Chapter 22C. Geohydrologic Summary of the Kunduz Celestite Area of Interest

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22C.1 Introduction

This chapter describes the geohydrology of the Kunduz celestite area of interest (AOI) in Afghanistan identified by Peters and others (2007) (fig. 22C–1*a*,*b*). The AOI is located in northeast Afghanistan in the Chahar Dara, Aliabad, and Qala-i-Zal Districts in Kunduz Province and the Baghlan Jadid District in Baghlan Provinces (fig. 22C–1*a*,*b*). The AOI encompasses an area of 2,266 km^2 (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), 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.

22C.1.1 Climate and Vegetation

Climate information for the Kunduz celestite 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.

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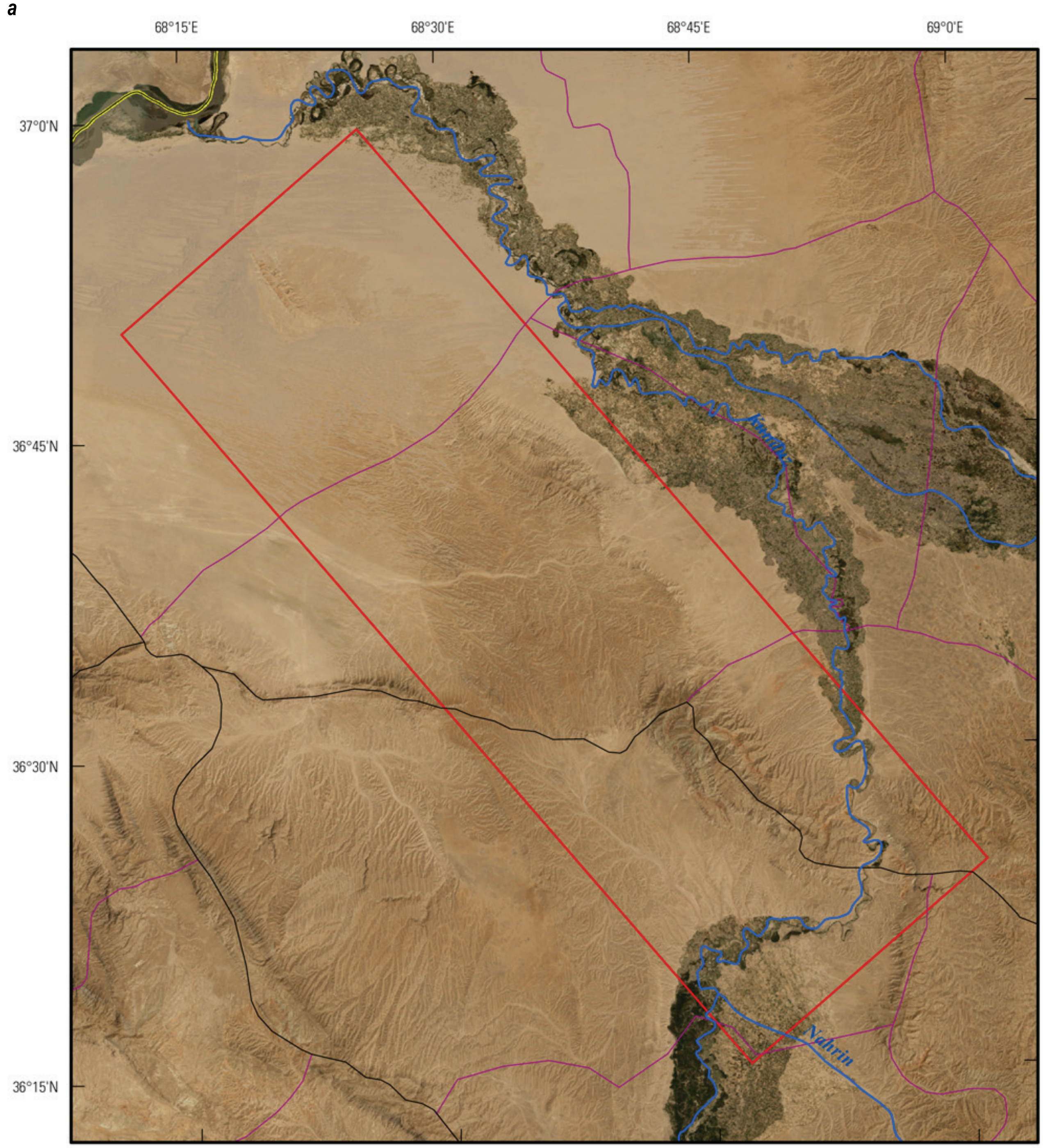


Base from U.S. Geological Survey Natural-Color Landsat Image Mosaic of Afghanistan Map Series, 2006,14.25-meter. Cultural data modified from Afghanistan Information Management System (www.aims.org).

EXPLANATION

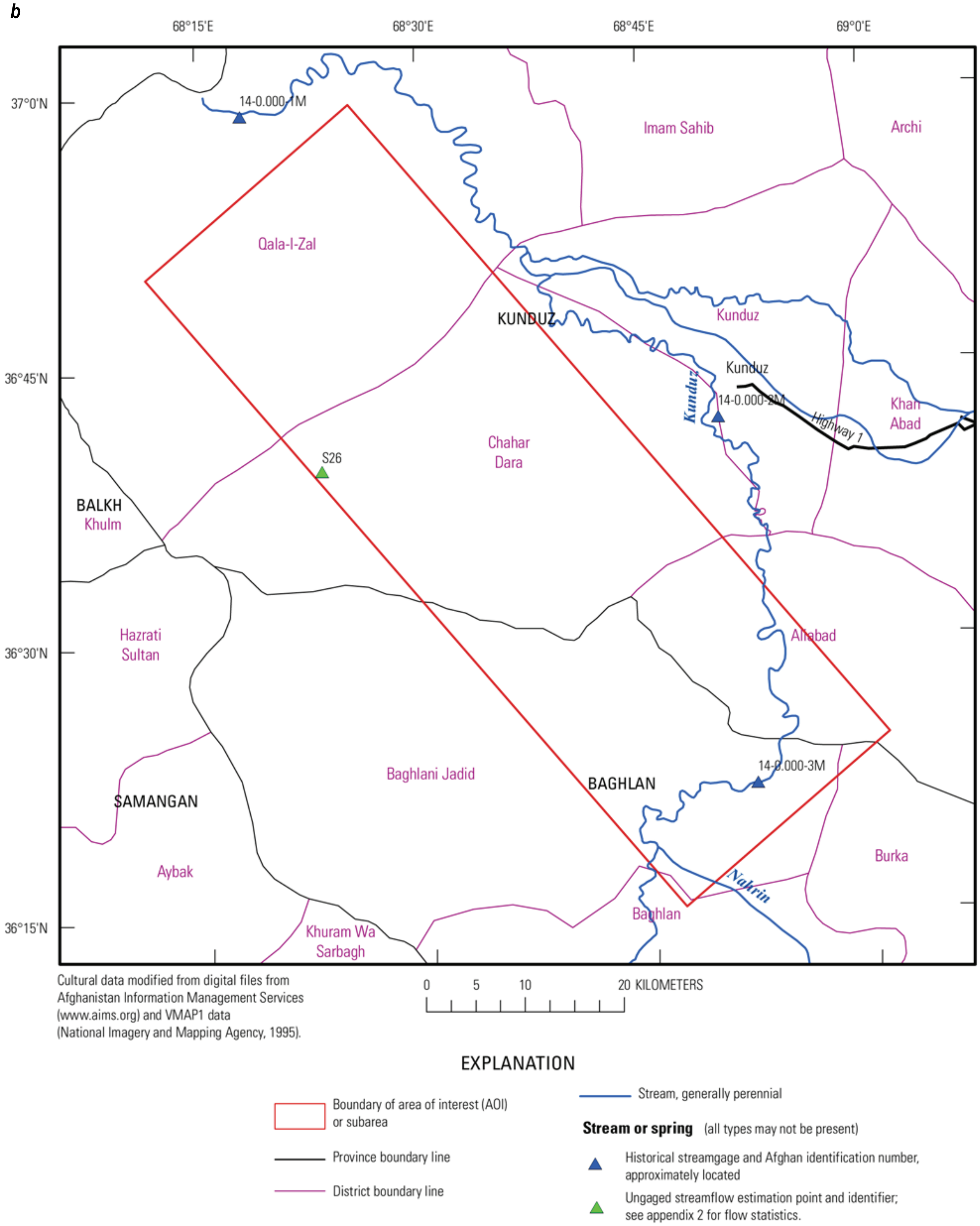


Figure 22C–1. (*a*) Landsat image showing the location of, and (*b*) place names, stream names, and streamgage station numbers in, the Kunduz celestite area of interest in Afghanistan.

The observed total precipitation for the AOI for the 2009–2010 water year, recorded at the Kunduz Agromet station and published in the Seasonal Bulletin (Ministry of Agriculture, Irrigation, and Livestock, 2010, map 2), is 336.3 mm (millimeters) (table 22C–1), and the AOI can be classified as semi-arid. The AOI received 61 to 80 mm of precipitation in February 2010, the month with the greatest precipitation (Ministry of Agriculture, Irrigation, and Livestock, 2010, map 3). The long-term average (LTA) precipitation for August and September is 0 mm (table 22C–1). Precipitation in October increased from northwest to southeast across the AOI.

The Kunduz Agromet station is located in Kunduz Province approximately 30 km (kilometers) northeast of the center of the AOI. This station is the Agromet station that is closest to the AOI for which 2009–2010 water year and LTA precipitation data are available. Precipitation data for the Kunduz Agromet station (Ministry of Agriculture, Irrigation, and Livestock, 2010) are shown in table 22C–1. Snowfall data were reported for the Kunduz Agromet station for the 2009–2010 water year. Snowfall was recorded on 4 days during February 2010, for a total of 41 cm (centimeters) during the 2009–2010 water year.

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

The vegetation in the AOI is varied. In the north, the vegetation as classified by Breckle (2007, p. 161) is ephemeral desert. The central AOI is *Pistacia vera*-Woodlands. Along parts of the Kunduz River is a thin strip of azonal riverine vegetation bordered in places by ephemeral desert (Breckle, 2007, p. 161). Most of the surface of the AOI is sparsely vegetated. The bedrock outcrop is covered by a thin alluvium and sparse vegetation. Most of the azonal riverine vegetation that was in the Kunduz River valley has been harvested for fuel and building materials. All land suitable for farming has been plowed and planted, especially along the Kunduz River. Irrigated fields are present in many of the valleys of the AOI where perennial streams are located (fig. 22C–2).

Table 22C–1. Annual, long-term annual average, and long-term average minimum and maximum precipitation and temperature at the Kunduz Agrometeorological (Agromet) station approximately 30 km northeast from the center of the Kunduz celestite area of interest, Afghanistan.

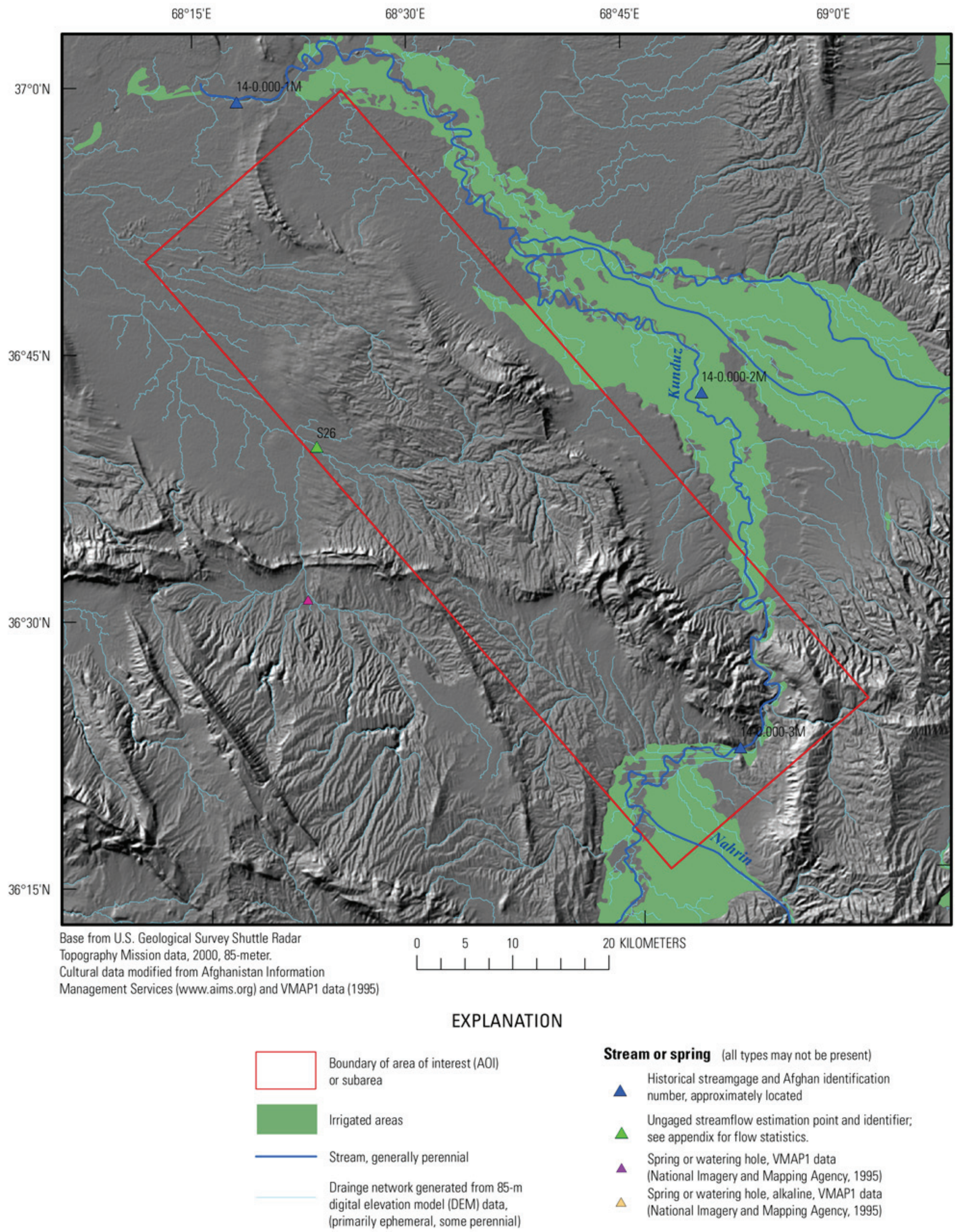
[AOI, area of interest; km, kilometers; m, meters; mm, millimeters; °C, degrees Celsius; nr, not reported]

			Precipitation				Temperature		
					Long-term average[1]		Long-term average[1]		
Agromet Station	Distance from AOI center (km)	Elevation (m)	2009–2010 Annual (mm)	Annual (mm)	Monthly minimum and month (mm)	Monthly maximum and month (mm)	Minimum and month (°C)	Monthly mean (°C)	Maximum and month (°C)
Kunduz	30	390	336.3	339.4	0 September August	75.3 March	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).

22C.1.2 Demographics

The Kunduz celestite AOI is sparsely populated, with most areas having from 1 to 25 inhabitants per square kilometer as mapped by LandScan (Oak Ridge National Laboratory, 2010) (fig. 22C–3). Only the area in the southwest corner of the AOI, around the confluence of the Kunduz and Nahrin Rivers, has a concentrated population, which ranges from 51 to 2,500/km^2. A considerable part of this area is irrigated (fig. 22C–2). Some areas of the AOI are estimated to be uninhabited, as indicated by the gray shading in figure 22C–3. The northern part of the AOI has no indicated population in the low-lying areas. The city of Kunduz immediately outside the eastern border of the AOI (fig. 22C–1*b*) is densely populated, with more than 5,000 inhabitants per square kilometer in central areas surrounded by populations that range from 101 to 5,000/km^2. The population density shown in figure 22C–3 has a pixel resolution of about 1 km^2 (Oak Ridge National Laboratory, 2010).



22C–2. Historical streamgage locations, digitally generated drainage network, and irrigated areas in the Kunduz celestite area of interest in Afghanistan.

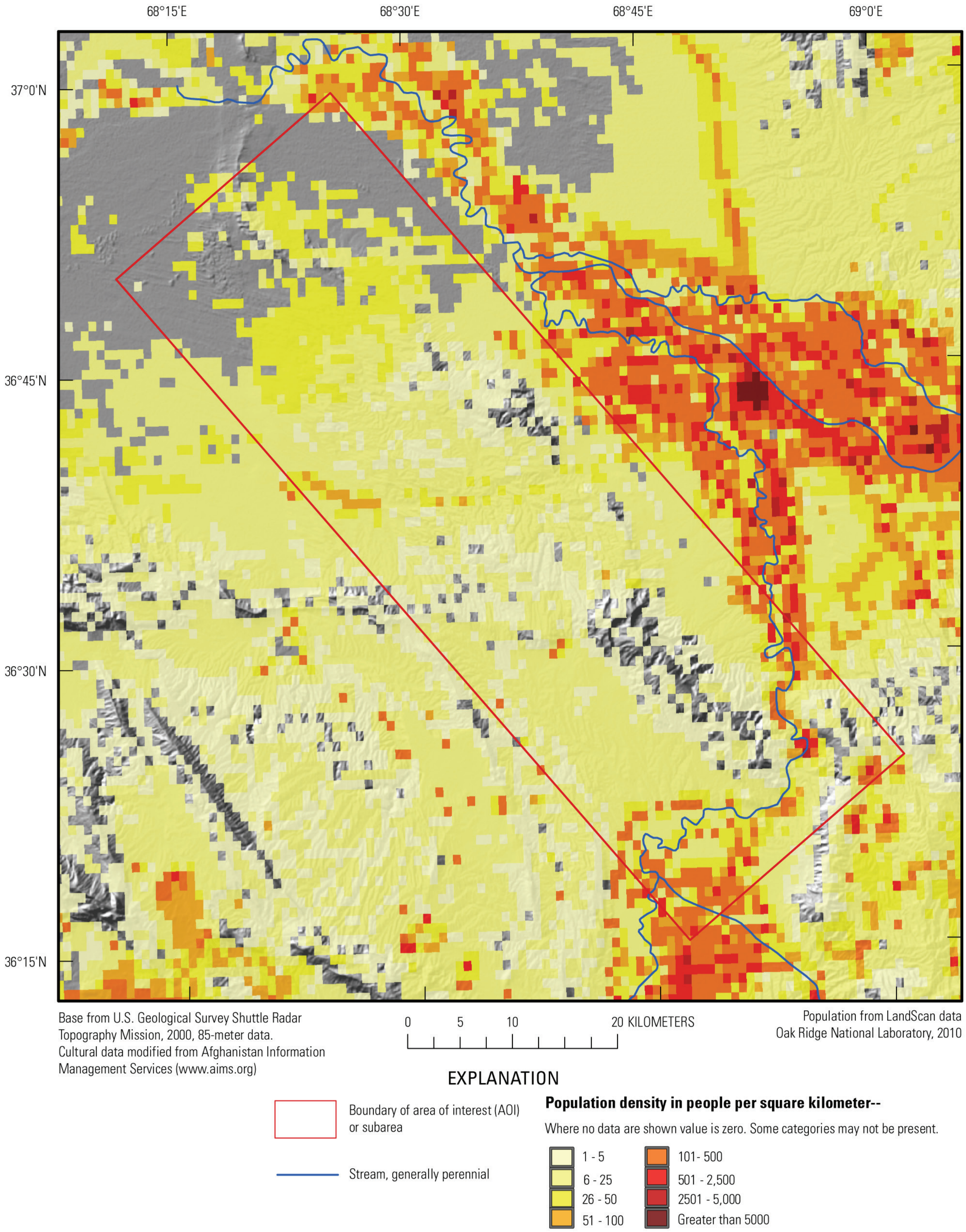


Figure 22C–3. Population density of the Kunduz celestite area of interest in Afghanistan.

22C.1.3 Topography

The topography of the Kunduz celestite AOI is fairly flat with only a few northwest-trending mountain ridges (fig. 22C–4) (Davis, 2006). The highest point in the AOI is 1,676 m (meters) above sea leval (asl) (Bohannon, 2005). The low areas range in elevation from about 350 to 600 m asl and are semi-arid desert, with the exception of irrigated land along the Nahrin and Kunduz Rivers. The valleys formed by these rivers are more than 10 km wide adjacent to the AOI. There are active dune fields in the northern part of the AOI that reflect the prevailing northwest-to-southeast wind direction.

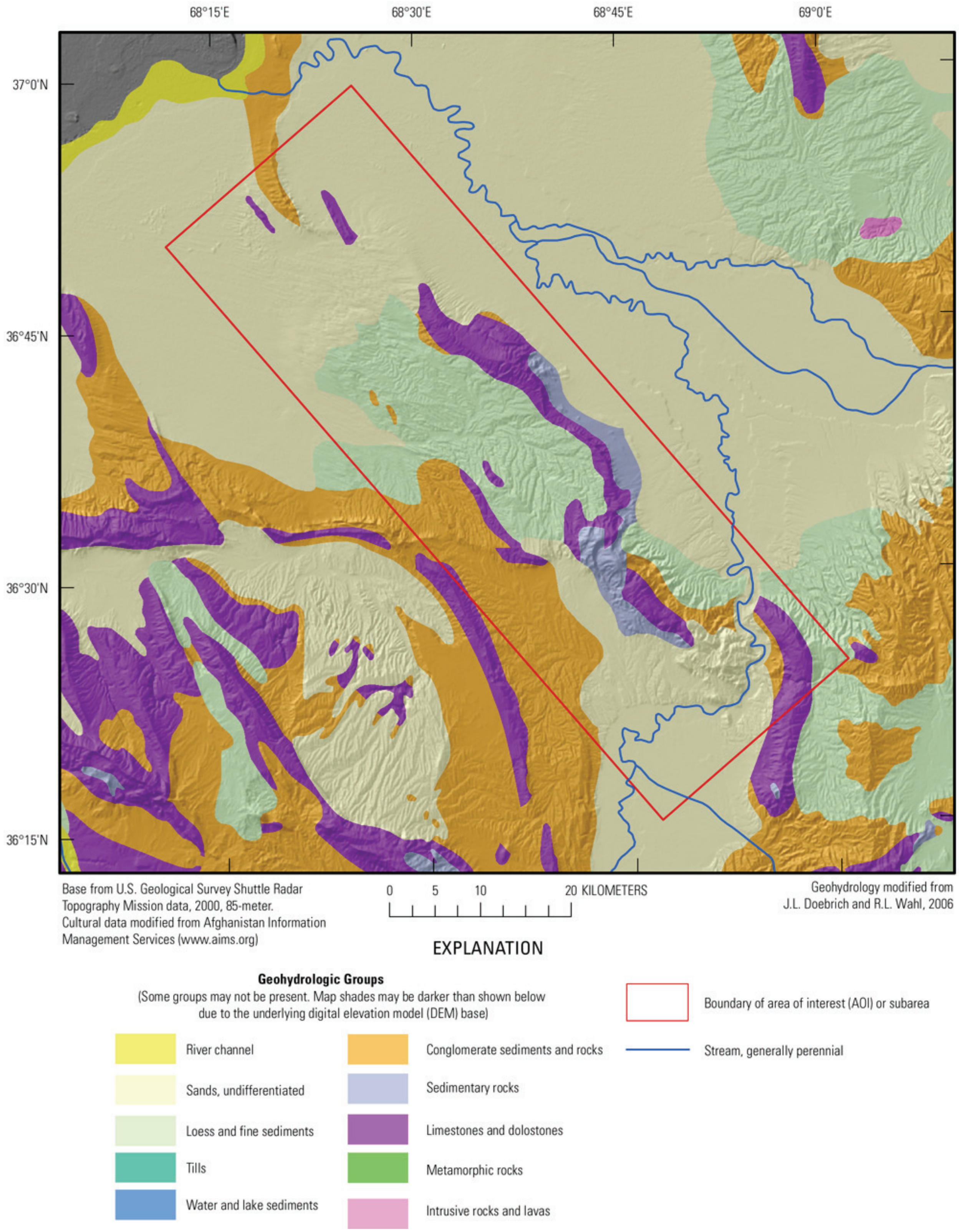


Figure 22C–4. Topography and generalized geohydrology of the Kunduz celestite area of interest in Afghanistan.

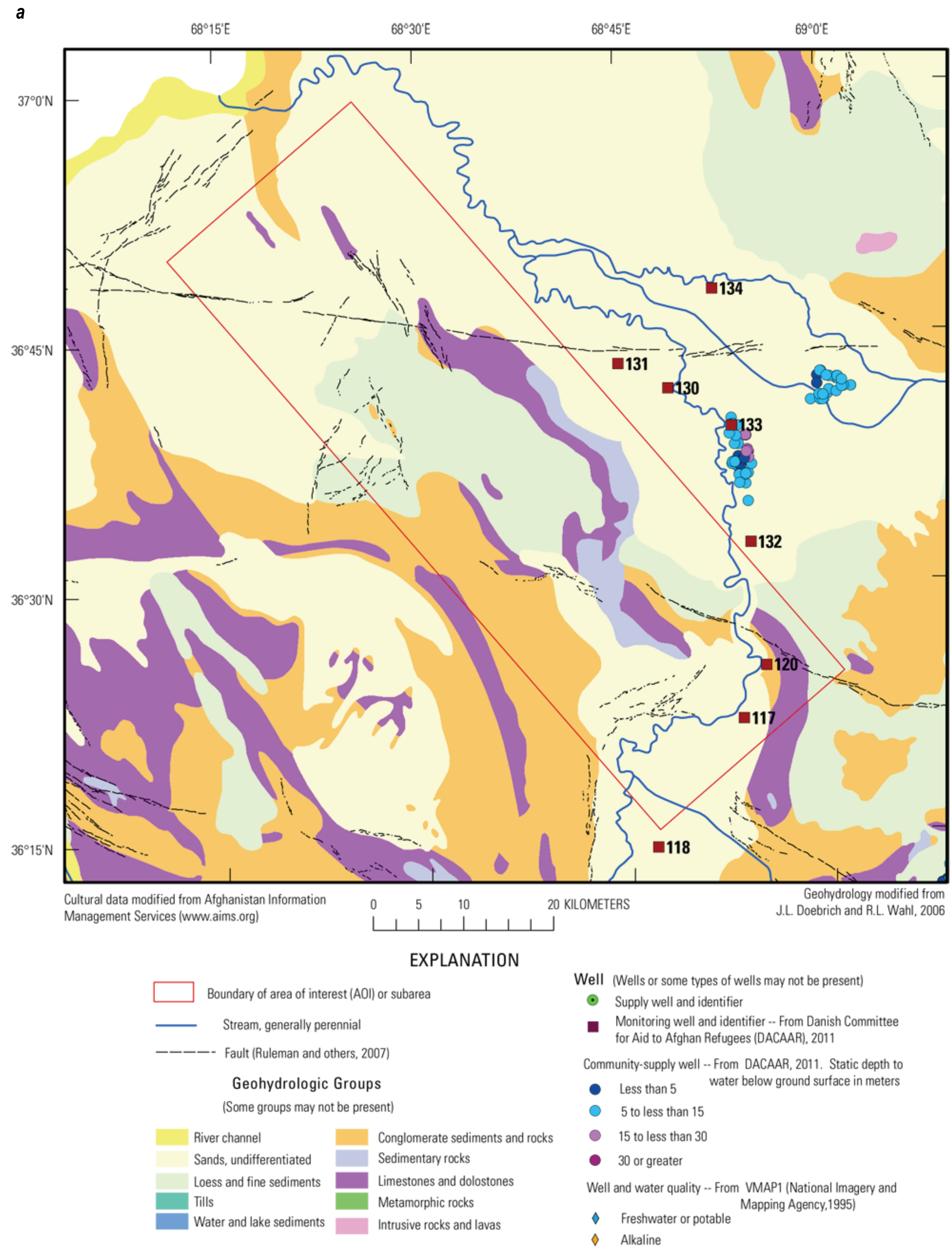
22C.2 Geohydrology

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 Kunduz celestite 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 22C–4 with the underlying topography to allow examination of the geohydrology in the context of relief. Figures 22C–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 22C–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; loess and fine sediments; limestones and dolostones; and sedimentary rocks" (figs. 22C–4, 22C–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 cover this AOI is provided by Fridrich and others (2005).

The sands, undifferentiated group is the largest geohydrologic group in the AOI. These sediments form the surface of the low-lying desert areas. No information on the thickness of this unit is available, but the depth to water in groundwater-monitoring well (GWM) 117 is as much as 9.3 m (Danish Committee for Aid to Afghan Refugees, 2011) (app. 3). Well 117, the only mapped well constructed in this unit, is near the Kunduz River near the southern border of the AOI (fig. 22C–5*a*). There are a number of wells in this unit adjacent to the rivers just outside the northeast border of the AOI. The sands appear to compose an aquifer that is able to supply water for local use. Locally, the sediments near perennial rivers may be river-channel sediments, but the scale of the geologic maps available (1:250,000) does not provide further detail. The loess and fine sediments geohydrologic group probably consists of wind-blown sediments that are deposited on the flanks of the ridges in the AOI. It is doubtful that this geohydrologic group is a source of groundwater in the AOI. The conglomerate sediments and rocks geohydrologic group overlies the sedimentary rocks in the AOI. Depending on the thickness of this unit, it could be a potential source of limited amounts of groundwater. The conglomerate sediments and rocks area within the AOI covers about 100 km^2, but there are extensive outcrops outside the AOI. The sedimentary rocks and limestones and dolostones geohydrologic groups crop out on the ridge in the center of the AOI (fig. 22C–4). The outcrop area of these units is limited, but this group may underlie the unconsolidated sediments in the AOI and could be a groundwater resource. Further studies would be needed to determine whether these units contain appreciable groundwater resources.

22C.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 22C–2. A network representing likely ephemeral streams, generated with a digital elevation model (DEM), also is shown in figure 22C–2. Names of major streams and identification numbers for any streamgages and ungaged streamflow estimation sites in the Kunduz celestite AOI are shown in figure 22C–1b.


a
68°15'E
68°30'E
68°45'E
69°0'E
37°0'N
36°45'N
36°30'N
36°15'N
134
131
130
133
132
120
117
118
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

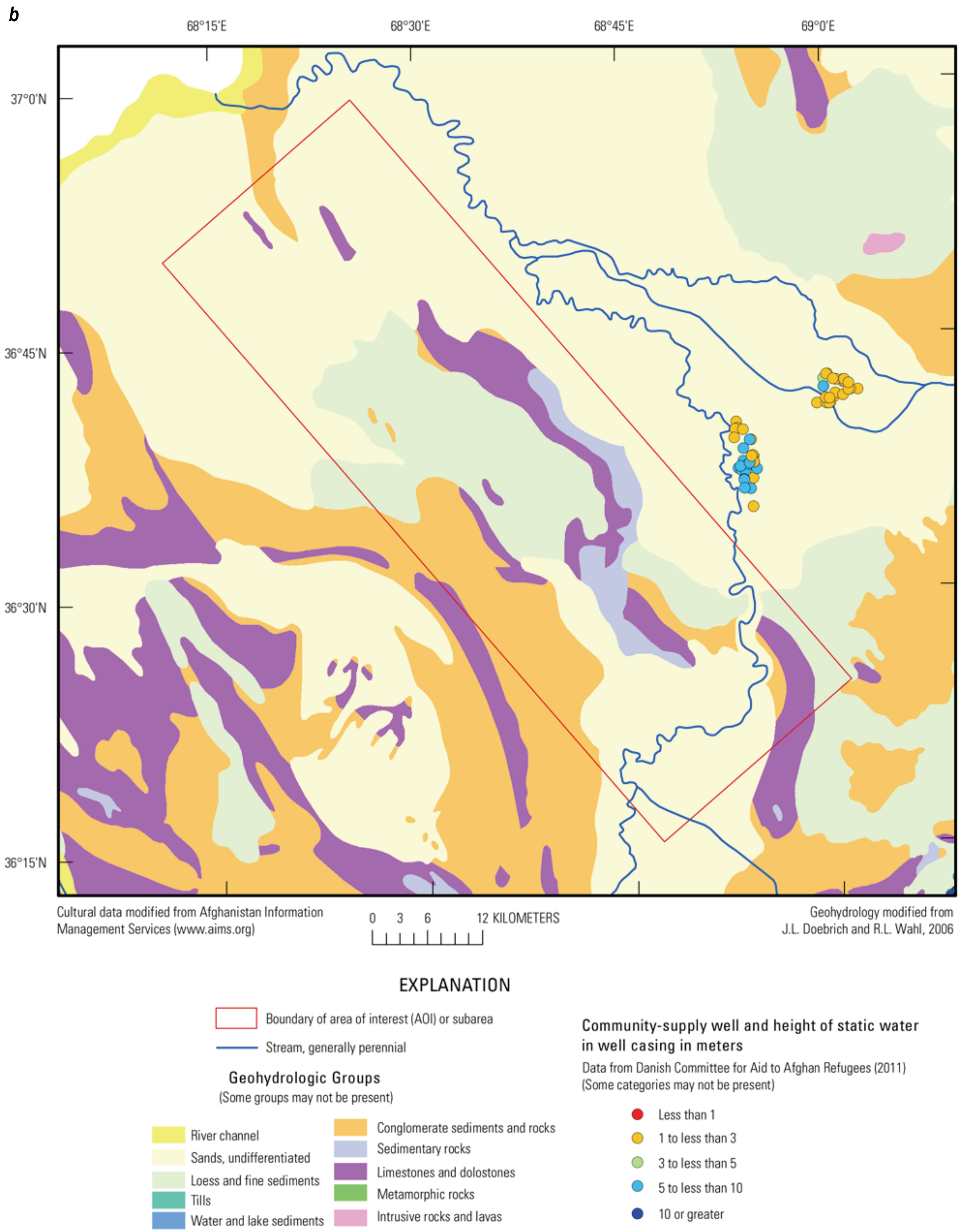


Figure 22C–5. (*a*) Generalized geohydrology, mapped faults, well locations, and depth to water, and (*b*) geohydrology and height of static water in well casings in community-supply wells in the Kunduz celestite area of interest in Afghanistan.

The streamgage within the AOI is the Kunduz River at Gerdab station (Afghan identification number 14-0.000-3M) (figs. 22C–1*b*, 22C–2). This station is at an elevation of 464 m asl and has a drainage area of 22,930 km^2 and a period of record that extends from 21 April, 1964, to

30 September, 1978 (Olson and Williams-Sether, 2010). The mean annual streamflow per unit area for this station is 0.0028 $m^3/s/km^2$ (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 from late summer through early spring. A statistical summary of monthly and annual mean streamflows for this station is presented in table 22C–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 other streamgage station is the Kunduz River at Kulukh Tepa station (Afghan identification number 14-0.000-1M) (figs. 22C–1*b*, 22C–2). This station is at an elevation of 320 m asl and has a drainage area of 37,100 km^2 and a period of record that extends from 1 October, 1965, to 30 September, 1978 (Olson and Williams-Sether, 2010). The mean annual streamflow per unit area for this station is 0.0029 $m^3/s/km^2$. The seasonal timing of maximum and minimum monthly streamflow is high flows in the late spring and early summer and low flows from late summer through early spring. A statistical summary of monthly and annual mean streamflows for this station is presented in table 22C–4.

Two streamgage stations are located outside and downstream from the AOI. One is the Kunduz River at Char Dara (Afghan identification number 14-0.000-2M) (figs. 22C–1*b*, 22C–2). This station is at an elevation of 401 m asl and has a drainage area of 24,820 km^2 and a period of record that extends from 5 August, 1964, to 30 September, 1978 (Olson and Williams-Sether, 2010). The mean annual streamflow per unit area for this station is 0.0022 $m^3/s/km^2$. The seasonal timing of maximum and minimum monthly streamflow is high flows in the late spring and early summer and low flows from late summer through early spring. A statistical summary of monthly and annual mean streamflows for this station is presented in table 22C–3.

Table 22C–2. Statistical summary of monthly and annual mean streamflows for the Kunduz River at Gerdab streamgage station (Olson and Williams-Sether, 2010).
[m^3/s, cubic meters per second]

14-0.000-3M KUNDUZ RIVER AT GERDAB

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	51.5	1969	23.3	1972	38.8	8.17	0.21	4.95
November	56.8	1970	29.4	1972	41.7	7.49	0.18	5.33
December	51.4	1969	28.4	1972	42.3	5.53	0.13	5.4
January	44.8	1969	28.3	1972	39.1	4.58	0.12	4.99
February	44.7	1974	29	1972	37.4	3.97	0.11	4.77
March	47.3	1970	31.1	1972	39	4.95	0.13	4.97
April	93.6	1973	27.1	1972	51.2	18.2	0.36	6.53
May	184	1973	63.5	1974	112	34.3	0.31	14.3
June	400	1968	77.5	1971	204	82.5	0.4	26
July	239	1968	18.9	1971	112	60	0.54	14.3
August	92.4	1968	10.6	1971	37.5	22.8	0.61	4.79
September	48.6	1968	13.5	1971	28.9	10.6	0.37	3.69
Annual	**105**	**1968**	**43.1**	**1971**	**65.5**	**17.2**	**0.26**	**100**

Streamflow statistics were estimated for selected ungaged streams that are prominent in the AOI to provide some probable estimates of flow for these locations. Streamflow statistics, presented in appendix 2, were calculated for point S26 (figs. 22C–1*b* and 22C–2) on a selected stream 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 14-1L0-1A) (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, as the drainage areas of the gages on the Kunduz River were much larger than that of the Bangi River at Pul-i-Bangi. The estimated mean annual streamflow for point S26 (app. 2), with a drainage area of 460.4 km^2, is about 2.31 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 late summer through early spring (app. 2), probably is similar to that of the Kunduz River at Gerdab station.

Table 22C–3. (on following page) Statistical summary of monthly and annual mean streamflows for the Kunduz River at Char Dara streamgage station (Olson and Williams-Sether, 2010).

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

14-0.000-2M KUNDUZ RIVER AT CHAR DARA

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	41.7	1969	10.0	1972	27.2	8.89	0.33	4.25
November	49.2	1970	19.7	1972	32.6	7.94	0.24	5.10
December	44.9	1969	21.0	1972	35.0	6.00	0.17	5.46
January	40.8	1969	21.0	1972	32.4	4.81	0.15	5.06
February	40.4	1969	21.0	1972	31.4	4.48	0.14	4.90
March	42.7	1966	24.6	1972	33.8	4.63	0.14	5.28
April	77.8	1973	16.8	1974	37.9	16.9	0.45	5.92
May	159	1973	45.1	1974	91.6	33.5	0.37	14.3
June	406	1968	72.2	1971	186	88.4	0.48	29.0
July	203	1968	13.1	1971	93.1	57.0	0.61	14.6
August	66.3	1968	2.16	1974	23.6	20.1	0.85	3.69
September	32.7	1968	2.59	1974	16.1	8.76	0.54	2.51
Annual	**91.9**	**1968**	**31.2**	**1974**	**53.4**	**16.6**	**0.31**	**100**

Table 22C–4. Statistical summary of monthly and annual mean streamflows for the Kunduz River at Kulukh Tepa streamgage station (Olson and Williams-Sether

14-0.000-1M KUNDUZ RIVER AT KULUKH TEPA

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	101	1970	40.9	1975	71.0	16.6	0.23	5.57
November	103	1970	61.4	1973	84.1	11.4	0.14	6.60
December	95.1	1969	66.3	1973	81.8	9.05	0.11	6.42
January	80.7	1969	58.3	1975	69.9	8.36	0.12	5.49
February	74.1	1970	53.8	1975	65.8	5.88	0.09	5.17
March	96.3	1969	55.2	1975	74.0	10.8	0.15	5.81
April	179	1969	30.8	1977	76.9	39.5	0.51	6.04
May	236	1973	28.1	1974	141	58.5	0.41	11.1
June	618	1968	148	1971	320	132	0.41	25.1
July	408	1968	12.0	1971	204	112	0.55	16.0
August	154	1969	5.47	1974	54.7	46.4	0.85	4.29
September	60.4	1969	4.44	1974	30.8	14.6	0.47	2.41
Annual	**168**	**1969**	**66.7**	**1974**	**106**	**29.9**	**0.28**	**100**

22C.2.2 Groundwater

Approximately 80 shallow community groundwater-supply wells have been installed by NGOs east of the Kunduz celestite AOI, in the town of Kunduz near the Kunduz River. 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. 22C–5*a*,*b*). About 80 percent of the supply wells in Kunduz are less than 15 m deep; one well is more than 30 m deep (37 m). The median well depth is 10 m. The depth to water in 85 percent of the supply wells in Kunduz is less than 15 m (fig. 22C–5*a*). The median depth to water is 6 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 22C–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 the well casings is 1 m. Less than 3 m of static water is present in 68 percent of the wells in Kunduz (fig. 22C–5*b*). Of the wells installed in Kunduz, 58 percent are described as having been constructed using concrete-ring casing, and 2 percent are described as tube wells. Given the small amount of static water in the wells, the other wells also are likely to be dug wells with concrete-ring casing. 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).

Two GWMs in the AOI (GWMs 117 and 120) and five wells east of the AOI (GWMs 130, 131, 132, 133, and 134) in Kunduz (fig. 22C–5*a*) are monitored by DACAAR for groundwater levels and specific conductance. Hydrographs of water levels in GWMs in 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 generally show a 1- to less than 2-m annual range in water levels; water levels generally were at a maximum in spring and a minimum in late fall or winter. This water-level range is smaller than that in many other areas of Afghanistan. It is possible that the water levels are relatively stable because of recharge from the Kunduz River; however, water-supply wells in the Kunduz area may still be susceptible to becoming dry because the amount of static water generally is small. Close monitoring and careful management of potential new surface-water or groundwater withdrawals would help to protect the quantity and quality of the current supply in existing wells. Specific conductance in most wells was 1,000 to 2,000 µS/cm, indicating a relatively low dissolved-solids content, whereas the specific conductance in GWM 120 was higher (about 8,000 µS/cm).

22C.2.2 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 Kunduz celestite AOI (B.E. Hubbard, T.J. Mack, and A.L. Thompson, unpub. data, 2011) were conducted using DEM and natural-color satellite imagery (fig. 22C–6) and Advanced Spaceborne Thermal Emission and Reflection Radiometry (ASTER) satellite imagery (fig. 22C–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 22C–6 were delineated visually, whereas those in figure 22C–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, particularly those determined by DEM and natural-color Landsat (fig. 22C–6), show a northwest trend that may reflect the regional bedrock structure and mapped fault trends in the AOI (fig. 22C–5*a*). Some lineaments reflect the east-west-trending mapped faults in the AOI (fig. 22C–5*a*). Areas where lineament density is high (figs. 22C–6, 22C–7*a*, 22C–7*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.

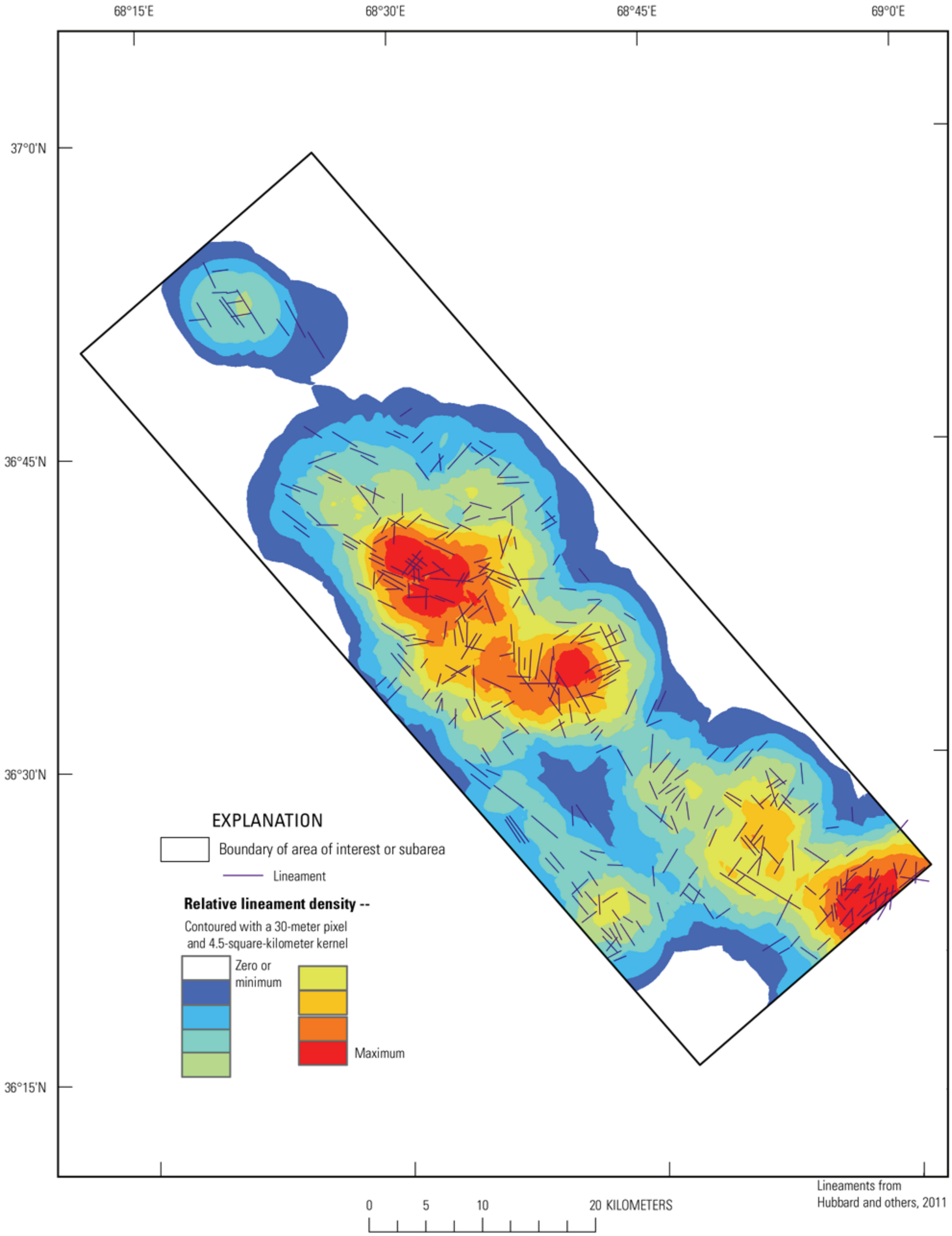
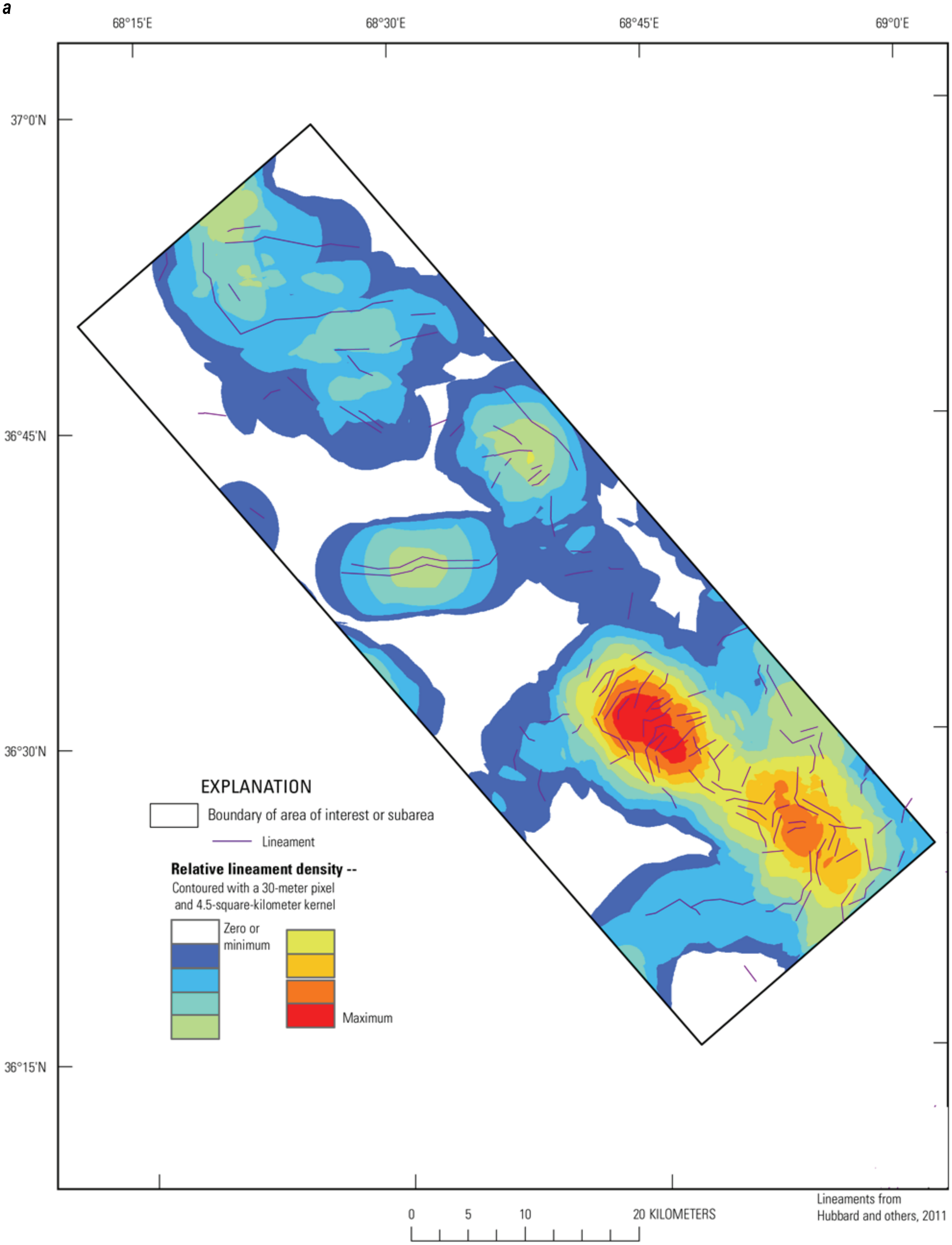


Figure 22C–6. Lineaments and lineament density based on 30-meter digital-elevation-model data and natural-color Landsat imagery in the Kunduz celestite area of interest in Afghanistan.

a


68°15'E
68°30'E
68°45'E
69°0'E
37°0'N
36°45'N
36°30'N
36°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

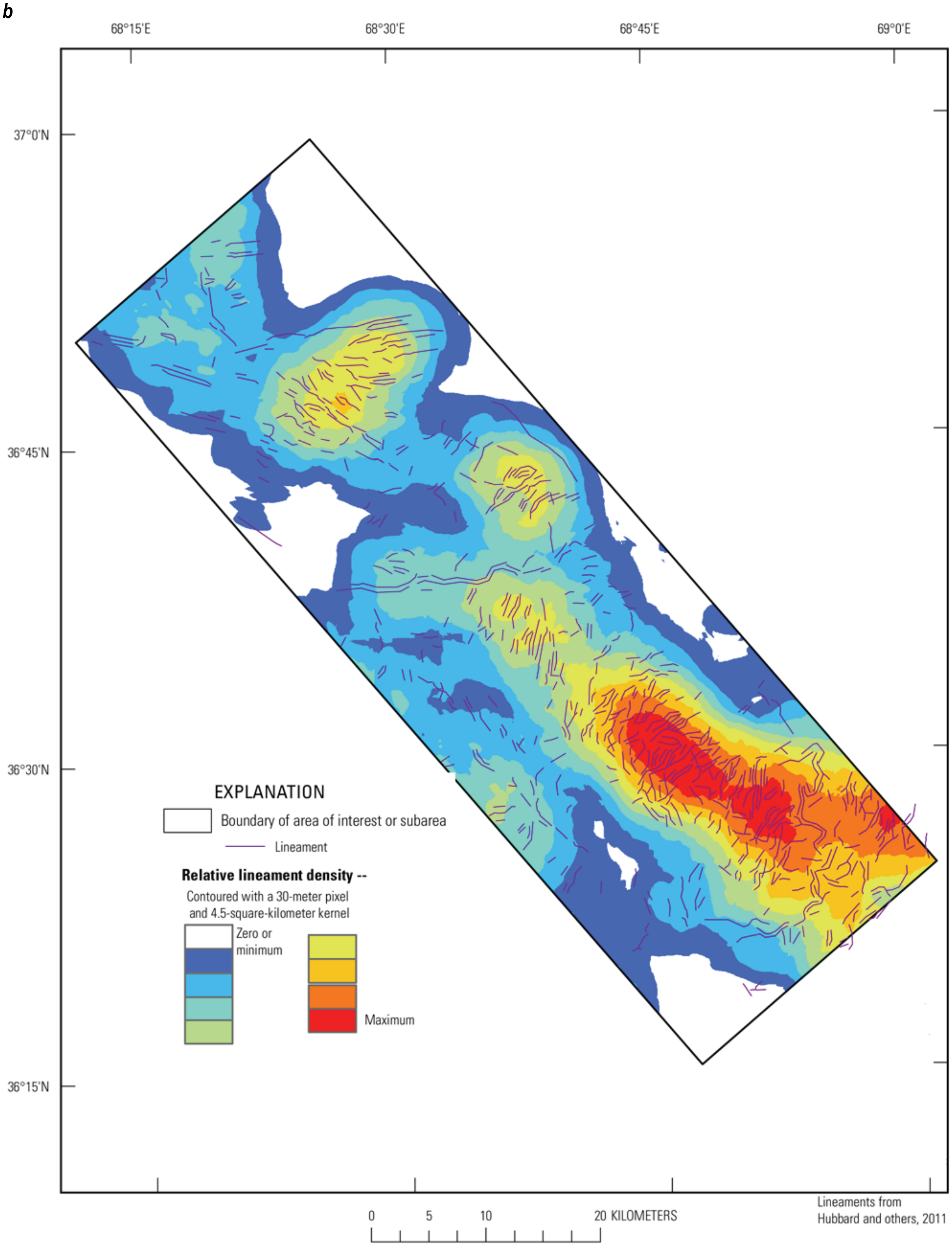


Figure 22C–7. (*a*) Lineaments and lineament density based on 30-meter multispectral Landsat imagery and (*b*) lineaments and lineament density based on 15-meter multispectral Landsat imagery in the Kunduz celestite area of interest in Afghanistan.

22C.3 Summary and Conclusions

Water resources are more likely to be available for mining and other uses in the Kunduz celestite area of interest (AOI) than in other areas of Afghanistan. Water resources in the AOI and surrounding area consist mainly of surface water, particularly in the Kunduz and Nahrin Rivers. Shallow alluvial, or river-channel sediment, aquifers are present in the valley bottoms of the AOI and 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. Any new diversion of water from the rivers to support mining activities would need to be closely monitored, particularly during low-flow periods. The quantity and quality of surface-water resources 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.

No information about deep groundwater in the AOI or adjacent areas is available; however, deep groundwater resources are likely to be present. Some areas of the AOI, as indicated by generalized geohydrologic maps and lineament analyses, are potential areas for further exploration for groundwater resources; these areas include the sands, undifferentiated geohydrologic group; the conglomerate sediments and rocks geohydrologic group; and the underlying clastic and carbonate sedimentary rocks. 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, hydraulic well testing, and chemical and isotopic analysis of surface water and groundwater are needed to adequately characterize the extent and availability of water resources in the AOI.

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