Chapter 19C. Geohydrologic Summary of the Dudkash Industrial Minerals Area of Interest

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19C.1 Introduction

This chapter describes the geohydrology of the Dudkash industrial minerals area of interest (AOI) in Afghanistan identified by Peters and others (2007). The AOI is located in northeast Afghanistan and covers parts of six districts in Baghlan Province (Dahana-i-Ghori, Dushi, Pul-i-Khumri, Nahrin, Baghlan, and Burkha) and parts of Aliabad District in Kunduz Province and Ishkamish District in Takhar Province (fig. 19C–1*a*,*b*). The AOI covers an area of 4,922 km2 (square kilometers).

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.

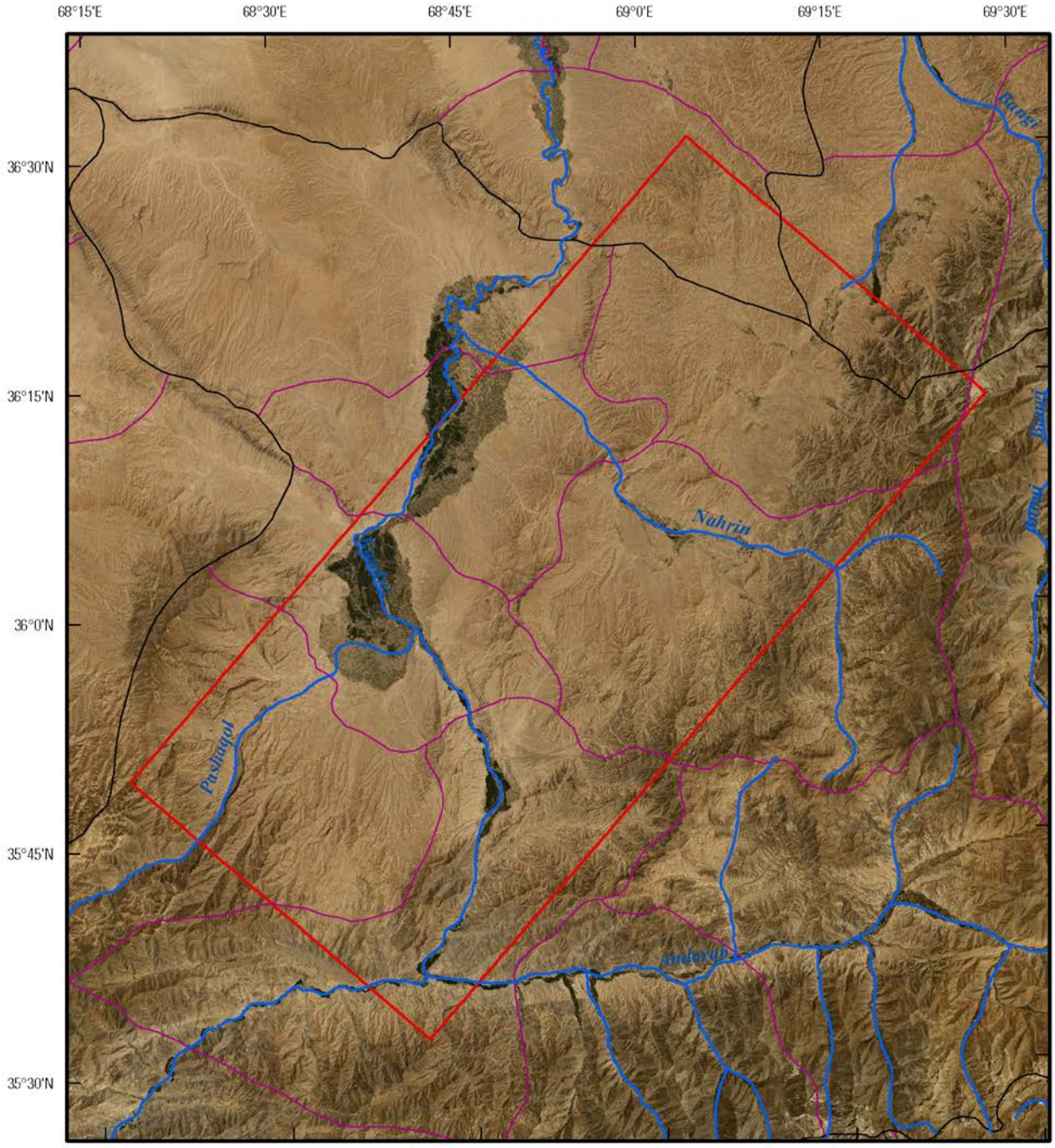
Afghanistan's recent turbulent history has left many of the traditional archival institutions in ruins, and most water-resource and meteorological data-collection activities had stopped by 1980. Recently (2011), non-governmental organizations (NGOs), foreign government agencies, and the Afghan government 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 these data and an understanding of conditions in other areas of Afghanistan.

19C.1.1 Climate and Vegetation

Climate information for the Dudkash industrial minerals 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



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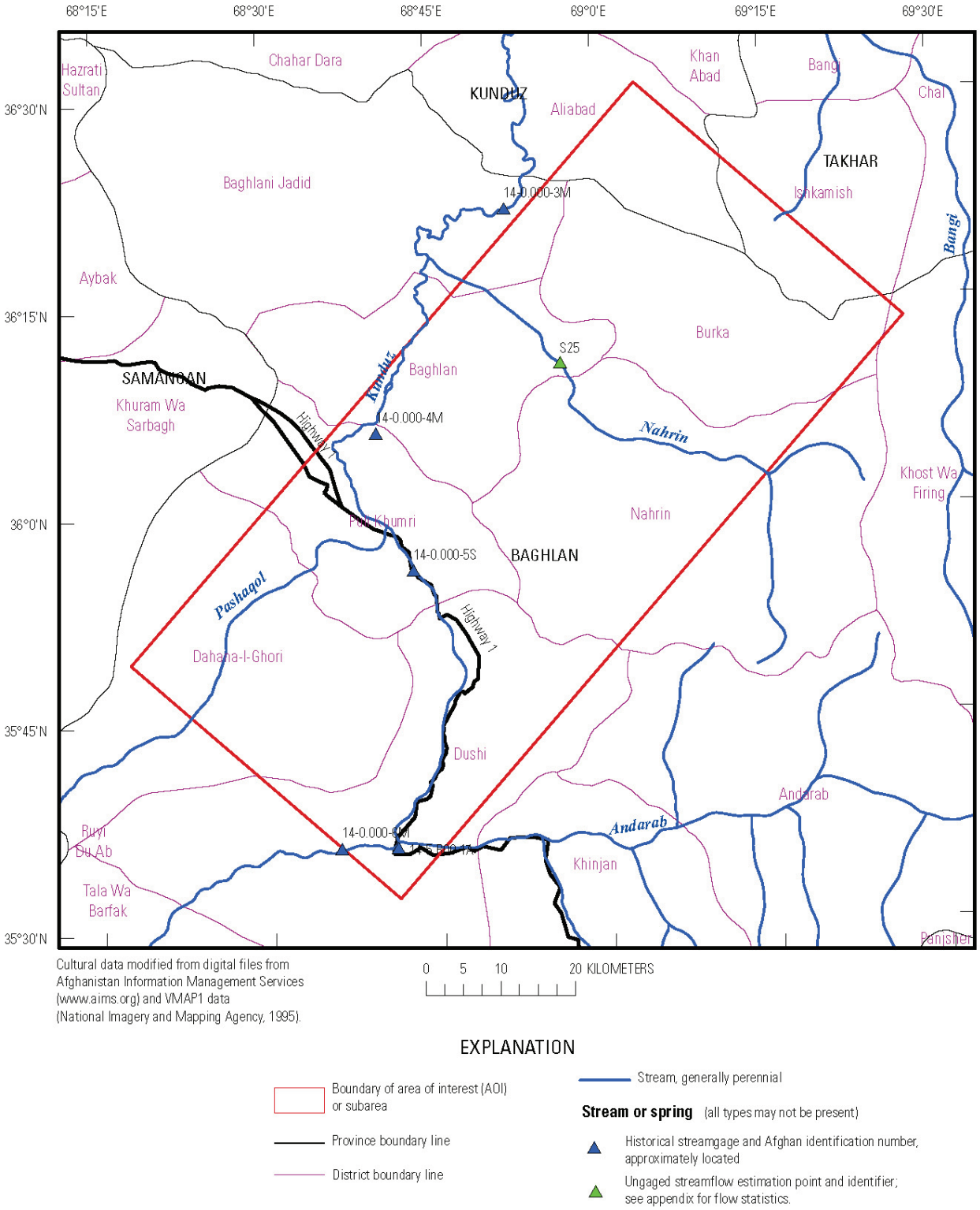


Figure 19C–1. *(a)* Landsat image showing the location of, and *(b)* place names, stream names, and streamgage station numbers in, the Dudkash industrial minerals area of interest in Afghanistan.

The observed total precipitation for the 2009–2010 water year for the AOI, as published in the Seasonal Bulletin (Ministry of Agriculture, Irrigation, and Livestock, 2010, map 2), ranged from 255 to 300 mm (millimeters). The AOI received 41 to 80 mm of precipitation during February 2010, the month

with the greatest precipitation (Ministry of Agriculture, Irrigation, and Livestock, 2010, map 3), and 19 to 47 mm of precipitation in October 2009, the month with the least precipitation (Ministry of Agriculture, Irrigation, and Livestock, 2010, map 4).

The Baghlan Agromet station is located in the AOI, in Baghlan Province approximately 20 km (kilometers) northwest of the center of the AOI. Precipitation data, both for the 2009–2010 water year and long-term average (LTA) precipitation data, are available for this station. Precipitation data for the Baghlan Agromet station (Ministry of Agriculture, Irrigation, and Livestock, 2010) are shown in table 19C–1. The total snowfall recorded at the Baghlan Agromet station during the 2009–2010 water year was 48 cm (centimeters). The 2008–2009 water year total snowfall was 33 cm.

Table 19C–1. Annual, long-term annual average, and long-term average minimum and maximum precipitation and temperature at the Baghlan Agrometeorological (Agromet) station in the Dudkash industrial minerals area of interest, Afghanistan.

[AOI, area of interest; km, kilometers; m, meters; mm, millimeters; °C, degrees Celsius; nr, not reported]

Agromet station	Distance from AOI center (km)	Elevation (m)	Precipitation				Temperature		
			2009–2010 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)
Baghlan	20	630	300	274.7	0 July–August	84.1 May	nr	nr	nr

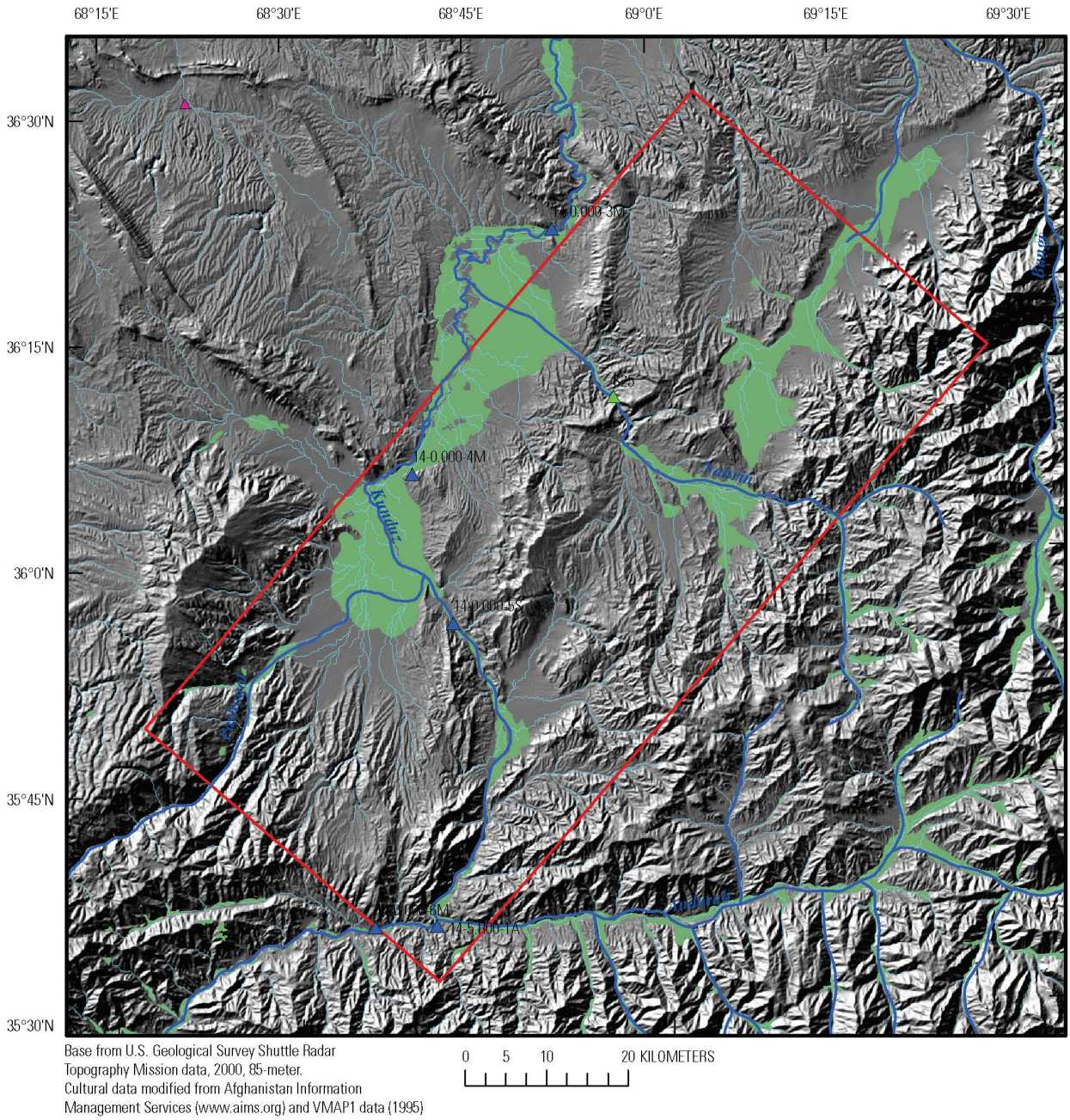
[1]Long-term averages are based on data from 1942 to 1993 and 2005 to 2010 as reported in the Afghanistan Agrometeorological Seasonal Bulletin (Ministry of Agriculture, Irrigation, and Livestock, 2010).

The "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.

A northeast-trending zone of *Pistacia vera*-Woodlands occupies the central part of the AOI. North of this zone along the Kunduz River is azonal riverine vegetation that transitions to Ephemeral Desert away from the river. The southeastern border of the AOI has some *Juniperus*-Woodlands. The vegetation types are controlled by availability of water and elevation. Much of the upland surface of the AOI is bedrock outcrop with thin alluvial cover. Azonal riverine vegetation was probably more prevalent 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. 19C–2).

19C.1.2 Demographics

The population in the Dudkash industrial minerals AOI is concentrated along the perennial streams as mapped by LandScan (Oak Ridge National Laboratory, 2010) (figs. 19C–2 and 19C–3). Population density in the areas along the streams ranges from 101 to 5,000/km^2 and in a few areas exceeds 5,000/km^2. Areas away from these perennial water sources are sparsely populated, with most areas having 1 to 50 inhabitants per square kilometer. The areas with concentrations of population generally consist of small farming settlements surrounded by cultivated fields. Some of the mountainous areas have an estimated population of 0 as indicated by the gray shading in figure 19C–3. The population density shown in figure 19C–3 has a pixel resolution of about 1 km^2 (Oak Ridge National Laboratory, 2010).



Base from U.S. Geological Survey Shuttle Radar Topography Mission data, 2000, 85-meter.
Cultural data modified from Afghanistan Information Management Services (www.aims.org) and VMAP1 data (1995)

EXPLANATION

Boundary of area of interest (AOI) or subarea

Irrigated areas

Stream, generally perennial

Drainage network generated from 85-m digital elevation model (DEM) data, (primarily ephemeral, some perennial)

Stream or spring (all types may not be present)

Historical streamgage and Afghan identification number, approximately located

Ungaged streamflow estimation point and identifier; see appendix for flow statistics.

Spring or watering hole, VMAP1 data (National Imagery and Mapping Agency, 1995)

Spring or watering hole, alkaline, VMAP1 data (National Imagery and Mapping Agency, 1995)

Figure 19C–2. Historical streamgage locations, digitally generated drainage network, and irrigated areas in the Dudkash industrial minerals area of interest in Afghanistan.

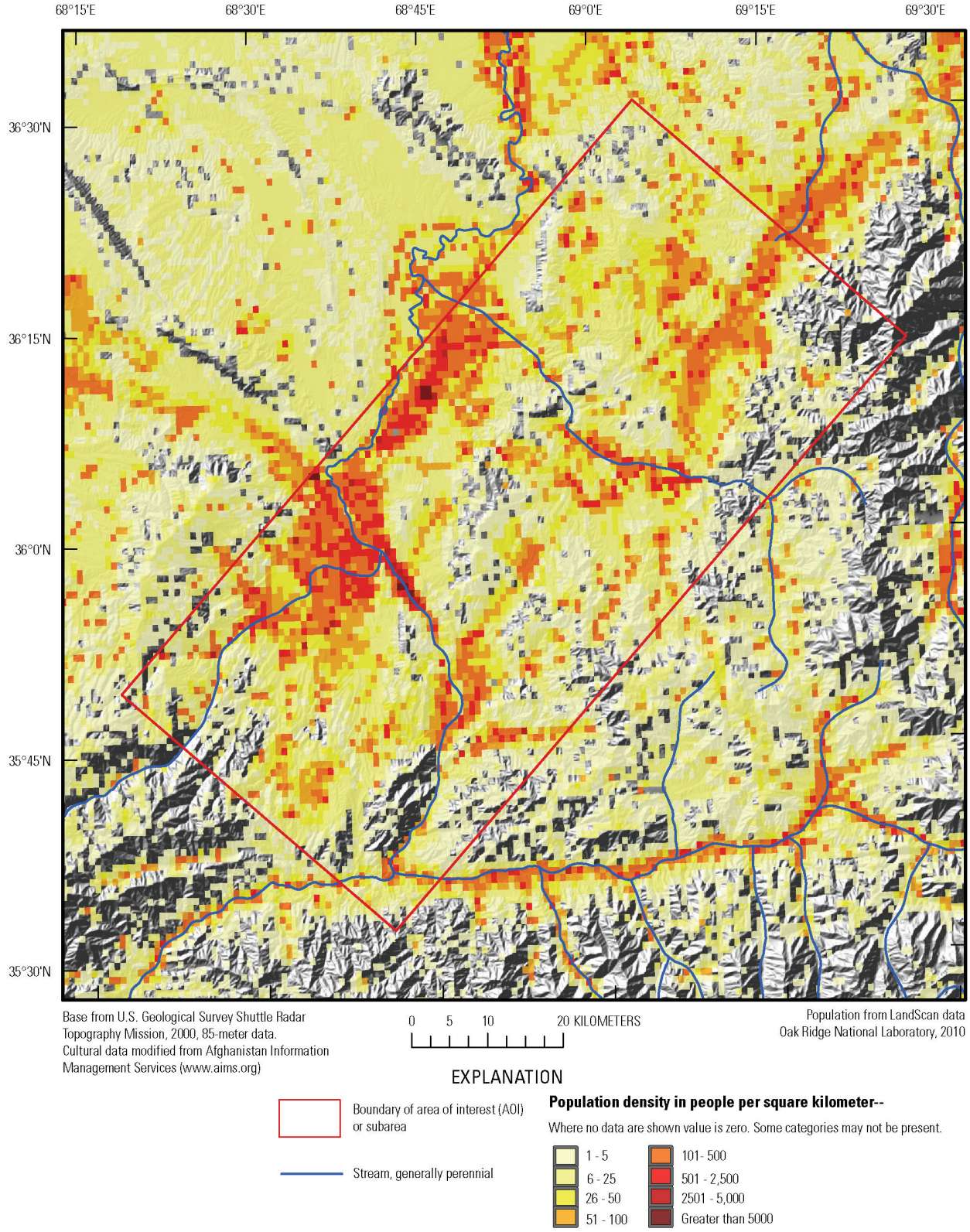


Figure 19C–3. Population density of the Dudkash industrial minerals area of interest in Afghanistan.

19C.1.3 Topography

The topography of the Dudkash industrial minerals AOI is varied, with wide valleys along the Kunduz River where tributary streams enter the river (Davis, 2006) (figs. 19C–1*a*, 19C–2, and 19C–4). The low areas range in elevation from 550 to 1,000 m (meters) above sea level (asl). A mountainous

ridge whose elevation exceeds 1,500 m asl in places runs northeast to southwest along the southeast to northeast corners of the AOI. The AOI becomes more mountainous along the southeast border, where many peaks are higher than 2,000 m asl and a few in the northeastern corner are higher than 3,000 m asl.

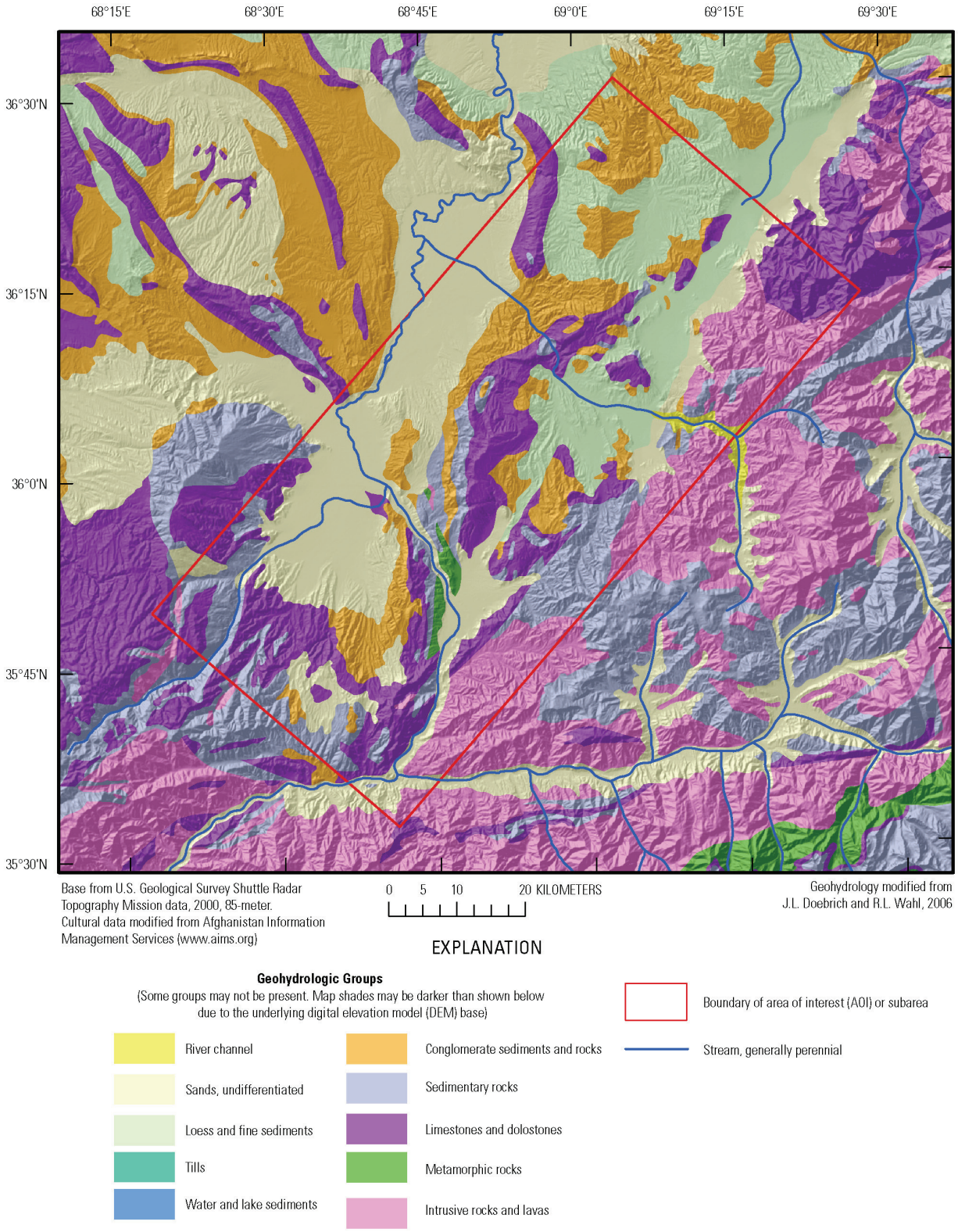


Figure 19C–4. Topography and generalized geohydrology of the Dudkash industrial minerals area of interest in Afghanistan.

19C.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 Dudkash industrial minerals AOI is in the North Afghanistan Artesian 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 19C–4 with the underlying topography to allow examination of the geohydrology in the context of relief. Figure 19C–5*a*,*b* shows 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 figure 19C–5*a*,*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 "river channel; sands, undifferentiated; conglomerate sediments and rocks; loess and fine sediments; limestones and dolostones; sedimentary rocks; metamorphic rocks; and intrusive rocks and lavas" (figs. 19C–4 and 19C–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 maps that cover this AOI are provided by Lindsay and others (2005) and Fridrich and others (2005).

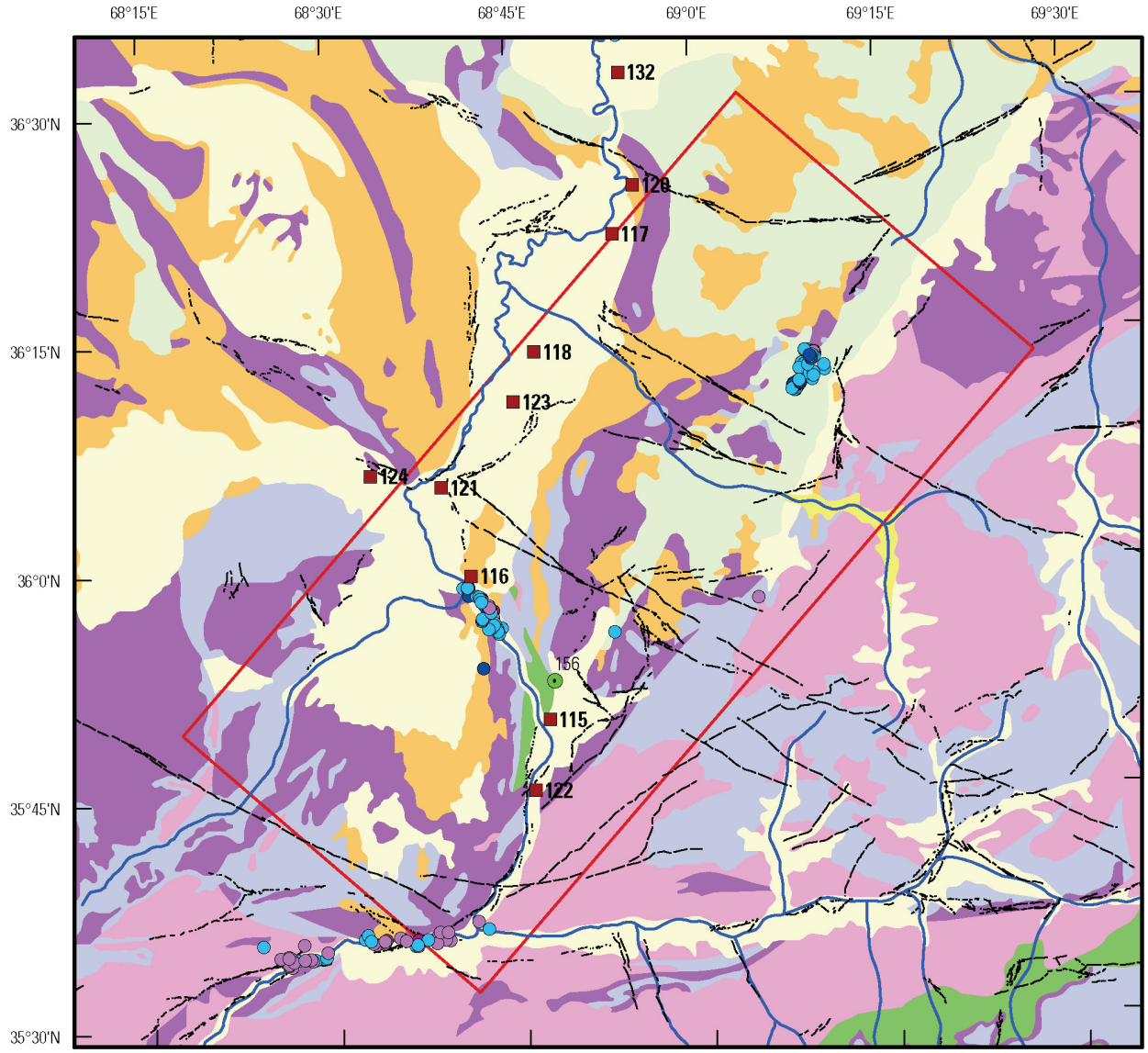
The river-channel geohydrologic group is mapped only where the Nahrin River flows across the outcrops of the intrusive rocks and lavas; however, coarse-grained river-channel sediments may be present in other, unmapped areas of the AOI. No information about the thickness of the river-channel deposits is available, but the area occupied by this geohydrologic group is limited. No wells are mapped in this unit, but it may be a significant source of groundwater adjacent to perennial streams. Many wells are constructed in the sands, undifferentiated geohydrologic group. The outcrop area is fairly large and covers areas of the Kunduz and Pashaqol River valleys. Information on the thickness of this unit is limited. The deepest reported well is 46 m deep (Danish Committee for Aid to Afghan Refugees, 2011). This unit may be a potential source of water to support mining activities, especially during periods of recharge or high flow in the perennial streams.

Outcrops of the conglomerate sediments and rocks geohydrologic group are generally restricted to the tops and flanks of the ridges and hills in the AOI. No information is available about the thickness of this unit in the AOI, but it appears to overlie the sedimentary rocks and the limestones and dolostones geohydrologic groups. No wells are constructed in this unit, and its characteristics in the AOI are not known. Limited outcrops of the sedimentary rocks and the limestones and dolostones are present in the AOI and, unless these units are more extensive than indicated and underlie the conglomerate sediments and rocks and the outcrops of loess and fine sediments, the potential for large quantities of groundwater to be present in these units is poor. The intrusive rocks and lavas geohydrologic group is present along the southeastern border of the AOI and extends outside the AOI to the southeast. This unit exhibits mapped faults (fig. 19C–5*a*) and, if fracture zones are associated with the faults, these zones could contain considerable amounts of groundwater.

19C.2.1 Surface Water

A network of major, mostly perennial streams, modified from AIMS (Afghanistan Information Management Services, 1997) and VMAP1 (National Imagery and Mapping Agency, 1995), is shown in figure 19C–2. A network representing likely ephemeral streams, generated with a digital elevation model (DEM), is shown in figure 19C–2. Names of major streams and identification numbers for any streamgages and ungaged streamflow estimation sites in the Dudkash industrial minerals AOI are shown in figure 19C–1*b*.

a


68°15'E
68°30'E
68°45'E
69°0'E
69°15'E
69°30'E
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36°15'N
36°0'N
35°45'N
35°30'N
132
120
117
118
123
124
121
116
156
115
122
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

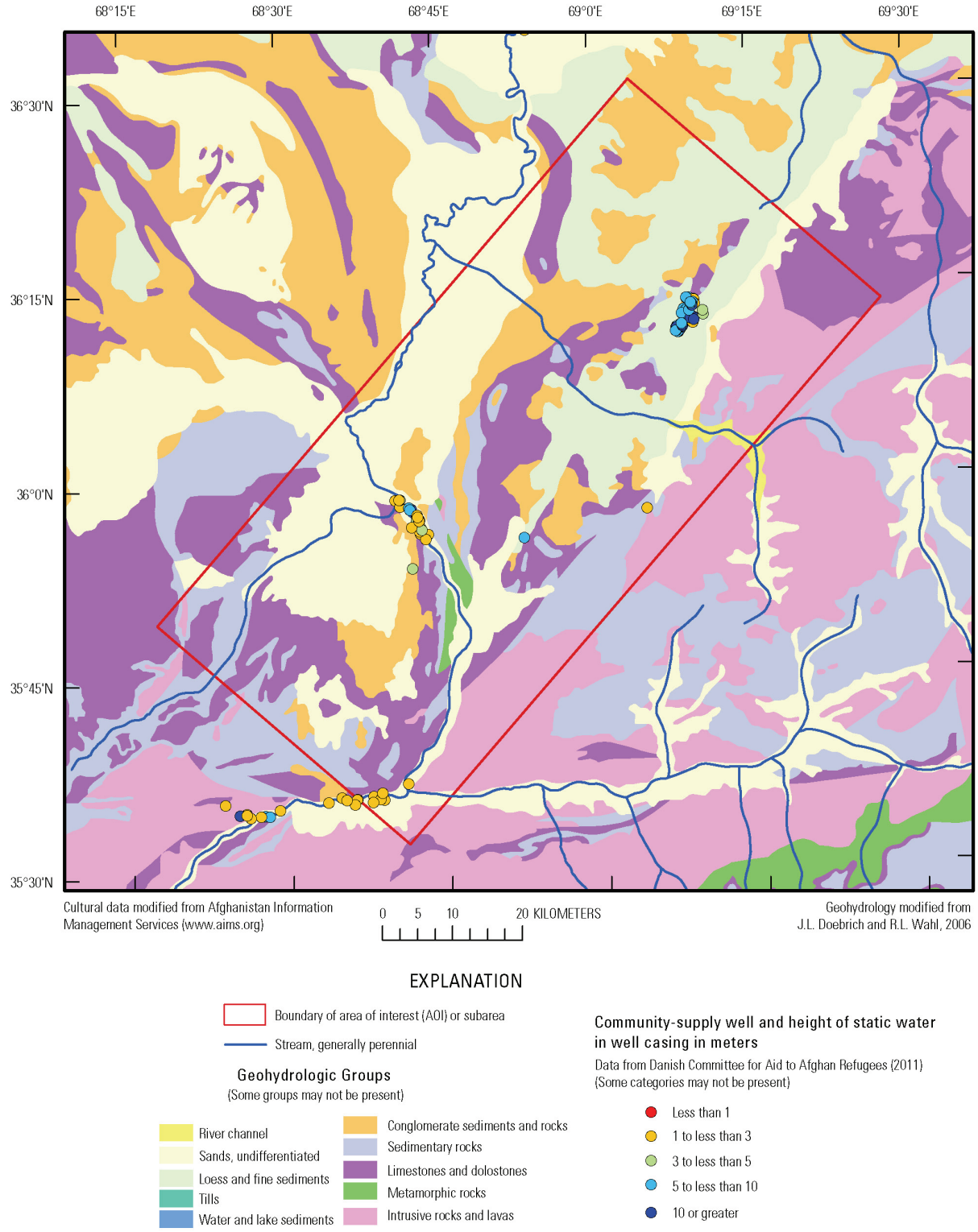


Figure 19C–5. *(a)* Generalized geohydrology, mapped faults, well locations, and depth to water, and *(b)* geohydrology and height of static water in well casings in community supply wells in the Dudkash industrial minerals area of interest in Afghanistan.

Four streamgage stations are present within the AOI (fig. 19C–1*b*). Three stations are on the Kunduz River and the fourth is on a tributary stream, the Andarab River (figs. 19C–1*b* and 19C–2). The

Andarab River at Doshi streamgage station (Afghanistan identification number 14–5.R00–1A) is at an elevation of 860 m asl, has a drainage area of 3,705 km^2, and has a period of record that extends from 1 October, 1964, to 30 September, 1978 (Olson and Williams-Sether, 2010). The mean annual streamflow per unit area for this station is 0.0092 $m^3/s/km^2$ (cubic meters per second per square kilometer). The seasonal timing of maximum and minimum monthly streamflow is high flows in the late spring and early summer and low flows in winter and early spring. A statistical summary of monthly and annual mean streamflows for this station is presented in table 19C–2. Statistical summaries of streamflow data for all available historical gages in Afghanistan can be accessed at *http://afghanistan.cr.usgs.gov/water.php*.

The Kunduz River at Pul-i-Konda Sang streamgage station (Afghanistan identification number 14–0.000–6M) is at an elevation of 899 m asl, has a drainage area of 12,610 km^2, and has a period of record that extends from 1 October, 1967, to 30 September, 1978 (Olson and Williams-Sether, 2010). The mean annual streamflow per unit area for this station is 0.0025 $m^3/s/km^2$. The seasonal timing of maximum and minimum monthly streamflow is high flows in the late spring and early summer and low flows in winter and early spring. A statistical summary of monthly and annual mean streamflows for this station is presented in table 19C–3.

The Kunduz River at Pul-i-Khumri streamgage station (Afghanistan identification number 14–0.000–5S) is at an elevation of 639 m asl, has a drainage area of 17,405 km^2, and has a period of record that differs for monthly mean and daily mean values, as follows: monthly mean values 1 April, 1950, to 30 September, 1959, and daily mean values 1 October, 1959, to 26 March, 1968 (Olson and Williams-Sether, 2010). The mean annual streamflow per unit area for this station is 0.0037 $m^3/s/km^2$. The seasonal timing of maximum and minimum monthly streamflow is high flows in the late spring and early summer and low flows in winter and early spring. A statistical summary of monthly and annual mean streamflows for this station is presented in table 19C–4.

The Kunduz River at Baghlan streamgage station (Afghanistan identification number 14–0.000–4M) is at an elevation of 562 m asl, has a drainage area of 19,740 km^2, and has a period of record that extends from 7 April, 1968, to 30 September, 1978 (Olson and Williams-Sether, 2010). The mean annual streamflow per unit area for this station is 0.0028 $m^3/s/km^2$. The seasonal timing of maximum and minimum monthly streamflow is high flows in the late spring and early summer and low flows in winter and early spring. A statistical summary of monthly and annual mean streamflows for this station is presented in table 19C–5.

Streamflow statistics were estimated for selected ungaged streams that may be prominent in the AOI or its subareas to provide some probable estimates of flow for these locations. Streamflow statistics, presented in appendix 2, were calculated for point S25 (figs. 19C–1*b* and 19C–2) on the Nahrin River in the AOI using a drainage-area-ratio method (Olson and Mack, 2011) based on historical flows at the Bangi River at Pul-i-Bangi streamgage station (Afghan identification number 14–1.1L0–1A) (Olson and Williams-Sether, 2010). The Bangi River at Pul-i-Bangi streamgage station was selected as the most representative historical gage for use with this method because of its similar drainage-area size and its proximity to the estimation points. The estimated mean annual streamflow for point S25 (app. 2), with a drainage area of 1,497.7 km^2, is about 7.86 m^3/s (cubic meters per second). The seasonal timing of maximum and minimum monthly streamflow, with high flows in the late spring and early summer and low flows in winter and early spring (app. 2), probably is similar to that at the Andarab River at Doshi streamgage station.

Table 19C–2. Statistical summary of monthly and annual mean streamflows for the Andarab River at Doshi streamgage station (Olson and Williams-Sether, 2010).

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

14–5.R00–1A Andarab River at Doshi

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	22.5	1969	11.7	1972	16.5	3.31	0.20	4.05
November	18.6	1978	10.3	1975	14.0	2.51	0.18	3.44
December	15.0	1973	9.40	1972	12.2	1.98	0.16	3.00
January	14.0	1973	8.49	1975	11.2	1.75	0.16	2.75
February	13.6	1973	8.13	1975	10.9	1.70	0.16	2.66
March	19.3	1966	8.12	1975	12.2	3.23	0.26	3.00
April	61.2	1973	10.1	1972	24.1	12.9	0.54	5.91
May	111	1973	37.9	1972	67.2	21.0	0.31	16.5
June	224	1968	57.7	1971	117	48.1	0.41	28.7
July	169	1968	28.3	1971	73.6	39.1	0.53	18.1
August	58.0	1968	17.8	1971	31.1	12.6	0.41	7.62
September	27.5	1969	10.9	1974	17.4	4.58	0.26	4.28
Annual	**56.6**	**1968**	**22.6**	**1974**	**34.0**	**9.62**	**0.28**	**100**

Table 19C–3. Statistical summary of monthly and annual mean streamflows for the Kunduz River at Pul-i-Konda Sang streamgage station (Olson and Williams-Sether, 2010).

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

14–0.000–6M Kunduz River at Pul-i-Konda Sang

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	29.6	1970	14.2	1978	22.2	4.64	0.21	5.78
November	28.6	1970	14.5	1978	21.3	4.20	0.20	5.56
December	25.9	1970	11.5	1978	19.4	4.00	0.21	5.06
January	23.2	1970	13.8	1978	18.1	2.94	0.16	4.73
February	23.0	1970	14.0	1976	17.6	2.87	0.16	4.58
March	22.8	1974	14.8	1978	18.1	2.71	0.15	4.71
April	29.3	1968	16.7	1971	21.3	4.52	0.21	5.55
May	64.3	1971	35.0	1972	51.4	11.7	0.23	13.4
June	166	1968	41.8	1971	92.6	33.4	0.36	24.2
July	98.9	1968	17.8	1971	52.8	23.6	0.45	13.8
August	42.9	1968	16.2	1977	26.6	8.56	0.32	6.92
September	33.3	1968	15.1	1977	22.2	6.06	0.27	5.78
Annual	**46.6**	**1968**	**26.0**	**1978**	**32.0**	**6.84**	**0.21**	**100**

Table 19C–4. Statistical summary of monthly and annual mean streamflows for the Kunduz River at Pul-i-Khumri streamgage station (Olson and Williams-Sether, 2010).

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

14–0.000–5S Kunduz River at Pul-i-Khumri

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	46.5	1968	26.6	1962	34.6	6.70	0.19	4.50
November	43.6	1968	25.3	1965	31.9	6.23	0.20	4.15
December	39.9	1968	22.6	1964	29.4	6.17	0.21	3.83
January	36.6	1966	20.0	1964	27.5	6.05	0.22	3.58
February	35.5	1966	20.6	1964	26.7	4.70	0.18	3.48
March	34.7	1966	20.3	1964	26.0	4.27	0.16	3.38
April	53.9	1966	26.5	1961	36.9	9.55	0.26	4.80
May	139	1966	67.5	1964	95.1	21.9	0.23	12.4
June	261	1963	153	1964	224	36.9	0.16	29.2
July	229	1960	97.2	1966	143	53.7	0.38	18.6
August	81.8	1960	40.2	1963	56.7	15.3	0.27	7.38
September	44.2	1966	28.8	1963	36.5	6.37	0.17	4.74
Annual	**74.3**	**1960**	**49.4**	**1964**	**63.6**	**9.31**	**0.15**	**100**

Table 19C–5. Statistical summary of monthly and annual mean streamflows for the Kunduz River at the Baghlan streamgage station (Olson and Williams-Sether, 2010).

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

14–0.000–4M Kunduz River at Baghlan

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	43.8	1969	21.0	1972	32.5	7.15	0.22	4.60
November	48.5	1970	27.0	1972	35.2	6.73	0.19	4.99
December	45.1	1969	25.9	1972	34.8	5.31	0.15	4.94
January	38.4	1970	26.0	1972	32.0	3.49	0.11	4.54
February	35.4	1970	24.8	1978	29.8	3.40	0.11	4.23
March	37.7	1970	26.4	1972	32.3	3.77	0.12	4.58
April	82.2	1973	22.0	1972	43.4	17.4	0.40	6.15
May	169	1973	58.9	1972	111	35.0	0.32	15.7
June	375	1968	79.8	1971	184	85.6	0.46	26.1
July	248	1968	25.1	1971	102	64.7	0.64	14.4
August	97.1	1968	15.0	1971	39.7	25.4	0.64	5.63
September	48.9	1968	15.8	1971	29.1	10.6	0.37	4.13
Annual	**82.3**	**1969**	**41.0**	**1971**	**55.0**	**12.9**	**0.23**	**100**

19C.2.2 Groundwater

Approximately 275 shallow community groundwater-supply wells have been installed in the Dudkash industrial minerals 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. 19C–5*a*,*b*). About 95 percent of the supply wells are less than 30 m deep and all are less than 46 m deep. The depth to water in the supply wells in the AOI is generally less than 15 m (fig. 19C–5*a*). The median depth to water is 7 m.

Available well-construction information is limited; however, most wells are reported to be dug wells with concrete-ring casing. Some wells may be "tube" wells, driven wells with polyvinyl chloride (PVC) 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 19C–5*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 5 m. In most of the AOI, particularly in western areas, less than 3 m of static water is present in most wells. Shallow wells with little static water 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 wells in a valley in the eastern area of the AOI are deeper than elsewhere in the AOI, with more static water (fig. 19C–5*b*), and are less likely to be prone to seasonal drying.

The six groundwater-monitoring wells (GWMs 115, 116, 118, 121, 122, and 123) in the AOI, and the one (GWM 124) just outside the AOI, (fig. 19C–5*a*), are monitored by DACAAR for groundwater levels and specific conductance. Hydrographs of water levels in GWMs in and near the AOI, provided by DACAAR, are shown in appendix 3. The hydrographs show the date in week number and year, groundwater specific conductance in microsiemens per centimeter at 25° Celsius (µS/cm), and depth to water in meters below ground surface (bgs). The GWMs likely are generally constructed in alluvial material. The hydrographs for GWMs 115, 116, and 122, near the Kunduz River, show a 1- to 3-m seasonal fluctuation in water levels; water-level trends in the other wells are either not apparent or less clear. Groundwater specific conductance in the GWMs in the AOI ranges from about 500 to 3,000 µS/cm.

19C.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 Dudkash industrial minerals AOI (B.E. Hubbard, T.J. Mack, and A.L. Thompson, unpub. data, 2011) were conducted using DEM and natural-color satellite imagery (fig. 19C–6) and Advanced Spaceborne Thermal Emission and Reflection Radiometry (ASTER) satellite imagery (fig. 19C–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 19C–6 were delineated visually, whereas those in figure 19C–7 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. Many lineaments in the AOI have a northeast trend and likely reflect the regional structure. A subset of the DEM and natural-color Landsat lineaments has a northwest trend that may indicate a conjugate fracture pattern in bedrock in the AOI. Areas where lineament density is high (figs. 19C–6 and 19C–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.

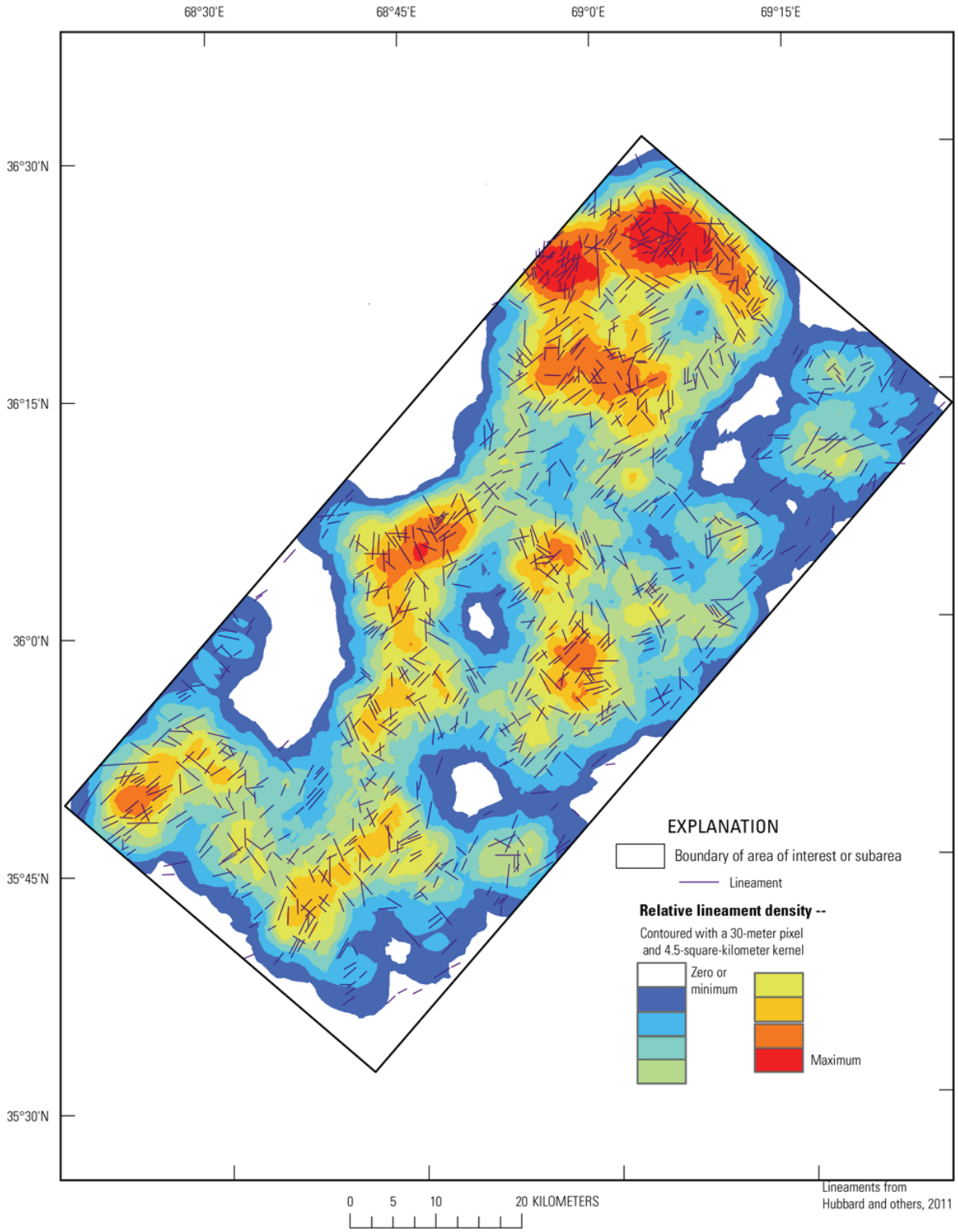
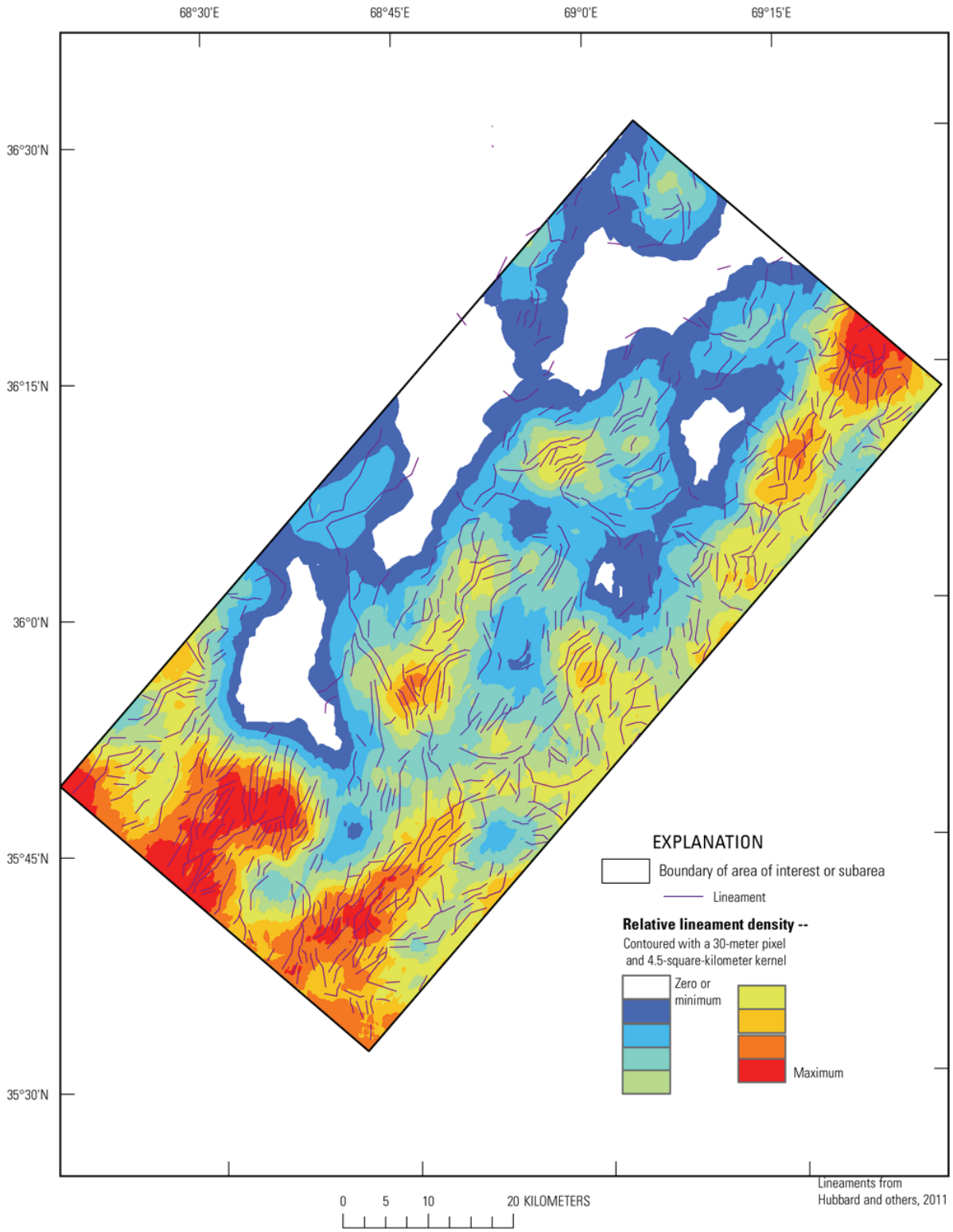


Figure 19C–6. Lineaments and lineament density based on 30-meter digital-elevation-model data and natural-color Landsat imagery in the Dudkash industrial minerals area of interest in Afghanistan.

a


68°30'E
68°45'E
69°0'E
69°15'E
36°30'N
36°15'N
36°0'N
35°45'N
35°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

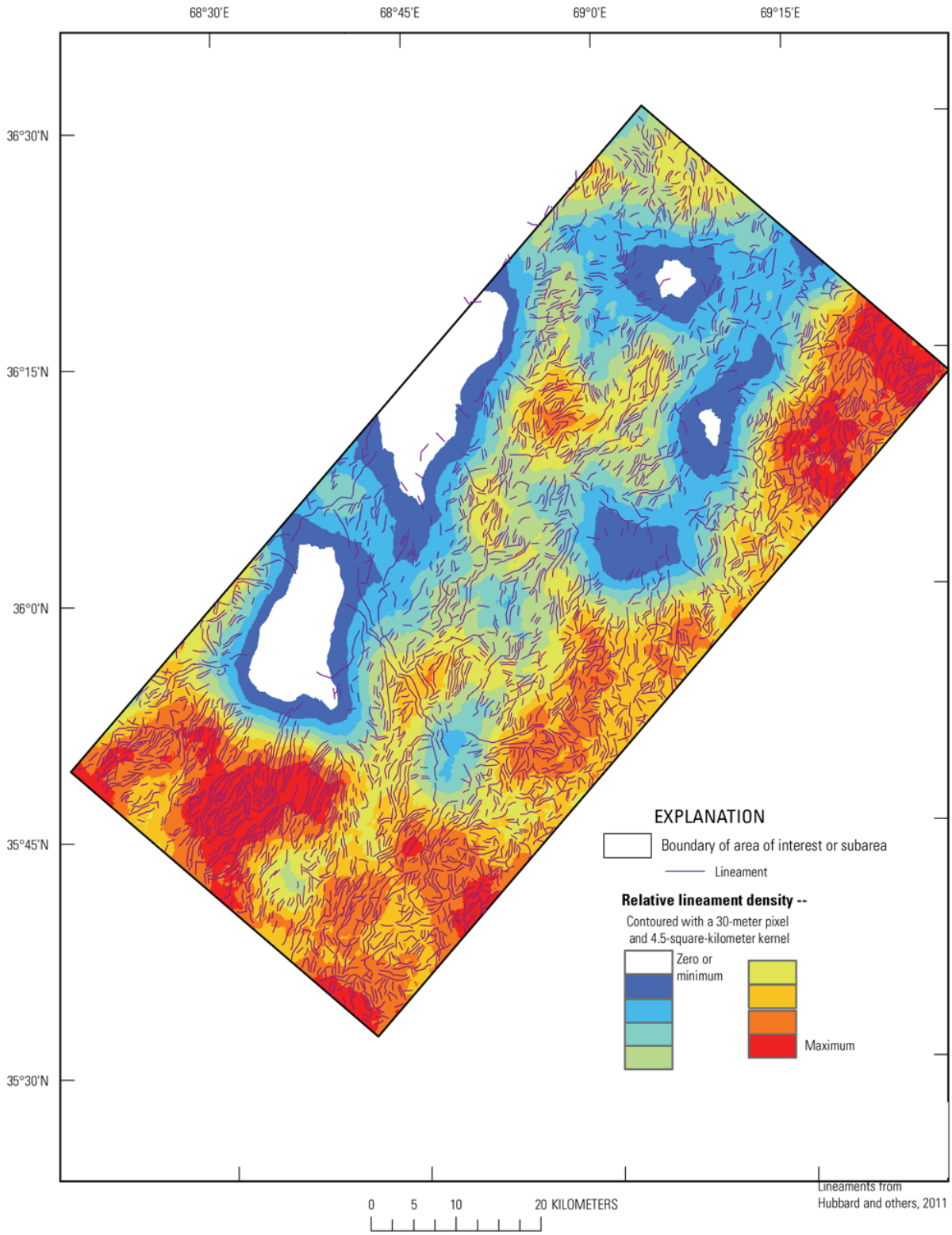


Figure 19C–7. *(a)* Lineaments and lineament density based on 30-meter multispectral Landsat imagery and *(b)* lineaments and lineament density based on 15-meter multispectral Landsat imagery in the Dudkash industrial minerals area of interest in Afghanistan.

19C.3 Summary and Conclusions

Water resources in the Dudkash industrial minerals area of interest (AOI) are likely to be more available for mining and other uses than in other areas of Afghanistan. Relatively high precipitation and streamflow rates indicate that there is likely to be considerable recharge and, therefore, groundwater resources in unconsolidated and consolidated aquifers in the AOI. Water resources in the AOI and surrounding area consist of surface water, particularly the Kunduz River and tributaries, and, potentially, groundwater resources in unconsolidated and consolidated aquifers. Shallow alluvial aquifers in the valley bottoms of the AOI are likely to be a highly utilized groundwater resource. Most streams are also likely to be highly utilized by the local population and represent the primary source of water for irrigation. The diversion of water from the rivers, or new groundwater withdrawals adjacent to the river, to support mining activities would need to be closely monitored to ensure that the quantity and quality of the water resource remains sufficient to supply water for irrigation and to provide recharge to the aquifers that supply groundwater to the shallow wells for domestic consumption.

No information about deep groundwater in the AOI or adjacent areas is available; however, some areas of the AOI, as indicated by generalized geohydrologic maps and lineament analyses, are likely areas for further exploration for groundwater resources. The quality and sustainability of water resources in the AOI remain to be determined. 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 well hydraulic testing are needed to adequately characterize the extent and availability of groundwater resources in the AOI.

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