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Remote sensing based strategy of stream sediment sampling for mineral exploration in Peshawar Basin, Khyber Pakhtunkhwa, Pakistan

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Abstract

Remote Sensing (RS) and Geographic Information System (GIS) are frequently and effectively used in exploration and sustainable utilization of mineral resources. Minerals of economic importance can play a significant role in the socio-economic development of the society. The initial step in mineral exploration at a regional scale is the stream sediments survey to locate the prospecting areas. The presence of heavy minerals and metals in stream sediments is used as an indicator for the existence of source rock in the watershed of the corresponding stream. The province of Khyber Pakhtunkhwa in Pakistan is blessed with minerals of economic importance. However, there is a need for their exploration and sustainable utilization.

In the present study RS and GIS techniques are used to assist in exploring the mineral resources in the Peshawar basin of the Khyber Pakhtunkhwa which mainly comprises of five districts. The freely available remote sensing based Digital Elevation Model (DEM) is used for hydrological modelling to map the streams network in the basin and their corresponding watersheds. The watershed outlets of the first order streams are mapped and are proposed as the optimal sites for collection of stream sediments samples for subsequent mineralogical and geochemical analysis. The geochemical analyses of stream sediments can be used to demarcate watersheds with potential minerals concentrations. The proposed methodology can be effectively replicated in any minerals prospecting area.

Keywords: Hydrological modelling; DEM; Mineral exploration; ArcHydro.

1. Introduction

Mineral resources have the potential to significantly contribute to the socio-economic development around the world. Advanced industrialization, urbanization, communication systems and transportation are dependent on sustainable availability of mineral resources (Akhtar, 2005). However, minerals exploration and their sustainable utilization require extensive investment in technology and research. Minerals exploration at regional scale usually begins with the geochemical analysis of stream sediments and subsequently traces the location of the source rock of possible mineralization (Ohta et al., 2005; Yousefi et al., 2012; Yousefi et al., 2013). Site selection for optimal stream sediment collection is of crucial importance and often requires information of the drainage network of the potential areas. Digitizing the drainage network from existing maps or field based mapping of drainage network is a laborious and time consuming task.

The modern tools of Remote Sensing and Geographic Information System (GIS) are effectively and efficiently used to assist in exploration and sustainable utilization of mineral resources at a regional scale. Remote sensing involves collection of spatial data of the ground features by detecting and measuring the reflected electromagnetic radiations without direct contact with the object. Remote sensing derived open source Digital Elevation Models (DEM), such as Shuttle Radar Topography Mission (SRTM) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER DEM), can be effectively and efficiently used to acquire topographic information with global coverage. A DEM is a thematic raster model where each grid holds the value of elevation. The SRTM and ASTER DEMs can be used to map drainage network and subsequently propose sites for stream sediment samples collection.

The province of Khyber Pakhtunkhwa, Pakistan is blessed with minerals of economic importance. However, there is lack of advance tools and techniques to explore the mineral resource of the region. The Directorate General Mineral and Mines (DGMM), Government of Khyber Pakhtunkhwa is interested in utilization of modern techniques of RS and GIS, aiming for mineral exploration in the province. The DGMM has, therefore, given the responsibility to the National Center of Excellence in Geology (NCEG), University of Peshawar to provide a regional mineralogical and geochemical overview of the stream sediments in the central (i.e., Peshawar basin) and southern parts of the Khyber Pakhtunkhwa province. The Peshawar basin is comprised of five districts i.e. Peshawar, Charsadda, Nowshera, Mardan and Swabi (Fig. 1). Because of the large spatial extent of the study area, geochemical analyses of stream sediment samples are used as a key indicator for mineral exploration. In this study, we have used ASTER DEM to map drainage network in the area and subsequently propose suitable sites for collecting the stream sediments samples that can be subsequently analyzed for their minerals and metals concentrations.

2. Methodology

2.1. Data used

The ASTER imaging system was designed to generate along-track stereo images and launched in December 1999 as part of the NASA's Earth Observing System (EOS) (Yamaguchi et al., 1998; Abrams, 2000). ASTER consists of three different subsystems, the visible/near infrared (VNIR) with a spatial resolution of 15 m, the shortwave infrared (SWIR) with a spatial resolution of 30m and the thermal infrared (TIR) with spatial resolution of 90 m. The VNIR subsystem consists of a nadir- and a backwards-looking telescope generating along-track stereo images that can be used to generate DEM (Abrams, 2000).

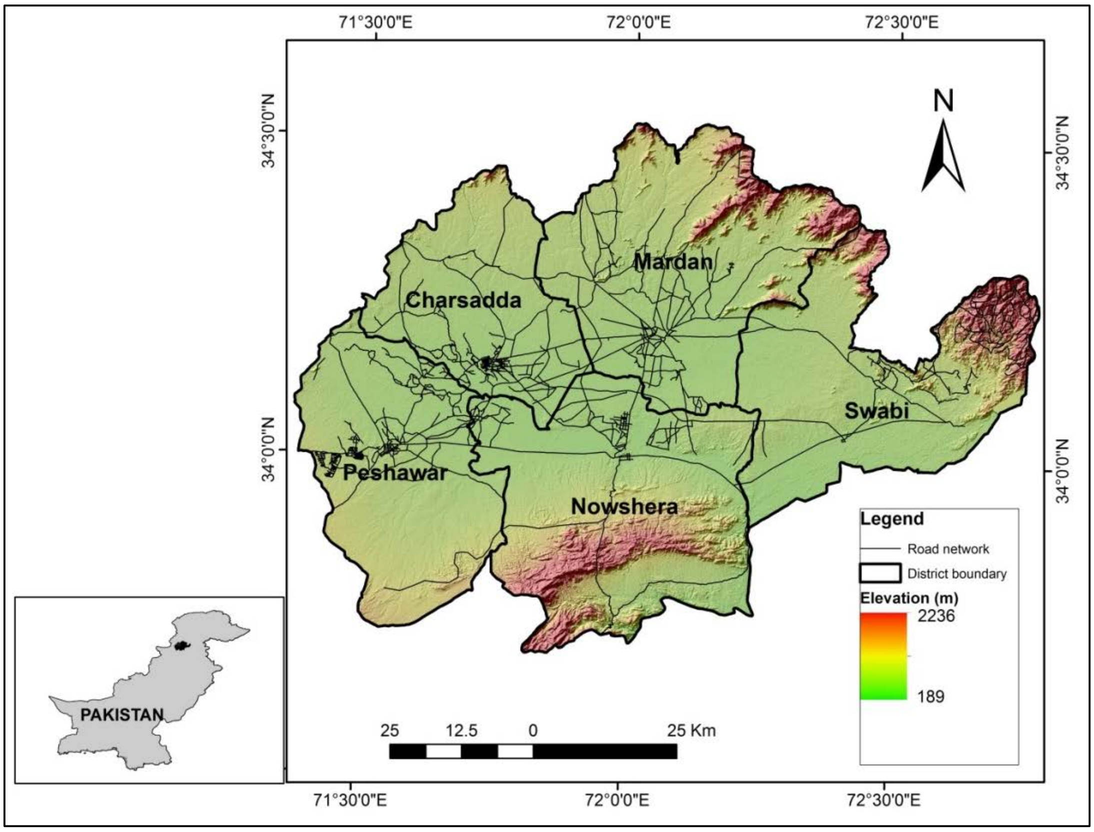

Fig. 1. Location map of the Peshawar basin with ASTER DEM derived topography.

The Ministry of Economy, Trade, and Industry (METI) of Japan and the NASA, USA jointly released the ASTER Global Digital Elevation (ASTER GDEM) in June 2009. ASTER GDEM provides spatial coverage spans from 83 degrees north latitude to 83 degrees south, encompassing 99 percent of Earth's landmass. In October 2011, the improved ASTER GDEM Version 2 (GDEM V2) was launched. The improved GDEM V2 adds 260,000 additional stereo-pairs and reducing the occurrence of artifacts. The refined production algorithm provides improved spatial resolution, increased vertical and horizontal, and superior water body coverage and detection (Tachikawa et al., 2011).

2.2. Hydrological modelling

The ASTER DEM is analyzed in the ArcHydro tool of ArcGIS for hydrological modelling. The ASTER DEM was used to extract the flow direction and flow accumulation in the study area. These maps were subsequently used to extract the streams network. The watershed for each stream was mapped and the outlets of these watersheds were suggested as sites for collection of stream sediment samples.

The flow direction map shows the overall drainage pattern in the study area. The process of flow direction computation leads to an integer raster layer that shows flow direction from each pixel to its steepest downslope surrounding eight neighbors. If there is no lower neighbor available, the algorithm assumes it as a lake, pond or a flat area. If all the neighbors are higher, it is computed as local minima. The ASTER DEM is used as input to generate the flow direction map for the study area.

Subsequent to flow direction, the number of pixels contributing flow to each downslope pixel is computed. Each pixel in the flow accumulation map gets a value that refers to the number of pixels accumulating into that pixel. Multiplying the pixel value with the spatial resolution of the DEM calculates the area as the watershed of each pixel. The pixels with zero flow accumulation can be used to detect mountains ridges. Pixels with relatively higher flow accumulation values are areas accumulating flow from the surrounding areas and are identified as the stream channels.

Subsequent to the flow accumulation map, the stream network can be extracted considering the level of required information. Streams can be extracted by selecting the maximum area of accumulation as threshold in the flow accumulation map. By giving less area of accumulation, minor streams will be selected and hence a dense stream network can be extracted. The area of higher accumulation extracts only the major stream network in the study area. Considering the required details of the stream network for this study, we have selected streams with flow accumulation of a minimum of 10 km^2. The selected streams are further reclassified following the Strahler classification scheme (Strahler, 1964). To avoid duplication of the samples collection, we have selected only the first order streams. Subsequently, the watershed for each of the extracted stream was demarcated. Outlets of the demarcated watershed are computed. Since any minerals in sediments eroded and transported by water passes through the watershed outlets, and hence the streams outlets just above the junction with another stream are proposed as sites for collection of stream sediment samples.

3. Results

3.1. Flow direction map

The flow direction map (Fig. 2) shows overall drainage pattern in the Peshawar basin. The drainage pattern in the five districts differs in their direction of flow. The flow direction in Peshawar district shows that water flows predominantly from southwest to northeast. The flow direction in the Swabi and Mardan district is mainly from north to south. In Charsadda district, it is from north-west to southeast and in Nowshera it is from west to east. Water from the Mardan, Charsadda and Peshawar districts is flowing towards Nowshera district.

3.2. Flow accumulation

Flow accumulation map of the Peshawar basin (Fig. 3) shows the accumulation of water at different locations in the region. Pixels with higher flow accumulation values represent the streams (Fig. 3a). Flow accumulation map of the basin shows that water from Peshawar, Mardan and Charsadda are subsequently accumulating in the Nowshera district and hence the streams of Nowshera have higher accumulation values than the streams of Peshawar, Mardan and Charsadda districts (Table 1). The major stream from Nowshera district is later entering in the Swabi district for short distance and hence it has higher flow accumulation than the Nowshera district (Table 1). The pixels with maximum flow accumulation value in each district and its corresponding area is shown in the Table 1.

Table 1. Flow accumulation in the districts of the Peshawar Basin.

Districts	Maximum flow accumulation (number of pixels)	Area in km^2
Mardan	2558650	2302.79
Charsadda	1442892	1298.60
Peshawar	573541	516.19
Swabi	6207609	5586.85
Nowshera	6184424	5565.99

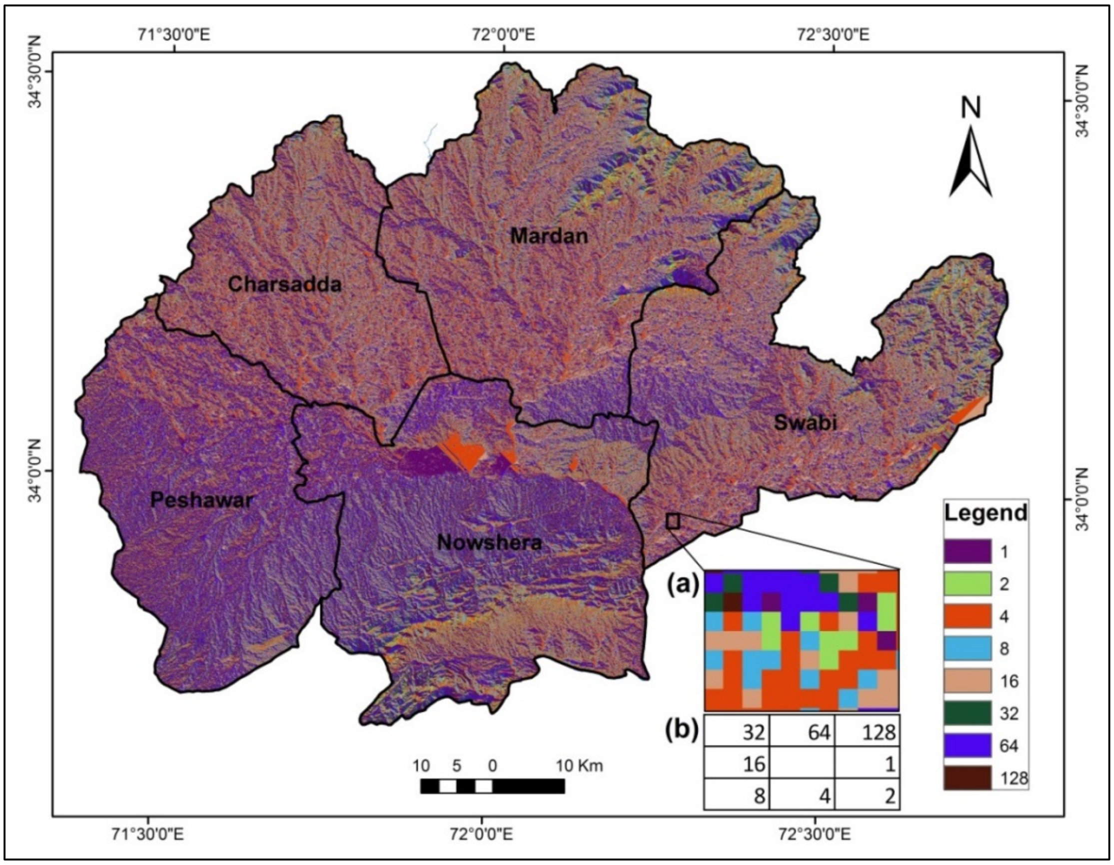

Fig. 2. Flow direction map of the Peshawar basin. (a) inset of the map showing the flow direction of different pixels and (b) the values for each direction from the center pixel and corresponding colours are assigned in map.

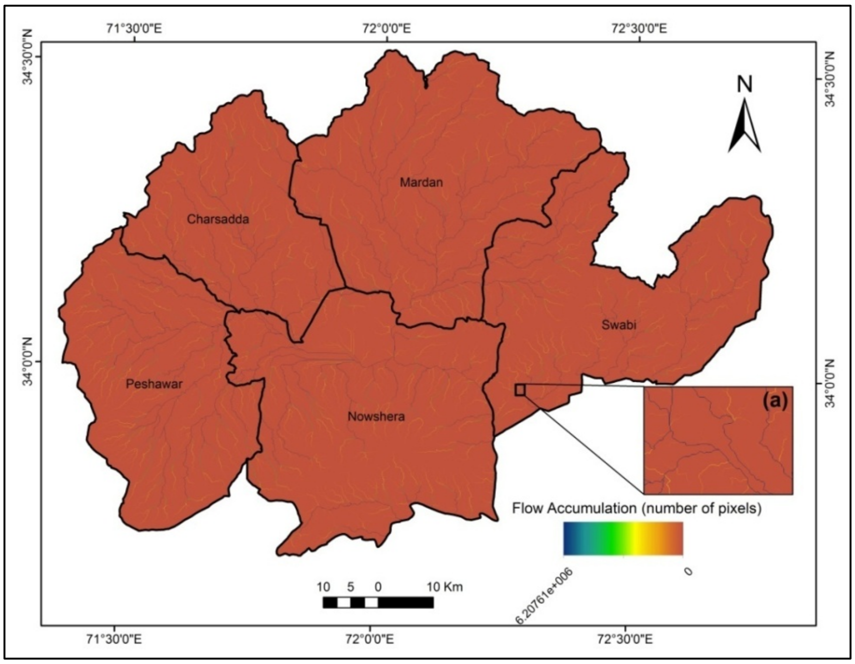

Fig. 3. Flow accumulation map of the Peshawar basin. (a) inset of the flow accumulation map.

Table 2. Statistical summary of the streams network in Peshawar basin.

District	Total length (km)	Maximum (km)	Minimum (km)	Mean (km)	Number of streams
Mardan	592.51	24.192	0.03	2.62	226
Charsadda	368.86	22.22	0.03	1.47	251
Peshawar	496.14	19.63	0.03	3.39	146
Swabi	435.79	15.19	0.03	2.72	160
Nowshera	624.626	22.59	0.03	2.52	247

3.3. Stream network

The streams with more than 10 km^2 of flow accumulation are shown in Figure 4. Minor streams ignored in this study can be extracted if the selected threshold is reduced. The length of streams network in each district of the Peshawar basin is shown in Table 2. The total length of stream in each district also depends on the area of the district. The density of drainage network in Peshawar (0.39 km/km^2) and Charsadda (0.37 km/km^2) is higher than the Nowshera (0.36 km/km^2) and Mardan (0.36 km/km^2) with minimum density in Swabi district (0.28 km/km^2), also evident from Figure 4.

3.4. Watershed delineation and outlets location

Subsequent to the stream network delineation, we have derived the watershed for the first order streams (Fig. 5). It is assumed that the sediments in these streams transported weathered material of the source rocks in the respective watersheds. Hence the outlets of these watersheds (Fig. 6) are proposed as sites to collect stream sediment samples for subsequent geochemical analysis aiming for mineral exploration. Number of sample proposed in each district in shown in Table 3. The spatial locations (geographic coordinates) of these outlets are shared with the sample collection teams to assist them in the field.

Table 3. Number of proposed samples in each district.

District	Proposed sampling sites
Mardan	53
Charsadda	25
Peshawar	46
Swabi	54
Nowshera	53

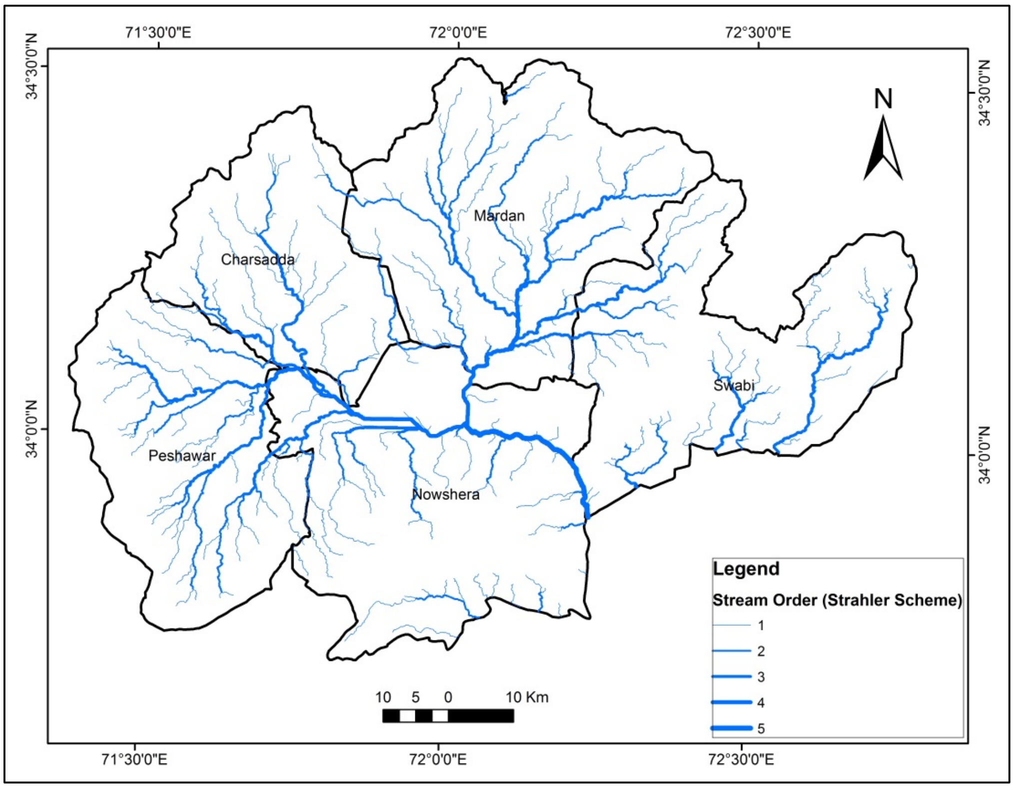

Fig. 4. Streams in the Peshawar basin with flow accumulation of more than 10 km[2.] Stream are arranged according to the Strahler stream order scheme.

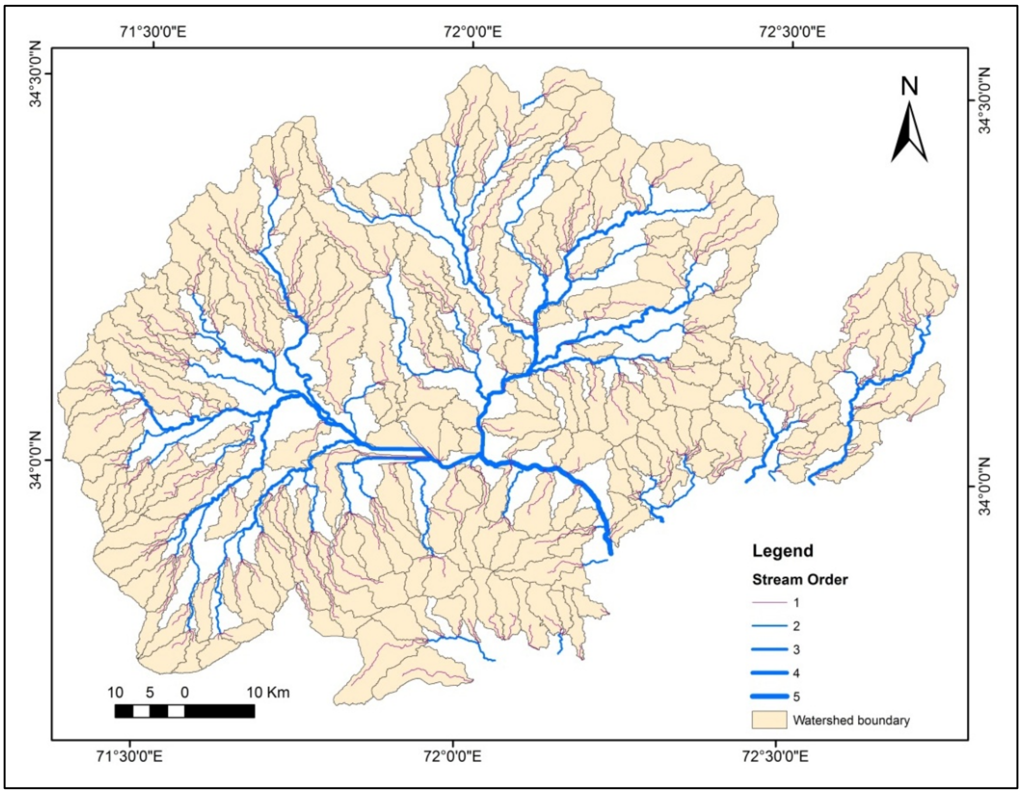

Fig. 5. Watersheds in the districts with minimum catchment of 10 km^2.

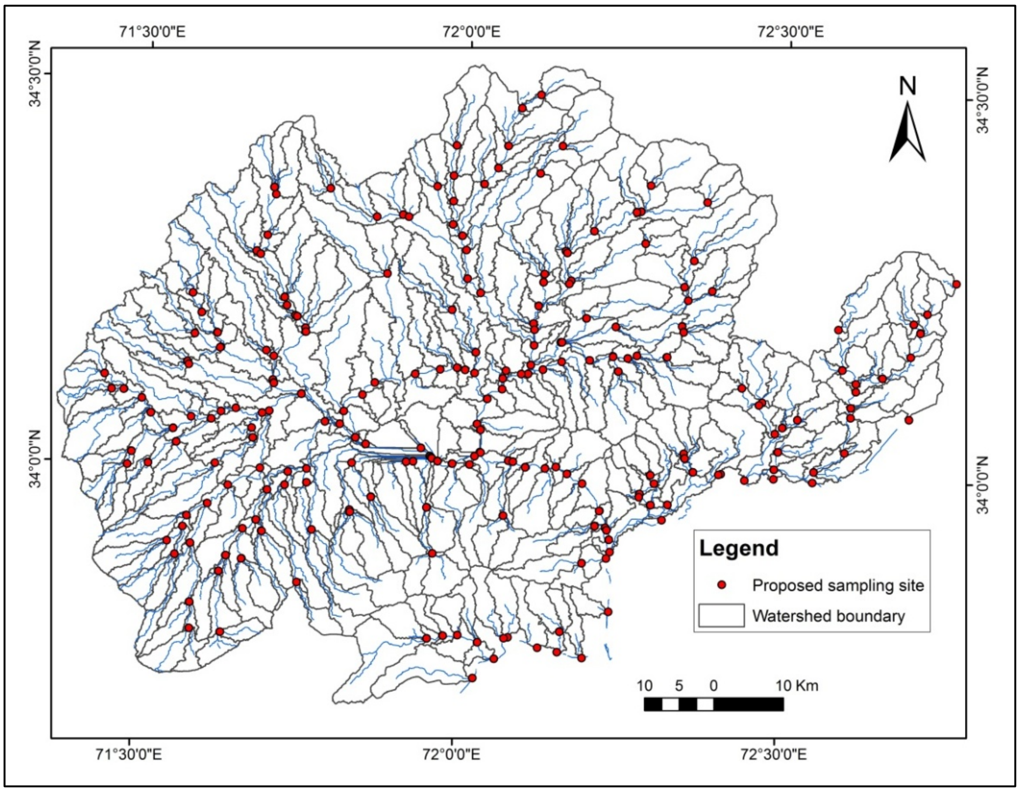

Fig. 6. Proposed sampling sites for the collection of stream sediments samples.

4. Conclusions

Geographic Information System and Remote Sensing are frequently and efficiently used to assist exploration geologists in the mineral exploration. In this study, a RS based methodology is proposed which can be effectively used to locate sites for the collection of stream sediments samples for geochemical exploration at regional scale. The freely available ASTER DEM is used to propose the sites for stream sediments samples. The streams with a minimum flow accumulation of 10 km^2 are extracted. Subsequently only first order streams are selected in the present study. The watershed for these streams is delineated and the outlets of the streams are proposed as the appropriate sites for the collection of stream sediments samples. This study concludes that the proposed methodology can be effectively used to utilize freely available ASTER GDEM to assist in mineral exploration at regional scale.

5. Acknowledgement

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