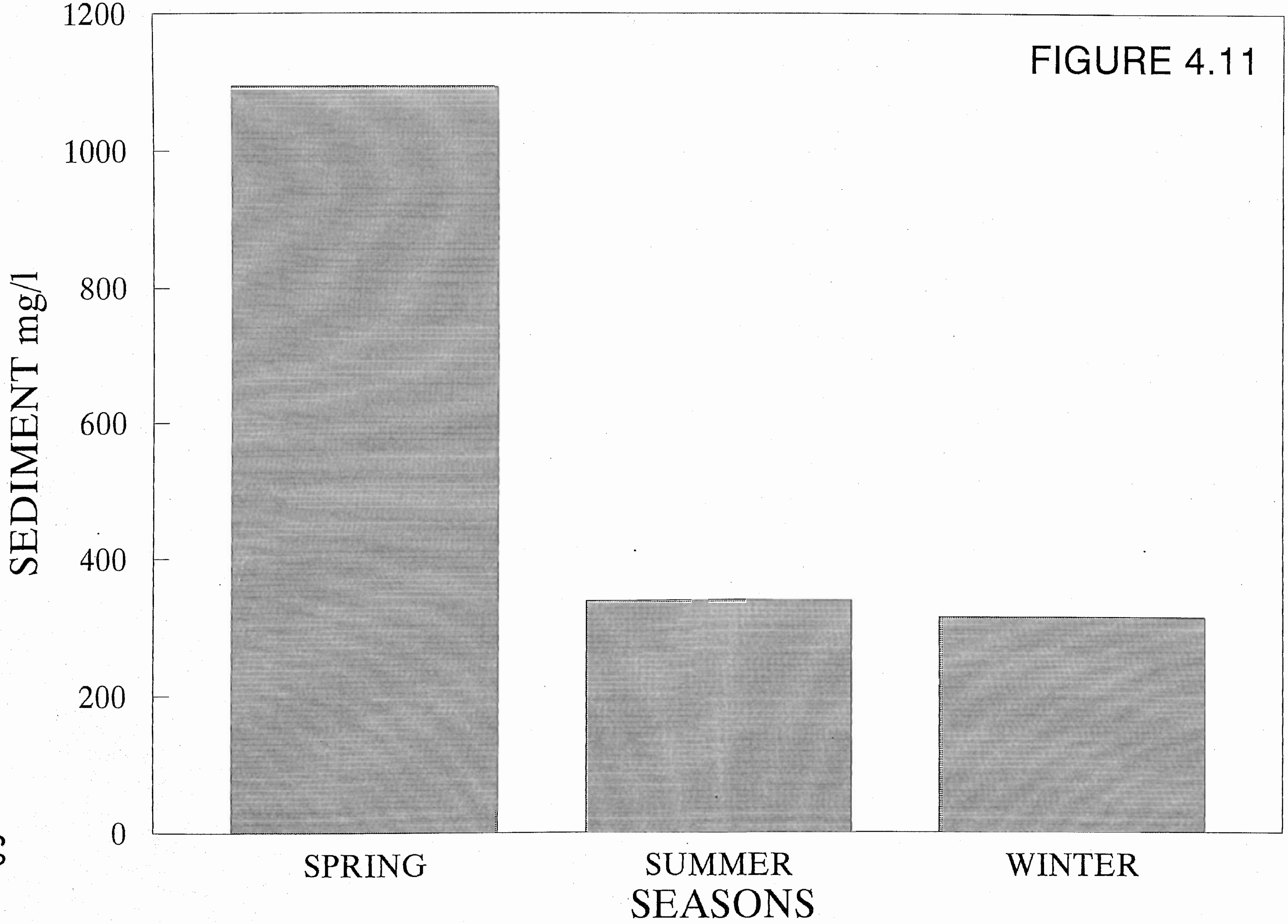
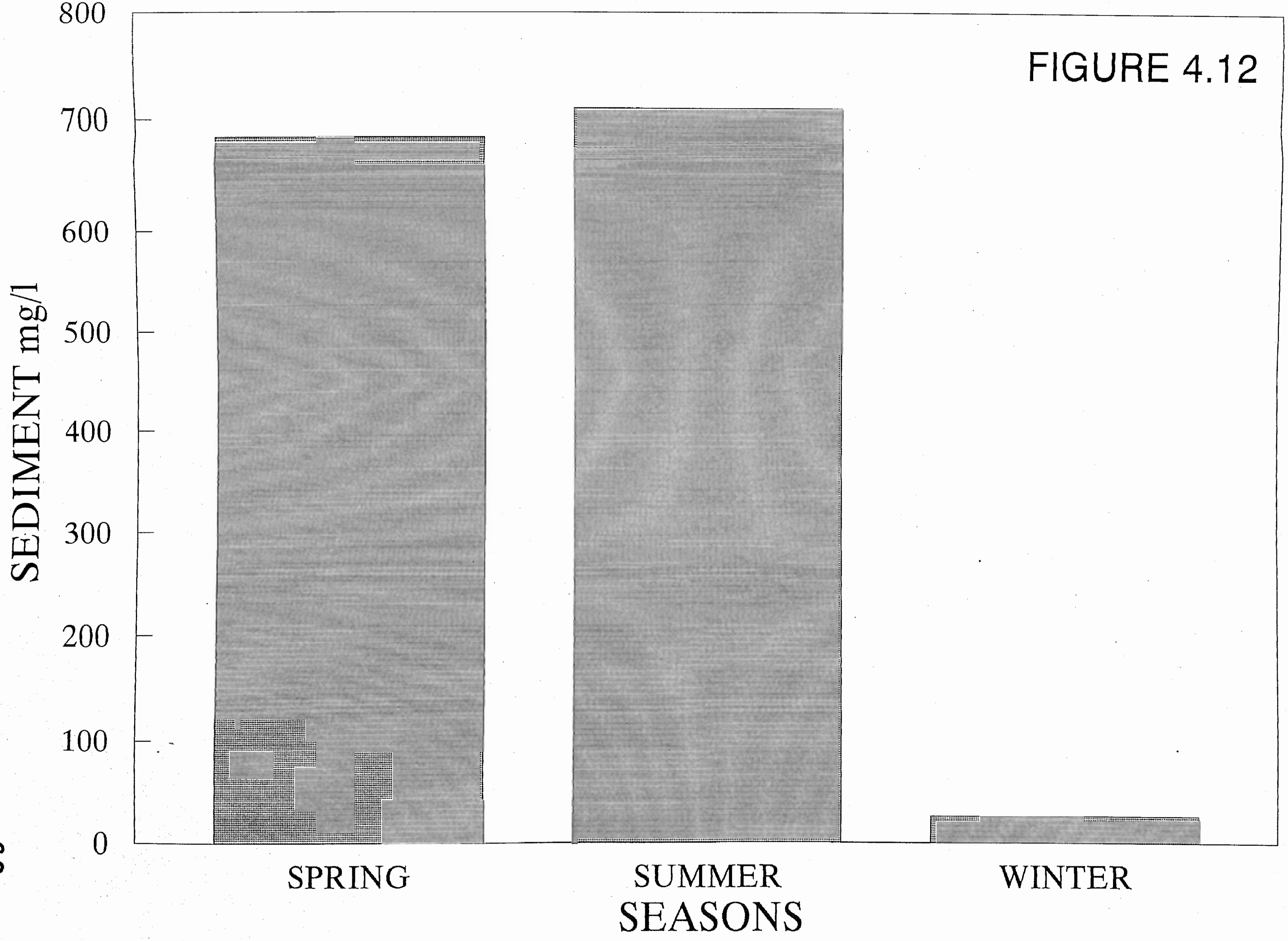
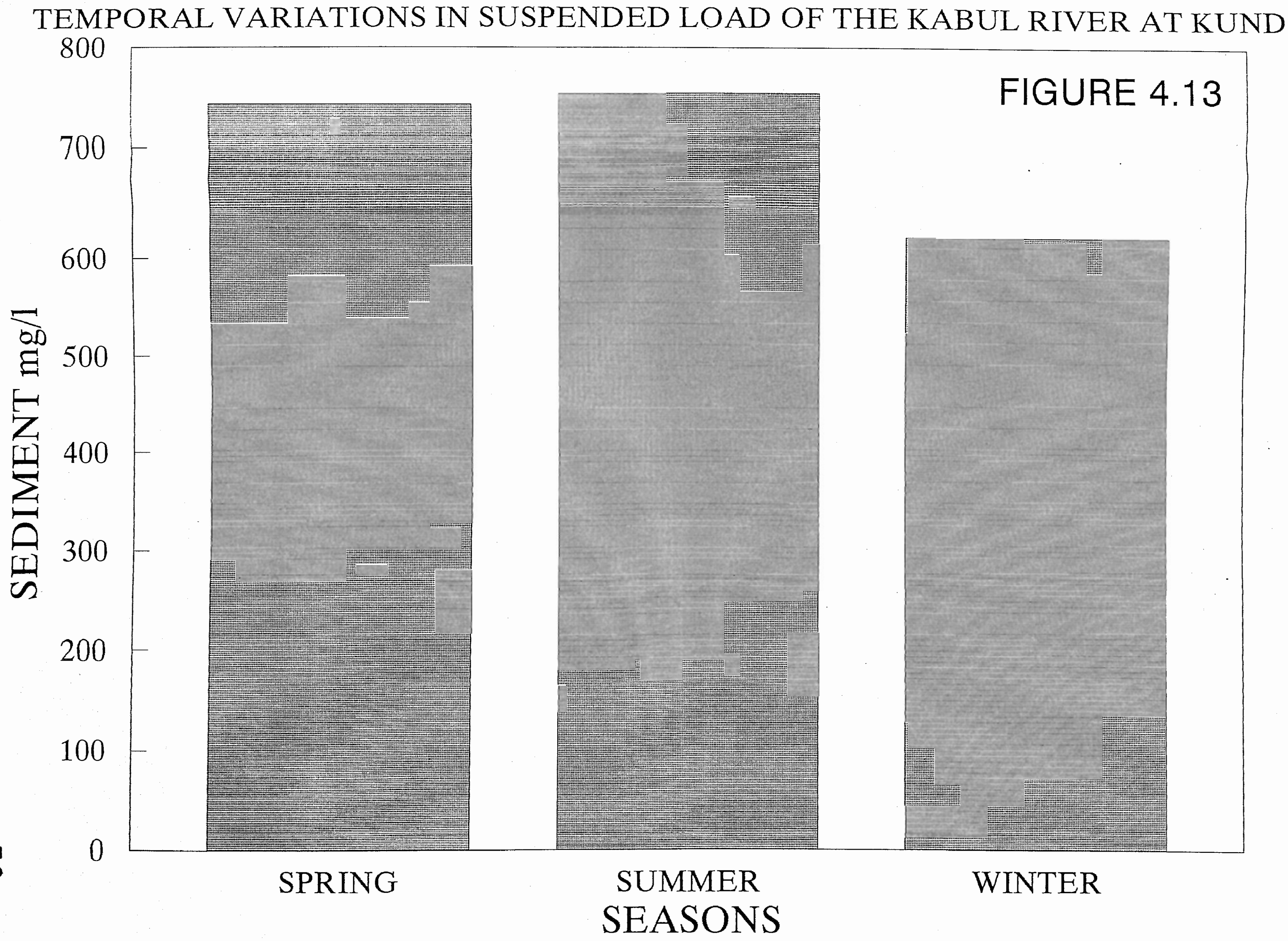


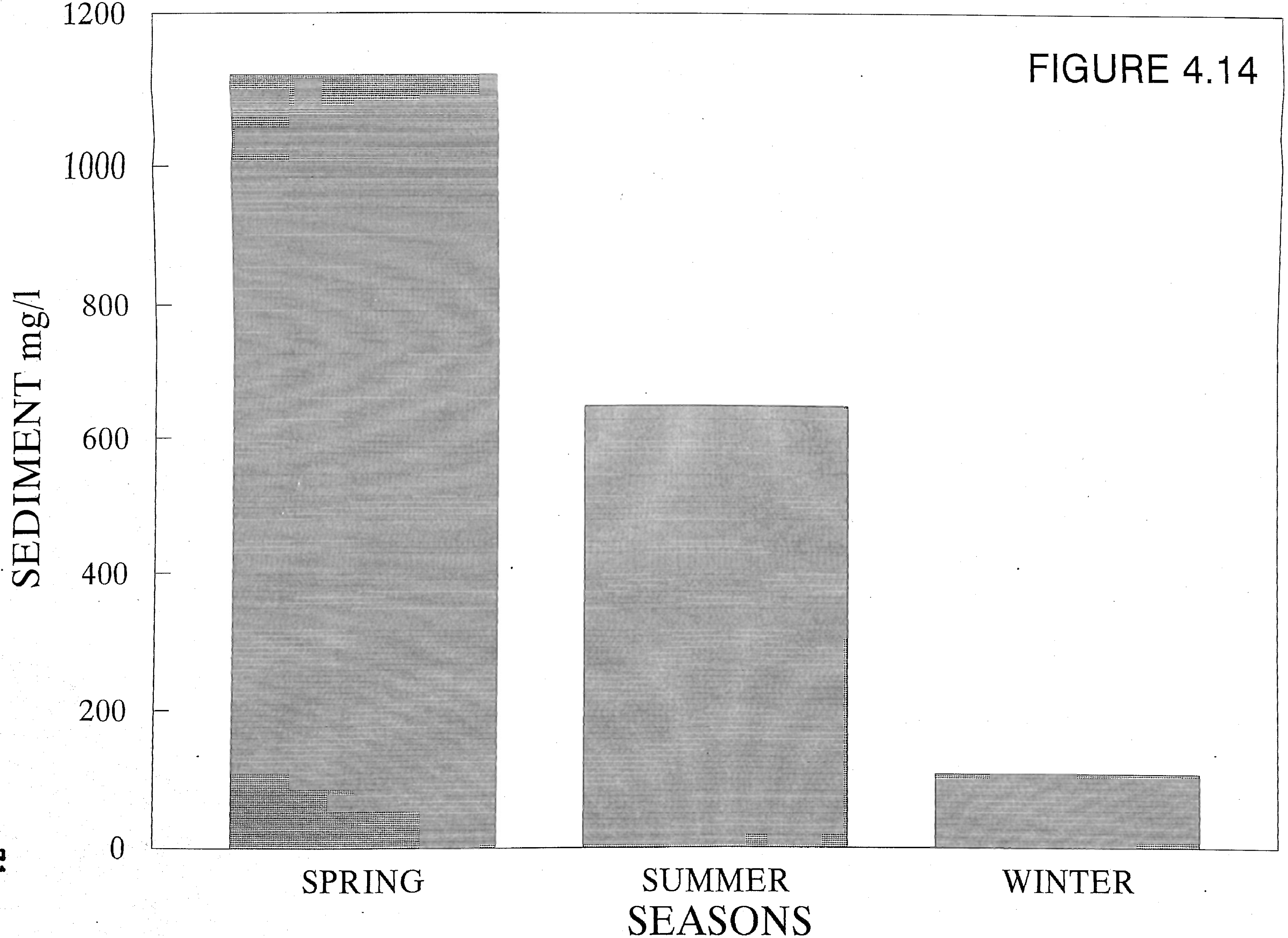
FIGURE 4.11

TEMPORAL VARIATIONS IN SUSPENDED LOAD OF THE KABUL RIVER AT NOSHERA

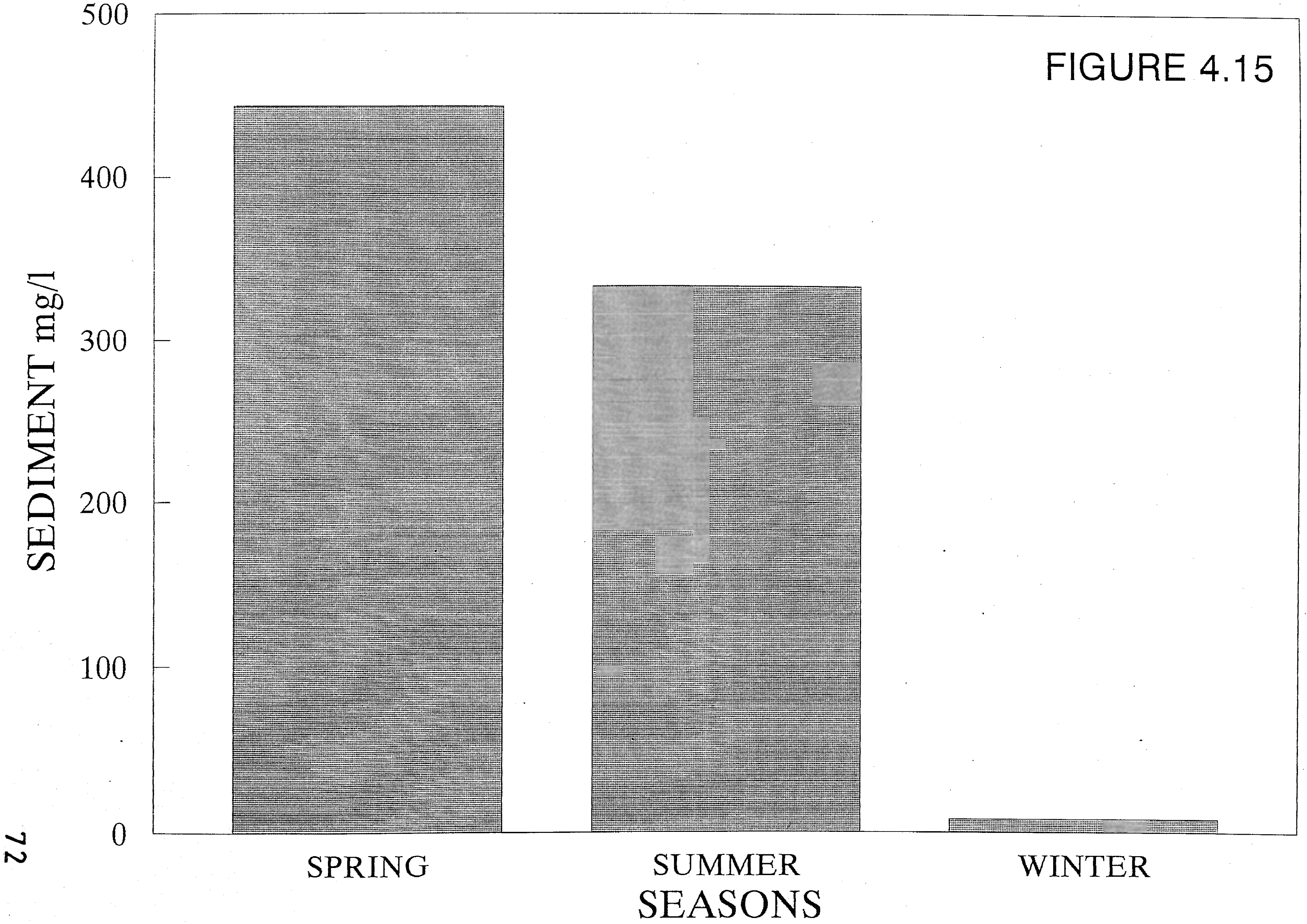



TEMPORAL VARIATIONS IN SUSPENDED LOAD OF THE KABUL RIVER AT KUND
FIGURE 4.13
SEDIMENT mg/l
800
700
600
500
400
300
200
100
0
SPRING
SUMMER
WINTER
SEASONS

TEMPORAL VARIATIONS IN SUSPENDED LOAD OF THE CHITRAL RIVER AT CHITRAL



TEMPORAL VARIATIONS IN SUSPENDED LOAD OF THE PANGKORA RIVER NEAR TEMARGARA



TEMPORAL VARIATIONS IN SUSPENDED LOAD OF THE SWAT RIVER AT CHAKDARA

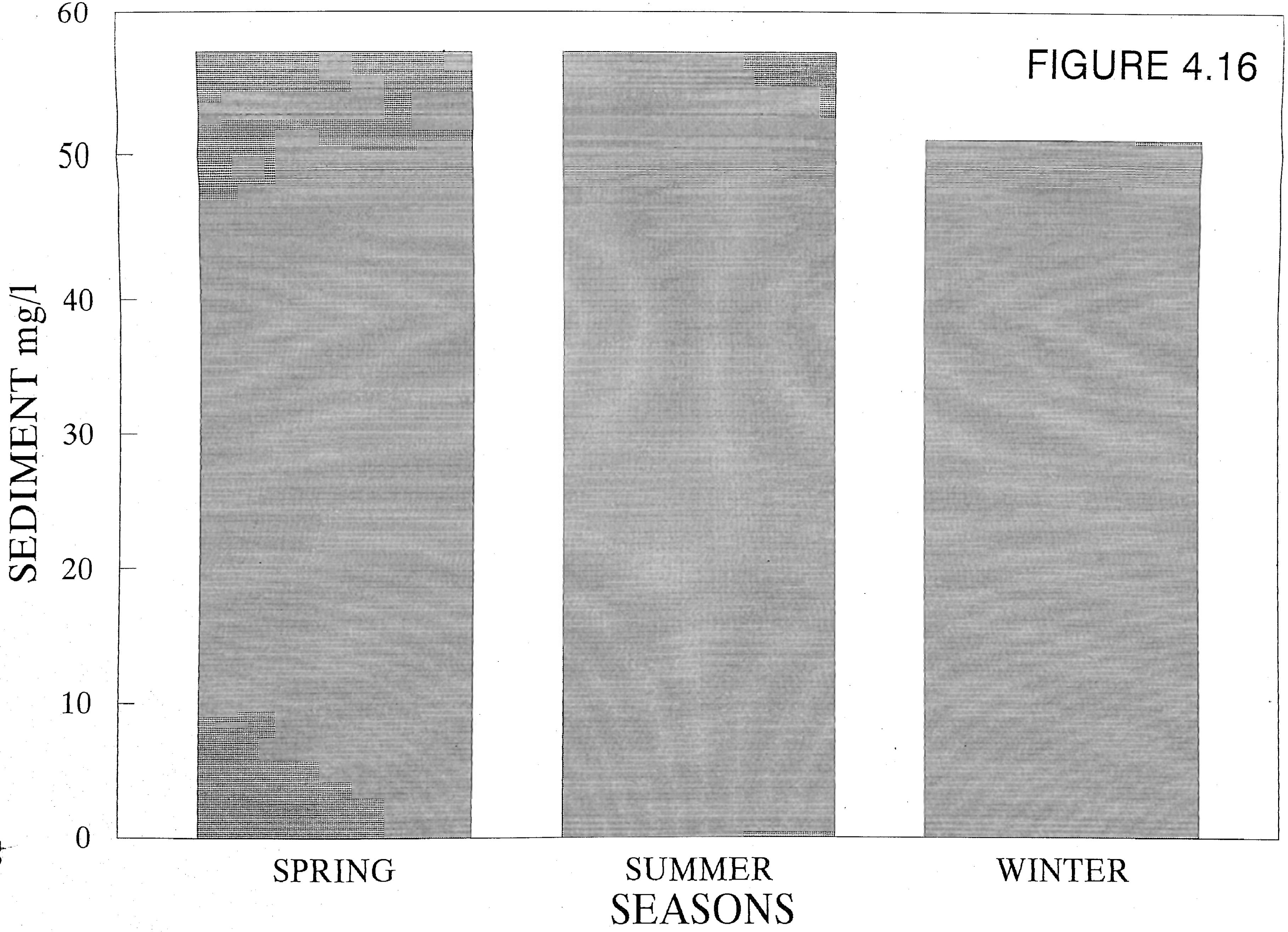
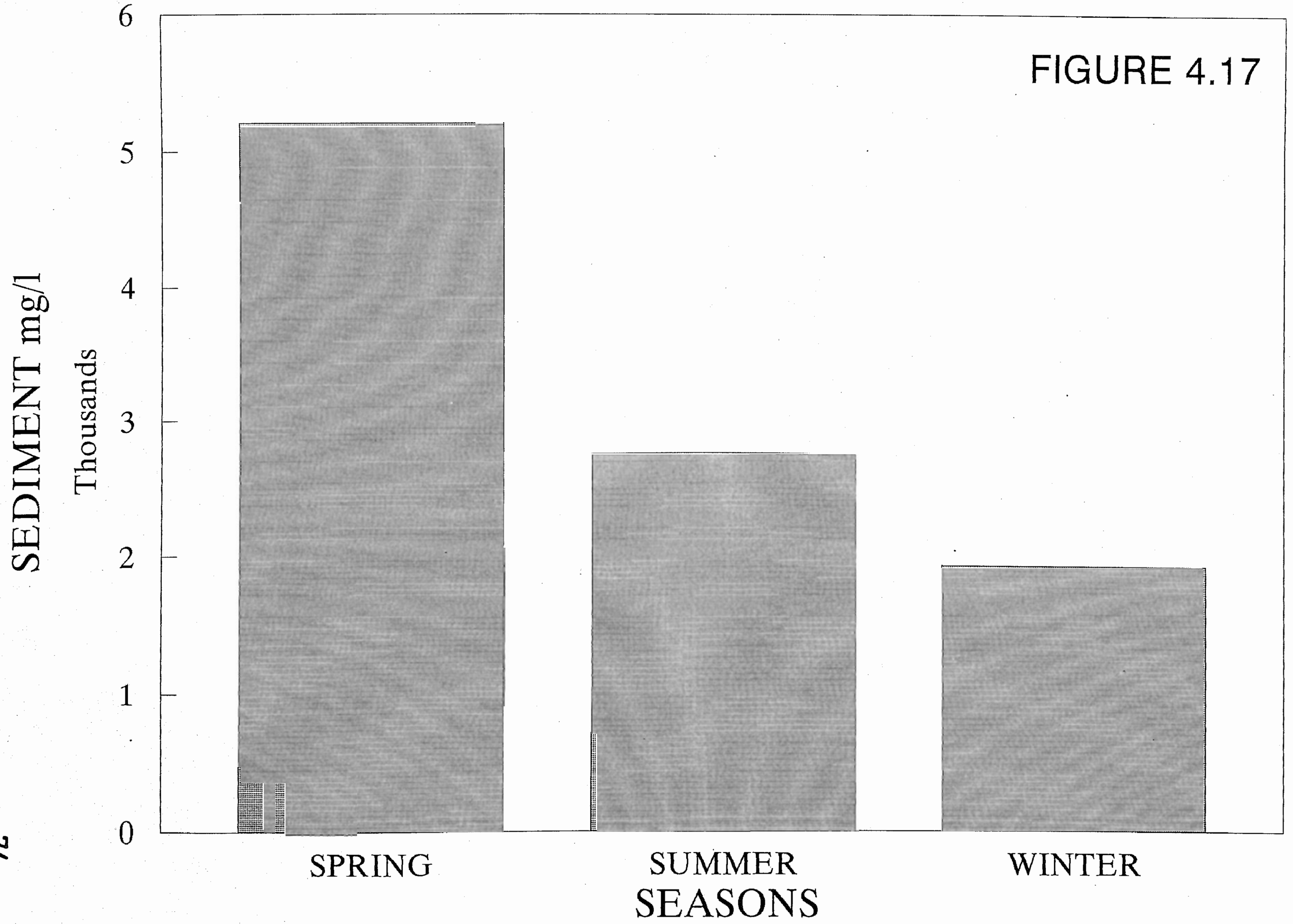
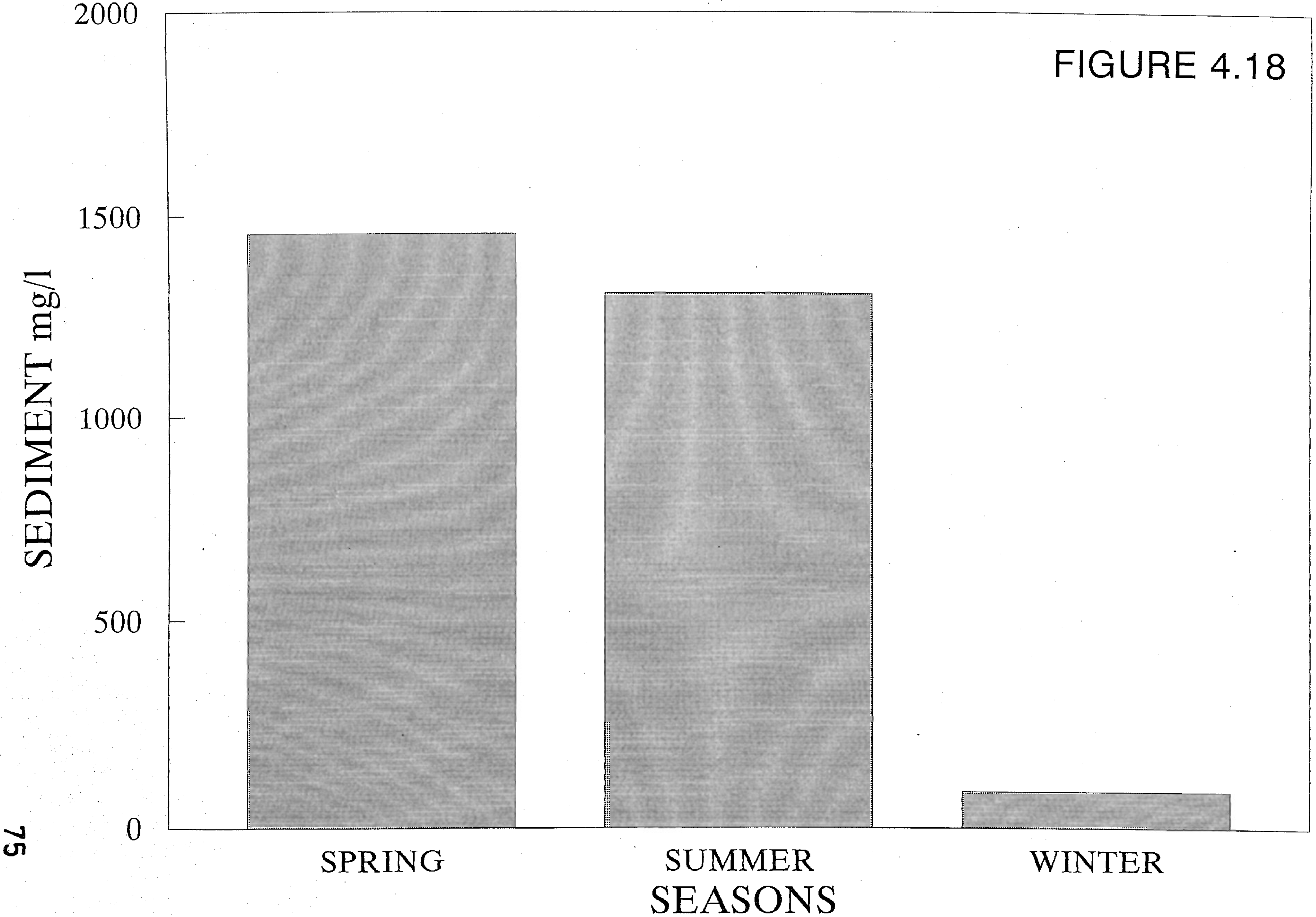


FIGURE 4.16

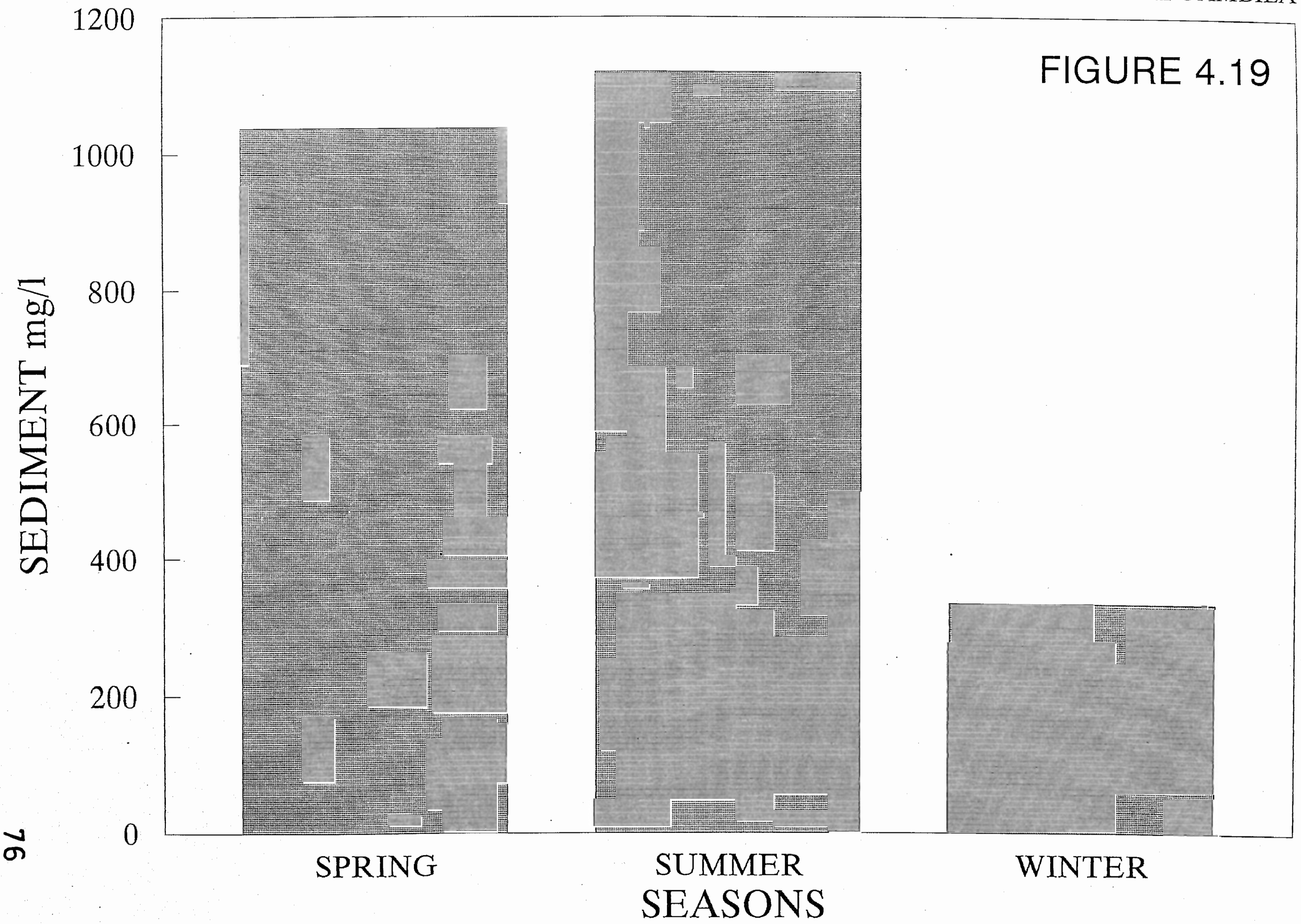
TEMPORAL VARIATIONS IN SUSPENDED LOAD OF THE KUNHAR RIVER AT GARHI HABIBULLAH



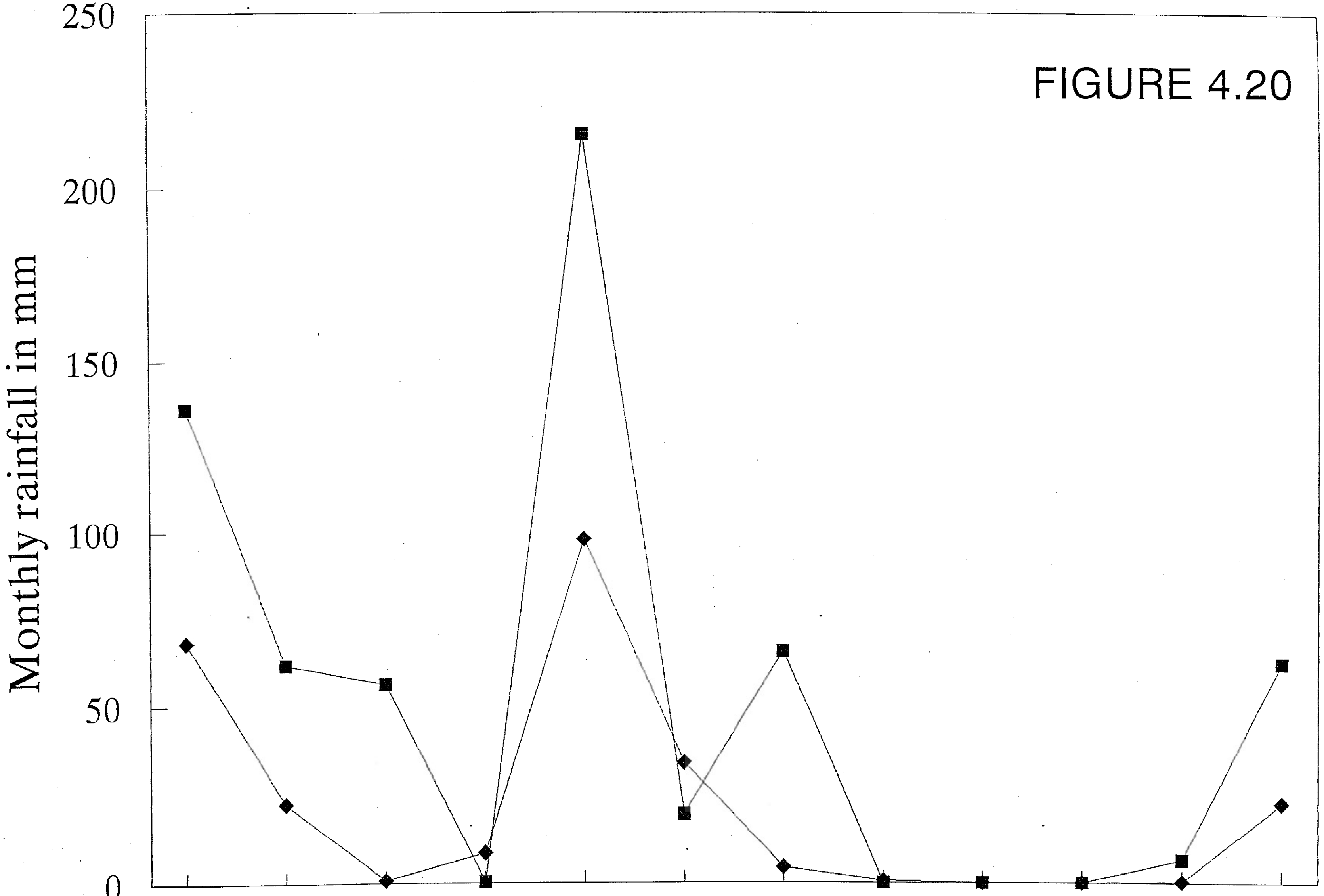
TEMPORAL VARIATIONS IN SUSPENDED LOAD OF THE KURRAM RIVER AT BANNU



TEMPORAL VARIATIONS IN SUSPENDED LOAD OF THE GAMBILA RIVER AT SARAI GAMBILA

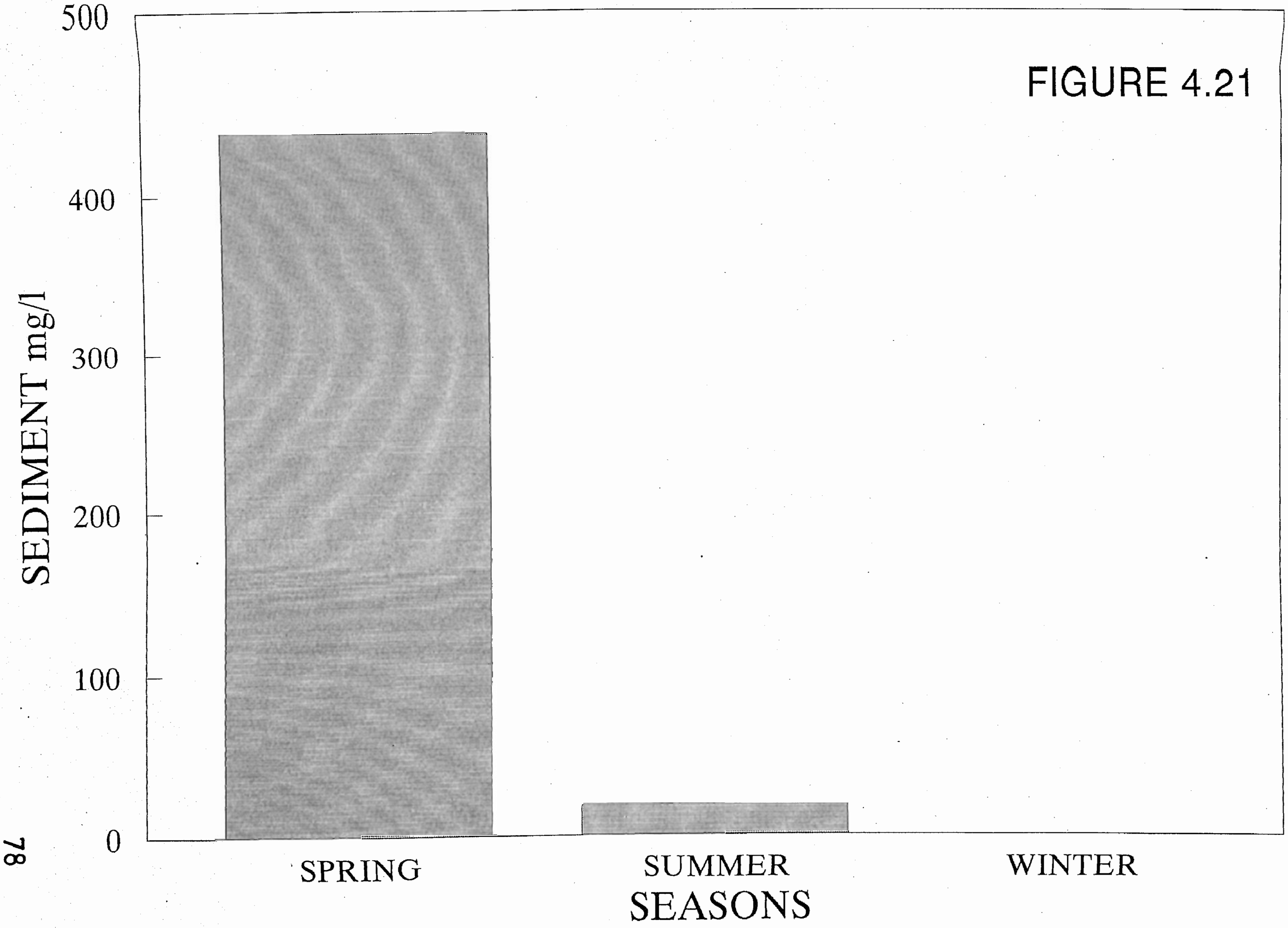


MONTHLY RAINFALL (FROM MAR. 93 TO FEB. 94) IN CATCHMENT OF THE SOUTHERN RIVERS OF NWFP



Months	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
BANNU	136	61.6	56.3	0.3	215.3	19.2	65.7	0	0	0	6.6	62.2
D.I.KHAN	68.1	22.3	0.7	8.5	97.8	33.6	4.3	0.6	0	0	0.3	22.5

TEMPORAL VARIATIONS IN SUSPENDED LOAD OF THE GOMAL RIVER AT D.I.KHAN



TEMPORAL VARIATIONS IN SUSPENDED LOAD OF THE BARA RIVER AT PESHAWAR

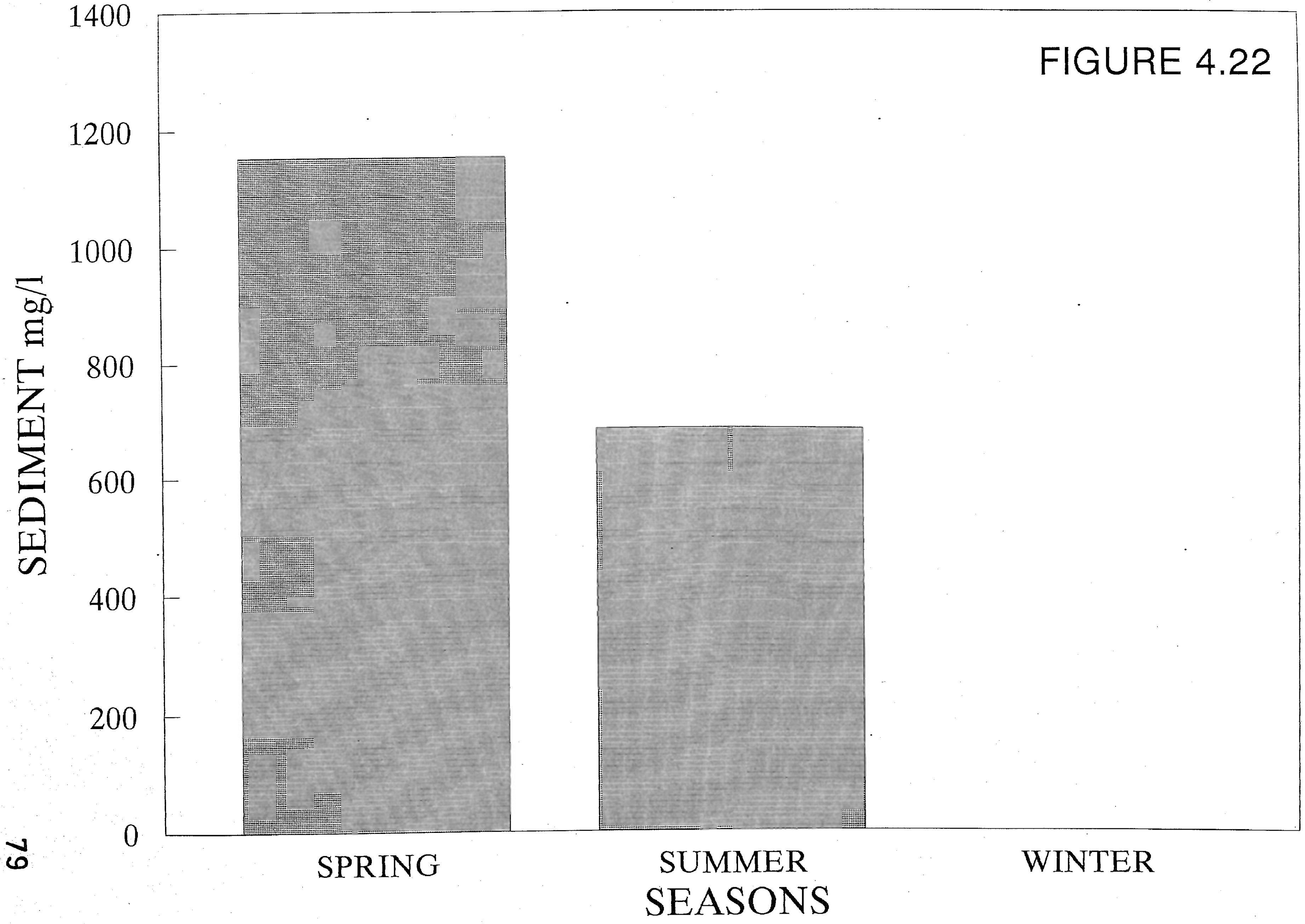


FIGURE 4.22

CHAPTER- 5

CONCLUSIONS AND SUGGESTIONS

This study has brought to light important variations in the soil erosion rates across the region and also the fact that some of these streams are inappropriate for the construction of reservoirs because of their high sediment load.

The study has indicated that most parts of NWFP suffer from high rates of soil erosion because of natural and anthropogenic factors.

An inter-seasonal comparison of the suspended load from various rivers of NWFP suggests that its quantity usually varies from a maximum during spring and early summer (Apr-May) to a minimum during the winter (Dec-Feb).

Out of the 10 rivers studied during this project it has been observed that the Kunhar River, a tributary of the Jehlum River which drains the Kaghan Valley in northern Hazara, transports maximum load during all seasons, whereas, the Swat River was found to be most clear round the year.

The results also show that Gomal and Bara rivers remain almost dry during winter months but the latter becomes very turbid during spring and summer (1.15 $g\ l^{-1}$ in Spring).

Since the Tarbela Reservoir is also used for irrigation purposes besides hydro-electric power generation, the residence time of water in the lake is large. As a result at least three fourth of the suspended load settles down in the lake before the water is let to pass through the tunnels. This problem can be controlled by effective watershed management and extensive afforestation on the barren and steep mountain slopes upstream the lake.

In order to maintain the required water level in the Tarbela Reservior, the outflow is regulated accordingly which determines the length of residence time of water in this lake from season to season. Thus during winters, when the inflow and outflow are minimum and subsequently residence time greatest, there is relatively more silting.

As hydel power remains our most important source of energy it would be more appropriate if the power plants utilize river runoffs for electricity generation instead of stored water of reservoirs. The Sarhad Hydel Development Organization (SHYDO) is already pursuing the same policy in most of its power generation projects. All tributaries of major streams in the northern area of Pakistan, including Swat, Kohistan, Dir and Chitral provide excellent opportunities of electricity generation using steep gradient and fast flow velocity.

Similarly, construction of relatively smaller reservoirs upstream of a major reservoir will increase the life span of the major structure. This gives us the added benefit of desilting the smaller reservoirs by temporarily diverting the flow during least flow periods. The study has also indicated that by monitoring spatial variation of the suspended load concentration along profiles of various rivers areas of exceptionally high sediment influx can be positively identified. This information can be cleverly used by the watershed management people as a feedback to concentrate on those areas and implement their plans more carefully.

The Kurram and Gambila rivers are very turbid and their sediment input is relatively much higher than the Indus' load at D.I. Khan.

The observed suspended load of the Indus at D.I. Khan reaches a maximum of ~550 mg l^{-1} during spring which seems a much lower value as compared to its other local tributaries, which is due to the reduced current velocity attributed to the fact that the channel suddenly widens several kilometers as the river divides itself into many distributaries upon entry into the plain area.

The water chemistry shows a variable list of charecteristics for these rivers with a clear conclusion which reduces the chances of their utility of their utility as potable water because of one parameter or the other.

The results of the qualitative analysis are given with a note of caution that identification of unknown minerals is not always 100% reliable when matching is performed manually.

From the mineralogical study of the suspended sediment it is evident that illite is the most widely occuring mineral in rivers of the study area.

Although the primary source of sediment to rivers of the project area is glacially derived detritus, yet a significant amount of chemical weathering also takes place in the region.

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