The Kabul River Basin - the source of the Naglu and other reservoirs

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Abstract. The article is devoted to the assessment and study of the Kabul river basin fed by 7 existing (Jabal-Saraj, Karga, Mahipar, Naglu, Sarubi, and Darunta) and numerous planned (including Gulbahor, Baghdara, Sarubi II, Kunar I, Kunar II, Shatut) reservoirs. The article discusses the Kabul basin's annual precipitation, land cover, and runoff. In addition, it sheds light on soil erosion and the concentration of river and reservoir sedimentation in the Kabul River Basin. Recommendations are also given for solving the problem of soil erosion and the siltation of reservoirs.

There is very little data on the Kabul River and its basin due to the lack of detailed hydrological data. Most of the hydrological and meteorological posts did not function or were destroyed during the crisis in the country for about two decades, which led to little or no information on the river's hydrology during this period. Because of this problem, many organizations working in basin water management and designing new hydraulic structures face difficulties in properly planning and designing new hydraulic structures and reservoirs. As a result, most researchers, planners, and designers use old data with a limited observation period, which is insufficient for adequate design and planning of hydraulic structures and other basin development projects.

Due to four decades of unrest in the country, the watersheds of the Kabul Basin have been used without any rules or management, resulting in land degradation and watershed erosion.

Three main problems, namely overgrazing in rangelands, rain-fed fields, and deforestation, have caused land degradation in the basin. In addition, the situation has been aggravated by the cutting of bushes for fuel in hilly and semi-hilly areas. The basin is overpopulated, and there are many industries in the major cities of the basin, which contributes to water pollution in the Kabul river. Despite water availability, due to a lack of proper planning, the major cities in the basin cannot use the basin's water for domestic needs. In cities like Kabul and Jalalabad, people mainly use groundwater, resulting in the continuous sinking of the groundwater level. For the proper management and development of the Kabul river basin, much work needs to be done, which may yield promising results for developing the country's economy and improving the environment in the Kabul basin region.

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1 Introduction

The Kabul River Basin is one of the five river basins in Afghanistan. This basin feeds the Kabul River, one of Afghanistan's very important rivers. The Kabul River Basin is located in the eastern part of Afghanistan, between 36° 3' 7" to 31° 34' 33" latitude and 67° 36' 50" to 71° 41' 27" longitude. The area of the pool is about 71,139 sq. km, and it contains thirteen provinces, including Kabul, the capital of Afghanistan [1-3].

The basin is divided into eight watersheds: Kabul, Chak wa Logar Rod, Gorband wa Panjshir, Alingara, Kunar, Shamal, Gomal, and Pishin Lora watersheds, shown in Fig. 1.

Fig. 1. Location of watersheds in the Kabul River Basin

The basin includes all Afghan rivers that eventually empties into Pakistan's Indus River. These rivers are Kabul, Logar, Maidan, Shutol, Panjshir, Gorband, Alishing, Alinegar, and Kunar. The UN-FAO estimates that the basin has a potential of 22 billion cubic meters per year, equal to 26% of Afghanistan's total water resources. It occupies 12% of the total area of Afghanistan and is considered the most important river basin in the country. The total population of the Kabul River Basin is about 13 million people with a density of 172 people per sq. km, which is 35% of the total population of the country [4-8].

This basin has a large hydropower potential, which has been partially exploited. Several hydroelectric power plants have been built along the river: Jabul Saraj, Surobi, Mahipar, Naglu, and Darunta. Many irrigation and hydroelectric power plants are planned to be built in the Kabul river basin, like Shah wa Arus, Shatut, Gulbahor, Baghdara, Kunar, etc.

Figure 2 presents a map of the location of the Kabul river basin. It also includes the river system, existing dams, proposed dams, and major cities in the basin.

The average height of the Kabul river basin is 2430 m above sea level, and the average slope of the basin is 30.56%. The mean annual temperature is extremely variable across the basin; it is almost 1 in the north, where there are several high mountains, and 16 in the south, where the relief of the basin becomes softer and wider. The average annual precipitation in the basin, which is very variable, is about 400 mm. About two-thirds of the annual rainfall occurs during the three months of the year, between February and April when most flooding occurs [9-13].

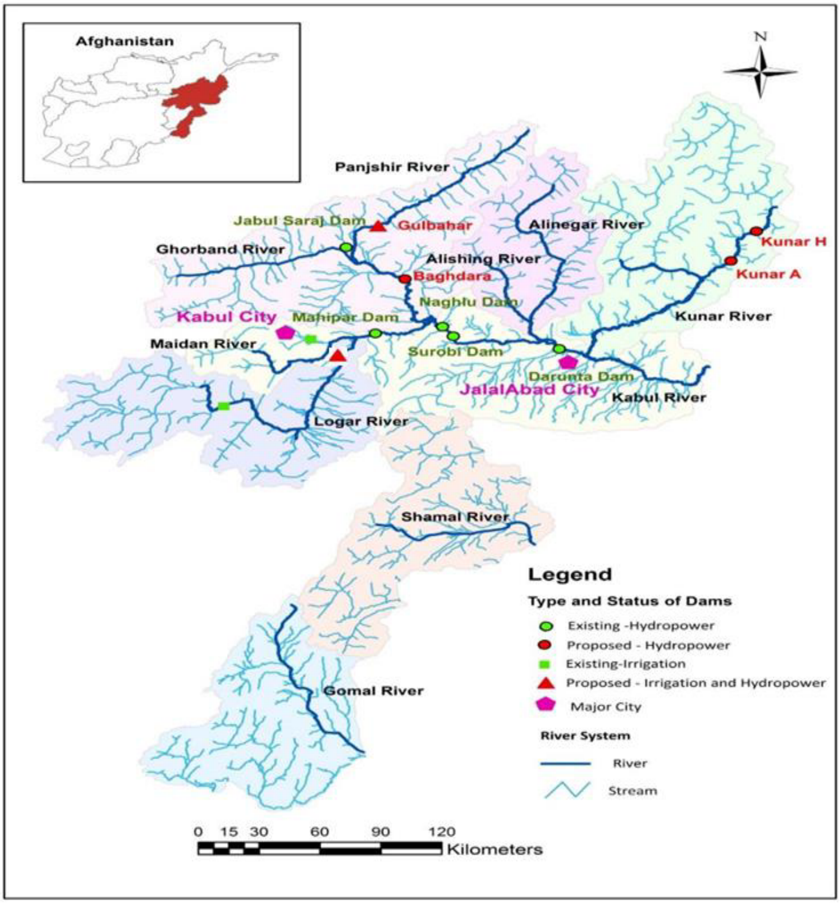

Fig. 2. Location map of the Kabul river basin

The main river in the Kabul river basin and its tributaries are fed mainly by snowmelt in the Hindu Kush mountains. The Kabul River is shallow in summer and winter. The river and its tributaries are filled with water from seasonal rains and snowmelt in spring. Two large tributaries in which there is always water are Panjshir and Kunar.

In its upper course, the Kabul River experiences low water in the summer. In some years, it completely dries up in the summer on its section passing through Kabul.

Since the 1990s, the river has experienced severe droughts in summer. Around March 2019, ten thousand gallons of raw sewage from the Makroyan sewage treatment plant was dumped monthly into the Kabul River, reportedly causing a gastrointestinal upset in 3,000 families living along the river. In general, the city of Kabul contributes greatly to the pollution of the river. In addition to the discharge of raw sewage, hazardous materials such as plastic, household waste, chemical mixtures, and so on are also dumped into the river.

2 Method

Studying the results of field studies in the Kabul river basin and the reservoirs in the area in combination with historical data and findings of the RUSLE method, as well as analysis of previous research, reports, and papers on the Kabul river basin, is the method for this work.

3 Results and discussion

Due to 4 decades of instability in Afghanistan, little data on the river basin, the tributaries feeding the Kabul river system, and the reservoirs within the basin is available. Field studies were carried out to study the basin, and data from multiple sources was used. The results and findings are discussed in the section.

3.1 Precipitation Information

Due to instability in the country for four decades, most of the hydrological and meteorological stations in the basin were destroyed or did not function in the 80s and 90s. The data used here is from the Meteorological Elements Yearbook published by the Ministry of Transport and Civil Aviation of Afghanistan. Numerous rain gauge stations within and outside the basin were selected for the study. Stations located outside the basin were chosen to facilitate the interpolation of precipitation data for hydrometric stations far from the basin's edges. Figure 1 shows the stations' names and the annual precipitation of each observatory station located in the Kabul River Basin. The duration of the observations varies from station to station, from 10 to 45 years.

According to stations, the average annual rainfall in the Kabul River Basin is about 400 mm, with a maximum of 735 mm/year on the Asadabad FOB and a minimum of 100 mm/year on the Naglu FOB.

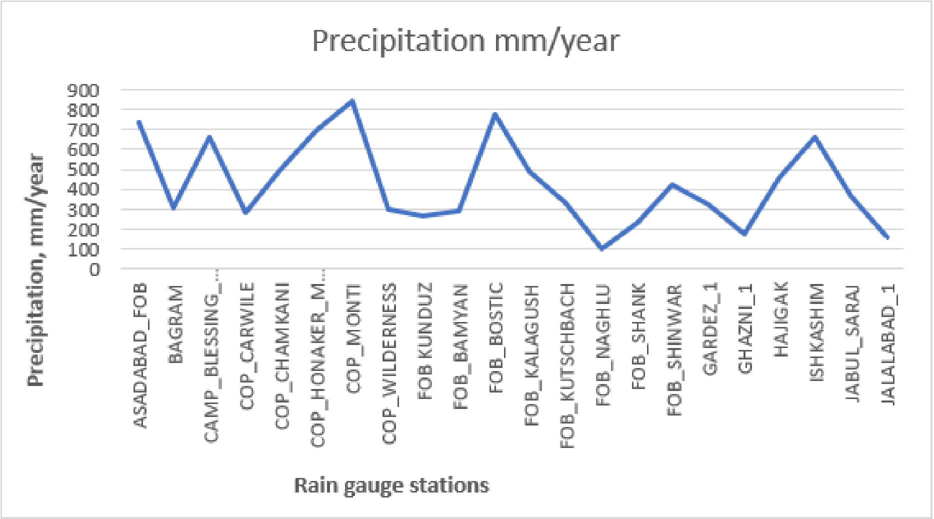

Fig. 3. Precipitations in the Kabul Basin

3.2 Land cover information

The first land cover map of Afghanistan was published 50 years ago. The country's land cover information has been further improved by the Food and Agriculture Organization of the United Nations by interpreting image data from the Landsat Thematic Mapper (UN-FAO) earth observation satellites. According to the UN-FAO map, the Kabul Basin area has been divided into 11 main land classes with several mixed classes as follows:

1) Urban areas; 2) Irrigated agricultural land 3) orchards/fruit trees, with 3 sub-classes; 4) Rainfed agricultural land with 2 subclasses; 5) Pistachio forests; 6) natural forests with 2 subclasses; 7) Pastures with 2 subclasses; 8) Barren lands, with 3 subclasses; 9) Wetlands with 2 subclasses; 10) Water bodies; 11) Eternal snow

Figure 3 shows the information on land cover. As can be seen in the figure, the basin consists of 18 classes, which are defined as follows: degenerate forests/tall shrubs (more than 1.5 m high), fruit trees, orchards, irrigated - intensively cultivated (1 crop per year), intensively cultivated (2 crop/year), Intermittently cultivated, Swamps Permanently flooded, Seasonal swamps, Natural forests with cover (>60% coverage), Natural forests with open cover (coverage 20%-60%), Permanent snow, Rainfed crops (flat) zones bookmarks), rainfed crops (slopes), pastures (grasslands/forbs/low shrubs), rock outcrops/bare lands, settlements, vineyards and water bodies.

Grassland is the most extensive vegetation cover in the basin, covering about 51% of the basin area. Barren soil comes in second, covering about 19%, and Forest comes in third, covering only about 16%. Barren soil and pastures are the basin's main sources of erosion and sedimentation.

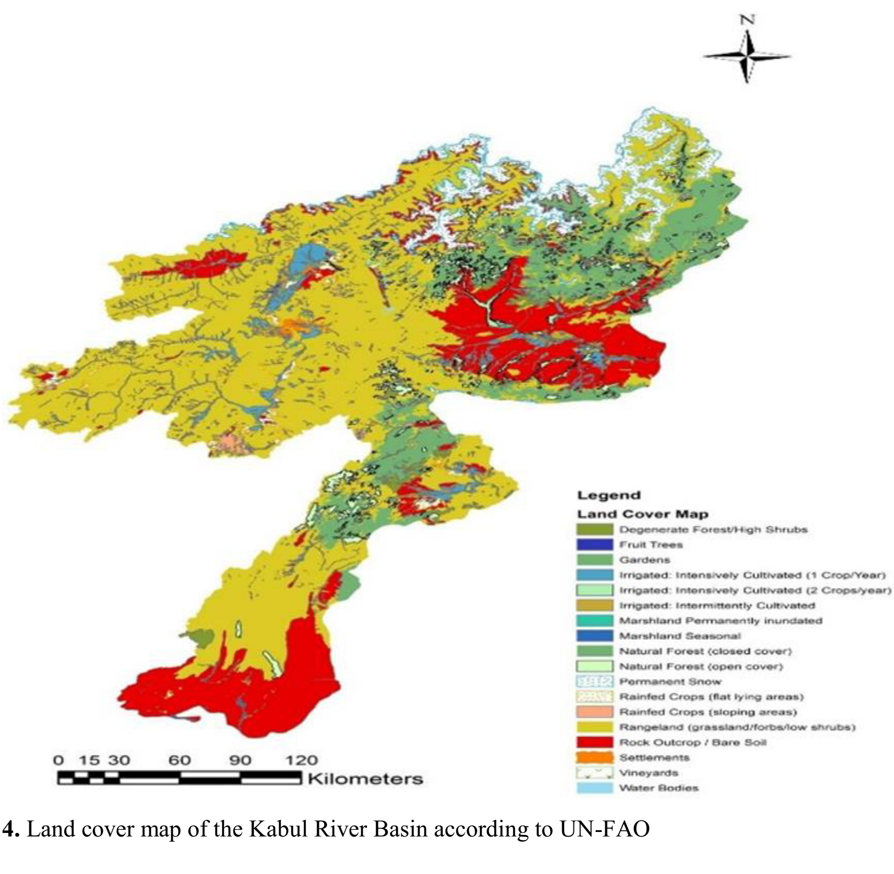

Fig. 4. Land cover map of the Kabul River Basin according to UN-FAO

The structure nature of the river network of the Kabul river basin is determined by the characteristics of the river runoff. Thus, in the upper reaches of the river, up to the mouth of the Logar River, the flow of the Kabul (Maidan) River is small and is largely deformed by water intake for irrigation. Below the city of Kabul, the flow of the river increases sharply due to the first large right tributary of the Logar River, the flow of which is three times the flow of the Kabul River. Completely different from the rest of the basin are the features of the formation of the flow of the Panjshir River - the first large left tributary of the Kabul River - due to the flow from the slopes of the southern spurs of the Hindu Kush. Areas with a large specific water content provide, after the confluence of the Panjshir River, a six-fold increase in runoff (Naglu alignment). Significant jump-like increases in average annual discharges are observed after the confluence of the Laghman River and especially the Kunar River, the flow of which is also almost three times the flow of the Kabul River before their confluence. The impact of water diverted for irrigation is particularly strong on the discharges of the Logar River, the upper Kabul River, and the Gorband River (a tributary of the Panjshir). Traditional forms of irrigation are used so firmly and for a long time on all lands practically suitable for irrigation in river valleys that they were obtained without considering irretrievable water losses [14-22].

The first hydrological post on the Kabul River - Maidan - is 58 km from the source. Above this post, there is a significant water withdrawal for irrigation: more than 1.7 m^3/s, which is about 24% of the average annual flow. To the Tangi-Saidan post, located 30 km downstream of the Maidan, the flow rate decreases even considering water losses for irrigation. A relatively large runoff and its lower variability are characteristic of the river. Logar caused a jump in the flow rate at the Tangi-Garu post up to 16.6 m3/s (and adjusted for irretrievable losses up to 27.9 m^3/s). Since the runoff modulus in the mouth section of the Logar River is less than in the Tangi-Saidan section, a sharp decrease in the runoff modulus is observed in the Tangi-Garu section, which remains almost unchanged up to the Naglu site since there are no noticeable water intakes and irrigated areas.

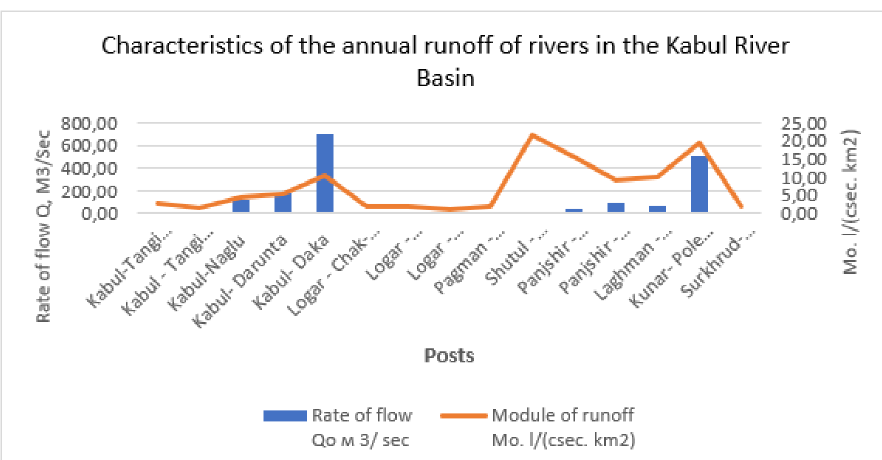

Fig. 5. Characteristics of the annual runoff of rivers in the river basin. Kabul

In the Naglu site, the runoff rate increases abruptly and reaches 122 m^3/s due to the runoff of the Panjshir and Tagab rivers, and, taking into account water withdrawal for irrigation (irretrievable losses), it reaches 146 m^3/s. Thus, even in the Naglu site, water losses for irrigation amount to 16.5% of the runoff volume.

After our research work, there were large fluctuations in flow rates (Qmin = 56.2 m^3 / s, and Qmax = 162 m^3 / s). Still, the coefficient of variation established by the thirty-year extended series is 0.3, and taking into account water withdrawal for irrigation, coefficient of variation Cv= 0.27, which almost coincides with Schultz's assumptions.

In the section Naglu - the mouth of the Laghman River, there is no significant increase in discharge, and the flow rate can be taken almost constant. In this case, an increase in the catchment area will cause a gradual slight decrease in the rate of the runoff modulus.

Downstream of Naglu, the decrease in annual runoff variability to Cv=0.188 (Darunta) is somewhat strange, which can only be explained by partial long-term flow regulation by the Mahipar and Surobi reservoirs. However, these reservoirs are reservoirs of seasonal regulation.

The flow of the Laghman River, which flows into the Kabul River upstream of the Darunta gauge, cannot reduce the variability of the average annual flow of the Kabul River since the variability of the Laghman River runoff is much higher than that of the Kabul River at the Darunta gauge (Cv = 0.25).

The significant runoff of the Laghman River causes an increase in the flow rate of the Kabul River near Darunta to 180 m^3/s, and, taking into account irretrievable losses for irrigation, up to 212 m^3/s. The runoff modulus also increases since the runoff modulus is more than (10 l/s - km^2) at the mouth of the Lagman River. It is characteristic that the determination of the coefficient of variation for the Darunta gauge by the coefficient α obtained for the Naglu gauge ($\alpha = 1.49$) allows us to consider Cv = 0.25 normal for the Darunta gauge.

From Darunta to the mouth of the Kunar River, all characteristics are practically stable. Due to the low flow of the Sarkhrud River, its influence is small, and below its mouth, only a slight increase in the coefficient of variation can be expected. The flow of the Kunar River, the largest and most water-bearing tributary, has the greatest influence on the flow characteristics of the Kabul River. The flow rate increases by more than 500 m^3/s, and considering the flow rate of the Darunta and Surkhrud rivers, it reaches 688 m^3/s. Because of the very high value of the flow modulus of the Kunar River at the mouth (Mo = 19.3 l/s-km^2), below its confluence, the flow modulus of the Kabul River also sharply increases.

In the section from the mouth of the Kunar River to the Dhaka alignment, located only 27 km from the border with Pakistan upstream of the river, the flow rate slightly increases due to the discharge of the right small tributaries of the Hazarnau, Chapliar, and Pachir, reaching 705 m^3/s. At the same time, the runoff modulus somewhat decreases, and the variability of discharges and, consequently, the characteristics Cv, Q_1/Q_{31}, and K_1–K_{31}, the water content coefficient remains almost unchanged.

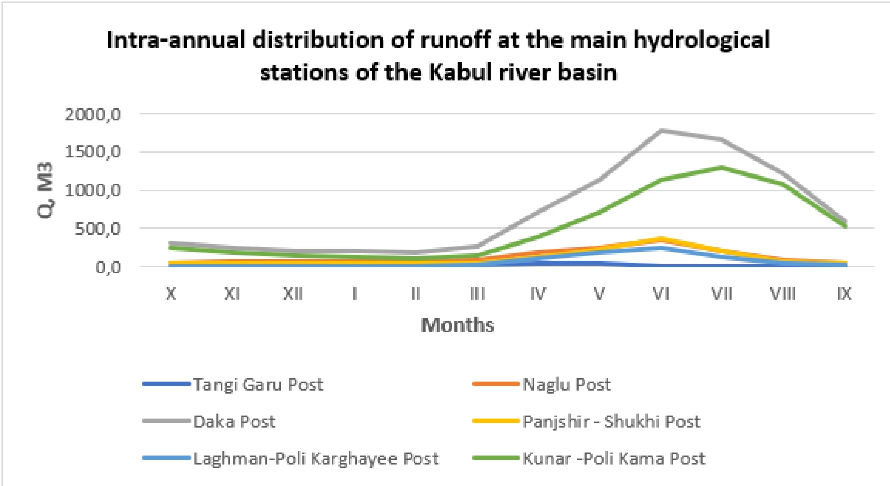

Fig. 6. Intra-annual distribution of runoff at the main hydrological stations of the Kabul River Basin

The tributaries of the Kabul River have a maximum flow in the spring from March to May. At the same time, despite the large volume of meltwater during the spring-summer floods, the maximum discharges of the left tributaries of the Kabul River still have a predominantly rain origin. At the peak highs of the left tributaries of the Kabul River, rainwater accounts for 52%. Regarding minimum flows, the left tributaries of the Kabul River have the least amount of water during the summer months from June to October. Some tributaries, such as the Paghman, dry up completely during the summer.

Table 1. Characteristics of the maximum and minimum flows of the Kabul River

River - Post	Qmax m^3/s	Qmin m^3/s
Kabul - Maidan	54.20	0.82
Kabul - Tangi Saidan	44.50	0.25
Kabul - Tangi Garu	108.00	0.53
Kabul - Naglu	570.00	37.80
Kabul - Darunta	670.00	55.00
Kabul - Daka	2525.00	120.00
Logar-Chak-e-Wardak	45.90	9, 8 6
Logar-Shaikhabad	46.30	26,0
Logar- Sangi Navishta	52.00	0.46
Paghman- Pole Sokhta	18.80	0.11
Chakari Amir Ghazi	1.03	0.00
Surkhrud Sultanpur	96.40	0.33

3.3 Sediment yield data

A full and comprehensive study of sediment concentrations in the Kabul River Basin has not been carried out due to many factors, including four decades of crisis in the country and the low capacity of the relevant government agencies in Afghanistan. However, the Montreal Engineering Company of Canada did the most extensive sediment runoff study some years ago. This study evaluated the sediment yield for proposed dam sections on the Logar, Maidan, Panjshir, Gorband, and Kabul rivers, such as Mahibpar, Naglu, and Sarubi. The study was based on a two-week sediment survey combined with data collected from established gauge stations by Afghan ministries. The study did not specifically state how the amount of bed sediment was accounted for by the sediment yield. Sediment yield data was obtained from the Kabul River Valley Development Project Master Plan (Montreal). Sediment yield data is also obtained from the UN-FAO Global Sediment Runoff Database (UN-FAO 2013). Table 2 presents sediment runoff for stations located in the Kabul River Basin.

Table 2. Sediment yield at stations located in the Kabul River Basin

No	River	Station Name	Drainage Area Sq.km	Sediment Yield/Area tons/sq.km/year
1	Panjshir	Panjshir I	1280	275
2	Panjshir	Baghdara	10850	455
3	Maidan	Hajian	1520	250
4	Logar	Gat	3780	150
5	Kabul	Tangi Gharu	12850	148
6	Kunar River	Dahana	11664	780
7	Ghorband	Pul-i-Ashawa	4020	420
8	Kabul	Naghlu	26046	410
9	Panjshir	Gulbahar	3565	750

The unit of sediment yield for the river is given in tons of sediment per square kilometer of catchment area per year. The Panjshir and Kunar rivers have the highest sediment output in the basin due to their location in the upper part of the basin, with steeper slopes and higher precipitation intensity. There are also local differences in sediment runoff along rivers. For example, the Kabul River at Tangi Gharu has the lowest sediment output at 148 tons/sq km/year.

However, it increases to its highest yield value of 410 tons/sq. km/year when the river joins other tributaries near Naglu Dam (about 80 km downstream).

Studies using ArcGIS and the RUSLE method show that the average annual rate of soil loss in the Kabul River Basin is estimated at 19 tons/acre/year (4748 tons/km^2/year). Rangelands are the main contributor to the soil loss rate in the basin as they cover the largest part of the basin area and produce about 57% of the total annual soil loss rate.

The average annual fluctuations in the rate of soil erosion caused by changes in forest cover in the Kunar watershed are considered. Based on the UN-FAO land cover map, the watershed produces about 29 tons per acre per year, but this figure rises sharply when the degradation process reduces dense forest cover.

4 Conclusions

The Kabul River Basin has great potential for creating hydropower, irrigation systems, and water supply. Various hydraulic structures, such as dams, water intakes, power plants, etc., can be built along most of the river's tributaries. Hundreds of millions of cubic meters of water leave the Kabul basin unused yearly. Some of this water can be stored in reservoirs and used for various purposes, such as water supply, especially in Kabul, where water shortages will soon become a big problem. In addition, a cascade of hydroelectric power plants could be built along the Kabul River. With proper use of the rivers in the basin, thousands of MW of hydropower can be generated, millions of hectares of agricultural fields irrigated, and drinking water provided to millions of residents of major cities throughout the basin. In short, through the proper use of the water resources of the Kabul River Basin, the economy and environment of Afghanistan will be greatly improved.

Spring and summer time intense precipitations and floods greatly contribute to soil erosion and sedimentation concentration of the river bed and the reservoirs. The silting problem is very problematic in the two reservoirs of Naglu and Darunta. In the Naglu reservoir, the main pollutant is the Panjshir tributary of the Kabul River. The Panjshir River is mountainous with steep slopes causing erosion of watersheds, river banks, and beds, eventually leading to sediment concentration in the Naglu reservoir. When comparing the Panjshir tributary with the Kabul tributary of the Kabul River, the former contributes almost three times as much sediment to the Naglu reservoir. Due to silting, the Naglu reservoir has lost about 40% of its capacity over the past 50 years. The Darunta reservoir, located downstream of Naglu, about 70 km away, is also heavily silted. The Mehtarlam River is an additional tributary that feeds the reservoir along with the main Kabul River. Most of the Darunta reservoir is filled with sediment, which has reduced its usable storage capacity.

Much work needs to be done to control siltation in the Kabul River Basin and reservoirs along the river. Several measures are recommended to reduce soil erosion in watersheds, including 1) An immediate ban on deforestation, especially in the Kunar watersheds. If deforestation continues at its current rate, soil erosion and sedimentation will increase five times within a few years, with huge environmental and economic consequences. 2) An immediate ban on bush cutting in the Kabul Basin area. Cutting bushes for fuel has led to the denudation and degradation of watersheds, resulting in land degradation and sediment accumulation in rivers and reservoirs, which needs to be addressed immediately. 3) Particular attention should be paid to properly managing rainfed fields. The problem of soil erosion in fields with slopes can be mitigated by creating terraces and practicing contour plowing. 4) In areas where ra erosion predominates, it is recommended to reduce erosion by creating anti-recoil dams. 5) Ponds are recommended for erosion control and groundwater enrichment on steep bare hills.

For addressing sedimentation in existing reservoirs, hydraulic and mechanical removal of sediments through flushing, sluicing, dredging, and excavation is recommended. As studies show, drainage outlets in most of the reservoirs of Afghanistan are blocked due to improper operation and maintenance practices. As a result, tackling siltation problems in the reservoirs becomes more difficult. Unfortunately, dredging has not been practiced in Afghanistan so far. It is a very useful technique for removing sediments in most of reservoirs. It is recommended that at least one dredger be utilized for each of the main reservoirs. For easy operation and maintenance, it is recommended that such machinery be imported from regional countries with similar climatic conditions.

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