LITHO-STRUCTURAL AND TECTONIC STUDY OF INTERMONTANE KASHMIR BASIN, NW HIMALAYA INDIA: USING GEOLOGICAL AND GEOSPATIAL TECHNIQUES

ABSTRACT

The southward convex Himalayan arc is probably the most profound tectonic belt that has existed in the geological past. The Himalaya is the greatest mountain chain about 2500 km long and 250 to 350km wide with highest peaks from west to east in the world. The entire Himalayan arc evolved as a result of collision of the Asian and the Indian continent some 50m.y. ago, spreads from northwest Kashmir to northeast Arunachal Pradesh. These two tectonic plates collide at geologic and geodetic convergence rates of 30–50 mm/yr. Based on the regional tectonic framework, the whole Himalayan arc can be subdivided into following tectonic units bounded by series of major thrusts. All these faults/thrusts are characterised by topographic breaks which split the Himalayan range into four physiographic subdivisions; from north to south these are: Tibetan or Tethys Himalaya, Higher Himalaya or Great Himalaya, Lesser Himalaya and sub Himalaya or Outer Himalaya. There is a prominent syntaxial bend at each end of the Himalaya; the western syntaxis and the eastern syntaxis. Along strike, the Himalayan orogen can be separated into the western (66°–81°), central (81°–89°), and eastern (89°–98°) segments. The western Himalayan orogen covers the following regions that commonly appear in the literature: northern Pakistan with Salt Range, Kashmir (NW India), Zanskar, Spiti, Chamba, Himachal Pradesh, Lahul, Garhwal, and Kumaun (also spelled as Kumaon). The central Himalayan orogen occupies Nepal, Sikkim, and south-central Tibet, while as the eastern Himalayan orogen includes Bhutan, Arunachal Pradesh of NE India, and southeastern Tibet.

Kashmir Himalaya is divided into three main physiographic divisions from south to north, the Outer/Sub-Himalaya/Siwalik, the Middle/Lesser Himalaya and the Great/Inner Himalaya. The Sub-Himalaya configures the foothills of the Himalayan Range which rise gently from the plains of Punjab and reaches an altitude of up to 2440 m. The region forms a succession of narrow parallel ridges of the Tertiary rocks and is structurally bounded by the Main Boundary Thrust (MBT) in the north and the Main Frontal Thrust (MFT) in the south. The Lesser Himalaya is composed of Late-Proterozoic metamorphosed rocks and unfossiliferous to fossiliferous lower Paleozoic
sedimentary rocks showing complex structural features such as folding and faulting. It is about 1300m thick rock sequence, with variable altitude of up to 4500m, and includes the Pir Panjal Range. Tectonically, it is bounded by the Main Central Thrust (MCT) in the north and Main Boundary Thrust (MBT) in the south. These major thrusts have recognized it as seismically active zone, because of continuous convergence and collision between the Indian and Eurasian plate. It shows an average width of about 80-100 km. The Lesser Himalaya zone is also characterized by numerous klippen and nappes of high grade metamorphic rocks. The Lesser Himalayan zone consists of series of parallel thrusts. The most prominent being the Main Boundary Thrust (MBT), Panjal Thrust (PT) and Zanskar Thrust or Main Central Thrust (MCT). The Kashmir Valley (Intermontane basin) lies within this tectonic zone of the Himalayas.

The Kashmir basin/valley comprises an important position in the geotectonics of Kashmir Himalaya. The general strike of the Kashmir basin is from NW to SE with ~150 km length and ~50 km width, running parallel to Great Himalayan and Pir-Panjal mountain ranges, about ~100 km away from the actively growing frontal part of the Himalaya. The valley takes the form of graben bounded by NW-SE trending parallel Panjal Thrust (PT) and Zanskar Thrust (ZT). Wadia described the thrust-bounded basin, as ‘Kashmir Nappe Zone’ comprising of rocks of Paleozoic-Mesozoic marine sediments with Precambrian Basement. It is thrusted along a regional tectonic plane viz., Pir-Panjal Thrust over the younger rocks of the autochthones belt. The ‘Kashmir Nappe’ forms two major axes of orogenic upheaval along the Pir-Panjal and the Great Himalayan Ranges. Its geographical location and the structural disposition is resultant effect of the Great Himalayan Orogeny. The present tectonomorphic features of the basin have been linked to the Plio-Pleistocene to recent uplifts in the Pir Panjal Range.

In the area, a number of previous studies have mapped traces of active thrust faults. These faults are formed in response to the active continent–continent collision of the Indian and the Eurasian plate. Their activities are preserved in the form of faults or folds, other mesoscopic structures (in hard rocks on peripheries) and soft sediment deformation structures in the plio-pleistocene deposits known as Karewas of Kashmir. Thus, Kashmir basin (Geologically) presents wonderful opportunity of study to geologists of different disciplines. In the present study, work has been carried out on following aspects: (i) morphostructural lineaments and their tectonic and seismic
implication, (ii) morphotectonic and morphometric study with implication in assessment of relative tectonic activity and disaster vulnerability (flood ad soil erosion risk), (iii) soft rock studies like soft-sediment deformation structures: implication to deformation mechanism and paleo-earthquake activity, and (iv) Structural (Mesoscopic) study: implications to tectonics, paleostress analysis and crustal shortening using minor folds.

With the advent of satellite imagery and digital elevation model (DEM) providing synoptic view, higher spatial and better spectral resolution, it has been possible to recognize linear geological features in a better and more reliable way. The structures are identified using the edge enhancement filters (Laplacian and Sobel), false color composite (FCC) and DEM derived products like shaded relief, aspect, slope, drainage map, and 3D profiling. Geological structure mapping often involves the mapping of lineaments, regional features that are caused by linear alignment of regional topographic features, such as streams, escarpments, V-shaped valleys, linear valleys, triangular facets, and linear mountain ranges that in many areas are surface expressions of fractures, folds and fault zones etc. The lineaments identified shows wide distribution and are cutting Plio-Pleistocene karewas deposits and are in maximum concentration towards western flank and dominantly in Southwestern part of the Kashmir Basin. The highest densities obtained are oriented NW-SE, E-W and N-S, with the predominance of the first direction structures with trend similar to tectonic structures like Panjal thrust (MCT), Murree thrust (MBT), Riasi thrust (RT) and Balakot-bagh fault (BBF) which are considered to be imbrications of the northward-rooted basal decollement known as the Main Himalayan Thrust (MHT). These results correspond to the overall direction NW-SE of the structures resulted from the NE-SW compression of the regional tectonic units. Balapur fault (out-of-sequence fault) previously mapped in Pleistocene deposits, Tosamaidan fault (TF) in Pir-Panjal range, Gulmarg fault (GF) and others possible faults shows a linear trend with the tectonic structures and earthquake epicenters present in the region. The Kashmir Basin in NW Himalaya is one the seismically active zone situated in seismic V of the Himalaya. Historical records of seismicity including damaging earthquakes in 1555, 1885 and 2005 in and around, give an idea about the active deformation in Kashmir basin and its surroundings. The depth map of past earthquakes shows maximum occurrence of earthquakes of shallow depth (4-24 km) along the NW-SE extension of Kashmir Basin. The earthquake epicenter and morphostructural
Abstract

Lineament map were correlated to assess the seismic hazard in the area. Using the three dimensional expression of the tectonic features and presence of Jhelum River towards eastern half clearly suggest the northeast tilt of Kashmir Basin. These structures/features delineated in the area shows maximum resemblance in trend with the regional tectonic structures like Panjal thrust (PT)/Main Central thrust (MCT), Muree thrust (MT)/Main Boundary thrust (MBT), Balakot-Bagh fault (BBF) and Riasi thrust (RT) in surrounding. The Historic seismicity and observed evidences of deformation in the Plio-Pleistocene deposits and at some places in fluvial terraces on the southwest side of the Kashmir Basin (KB) indicate that deformation is still going on, north of the deformation front in NW Himalaya. This approach of applying remote sensing for structural feature identification and mapping will prove to be very crucial for further investigations in future for seismic and landslide hazard assessment, and mitigation. The morphostructural lineaments which showed dominance in the SW in western flank; were further supported using morphotectonic and morphometric approach utilized to assess the lithological and structural variation and natural hazard assessment in terms of floods and soil erosion risk.

Therefore, morphotectonic and morphometric analysis was carried by applying remote sensing and GIS techniques. The remote sensing and GIS with the aid of satellite data is emerging as the most effective and time saving technique for tectonic investigation, drainage analysis and natural disaster assessment. For detailed morphometry, drainage map was prepared using aerial photographs, digital elevation model (DEM) and Survey of Indian (SOI) toposheets manually as well as automatically by Archydro tool in ArcGIS 10.2 software. This technique is found applicable for the extraction of drainage basin and its drainage networks using ASTER and SRTM (DEM) supported by satellite imagery. The drainage behavior is observed of immense utility in examination of geological structures and lithological variation in the area. Drainage maps were used for the sub-basin wise morphometric and morphotectonic analysis of 26 sub-basins of three catchments. Tectonic processes prevailing in the area have considerably contributed to the formation and arrangement of present drainage systems and landforms of the area. Existence of high bifurcation ratio signifies a strong structural control on the drainage network. The deviation from straight line of the logarithm of stream number vs. stream order indicates regional uplift in southwest of the area. Elongation and circulatory ratio highlights that most of the sub-basins are elongated in shape with younger origin. High drainage density
value in mountainous terrain suggests that the area is having impermeable subsurface as compared to plainer areas with low drainage density values.

This study also focuses on the evaluation of morphotectonics in three catchments which showed higher lineament variation in western flank. The Kashmir basin is present in seismically active belt resultant of collision; being present in tectonically active region, development of landforms, behavior of fluvial system, and design of mountain fronts has significantly been affected and sculptured by neotectonic activity. Six geomorphic indices viz. the stream length-gradient index (SL), drainage basin asymmetry (Af), hypsometric integral (Hi), valley floor width-valley height ratio (Vf), drainage basin shape (Bs), and mountain-front sinuosity (Smf) have been applied to assess tectonic activity supported by drainage network anomalies, topography, stream longitudinal profiles and river sinuosity etc. Result from these indices together was utilized to yield the relative tectonic activity (Iat) in Geographic Information System (GIS). On the basis of Iat value, the area was separated into four classes: Class 1 (very high relative tectonic activity, 15.07% in area); Class 2 (high, 23.53 %); Class 3 (moderate, 28.41%); and Class 4 (low, 32.97%). The very high to high relative tectonic activity class falls in southwest and in the direction of the identified major faults, concords with high structural lineaments and linear trend shown by distribution of earthquake epicenters in the region. In addition to above application, morphometric analysis has been applied in flood and soil erosion risk assessment in selective catchment damaged in 2014 Kashmir flood.

Sukhnag-Ferozpur catchment being located in hilly terrain of Kashmir basin, during heavy rainfall events all the water flows towards plainer low lying area causing floods in the urban areas along different drainage pathways. The drainage analysis of catchment helps to understand the physical behaviour with respect to floods. The sub-basins which contribute most in bringing floods in downstream plainer area were delineated. The analysis of 14 sub-basins (coded from SF1- SF14) reveal that SF1, 2, 5, 6, 7 and 8 lying in hilly terrain with high relief ratio (Rh), high drainage density (Dd), high ruggedness number (Rn), and less time of concentration (Tc) has greater peak discharge in a shorter period of time to the plainer low lying areas. The low lying downstream area of SF10, 12, 13, and 14 are found most vulnerable to floods enhanced by other factors like anthropogenic activities, chaotic construction on river banks, and death of drainage channels. The mud and silt coming with flood water ultimately causes siltation problems to population and other aspect of life in low lying
areas. The other ill effects of siltation; with time leads to river course change, rise in bed level, change in rate of flow, and occurrence of frequent floods in the area. Thus, systematic evaluation of morphometric parameters using DEM in GIS environment helps to assess the flood behavior of catchment and apply suitable mitigation measures to reduce the hazard.

In the same way, Dudhganga-Shaliganga catchment with 7 sub-basins (coded as DS1-DS7) were analyzed to assess the soil erosion risk using detailed measurement of drainage and morphometric parameters in remote sensing and GIS environment. Linear, shape and relief parameters have been determined for each sub-basin and assigned rank on the basis of value/relationship with soil erodibility. The stream order up to 6 has been analyzed with drainage density of 1.881 with sub-parallel drainage pattern. In the area, drainage network is controlled by lithological and geomorphic conditions with effect of subsurface structures dominant in SW sub-basins. The sub-basins were divided into high, medium and low category in terms of priority for soil conservation and management. Ranking reveals that DS1, DS2 and DS6 come under very high soil erosion susceptibility. Existence of these sub-basins towards Pir Panjal side having high altitudinal, high slope and deep valley topography enhance soil erosion risk supported by deforestation, unmanaged cultivation on hill slopes and changing face of landscape by human activities. Besides, the sub-basins showing higher erosion risk have higher concentration of lineaments which acts as weak planes and allows easy water flow and increases chances of landslides by lubrication. Consecutively, soil erosion during heavy rain fall also gives birth to siltation problems in the plainer low lying areas as said above, which is a very serious problem to eradicate. Thus, morphotectonic and morphometric analysis applied has given an importance inferences related to tectonics, flood and soil erosion risk assessment; structural and lithological variation in the area. Finally, the areas having soft rock like karewas of Kashmir spreading basin floor has been taken for investigation of soft sediment deformation structures, and hard rock peripheries on eastern and western flank of Kashmir basin were studied for mesoscopic structures.

Recent uplift in the northwestern Himalaya has exposed over 1000 m of basin sediments which were named as the ‘Karewas’. The past results indicate that sedimentation of karewas had started by about 4 m.y. ago. Subsequently, over 1300 m Karewas deposits were deposited at an inferred average rates variable from 16 to 64 cm per 1000 yr. The basal part of the sequence is slightly older ~5 Ma, but much of
the sequence is of late Pliocene-Pleistocene time, with deposition continuing locally into the Holocene epoch. These show dominance of lacustrine and deltaic sediments and has responded to tectonic activity along the basin margins in the form of faults and folds. Karewa sediments have been classified in two divisions (the Lower Karewas and Upper Karewas) since 1800s, which were separated at most of places by an unconformity and frequently a boulder conglomerate. The thickness of Lower Karewas is more than the Upper Karewa deposits. Being located on a very active mountain system, the Karewa sediments show varied deformation structures indicating active tectonics during and after the deposition. The karewas being mostly horizontal stratified deposits formed of beds of different lithologies (mostly made of sand, silt, clay, laminated clay, conglomerates, lignite beds), were taken for investigation of soft-sediment deformation structures. The Intermontane Kashmir basin in NW Himalaya is one the seismically active zone, falling in seismic zone V and has faced a large number of damaging earthquakes in the past, thus Karewa sediments must show the presence of soft sediment deformation structures. The soft-sediment deformatonal structures which include escape of pore fluids in fine sediments are linked to seismic shocks and determine the neotectonics activity in the area. The continuous uplift of Pir Panjal range and basin tectonics is reflected by the structures present in these Karewas sediments.

Different kinds of soft-sediment deformation structures were encountered in the Karewa sediments particularly in sand, silts and clay; include load structures like load casts, flame structures, ball-and-pillow structures, Pseudonodules, water escape structures like dish and Pillar structure, water escape cusps, soft sediments intrusions like clastic dikes and sills, and other structures like convolute bedding/laminations, disturbed laminites, slump structures and synsedimentary faults. The deformation mechanism and driving force are essentially linked to gravitational instabilities, dewatering, liquefaction-liquidization, and brittle deformation.

Regional geological scenario and field validation corroborates to seismicity as the most possible triggering mechanism for SSDS in active collision zone in Himalaya rather than the influence of storm activity or deformation related to sediment loading; thus are resultanty inferred as seismites. Therefore, occurrence of earthquakes and geological record with both syn-and post depositional faulting is related to the collision tectonics of Himalaya. The drainage anomalies and presence of structural features like faults and folds in the plio-pleistocene Karewas deposits is
evidence for continuing neotectonic activity in the Kashmir Basin. Moreover, the presence of SSDS between undeformed sedimentary layers and their areal extent reveals that these structures were as a result of devastating seismic events in the area. Thus, the presence of soft sediment deformation structures (seismites) in the Karewas Group supports the neotectonic activity in the area during their depositional period (plio-pleistocene) and elucidates an earthquakes of magnitude >5 had occurred of in past in the Kashmir basin.

Lastly in structural study, various types of mesoscopic structures has been encountered and analyzed to depict the poly-phase deformation and paleostress orientation by their differently distributed and oriented tectonic imprint in the rocks in peripheries. The structural features identified and analyzed are joints, veins, boudins, pitch-and-swell, mullions, crenulation cleavage, fracture cleavage and folds with associated attitude (strike and dip). The parameters obtained in the field for these structures were investigated using different software generated data like stereo plots, rose diagrams, and graphic plots to elucidate paleostress field orientations and heterogeneity. The dominant trend of different joint sets observed is NNE-SSW and ESE-WNW, with subordinate joint set orientation of NW-SE and E-W in limestones, slates, punjal volcanics, and other rocks types of different age. The diversity in joint orientation suggests and can possibly be related to fault-related and fold-related fractures developed in different phases of deformation in the fold-thrust belt.

The pinch-and-swell and boudinage structures are structures ranging from ductile to brittle deformation respectively. In an intensely deformed rock, these structures are applied to determine the direction of extension and strength of layers. The boudins axis or neck lines has been observed mostly parallel to fold axis with $\sigma_2$ in 320-350° (NW-SE) direction but are perpendicular at some places. The presence of mullion like structure is formed and is an indication of early stages of Indian-Eurasian shortening. The analysis of various types of NE-verging folds like asymmetrical and overturned with SE dipping axial planes, occurrence of Z-shaped folds in left limb, and existence of en-echelon gash veins reveals an existence of dextral shear sense east of the Hazara Kashmir Syntaxis. Dominance of these asymmetrical and overturned folds with overturned limbs and NW-SE trend, and en-echelon gash veins with dextral shear sense are originated due to latter phases of deformation attributed to the intense tectonism associated with Indian and Eurasian collision.
In the present work, an attempt has also been made to study the fold profile geometry and an estimation of strain in folds developed in area around Khanpora, Beru, khajigund, Ganderbal and other places. Geological and structural mapping can be applied to establish the nature, form and geometry of folds in different rocks of the area. Simple statistical techniques and equal area projection can be applied to analyze single fold or multiple folds of an area. To investigate the geometry, form, orientation, homogeneity and symmetry as well as preferred orientation of minor structures (folds) with respect to the major/macroscopic folds can be established, using maximum concentration of dip-strike data of structural elements collected during geological fields from different locations of the area. The interpretation and analysis of rosette plot highlighted 310° to 340° i.e., NW-SE regional strike, possibly the elongation or extension direction of the area. The minor folds were analyzed geometrically based on dip isogon method, $t'_d/\alpha$ plot, belong dominantly to Class 1C with sub-ordinate fold geometries of Class 1A, 1B, Class 2 & Class 3. Dominance of Class 1C folds suggests that the folds were developed by flexure-slip mechanism. Folds were used for estimation of strain expressed in terms of shortening calculated using wave length by arc length ratio in all the minor folds. The buckle shortening measured for most of folds ranges between -30% and -89%. The analysis of these mesoscopic structures in relationship with the major structures inferred three phases of deformation with dominance of two phases for the rocks exposed in eastern and western flanks of Kashmir basin. The dynamic analysis which involves estimation/measurement of force or stress that affected rocks was carried out in mesoscopic ductile and brittle-ductile shear zone structures, these structures with average NW-SE trend gave an inference of NE-SW paleo stress/compression direction in the Kashmir basin situated in fold-thrust belt of the Indian and Eurasian Plate.