Chapter 7C. Geohydrologic Summary of the Haji-Gak Iron Area of Interest

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7C.1 Introduction

This chapter describes the geohydrology of the Haji-Gak iron area of interest (AOI) in Afghanistan identified by Peters and others (2007). The AOI is located in southeast Bamyan, northeast Wardak, and western Parwan Provinces (fig. 7C–1*a*,*b*). The three identified subareas, Haji-Gak Prospect, NE Haji-Gak, and Farenjal, occupy 180, 381, and 557 km^2 (square kilometers), respectively, of the 2,079-km^2 area of the AOI.

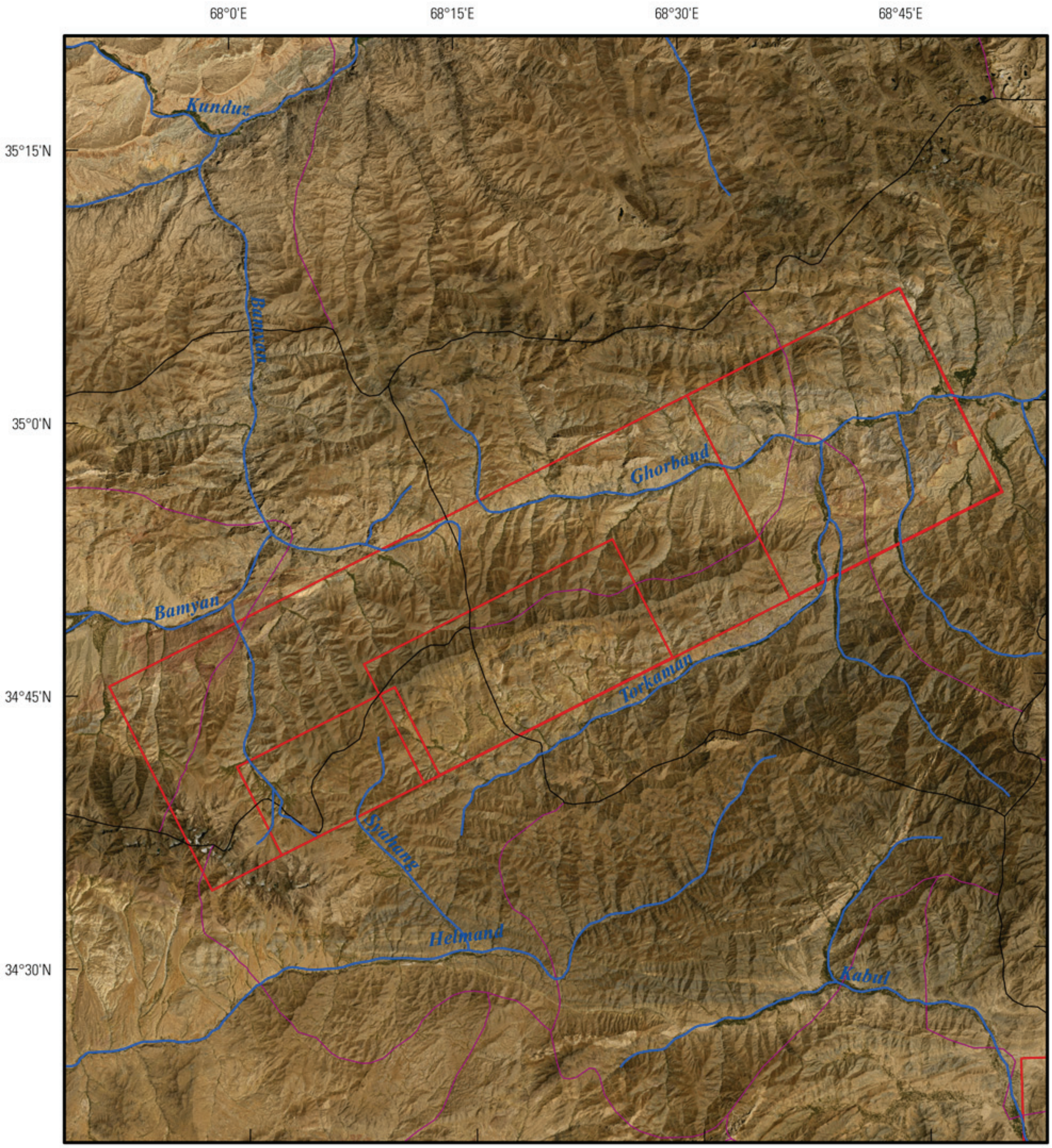
Water is needed not only to process mineral resources in Afghanistan, but also to supply existing communities and the associated community growth that may accompany a developing mining economy. Information on the climate, vegetation, topography, and demographics of the AOI is summarized to provide information on the seasonal availability of, and seasonal demands for, water. The geohydrology of the AOI is described through the use of maps of streams and irrigated areas, generalized geohydrology and topography, and well locations. Where these data are available, the depth to water and height of static water in wells are documented. The results of lineament analyses are presented to identify areas where the rock may be more fractured than in other areas, which may be an indicator of high relative water yield and storage in bedrock aquifers.

Afghanistan's recent turbulent history has left many of the traditional archival institutions in ruins, and most water-resource and meteorological data-collection activities had stopped by 1980. Recently, non-governmental organizations (NGOs), foreign government agencies, and the Afghan government have begun water-resource investigations; however, these activities and the amount of data collected are limited. This report summarizes the satellite imagery and climatic, topographic, geologic, surface-water, and groundwater data available. Geohydrologic inferences are made on the basis of an integrated analysis of this data and an understanding of conditions in other areas of Afghanistan.

7C.1.1 Climate and Vegetation

Climate information for the Haji-Gak iron AOI is based on data generated for the Afghanistan agricultural-meteorological (Agromet) project. Agromet was initiated by the U.S. Agency for International Development and the United Nations Food and Agriculture Organization in 2003 to establish data-collection stations and develop country-wide agrometeorological services. Scientists with the Agromet project are assisting the Afghan Government to collect and analyze agricultural and meteorological data as they relate to crop production, irrigation, water supply, energy, and aviation. The U.S. Geological Survey (USGS) assumed responsibility for the operation of the project in 2005; by the end of August 2010, 87 Agromet stations were recording precipitation data and other parameters. Additionally, the Agromet project receives data from 18 Afghanistan Meteorological Authority (AMA) weather stations. The Agromet project has developed a database that includes data collected at the Agromet stations over the past 6 years (2005–2011), data collected at the AMA weather stations, and historical data collected at weather stations from 1942 to 1993. Data collected as part of the Agromet project are compiled annually by water year (September through August) and are reported in the Afghanistan Agrometeorological Seasonal Bulletin (Seasonal Bulletin) published by the Ministry of Agriculture, Irrigation, and Livestock. Unless otherwise specified, the Agromet data cited in this report are from the agricultural season that extends from 1 September, 2009, to 31 August, 2010.

a



Base from U.S. Geological Survey Natural-Color Landsat Image Mosaic of Afghanistan Map Series, 2006,14.25-meter. Cultural data modified from Afghanistan Information Management System (www.aims.org).

0 5 10 20 KILOMETERS

EXPLANATION

Boundary of area of interest (AOI) or subarea

Stream, generally perennial

Province boundary line

District boundary line

b

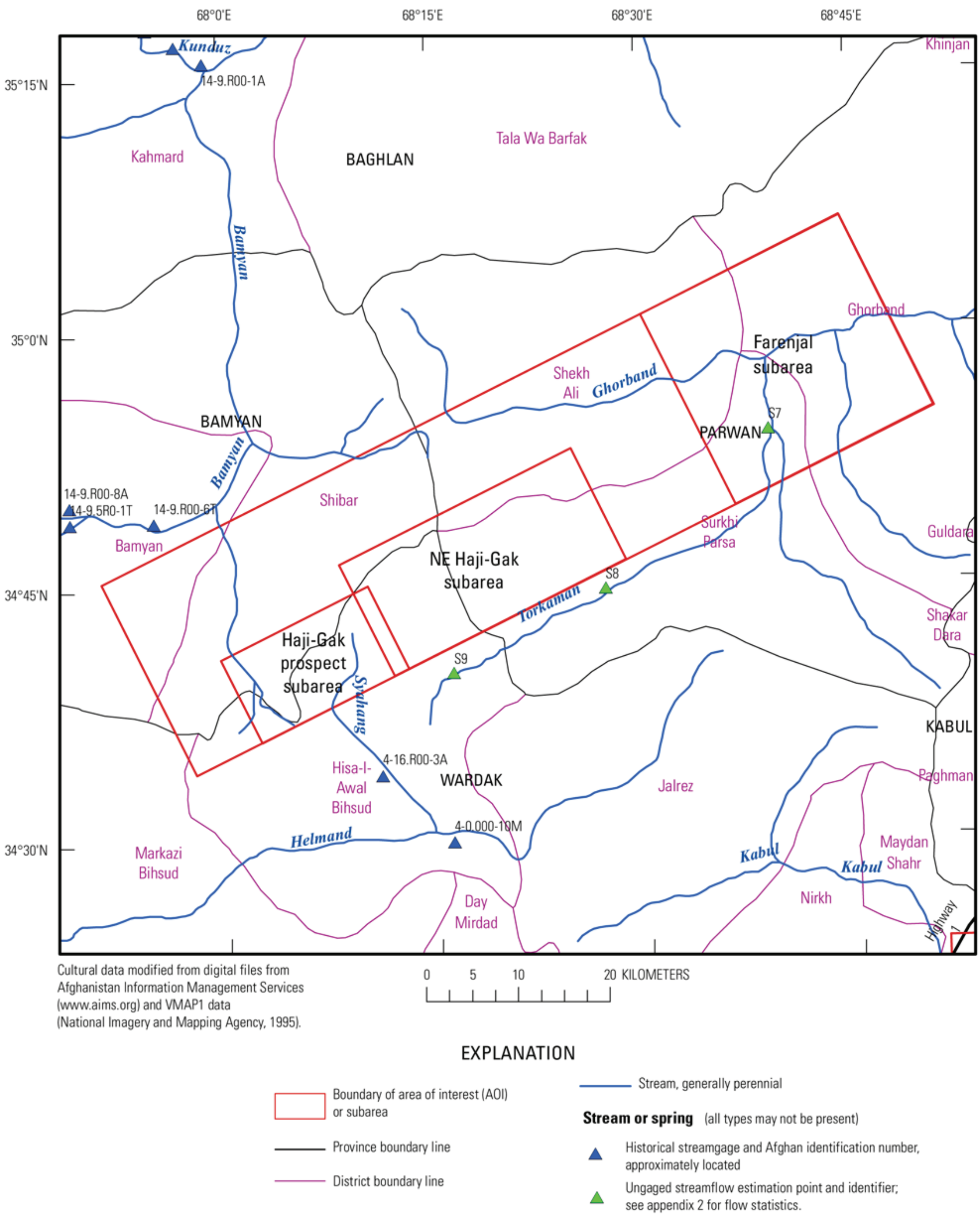


Figure 7C–1. (*a*) Landsat image showing the location of, and (*b*) place names, stream names, and streamgage station numbers in, the Haji-Gak iron area of interest in Afghanistan.

The AOI is located in the Capital and Central Highlands regions of the Afghanistan Agromet network (Ministry of Agriculture, Irrigation, and Livestock, 2010). There are no Agromet stations within the AOI, but there are stations to the west, south, and east. The Seasonal Bulletin states that “October 2009 was a very dry month during the rainfall season (2009–2010) and it is typical in this time of the year. However, the Eastern and some parts in the Capital region experienced moderate rainfall, while in the remaining regions of the country seasonal dryness continued” (Ministry of Agriculture, Irrigation, and Livestock, 2010).

The Agromet station located in Bamyan is the closest station to the AOI for which 2009–2010 water year and long-term average (LTA) precipitation and temperature data are available. The Bamyan Agromet station is about 95 km west of the center of the AOI at an elevation of 3,100 m (meters) above sea level (asl). The elevation at this station is similar to the elevation of much of the AOI and the climate probably is similar. Table 7C–1 presents available precipitation and temperature data for the Agromet station located in Bamyan.

Table 7C–1. Annual, long-term annual average, and long-term average minimum and maximum precipitation and temperature at the Bamyan Agrometeorological (Agromet) station 90 km west of the Haji-Gak iron area of interest, Afghanistan.

[AOI, area of interest; km, kilometers; m, meters; mm, millimeters; °C, degrees Celsius]

			Precipitation				Temperature		
					Long-term average[1]		Long-term average[1]		
Agromet Station	Distance from AOI center (km)	Elevation (m)	2009–2010 Annual (mm)	Annual (mm)	Monthly minimum and month (mm)	Monthly maximum and month (mm)	Minimum and month (°C)	Monthly mean (°C)	Maximum and month (°C)
Bamyan	55	3,100	207.4	142	0 August	34.3 April	–6.8 January	5.3	18.2 July

[1] Long-term averages are based on data from 1942 to 1993 and 2005 to 2010 as reported in the Afghanistan Agrometeorological Seasonal Bulletin (Ministry of Agriculture, Irrigation, and Livestock, 2010).

The closest Agromet station to the AOI is located in Chack, Wardak Province. This station is located about 80 km south of the center of the AOI. The elevation of this station is approximately 2,325 m asl. The only data reported for this station are the 2009–2010 water year precipitation data. The total precipitation recorded at this station for the 2009–2010 water year was 189 mm (millimeters). The highest monthly precipitation was 40 mm in August 2010 and the lowest was 0 mm in September 2009 and July 2010 (Ministry of Agriculture, Irrigation, and Livestock, 2010).

The Bamyan Agromet station had a total of 17 reported snow days during the 2009–2010 water year, with the following distribution: November 2009, 4 days; December 2009, 2 days; January 2010, 3 days; February 2010, 6 days; and March 2010, 2 days. A total snowfall of 99 cm (centimeters) was reported for Bamyan during the 2009–2010 water year. The snow-depth map for 17 January, 2010 (Ministry of Agriculture, Irrigation and Livestock, 2010, map 6), indicates a snow depth from 10 to 30 cm in the AOI, but this estimate was made before the snowfall in February. Some mountain peaks and ridges in the southwest corner of the AOI are higher than 4,000 m asl (Bohannon, 2005a). Some perennial snow fields probably are present at these higher elevations, especially on north-facing slopes.

The maximum temperatures for the AOI during the 2009–2010 water year ranged from 35.5°C (degrees Celsius) to 36.4°C (Ministry of Agriculture, Irrigation and Livestock, 2010, map 12). The closest Agromet station to the AOI for which temperature data are available is in Bamyan. The average monthly high temperature at this Agromet station for the 2009–2010 water year was 19.5°C in July 2010 and the average monthly low temperature was –4.51 in January 2010. The LTA high and low temperatures at this station are 18.2°C for July and –6.8°C for January (Ministry of Agriculture, Irrigation and Livestock, 2010).

The "Potential Natural Vegetation" described in Breckle (2007) is the vegetation cover that would be present if it had not been modified by human activity. Today, as a result of continued exploitation such as grazing, farming, and deforestation, much of the original natural vegetation is found only in a few remote areas of Afghanistan. The destruction of the natural vegetation has resulted in the degradation and erosion of the soil cover in some areas. Many areas exhibit signs of long-lasting desertification caused by human activity.

The vegetation in the AOI is mostly alpine vegetation classified by Breckle (2007, p. 161) as "thorny cushions, subalpine and alpine deserts and meadows." Much of the upland surface of the AOI is bedrock outcrop with thin alluvial cover. Azonal riverine vegetation likely was present in the stream valleys, but the trees have been harvested for fuel and building materials. Most land suitable for farming has been plowed and planted, especially along major stream valleys and some of the ephemeral tributary stream valleys. Irrigated fields are present in many of the valleys in the AOI (fig. 7C–2).

7C.1.2 Demographics

The Haji-Gak iron AOI is sparsely populated, with the number of inhabitants ranging from 1 to 50/ km^2 as mapped by LandScan (Oak Ridge National Laboratory, 2010) (fig. 7C–3). Some of the higher mountains are uninhabited as indicated by the gray shading in figure 7C–3. Some areas of concentrated population are present in the wider stream valleys, but the maximum population per square kilometer in these areas rarely exceeds the 101-500/km^2 category. There are large settlements in eastern areas of the AOI (fig. 7C–4*a*), whereas western areas of the AOI are sparsely populated (fig. 7C–4b). The population density shown in figure 7C–3 has a pixel resolution of about 1 km^2 (Oak Ridge National Laboratory, 2010). There are very few mapped roads or tracks in the AOI. One road mapped as "all weather secondary" follows the Ghorband River valley through the northeast corner of the AOI (Afghanistan Information Management Service, 2003). A road mapped as "track" follows the Torkaman River from its confluence with the Ghorband River to the end of the Torkaman River (fig. 7C–1*b*).

7C.1.3 Topography and Geomorphology

The topography of the Haji-Gak iron AOI is dominated by an east-northeast-trending mountain range that runs the length of the AOI. The highest mapped peak in this mountain range is 4,602 m asl, and some peaks at each end of the range in the AOI exceed 4,000 m asl (Bohannon, 2005b). The southwest corner of the AOI contains a northwest-trending mountain range with peaks that exceed 4,800 m asl. The elevation of the highest peak within the AOI in this mountain range is 4,927 m asl (Bohannon, 2005a). The rugged mountain terrain limits the number of roads and tracks. The valleys formed by the Ghorband and Torkaman Rivers flank the north and south sides of the central mountain ridge and are major topographic features in the AOI. The elevation of the Ghorbank River decreases from about 2,600 to about 1,900 m asl from west to east through the AOI. The Torkaman River is a major river parallel to and just outside the southern border of the AOI. The headwaters of the Torkaman River are in the mountains just south of the overlap between the Haji-Gak and NE Haji-Gak subareas (fig. 7C–1*b*, fig. 7C–4b). The elevation of this river decreases from about 3,000 m asl in the headwaters to 2,000 m asl at its confluence with the Ghorband River. The relief between the Ghorband and Torkaman River valleys and the adjacent 4,602-m-high peak in the central mountain range is about 1,900 m (Bohannon, 2005b). There is considerable relief between the river valleys and along the entire length of the central mountain ridge (figs. 7C–4*a* and 7C–4*b*).

The geomorphology of the AOI is controlled by erosion-resistant metamorphic and intrusive rocks that form high, rugged mountains and softer sedimentary rocks that form stream valleys (fig. 7C–5). The high mountains in the southwest corner of the AOI exhibit alpine glacier features such as arêtes, cirques, and cirque lakes (Davis, 2006). There is a strong east-northeast structural fabric in the AOI that determines the location and trend of the valleys. Perennial streams in and adjacent to the AOI exhibit a rectangular drainage pattern that may be fracture controlled. The ephemeral streams that drain the mountain slopes are linear and steep sided.

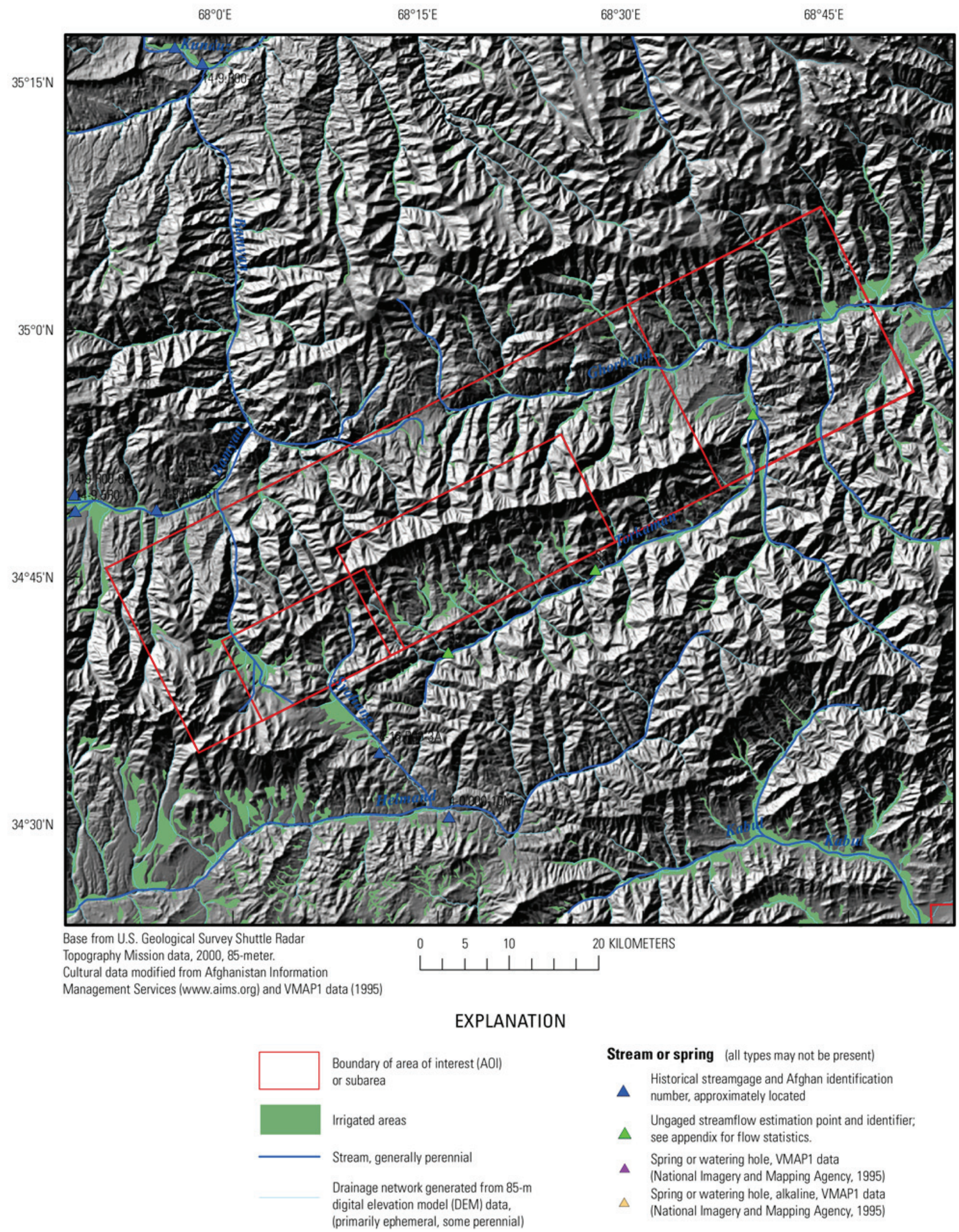


Figure 7C–2. Historical streamgage locations, digitally generated drainage network, and irrigated areas in the Haji-Gak iron area of interest in Afghanistan.

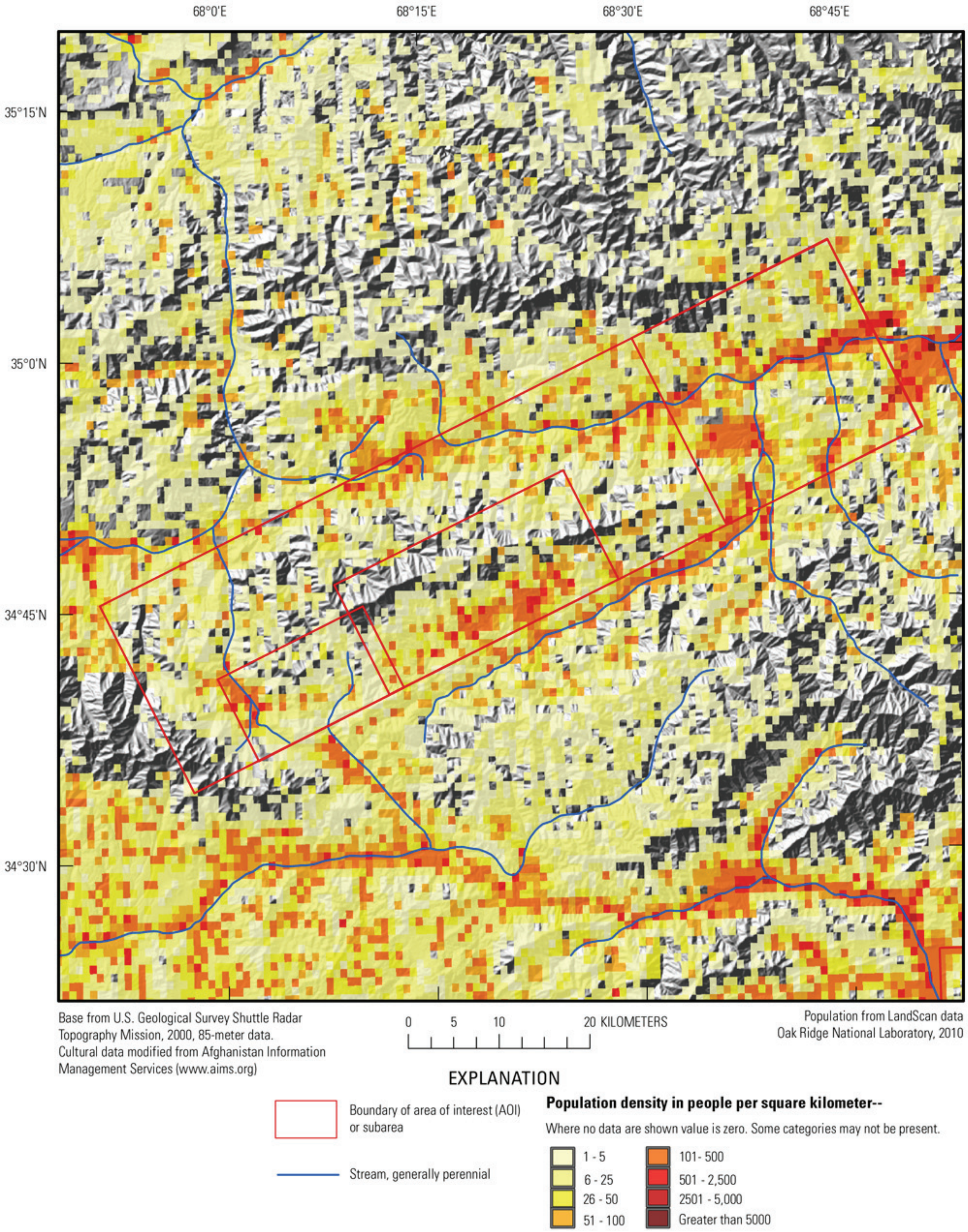


Figure 7C–3. Population density of the Haji-Gak iron area of interest in Afghanistan.

a

b

Figure 7C–4. Photograph of (*a)* the Torkaman River valley in the Farenjal subarea, and (*b*) the headwaters area of the Syahang River in the Haji-Gak subarea (iron ore in the foreground) in the Haji-Gak iron area of interest in Afghanistan.

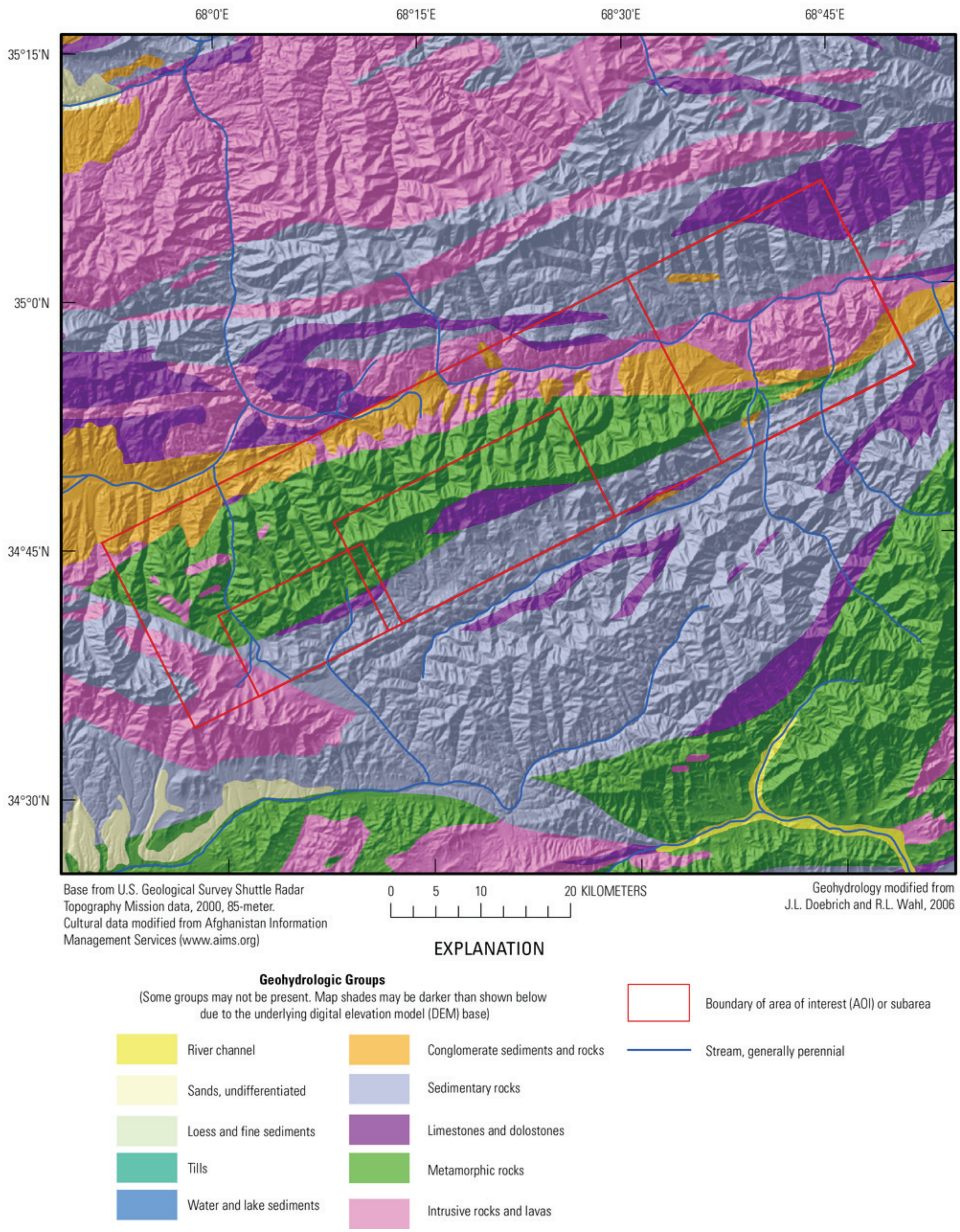


Figure 7C–5. Topography and generalized geohydrology of the Haji-Gak iron area of interest in Afghanistan.

7C.2 Geohydrology

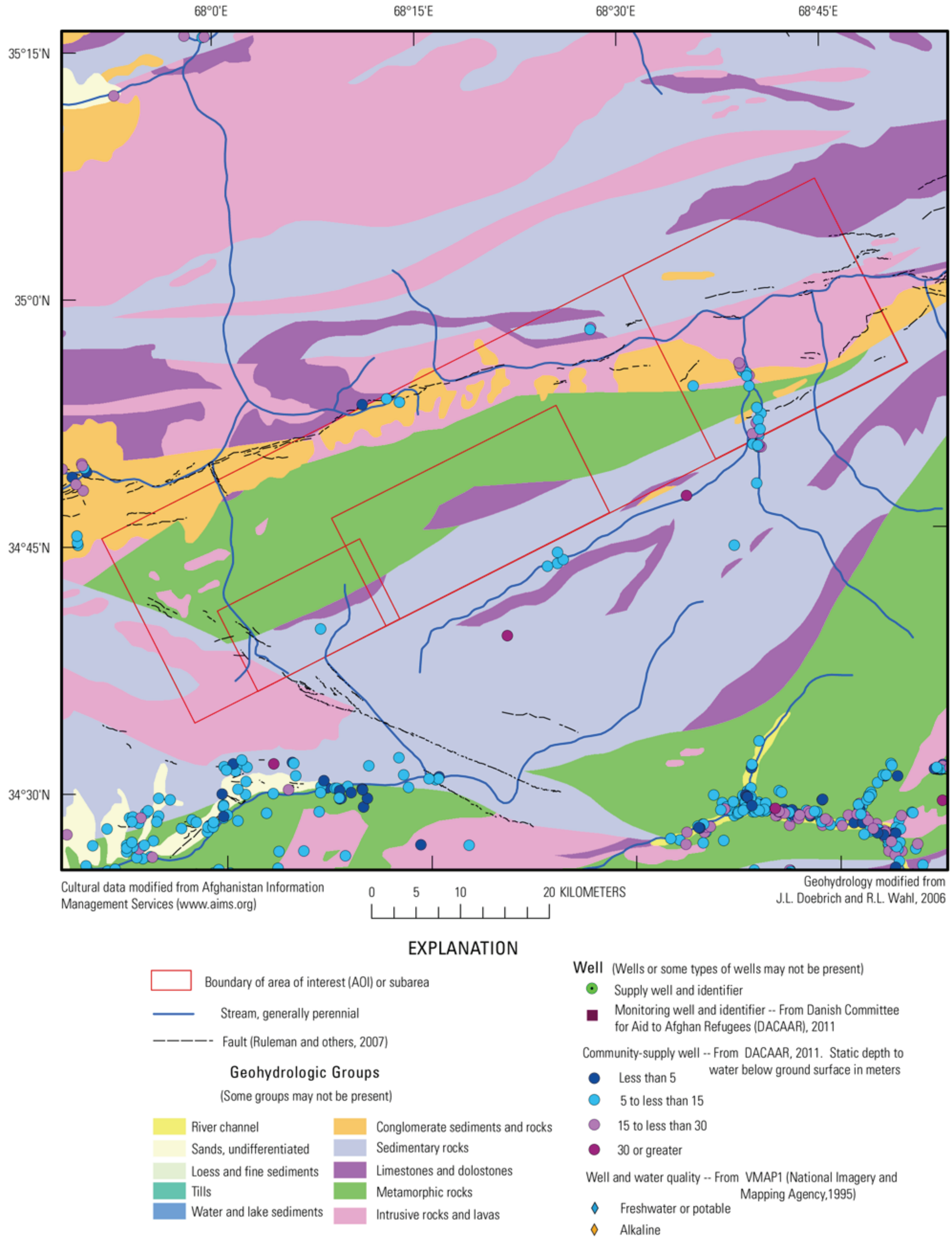
The geohydrology of Afghanistan has been described in general terms by Abdullah and Chmyriov (1977, book 2). As defined in their "Geology and mineral resources of Afghanistan," the Haji-Gak iron AOI is in the "Central Afghanistan Hydrogeological Folded Region that occupies the central part of the country with a predominantly mountain climate." The outcrops and near-surface rocks in the AOI can be grouped according to their physical and hydraulic properties. The generalized geohydrology of the AOI is shown in figure 7C–5 with the underlying topography to allow examination of the geohydrology in the context of relief. Figures 7C–6*a* and *b* show the generalized geohydrology without topography for a clearer depiction of the geohydrologic units. Wells in the AOI (discussed in the Groundwater section) are shown in figures 7C–6*a* and *b*. Generalized geohydrologic groups were created from a country-wide geologic coverage (Doebrich and Wahl, 2006) by combining sediments and rocks into major sediment- or rock-type groups of similar hydrologic characteristics. The geohydrologic groups in the AOI, ranked from high to low relative hydraulic conductivity (Freeze and Cherry, 1979, table 2.3), are "conglomerate sediments and rocks, limestones and dolostones, sedimentary rocks, metamorphic rocks, and intrusive rocks and lavas" (fig. 7C–5). Doebrich and Wahl (2006) used geologic maps at a scale of 1:250,000, modified from Russian and Afghan Geological Survey (AGS) mapping, to generate the country-wide geologic coverage. The 1:250,000-scale geologic maps that cover this AOI are provided by Bohannon and Turner (2005) and Yount (2005).

The conglomerate sediments and rocks geohydrologic group forms a string of outcrops from the northwest corner to the southeast corner of the AOI. This unit probably has good water-storage capacity but accounts for only about 10 percent of the outcrop in the AOI. No information is available about the thickness of this unit, but where it overlies the intrusive rocks and lavas geohydrologic group it probably is not very thick. This unit is not likely to be a significant source of groundwater within the AOI. Alluvial sediments probably are present in the bottoms of valleys in the AOI, as indicated by the distribution of irrigated areas (fig. 7C–2). The limited areal extent and thickness of these alluvial deposits precluded their depiction on the 1:250,000-scale geologic maps.

Sedimentary rocks are present within and outside the southern border of the AOI and cover about 30 percent of the AOI (fig. 7C–5). The area of the sedimentary rocks adjacent to the AOI, in the populated valley south of the AOI, is also large. There is no reported information on the thickness of this group but, where these rocks are cut by the Torkaman River, the relief from the bottom to the top of the valley is 1,000 m (Bohannon, 2005a, 2005b). This geohydrologic group could be a potential aquifer in and adjacent to the AOI. There is potential for recharge from the infiltration of water from snowmelt in the spring and early summer, and infiltration from the Torkaman River is possible throughout the year. Sedimentary rocks also crop out in the northern third of the Farenjal subarea (figs. 7C–1*b* and 7C–6). Outcrops of the limestones and dolostones consist of small, isolated fault blocks. These rocks almost certainly do not yield large or sustained quantities of groundwater.

The prominent mountain ridge in the center of the AOI is composed of metamorphic rocks that make up about 30 percent of the outcrop in the AOI (figs. 7C–5 and 7C–6). In the absence of extensive fracturing, the metamorphic rocks generally are not good aquifers. Intrusive rocks and lavas form the high mountains in the southwest corner of the AOI and an east-west-trending band of outcrop that cuts through the AOI (fig. 7C–5). In the absence of extensive fracturing, the intrusive rocks and lavas generally are not good aquifers.

a



68°0'E
68°15'E
68°30'E
68°45'E
35°15'N
35°0'N
34°45'N
34°30'N
Cultural data modified from Afghanistan Information Management Services (www.aims.org)
0 5 10 20 KILOMETERS
Geohydrology modified from J.L. Doebrich and R.L. Wahl, 2006
EXPLANATION
Boundary of area of interest (AOI) or subarea
Stream, generally perennial
Fault (Ruleman and others, 2007)
Geohydrologic Groups
(Some groups may not be present)
River channel
Sands, undifferentiated
Loess and fine sediments
Tills
Water and lake sediments
Conglomerate sediments and rocks
Sedimentary rocks
Limestones and dolostones
Metamorphic rocks
Intrusive rocks and lavas
Well (Wells or some types of wells may not be present)
Supply well and identifier
Monitoring well and identifier -- From Danish Committee for Aid to Afghan Refugees (DACAAR), 2011
Community-supply well -- From DACAAR, 2011. Static depth to water below ground surface in meters
Less than 5
5 to less than 15
15 to less than 30
30 or greater
Well and water quality -- From VMAP1 (National Imagery and Mapping Agency,1995)
Freshwater or potable
Alkaline

b

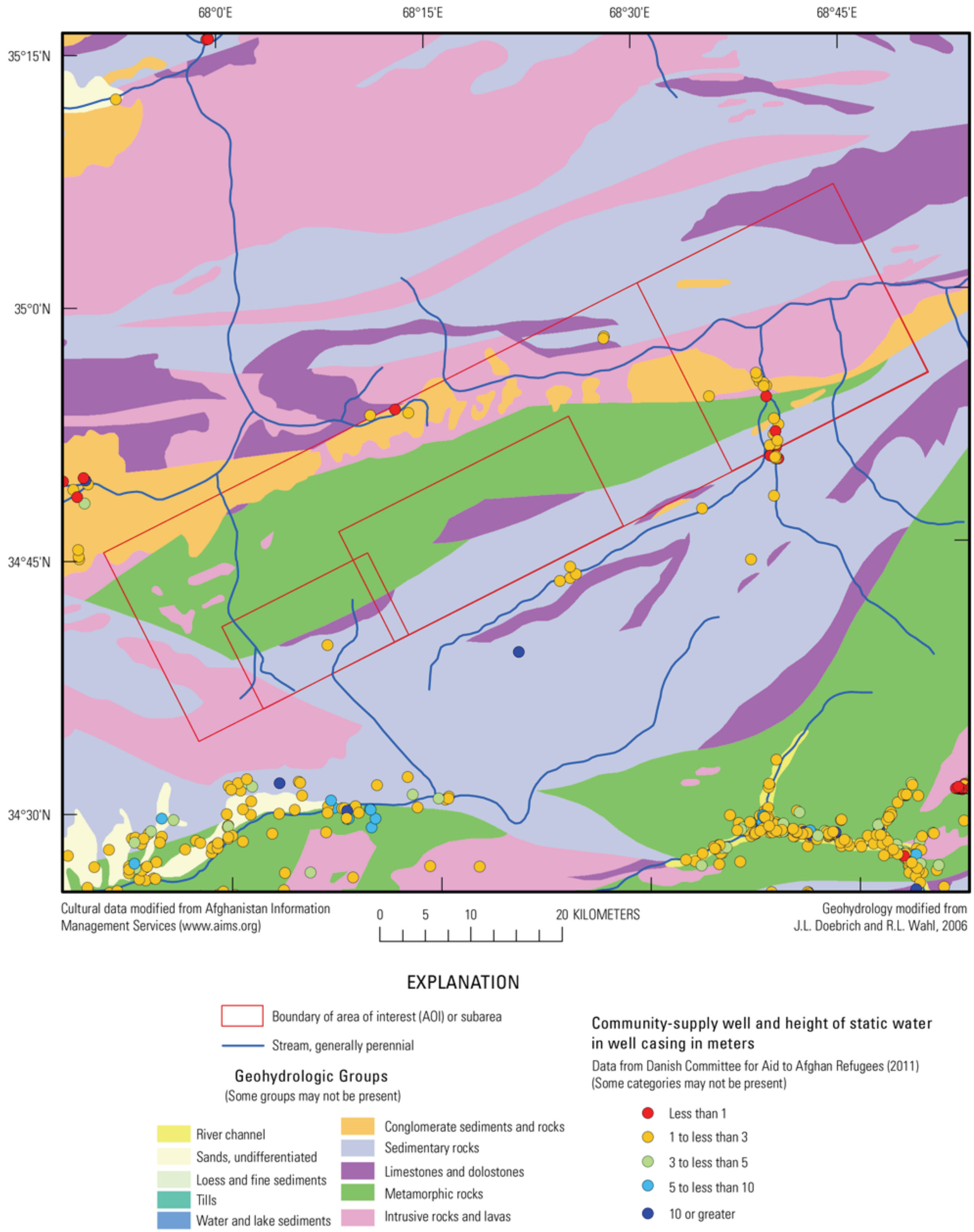


Figure 7C–6. (*a*) Generalized geohydrology, mapped faults, well locations, and depth to water, and (*b*) geohydrology and height of static water in well casings in community supply wells in the Haji-Gak iron area of interest in Afghanistan.

7C.2.1 Surface Water

A network of major, mostly perennial streams in the Hagi-Gak iron AOI, modified from AIMS (Afghanistan Information Management Service, 1997) and VMAP1 (National Imagery and Mapping Agency, 1995), is shown in figure 7C–2. A network representing likely ephemeral streams, generated with a digital elevation model (DEM), also is shown in figure 7C–2. Precipitation in these areas where many of the streams originate is probably similar to that in other mountainous regions in Afghanistan, with most precipitation falling as snow during the winter season (Breckle, 2007). The seasonal snowmelt and runoff account for the increase in streamflow during the months of March, April, and May. The snowfall that accumulates in the high mountains in and adjacent to the AOI (fig. 7C–4*b*) contributes surface-water flow to the streams in the spring and summer.

The course of the Ghorband River extends about 45 km through the AOI. Water from the Ghorband River and tributary ephemeral streams is heavily used to irrigate fields (fig. 7C–2). There are also concentrations of inhabitants in the Ghorband River valley (fig. 7C–3). The Torkaman River, a tributary to the Ghorband River, joins the Ghorband River in the Farenjal subarea. The course of the Torkaman River is parallel to and just outside the southern border of the AOI. Three ungaged streamflow estimation points are located on the Torkaman River (fig. 7C–2), and historical streamgage stations are located near the AOI on the Syahang (Syahsang), Helmand, and Bamyan Rivers (Olson and Williams-Sether, 2010; Vining, 2010; Williams-Sether, 2008). The headwaters of the Syahang River are located in the Haji-Gak Prospect subarea more than 4,000 m asl (Bohannon, 2005a). The Syahang River is a tributary to the Helmand River and the streamgage station (Afghan identification number 4-16.R00.3A) is about 9 km upstream from their confluence. This station is 3,010 m asl, has a drainage area of 160 km^2, and has a period of record that extends from 7 May, 1970, to 30 September, 1980 (Vining, 2010). The annual mean streamflow for the period of record is 1.66 m^3/s (cubic meters per second), with a standard deviation of 0.48 m^3/s. The annual mean streamflow per unit area for this station is 0.010 $m^3/s/km^2$. The month with the highest annual mean streamflow is May, with 6.60 m^3/s, and the month with the lowest annual mean streamflow is August, with 0.62 m^3/s. Mean flows during the months of December through February ranged from 0.63 to 0.64 m^3/s for the period of record. The highest maximum monthly mean streamflow was 12.5 m^3/s for May 1976 and the lowest minimum monthly mean streamflow was 0.82 m^3/s for January and February 1973. Table 7C–2 presents a statistical summary of monthly and annual mean streamflows for this station (Vining, 2010). Statistical summaries of streamflow data for all available historical gages in Afghanistan can be accessed at *http://afghanistan.cr.usgs.gov/water.php.*

The Helmand River is south of the AOI. The streamgage station is about 3 km upstream from where the Syahang River joins the Helmand River (Afghan identification number 4-0.000-10M). This station is 2,955 m asl, has a drainage area of 605 km^2, and has a period of record that extends from 8 August, 1969, to 30 September, 1980 (Vining, 2010). The annual mean streamflow for the period of record is 3.90 m^3/s, with a standard deviation of 0.96 m^3/s. The annual mean streamflow per unit area for this station is 0.006 $m^3/s/km^2$. The month with the highest annual mean streamflow was May, with 15.3 m^3/s, and the month with the lowest mean streamflow was October, with 1.19 m^3/s. Mean flows during the winter months ranged from 1.22 to 1.31 m^3/s for the period of record. The highest maximum monthly mean streamflow was 24.2 m^3/s for May 1976 and the lowest minimum monthly mean streamflow was 0.811 m^3/s for October 1978. Table 7C–3 presents a statistical summary of monthly and annual mean streamflows for this station (Vining, 2010).

The Bamyan River is just outside the northwest corner of the AOI, but has a tributary stream that originates in the high mountains in the southwest corner of the AOI (fig. 7C–1*b*). The streamgage station on the Bamyan River (Afghan identification number 14-9.R00-6T) is about 7 km upstream from the confluence of the river with the tributary stream. This station is 2,450 m asl, has a drainage area of 1,660 km^2, and has a period of record that extends from 14 April, 1975, to 21 May, 1976 (Olson and Williams-Sether, 2010). Only 1 year of record and no annual streamflow statistics are available for this station. The month with the highest streamflow was June 1975, with 12.8 m^3/s, and the month with the lowest streamflow was March 1976, with 2.24 m^3/s. The calculated annual streamflow for this station is 4.5 m^3/s. Table 7C–4 presents the statistical summary of monthly streamflows for this station (Olson and Williams-Sether, 2010).

Table 7C–2. Statistical summary of monthly and annual mean streamflows for the streamgage station on the Syahsang River near Gardandewal (Vining, 2010).
[m^3/s, cubic meters per second]

4- 16.R00-3A SYAHSANG RIVER NEAR GARDANDEWAL

Month	Maximum		Minimum		Mean			
	Streamflow (m^3/s)	Water year of occurrence	Streamflow (m^3/s)	Water year of occurrence	Streamflow (m^3/s)	Standard deviation (m^3/s)	Coefficient of variation	Percentage of annual streamflow
October	1.12	1973	0.554	1972	0.75	0.18	0.24	3.81
November	1.06	1977	0.513	1972	0.72	0.18	0.25	3.66
December	0.916	1973	0.386	1972	0.64	0.16	0.25	3.27
January	0.820	1973	0.451	1972	0.63	0.13	0.21	3.18
February	0.820	1973	0.470	1972	0.63	0.11	0.18	3.22
March	1.31	1977	0.588	1972	0.91	0.24	0.26	4.63
April	6.79	1973	2.32	1980	3.97	1.37	0.34	20.2
May	12.5	1976	2.80	1979	6.60	3.62	0.55	33.6
June	4.89	1972	1.12	1971	2.46	1.43	0.58	12.5
July	2.72	1980	0.181	1971	0.99	0.67	0.67	5.04
August	0.925	1978	0.125	1971	0.62	0.24	0.39	3.15
September	1.00	1972	0.486	1971	0.74	0.18	0.24	3.77
Annual	**2.29**	**1976**	**1.07**	**1971, 1979**	**1.66**	**0.48**	**0.29**	**100**

Table 7C–3. (on following page) Statistical summary of monthly and annual mean streamflows for the streamgage station on the Helmand River at Gardandewal (Vining, 2010).
[m^3/s, cubic meters per second]

4- 0.000-10M HELMAND RIVER AT GARDANDEWAL

Month	Maximum		Minimum		Mean			
	Streamflow (m^3/s)	Water year of occurrence	Streamflow (m^3/s)	Water year of occurrence	Streamflow (m^3/s)	Standard deviation (m^3/s)	Coefficient of variation	Percentage of annual streamflow
October	1.54	1970	0.811	1978	1.19	0.24	0.20	2.55
November	1.62	1973	1.00	1972	1.24	0.21	0.17	2.65
December	1.87	1973	0.935	1980	1.22	0.27	0.22	2.60
January	1.85	1973	0.889	1976	1.24	0.30	0.25	2.64
February	1.77	1970	0.960	1976	1.31	0.33	0.25	2.80
March	2.53	1978	1.58	1980	2.05	0.38	0.18	4.37
April	13.5	1976	5.52	1971	8.93	2.74	0.31	19.1
May	24.2	1976	8.78	1971	15.3	5.91	0.39	32.7
June	17.1	1972	3.03	1971	8.47	4.38	0.52	18.1
July	5.68	1980	1.68	1971	2.91	1.09	0.37	6.22
August	2.08	1979	0.945	1971	1.58	0.32	0.21	3.37
September	1.79	1969	0.910	1977	1.39	0.32	0.23	2.97
Annual	**5.21**	**1976**	**2.52**	**1971**	**3.90**	**0.96**	**0.25**	**100**

Streamflow statistics were estimated for selected ungaged streams that may be prominent in the AOI or subareas to provide some probable estimates of flow for these locations. Streamflow statistics, presented in appendix 2, were calculated for points S7, S8, and S9 (figs. 7C–1*b* and 7C–2) using a drainage-area-ratio method (Olson and Mack, 2011) based on historical flows at the Syahang River near Gardandewal (Afghan identification number 4-16.R0.00-3A). The Syahang River near Gardandewal streamgage station was selected as the most representative historical gage, on the basis of drainage-basin size and location in Afghanistan, for use with this method at this location. The mean annual streamflow estimate for point S7 (app. 2), with a drainage area of 1,204 km^2, is about 13.3 m^3/s. By applying the same method to the other two points, the mean annual streamflow estimates for points S8 and S9 are 5.69 and 1.97 m^3/s, respectively. The seasonal timing of maximum and minimum monthly streamflow is probably similar to that of the Syahang River near Gardandewal, with high flows in the spring to early summer and low flows in late fall and winter (app. 2).

The concentration of population and irrigated areas along the streams indicates that the surface-water resources in the AOI are heavily utilized by the local inhabitants (figs. 7C–2, 7C–3, 7C–4*a*). The diversion of water from the rivers to support mining activities would need to be closely monitored, particularly during low-flow periods, to ensure that the quantity and quality of the surface-water flow remain sufficient to supply water for irrigation and to provide recharge to the aquifers that supply groundwater to the shallow wells for domestic consumption.

Table 7C–4. (on following page) Statistical summary of monthly streamflows for the streamgage station on the Bamyan River at Ahangaran (Olson and Williams-Sether, 2010).

[m^3/s, cubic meters per second; ng., no data]

14-9.R00-6T BAMYAN RIVER AT AHANGARAN

Month	Maximum		Minimum		Mean			
	Streamflow (m^3/s)	Water year of occurrence	Streamflow (m^3/s)	Water year of occurrence	Streamflow (m^3/s)	Standard deviation (m^3/s)	Coefficient of variation	Percentage of annual streamflow
October	2.97	1976	2.97	1976	2.97	ng	ng	5.49
November	2.59	1976	2.59	1976	2.59	ng	ng	4.79
December	2.53	1976	2.53	1976	2.53	ng	ng	4.68
January	2.29	1976	2.29	1976	2.29	ng	ng	4.23
February	2.32	1976	2.32	1976	2.32	ng	ng	4.29
March	2.24	1976	2.24	1976	2.24	ng	ng	4.14
April	3.24	1976	3.24	1976	3.23	ng	ng	5.98
May	6.77	1975	6.77	1975	6.77	ng	ng	12.5
June	12.8	1975	12.8	1975	12.8	ng	ng	23.7
July	7.75	1975	7.75	1975	7.75	ng	ng	14.3
August	4.47	1975	4.47	1975	4.47	ng	ng	8.26
September	4.12	1975	4.12	1975	4.12	ng	ng	7.62
Annual	ng	ng	ng	ng	ng	ng	ng	100

7C.2.2 Groundwater

Approximately 22 shallow community groundwater-supply wells have been installed in the Haji-Gak iron AOI by NGOs; there are likely other wells but information about groundwater resources in the AOI is limited. Nearly all of the community supply wells are in the Farenjal subarea (fig. 7C–6*a*). Information about the wells can be found in a database maintained by DACAAR (Danish Committee for Aid to Afghan Refugees, 2011). Well-depth and static-water-level information is available for most of the wells in this database (figs. 7C–6*a*,*b*). All but one of the supply wells are less than 25 m deep and the other well is 30 m deep. The median well depth is 13.4 m. The depth to water in the supply wells in the AOI is generally less than 20 m (fig.7C–6*a*). The median depth to water is 12.4 m.

Available well-construction information is limited; however, most wells are “tube” wells (driven wells with polyvinyl chloride (PVC) casing) or dug wells with concrete-ring casing. Wells are generally installed in unconsolidated sediments, completed a few meters below the depth at which water is first encountered, and equipped with a hand pump. Figure 7C–6*b* shows the height of static water in the casings of the water-supply wells (well depth minus static depth to water). The median height of static water in well casings is 1.3 m. In the AOI, 2 m or less of static water is present in the wells. Such shallow wells were found to be vulnerable to seasonal water-level fluctuations and becoming dry for extended periods of time, or even permanently, in areas of the Kabul Basin where groundwater withdrawals are increasing (Mack and others, 2010). The NGO groundwater-supply wells are concentrated along the Torkaman River and a tributary stream in the Farenjal subarea (fig. 7C–6*a*). Although these wells are located in mapped outcrops of the conglomerate sediments and rocks, sedimentary rocks, metamorphic rocks, and intrusive rocks and lavas geohydrologic groups, the wells are likely installed in alluvium that consists of sand and gravel deposits in the bottom of stream valleys.

The shallow aquifers that are accessed by these wells are likely to be recharged from flow in the streams. The water levels in these wells may fluctuate seasonally. A few wells are located in outcrops of the conglomerate sediments and rocks geohydrologic group in an unnamed stream valley along the northern border of the AOI. The wells along this stream are probably also constructed in alluvial sediments in the bottom of the stream valley, and water levels in these wells fluctuate seasonally. The alluvial aquifers located in the stream valleys, where sufficiently thick, may have the capacity to supply water for local needs and other uses such as mining activities.

The sedimentary rocks are mapped within and outside the southern border of the AOI (fig. 7C–6*a*). The Helmand River valley exposes as much as 1,000 m of the sedimentary rocks, indicating that this unit attains considerable thickness (Bohannon, 2005*a* and 2005*b*). The headwaters of the Helmand River are located in this geohydrologic group (figs. 7C–2, 7C–4*b*, and 7C–6*a*), indicating that considerable water, probably in the form of snowmelt, likely is available for recharge to sedimentary- rock aquifers in the AOI. A component of spring discharge almost certainly supplies water to the Helmand River near its source. Sedimentary bedrock aquifers may be a promising resource in the AOI; however, no information is available about the characteristics of, or the quality of water in, the bedrock aquifers in the AOI. Field investigations including well drilling and testing would be needed to identify and quantify this potential resource.

7C.2.3 Lineament Analyses

Lineaments are photolinear features that could be the result of underlying zones of high-angle bedrock fractures, fracture zones, faults, or bedding-plane weaknesses. Lineament analyses of the Haji-Gak iron AOI (B.E. Hubbard, T.J. Mack, and A.L. Thompson, unpub. data, 2011) were conducted using DEM and natural-color satellite imagery (fig. 7C–7) and Advanced Spaceborne Thermal Emission and Reflection Radiometry (ASTER) satellite imagery (fig. 7C–8*a*,*b*). Lineament identification and analysis have long been used as a reconnaissance tool for identifying areas in carbonate bedrock environments where groundwater resources are likely to be found (Lattman and Parizek, 1964; Siddiqui and Parizek, 1971). Lineament analysis is increasingly used to identify areas of high relative well yields in other bedrock settings, including crystalline bedrock (Mabee, 1999; Moore and others, 2002). The lineaments shown in figure 7C–7 were delineated visually, whereas those in figure 7C–8 were delineated using an automated process and on the basis of the multispectral characteristics of the land surface (B.E. Hubbard, T.J. Mack, and A.L. Thompson, unpub. data, 2011). There are many east- to northeast-trending lineaments in the AOI that follow the regional structure, as well as mapped faults (fig. 7C–6*a*). Figure 7C–9 also indicates many north-trending lineaments, which may indicate the presence of a conjugate fracture pattern in the AOI. Water wells in bedrock aquifers generally are most productive where boreholes are located in areas of highly fractured bedrock. Areas where lineament density is high, such as in the Farenjal and NE Haji-Gak subareas (figs. 7C–7, 7C–8*a*, 7C–8*b*), potentially are areas where bedrock fractures are more prevalent than in other areas of the AOI. Lineaments provide an indication of areas that warrant further investigation for optimal bedrock water-well placement. Lineaments may also indicate areas of preferential flow and storage of groundwater, and areas with a high density of lineaments may indicate high secondary porosity. Any lineament analyses, including those presented in this investigation, need to be corroborated by field investigations and additional data to confirm the nature of the lineaments and their relation to water-filled bedrock fracture zones.

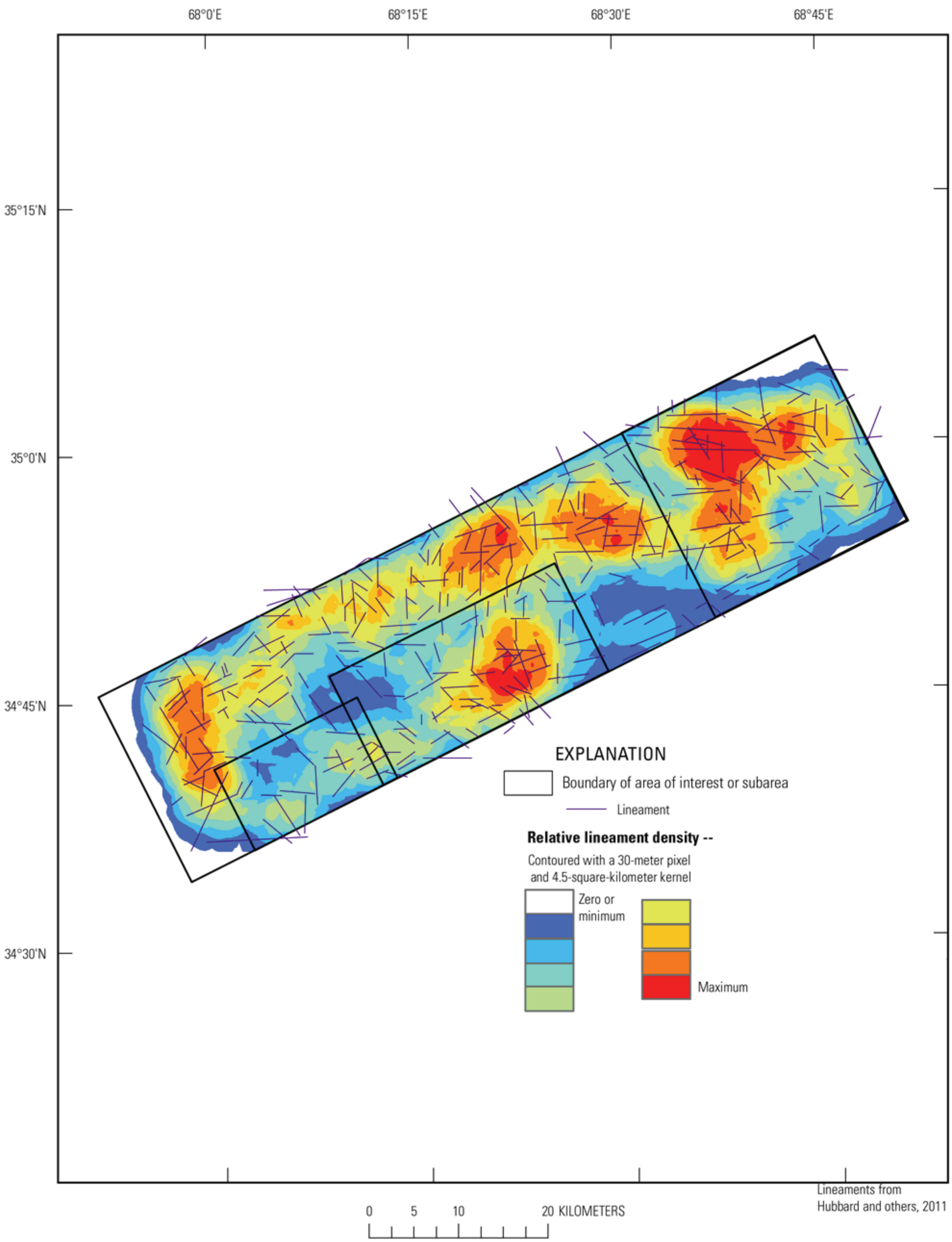
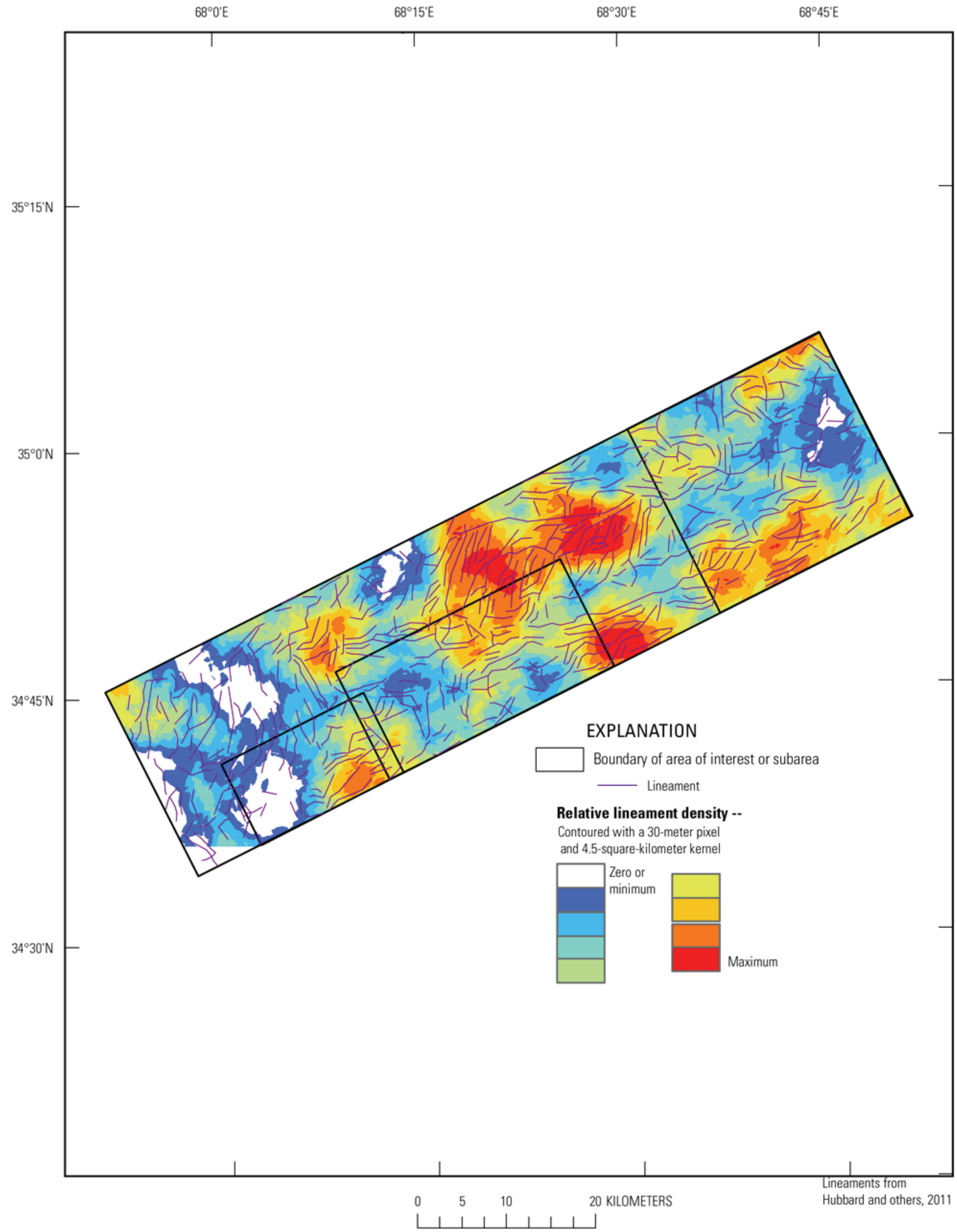


Figure 7C–7. Lineaments and lineament density based on 30-meter digital elevation model data and natural-color Landsat imagery in the Haji-Gak iron area of interest in Afghanistan.

a


68°0'E
68°15'E
68°30'E
68°45'E
35°15'N
35°0'N
34°45'N
34°30'N
EXPLANATION
Boundary of area of interest or subarea
Lineament
Relative lineament density --
Contoured with a 30-meter pixel
and 4.5-square-kilometer kernel
Zero or
minimum
Maximum
0
5
10
20 KILOMETERS
Lineaments from
Hubbard and others, 2011

b

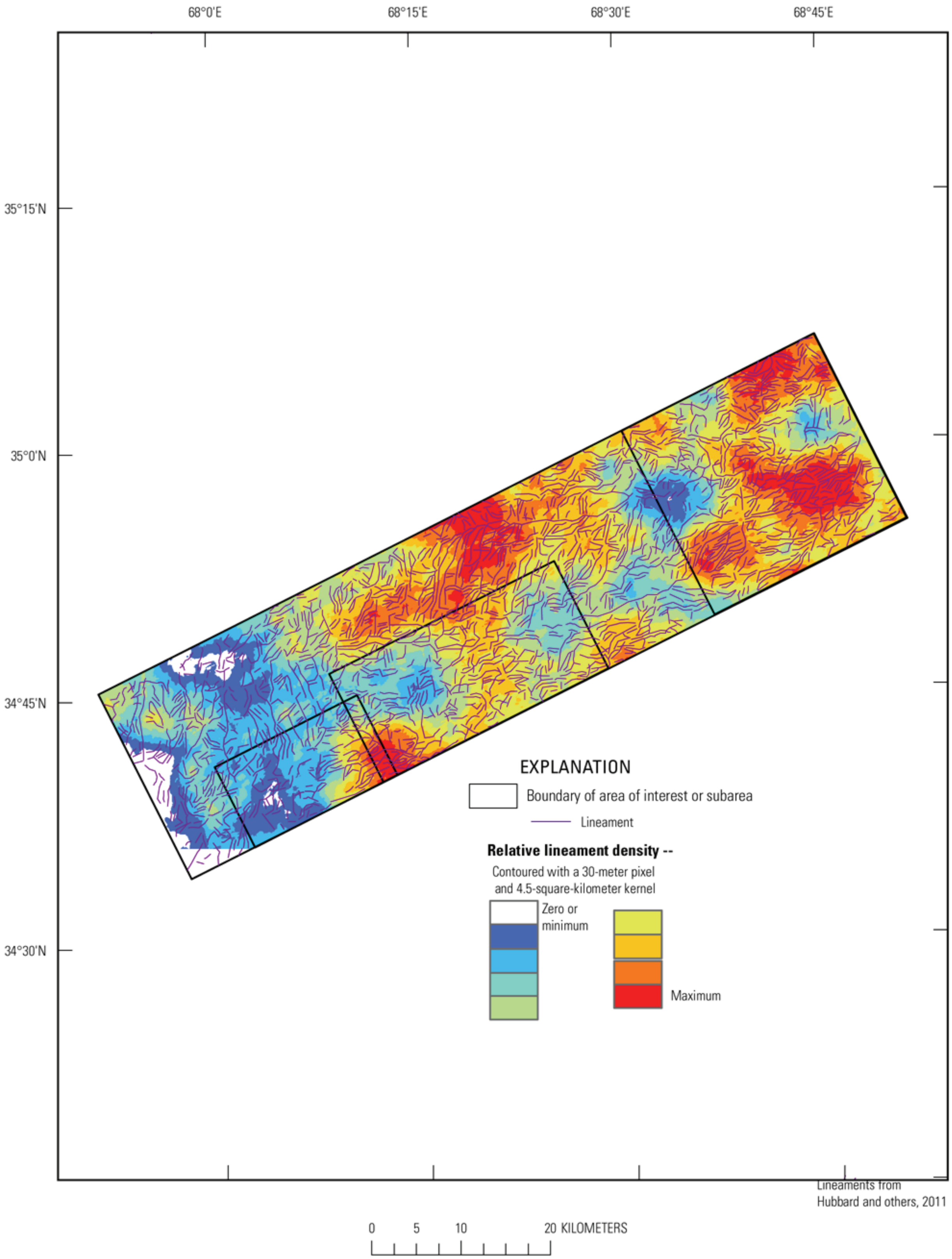


Figure 7C–8. (*a*) Lineaments and lineament density based on 30-meter multispectral Landsat imagery in the Haji-Gak iron area of interest and (*b*) lineaments and lineament density based on 15-meter multispectral Landsat imagery in the Haji-Gak iron area of interest in Afghanistan.

7C.3 Summary and Conclusions

Water resources in the Haji-Gak iron area of interest (AOI) and surrounding area consist of both surface water and groundwater and are likely to be more available for mining and other uses than in other areas of Afghanistan. The elevations of some of the high mountains in the AOI exceed 4,000 meters above sea level and likely receive considerable precipitation, especially as snowfall during the winter months. The runoff from the snowmelt in the spring and summer provides surface-water flow in the perennial and ephemeral streams in the AOI. The Ghorband and Torkaman Rivers flow through sections of the AOI, but the flow in these rivers fluctuates seasonally. Water from these rivers is used for irrigation and recharges the shallow alluvial aquifers located in the river valleys. Most water-supply wells in the AOI are located in the alluvial aquifers in the stream valleys, which are likely a highly utilized groundwater resource. Where valley-bottom alluvial aquifers are sufficiently thick, they may contain a limited amount of untapped groundwater that would be available to support mining activities. The diversion of water from the rivers to support mining activities would need to be closely monitored, particularly during low-flow periods, so that the quantity and quality of the surface-water flow remain sufficient to supply water for irrigation and to provide recharge to the aquifers that supply groundwater to the shallow wells for domestic consumption.

There is no known information available on bedrock aquifers in the AOI or adjacent areas. Some areas of the AOI are likely areas for further exploration for groundwater resources as indicated by generalized geohydrologic maps and lineament analyses. Such areas may include the sedimentary rocks within and outside the southern border of the AOI. The quality and sustainability of water resources in the AOI remain to be determined, however. Careful evaluation and management of potential new surface-water or groundwater withdrawals would help to protect the quantity and quality of the existing supply for current local water uses. Field investigations including geologic mapping, geophysical surveys, and hydraulic well testing are needed to adequately characterize the extent and availability of groundwater resources in the AOI.

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