EXPLOITATION OF GEOSPATIAL TECHNIQUES FOR STUDYING THE SNOW AND WATER RUNOFF PARAMETERS

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Abstract

The current research involves the study, classification and interpretation of Landsat Thematic Mapper image dataset and the analysis of snow monitoring and surface runoff data for a selected area of the Indus River catchments in Northern Pakistan. The prominent places in the area comprise, Deosai plane, Shogran, Saif-ul-Maluk, Terbela, Swat valley, Muzaffarabad, Mansehra, Balakot and the adjoining regions across the Indus and Kunhar rivers. Having completed the preliminary processing, supervised image classification of aforesaid satellite image was performed for vegetation, snow, areas with mixed features, patches of human settlements and bare soil. In addition, ground data were obtained from Snow Monitoring Stations and Water Discharge Stations to study behavior and relationship among various parameters contributing towards water runoff in the Indus River. The geographic information layers were also developed, analyzed and overlaid on to the satellite imagery to be cognizant of the actual locations of those stations. The characteristics curves among various data fields suggested logical relationships enabling research to go steps ahead in to deciphering actual causes of water runoff. The study was found highly relevant to the conceived objectives and also, significant being a unique effort in the application of Remote Sensing and GIS in Pakistan. The state of the art techniques of spatial sciences can be suitably exploited to accomplish such studies for achieving reliable results, especially in inaccessible mountainous areas.

INTRODUCTION

With the advent of space age, satellite imaging is progressively becoming an imperative element of studies related to environmental mapping and monitoring. Pakistan is also benefiting this technology by using multi-spectral, multi-resolution and multi-temporal remotely sensed data for various applications. This field is quite new in Pakistan, but even then, with available resources and imagery datasets, professionals especially the academicians take initiatives and carry out research pertinent to the applications of remotely sensed data for disparate geospatial applications, sometimes leading to interesting and encouraging results. The current research is about the study of snow as a contributing element of water run-off in the Indus river of Pakistan.

Hydrologically, Pakistan can be divided into two regions. One is the Indus Basin and other is the dry area of Balochistan. The Indus Basin is a part of the catchment of the Indus river system. The Indus river system has several tributary rivers. The important ones joining the Indus on its left side are the Jhelum, Chenab, Ravi and Sutlej. Each river has its own tributaries. The catchment areas of the Indus and its tributaries extend in the adjoining countries. The total catchment area of the Indus River System is 364,700 sq. miles of which that exists in Pakistan is 204,300 sq. miles, forming 56 percent of the total. The Indus river
basin constitutes 213674 sq. miles of which 204,300 sq. miles constitute the catchment of Indus River System, and the rest lies in the desert area of Sind, Bahawalpur and Rann of Kutch.

Many areas of the world rely on the snowmelt for irrigation and drinking water. It is necessary to monitor snow cover closely throughout the winter and spring for assessment of water supply and flooding potential (Carroll et al., 1989). In addition, spatial and temporal variation in snow extent could prove a useful indication of climate change (Simpson et al., 1998). Ground monitoring of snow is normally based on point measurement, subject to numerous problems especially in inaccessible mountainous regions. An enormous amount of snow is deposited on the Himalayan slopes during the winter months forming biggest water resources in the northern parts of Pakistan which continuously melt and feed the rivers thus making them perennial. The estimation of snowmelt runoff and resulting stream flow from Himalayan catchments is of considerable use in planning and operation of river valley projects. Subsequent to this different models have been developed in various parts of the world and the temperature index model is among the notable ones developed by Martinec & Rango (1979) and is used by various organizations in many parts of the world.

Many studies regarding the snow cover estimation and subsequent water discharge in the rivers have been conducted e. g., Lucas et al. (1989) used unsupervised multispectral classification for separation of snow and cloud in AVHRR images by using channel 1, 3 and 4. Cracknell (1997) emphasized on using AVHRR images to determine snow cover extent. He recommended the threshold methods in snow and cloud separation. Simpson and Gobat (1995) used AVHRR channel 2, 3, 4 and 5, to detect cloud. Simpson et al. (1998) used a multispectral-multistage method to separate snow and cloud in AVHRR images. They used channels 2, 3, 4 and 5 and proposed a three-stage algorithm to separate snow from cloud.

In the present research, multi-spectral Landsat-5 Imagery was exploited to classify the study area into prominent landcover categories, snow being one of the major classes. In addition, snow cover and water discharge data were geographically referenced with the satellite imagery to generate thematic overlays and study the relationship of amount of snowmelt and subsequent water runoff. Various Image processing and band ratioing techniques, like Normalized Difference Snow Index (NDSI) were also employed for precise demarcation of the snow cover extents. The scope of research requires rainfall measurements in the catchments to be encompassed to complement existing parameters.

**STUDY OBJECTIVES**

Following objectives were conceived for accomplishing the current research:

- Digital processing and classification of Landsat Thematic Mapper (TM) dataset for appraisal of snow cover extents and categorization of other landcover features.
- Integration and analysis of on-site measured Snow Monitoring and Water Discharge Data with the satellite imagery
- Study of the amount of water run-off in relation to the average temperature.
METHODOLOGY

Image interpretation is a process of exploiting innovative, pragmatic and professional spatial techniques of Information Technology. Landst TM data are useful for quantitative measurement of snow reflectance (Winther, 1992). The effort was made to put into practice some of the basic steps that image interpreters apply to examining and analyzing an image of a small part of Earth as seen from space. The concentration was almost entirely on analyzing a single Landsat image, being this to be a major source of data. This image and its derivatives were more intensely scrutinized than most of the other conventional datasets collected for the present study.

Satellite image procurement and rectification

In tandem with the snow cover and water discharge data, one landsat scene, in multispectral mode, captured on May 16, 1998 was used to carry out the present research. The region contained Indus catchment comprising Muzaffarabad, Kaghan Valley, and the adjoining areas of Kunhar River. The image geo-referencing was achieved by measuring uniformly distributed GCPs on the image to gain maximum correctness and conformability of the image with the actual geographic coordinates. The rectification exercise was done to make the image ready for its integration with the pertinent geographic information layers. To stay objective specific, dataset was truncated on the area of interest, so that the areas beyond the scope of study should not come under the processing procedures. The subset of the image contained mainly the snow covered area and the adjoining areas containing the locations of Snow Monitoring and Water Discharge stations.

Preparation of false color composites and image interpretation

The first False Color Composite (FCC) was made by assigning TM band 2 (green) to the blue electron gun in the monitor, band 3 (red) to the green gun, and 4 (the near or photographic reflective IR) to the red. Two color patterns dominate the land classes: reds, depicting vegetation, and medium grayish-browns, found mainly along the bright sun-facing slopes. The water in Terbela dam and in the Indus River is manifested in deep blues that, near banks, become a bit lighter where thicker sediments add reflectance. The 2nd FCC in RGB-742 represents water and snow in blue, Vegetation in green and the mixed features of settlements and bare soil in yellow color. The RGB-742 FCC is shown in Figure 4.

Image classification

Classification is a process in which all the pixels in an image that have similar spectral signatures are identified. Supervised classification is much more effectual in terms of accuracy in mapping substantial classes whose validity depends largely on the cognition and skills of the image specialist. The strategy is simple: conventional classes (real and familiar) or meaningful (but somewhat artificial) classes are recognized in the scene from prior knowledge such as personal experience with the region in question, or by identification using thematic maps or actual on-site visits. This allows one to choose and set up discrete classes (thus supervising selection) to which identifying category names are then assigned. Training sites, areas representing each known land cover category that appear fairly homogeneous on the image (as determined by similarity in tone or color within shapes delineating the category), are located and circumscribed by polygonal boundaries drawn (using the computer mouse) on the image display. Classification now proceeds by statistical processing in which every pixel is compared with the various signatures and assigned to the class whose signature comes closest.
A total area of about 30,000 Sq.km. was selected for classification of Snow covered areas, Deep water, Shallow water, Green vegetation and Mixed features (Table 1).

Table 1: Results of digital image classification of satellite imagery for six land-cover features.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Class</th>
<th>Hectares</th>
<th>Sq. km.</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Snow</td>
<td>809072.190</td>
<td>8090.722</td>
<td>1999261.071</td>
</tr>
<tr>
<td>2.</td>
<td>Deep water</td>
<td>2092.590</td>
<td>20.926</td>
<td>5170.903</td>
</tr>
<tr>
<td>3.</td>
<td>Shallow water</td>
<td>16660.530</td>
<td>166.605</td>
<td>41169.069</td>
</tr>
<tr>
<td>4.</td>
<td>Green vegetation</td>
<td>150775.170</td>
<td>15077.532</td>
<td>3725739.502</td>
</tr>
<tr>
<td>5.</td>
<td>Bare soil</td>
<td>84241.800</td>
<td>842.418</td>
<td>208166.037</td>
</tr>
<tr>
<td>6.</td>
<td>Mixed features</td>
<td>108352.620</td>
<td>1083.526</td>
<td>267745.175</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2989047.690</strong></td>
<td><strong>29890.477</strong></td>
<td><strong>7386098.251</strong></td>
<td></td>
</tr>
</tbody>
</table>

Based on the prior knowledge of the area the training areas were drawn on the rectified image of the study area, those were later used as seed pixels for entire image classification. The major objective was to compute the area extent of snow cover for its later correlation with data measured on ground at different stations (Figure 1).

Figure 1: Left: Image classified land-cover features. Right: Classification legend and relative area extents of land-cover features in the study area.

The ground-measured, snow and water discharge, data was found useful for the appraisal of resulting run-off in the gullies heading towards the Indus River. The station data involved, Station Code, Geographic Location, Agency Name, Province, ground elevation, Catchment area extents, and River and Basin names, and the year of taking measurements.

In addition to the Month-wise details of the data, the archive also contained monthly summary of, Average Discharge of water, Specific Density and Run-off data. The station locations were thus overlaid on to the image for visualization of image and station datasets. Table 2 below indicates the names, locations and related information about five of the stations which have been used in this research work.

Table 2: Ground elevation of water discharge stations – Meters above sea level (masl).

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Station Name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (masl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Yogo</td>
<td>35-11</td>
<td>76-6</td>
<td>2469</td>
</tr>
<tr>
<td>2.</td>
<td>Kachura</td>
<td>35-27</td>
<td>75-25</td>
<td>2391</td>
</tr>
<tr>
<td>3.</td>
<td>Daggar</td>
<td>34-29</td>
<td>72-27</td>
<td>700</td>
</tr>
<tr>
<td>4.</td>
<td>Phulra</td>
<td>34-18</td>
<td>73-4</td>
<td>732</td>
</tr>
<tr>
<td>5.</td>
<td>Besham</td>
<td>34-55</td>
<td>72-52</td>
<td>580</td>
</tr>
</tbody>
</table>

(Courtesy of Water and Power Development Authority (WAPDA) Hydrology office Lahore, Pakistan.)
Preparation of thematic overlays
Thematic maps are the GIS overlays that were prepared to locate the points of interest on the image. When image is accurately rectified, other information can be geographically represented in the form of transparent layers of information. In the present study two types of data was procured from the field stations, Snow Monitoring data and Water Discharge Data. The locations where the data used to be collected by different responsible organizations were transformed into Geographic Information layers following the same coordinate type that was used to rectify the satellite image. The purpose was to pinpoint the station locations where the aforementioned measurements were regularly taken. Resultantly, two GIS layers were created and overlaid on to the image to see the exact locations of Water Discharge and Snow Monitoring Stations (Figure 2).

Application of image ratioing techniques
Another image manipulation technique is known as ratioing. To be able to identify snow covered areas on the image more precisely, Normalized Difference Snow Index (NDSI), Principal Component 2 (PC2) and Principal Component 3 (PC3) were made and exposed by red, green and blue colors respectively, the snow covered areas on the resulting image appeared very sharp and carrying more details as compared to raw imagery. The RGB composite of these images is shown in Figure 3.
Normalized Difference Snow Index (NDSI)
Normalized Difference Snow Index (NDSI) is a modification of previously well-known
formula, Normalized Difference Vegetation Index (NDVI). It has been documented by Hall
et al. (2001) that if the reflectance of the NDSI is greater or equal to 0.4 then snow or ice
covers at least 50% of the pixel. The difference lies in the type of bands used to compute
the
Snow Index: \[
\text{NDSI} = \frac{(TM5-TM2)}{(TM5+TM2)}
\]
The result of this ratio formula transforms the TM Dataset in sharply visible snow covered
areas at the expense of remaining features (Figure 4).

Figure 4: Left: False color composite RGB-742. Right: NDSI image – snow looks prominent in yellow tone.

RESULTS AND DISCUSSION
Snow is a form of precipitation; however in hydrology it is treated differently because of
the lag between when it falls and when it produces run off, ground water recharge and due
to its involvement in other hydrological processes. Remote sensing is a valuable tool for
obtaining snow data to predict snowmelt runoff as well as climate studies.

Since the satellite image does not cover the entire northern area, only three snow stations
could be located on the image. Snow monitoring stations consisted of a scaffold tower,
having the humidity and temperature sensors, rain sensor, solar radiation sensor and wind
sensor giving speed and direction. The snow density is measured with the help of snow
pillows filled with glycol is placed on the ground. As the snow falls, level on the pillow and
the scaffold tower measures the snow depth. Snow stations data was correlated with the
water discharge stations located in the vicinity of snow monitoring stations. The graphs so
drawn gave the fair idea on behavior of snow at different temperature levels. The curves
were also plotted between monthly average run-off and monthly average temperature for
water discharge stations covered in this image. This indicates run-off behavior of the River
Indus at the selected sites for the whole year of 1998.

Water discharge stations
In order to estimate water discharge or snow water equivalent, the water discharge stations
established in the close vicinity of the snow monitoring stations comprising Phulra and
Daggar were selected. Table 3 is indicative of temperature and runoff data for Phulra only.
Exploitation of geospatial techniques for studying the snow and water runoff parameters

Table 3: Data on average temperature and amount of run-off at discharge station Phulra.

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Data Acquisition</th>
<th>Average Temperature (°C)</th>
<th>Run-off (cusecs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>12.05.1998</td>
<td>07.4</td>
<td>39.73</td>
</tr>
<tr>
<td>2.</td>
<td>15.05.1998</td>
<td>14.5</td>
<td>35.22</td>
</tr>
<tr>
<td>3.</td>
<td>19.05.1998</td>
<td>11.0</td>
<td>36.53</td>
</tr>
<tr>
<td>4.</td>
<td>22.05.1998</td>
<td>13.2</td>
<td>27.20</td>
</tr>
<tr>
<td>5.</td>
<td>27.05.1998</td>
<td>12.5</td>
<td>24.92</td>
</tr>
<tr>
<td>6.</td>
<td>28.05.1998</td>
<td>11.5</td>
<td>24.32</td>
</tr>
</tbody>
</table>

(Data is a Courtesy of the Department of Hydrology, Lahore, Pakistan.)

The data from discharge stations does not only indicate the snow water equivalent but also includes water due to rains and ice melt of the glaciers, but in May which is the image acquisition month, the temperature is not high, so most of the precipitations fall as snow.

The values indicate that the river run off varies with changing values of temeprature. The amount of run-off is almost same at temperatures 7.4, 14.5 and 11 degrees. But there is a sudden decrease in it measured on 22 may, 27 may, and 28 may, although the temperature is high. This phenomenon occurs due to redistribution of snow because of wind, avalanche and due to evaporation of water content in the snow.

After analyzing the values obtained from ground stations’ data for the month of May, 1998, the graph given below, Figure 5, was prepared from Table 4 to observe the relationship of average monthly run-off and average monthly temperatures for entire year of 1998.

Table 4: Data on average temperature and amount of run-off at discharge station Phulra.

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>09.45</td>
<td>47.5</td>
<td>37.18</td>
<td>80.0</td>
<td>11.81</td>
<td>79.5</td>
</tr>
<tr>
<td>46.78</td>
<td>55.0</td>
<td>12.34</td>
<td>87.5</td>
<td>06.13</td>
<td>70.5</td>
</tr>
<tr>
<td>52.27</td>
<td>56.5</td>
<td>20.60</td>
<td>87.5</td>
<td>04.53</td>
<td>59.0</td>
</tr>
<tr>
<td>64.00</td>
<td>69.5</td>
<td>12.56</td>
<td>84.5</td>
<td>03.91</td>
<td>48.5</td>
</tr>
</tbody>
</table>

Figure 5: Discharge station Phulra, graph between average monthly run-off and average monthly temperature.

The graph reveals that the maximum discharge of water is the month of July and it decreases gradually up till January. But in February discharge value increases to 40.78 cusecs against temperature of 55°F and keeps on rising with small increase of temperature up till March. The trend line in the graph explains the behavior of water discharge as a function of temperature. Similar analysis was carried out for Yogo, Kachura and Besham.
qila and same trends were found for water run-off in relation to average monthly temperatures for the year 1998.

It was concluded that snow can be readily identified and mapped with the visible bands of satellite imagery because of its high reflections in comparison to non-snowy areas. Although snow can be detected at longer wavelength in the NIR region the contrast between the snow and non-snowy area is considerably reduced compared to the visible region of the spectrum. However the contrast between clouds and snow is greater in the IR region and serves as useful discriminator between clouds and snow.

Snow can be considered as a vital component of water cycle. For making efficient use of melt-water run-off, relevant organizations must be able to make early predictions of the amount of water stockpiled in the form of snow. Coverage area, snow water equivalent, and snowpack wetness are the key parameters to be determined in the process. Visible/ near-infrared satellite imagery at disparate spatial and temporal resolutions can be used to accurately measure snow cover in the day-time in cloud-free areas. Monitoring of snow parameters is important both for meteorology and for forecasting the risk of flooding.

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