J. Mt. Sci. (2020) 17(1): 42-49 e-mail: jms@imde.ac.cn http://jms.imde.ac.cn
https://doi.org/10.1007/s11629-019-5384-0

Landsat based distribution mapping of high-altitude peatlands in Hindu Kush Himalayas – a case study of Broghil Valley, Pakistan

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Citation: Khan A, Said A, Ullah I (2020) Landsat based distribution mapping of high-altitude peatlands in Hindu Kush Himalayas – a case study of Broghil Valley, Pakistan. Journal of Mountain Science 17(1). https://doi.org/10.1007/s11629-019-5384-0

Abstract: In the alpine regions of Hindu Kush, Himalayas and Karakorum, climatic and topographic conditions can support the formation of peat, important for the livelihood of the local communities, and ecological services alike. These peatlands are a source of fuel for the local community, habitat for nesting birds, and water regulation at source for rivers. Ground-based surveys of high-altitude peatlands are not only difficult, but also expensive and time consuming. Therefore, a method using cost-effective remote sensing technology is required. In this article we assessed the distribution and extent of high-altitude peatlands in a 2000 ha area of Broghil Valley using Landsat 8 data. The composite image was trained using a priori knowledge of the area, and classified into peatland and non-peatland land covers using a supervised decision tree algorithm. The Landsat-based classification map was compared with field data collected with a differential GPS. This comparison suggests 82% overall accuracy, which is fairly high for high altitude areas. The method was successfully applied and has the potential to be replicated for other areas in Pakistan and the high-altitude regions of the neighbouring Asian countries.

Keywords: Peatland distribution; Chitral; Qurumbar; Wakhi; Hindu Kush; Yarkhun

Received: 10-Jan-2019
1st Revision: 25-Apr-2019
2nd Revision: 21-Aug-2019
Accepted: 11-Oct-2019

Introduction

Peatlands are characterized by the accumulation of organic matter (peat), which is derived from dead and decaying plant material under conditions of permanent water saturation (Parish et al. 2008). Peatlands worldwide are major carbon storage sites (Joosten et al. 2012; Biancalani and Avagyan 2014). The formation of peatlands in regions such as North America is traced to the exposure of land after deglaciation and is estimated at 13,000 Cyr BP (Calendar Years before present) in the south and 7000 Cyr BP and

4000 Cyr BP in the north (Prest 1970).

In Hindu Kush – Himalayas (HKH), naturally occurring high-altitude pastures above the tree line are characterized by wet conditions and low temperatures that result in incomplete degradation of organic material. The partially degraded organic material accumulates over time (Khan and Said 2012; Khan et al. 2010; Lafleur et al. 2005; Laiho 2006) to create high-altitude peatlands (Ranhotra and Kar 2011; Kumaran et al. 2016). These peatlands might date back to the deglaciation of the region after collision of the Indian Sub-continent with Asia and the consequent Himalayan orogeny, 50 million years ago (Kumaran et al. 2016; Frisch Meshed and Blakey 2011; UNDP 2002; Christopherson 2000).

Various disciplines define peat differently (Bond 1986). The American Geological Institute defines peat as "an unconsolidated early stage of coal deposit of semi-carbonized plant remains of a water saturated environment such as a bog or fen and of persistently at least 75% moisture" (Gary et. al 1974). Peat has less than 25% ash content, which distinguishes it from other organic soil materials. It has higher rank phytogenic material, and has lower British thermal unit (BTU) value on water saturated basis (Bond 1986).

Bond (1986) has described soil consisting of greater than 75% organic matter in dry state as the fuel grade peatlands in Florida. In order for a peat deposit to be classified as fuel grade, the deposit must be at least four feet thick (or deep), and not less than 80 contiguous acres per square mile and yield not less than 8,000 BTU per pound (moisture free).

Carbonization of peat results in carbon enrichment, which is essential for making it desirable fuel. This is also a basis for peat classification against wood (Hreibljan et al. 2015). According to one study, one pound of wood contains 20% fixed carbon and provides 9,300 BTU energy when is moisture/mineral free, while one pound of peat contains 28% fixed carbon and provides 10,600 BTU energy. Lignite contains 47% fixed carbon and provides 12,400 BTU energy (U.S. Department of Energy 1979). Thus, peat is a better fuel than wood and approaches lignite.

The fuel usefulness of peat can be determined from its fixed carbon, ash content, moisture, and volatile contents. Peat has higher volatile content than coal, a positive attribute that makes peat a suitable fuel. The fixed carbon content in peat is responsible for its combustion energy (U.S. Department of Energy 1979; Clark 2008). Volatile and fixed carbon contents are important attributes that can determine utility and suitability of a peat, and can categorize it for use. Based on the definitions applied, "peat in Broghil Valley could be defined as the organic soils created by impartial decomposition of plant material under humid cold environment, where thickness of peat is influenced by the terrain and geographic process taken place thousands of years ago". The definitions don't touch the incremental process in peat, which under cold environments is extremely slow.

Ullah and Khan (2010) analysed 30 samples of Peatlands from Broghil and found that organic matter ranged from 32% to 93% with average of 47% organic matter in peatlands samples collected above the water-level and 59% organic matter in peatlands samples collected from below the water levels. In addition to key ecological functions in furnishing nesting habitat for birds and regulating the hydrological processes of high-altitude meandering streams (Joosten et al. 2012), the Broghil Valley peatlands provide grazing grounds for around 20,000 goats, sheep, cows, oxen, donkeys, horses and yaks.

The 1600 people living in Broghil valley learned to use peat as a fuel from a migrant family that arrived from China in the 1940s. Peat use varies seasonally: in summer (May–September), when household energy is partly derived from fuelwood, animal dung or agriculture residues, daily consumption of peat *per* household is 40–50 kg. In winter, when people are mostly confined to their houses by heavy snowfall and cold weather, this rate jumps to almost 80–100 kg *per* day *per* household (discussions with local community during Broghil Valley visit in 2008, and subsequent surveys by Pakistan Wetlands Program 2008–2012). Local people are well aware of the importance of peatlands for their livelihoods and, accordingly, place high value on them. However, they are now obliged to mine peat because they have no access to alternative fuels such as wood, kerosene oil or liquid propane gas, and have become dependent on peat fuel for their heating and cooking needs (personal observations 2008). The resulting degradation of peatlands will be detrimental for local communities in the long run.

The distribution of high-altitude peatlands in the Pakistani Himalayas has not yet been studied in detail. Examples in Broghil Valley were noted by the author in July 2008 (PWP 2008) and, since then, have become a focus of research and conservation for concerned organisations in the region (Khan et al. 2010; Ning 2012; Rafae 2015; Shah and Ahmad 2013). Based on ecological value, landscape features, ecological significance and biodiversity of the area in addition to socio-economic significance of the peatlands, Broghil was declared a National Park in 2010 (Government of Khyber Pakhtunkhwa 2010). However, there is no inventory of the natural resources including high altitude peatlands of the valley to form a basis for conservation planning in the valley.

In view of the importance of the Broghil peatlands for carbon storage, their role in supporting the local flora and fauna, their function as water buffers (Joosten et al. 2012; Biancalani and Avagyan 2014), and the continuing use of peat by the local community, it is important to know the distribution of these peatlands for monitoring and conservation. Ground-based studies of the high-altitude peatlands in Broghil valley are expensive and difficult because of the harsh climatic conditions. These difficulties make remote sensing solutions highly desirable (Shrestha and Zinck 2001). Thus, the mapping of peatlands using Landsat data (Arvidson et al. 2001) would be an important step towards assessing the peatland resources of the valley, the impact of peat extraction on the ecosystem, and the livelihood of the local community. Once developed, the remote sensing method could also be applied to determine the extent of other high-altitude peatlands across the mountain ranges of Pakistan and neighbouring countries. It could also be used to analyse Landsat time-series data to estimate the rate of any changes due to natural phenomena such as global warming or due to extraction by the local community.

In this study, we developed and validated a technique for mapping high-altitude peatlands using a single date Landsat 8 image from northern Pakistan. The Landsat data are available from USGS at 30 metre spatial resolution for the whole world. We aim to demonstrate the utility of remote sensing data applications to map high altitude peatlands, as a key ecosystem feature. This technique provides a quick snap shot of target resources, such as high-altitude peatlands, that otherwise could only be studied with labor intensive field techniques requiring time and logistic resources.

1 Materials and Methods

1.1 Study area

The study area is bounded by the coordinates 36°54'43.5" N, 73°03'47.5" E in the northwest and 36°41'21.28" N, 73°53'18.86" E in the southeast. Broghil valley lies at the northern edge of the Chitral District of Khyber Pakhtunkhwa Province in Pakistan, at altitudes ranging from 3,100 m (10,200 ft) at Kishmanjah village to 4,300 m (14,000 ft) at Kurambar Lake. Broghil Valley has borders with Afghanistan to the north and west, where a narrow strip of Afghan territory (Wakhan) separates it from Tajikistan; with the Gilgit Baltistan province of Pakistan to the east; and with Yarkhoon Valley (also part of Chitral District) to the south (Figure 1).

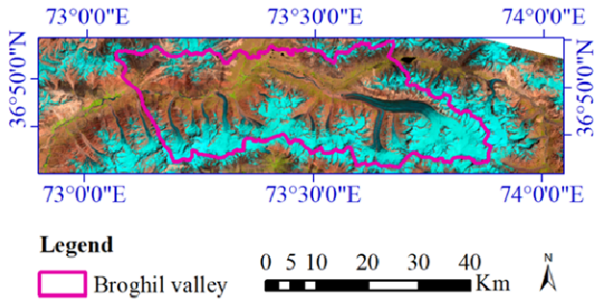

Figure 1 The study area, Broghil Valley in Khyber Pakhtunkhwa, Pakistan. (Landsat 8 image of July 28, 2013 (source: glovis.usgs.gov).

The climate of northern Pakistan is very cold and moist due to the presence of high mountain systems (Khan and Said 2012; Shah and Ahmad 2013). The eastern part of the country lies within the moist temperate zone of the western Himalayas, while to the north-west the Karakorum and Hindu Kush ranges present a much drier environment (Ives and Messerli 1989). In these areas, temperatures drop below freezing during winter. The maximum July/August temperature in the valleys is 20°C-25°C, while the minimum temperature in January drops to -10°C (Dijk and Hussein 1994).

1.2 Landsat image analysis

Application of low- and medium-resolution remote sensing data in high altitude landscapes is challenging due to snow cover, cloud cover and shadows. However, the high temporal resolution of these data is valuable and results in opportunities for image capture during periods of low clouds and snow cover. The data used in this research are derived from a single 185 km × 170 km scene from Landsat 8 OLI (30 m × 30 m spatial resolution), identified in the Landsat Worldwide Reference System 2 (WRS-2) as path/row 150/035. The peatlands of Broghil Valley, being snowbound for most of the year (November to June), could only be detected in images with minimum snow cover. We used the scene captured on 28 July 2013.

We stacked all the bands excluding the thermal band (Band 8) and pre-processed the imagery for radiometric and geometric corrections (Arvidson et al. 2001; Chander et al. 2009). For visualization in PCI Geomatics Focus we used three bands, band 6 (SWIR), band 5 (NIR), and band 4 (Red)—which enabled better visual interpretation of the land covers. The reflectance of peatlands, due to higher moisture content in comparison to other land covers in the valley, enabled identification of peatlands vs. non-peatlands land covers. Analyses were performed using the Easi programming language and Focus application of PCI Geomatics. Image analysis to separate peatland and non-peatland land covers was done using supervised classification with a bagged decision tree algorithm developed by the Global Land Analysis and Discovery Team at the University of Maryland (Breiman 1996; Breiman et al. 1984; Hansen et al. 1996; Khan et al. 2016).

To classify the area of interest in the image, the Broghil valley was marked with a polygon using Google Earth kml file, which was converted to a shapefile in ArcGIS10.2. The area falling outside of the Broghil region was masked as no-data. Using visual interpretation of the Landsat data, hand-drawn training samples for peatlands and non-peatlands (Figure 2) were created (Tokola et al. 1999). The Landsat-composite was related to training data via a bagged classification tree algorithm (Breiman 1996; Hansen et al. 1996; Potapov et al. 2012; Bwangoy et al. 2013). A classification tree software was developed by our research group following the algorithm described by Ripley (1996). Classification trees employ an

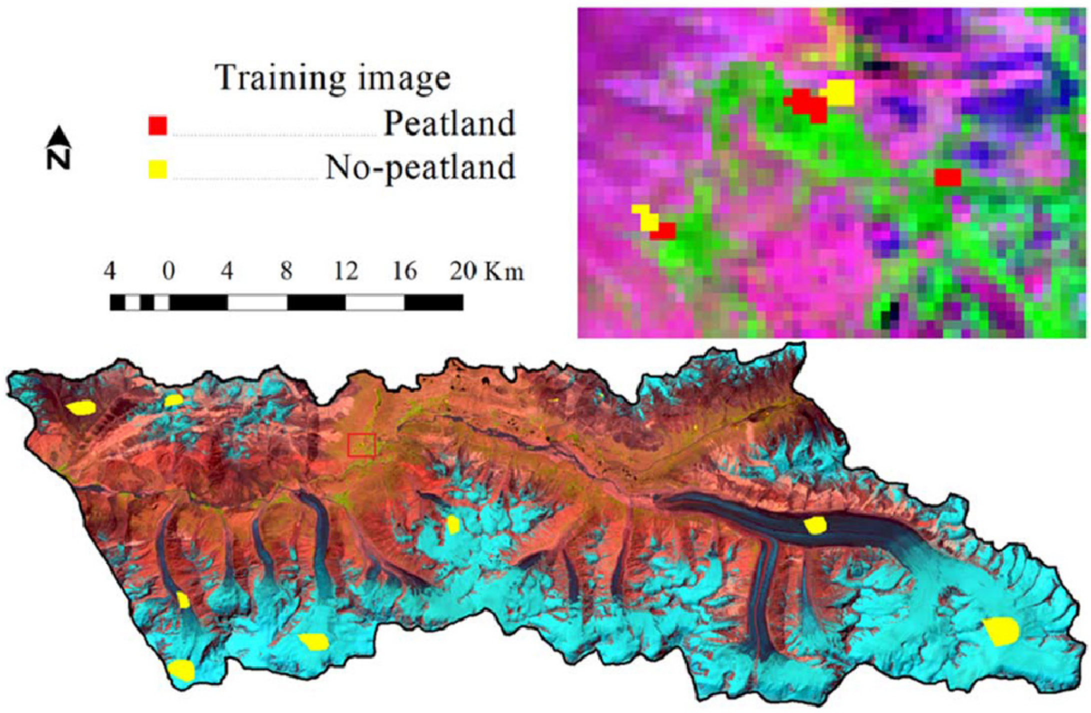

Figure 2 Peatlands and non-peatlands land covers training of Landsat image (July 28, 2013). Area marked in red box is projected above as inset.

entropy measure, referred to as deviance, to split multidimensional space of dependent variables into successively more homogeneous hyper volumes, called nodes. The best univariate split was sought from all independent variables, and the process was repeated until a perfect tree was fit or preset conditions for termination of tree growth were met. We terminated each classification tree when additional splits decreased model deviance by less than 0.001 of the deviance of the total training set population (Bwangoy et al. 2010, 2013). To further avoid overfitting, we used a set of seven bagged tree models each derived from a 20% random sample of training pixels. Each tree reporting a per-pixel probability of wheat cover class membership; the per-pixel median of the seven model outputs was taken as the result (Potapov et al. 2012). Peat was categorized if this median value was equal to or greater than 50%. The area of peatlands in the Broghil valley was calculated with pixel counts in PCI Geomatica Focus.

The classification script was run in perl to classify the image. The results were compared with high resolution images from Google Earth for corrections. The training data were revised accordingly and the classification script was run again. The iteration of classification was repeated several times to achieve a result that compared satisfactorily with a visual analysis of Google Earth images.

The validity of the classification was calculated with ground truth point samples, which were taken with a Differential GPS in the field. The GPS points were converted to KML format to overlay on Google Earth and then to a shape file in ArcMap 10.1. The shape file was overlaid on the classification results to calculate the Confusion Matrix for the accuracy assessment.

1.3 Ground-based survey

In 2010, during a survey of land use in the valley, 34 ground-surveyed points were recorded with differential GPS. These consisted of 26 points from peatlands and eight points from non-peatland areas (personal work with Pakistan Wetlands Program). These GPS points were used to validate the peatlands classification using Landsat 8 data. The GPS points were overlaid as a kml data layer on the Google Earth image to identify points falling in peatland and non-peatland areas. The kml data layer was converted into an ESRI shape file with ArcMap 10.1. The shape file was overlaid on the peatlands classification map to calculate the Confusion Matrix (Stehman and Czaplewski 1998; Xie et al. 2008) for estimating overall, user and producer accuracies of the Landsat based peatland map of the valley.

2 Results

The supervised classification map shows peatlands distributed along the Broghil river from Garum Chashma (lower valley) to near Qurumbar Lake (higher altitude). The total area covered by peatlands is about 1,933 ha, forming about 1.66% of the valley's total area (~118,500 ha). The total area of the valley, calculated with measuring tool in Google Earth, was about 1200 hectares (Figure 3).

The reference data were composed of 38 points, of which 26 (68%) were from peatlands, while 12 (32%) were from non-peatland area. According to the confusion matrix created from the 38 GPS points (Figure 3), 20 peatland points corresponded to peatland map, while six of the peatland points were mapped as non-peatland area. Eleven of the reference points from the non-peatland area correspond to non-peatland map, while one mapped as peatland (Table 1).

The ground reference points were recorded with differential GPS and overlaid on the Landsat-based map. This comparison resulted in user accuracy of 77% and a producer accuracy of 95% for peatlands, with user and producer accuracies of 92% and 65% respectively for non-peatland areas. The overall accuracy result was 82%, which demonstrates a highly reliable map product of the high altitude peatlands using Landsat data.

3 Discussion

Peat is defined in different ways in accordance to the local ecological setup. Peatlands in high altitude mountainous areas of Asia, such as Broghil in Pakistan, might have characteristic resemblances with the northern peatlands that occur in cold to cool areas of mountains, arctic and

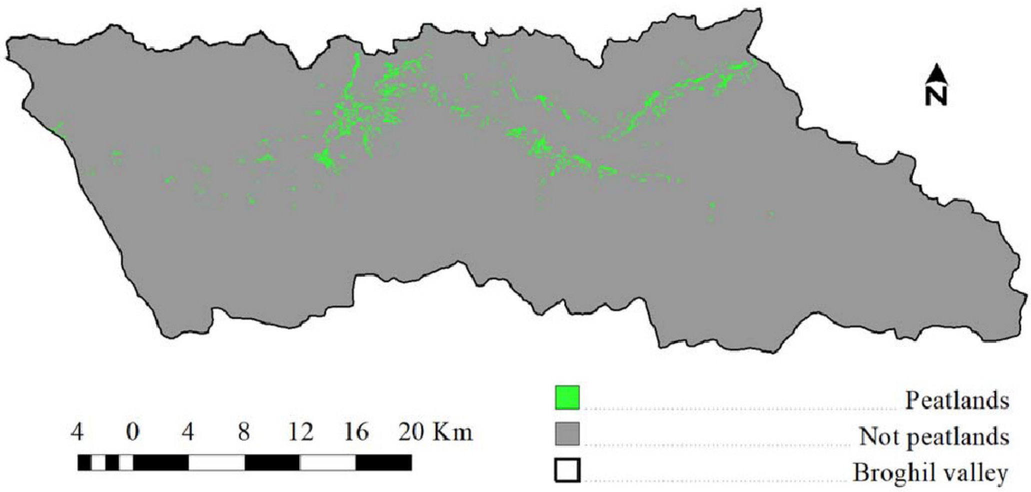

Figure 3 Landsat-based map of high-altitude peatlands of Broghil Valley, Pakistan. Peatlands are mapped as green, while gray is non-peatlands.

Table 1 Accuracy assessment of Broghil peatland map using field-based GPS reference points.

		Reference		Total	User accuracy
		Peatlands	Not Peatlands		
Map	Peatlands	20	6	26	77%
	No Peatlands	01	11	12	92%
Total		21	17	38	Over all accuracy 82%
Producer accuracy		95%	65%		

sub-arctic in Russia. A detailed phyto-sociological analysis has not been performed; however, based on observations of physical characteristics of the peatlands in Broghil Valley, these peatlands are located at high elevation above the tree line, have ground flora, have high moisture content and are subject to cold temperatures. While high altitude peatlands such as those of the Broghil valley have no tree cover, since they occur above the tree line, other types including boreal, prairie, temperate, and oceanic peatlands, have either dense or sparse tree cover (Tarnocai and Stolbovoy 2006).

The Broghil Valley is a typical high-altitude valley, where ground-based surveys are hindered by financial constraints, as well as accessibility constraints caused by the difficult and steep terrain. Application of the remotely sensed medium-resolution data presents a low-cost opportunity to investigate land covers. However, these approaches are generally limited by high cloud intensity and snow cover. Clear-sky satellite data such as 30 meter Landsat are scarce for the desired July-September period, when the Broghil valley is green, with only permanent snow cover left. In this study we searched the Landsat archive maintained by USGS and found images with minimum snow and cloud cover in the peak vegetation season. These images provided an opportunity to map peatlands, which otherwise are hard to access and study.

We found that classification of the Landsat 8 data successfully characterizes the occurrence and distribution of high-altitude peatlands, particularly when sample points from ground-based (such as differential GPS) surveys can be used to validate the results. Supervised classification was applied primarily on the basis that adequate *a priori* knowledge about the research area exists, and it is a small area covered in part of one scene (Cihlar 2000). Although we tested the application of Landsat data to map peatlands in a small area, this technique can be applied at a larger geographic scale. Our method, using remotely sensed data, could potentially be applied to large areas such as peatlands in Hindu Kush Himalayas, to easily distinguish vegetation cover in arid and barren high-altitude mountain landscapes for identification and monitoring purposes (Hansen & Loveland 2012). Supervised classification resulted in lower user accuracy compared to producer accuracy because some non-peatland areas, such as agricultural lands in the vicinity of peatlands, were mis-classified as peatlands. This mis-classification probably occurred because most of the agricultural lands are converted peatlands and contain high moisture content. This mis-classification could likely be reduced with further refinement of the training dataset. The method used for Broghil can be applied to wider mountainous areas for assessment of the extent of high-altitude peatlands in Pakistan and the HKH region. Additionally, there are other significant protected areas in the HKH region in Pakistan including Khunjerab, Central Karakorum, Qurumbar, Shandur-Handrap and Deosai National Parks. These protected areas have peatland resources which need inventory and mapping.

The high-altitude mountainous areas of Hindu Kush, Karakorum and Himalayas are not only difficult to access but logistically expensive for ground-based surveys. Application of the Landsat data, available free of cost and with a 16-day revisit cycle, can be a cost-effective method to assess distribution of the high altitude peatlands in the region. The Landsat time series data can also be applied to study changes in high-altitude peatlands such as loss over time due to harvesting by the local population, degradation due to livestock grazing, and loss due to natural disasters such as glacial lake outbursts, avalanches and landslides.

4 Conclusion

The method developed and applied in this paper can be extended to map high altitude peatlands in adjacent protected areas to understand their distribution, biodiversity value, and conservation needs, and also to map changes to peatlands over time. The Landsat data cover the high-altitude region of Pakistan from 1988 until present. This time series can be analysed to map and quantify land use changes in high-altitude peatlands, either as a natural or an anthropogenic/ human-caused process. Such a time series could also be effectively analysed for climate impacts on high altitude peatlands, which may be subject to warming in the region. Well-designed reference data will be required for peatland map validation. Finally, pixel-based random sampling to synchronize mapping unit for validation is recommended for any future studies.

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