Chapter 11C. Geohydrologic Summary of the Nalbandon Lead and Zinc Area of Interest

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11C.1 Introduction

This chapter describes the geohydrology of the Nalbandon lead and zinc area of interest (AOI) in Afghanistan identified by Peters and others (2007) (fig. 11C–1*a*,*b*). The Nalbandon lead and zinc AOI is located in west-central Afghanistan in the Chishti Sarif, Tulak, and Sharak Districts in Herat and Ghor Provinces (fig. 11C–1*a*,*b*). The Nalbandon District subarea and the Gharghananaw-Gawmazar subarea occupy 554 km^2 (square kilometers) and 385 km^2, respectively, of the 6,151-km^2 area of the AOI.

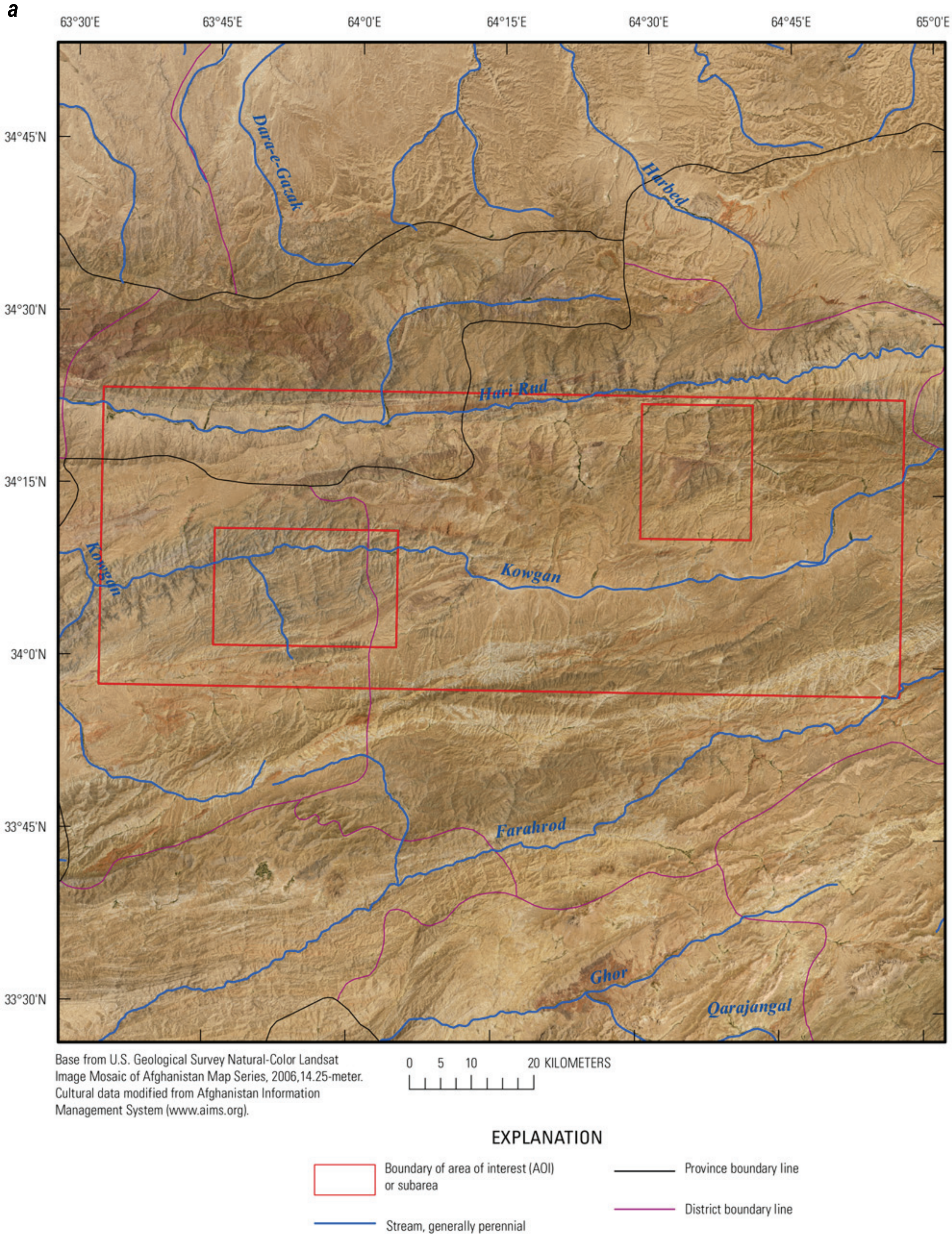
Water is needed not only to process mineral resources in Afghanistan, but also to supply existing communities and the associated community growth that may accompany a developing mining economy. Information on the climate, vegetation, topography, and demographics of the AOI is summarized to provide information 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, nongovernmental 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.

11C.1.1 Climate and Vegetation

Climate information for the Nalbandon lead and zinc 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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Farahrod
Ghor
Qarajangal
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

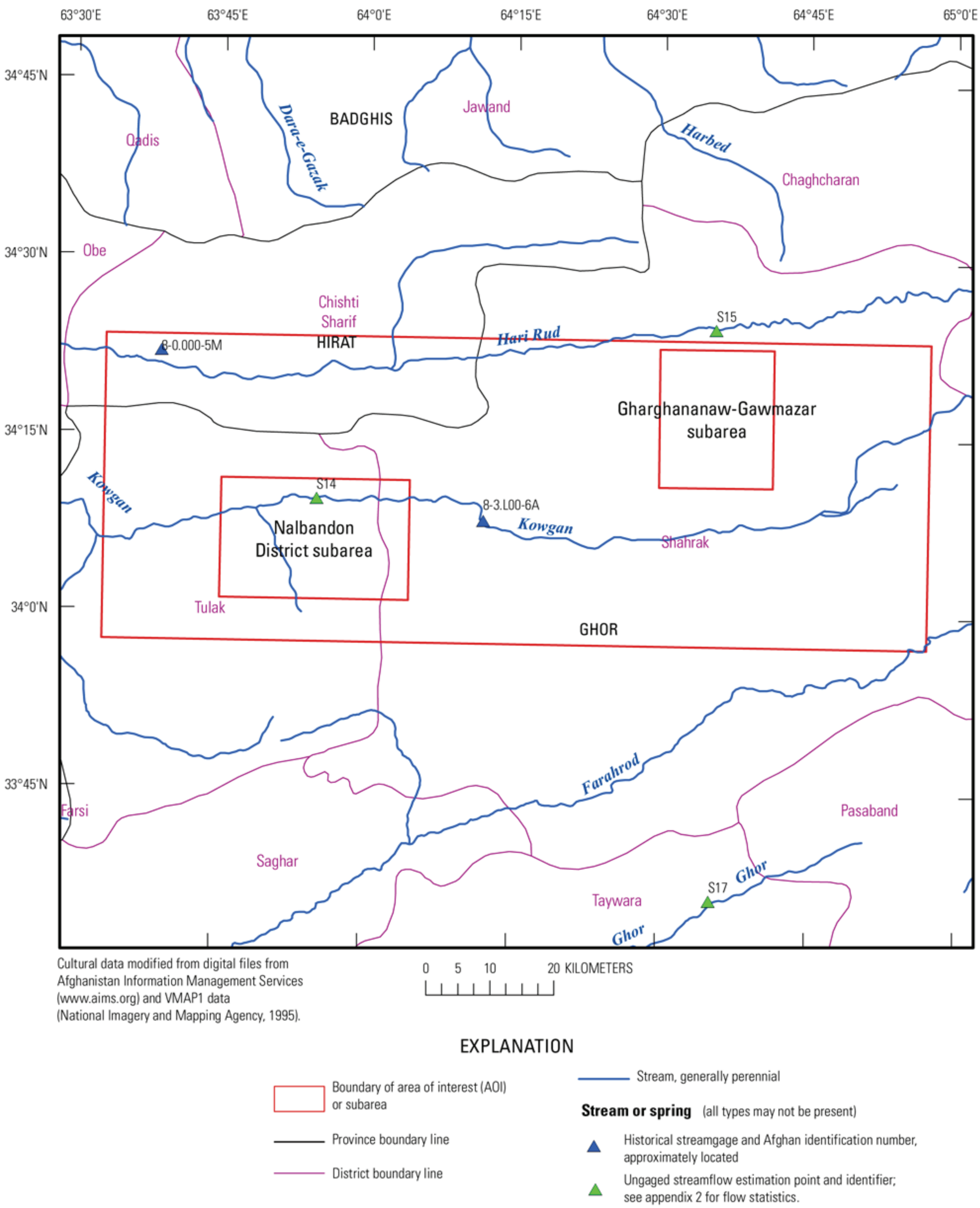


Figure 11C–1. (*a*) Landsat image showing the location of, and (*b*) place names, stream names, and streamgage station numbers in, the Nalbandon lead and zinc area of interest in Afghanistan.

11C.1.2 Demographics

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 201 to 255 mm (millimeters). The AOI received 41 to 80 mm of precipitation in the month of February 2010, the month with the greatest precipitation, with the amount decreasing from west to east across the AOI (Ministry of Agriculture, Irrigation, and Livestock, 2010, map 3). The AOI received 7 to 33 mm of precipitation in October 2009, the month with the least precipitation, with the amount increasing from west to east across the AOI (Ministry of Agriculture, Irrigation, and Livestock, 2010, map 4).

The Chakhcharan Agromet station is located in Ghor Province approximately 100 km (kilometers) northeast of the center of the AOI. This station is the closest Agromet station to the AOI for which 2009–2010 water year and long-term average (LTA) precipitation data are available. Table 11C-1 presents the precipitation data for the Chakhcharan Agromet station (Ministry of Agriculture, Irrigation, and Livestock, 2010).

Table 11C–1. Annual, long-term annual average, and long-term average minimum and maximum precipitation at the Chakhcharan Agrometeorological (Agromet) station 100 kilometers northeast of the Nalbandon lead and zinc area of interest in 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)
Chakhcharan	100	2,250	199.9	186.7	0 August–September	42.5 April	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 Chakhcharan Agromet station had a total of 11 reported snow days during the 2009–2010 water year, distributed as follows: November 2009, 2 days; December 2009, 3 days; January 2010, 2 days; and February 2010, 4 days. The snowfall reported at this station for the 2009–2010 water year was 58.6 cm (centimeters). The snow-depth map for January 17, 2010 (Ministry of Agriculture, Irrigation and Livestock, 2010, map 6), indicates a snow depth of 2 to 10 cm in the AOI.

The "Potential Natural Vegetation" (PNV) 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 locations of the vegetation types are controlled by water availability and elevation. There are three PNV types within the AOI as classified by Breckle (2007, p 161). The *Pistacia atlantica*-Woodlands would occur up to about 2,000 m (meters) above sea level (asl). The *Amygdalus*-Woodlands PNV occupies the areas between about 2,000 and 3,000 m asl. The thorny cushions, subalpine and alpine semi-deserts, and meadows vegetation is above 3,000 m asl. 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 some of the wider stream valleys, but the amount of irrigation and farming in the AOI is limited (fig. 11C–2).

The Nalbandon lead and zinc AOI is sparsely populated, with few areas having more than 5 inhabitants per square kilometer as mapped by LandScan (Oak Ridge National Laboratory, 2010) (fig. 11C–3). The higher elevations within the AOI are uninhabited, as indicated by the gray-shaded areas in figure 11C-3. Some areas along the Hari Rud and Kowgan Rivers appear to have population densities as high as 51 to 100 inhabitants per square kilometer. These areas coincide with irrigated areas in figure 11C–2 and are probably small farming settlements. The population density shown in figure 11C–3 has a pixel resolution of about 1 km^2 (Oak Ridge National Laboratory, 2010).

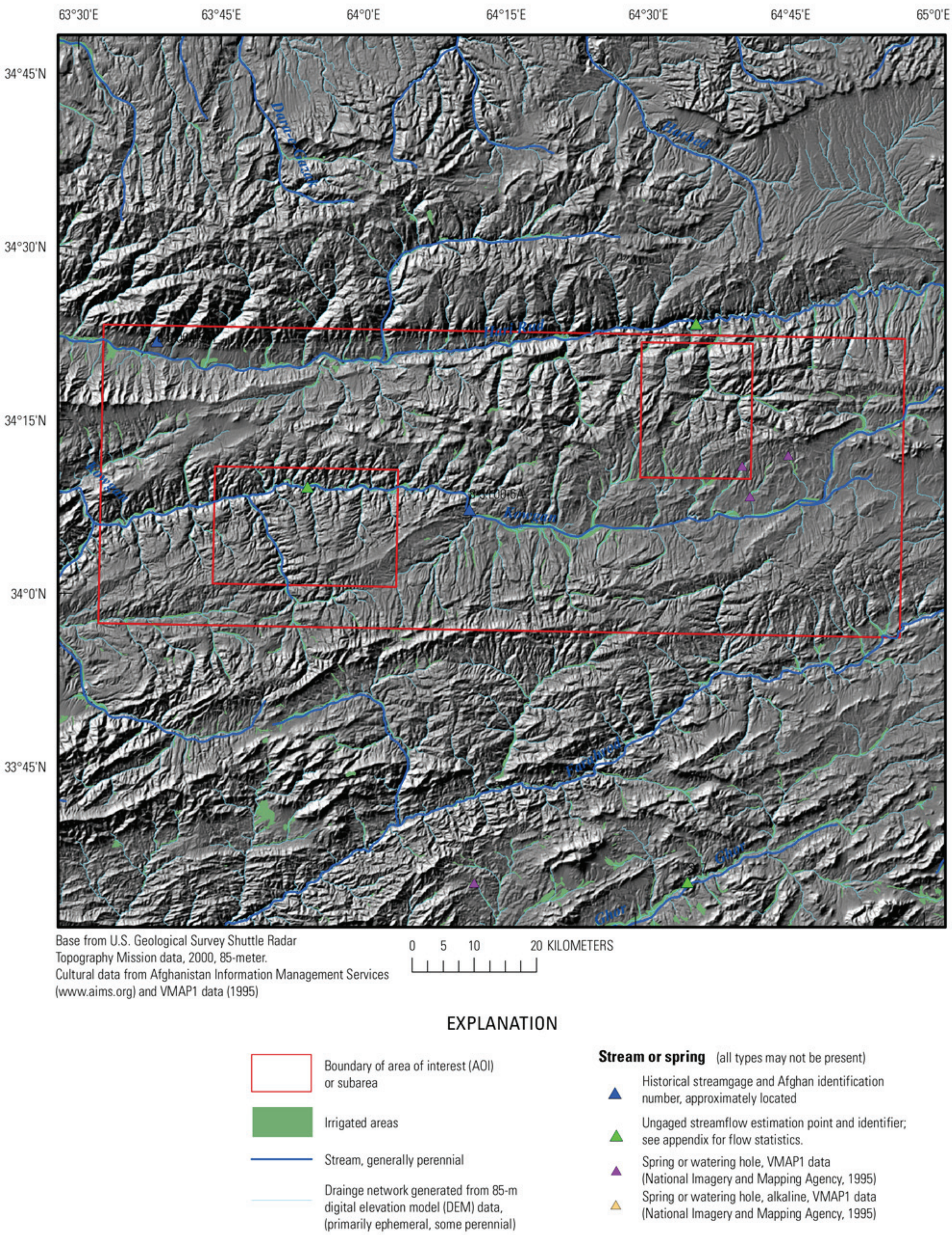


Figure 11C–2. Historical streamgage locations, digitally generated drainage network, and irrigated areas in the Nalbandon lead and zinc area of interest in Afghanistan.

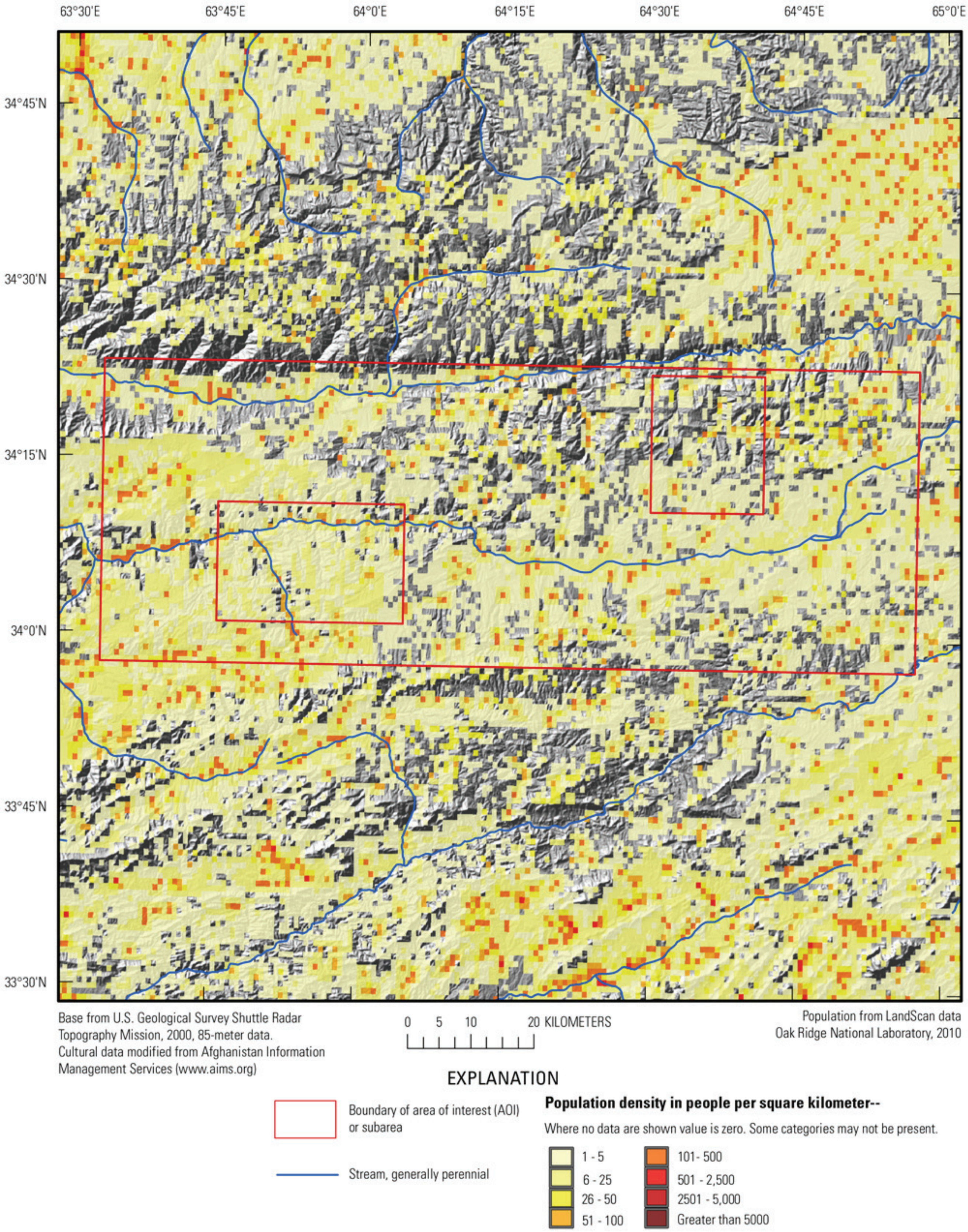


Figure 11C–3. Population density of the Nalbandon lead and zinc area of interest in Afghanistan.

11C.1.3 Topography

The topography of the Nalbandon lead and zinc AOI is mountainous, with a series of approximately east-west-trending ridges and valleys (Davis, 2006) (fig. 11C–4). The lowest elevations in the AOI, about 1,400 m asl, are along the Hari Rud River in the northwest corner of the AOI. Most valley bottoms elsewhere in the AOI are higher than 2,000 m asl. Several peaks within the AOI are higher than 3,000 m asl (Bohannon, 2005). A concentration of peaks higher than 3,000 m asl is just outside the western border of the Gharghananaw-Gawmazar subarea.

The Kowgan River flows from east to west through the center of the AOI. The course of the river is fairly straight and its valley bottom is as much as 500 m wide in some areas. The Hari Rud River enters the AOI at about the midpoint of the northern border and flows from east to west in the northwestern part of the AOI. In a few areas, such as where tributary streams join the river, the Hari Rud River valley bottom is 1 km wide.

11C.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 Nalbandon lead and zinc AOI is in the "Central Afghanistan Hydrogeological Folded Region that occupies the central part of the country with a predominantly mountain climate." The outcrops in the AOI can be grouped according to their physical and hydraulic properties. The generalized geohydrology of the AOI is shown in figure 11C–4 with the underlying topography to allow examination of the geohydrology in the context of relief. Figure 11C–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 11C–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; limestones and dolostones; sedimentary rocks; metamorphic rocks; and intrusive rocks and lavas" (figs. 11C–4 and 11C–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 Bohannon and Yount (2005) and Bohannon and Lindsay (2005).

The sedimentary rocks geohydrologic group has the largest areal extent of the geohydrologic groups and occupies about 65 percent of the surface area of the AOI (fig. 11C–5*a*). Sedimentary rocks and limestones and dolostones are likely potential bedrock aquifers in the AOI. The limestones and dolostones occur as scattered outcrops with a small total area. The metamorphic rocks crop out in an east-west-trending band just inside the northern border of the AOI. The outcrops of the intrusive rocks and lavas geohydrologic group form narrow northeast-trending zones and are concentrated near the outcrops of the metamorphic rocks.

The unconsolidated geohydrologic groups in the AOI are the river- channel; sands, undifferentiated; and conglomerate sediments and rocks geohydrologic groups. Conglomerates are known to be semi-consolidated sediments and rocks in many areas of Afghanistan. The river channel geohydrologic group is in the Hari Rud River valley in the northwest corner of the AOI. The sands, undifferentiated geohydrologic group is in the wider sections of the Hari Rud and Kowgan River valleys (fig. 11C–4). The conglomerate sediments and rocks geohydrologic group crops out in some of the upland basins and along the Hari Rud River. The unconsolidated geohydrologic groups are all potential aquifers in the AOI. The larger mapped outcrops of the sands, undifferentiated geohydrologic group are potential targets for groundwater exploration, especially along the Kowgan River (fig. 11C–5*a*).

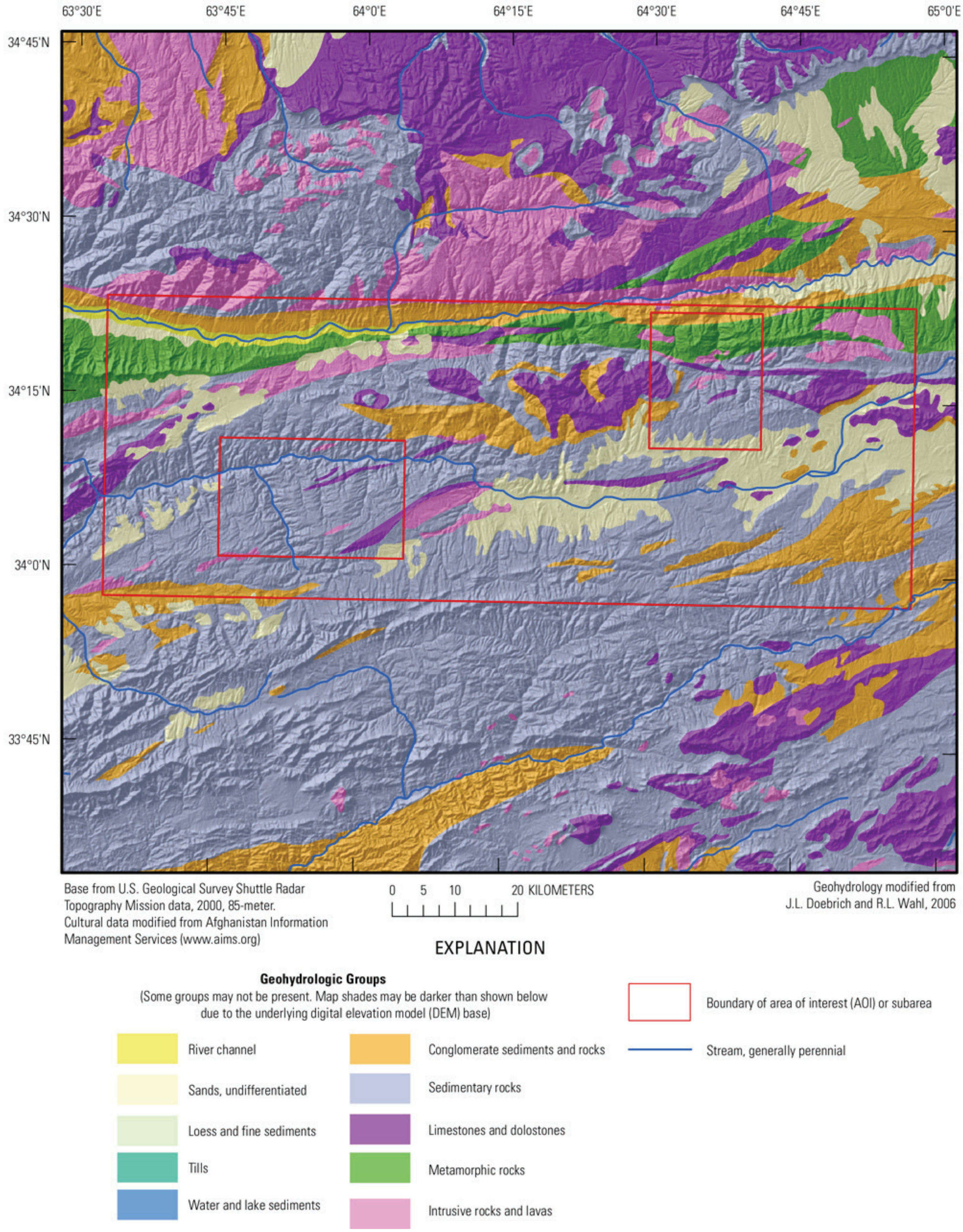
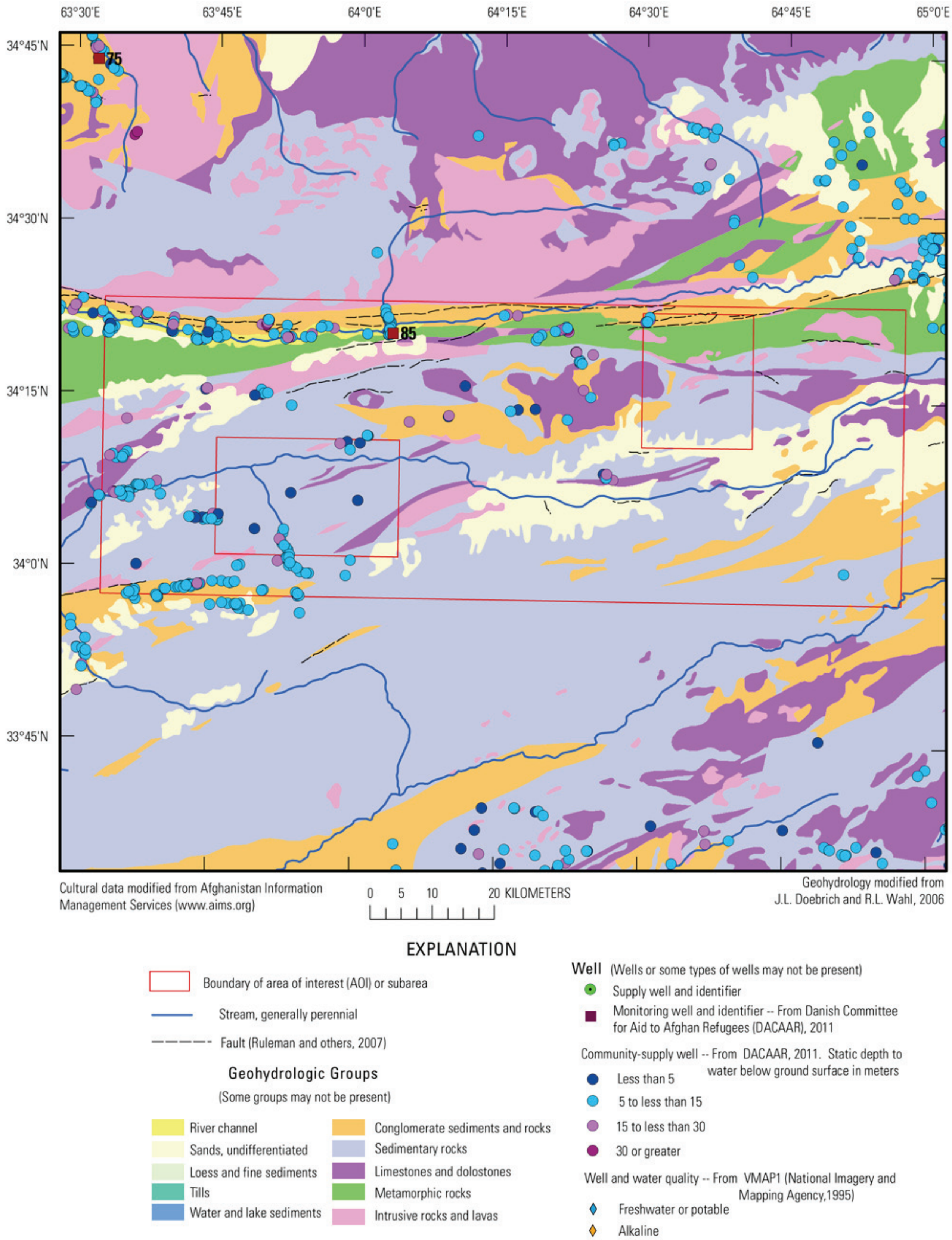


Figure 11C–4. Topography and generalized geohydrology of the Nalbandon lead and zinc area of interest in Afghanistan.

a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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

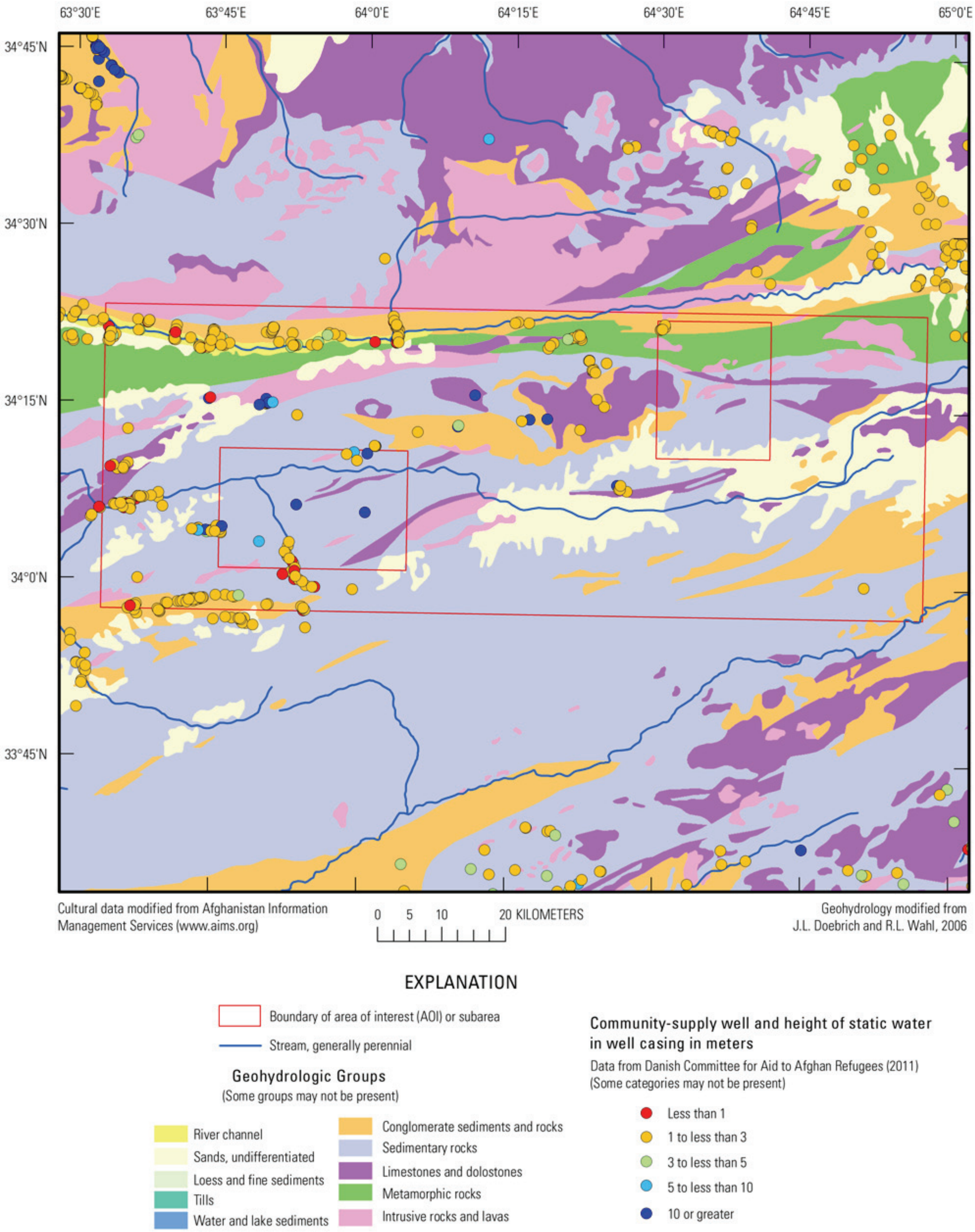


Figure 11C–5. (*a*) Generalized geohydrology, mapped faults, well locations, and depth to water, and (*b*) geohydrology and height of static water in well casings in community supply wells in the Nalbandon lead and zinc area of interest in Afghanistan.

11C.2.1 Surface Water

A network of major, mostly perennial streams, modified from AIMS (Afghanistan Infomation Management Services, 1997) and VMAP1 (National Imagery and Mapping Agency, 1995), is shown in figure 11C–2. A network representing likely ephemeral streams, generated with a digital elevation model (DEM), also is shown in figure 11C–2. Mapped springs, identified in the Vector Map (VMAP1) database (National Imagery and Mapping Agency, 1995), also are shown in and adjacent to the AOI. Names of major streams and identification numbers of any streamgages and ungaged streamflow estimation sites in the AOI are shown in figure 11C–1*b*.

There are two streamgage stations within the AOI (figs. 11C–1*b* and 11C–2). One station is located on the Kowgan River at Tangi Azu (Afghan identification number 8-3.L00-6A). This station is at an elevation of 2,200 m asl, has a drainage area of 2,030 km^2, and has a period of record that extends from 16 October, 1961, to 30 September, 1978 (Olson and Williams-Sether, 2010). The annual mean streamflow per unit area for this station is 0.0009 $m^3/s/km^2$ (cubic meters per second per square kilometer). The seasonal timing of maximum and minimum monthly streamflow is high flows in the spring and low flows in late summer through fall. A statistical summary of monthly and annual mean streamflows for this station is presented in table 11C-2. 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 other streamgage station in the AOI is on the Hari Rud River at Tagaw Ghaza (Afghan identification number 8-0.000-5M). This station is at an elevation of 1,460 m asl, has a drainage area of 11,920 km^2, and has a period of record that extends from 1 October, 1961, to 30 September, 1978 (Olson and Williams-Sether, 2010). The annual mean streamflow per unit area for this station is 0.003 $m^3/s/km^2$. The maximum monthly streamflow of the Hari Rud River occurs in mid to late spring, and the minimum monthly streamflow occurs in mid summer through mid winter. A statistical summary of monthly and annual mean streamflows for this station is presented in table 11C–3.

Table 11C–2. Statistical summary of monthly and annual mean streamflows for the streamgage station on the Kowgan River at Tangi Azu (Olson and Williams-Sether, 2010).

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

8-3.L00-6A KOWGAN RIVER AT TANGI AZU

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	1.62	1966	0.44	1971	0.79	0.36	0.46	3.54
November	1.49	1966	0.38	1970	0.84	0.36	0.43	3.76
December	1.60	1970	0.32	1971	0.86	0.34	0.39	3.86
January	1.47	1965	0.24	1971	0.81	0.35	0.43	3.64
February	2.29	1965	0.29	1971	0.90	0.54	0.60	4.04
March	8.36	1969	0.61	1967	3.15	2.29	0.73	14.2
April	17.7	1975	1.03	1971	6.99	5.12	0.73	31.5
May	9.84	1975	0.38	1971	4.54	3.18	0.70	20.4
June	3.78	1975	0.36	1971	1.39	1.08	0.78	6.24
July	1.38	1975	0.34	1978	0.64	0.29	0.44	2.88
August	1.22	1975	0.30	1978	0.62	0.25	0.41	2.78
September	1.58	1975	0.38	1978	0.71	0.35	0.50	3.20
Annual	**3.43**	**1965**	**0.52**	**1971**	**1.90**	**0.96**	**0.50**	**100**

Table 11C–3. Statistical summary of monthly and annual mean streamflows for the streamgage station on the Hari Rud River at Tagaw Ghaza (Olson and Williams-Sether, 2010).
[m^3/s, cubic meters per second]

8-0.000-5M HARI RUD RIVER AT TAGAW GHAZA

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	12.9	1970	5.34	1972	7.40	1.95	0.26	1.58
November	20.8	1970	5.49	1975	8.23	3.69	0.45	1.76
December	14.6	1970	5.12	1974	7.76	2.44	0.31	1.66
January	15.5	1969	5.18	1975	8.13	3.09	0.38	1.74
February	14.8	1973	6.20	1972	9.59	2.79	0.29	2.05
March	132	1969	10.8	1966	33.6	27.5	0.82	7.17
April	352	1969	43.8	1966	138	68.8	0.50	29.4
May	331	1969	56.0	1971	170	83.5	0.49	36.4
June	124	1969	10.9	1971	56.7	33.3	0.59	12.1
July	31.1	1969	4.26	1971	14.2	7.38	0.52	3.02
August	14.3	1969	3.17	1971	7.54	2.97	0.39	1.61
September	13.7	1969	4.47	1971	7.34	2.32	0.32	1.57
Annual	**87.9**	**1969**	**17.5**	**1971**	**39.1**	**17.2**	**0.44**	**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 S14 and S15 (figs. 11C–1*b* and 11C–2) using a drainage-area-ratio method (Olson and Mack, 2011). The estimate for S14 was based on historical flows at the Kowgan River at Langar streamgage station (Afghan identification number 8-3.L00-1A), about 90 km downstream (not shown), and the Kowgan River at Tangi Azu streamgage station (Afghan identification number 8-3.L00-6A), 25 km upstream (fig 11C–1*b*) (Olson and Williams-Sethers, 2010). Where the estimation point was bracketed by upstream and downstream stations, an interpolation between the data from these two stations was used to calculate the estimates. The estimated mean annual streamflow for point S14 (app. 2), with a drainage area of 2,574 km^2, is about 2.45 m^3/s (cubic meters per second). The estimated seasonal timing of maximum and minimum monthly streamflow at S14, with high flows in the spring and low flows in late summer through fall (app. 2), is similar to that at the Kowgan River at Tangi Azu station.

The estimate for S15 was based on historical flows at the Hari Rud River at Tagaw Ghaza streamgage station, 86 km downstream (Afghan identification number 8-0.000-5M) (fig. 11C–1*b*), and the Hari Rud River at Chekhcheran streamgage station (8-0.000-7M), 43 km upstream (not shown) (Olson and Williams-Sethers, 2010). An interpolation between the data from these two stations was used to calculate the estimates. The estimated mean annual streamflow for point S15 (app. 2), with a drainage area of 9,043 km^2, is about 35.89 m^3/s. The estimated seasonal timing of maximum and minimum monthly streamflow at S15 is similar to that at the Hari Rud at Tagaw Ghaza station.

11C.2.2 Groundwater

Approximately 320 shallow community groundwater-supply wells have been installed in the Nalbandon lead and zinc 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. 11C–5*a*,*b*). About

97 percent of the supply wells are less than 30 m deep and none is more than 40 m deep. The median well depth is 11 m. The depth to water in the supply wells in the AOI is generally less than 15 m (fig. 11C–5*a*). The median depth to water is 9 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 11C–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 1.2 m. Less than 3 m of static water is present in more than 90 percent of the wells in the AOI. 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).

There is one groundwater-monitoring well (GWM 85) in the AOI (fig. 11C–5*a*); this well is monitored by DACAAR for groundwater levels and specific conductance. Monitoring well GWM 53 is 36 km east of the Gharghananaw-Gawmazar subarea (not shown in fig. 11C–5*a*). Hydrographs of water levels in groundwater-monitoring wells in or 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°C (µS/cm), and depth to water in meters below ground surface (bgs). The groundwater-monitoring wells likely are generally constructed in alluvial material. The hydrograph for GWM 85 shows about 3 m of seasonal fluctuation, relatively little compared to the seasonal water-level fluctuation observed at other, nearby GWMs. This well is located within a few hundred meters of the confluence of the Hari Rud River and a large tributary, and is about 5 m higher in elevation than the Hari Rud River. The hydrograph for GWM 53, which is located about 1 km from the Hari Rud River and is about 40 m higher, shows a seasonal fluctuation of more than 15 m with peaks during spring snowmelt periods. The specific conductance in GWM 85 and GWM 53 is about 1,000 and 3,500 µS/cm, respectively. Supply wells with little static water that are close to the perennial rivers may have sufficient water for domestic supply; however, those farther from such rivers may be susceptible to seasonal drying and may also contain water with a greater dissolved-solids content.

11C.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 Nalbandon lead and zinc AOI (B.E. Hubbard, T.J. Mack, and A.L. Thompson, U.S. Geological Survey August 24, 2011, written commun.) were conducted using DEM and natural-color satellite imagery (fig. 11C–6) and Advanced Spaceborne Thermal Emission and Reflection Radiometry (ASTER) satellite imagery (fig. 11C–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 11C–6 were delineated visually, whereas those in figure 11C–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, U.S. Geological Survey August 24, 2011, written commun.). 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. 11C–6 and 11C–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. Lineaments in the AOI show a northeasterly pattern following the regional structure and, likely, bedding-plane weaknesses in sedimentary rocks. In some areas conjugate patterns, which drainage patterns appear to follow (fig. 11C–2), are observed; this feature is particularly evident in the DEM lineaments (fig. 11C–6). 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.

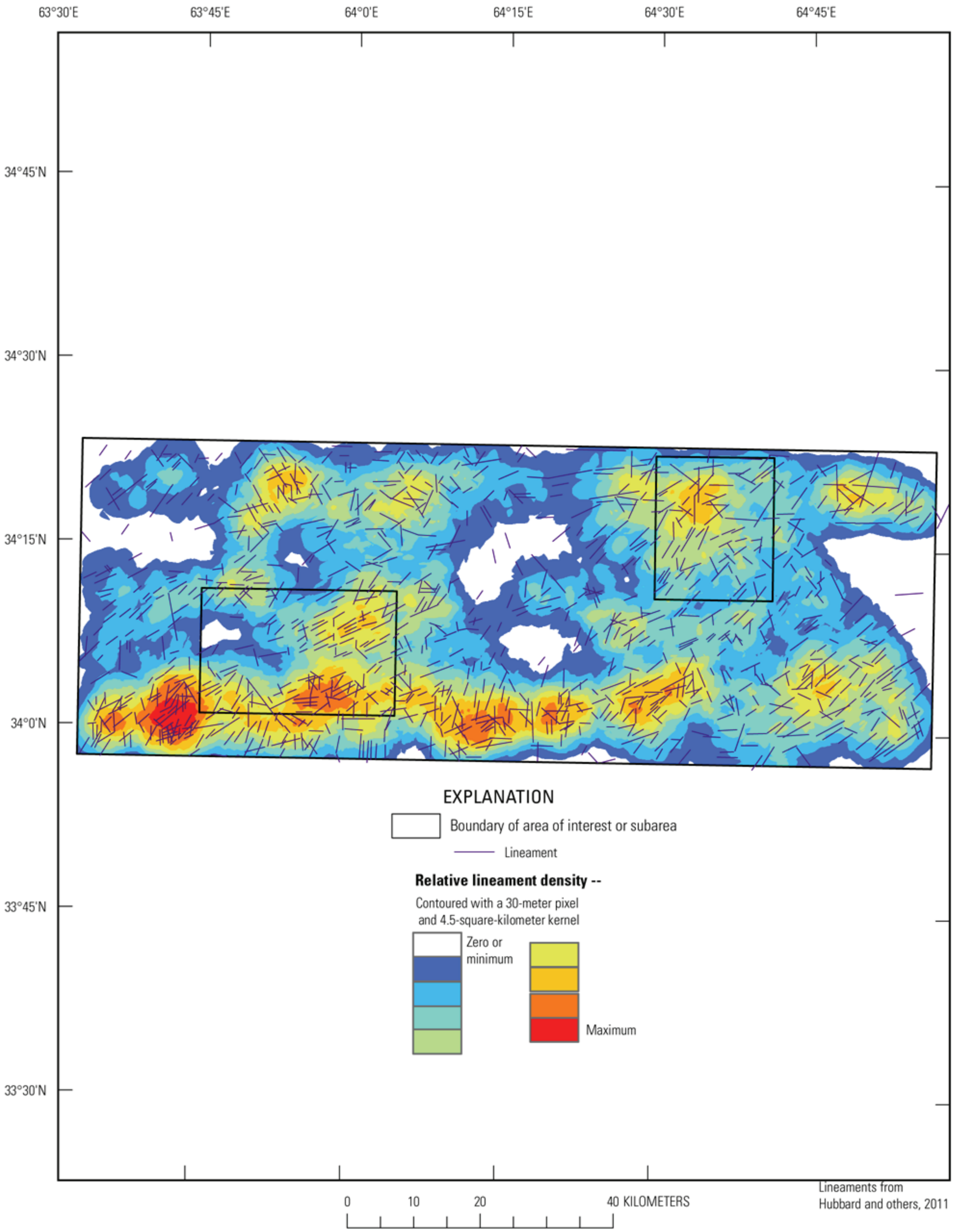
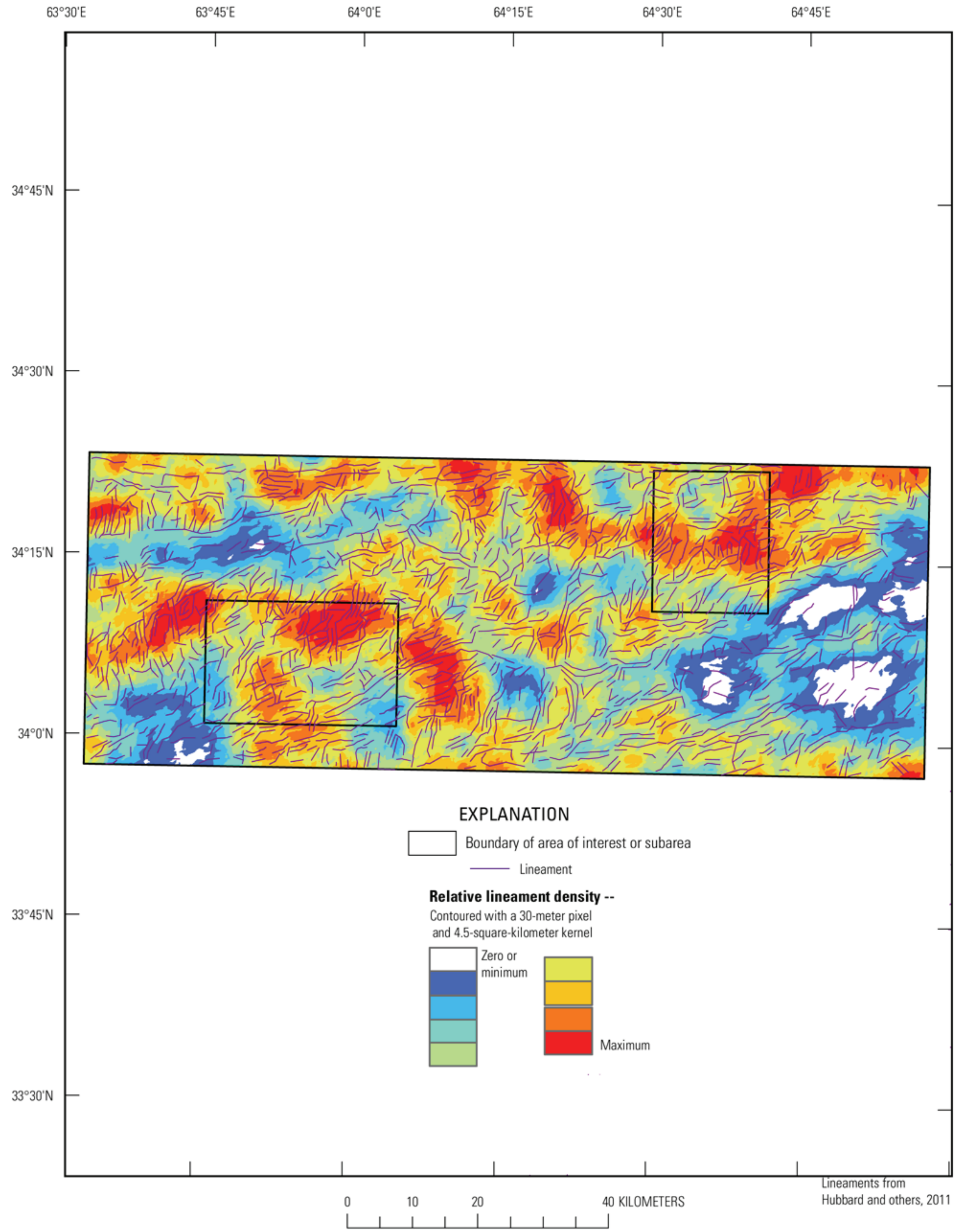


Figure 11C–6. Lineaments and lineament density based on 30-meter digital-elevation-model data and natural-color Landsat imagery in the Nalbandon lead and zinc area of interest in Afghanistan.

a


63°30'E
63°45'E
64°0'E
64°15'E
64°30'E
64°45'E
34°45'N
34°30'N
34°15'N
34°0'N
33°45'N
33°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
10
20
40 KILOMETERS
Lineaments from
Hubbard and others, 2011

b

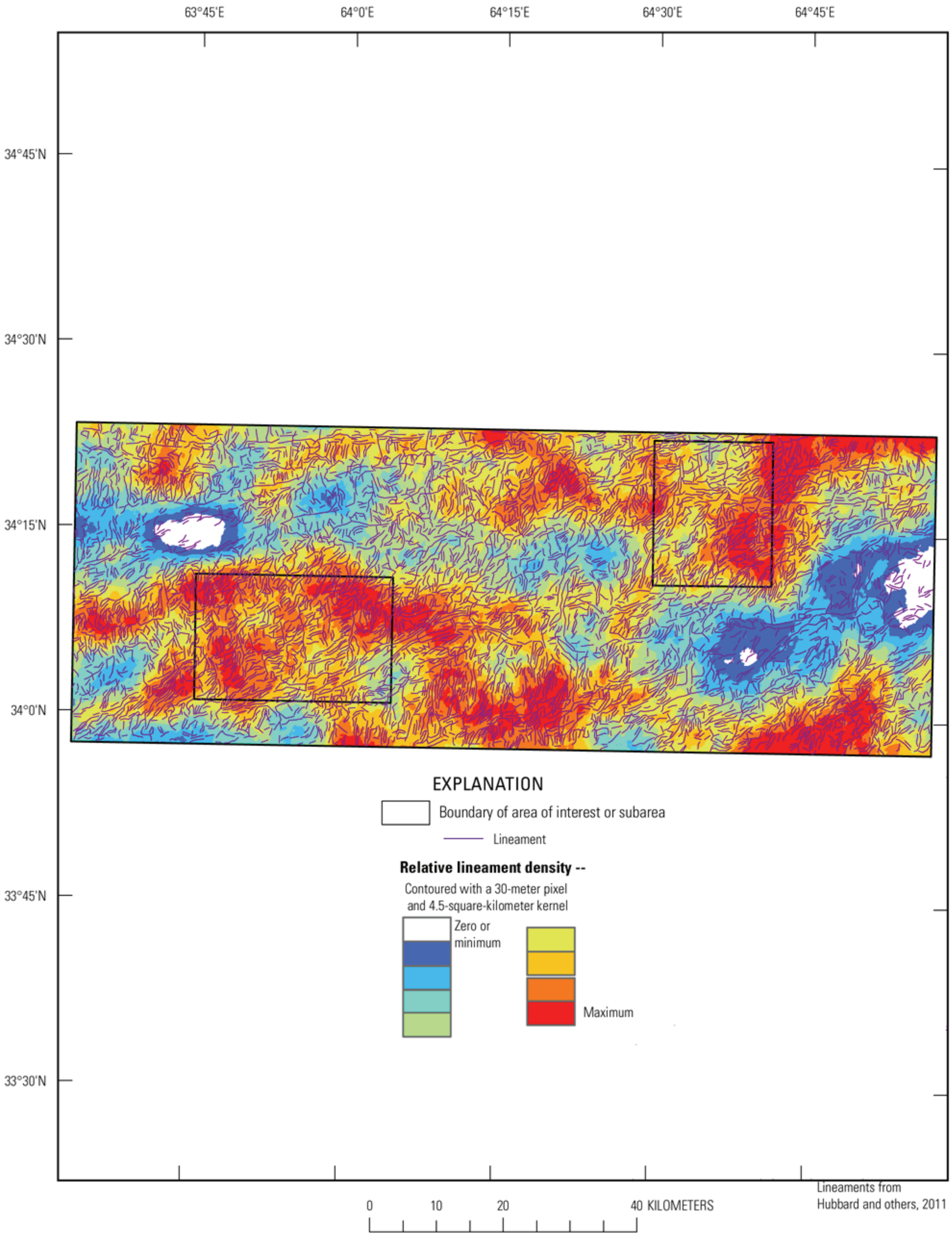


Figure 11C–7. (*a*) Lineaments and lineament density based on 30-meter multispectral Landsat imagery and (*b*) lineaments and lineament density based on 15-meter multispectral Landsat imagery in the Nalbandon lead and zinc area of interest in Afghanistan.

11C.3 Summary and Conclusions

The availability of water resources in the Nalbandon lead and zinc area of interest (AOI) is likely to be similar to that in other mountainous areas in central Afghanistan, and the availability of water for mining and other uses may be greater than in other areas of the country. Precipitation in the AOI, particularly snowfall, supplies water to the perennial streams that flow through the AOI. Water resources in the AOI and surrounding area that are currently being used consist of shallow tube wells and diversion of surface water for irrigation. Shallow alluvial aquifers located in the valley bottoms of the AOI are likely a highly utilized groundwater resource. Most streams are also utilized by the local population and represent the primary source of water for irrigation. Any new diversion of water from the rivers–for example, to support mining activities–would need to be closely monitored, particularly during low-flow periods, if the quantity and quality of this water resource are to be preserved. Sufficient flow must be maintained in the rivers to supply water for irrigation and to provide recharge to the aquifers that supply groundwater to the shallow wells used for domestic consumption.

Community water-supply wells in the AOI are generally located in shallow alluvial aquifers in the valley bottoms and are likely a highly utilized water resource. Most of these wells are less than 30 m deep, have 3 m or less of static water in the well casing, and are susceptible to seasonal water-level fluctuations or becoming dry during times of low precipitation. Increased water withdrawals from the shallow aquifers or rivers could cause some existing wells to become dry. There is no information about deep groundwater (deeper than 30 m) in the AOI or adjacent areas. Some areas of the AOI, as indicated by generalized geohydrologic maps and lineament analyses, are likely areas for exploration for groundwater resources. Outcrops of the sedimentary rocks are extensive in the AOI and are potential areas for groundwater exploration.

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 hydraulic well testing are needed to adequately characterize the extent and availability of groundwater resources in the AOI.

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