Chapter 5C. Geohydrologic Summary of the Daykundi Tin and Tungsten Area of Interest

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5C.1 Introduction

This chapter describes the geohydrology of the Daykundi tin and tungsten area of interest (AOI) in Afghanistan identified by Peters and others (2007). The AOI is in the Gizab, Day Kundi, and Shahristan Districts in Daykundi Province, and the Waras District in Bamyan Province (fig. 5C-1*a*,*b*). The area is entirely mountainous with the exception of a few areas along major river valleys and some rolling plateaus.

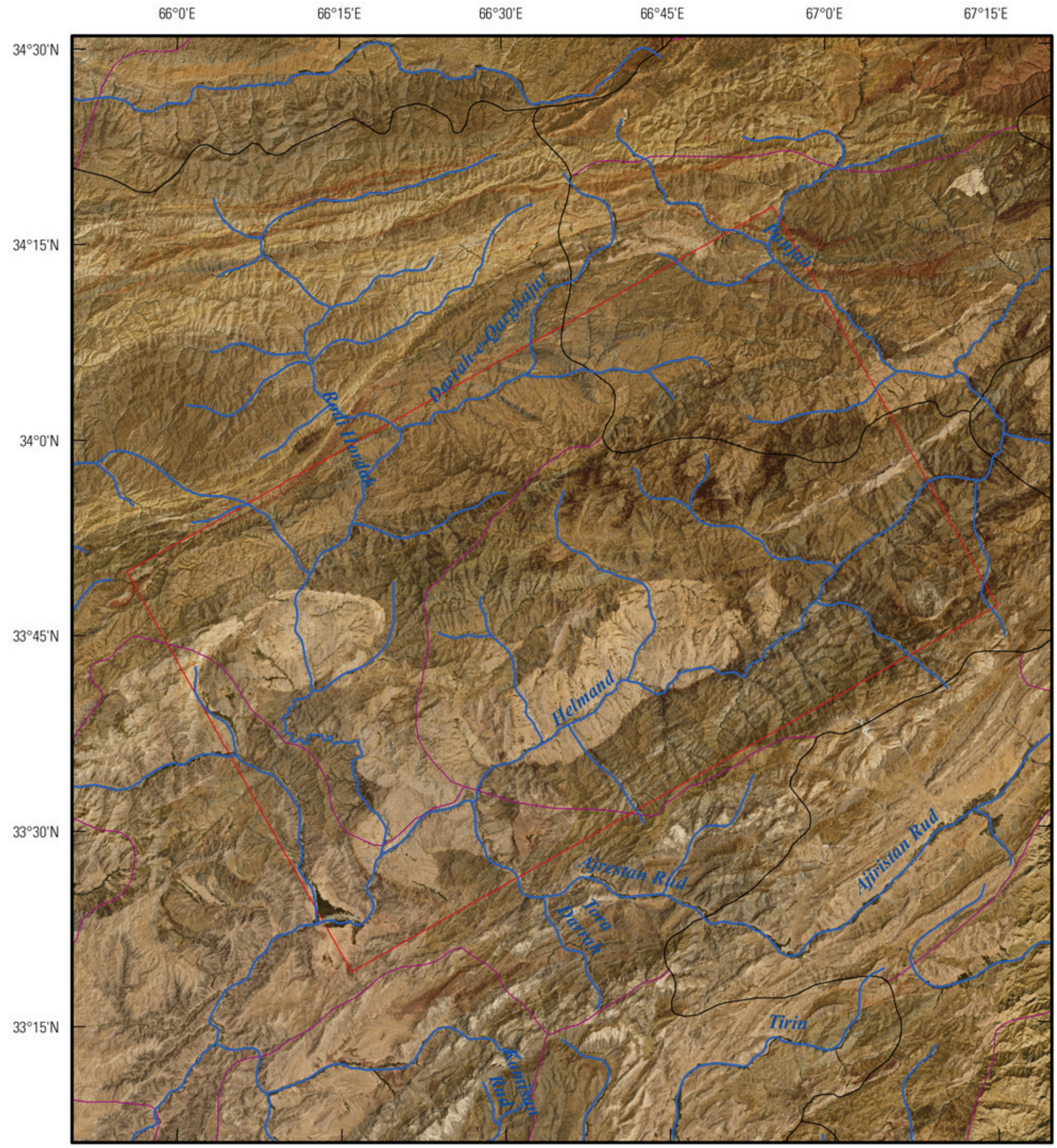
Water is needed not only to process mineral resources in Afghanistan, but also to supply existing communities and the associated community growth that may accompany a developing mining economy. Information on the climate, vegetation, topography, and demographics of the AOI is summarized to provide information on the seasonal availability of, and the 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, nongovernmental organizations (NGOs), foreign government agencies, and the Afghan government have begun water-resource investigations; however, these activities and the amount of data available are limited. This report summarizes satellite imagery and climatic, topographic, geologic, surface-water, and groundwater data available. Geohydrologic inferences are made on the basis of an integrated analysis of these data and an understanding of conditions in other areas of Afghanistan.

5C.1.1 Climate and Vegetation

Climate information for the Daykundi tin and tungsten 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 (2005–11), 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 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

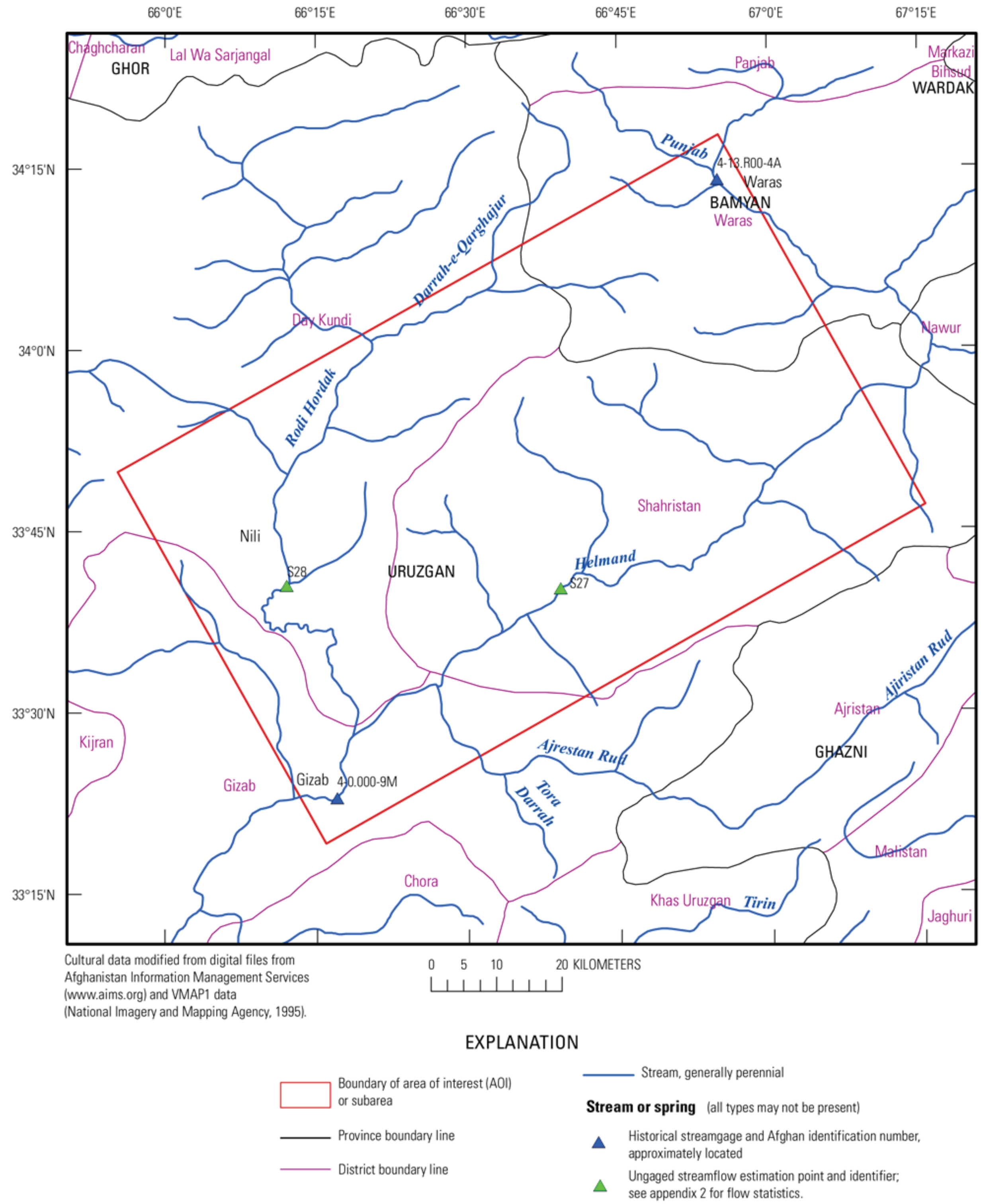


Figure 5C–1. *(a)* Landsat image showing the location of, and *(b)* place names, stream names, and streamgage station numbers in the Daykundi tin and tungsten area of interest in the central highlands region of Afghanistan.

The climate of the AOI is typical of the continental interior mountainous region of Afghanistan. The winters are characterized by cold temperatures and substantial precipitation, mostly in the form of snow, whereas the summers are warm and dry. Four Agromet stations are located in the central highlands region. The total rainfall in the central highlands region for 2009–2010 was 221 to 300 mm (millimeters) (Ministry of Agriculture, Irrigation, and Livestock, 2010). The amount of precipitation increases from west to east across the AOI. The Agromet station closest to the AOI is 20 km (kilometers) to the northeast, at Panjab, Bamyan Province; however, only precipitation data, and no long-term average (LTA) data, are available for this station. The total precipitation recorded at the Panjab Agromet station for the 2009–10 water year was 564 mm. The maximum monthly rainfall total of 269 mm occurred in May 2010. There was no rainfall in March, June, or July 2010. The Agromet station closest to the AOI for which 2009–2010 water year and LTA precipitation and temperature data are available is located in Bamyan, Bamyan Province, about 55 km northeast of the AOI at an elevation of 3,200 m (meters) above sea level (asl). Precipitation and temperature data for the Agromet station in Bamyan are shown in table 5C–1.

The maximum temperatures in the AOI during the 2009–2010 water year ranged from 35.5°C (degrees Celsius) to 44.8°C (Ministry of Agriculture, Irrigation, and Livestock, 2010). The average monthly high temperature at the Bamyan station for the 2009–2010 water year was 19.5°C in July 2010 and the average monthly low temperature was -3.7°C in December 2009. The LTA high and low temperatures at this station are 18.2°C for July and -6.8°C for January.

The natural vegetation in the AOI varies with elevation. Other factors that affect vegetation type are precipitation, soil type and depth, slope aspect, and human activity. Overgrazing has left much of the AOI with very sparse vegetation. In the stream valleys, where elevations are low, the natural vegetation is azonal riverine (Breckle, 2007). Much of the natural riverine vegetation in Afghanistan has been harvested for fuel and building materials (Breckle, 2007, p. 181), and has been replaced by cultivated crops and orchards. The natural vegetation on the slopes above the streams is classified as Amygdalus Scrublands (Breckle, 2007, p. 161). The higher elevations are dominated by alpine vegetation and are classified as “thorny cushions, subalpine and alpine deserts and meadows” (Breckle, 2007). Agricultural development is present in stream valleys but is limited in upland areas (fig. 5C–2).

Table 5C–1. Annual, long-term annual average, and long-term average minimum and maximum monthly precipitation and temperature at the Bamyan Agrometeorological (Agromet) station, Afghanistan.

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

Agromet station	Distance from AOI center (km)	Elevation (m)	Precipitation				Temperature		
			2009--10 annual (mm)	Long-term average[1]			Long-term average[1]		
				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	3,200	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).Snow days were recorded at all four Agromet stations in the central highlands region. The Agromet station at Panjab recorded a total of 33 snow days with a total accumulation of 257 cm (centimeters). The total snowfall for the previous year (September 2008 through August 2009) was 279 cm. Snow was recorded from November 2009 to February 2010, with February having the most snow days and the greatest accumulation. This station is at an elevation of about 2,700 m asl, which is comparable to the elevations in the AOI. The snow-depth map for January 2010 (Ministry of Agriculture, Irrigation, and Livestock, 2010, map 7) indicates snow in the AOI was from 2 to 30 cm deep. The snow-depth map for September 2010 (Ministry of Agriculture, Irrigation, and Livestock, 2010, map 7) shows less than 2 cm of snow in the AOI and at the Panjab Agromet station. It is likely that no snow was present in the AOI in September, but “less than 2 cm” is the lowest snow-depth category shown on the map.

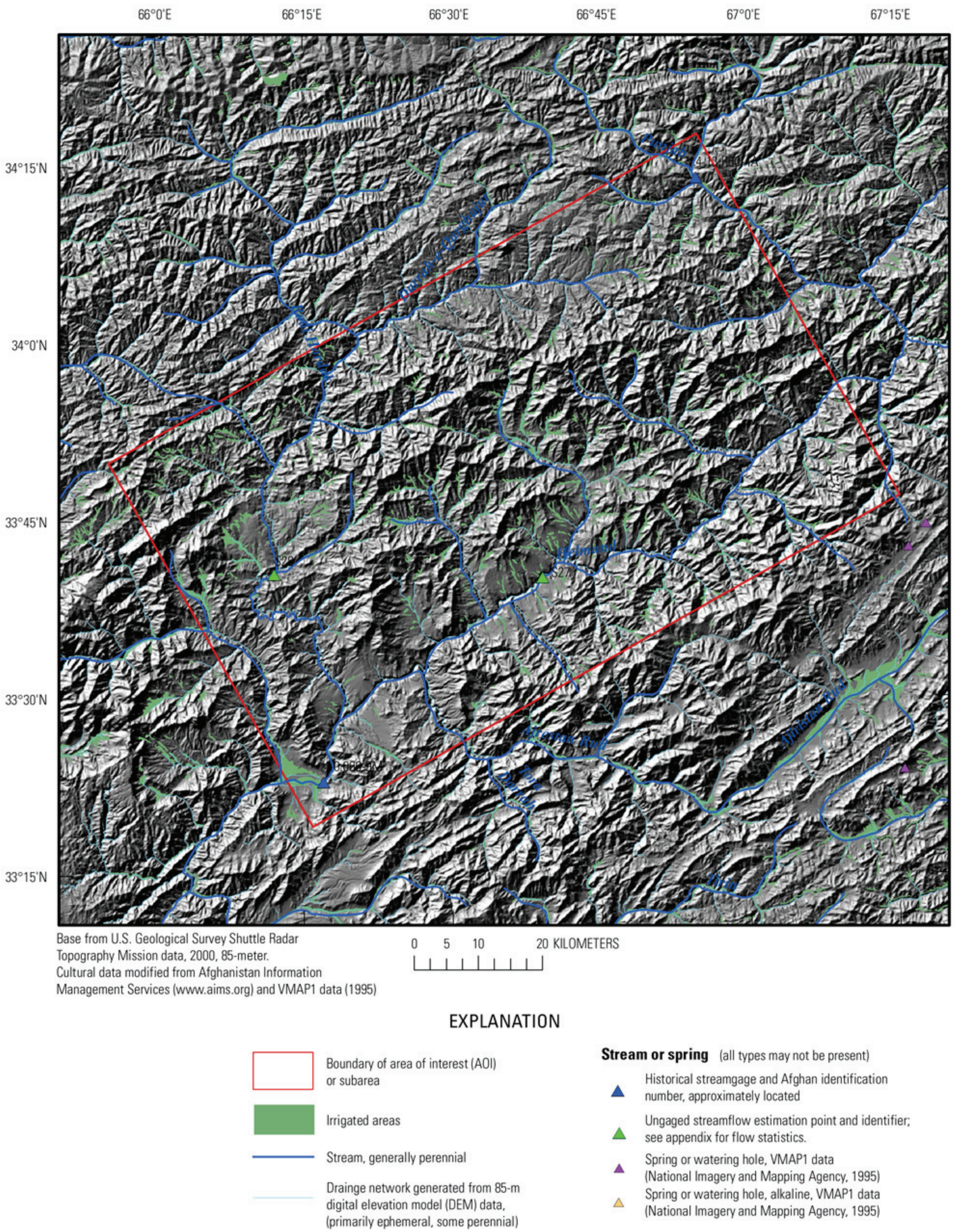


Figure 5C–2. Historical streamgage locations, streamflow estimation points, digitally generated drainage network, and irrigated areas in the Daykundi tin and tungsten area of interest in the central highlands region of Afghanistan.

5C.1.2 Demographics

The population density of the Daykundi tin and tungsten AOI as mapped by LandScan (Oak Ridge National Laboratory, 2010) with a pixel resolution of approximately 1 km^2 (square kilometer) is shown in figure 5C-3. Few areas in the AOI have a population density greater than 500 per km^2, and in most areas it is less than 50 per km^2. One of the larger settlements is the Daykundi Province center of Nili (figs. 5C–1*a*,*b*); however, the population density of the Nili area is less than 500 per km^2 and generally less than 100 per km^2. Nili is located in a valley formed by a number of ephemeral streams and much of the land area is irrigated (fig. 5C–2). The area with the greatest population density is probably Gizab, located at the confluence of the Helmand and Rodi Hordak Rivers (fig. 5C–1*b*), with a few locations having a population density of about 1,000 per km^2. Most of the inhabitants live in small farming communities that are located in perennial- and ephemeral-stream valleys. Agricultural development in the larger valleys in the AOI is extensive. Agricultural development and settlements along the Helmand River in the AOI are limited because the valley is narrow with steep sides that limit the amount of land available for development. Streamflow data (discussed in the Surface Water section) indicate that flow in the Helmand River in April and May could result in seasonal flooding that would prevent, or at least limit, development within the flood plain of the river. Another more populated area is an area of relatively low relief in the northeastern part of the AOI between the Darrah-e-Qarghajur and Punjab Rivers (figs. 5C–2 and 5C–3). The roads in the AOI are mapped as “tracks” (Afghanistan Information Management Service, 2007), with only a few bridges that cross perennial streams.

5C.1.3 Topography and Geomorphology

The Daykundi tin and tungsten AOI is in the central highlands region of the Hindu Kush Mountains in Afghanistan. The AOI is mountainous and contains several peaks that are higher than 3,500 m asl. The highest peak, in the southeast corner of the AOI, has an elevation of 3,511 m asl (Bohannon, 2005b). The AOI is located in the upper drainage basin of the Helmand River (Williams-Sether, 2008). The Helmand River flows through the southern part of the AOI. The elevation of the streamgage station at Gizab (fig. 5C–1*b*) on the Helmand River is reported to be 1,325 m asl (Williams-Sether, 2008). The AOI can be described as rugged, mountainous highlands incised by dendritic stream valleys. Some of the more deeply incised stream valleys have as much as 800 m of relief. The topography of the AOI is influenced by the lithology of the bedrock outcrops and the structural geology of the region.

The geomorphology of the AOI is a product of fluvial processes and local geology. Stream valleys are V-shaped and narrow along most of their lengths (Davis, 2006). Some areas along the streams are wide enough to support small settlements and cultivated fields. Areas of settlements and agriculture are found at the confluences of stream valleys and large oxbow curves (fig. 5C–2). Low-relief upland areas are developed in some parts of the AOI. The outcrops of sedimentary rocks form steeply dipping ridges, but are of limited extent in the AOI (fig. 5C-4). About half of the outcrops in the AOI are composed of metamorphic rocks. Much of the area where these rocks crop out is above 2,500 m asl. Many peaks in the metamorphic-rock highlands are more than 3,500 m asl. The area is cut by streams that exhibit dendritic drainage patterns, but some long, fault-controlled ridges and valleys also are present (Bohannon, 2005a,b).

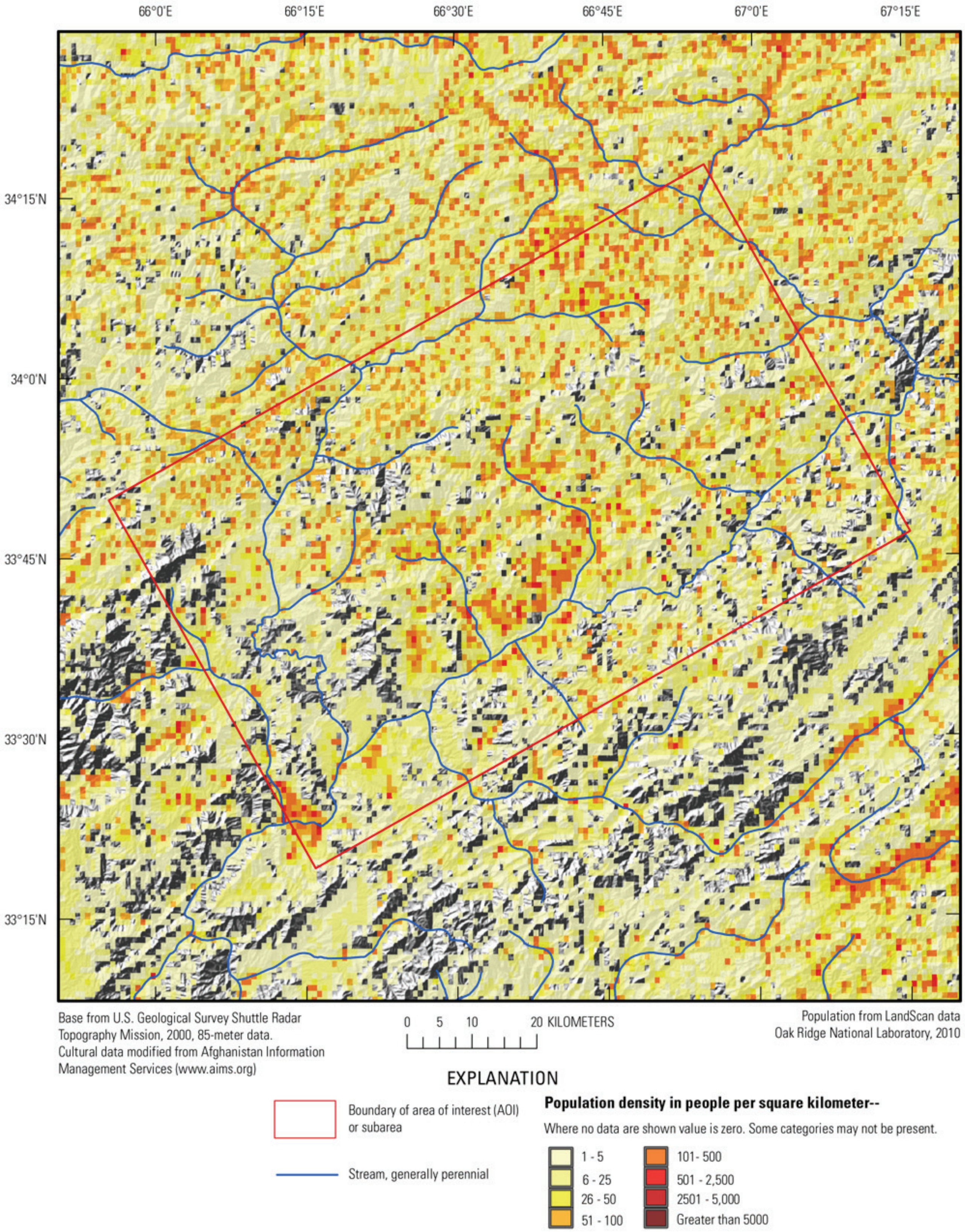


Figure 5C–3. (on previous page) Population density of the Daykundi tin and tungsten area of interest in the central highlands region of Afghanistan.

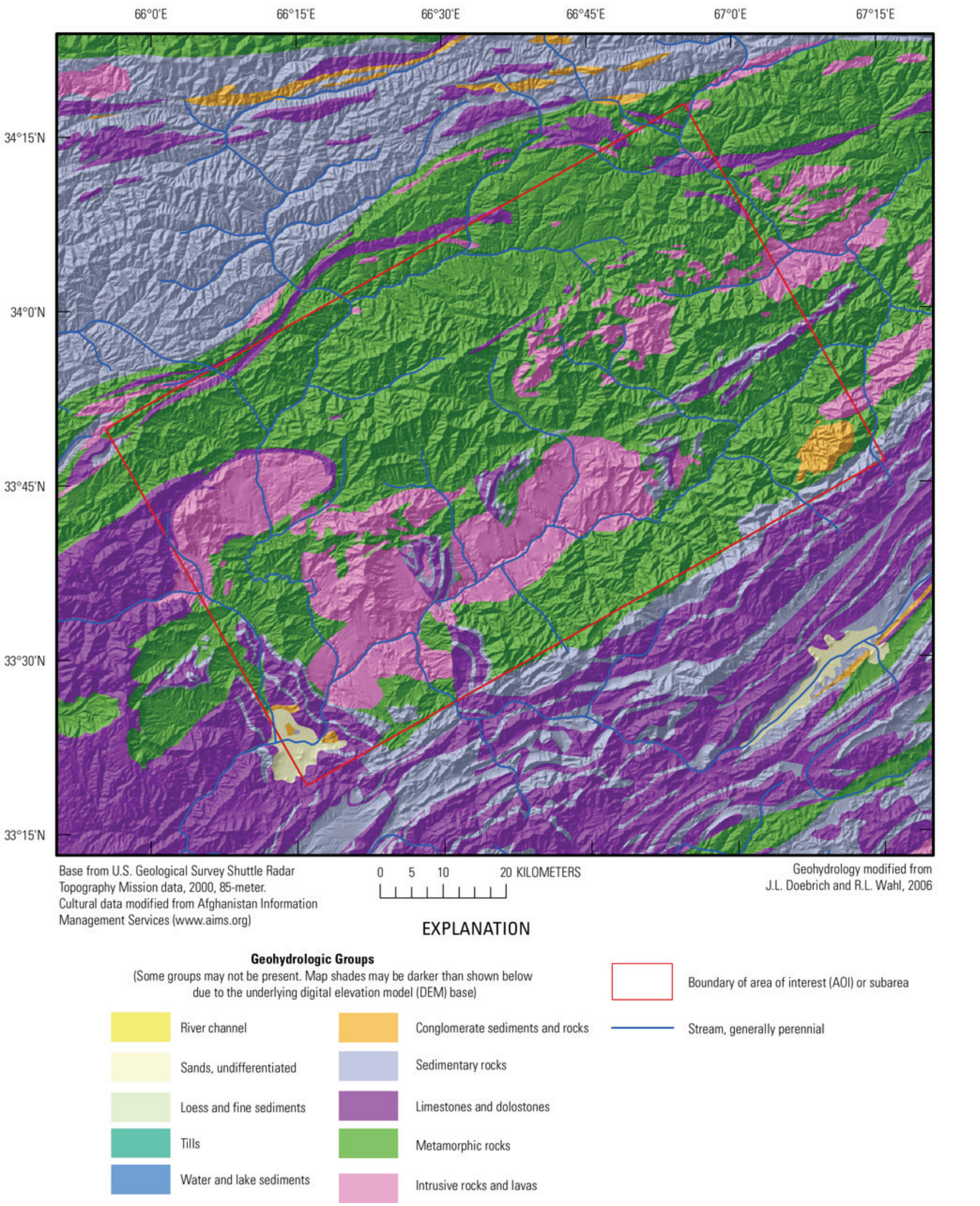


Figure 5C–4. (on previous page) Topography and generalized geohydrology of the Daykundi tin and tungsten area of interest in the central highlands region of Afghanistan.

5C.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 Daykundi tin and tungsten AOI is in the Upper Helmand hydrogeologic massif of the central hydrogeologic folded region. 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 5C–4 with the underlying topography to allow examination of the geohydrology in the context of relief, whereas figures 5C–5*a* and *b* show the generalized geohydrology without topography for a clearer depiction of the geohydrologic units. Wells present in the map area (discussed in the Groundwater section) are shown in figures 5C–5*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 "sands, undifferentiated; conglomerate sediments and rocks; limestones and dolostones; sedimentary rocks; metamorphic rocks; and intrusive rocks and lavas" (figs. 5C–4 and 5C–5*a*). 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 map that covers this AOI is provided by Bohannon (2005a).

The AOI consists largely of the metamorphic rocks group and, secondarily, the intrusive rocks and lavas group (figs. 5C–4 and 5C–5*a*). Minor outcrops of the sedimentary rocks group and the limestones and dolostones group are found within the AOI. Mapped unconsolidated deposits are confined to a few areas along the active channels of perennial streams. An area of about 20 km^2 around the settlement of Gizab at the confluence of the Rodi Hordak and Helmand Rivers is mapped as sands, undifferentiated, with some conglomerate sediments and rocks (figs. 5C–4 and 5C–5*a*,*b*). Google Earth aerial images show evidence of minor alluvial and colluvial deposits along all of the perennial and some of the ephemeral streams in the AOI. The alluvial and colluvial deposits are limited in areal extent and likely are limited in thickness as well.

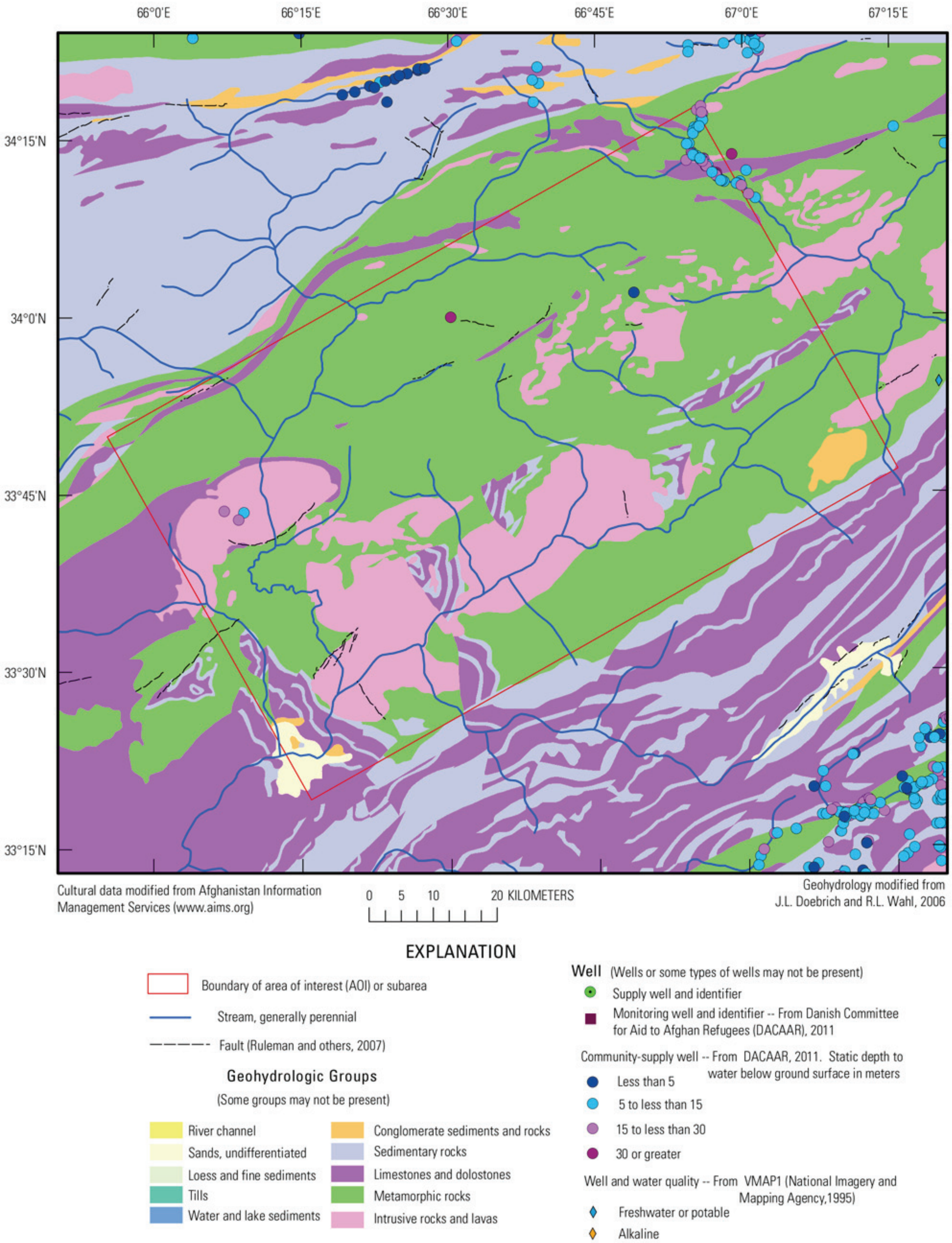
Abdullah and Chmyriov (1977) provide the following general descriptions of the water-bearing deposits in the region that includes the AOI: "The aquifer, composed of alluvial-fan and talus deposits, occur in the Herat, Sehdara, Dakke-Tundi (Daykundi), Kabul, and Aynak intermontane depressions, in the Dashte Nawer Depression, and in numerous intermontane valleys. Water-bearing deposits are gravel, shingle, sandy loam and loam totaling in thickness from a few meters in intermontane depressions (valleys or basins) in the west to 400 m at Shekar Darah." There is no evidence of karezes (hand-dug water-supply tunnels) in the AOI, probably because the amount of alluvial and colluvial sediments is limited.

The known mineral deposits in the AOI are found in the metamorphic rocks group and the intrusive rocks and lavas group. As indicated by Abdullah and Chmyriov (1977), the hydraulic properties of intrusive and metamorphic rocks are dependent on secondary porosity due to fracturing. Fractures in rocks in the AOI are likely to be found adjacent to faults and at intrusive-rock contacts (fig. 5C–5*a*). Several faults have been mapped in the AOI (fig. 5C–5*a*), and other, unmapped faults likely are present in the area as well.

5C.2.1 Surface Water

A network of major streams, mostly perennial streams, modified from AIMS (Afghanistan Information Management Services, 1997) and VMAP1 (National Imagery and Mapping Agency, 1995), is shown in figure 5C–2. A network representing likely ephemeral streams, generated with a digital elevation model (DEM), also is shown in figure 5C–2. Mapped springs, identified in the Vector Map (VMAP1) database (National Imagery and Mapping Agency, 1995), are also shown where present in and adjacent to the Daykundi tin and tungsten AOI. Names of major streams and identification numbers for any streamgages and ungaged streamflow estimation sites in the AOI are shown in figure 5C–1*b*.

a



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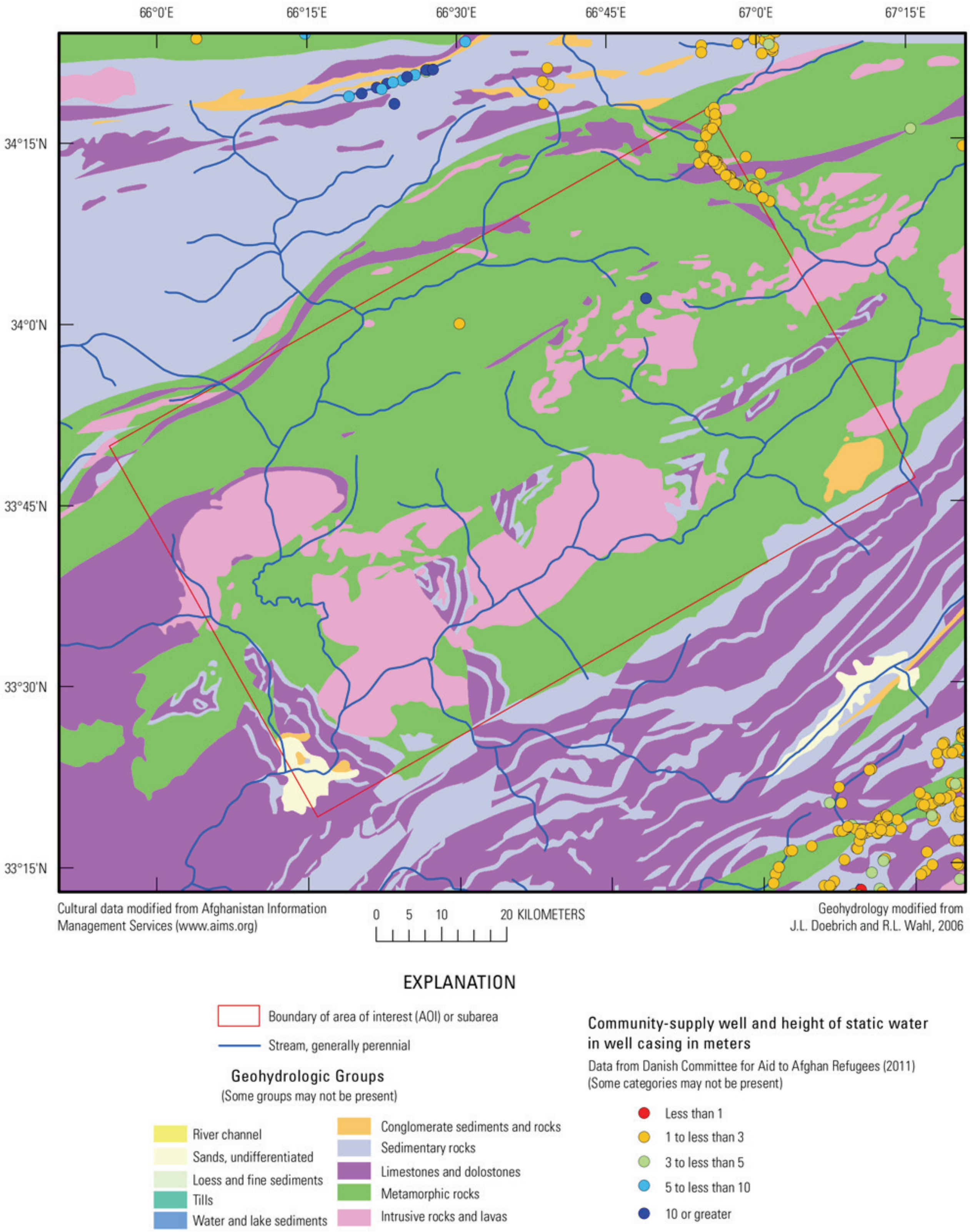


Figure 5C–5. *(a)* Generalized geohydrology, mapped faults, well locations, and depth to water, and *(b)* geohydrology and height of static water in well casings in community-supply wells in the Daykundi tin and tungsten area of interest in the central highlands region of Afghanistan.

The AOI lies within the upper drainage basin of the Helmand River, which is the largest perennial stream in southern Afghanistan. Many perennial tributary streams transect portions of the AOI (figs. 5C–1*b* and 5C–2). Historical streamflow data are available for two streamgage stations within the AOI in the Helmand River Basin (Williams-Sether, 2008) (fig. 5C–1*b*). The Punjab River at Waras station (Afghan identification number 4-13, R00-4A) is in the northeast corner of the AOI in Bamyan Province. A statistical summary of monthly and annual mean streamflows for this station (Williams-Sether, 2008) is shown in table 5C–2. The Punjab River is a tributary to the Helmand River that transects the northeast corner of the AOI. The period of record for this station is from 1 October, 1969, to 20 January, 1979. The drainage area is 1,710 km^2 and the elevation of the station is reported as 2,480 m asl. The annual mean streamflow for the period of record is 8.54 m^3/s (cubic meters per second), with a standard deviation of 3.95 m^3/s. The annual mean streamflow per unit area for this station is 0.005 $m^3/s/km^2$. The highest maximum monthly mean streamflow was 93.6 m^3/s in May 1976, and the lowest minimum monthly mean streamflow was 0.75 m^3/s in July 1971. Statistical summaries of the streamflow data that are available for all historical gages in Afghanistan can be accessed at *http://afghanistan.cr.usgs.gov/water.php*.

The Helmand River at Gizab streamgage station (Afghan identification number 4-0.000-9M) is located in the southwestern corner of the AOI at an elevation of 1,325 m asl. A statistical summary of monthly and annual mean streamflows for this station (Williams-Sether, 2008) is shown in table 5C-3. The period of record for this station is from 19 July, 1971, to 11 March, 1979, and its drainage area is 20,750 km^2. The annual mean streamflow for the period of record is 111 m^3/s, with a standard deviation of 28.1 m^3/s. The annual mean streamflow per unit area for this station is 0.005 $m^3/s/km^2$. The highest maximum monthly mean streamflow during the period of record was 563 m^3/s in April 1976, and the lowest minimum monthly mean streamflow was 18.3 m^3/s in August 1971. Statistical summaries of streamflow data for all available historical gages in Afghanistan can be accessed at *http://afghanistan.cr.usgs.gov/water.php*.

The Rodi Hordak is a perennial stream that flows through the western part of the AOI and its headwaters are north of the AOI (fig. 5C–1*b*). The stream valley is deeply incised and meandering in the outcrops of the metamorphic rocks, but displays a rectangular pattern in the outcrops of the intrusive rocks and lavas. The Ajrestan Rud is the other named tributary to the Helmand River in the AOI (fig. 5C–1*b*). The headwaters of the Ajrestan Rud are in the mountains south of the AOI. Other unnamed steams flow through or originate in the AOI (fig. 5C–2); flow in these streams is probably much smaller than flow in the named tributaries.

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 S27 and S28 (fig. 5C–1*b*) using a drainage-area-ratio method (Olson and Mack, 2011) based on historical flows at streamgage stations in the AOI. Point S27 is located on the Helmand River and has as a drainage area of 11,568 km^2. The streamflow at point S27 was estimated using data from the Helmand River at Gizab (Afghan identification number 4-0.000-9M) streamgage station (app. 2–S27). The mean annual streamflow at point S27 is estimated to be 60.61 m^3/s. Point S28 is on the Rodi Hordak and has a drainage area of 4,331 km^2. The streamflow at point S28 was estimated using data from the Punjab River at Waras streamgage station (app. 2–S28). The Punjab River at Waras streamgage station was selected as the most representative historical gage, on the basis of drainage-basin characteristics, for use with this method. The mean annual streamflow at point S28 was estimated to be 22.53 m^3/s. The seasonal timing of maximum and minimum monthly streamflow at S27 and S28 would likely be similar to that at the two stations used to calculate the estimates, with high flows in the spring and low flows in the late summer.

Table 2. Statistical summary of monthly and annual mean streamflows for the Punjab River at Waras streamgage station.

[m^3/s, cubic meters per second]

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	5.20	1977	1.65	1972	3.26	1.11	0.34	3.18
November	5.60	1970	1.85	1972	3.21	1.25	0.39	3.13
December	4.19	1977	1.56	1973	2.97	0.92	0.31	2.89
January	6.25	1977	1.33	1973	3.38	1.34	0.40	3.30
February	7.95	1977	1.78	1973	4.17	1.80	0.43	4.07
March	10.7	1977	3.24	1972	5.76	2.63	0.46	5.61
April	53.9	1976	7.73	1971	30.3	13.5	0.45	29.6
May	93.6	1976	3.45	1971	33.9	27.6	0.81	33.0
June	20.5	1976	0.997	1971	7.47	6.27	0.84	7.28
July	5.03	1976	0.753	1971	2.73	1.43	0.52	2.66
August	4.84	1978	1.06	1971	2.54	1.13	0.45	2.47
September	4.50	1976	1.44	1971	2.88	0.88	0.30	2.81
Annual	**16.9**	**1976**	**3.11**	**1971**	**8.54**	**3.95**	**0.46**	**100**

Table 5C–3. Statistical summary of monthly and annual mean streamflows for the Helmand River at Gizab streamgage station.

[m^3/s, cubic meters per second]

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	50.0	1977	28.2	1972	41.3	6.56	0.16	3.11
November	61.2	1977	32.2	1972	47.4	8.58	0.18	3.57
December	57.3	1977	30.5	1972	46.8	8.09	0.17	3.53
January	60.8	1977	32.7	1972	48.0	8.42	0.18	3.61
February	102	1973	35.7	1972	66.8	22.4	0.33	5.03
March	259	1972	143	1978	186	39.4	0.21	14.0
April	563	1976	230	1974	360	112	0.31	27.1
May	543	1976	137	1974	286	142	0.50	21.5
June	189	1976	71.5	1974	119	52.7	0.44	8.99
July	95.3	1976	30.2	1974	57.8	22.0	0.38	4.35
August	45.1	1975	18.3	1971	34.1	8.87	0.26	2.57
September	46.3	1976	22.0	1971	35.0	8.47	0.24	2.64
Annual	**159**	**1976**	**76.9**	**1974**	**111**	**28.1**	**0.25**	**100**

5C.2.2 Groundwater

Approximately 40 shallow community groundwater-supply wells have been installed near the Punjab River in the Daykundi tin and tungsten AOI by NGOs. Information about these 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 (fig. 5C–5*a*,*b*). Available well-construction information is limited; however, most of these wells are shallow dug wells, generally less than 10 m deep, or "tube" wells (driven wells with polyvinyl chloride (PVC)) casing), generally 10 to 20 m deep, constructed with concrete-ring casing. They are typically constructed in unconsolidated sediments near stream channels; depth to water generally is less than 15 m. About four NGO wells are in Nili and a few are in other areas of the AOI (fig. 5C–5*a*). It is likely that additional water wells are present in the AOI, especially in the larger settlements such as Nili, Gizad, and Waras. Figure 5C–5*b* shows the height of static water in the casings of the water-supply wells (well depth minus static depth to water), which was typically 1 to 3 m. Such shallow wells, with little static water, were found to be vulnerable to seasonal water-level fluctuations and to 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). Community supply wells are generally equipped with hand pumps. Wells constructed for irrigation may be more likely to have electric pumps, powered by generators; however, powered pumps are not common in remote areas because of the prohibitive expense of fuel.

One groundwater monitoring well, GWM 54 (not shown in figure 5C–5*a*), is about 40 km north of the AOI boundary and is monitored by DACAAR for groundwater levels and specific conductance. A hydrograph of water levels in GWM 54, provided by DACAAR, is shown in appendix 3. The hydrograph shows the date in week number and year, the specific conductance of groundwater in microsiemens per centimeter at 25°C (µS/cm), and depth to water in meters below ground surface (bgs). The water level in GWM 54, which likely is constructed in alluvial material, fluctuated about 3 m seasonally, with a peak in the spring and a low in the late fall. Specific conductance of the water from this well was about 1,400 to 1,600 µS/cm.

The geohydrology and climate of the AOI are favorable for recharge of groundwater. The alluvial and colluvial sediments in stream valleys and upland basins probably are local aquifers of limited extent and thickness. The alluvial-colluvial aquifer probably is capable of supplying groundwater only for local use and likely would not support large-scale withdrawals for mining operations. The largest outcrop area in the AOI is composed of the metamorphic rocks group and the intrusive rocks and lavas group. These two geohydrologic groups are potential aquifers in the AOI. The water yields of these potential aquifers are unknown, but may be considerable where the bedrock is highly fractured; these areas may be indicated by lineaments. The AOI receives about 300 mm of precipitation per year, mostly in the form of snow during the winter months. The bedrock units are weathered and fractured at the land surface—conditions that are favorable for the infiltration of precipitation, including snow melt, into the subsurface. Additional study, including geologic mapping, geophysics, and drilling and testing of boreholes, would help to characterize these geohydrologic groups as potential aquifers.

5C.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 Daykundi tin and tungsten AOI were conducted using DEM and natural-color satellite imagery (fig. 5C–6) and Advanced Spaceborne Thermal Emission and Reflection (ASTER) radiometer satellite imagery (fig. 5C–7*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 5C–6 were delineated visually, whereas those in figure 5C–7*a*,*b* 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). 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 (figs. 5C–6 and 5C–7*a*, *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.

The westernmost outcrop of the intrusive rocks and lavas geohydrologic group in the AOI (fig. 5C–4) exhibits a prominent set of northwest-southeast-trending lineaments (fig. 5C–6) and is partially surrounded by a thin band of steeply dipping sedimentary rocks. The fractures in this outcrop have a strong influence on the drainage pattern (Bohannon, 2005a,b). Lineament groups are densest in the northern area of the AOI, in southern areas of the Darrah-e-Qarghajur stream basin (figs. 5C–6 and 5C–7*a*). This area is characterized by metamorphic rocks and has less relief than other areas of the AOI (fig. 5C–5*a*); the lineaments generally trend southwest-northeast and likely follow regional bedrock foliation. These features may be indicative of highly fractured bedrock with low relief and may represent areas where groundwater is available in bedrock. ASTER lineament density is greater in metamorphic rocks in some areas along the southeastern boundary of the AOI than in other areas (fig. 5C–7*a*,*b*).

5C.3 Summary and Conclusions

Water resources for mining and other uses are likely to be more available in the Daykundi tin and tungsten area of interest (AOI) than in other areas of Afghanistan. Streamflow estimates based on historical records indicate that surface-water resources potentially are available for uses such as mining-related activities. The diversion of water from the upper Helmand River basin would need to be closely monitored, particularly during low-flow periods. The quantity and quality of the water resource need to be assessed so that surface-water flow remains sufficient to supply water for irrigation and to provide recharge to the aquifers that supply groundwater to the shallow wells for domestic consumption. Perennial streams that transect or are within the AOI are also potential sources of water that may support mining activities.

The groundwater resources of the AOI are not well known; however, the climate and geohydrology of the AOI are favorable for groundwater recharge. The limited areal extent and thickness of alluvial deposits in the AOI indicate that the potential for groundwater availability in the alluvial aquifers probably is limited. Additionally, the local population is probably highly dependent on the shallow water resources in these aquifers. Some areas of the AOI, as indicated by generalized geohydrologic maps and lineament analyses, are likely areas for further exploration for groundwater resources. The greatest potential for additional quantities of groundwater is in the weathered and fractured metamorphic rocks and the intrusive rocks and lavas geohydrologic groups. Mapped lineaments, which may indicate faults and associated fractures zones, are likely areas for further exploration for groundwater resources. The contact between the intrusive rocks and lavas and the metamorphic rocks also may be an area that is promising for groundwater exploration. Lineament-density maps indicate that the metamorphic rocks may be more highly fractured than the intrusive rocks and lavas. Additionally, shallow saturated zones could be present in the intrusive rocks and lavas in the upland basins. The quality and sustainability of water resources in the AOI remain to be determined, however. Close monitoring and careful 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.

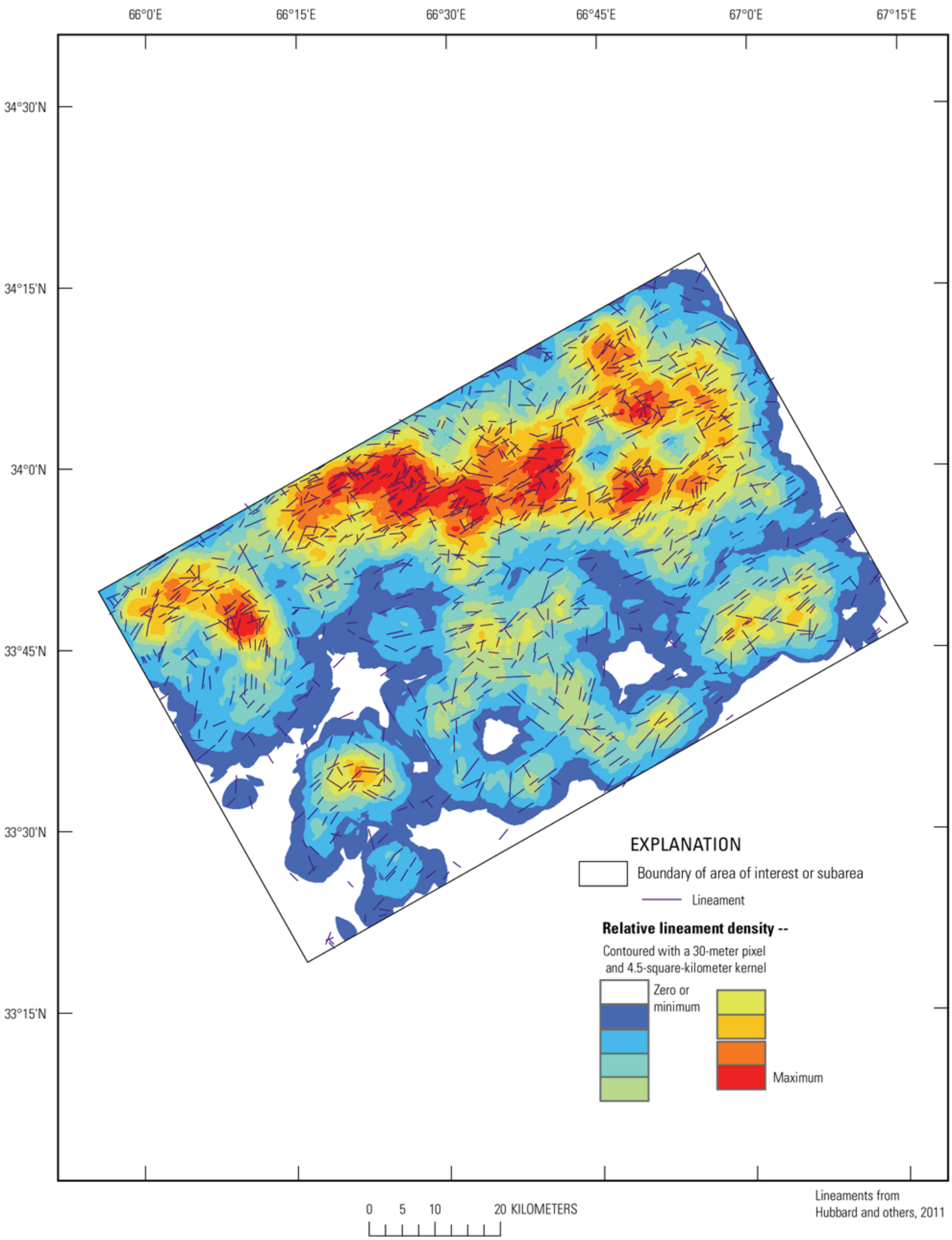
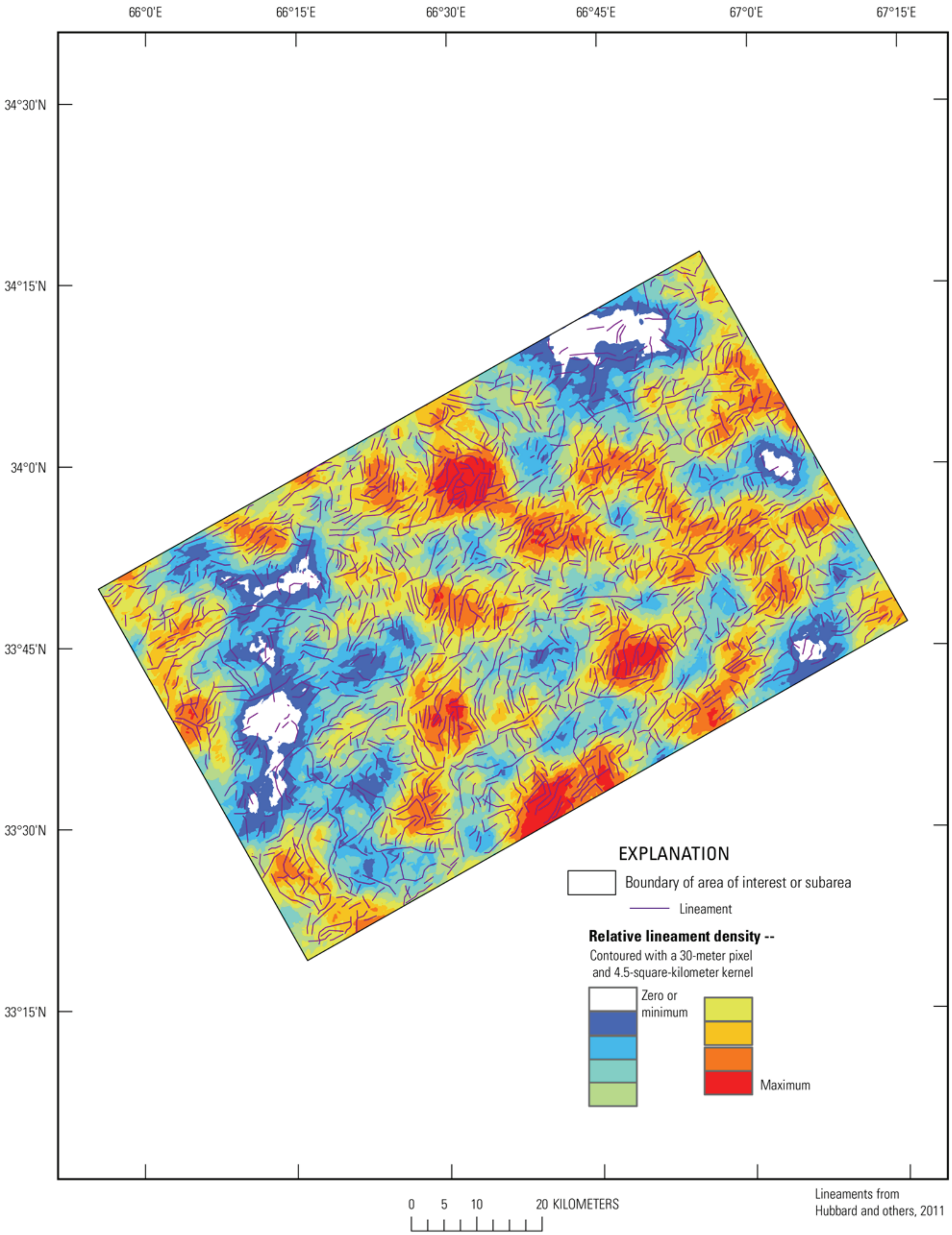


Figure 5C–6. Lineaments and lineament density based on 30-meter digital-elevation-model data and natural-color Landsat imagery in the Daykundi tin and tungsten area of interest in the central highlands region of Afghanistan.

a



66°0'E
66°15'E
66°30'E
66°45'E
67°0'E
67°15'E
34°30'N
34°15'N
34°0'N
33°45'N
33°30'N
33°15'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

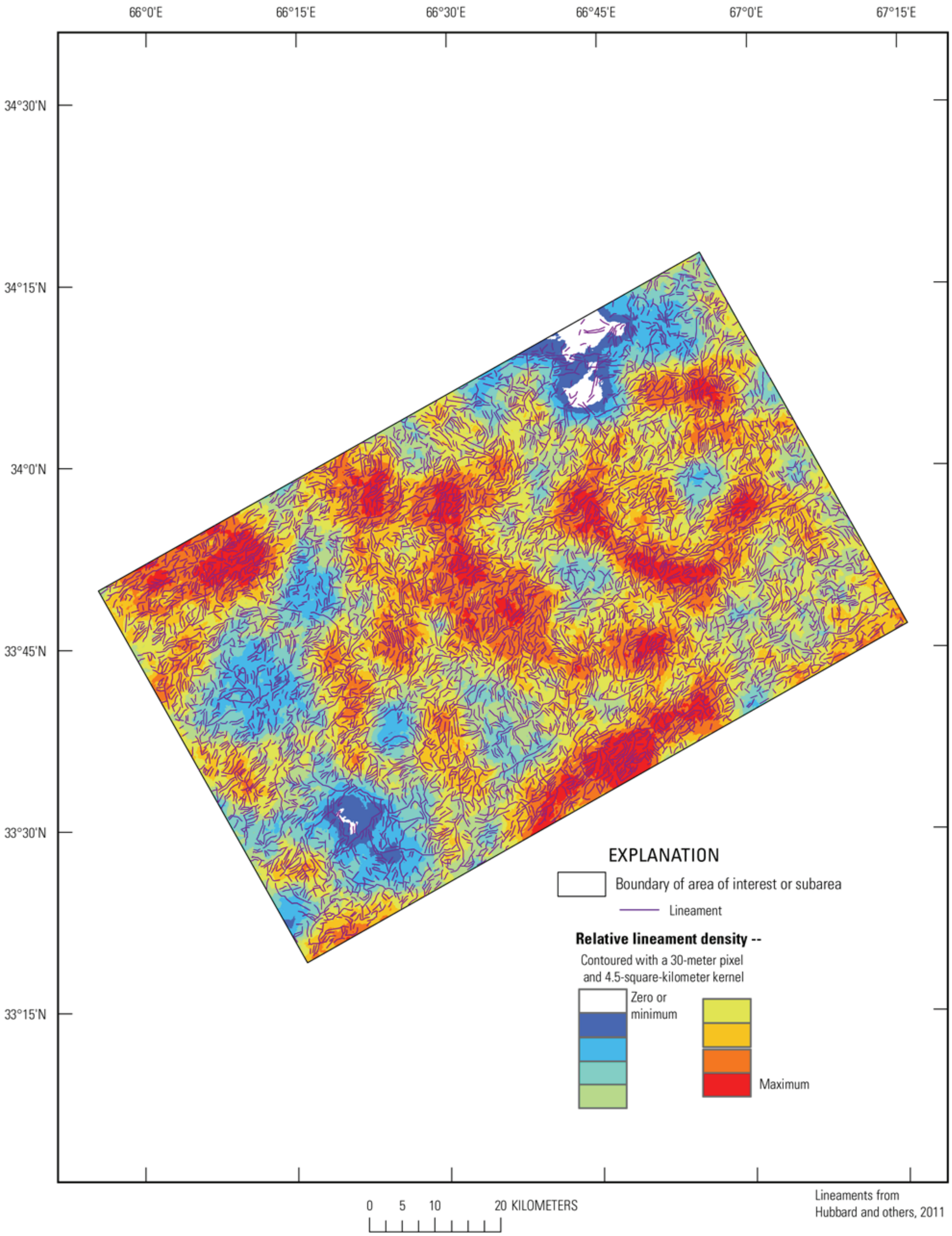


Figure 5C–7. *(a)* Lineaments and lineament density based on 30-meter multispectral Landsat imagery and *(b)* lineaments and lineament density based on 15-meter multispectral Landsat imagery in the Daykundi tin and tungsten area of interest in the central highlands region of Afghanistan.

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