

**GEOENVIRONMENT AND METABOLISM OF
SHILLONG CITY ECOSYSTEM**

ABSTRACT

BY

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ABSTRACT

Geoenvironment has been a key area of concern particularly during the last few decades due to increasing manifestation of adverse impact of anthropogenic forces on most parts of the earth. The top stratum of the earth's crust with diverse geological and geomorphic setting as well as under different climate regime, having interface with the hydrosphere, atmosphere and biosphere has borne the brunt of exploitation of earth's resources throughout the human civilization, more so in the post industrial era. The resultant impact on the structure and function of earth ecosystem is now all too apparent. It is often felt that there is a need for continuous evaluation and appraisal of the environment in terms of the physical parameters of the earth system vis-a-vis the man made ecosystems. Geoenvironmental study in combination with metabolism analysis in spatio-temporal context can be a very effective tool for rational evaluation of changing status of the environment and overall functioning of the ecosystem.

The geoenvironmental view of resource exploitation takes into account both the mass of minerals produced and the masses of overburden, wastes and by-products created. This view lead to a recognition that the material flows driven by human activities can be seen as part of a broader anthropogenic transformation of the earth's surface which has implications not only for supplies and environmental costs of materials, but also for the nature of the lands on which we live and the landscapes surrounding our daily lives. Materials flow accounting and quantification of the urban metabolism can help

in the development of indicators of the degree to which a city is becoming more sustainable in its behavior. Integrated appraisal of geoenvironment together with urban metabolism is an emerging field of applied research which has received ample attention of researchers in recent times. In a number of cities world over, the planners and researchers are engaged in evolving a holistic model of urban development based on modern ecological principles.

Shillong, the capital city of Meghalaya, is a growing urban centre with three and half lakh population, covering about 208 km² land. The growth has caused an immense pressure on the available resources and environment resulting into an imbalance in the city ecosystem. Therefore there is a need of regular monitoring of environment and inventorisation of the resources for proper planning and management of the city ecosystem. In doing so the status of geoenvironment has to be known for present and future development activities. In absence of a comprehensive base line data on the different geoenvironmental parameters it is difficult to comprehend any change that has taken place in terms of quantum and rate. Present study aims to fill in this gap in our knowledge on the dynamics, structure and function of Shillong city ecosystem. This study also intends to generate the base line data on Geoenvironment and Metabolism of Shillong city which can be used for monitoring of change and in planning for sustainable development of the city.

With availability of high resolution satellite data with repetitive coverage of the earth, development in location based technology viz., Global Positioning System (GPS) and enhanced capability of value addition to geospatial database in Geographic Information System (GIS) platform, have proved to

be a valuable tool for evaluation of resources, appraisal of geoenvironmental status of a region as well as for assessing their spatio-temporal variability. Therefore, for the present study basic spatial data was generated based on satellite data (IRS LISS III, FCC) and Survey of India (Sol) topomaps in 1:50000 scale. Preprocessing of topomaps and satellite data was done in GIS environment using the Orthoengine module of Geomatica 9.1 giving input of same projection parameters as earth model. Extensive fieldwork was carried out, both along and across strike for identifying the geological and geomorphological attributes. Satellite images (IRS LISS III, FCC) and DEM were studied for identifying the susceptible areas for landslides. On-site investigation and documentation of the existing landslides were carried out to develop an inventory. Flash flood prone areas were identified based on their record in news media and the actual events that happened during the year 2003 and 2004. The prefield maps were edited and finalized based on the field inputs and a spatial database was generated in GIS environment. Morphometric analysis was carried out based on the drainage segments and elevation contours extracted from Survey of India topomaps in 1:50000 scale. The LULC thematic mapping was done through standard visual interpretation techniques. Different thematic layers were prepared after digitizing and their attributes were entered accordingly. Thematic information gathered from laboratory analysis and fieldwork has been brought to GIS platform for further processing and analysis. Published geological maps, soil map, boundary map, municipal ward and township map, meteorological data, water sources location, water supply and production pattern, ground water level, water quality and consumption of construction materials data were used as

collateral data. The GIS database generated in the form of raster, vector and attribute data was integrated for generation of composite data sets and queries buildings.

Shillong Master Plan Area is a Precambrian terrain with low grade metamorphic rocks occupying more than 90% of the total area. The oldest lithounit of the study area is composed of granite gneiss, forming part of the Basement Gneissic Complex. They are overlain by the Shillong Group of metasediments following an intervening hiatus marked by a conglomerate horizon. These sediments were deposited in a Proterozoic intracratonic basin under fluvial environment. Stratigraphically older horizon within the Shillong Group is mainly argillaceous, which are well exposed in northern and southern part of the basin, while the upper horizons are predominantly arenaceous with intermittent argillaceous and impersistent conglomerate beds. The Shillong Group of rocks are intruded by mafic sills and dykes which have undergone amphibolite facies metamorphism. They are now found as discontinuous bodies exposed at places as well as under a thin veneer of quartzites and locally known as Khasi greenstones. The youngest event of the Precambrian sequence in Shillong Plateau is marked by emplacement of acid intrusives which form batholiths, stocks and bosses. A small part of a batholithic porphyritic granite known as Myllem granite is exposed in the western part of the study area. The quartzites of Shillong Group of rocks and Khasi greenstones are affected by numerous cross cutting quartz veins, which mark a post deformational phenomenon. Colluvial hill wash and a few patches of alluvium constitute the Quaternary sediments of the area which locally occur along the hill slopes and in intermittent valleys.

Both diastrophic and non-diastrophic structures are recorded in the study area. Non-diastrophic structures include primary sedimentary structures like bedding plane, current bedding and ripple marks, mostly symmetrical and sharp crested, which are well preserved in the arenaceous member of the Shillong Group. Deformation structures are well developed in Shillong Group of rocks which include at least three phases of folding resulting in both plunging and non-plunging types. Three sets of joints trending NNE-SSW, ENE-WS and NW-SE have been encountered in the quartzites. Minor local faults and shears can be deciphered from brecciation within quartzites at some places. Lineaments trending NE-SW conforming to the structural trend of the area are commonly found in higher frequency towards north. Average lineament density is $0.4 - 3 \text{ km}^{-2}$ while lineament frequency varies between $\sim 3.25 - 0.7 \text{ km}^{-1}$. Major drainage control in the area is found to be due to the predominant NE-SW trending lineaments. A major shear zone known as Tyrsad-Barapani shear trending NE-SW occur in the northern part that affect mainly the Phyllites of Shillong Group near Tyrsad and between Mawiong and Umiam along the GS Road. The Shillong Master Plan Area is part of the central upland of the greater Shillong Plateau with elevation varying between 1400–1900m amsl. A gently undulating plateau top, the Laitkor range trending East-West direction with an average elevation of 1900 m above msl, is a prominent landmark in the southern extremity of the Shillong town. The Shillong Peak (1964 m) and Laitkor peak (1960 m) forms the highest points in the area of mapping. The main urban growth center of Shillong Master Plan Area is situated on a broad topographic low with several flat topped low relief

hillocks and gently undulating valleys. Polo ground or Umkhrah valley skirts the northern edge of the town and is situated at a much lesser elevation.

The present day landscape of the study area is the result of a competing interaction of lithology and structure as well as climatic factors. Mass movements have played a major role in evolution of the numerous hillslopes while geomorphic work by high gradient rivers is evidently a controlling factor for the present day landscape development. Because of effective transfer of eroded debris, both from fluvial erosion and mass movement, the valleys are deeply incised bordered with cliff faces. Sheet erosion due to non-channel overland flow is very effective in the study area particularly during monsoon when precipitation may be as high as >1000 mm.

Broadly the geomorphology of Shillong Master Plan Area can be subdivided into two major geomorphic domains viz., plateau landform and fluvio denudational landforms. The entire area comprises mostly of erosional landform which can be further subdivided into three categories viz., highly dissected, moderately dissected and less dissected. The fluvio-denudational landforms can be further subdivided into sub-domains namely, the narrow infilled valleys and the terraces. Narrow valley fills and recent terraces have been deposited along the main streams cutting through the erosional surfaces.

DEM profiles shows that the area is having an undulating topography within the plateau domain with various degree of erosional dissection imparting the corrugation. Slopes vary between 2° - 35° . The main urban agglomeration of the city is developed in and around the moderate slope category which form

~28% of the total area. Out of the eight aspect classes representing direction of slope viz., NNW (18.87%), WNW (14.66%), NNE (13.66%), ESE (12.19%), ENE (11.68%), SSE (12.18%), SSW (8.87%) and WSW (7.90%), the maximum of slopes are found to be sloping towards NNW.

Dentritic, sub-dentritic, trellis and rectangular type drainage could be delineated in the study area. The main drainage of Shillong town is constituted by northwesterly flowing Wah Umkhrah and Umshirpi streams which are following the general strike of the area. These two streams join near Beadon and Bishop falls to form the westerly flowing Wah Ro-Ro, a joint controlled deep gorge and a tributary to Wah Umiam. The major trend of rivers synchronizes with the major structural trend of the region which is NE-SW, while a set of tributaries have developed as a result of erosional dissection across the structural trend and also following offset faults and joints across this trend. The lower plateau region in the central part of the area is characterized by moderately high drainage density with subdendritic to trellis type of drainage pattern. Rectangular drainage developed at many places is directly controlled by the two dominant joint patterns viz. NE-SW and NW-SE.

The development of soil cover in the study area is highly irregular and range in thickness from a thin veneer to more than 10 m at places. Inceptisol, and ultisols are the two major soil types of the study area. Ultisols are found in places dominated by quartzites and inceptisols occur in places where amphibolites are emplaced. The soils developed on the hills sides and/or escarpments are moderately shallow to deep, loamy skeletal to fine, excessively drained and subjected to moderate to very severe erosion

hazards. These soils have well developed B horizon. Entisols have also been observed on very recent geomorphic surface along Wah Umkrah and its tributary in the Polo ground area and the minor valley fills in the area.

The fourth-order drainage basin is occupied by diverse lithological units and covers almost 80% of the area under study. The variation in size of the fourth-order drainage basins is largely due to physiographic and structural conditions prevailing in these drainage basins. Higher drainage development giving high mean bifurcation ratio is found in highly dissected drainage basins with strong structural control while elongated basins with high value of weighted mean bifurcation ratio shows variation in lithology dominated by Khasi greenstones, quartzites, weathered mantle and valley filled sediments, while lower values drain through pure quartzitic area. Higher drainage development giving high drainage density and stream frequency is characteristically found in the quartzite dominated terrain while lowest drainage development is found in the area occupied by the valley filled sediments. Values of elongation ratio range from 0.5 to 0.7 and circulatory ratios vary from 0.3 to 0.6. High values of elongation ratio and circularity values, especially in the south-western and south-eastern part is due to the combination of lithology and structural control and suggest an intermediate shape with a tendency to elongation associated with strong relief and steep slope. In the southeastern part the basins show a fully elongated shape, the central basin show a stronger tendency to circular shape, the northern basins show a slight tendency to circularity and the southwestern basins show an intermediate shape with a tendency to elongation. The elongated shape of the basins indicates a young stage of evolution, while the intermediate shape with a tendency to circularity suggests

an early mature stage. Lower values of the basins in northern part may be due to strong structural control on the drainage development. Minimum infiltration number shown by the Wah Umkrah basin is possibly due to its lower catchment being in valley fill sediments, while the sub-basins draining the metasediments of Shillong Group show an invariably higher infiltration number.

The high hypsometric integral values of Wah Umiam (tributaries), Wah Umkrah, Wah Umkhen, Wah Umkhen (tributaries) represents younger stage of development with deep incised and high down cutting with concave-down hypsometric curve, while Um Baniun and Wah Tamdong show lower values with hypsometric curve approach monadnock stage (i.e. old stage) of geomorphic development and Umshirpi, Wah Umbah, Wah Shella (tributaries), Phud-Umsning (tributaries) and Phud Mawiong have the shape of mature landform. Concavity of the hypsometric curve (E_h) shows that sub-basin D2, D3, D4, D5 and D6 are least incised, and sub-basin D7, D8, D10 and D11 are least eroded while most erosion prevails in sub-basin D1 and D9. From the position of the slope inflection point, a^* and h^* it is found that degree of peneplanation caused by strong erosion is highest in D1 and D9 followed by D8, D10 and D11 with the least in D2, D3, D4, D5, D6. D7, D1 and D9 sub-basin show least effect of diffusive process, while those of D7, D8, D10 and D11 show moderate diffusive erosion in the upstream segments and consist large mass accumulation at the sub-basin mouth.

Morphometric studies show differential tectonic upliftment in the study area which is reflected in the hypsometric parameters. A measure of a relative

terrain uplift varying from 0.78 to 0.90 indicates high upliftment in the SW and SE sides compared to the NE corner. In general the longitudinal profiles of the trunk channels shows major structural controls. Differences in the materials along the course of a stream commonly caused an abrupt change from low concave to flat profile. The longitudinal profiles of most of the trunk channels show the presence of one or more knick points which is related to offset faults in the region. A number of waterfalls dotting the study area are found to have been formed following these offset faults across the general strike in the Shillong quartzite, suggestive of profile adjustments to the continuous tectonic activities. The analysis of morphometric parameters of the drainage network showed that drainage development is largely controlled by structure and lithology.

Limited hydrological data used in this study indicates that groundwater occur both under artesian as well as water table condition with moderate to high yield. Occurrence of ground water in Shillong group of rocks is under water table condition in the weathered zones of underlying hard rocks whereas in consolidated rocks it occurs under semi-confined condition. In general depth of water level is shallower in topographic depression than in the upland areas or slopes. The water of the area is mildly acidic to alkaline, soft and poorly mineralized. The elements present in the water are far less than the toxic limit excepting Fe which shows concentration more than 0.3 mg/litre. Average chemical quality of the water sources is within safe limits as per national and WHO certified values. However, a higher degree of mineralization would have made the water more suitable to public health. The near deficiency of vital elements is due to non-availability of these elements in the Shillong group of

rocks. Further, due to higher gradient, available elements are also washed away during heavy precipitation.

Six land use classes have been identified namely, built up land, dense forest, open forest, scrub, agricultural crop land and water bodies. For the year 2000, built up land occupies 8.96 % of the study area. Water bodies cover 4.28 % of the area and are mainly represented by the Umiam lake and Wards lake. Agricultural crop land usually bun cultivation covers 6.58 %, with scrubs occupying 10.03 % of the study area. The area covers under pure pine and pine with broad leaf trees has been classed as dense forest which occupies 50.92 % with open forest consisting 19.2 % of the study area. Similarly, for the year 2005, built up land, dense forest, open forest, scrub, agricultural crop land and water bodies cover 9.35 %, 50.04 %, 18.90 %, 10.15 % and 6.93 % and 4.38 % respectively. From the analysis it has been observed that there has been a change in the landuse/ landcover pattern within a span of five years. Area under dense forest has reduced to 7.74 km² which is replaced either by open forest, scrubs and agriculture and urbanization. A decrease of 2.28 km² is observed in open forest mainly due to deforestation, agricultural activities and urbanization. The reserved and protected forest forms almost a complete ring around Shillong comprises around 12.26 % of the total study area. Although agriculture area has increased to 0.71 km² mainly due to bun cultivation, this can create severe erosion problem and increase of siltation rate. Built up land class has an increase of 0.80 km², this is due to rapid expansion over the years where the town has spread to the forests areas which once skirted the town. Built up land have expanded especially towards northeastern part of the study area.

The twin hazards of landslides and flash floods are recurrent geoenvironmental hazards causing loss of life and extensive damage of properties along certain sectors of the city and adjacent areas. With growing anthropogenic activities and urban development, these twin problems have become more acute over the study years. As many as 60 minor and major landslides have been documented through on site inventerisation during the study years within the city, some of which are recurring type while most of them being found in new localities. Their distribution is predominantly along NH-40 apart from those in thickly populated urban areas. Most of the slides include slumping, debris fall and flow. The factors that have a direct bearing on the stability of the study area are: the changes in the slope gradient both natural and man-made, changes in antecedent moisture content, vegetation and lithology. Most of the slides in the study area are confined to the regolith overlying the parent rocks. An integrated study of the causal factors using remote sensing data analysis, GIS and field investigation in respect of geological, geomorphological and meteorological parameters suggest that a multiple of factors are responsible for landslide in the study area.

Landslide prone areas within urban areas are mostly debris fall and are located on steep hill slopes where the settlements have come up in a haphazard and unplanned manner. Unnatural load imposed on the rocks by the haphazard civil structures without slope management is another triggering factor. Landslides are mostly encountered along the NH 40 that cause frequent disruption of vehicular traffic. Majority of the recent failures along the NH 40 are characterized by slumps with an average width of about 30 m and

a length of 50 m from the toe to the highest back scarp. Toe cutting through unscientific method has been attributed as the main causative factor for these slides. The study suggests that high positive pore pressure developed in the fissile rocks and thin soil cover overlying bedrocks due to seepage of water from continuous precipitation is the triggering factor for slope failure. Landslide occurrence is higher in quartzite and phyllite. Correlation of landslide frequency with respect to lineament density shows that most of the slides are confined to areas with lineament density $1-3\text{km}^{-1}$ having NE-SW trend conforming to the structural trend of the area. Flash floods have been recorded in recent years in few localities particularly the topographic lows around Polo ground areas. The immediate cause of flash floods is however, constriction of the floodplain of Wah Umkhrah river by settlement, uncontrolled input of debris from the surrounding cliffs following high intensity rain and high relief of the terrain.

Siltation, though not a major cause of concern as of now, is slowly showing the sign of becoming a major problem in near future. Numerous rock and sand quarry sites are located along streams in and around the Shillong town. These quarries discharge huge quantum of silt on regular basis to the streams which is beyond the capacity and competence of the rivers to dissipate downstream. This result in aggradations of riverbeds and many a times leads artificial damming that becomes a cause of flashflood during rainy season. Urbanization of steep hill slopes involving development of roads, expansion of habitation and new commercial establishments have come up in a haphazard way at the expense of forest. This also has contributed to enormous silt generation in the study area.

The extraction of stones aggregates and sand is the most significant human contribution through material production to the geomorphic change in Shillong city landscape. From the limited study carried out during last few years it is found that the production of stone aggregates and sand has increased substantially and has become the largest source of primary aggregates used in Shillong city. The quarries located within the study area are worked as small enterprises and produce 61% and 72% of stones aggregates and sand consumed respectively for construction projects. This is because people seeking stone aggregates, sand and gravel tend to procure these materials that they need from the nearest and most convenient place. Active quarries or former quarries are not yet reclaimed due to which the scar faces of these extractive activities are vividly visible in the landscape. Such direct landform reshaping by such activities is high in areas of Nongthymmai, Laitkor, Pynthorumkhrah, Mawdiangdiang, Mawlai, Mawpat, Umroi and Umlynka. Out of 730 Mt of construction waste produced during the year 2006-2007, a considerable part of this dumping of waste may be seen as a massive human contribution to changing the geomorphology of Shillong city through material aggregates extraction in some of the localities.

Increase in local production of stone aggregates and sand for consumption by different engineering projects in Shillong city, has raised the amount of siltation in the streams located near the quarry sites viz., Wah Umkhrah, Umshirpi and creating new level land which have been landfilled raising the height of the ground surface. This material transfer is modifying the landscape at a rapid pace, particularly at the sites of extraction and waste disposal. With

the present pace of urban growth, the waste materials are bound to increase. The rapid growth of urban areas with relatively weak planning and environmental controls means that the geomorphic changes related to urban ecology are likely to become more extensive in the near future.

Materials flow accounting and quantification of the urban metabolism has helped in the development of indicators of the degree to which the Shillong Master Plan Area is becoming more susceptible in its behaviour vis-à-vis the geoenvironmental setup. The study suggests recycling of construction materials to reduce the rate of geomorphic transformation by reuse and disposal of construction material. The examination of geomorphic consequences of urban growth activities confirms the importance of looking at and encouraging of re-use of materials everywhere. It is important to identify the key areas of intervention to reduce off-site impacts and cost.

In terms of land consumption, both material extraction and dumping of wastes if continues at present rate, the demand for large areas of land for such activities will grow. Since these areas have become unsuitable for other productive use and agriculture, the pressure will mount on the fringe areas to feed the city or for housing and infrastructure development which is bound to be unsustainable in the long run. The excavations of materials for major developments requiring substantial earth removal and relocation needs to be examined to find ways and means for more balanced use of earth resources.

The present study takes a holistic look into the geoenvironmental status of the Shillong urban agglomeration and its adjoining areas. The urban ecosystem has been analysed with the concept of urban material metabolism

and it has been tried to find a link between the physical and biological parameters vis-à-vis their spatio-temporal variability. Lithological units, landforms and prevalent geomorphic setting are focused as platform to understand the urban ecosystem. This study has brought out a set of baseline data pertaining to the physical attributes which is expected to fill an information gap and be useful as future reference to understand and manage their spatio-temporal variability vis-à-vis changing status of the urban ecosystem in a scenario of ever increasing human interference with the natural systems. The study however, can be treated as the first approximation considering the resolution of mapping adopted. A further high resolution study, taking advantage of advanced technology available, both in temporal and spatial contexts and with direct field measurement of attributes to calibrate the changes imposed, will be the next step in right direction.

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SHILLONG
2009**

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December, 2009

I, Van Jennifer Joan Wallang, hereby declare that the subject matter of this thesis entitled, "Geoenvironment and Metabolism of Shillong City Ecosystem" is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

This is being submitted to the North-Eastern Hill University, Shillong for the award of the degree of Doctor of Philosophy in Environmental Science.



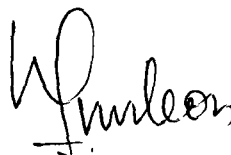
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Shillong
Dated: 10/12/09


(Van Jennifer Joan Wallang)

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CHAPTER 1

GENERAL INTRODUCTION

Geoenvironment has been a key area of concern particularly during the last few decades due to increasing manifestation of adverse impact of anthropogenic forces on most parts of the earth. The top stratum of the earth's crust with diverse geological and geomorphic setting as well as under different climate regime, having interface with the hydrosphere, atmosphere and biosphere has borne the brunt of exploitation of earth's resources throughout the human civilization, more so in the post industrial era. The resultant impact on the structure and function of earth ecosystem is now all too apparent. It is often felt that there is a need for continuous evaluation and appraisal of the environment in terms of the physical parameters of the earth system vis-a-vis the man made ecosystems. Geoenvironmental study in combination with metabolism analysis in spatio-temporal context can be a very effective tool for rational evaluation of changing status of the environment and overall functioning of the ecosystem.

Availability of high resolution satellite data with repetitive coverage of the earth, development in location based technology viz., Global Positioning System (GPS) and enhanced capability of value addition to geospatial database in Geographic Information System (GIS) platform have proved to be a valuable tool for evaluation of resources, appraisal of geoenvironmental status of a region as well as for assessing their spatio-temporal variability. Digital techniques employed in generating spatial information on natural resources greatly enhance the decision support system

providing direct field feedback to an open access technology disseminating information to the public. An essential prerequisite to the assessment of any change in geoenvironmental parameters due to anthropogenic activities or otherwise, is a set of benchmark database. Reliable baseline data is however, still lacking in many parts of the world in spite of the giant stride in relevant technological fields during last few decades. In the backdrop of these technological developments, it is imperative and prudent to prepare basic inventory of natural resources. This approach is also quite useful for planning and development of urban growth centres with optimal utilization of the natural resources in an ecofriendly and cost effective manner.

Knowledge of geomorphology, lithology, stratigraphy, structure and groundwater conditions are fundamental for the study of geoenvironment of any place. Geoenvironment approach towards management and conservation of urban resources has proved to be a successful strategy for mitigating environmental problems of cities. Development through geoenvironmental management has been a key area of interest throughout the world for quite some time now. The planners and development managers have amply realized the importance of geoenvironmental studies and have drawn few guidelines for making environmental appraisal of megacities and projects likely to be executed in future. In Indian cities in general and hill cities in particular, a number of studies on geoenvironmental aspects have been carried out. Sharma and Nathawat (1993) worked out land transformation and environment degradation that resulted from human interference in the fragile ecosystem of Jaipur and its environs. The outcome of the study enabled the planners and administrators in formulating development plan guidelines for maintaining the environment and deciding the parameters for evaluating the quality of life. The geoenvironmental appraisal of Jammu district was made by Vaid et.al. (1998) where a field traverse was made with

analysis of water and soil samples. Thematic maps were prepared depicting various geoenvironmental parameters, viz., geology and geomorphology, depth to groundwater, groundwater quality and land use / land capability. Geoenvironmental degradation of Jammu district was identified on account of various geological and anthropogenic factors. The study suggested that the geoenvironmental aspects derived from the study need to be taken into account for any further development plans in the district, along with measures for mitigation of environmental hazards. An in-depth study on the physical, socio-economic and urban environmental problems caused due to unplanned growth of Gorakhpur city was conducted by Singh et.al (1998). They prepared a planning proposal to improve the housing conditions, land use, health and sanitation, educational and recreational facilities of the city. Sharma (2001) while assessing the natural slope condition using Kinematic analysis identified unstable zones around Nainital township and found that the geoenvironmental setup of the town is prone to mass movement. Gupta (2001) worked on the geological and anthropogenic hazards of Delhi metropolis, and found that geoenvironmentally Delhi suffers from a host of natural as well as anthropogenically induced hazards. He concluded that it is imperative to pay more attention to the geological parameters in order to rectify landuse mismatches. Singh and Sangwan (2001) have reported that urbanization in Haryana is characterized by an appreciable increase in its urban population, declining pace of growth and a considerable change in pattern of urbanization since independence. Spatially the focus of urbanization in Haryana had shifted to the region surrounding Delhi, strongly supported by industrial development and liberalization of economy. Geo-environmental scenario of Bangalore Metropolitan region has been studied by Hedge (2002).

Geoenvironmental issues of the northeastern India was studied by Barman and Bhattacharjee (2008) highlighting the emerging geoenvironmental problems and their present status in northeastern India. They explained how the assessment of the geoenvironmental potential and geo-factors of this region can help to formulate strategies for sustainable management by mitigating the probable geoenvironmental hazards. Bhagabati (2008) focused on environmental problems, such as deforestation, land degradation, flood and bank erosion, loss of biodiversity and human-animal conflict with the existing physical background and growing population pressure on the northeastern region. Bora (2008) broadly discussed the water resources of northeast India in term of potential and development pattern, and classified these resources into four sectors, viz., hydropower, irrigation, navigation and flood management. He concluded that geo-tectonics combined with high seismicity are major problem in water resources development as well as hydropower generation. Agarwal (1993) reported that the urban structure of northeastern India is steadily evolving towards a higher degree of primacy and the rapid rate of urbanization has caused strain on the basic urban services and amenities.

Literature on the status of geoenvironment of Shillong city is very scanty. A few snapshots are available in the form of abstracts and brief reports which, however, do not cover all aspects of the problem. The geoenvironmental appraisal of Shillong Urban Complex was first made by Kumar (1988) where he worked out the terrain characteristics and slope elements of Shillong area. Thematic maps on land use, surface and ground water resources were also prepared as part of the study. It was followed by Roy et. al. (1988) who analyzed base line data on geofactors and prepared thematic maps on geology, geomorphology, slope, landuse and environmental hazards with the help of field data and aerial photographs. The State

Council of Science, Technology and Environment, Shillong commissioned a study on the use and applicability of remotely sensed data in geoenvironmental mapping and appraisal of Greater Shillong region (SCSTE, 2002). An account of the socio-economic and geographical aspects for the Shillong Urban Agglomeration and proposed New Shillong City can be found in the Project Report on New Shillong (DOUA, 1997). Meghalaya State Pollution Control Board (2002) has also prepared a report entitled, "The State of Environment of Shillong City". The proposal of Master Plan of Shillong (1991-2011) prepared by, Directorate of Urban Affairs Meghalaya aims to achieve the objectives such as integration of various areas within the Shillong city, development of transport and communication network and functional disposition of urban areas(DOUA, 1991).

The geoenvironmental view of resource exploitation takes into account both the mass of minerals produced and the masses of overburden, wastes and by-products created. Knowledge of the degree and magnitude of the "rucksack" associated with mineral working is an important contribution to "geoindicators" or sustainability indicators which monitor consumption of natural resources and the impact of that consumption (Lawson and Douglas, 1998). The impacts of such rapid transfers of materials from the natural environment to the urban and industrial built environment are two-fold, a removal of material from the earth's surface (a change in geomorphology) and the accumulation of a stock of concrete and other materials elsewhere in cities (a change in urban morphology) (Douglas and Lawson, 2001). The metabolism of cities and industries transform the natural landscapes and has emerged as a highly efficient geological and geomorphological agent in comparison with the rates at which rivers and water running over the ground changes the landscape.

In order to appreciate the position of the flows of concern to urban ecology within the spatial and temporal scales of geological processes, we have to consider human urban activity as one of the sets of actions by organisms that contribute to the earth surface component of the rock cycle. This rock cycle contains many shorter term, localized re-distributions and circulations of chemical elements between the mineral material of the earth's crust and the organisms that live within it and on it. Such biogeochemical cycling is fundamental to life and is part of biological production and decay. The biogeochemical cycling is best interpreted in the way ecologists, such as Odum (1971), examine turnover of material in natural ecosystems such as tropical forests or coral reefs. However, it can be conceptually extended to incorporate an urban system, in which the urban fabric is added as an additional repository of substances, alongside the lithosphere, biosphere, hydrosphere and atmosphere (Odum, 1971). Urban fabric is often constantly being renewed through demolition creating a recycling opportunity for crushed concrete to be used as aggregate. The urban fabric can thus be interpreted as the "urban deposit" (Wilburn and Goonan, 1998), a form of renewable resource, constantly being restocked with new structures. In this way, people's activities are seen as part of the processes changing the earth's surface at geological scales (Douglas and Lawson, 2001). Viewing cities as centres of accumulation of materials is repeating a geomorphological view of a city as a recent earth surface deposit where structures and drainage have greatly modified earth surface processes. This view then leads to a recognition that the material flows driven by human activities can be seen as part of a broader anthropogenic transformation of the earth's surface which has implications not only for supplies and environmental costs of materials, but also for the nature of the lands and seas on which we live and the landscapes surrounding our daily lives.

The role of human activity in earth surface processes and geological transformations has long been acknowledged. Sherlock's (1922) studies provide many illustrations of the quantities of material involved in mining, construction and urban processes. In the concern over making land use and urban life more sustainable in the 1990's, much greater attention than ever before has been paid to the ecological footprints of cities (Rees 1994) and the environmental "rucksack" of mining (Bringezu and Schütz 1996). The importance of the analysis of materials flows, the study of product life cycles, and resource and waste accounting (Ayres and Ayres, 1996; Masini and Ayres, 1996). Analyses of materials fluxes, with parameters of direct geomorphological interest, have been produced for China, Germany, Japan, the Netherlands and the USA (Chen and Qiao 2000; Adriaanse et al. 1997, De Marco et. al. 1999). Girardet has calculated the resource use in Greater London's metabolism (Sustainable London Trust, 1996).

Geoenvironmental view of national earth resource exploitation which considers both the mass of minerals produced by national extractive industries and masses of overburden, wastes and by-products was created by Lawson and Douglas, (1998) to see how those flows compare with the rates of change of the surface of those countries by natural erosive processes. Materials flow accounting and quantification of the urban metabolism can help in the development of indicators of the degree to which a country or a city is becoming more sustainable in its behavior. The geomorphic work associated with urban and industrial growth thus involves materials use, the hidden flows, such as mining and construction waste, and the accelerated erosion by natural processes. Hence metabolism of a city can be seen as the process of transforming all the materials and commodities for sustaining the city's economic activities (Huang and Hsu, 2003).

Integrated appraisal of geoenvironment together with urban metabolism is an emerging field of applied research which has received ample attention of researchers in recent times. In a number of cities world over, the planners and researchers are engaged in evolving a holistic model of urban development based on modern ecological principles. The development managers and planners have used the geoenvironmental approach of different parameters to study specific areas for sustainable development.

Shillong, the capital city of Meghalaya, is a growing urban centre that has witnessed high population growth particularly after 1972 when a separate state of Meghalaya was formed with Shillong as the State Capital. It has a three and half lakhs population as per census 2001. The early growth of Shillong was due to the expansion of offices and commercial activities to serve the administrative population. However, after independence the importance of Shillong grew as an educational centre for the people of the northeastern states. This accelerated the immigration of people from neighbouring states as well as from other parts of the country. This growth causes an immense pressure on the available resources and environment resulting into an imbalance in the city ecosystem. Therefore there is a need of regular monitoring of environment and inventorisation of the resources for proper planning and management of the city. In doing so the status of geoenvironment has to be known for present and future development activities. So far no work has been carried out on the Geoenvironment Metabolism of Shillong City Ecosystem. Some data are available on the Geoenvironment of Shillong but an integrated metabolism approach towards problem using modern tools and techniques is lacking. Present study aims to fill in this gap in our knowledge on the dynamics, structure and function of city ecosystems. In absence of a comprehensive base line data on the different geoenvironmental

parameters it is difficult to comprehend any change that has been taken place in terms of quantum and rate. This study intends to provide the base line data on Geoenvironment and Metabolism of Shillong city which can be used for monitoring of future change and in planning for sustainable development of the city.

The study aims to conduct an integrated analysis of the multidisciplinary spatial and aspatial auxiliary data pertaining to geoenvironment and metabolism. It involves study of lithological and geomorphological attributes of the area, lineament identification, slope analysis and delineation of potential landslide prone zone, to evaluate the land use/land cover and its changes in spatial and temporal context, drainage pattern identification and drainage analysis as well as water quality analysis, and geoenvironmental hazards. The urban metabolism has been studied to learn the materials flow for construction major engineering projects such as roads, bridges, storm water drainage and buildings. An attempt has been made to integrate the geoenvironment and metabolism and their common areas of influence to address the issue of establishing the rate of transformation of the land surface of Shillong city by human action in terms of the annual quantities of rock materials extracted and the volumes of waste created by human activities.

The thesis has been divided into 9 chapters. Chapter-1 introduces the problem and sets the objectives of the work. Chapter-2 describes the location, salient features of the study area and the methodology followed. Chapter-3 deals with geological settings and geomorphology while the results of morphometric parameters of the fourth-order drainage basins and the stage of geomorphic development is given in Chapter-4. Chapter-5 gives an account of water availability from ground water and surface water sources, evaluation of water quality and hydrogeomorphological study for ground

water prospects. Chapter-6 discusses the land use/ land cover change of the study area between 2000 and 2005. Chapter-7 reports the causal factors of landslides and flash flood while the study on metabolism on consumption of construction materials and discharge of wastes is given in Chapter-8. General discussion of the research is given in Chapter-9.

CHAPTER 2

STUDY AREA AND METHODOLOGY

Study area

The study area encompasses the urban growth centre in and around Shillong, the capital of Meghalaya covering about 208 sq km as per the Shillong Master Plan 1991-2011 (Figure 2.1, 2.2, 2.3). It is defined by the boundary coordinates 25°30'29" to 25°42'10" North and 91°46'50" to 92°00'32" East within the SoI toposheet 780/14. The Shillong Master Plan Area (SMPA) is an agglomeration of seven urban centres viz., Shillong Municipality, Shillong Cantonment, Townships such as Nongthymmai, Madanriting, Mawlai, Pynthorumkhrah, Nongmynsong and 40 fringe villages.

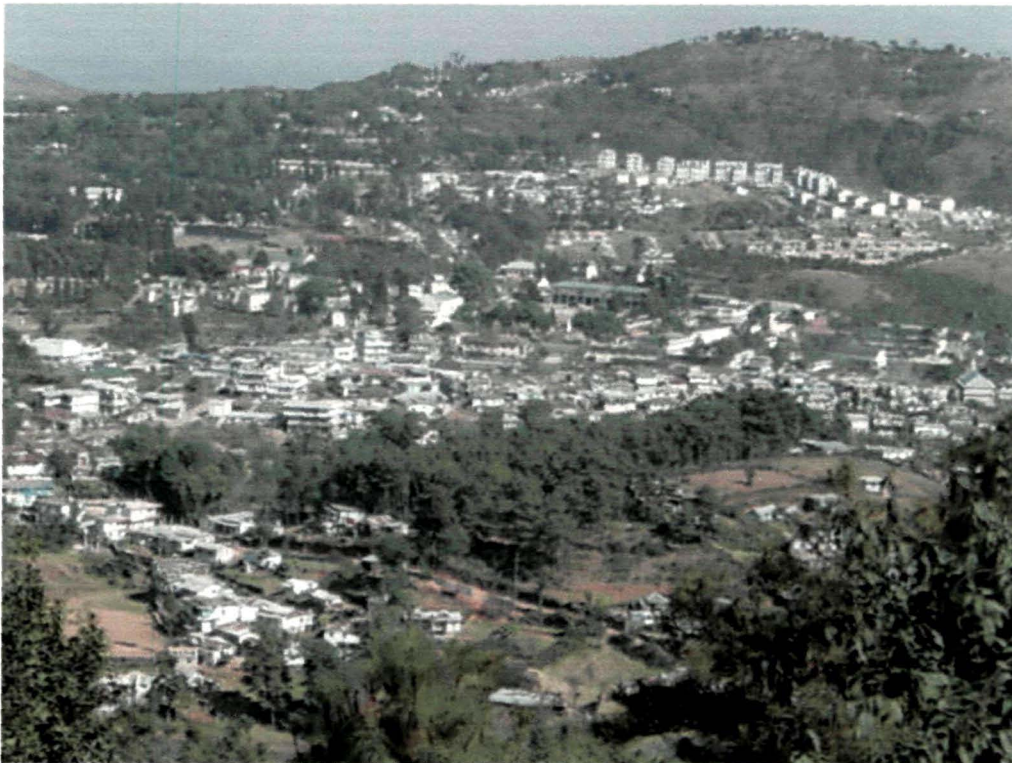


Figure 2.1: A panoramic view of the study area

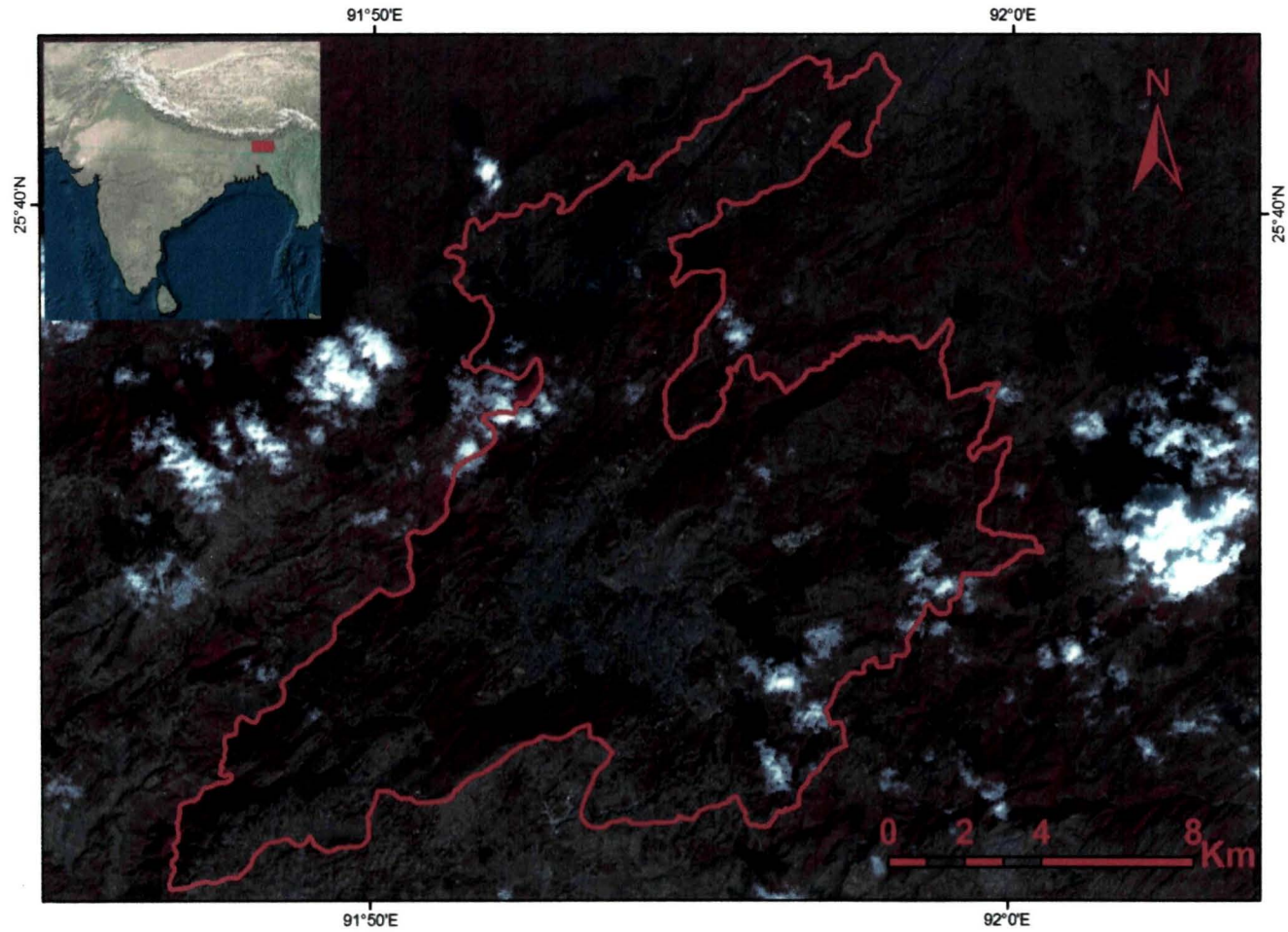


Figure 2.2: Location map of the study area shown as overlay on the IRS LISS III FCC image

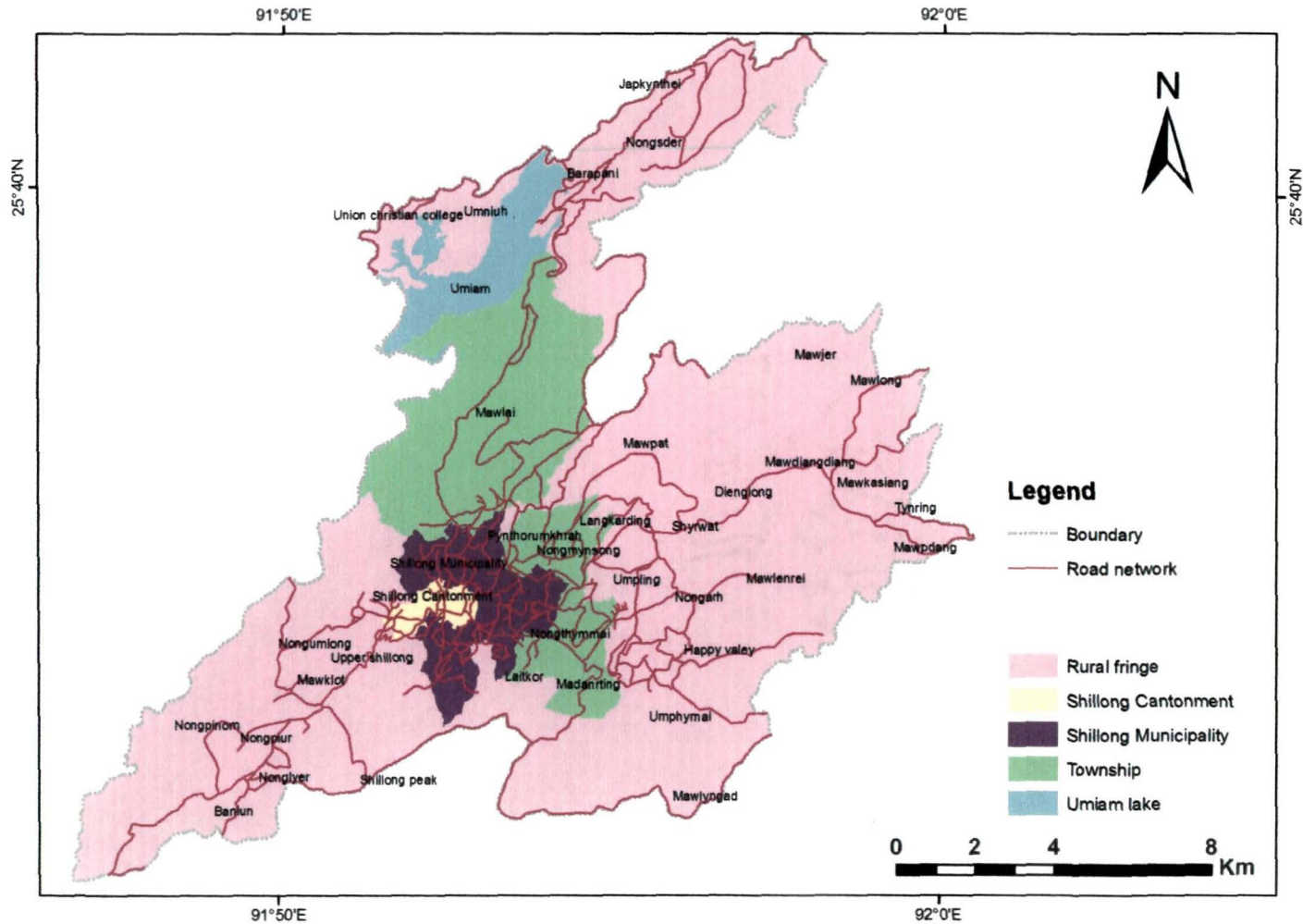


Figure 2.3: Base map showing the Shillong Master Plan Area.

The total area of the Shillong municipality is 10.36 sq km with 27 separate single-member wards under the administration of Shillong Municipal Board (SMB) while Shillong Cantonment has its own Cantonment Board. The Cantonment and Townships constitute Shillong Urban Agglomeration (SUA).

Accessibility

The Shillong city is well connected with rest of the states of northeast India through NH-40 and NH-44. The main gateway for rail and air connectivity is through Guwahati which is at a distance of about 100km towards north. Towards south, the city is connected with Jowai, the district headquarters of Jaintia Hills at a distance of 65km while towards west Cherrapunjee is located at a distance of about 55km. Within the study area there is a network of good all weathered roads, besides numerous foot tracks and fair weather jeepable roads that connect the interior parts of the area. Helicopter service is available between Shillong-Guwahati and Shillong-Tura. The only airport at Umroi is 35 km from Shillong.

Demographic profile

As per the statistics from Census of India 2001, the Shillong Master Plan Area (SMPA) population is 336901, which is 14.53% the total state population. Out of State's total urban population, Shillong Urban Agglomeration (SUA) has a population of 267662 which represents nearly 59% of the State's urban population (Table 2.1).

Table 2.1: Decadal growth of population of Shillong Master Plan Area

Sl no	SMPA Components	1971	1981	1991	2001
1	Shillong Municipality	87659	109244	131719	132867
2	Shillong Cantonment	4730	6520	11076	12396
3	Nongthymmai	16103	21558	26938	34292

4	Mawlai	14260	20405	30964	38303
5	Madanrting	-	6165	8987	16318
6	Pynthorumkhrah	-	10711	13682	22115
7	Nongmynsong	-	-	-	11371
	Shillong Urban Agglomeration	122752	174703	223366	267662
8	32 Villages	32848	42571	47747	63711
9	8 Villages	-	-	-	5528
	Total	155600	217274	271113	336901

(Source: Master Plan of Shillong and Reports of Census of India 1991, 2001)

Climate and rainfall

Climate of the area is subtropical, characterized by mild summer and cold winters. The maximum average summer temperature is 24.83°C, winter temperature 15.6°C while the minimum average temperature in the summer is 21.93° and in the winter it is 5.83°C. Summer season witnesses heavy monsoonal rainfall, brought about by southwest monsoon winds during the months of June to September with an average of 25 rainy days in a month. Average mean annual rainfall is 2326 mm which is variable in different parts of SMPA with the maximum of rainfall concentrated towards south-western part. Pre-monsoon gets only one fifth of the total rains mainly by thunderstorms. The winter is almost dry. Relative humidity varies between 50 to 91. The average monthly variation in maximum and minimum temperature and rainfall are depicted in Figures 2.4 and 2.5.

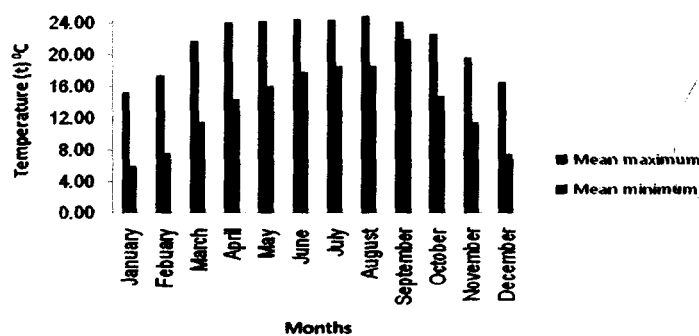


Figure 2.4: Mean monthly maximum and minimum temperature of the study area.

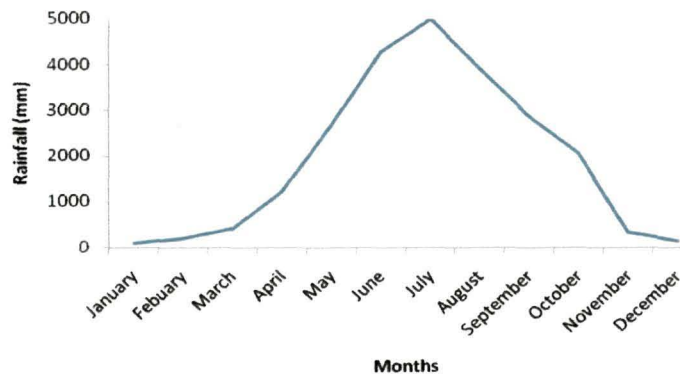


Figure 2.5: Mean monthly variation in rainfall of the study area.

Natural vegetation

The natural vegetation varies from a mixed tropical evergreen to that of temperate and sub-montane forests. The mixed subtropical forest is confined to the protected and reserve forest and green blocks. The dominant tree species of the area is pine (*Pinus kesiya*) which is almost pure in most areas and in others it is found mixed with a few broad leaf species. In and around the Umiam lake the dominant tree species are: *Schima khasiana*, *Clerodendron fistulacum*, *Docynia indica*, *Shorea robusta*, *Betula alnoides* and *Schima wallichii*. *Quercus montana*, *Myrica esculenta*, *Michelia champaca* and *Prunus nepalensis* are found in the forest of Upper Shillong area. Miscellaneous hardwood species found in association with pine are: *Schima khasiana*, *Exbucklandia populnea*, *Betula alnoides*, *Alnus nepalensis*, *Castanopsis sp.*, *Quercus fenestrata*, *Acer oblongum*, *Prunus nepalensis*, *Rhododendron arboretum* and *Engelhartia spicata*. The under growth consist of *Rubus ellipticus*, *Viburnum foetidum*, *Osbeckia crinata*, *Trifolium ripens*, *Artemisia vulgaris*, etc. Close to the drainage and river system at altitudes of 1100 meters above msl., patches of sub-tropical evergreen and tropical moist deciduous forest are found. Major portion of

these forest are formed by *Castanopsis indica*, *Quercus serrata*, *Cinnamomum* sp., *Michelia champaca*, *Syzygium jambos*, *Duabanga* sp., *Acer* sp., etc. *Pinus kesiya* is found mixed with these species.

Methodology and Database

The outline of work elements and research design adopted for this study involved collection, compilation and collation of background information. This was followed by procuring satellite data (IRS LISS III, FCC) and Survey of India (SoI) topomaps in 1:50000 scale. Basic spatial data was generated based on satellite data (IRS LISS III, FCC) and Survey of India (SoI) topomaps in 1:50000 scale. Preprocessing of topomaps and satellite data was done in GIS environment using the Orthoengine module of Geomatica 9.1 and giving input of same projection parameters using UTM projection of zone 46 (90°E-96°E) and row R (24°N-32°N), datum in 'D076' Indian (India, Nepal) and Everest Ellipsoid (1956) as earth model.

The IRS LISS III, FCC images were georeferenced collecting GCPs from the SoI toposheets by picking identical points in both topomap and satellite imagery. The projection parameters for georeferencing the satellite images were same as that of the toposheet. The study area boundary was first geocoded by picking identical points from the topomap and then followed by vectorisation as polygon from the raster Shillong Master Plan Area boundary map and the area was noted directly from the attribute table of the layer. In the case of municipal ward and township boundary map, total RMS error was not taken into consideration as the original map was geometrically not accurate. The technique of rubber sheeting was applied to this map to correct the shape. Reconnaissance survey was conducted to identify the key area of interest.

Satellite data (IRS LISS III, FCC) and Survey of India topomaps in 1:50000 scale were studied for extraction of information on lithology and structure as well as geomorphology. Integrating these studies and available collateral data in the form of published literatures, maps etc. prefield maps were prepared for geology and geomorphology which were used as basis for identification of traverses for detailed field study. The recording of surface irregularities and relief patterns on satellite imagery facilitated the mapping of these geomorphic units. Besides standard visual interpretation technique as described by Lilles and Kiefer (1999) was used for indentifying individual landforms.

Extensive fieldwork was carried out, both along and across strike for identifying the geological and geomorphological attributes. The prefield maps were edited and finalized based on the field inputs and a spatial database was generated in GIS environment. All positional data were recorded as latitude/longitude waypoints in a handheld GPS (Garmin eTrex Vista) with 6-10m spatial resolution and the location based information were integrated as attribute of the point vector layer representing the GPS waypoints.

Remote sensing techniques were employed to delineate the lineament occurring in SMPA in order to examine the structural characteristics of the terrain. For manual lineament extraction, the image (IRS L3 FCC) was first smoothed with an average low pass filter in order to eliminate the noise using Geomatica Focus 9.2. Following the smoothed process, Sobel's directional filter (NE-SW) was applied to make the lineaments prominent, as the dominant structural trend of the area is NE-SW (Suzen and Toprak, 1998, Table 2.2). After the filtering operation, the lineaments were digitized manually.

Table 2.2: Sobel Kernels in two principal directions

NE-SW		
-2	-1	0
-1	0	1
0	1	2

The length and orientation of the lineaments mapped were recorded and morphometric analysis i.e, lineament frequency (the total number of lineaments per unit area) and lineament density (the total length of lineaments per unit area), was calculated by taking 2km X 2km grids. The lineaments were analyzed in terms of their dominant trend by preparing Rose diagram.

The DEM was generated by vectorised spot heights and elevation contours in 20m interval from the toposheet in GIS environment using Geomatica 9.1. The contours were stored, as separate vector layer and their associated elevation were stored in associated attributes. After the digitization, a 30m DEM was generated from the vector layer containing contours and spot heights using VDEMINT algorithm. The extraction of DEM was accomplished by interpolating elevation values of contours and spot heights to the whole area and a raster image was formed in which gray levels of the pixels were the elevation values of the corresponding points on the ground. Overlay analysis was done to subset the DEM for the present study area from the whole DEM. For this purpose the polygon representing the study area was overlaid upon the DEM and by Boolean logic and the DEM for the present study area was cut out. DEM profile was obtained by plotting the pixel value against each of the point in the profile axes. A vertical profile of a DEM was plotted along a given azimuth. This was useful in visualizing the slope along a particular trend.

Gradient was expressed in degrees or percentage and aspect in degrees was converted to a compass bearing.

The gradient is given by the equation:

$\text{Tan } G = [(dZ/dX)^2 + (dZ/dY)^2]^{1/2}$, where Z is altitude and X and Y are the co-ordinates axes.

The aspect is given by the equation: $\text{Tan } A = \frac{\delta Z/\delta Y}{\delta Z/\delta X} (\pi < A < \pi)$

The derivation of slope and aspect from DEM was created using SLP algorithm for slope and ASP algorithm for aspect. The slope calculation algorithm was based on a best plane determination method, using a grid of 3·3. Thus the slope of a 10 m-sided grid was calculated by interpolation on a ground pixel size of 30x30 m square. The process of generating Shaded relief was done interactively with the user selecting different sun azimuth and elevation positions. As a result of shadows the structural features present as part of the topography were highlighted e.g., linear features trending N-S were highlighted with sun azimuth of 90⁰ while E-W trending features were highlighted with a sun azimuth of 180⁰. Shaded relief was generated using REL algorithm with input parameter of 315⁰ azimuth angle and 30⁰ elevation of the sun. An elevation map was created from DEM using Pseudo Colour Transformation (PCT). The soil map of Meghalaya prepared by National Bureau of Soil Survey and Land Use Planning prepared in 1,250,000 scale and printed in 1,500,000 scale was used for the study.

Morphometric analysis was carried out based on the drainage segments and elevation contours extracted from Survey of India topomaps in 1:50000 scale. The digital database was created through on-screen digitization the attributes were assigned in GIS environment. All measurements were directly computed from the vector data

extracted from the topomaps. The drainage segments were digitized as lines separately and hierarchical stream order was assigned to all (Strahler, 1952). Detailed morphometry the fourth order basins within the study area were delineated following surface water divide from Survey of India topomaps. Topological polygons were created in Geomatica 9.1 and the relevant attribute tables were generated. IRS LISS III images were used as supplementary spatial data source. Linear, aerial and relief aspects of the basin were computed in GIS environment followed by simple linear regression analysis to see the mutual dependency of the variables viz., stream order vs. stream number, stream order vs. stream length etc. For hypsometric analysis, the elevation contours were vectorised in GIS environment as lines using Geomatica 9.1 for the topomaps and their corresponding elevation values were entered in the attribute table. The elevation contours and the basin boundary were merged in a single layer and converted into polygon for further analysis.

The morphometric parameters of the drainage basins were directly computed from the vector data extracted from the topomaps (basic parameters) or were derived from the measured data. The data in the first category included area, length, perimeter, relief, maximum order of the streams, number of streams in each order, and the total length of streams for each of the basins. Those of the second category were the bifurcation ratios, elongation factor, circularity index, shape factor, drainage density, stream frequency, texture ratio, relief ratio, length of overland flow, constant channel maintenance and infiltration number (Table 2.3). Information on the geological attributes was based on available collateral data in the form of published maps and documents of Geological Survey of India and individual workers, satellite image interpretation and field inputs.

Table 2.3: Symbols and parameters used in morphometric analyses

Parameters	Symbol	Formula	Units	Reference
Basic parameters				
Basin area	A	Area bounded by the drainage basin boundary.	km ²	
Basin length	Lb	The maximum length of the basin.	km	
Basin perimeter	P	The total length of the drainage basin boundary.	km	
Basin relief	H	The difference in height (m) between the highest (Z) and the lowest (z) points (summit and the mouth) of the basin.	m	
Stream order	U	Hierarchical rank	dimensionless	Strahler (1964)
Number of stream in each order	Nu	Total number of streams (N) of a given order (U) within each basin boundary.		
Stream length	Lu	Length of all streams within each basin boundary.	km	Horton (1945)
Derived parameters				
Mean Stream Length	Lsm	Lsm=Lu/Nu Lu=Total stream length of order 'u' Nu=Total no. of stream segments of order 'u'	dimensionless	Strahler (1964)
Bifurcation ratio	Rb	Rb= Nu/Nu+1 Nu = Total no. of stream segments of order 'u' Nu+ 1 = Number of segments of the next higher order	dimensionless	Schumm (1956)
Mean bifurcation ratio	Rbm	Rbm = Average of bifurcation ratios of all orders	dimensionless	Strahler (1957)
Drainage density	D	D= $\sum Lu / Au$ Lu=Total stream length of all orders Au= Area of the Basin (km ²)	km ⁻¹	Horton (1932)
Stream frequency	Fs	Fs= $\sum Nu / Au$ Nu=Total no. of streams of all orders Au= Area of the Basin (km ²)	km ⁻²	Horton (1932)
Drainage texture	Rt	Rt=Nu/P Nu=Total no. of streams of all orders P=Perimeter (km)	km ⁻¹	Horton (1945)
Form factor	Rf	Rf=Au/Lb ² Au=Area of the Basin (km ²); Lb ² =Square of Basin length	dimensionless	Horton (1932)
Circularity ratio	Rc	Rc=($\pi 4Au$)/P ² Pi='Pi' value i.e. 3.14 Au=Area of the Basin (km ²); P = Perimeter (km)	dimensionless	Miller (1953)
Elongation	Re	Re=2{ $\sqrt{(Au/\pi)}$ }/Lb	dimensionless	Schumm

ratio		Au=Area of the Basin (km ²) Pi='Pi' value i.e. 3.14; Lb=Basin length		(1956)
Length of overland flow	Lg	Lg=Au/2.∑Lu, Au=Drainage Area; Lu=Total stream length	km	Horton (1945)
Constant channel of maintenance	C	C=I/D D= Drainage density;	km ⁻² .km ⁻¹	Schumm (1956)
Infiltration number	If	If=D.Fs D= Drainage density; Fs= stream frequency	km ⁻²	

For linear aspects number of streams (Nu) for each order and their length (Lu) were counted and noted from the attribute table. All the values were tabulated in an excel sheet. For graphical plot of stream order vs stream number, stream order and vs stream length a regression equation was used, which is

$$Y=a+bx \quad (1)$$

Where 'b' is the regression Coefficient calculated from the relation:

$$b = \frac{\sum xy - \sum x \sum y / n}{\sum x^2 - (\sum x)^2 / n}$$

Again the value of 'a' can be calculated from

$$a = \bar{y} - b \bar{x}$$

where, \bar{y} = Mean of y
 \bar{x} = Mean of x

By plotting the values of 'x', 'a' and 'b' in the regression equation, we get the value of 'y' for corresponding number of stream number and stream length. Plotting the antilog values of 'y' against 'x' the stream order vs stream number and stream order and vs stream length were drawn.

The mean bifurcation ratio (Rbm) was calculated as the arithmetic mean bifurcation ratio and weight mean bifurcation ratio using Strahler (1957) method by taking into consideration the actual number of streams that were involved in the ratio.

For aerial aspect the drainage area (A_u) and basin perimeter (P) were noted from the attribute table and the maximum basin was measured using measuring tool in Geomatica 9.1. Drainage Density (D), Stream Frequency (F_s), Elongation Ratio (R_e), Circularity Ratio (R_c), Form Factor (R_f), Length of overland flow (L_g), Constant Channel of Maintenance (C) and Infiltration Number (I_f) were calculated in the excel sheet using formula given in Table 2.3.

For the present study hypsometric curves were drawn and classified following Strahler (1964), pertaining to hypsometry of the fourth-order drainage basins where the ordinate represent the basin elevation (h) normalized against its maximum height (H), while abscissa represents the corresponding area (a) normalized against the total basin area (A). Two ratios were used for construction the hypsometric curve. Relative height or h/H ; where ' h ' was the highest elevation between each pair of contours above the base and ' H ' was the total basin height, and Relative area or a/A ; where ' a ' was the area enclosed by a pair of contours and ' A ' was the total basin area. The curve also shows the three segments as proposed by Willgoose and Hancock (1998). The “toe” of the curve is the downward concave part of the curve on the right – hand side; the “head” of the curve is the upward concave part of the left–hand side; and the body of the curve is the upward concave segment in the center of the curve between the toe and the head. The toe and the head represent the downstream mouth and the upstream water–divide segments respectively of the catchment.

The hypsometric parameters were measured following Strahler (1964). The abscissa was the relative area given by a/A and the ordinate was the relative elevation given by h/H . The maximum concavity of the hypsometric curve (E_h) was measured from the profile A-C of a hypothetical plane that joins the maximum (head) and the minimum

(toe) elevations of the catchment. Line A-C is the profile of a hypothetical plane. The hinge both at the river mouth and at the catchment head, represents an ideal planar landform surface that would develop under uniform boundary conditions, especially of catchment erodability. Inflection Point (I) represents the junction between the head and the body segment of the curve. The coordinates of the Inflection Point (I) i. e. change over from either concave to convex on a/A and h/H were measured by a^* and h^* , respectively. Apart from these, the position of head, body and toe of the curve was depicted by the ordinate values corresponding respectively to $a/A=0.2, 0.5$ and 0.8 , for finer height definition of the toe $a/A=0.9$ value was used. These parameters are shown as $h(0.2), h(0.5), h(0.8)$ and $h(0.9)$ respectively.

Hypsometric Integral was measured following Wood and Snell (1960) that expresses the relative proportion of upland to lowland within a sample region, designated as E_a and is defined:

$$E_a = \frac{\text{Mean Elevation} - \text{Minimum Elevation}}{\text{Maximum Elevation} - \text{Minimum Elevation}}$$

Where Mean Elevation was calculated with the help of statistical method by calculating average area (x) and average contour (y) from the hypsometric analysis data following the statistical formula: $\sum xy / \sum x$.

Tectonic uplift and downwasting due to erosion are the two competing factors that control the landscape form and its evolution. The shape of hypsometric curves depends on the degree and type of downwasting apart from the catchment geometry. Landscape evolution can be formulated as a continuity equation relating uplift, elevation and erosion for sediment transport (Willgoose and Hancock, 1998).

$$Dz/dt = U - \Delta qs \quad (1)$$

Where u = tectonic uplift; z = elevation at any point; t = time; qs = mass flux of combined fluvial and diffusive downwasting processes

For comparison of catchments in terms of relative uplift in finite time-frame equation (1) can be written as:

$$U = z + qs \quad (2)$$

For comparing the tectonic uplift in subcatchments z in equation (2) can be replaced by the mean elevation (hm) of the subcatchment (Sinha-Roy, 1981), obtained from the elevation covering 50% of the area and normalized against the maximum height of the master drainage basin. The hm values can be estimated from the hypsometric curve. Thus the equation (2) can be written as:

$$U = hm + (1 - Ea) \quad (3)$$

The equation (3) was used for the present study to assess the tectonic uplift along the river channel. Here U is the relative tectonic uplift in the individual sub-basin, hm is the mean elevation of the sub-basin and Ea is hypsometric integral.

Longitudinal Profiles were plotted by taking the longest stream channel of a considered basin on SoI topomaps of 1:50000 of 20m interval. The distance from the source to the intersect contour elevation was measured and the profile was constructed using distance as abscissa and elevation as ordinate in the GIS environment for total eleven basins.

Available data on hydrological aspects particularly on status of ground water in the Shillong Master Plan Area is very scanty. Considering limited scope for primary data collection, the present study for water resources was made based on the secondary data available with agencies like Public Health Engineering Department, Government of Meghalaya and Shillong Municipal Board, Government of Meghalaya, Shillong.

Data on ground water level and water quality were collected from Public Health Engineering Department (PheD), Government of Meghalaya and Meghalaya State Pollution Control Board. The analysis for water supply and production was confined to Greater Shillong Planning Area due to non-availability of data for the whole study area. Thirty six sample points were obtained for hydrogeological data of wells during dry seasons, and 66 sample data were obtained for the water quality distributed over the study area from various sources such as gravity, deep tube wells, hand pumps, springs, dug wells, Wards lake and Umiam lake. The location of these sources were brought to GIS format, and were used for extrapolation over the study area by kriging methods for water level, pH value, chloride content (mg/l), turbidity (NTU) and iron content (mg/l). Areas where data was not available were designated as unclassified in the thematic map.

For generation of spatial database for temporal analysis of land use /land cover, the primary datasets inputs included SoI toposheet 76 O/14 in 1:50000 scale and its corresponding IRS 1C and 1D Geocoded FCC of LISS III. The interpretation was done in three phases such as pre-field interpretation, field verification and post-field analysis. Study of changes in land use pattern using remotely sensed data was based on the comparison of the time sequential data. Differences in surface phenomenon over time was determined and evaluated by visual interpretation with local knowledge (Garg et al. 1988). The LULC thematic mapping was prepared through standard visual interpretation techniques (Lilles and Kiefer, 1999) for two different years.

Satellite images (IRS LISS III, FCC) and DEM were studied for identifying the susceptible areas for landslides. On-site investigation and documentation of the existing landslides were carried out to develop an inventory. Flash flood prone areas

were identified based on their record in news media and the actual events that happened during the year 2003 and 2004. Information points gathered from fieldwork was brought to GIS platform for further processing and analysis. A map of landslide and flash flood occurrence was prepared in 1:50,000 scale using the GIS software ARC/INFO to evaluate the distribution and frequency of landslide. To understand the causal factors for landslides as well as flashfloods, a convergence of evidence method was followed. For the purpose, the GIS database in the form of vector and attribute data was integrated with relevant spatial maps using overlay analysis of the landslide and flashflood map over thematic layers of lithology, slope, drainage, landuse and structure for generation of composite data sets, queries buildings etc. Meteorological parameters were used to find out the causal factors for a similar geoenvironmental condition.

To analyse the volumes of materials shifted in major urban construction projects, data on the material inputs to, and waste outflow from Shillong Urban Areas (SUA) were used. The urban construction projects included in this research are road, building, bridge, and storm water drainage. The construction materials include stone aggregates, sand, cement and bitumen. Data for major urban construction projects were gathered for three years i.e., April 2005- March 2006, April 2006-March 2007, and April 2007-March 2008, from the Public Works Department, Government of Meghalaya and Shillong Municipal Board. The quantities of construction materials required per unit length or area for different projects and construction waste were based as per the data provided by these organizations. From these records an overall figure for materials movement in and out the city for each major urban construction project was computed. Data on local production for stone aggregate and sand was collected through field survey and interview with the producers. Study was conducted

in Shillong Urban Areas (SUA) only. The repair of National Highway (NH) passing through the city was not considered as data pertaining to the same was not available.

The toposheet 78 0/14, scale 1:50,000 was collected from Survey of India, northeastern region, Shillong. IRS LISS III, FCC images of 23.5 meter resolution with path -111 and row-54 whose date of acquisition is 24th March, 2000 and 6th November, 2005 was collected from National Remote Sensing Agency (NRSA), Hyderabad. The study area boundary, municipal ward and township boundary was prepared on 1:50,000 scale with the help of data collected from Urban Affairs Department of Government of Meghalaya. Reserve and protected forest map was obtained from Forest Department of Government of Meghalaya. From Meteorological Department, Government of India, Shillong, meteorological data was procured. Hydrological data, water quality data, consumption and data on distribution pattern of water was collected from Public Health Engineering Department (PHeD), Government of Meghalaya ; Shillong Municipal Board (SMB) and Meghalaya State Pollution Control Board (MSPCB), Government of Meghalaya. Plinth area of buildings was collected from Meghalaya Urban Development Authority (MUDA), Government of Meghalaya. Data on length of roads, bridges and storm water drainage was collected from Public Work Department (PWD), Government of Meghalaya.

CHAPTER 3

GEOLOGICAL SETTING AND GEOMORPHOLOGY

Introduction

Geology of an area is primarily responsible for the evolution of the landform under the operation of physico-chemical processes on the earth's surface. Therefore, the prerequisite of any geoenvironmental appraisal is the knowledge of geology of the area. Geomorphology involves both terrain evaluation and investigation of the processes which shape the land form (Fairbridge, 1968). Geomorphic knowledge plays a valuable role in the management of land resources, planned utilization of land and mitigation of geohazards. Urbanization and development are related to topographic, hydrographic and socio-economic features. Therefore, geomorphology comes in the forefront wherever land-man interaction and environmental exploitation takes place (Kumar and Pandey, 1989, Coates, 1974). As a result, contemporary geomorphological studies have begun to consider ecological factors in greater depth (Viles, 1988).

Scientific research on the geology of Shillong Plateau was first initiated by Oldham (1858). Medicot (1869), Bose (1901), Palmer (1924), Dasgupta (1934), Chatterjee (1937), Fox (1949), Pasoe (1950) made fundamental contribution to the subject. Singh (1968) carried out geomorphological studies of Shillong Plateau, followed by Chatterjee (1968), Machatchek (1969) Majumdar (1986), and Roy et.al. (1988).

However, Anon(1974) and Mazumdar (1978) gave a very generalised regional physiography while discussing the geological framework of the northeastern India. Photogeological and photogeomorphological maps of Shillong Plateau were prepared by Chopra (1984) confining to the southern fringes of Meghalaya. Although the Plateau has been studied fairly well, scientific analyses of the geomorphology of the human inhabited regions of the area is scarce. The purpose of this research is to conduct a detailed geological and geomorphological mapping for Shillong Master Plan Area in the scale of 1:50,000. The study also brings out comprehensive topographical information of the study area using Digital Elevation Model.

Regional Geology

The geology and geomorphology of Shillong Plateau in relation to its regional framework relevant to the present area is discussed hereunder:

The Shillong Plateau is dominantly covered by Precambrian rocks characterized by basement gneissic complex of para and ortho gneisses, amphibolite, granulite, etc. Towards south and southeast, thick piles of sediments belonging to Cretaceous and Cenozoic are unconformably overlying the Precambrian rocks. A NE-SW trending Proterozoic shallow basin has developed in an intracratonic setting in central and eastern part of the plateau. The sediments deposited in this basin are now known as the Shillong Group comprising mainly an argillaceous and arenaceous sequence unconformably overlying the gneisses. The Shillong quartzite, having a general trend of NE-SW similar to the northern part of the Eastern-Ghat trend, are commonly found interbedded with thin layer of phyllite. There were two Precambrian intrusive events leading to the emplacement of metabasic Khasi greenstone and a number of granite bodies. The well known Myllem granite marks the stabilization of the Shillong craton

towards the later part of Proterozoic. Another Cretaceous basaltic emplacement took place in the south eastern part of Shillong Plateau resulting in what is now known as the Sylhet Traps composed of basalt, alkali basalt and acid tuff. The Cretaceous Khasi Group divided into two formations viz., lower Jadukata and upper Mahadek is composed of coarse to fine sandstone and conglomerate. During Paleocene-Eocene, Jaintia Group of rocks composed of both carbonates and clastics were deposited in a fluctuating transgressive-regressive regime. The Jaintia Group is divided into three formations, viz., Simsang, Shella, and Langpar. In the Oligocene and Miocene time the Garo Group was formed over Jaintia Group composed of sandstone, siltstone, clay-marl, conglomerate and feldspathic sandstone. Garo Group is further divided into three formations, Chengapara Baghmara and Kopili. Alluvium development in Meghalaya is not significant in the northern part. Along the southern fringe bordering Bangladesh and along few narrow intermontanne lows viz., Wah Umkhrah valley, discontinuous alluvial deposits are encountered. The general lithostratigraphic setup of the Shillong Plateau is given in Table 3.1 (G.S.I, 1974).

Table: 3.1 General lithostratigraphic sequence of Shillong Plateau

Age	Group	Formation	Member
Recent	Alluvium		
-----unconformity-----			
Oligocene to Miocene	Garo group	Chengapara Baghmara Kopili	
Eocene	Jaintia group	Simsang Shella Langpar	
Upper Cretaceous	Khasi group	Mahadek Bottom Conglomerate Jadukata	
-----unconformity-----			
Jurassic (?)	Sylhet Trap		Basalt, alkali basalt, rhyolite, acid tuff.
-----unconformity-----			
Pre-cambrian		Intrusives (Acid and basic)	Porphyritic and coarse granites, pegmatite, aplite, quartz veins epidiorite, dolorite, basalt.
		Shillong Group	Quartzite, phyllite, conglomerate.
-----unconformity-----			
Archean		Gneissic Complex	Biotite-gneiss, biotite-hornblende gneiss, granitic gneiss, migmatite, mica- schist, sillimanite- quartz schist, biotite- granulite-amphibolite, pyroxene-granulite, etc.

(Source: Stratigraphy after G.S.I 1974)

Geomorphologically, Shillong Plateau is characterized with rolling hills and variable erosional dissection. Southern face of the plateau is marked by deep gorges and cliffs with a narrow strip of gently sloping plain in southern part adjoining Bangladesh. The broad plateau is segmented by intervening deep gorges into smaller parts e.g., Mawsynram plateau with their edges characterized by triangular facets and talus. A number of rivers viz., Lubha, Myntdu, Jadukata, Umsohrynku etc. flowing north to south dissect the terrain and provide a good exposure of the depositional sequences

along the southern shelf. Some of these rivers have deeply incised down to the basement. Narrow gorges have formed along the two prominent joint systems of the plateau which also influence the drainage pattern in some regions. Control of structural trend on the river regime is also apparent from the river courses like that of Umiam flowing along the prominent strike. The narrow, E-W trending sedimentary terrain in the southern part of Shillong Plateau show development of moderately dissected structural hills viz., the Barail range where the sediment sequence has been subjected to both ductile and brittle deformation.

Review of literature

The earliest geological study on the Khasi hills region was initiated by Oldham (1858). He discovered two types of metamorphic rocks in the Khasi hills. The older, and more altered group, is represented by alternating bands of gneiss, quartzite and schist, greatly traversed by veins of fine crystalline granite. The younger group of rocks is “essentially slaty” consisting of blue and gray flaky schists with some micaceous and quartzose layers.

Medlicott (1869) really laid down the foundation of the geology of the Khasi hills. He mapped a portion of the Shillong plateau. He concluded that the metamorphic rocks are divisible into an older “Gneiss Series” and a younger “Shillong Series” which consists of a considerable thickness of quartzite, locally largely conglomeratic. He noted compact, sharply bedded varieties and also coarse forms, in which, false bedding is closely seen. He stated that the Khasi greenstones is undoubtedly an igneous rock, a dense basic trap in which the feldspathic element is subordinate, and for the porphyritic granites. He opined that “there can be little doubt that these granitic masses are truly intruded” and so he assigned to it a younger age than the

Khasi greenstone. The contact between the Sylhet Trap and the metamorphics was tentatively considered a fault. Later Talukdar (1966) confirmed his opinion. Bose (1901) found xenoliths of quartzite of the Shillong Series in the granites, which was observed to be cut obliquely across the strike of the rocks of the Shillong Series.

Palmer (1924) dealt with the main structural features of the Shillong Plateau and indicated that the plateau is an ancient mass of the gneiss. He mapped the southern contact of a granitic pluton and stated that “the granite is a structureless aggregation of large porphyritic pink orthoclase, quartz and biotite. Bradshaw (1925) confirmed the earlier reports of Palmer and observed that the porphyritic granite is to some extent foliated to the south which he believed to be a primary structure induced at the time of intrusion when the rock was in a semi-molten condition. Dasgupta (1934) noted that the orientation of the granite is fairly parallel to the tectonic axis of the Khasi hills and states that the granite intrusion took place in early Precambrian. Fox (1949) described that in Meghalaya the terrain is made up largely of a complex in which an older series of banded gneissic hornblendic rocks and other foliated types were intruded by younger pink granite. Pascoe (1950) stated that the dip and strike of the Shillong quartzites along the Myllem granite boundary are quite independent of the granite, and the contortions of the quartzites must have been effected before the granite was intruded.

Choudhury (1962) stated that “the Khasi greenstones are derived from basic igneous rocks and had undergone regional metamorphism alongwith the quartzites of the Shillong Series prior to the intrusion of the Myllem granite. The mineralogy indicated that the Khasi greenstone belong to the almandine-amphibolite facies. Gannser (1964) reported that the greenschist facies of most of the Shillong rocks

contrasted with the high grade metamorphics reported to be influenced by granite contacts.” He subdivided the Archaean Shillong rocks into the Shillong Group and an older gneisses and granites.

Mathur and Evans (1964) opined that the drainage directions of Shillong Plateau are strikingly adjusted to the fracture directions riddling the entire region. Bhattacharjee (1968) stated that during the Precambrian, the Shillong Plateau experienced alternate period of igneous activity and sedimentation till all the depositional activities ceased after the intrusion of the Myllem granite. Sarkar (1968) concluded that the granite of the Shillong Plateau is about 795 million years old. Machatchek (1969) observed that in Shillong Plateau when a traverse is taken from Shillong peak to Barapani it reveals a three step structure of the plateau with an elevation difference of about 400 m between the successive steps. The abrupt scarp junction between different topographic levels may be partly supported by the fold movements and partly due to younger block movement fragmenting a more extensive erosion surface to separate levels.

Murthy et.al., (1969) reported that the Dawki fault is actually a system of fault, where three major E-W faults have been mapped between Jadakuta river and and Therriaghat and have been named as Dawki fault-I, Dawki fault-II, Dawki fault-III. They concluded that each of these fault exhibits different geometric type along its trace. Mazumdar (1971) reported that the porphyritic granite of the Khasi hills were late tectonic plutons, intrusive as diapirs with contact aureole in some parts. The Khasi greenstones were intrusive into the Shillong Group and metamorphosed together with the latter their emplacement seemed to be related to a tensional field. About the Shillong Group he stated that they lie unconformably over gneissic complex with migmatitic granitoids and that they were laid down in a molasse setting.

Baroah (1971) marked at least three phases of deformation in the rocks of the Shillong Group.

Anon (1974) was of the view that the present physiographic configuration of the Plateau was attained through different geological events since Mesozoic to the present day as indicated by the polycyclic erosional surfaces at various levels. Mazumdar (1976) stated that a number of discordant granitic plutons intrude the basement gneissic complex and the overlying Proterozoic metasediments of the Shillong Group in the Meghalaya plateau and observed that the strike of the Shillong Group remains characteristically NE-SW with alternate rolling dips and steep subvertical zones. A synthesis of the tectonic pattern of northeastern India was carried out by Nandy (1980) based on the MSS imagery, where he was able to distinguished various tectonic and geologic domains of the region viz., Shillong Platform and Mikir hills, Surma basin, Naga-Lusai- Arakan Yoma fold belts, Central Burma Molasse basin, Mishmi block, Eastern Himalaya fold belt, Trans-Himalayan region and Bengal – Brahmaputra basins. He also observed that the boundaries of the tectonic domain are marked and identified by pronounced lineaments which are either straight or curved which includes the Dawki fault, Jamuna lineaments, Tista and Padma lineaments, Main boundary fault of the Himalaya, Siang fracture, Tangspo suture, Mishmi and lohit thrust, Naga and Disang thrust, axial zone, Volcanic line of Burma and Red river faults. He also stated that the most prominent lineament is the NE-SW fault which delimits the northwestern boundary of the outcrop of the Shillong Groups extends upto Mikir Hills. A shear zone extending from Tyrsad to Barapani was described by De (1981) on the evidence of slikenlide. Rahman (1981) stated that the average composition of the Khasi greenstone (metadolerite) of Shillong area corresponds to the common tholeiitic basalt and dolerite. He observed skeletal structures of

pyroxene, complex twin in plagioclase and relict ophitic structure in the greenstone.

Bhattacharjee and Rahman (1985) on the basis of lithological and structural evidences separated the Shillong Group into two divisions - a lower argillaceous (Manai formation) and an upper arenaceous division (Mawphlang formation). Mazumdar (1986) was of the opinion that plutons of the Meghalaya plateau (viz., Myllem, Nongpoh, south Khasi) were late to post-tectonic fracture controlled diapses resulting from major thermal event subsequent to the evolution and metamorphism of the Shillong Group of metasediments. He concludes that most of these fractures are vertical, the rivers controlled by these have not deviated from the strike of the fractures and overall the area exhibits a very pronounced structural control on physiography.

Rahman (1987) stated that the Myllem Granite is normal two-feldspar biotite granite. The granitic magma was believed to have been intruded along the trough of the tectonically controlled synclinal basin and exerted lateral pressure on the wall rocks, which in turn warped around the granite body. All evidences clearly suggested that the pink color of the Myllem granite was due to dominance of pink colored microcline which contained higher proportions of ferric oxide impurities than the gray granite. Besides, the enrichment of Sr and alkalis and impoverishment of CaO and MgO contents of the pink granite compared with the gray granites suggests that former was the late fraction of crystallization of the later. Rahman and Borah (1990) studied the Khasi greenstone occurring as intrusives within the metasediments of the Shillong Group and stated that the meta-dolerite had initially a mineral assemblage of clino-pyroxene-calcic plagioclase-iron ore of a basic igneous rock. The low grade

metamorphosed greenstones have the composition - actinolite-chlorite-albite-epidote, equivalent to low greenschist facies, preserving some of the original igneous textures.

Rahman (1991) studied the emplacement of some Precambrian granite plutons in the Shillong plateau and observed that the general lie of the granite body to be E-W to NE-SW and thereby followed the tectonic axis or the major lineament ENE-WSW of the Shillong plateau. The thermal aureoles around the granite plutons were very narrow (maximum of 400 m). He was of the opinion that low temperature granitic magma was emplaced at comparatively higher level of the crust as post-tectonic high level pluton. Ghosh et al. (1991) were of the opinion that a protracted thermal event during the Proterozoic and early Paleozoic (500-700 Ma), possibly related to mantle upwelling, might have triggered the generation of granitoids of the Shillong Plateau. Rahman (1996) stated that the Myllem granite is a funnel-shaped pluton emplaced in a synformal basin formed by the downwarping in the metasediments of the Shillong Group. The granite was post-tectonic in origin. A recent study on structural history of metasedimentary rocks belonging to Shillong Group of rocks by Mitra (1998) has established four phases of fold deformation in Shillong Group of rocks. The earlier structure is very tight to isoclinal folds (F_1) on bedding plane (S_0). These folds have a high amplitude/wave length ratio, with pervasive axial linear cleavage (S_1). They have been affected by coaxial, open to tight, upright F_2 folds with axial plane striking NNE-SSW and having an axial planer crenulation cleavage (S_2). Both F_1 and F_2 folds are of buckling origin. In more schistose units NE trending open recumbent folds (F_3) affecting S_1 and S_2 planes represent structures of third generation conjugate folds and kink band (F_4) with axial plane striking N-S, E-W and chevron folds with NW-SE striking axial plane.

Results and Discussion

Lithostratigraphy of study area

Shillong Master Planning Area is characterized by low grade metamorphic rocks of Shillong group of Precambrian age. The rocks are dominantly quartzites with subordinate phyllites and slates, quartz-sericite schist and conglomerate. These rocks are intruded by mafic sills and dykes comprised of epidiorite, dolerite, amphibolites, pyroxenite rocks known as Khasi greenstones which occur mostly as sills concordant with the formation and acid intrusive such as Myllem Granite. A part of the southwestern fringe of the study area is covered by the Myllem Granite, which is a batholithic intrusive body (Figure 3.1). The general lithostratigraphy of the study area worked out from field investigation and based on collateral data is given in Table 3.2

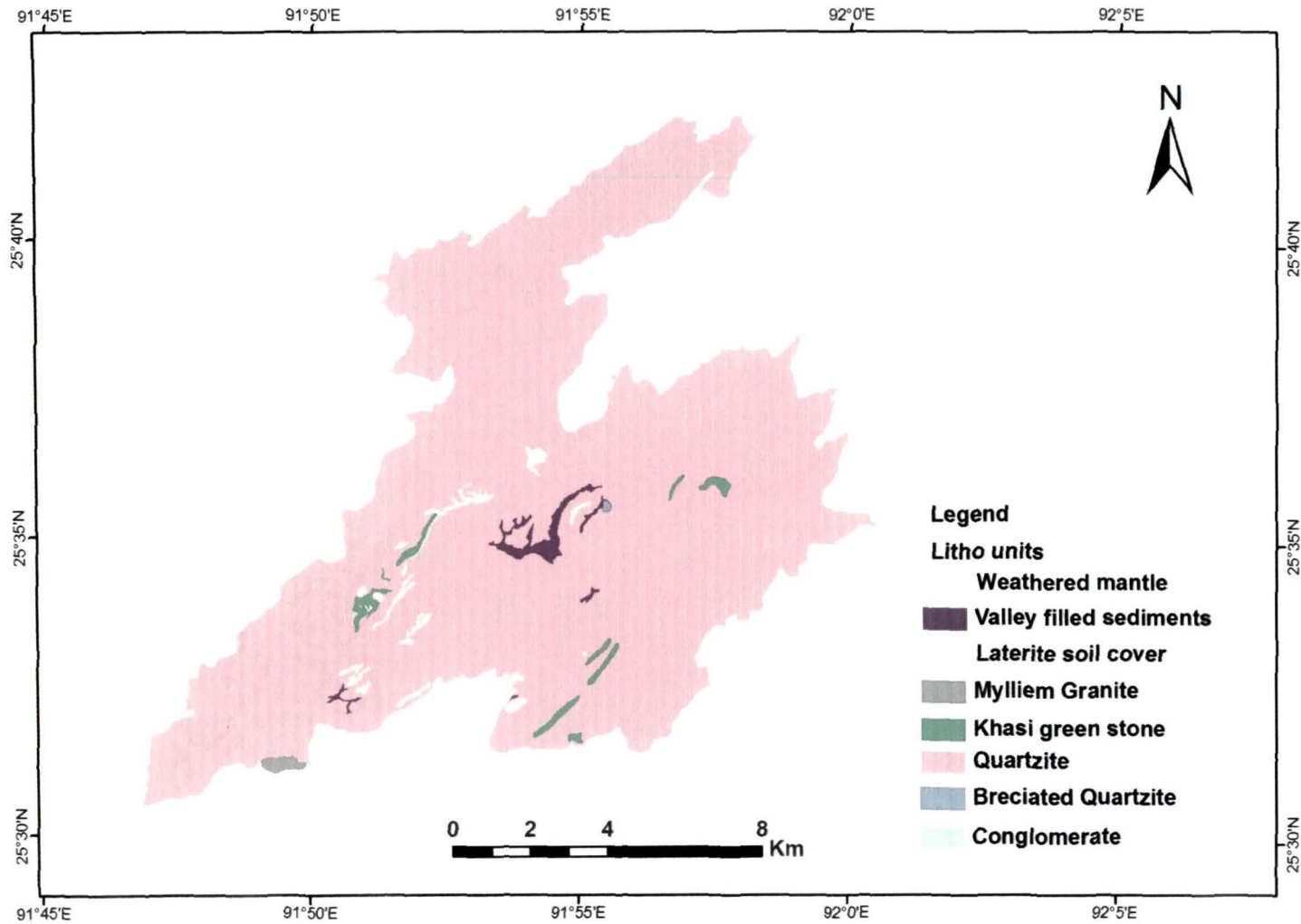


Figure 3.1: Geological map of the study area modified after GSI (1989)

Table 3.2: Lithostratigraphy of the study area

Unclassified	Alluvial valley fills
Quaternary sediments	Residual/lateritic soil cover
Sediments and Soils	Stabilized colluvium (Recent Conglomerate) unconformity
	Acidic igneous intrusives – Porphyritic granite/Quartz veins (Myllem granite) Intrusives contact
	Basic igneous intrusives – Metadolerite and (Khasi greenstone) amphibolites Intrusives contact
Shillong Group	Phyllites Reddish brown, pinkish to purple coloured phyllite, quartz, sericite-schist, mica-schist.
	Quartzites Coarse to fine grained quartzite with phyllite partings and bands of intraformational conglomerate.
	Basal conglomerate Quartz pebbles embedded in clastic compact sandy matrixunconformity

Shillong Group

The Shillong Group of rocks comprises arenaceous and argillaceous members with intermittent and impersistent intraformational conglomerates unconformably overlying the basement gneisses. A thickly bedded conglomerate horizon with persistent litho-characters marks the lithological interface between the gneiss and Shillong Group of rock. Differential competence of the quartzites and phyllites has resulted in strike ridges composed of the quartzites and linear topographic lows composed of phyllites. Salient lithological characteristics of the lithounits are described in subsequent sections.

i. Basal conglomerate

The Basal Conglomerate which can be found towards the northeastern fringe of the study area marks the hiatus between the two dominant lithology. In the west and northwest of Union Christian College a thick horizon of basal conglomerate comprising of pebbles of quartz was observed (Figure 3.2). However along the western flank this conglomerate horizon continues northeasterly parallel to the structural trend and forms a conspicuous scarp. The pebbles are almost entirely of vein quartz, and bedding is defined by alternate pebble free layers and gradually this conglomerate grades upward into fine grained quartzite.

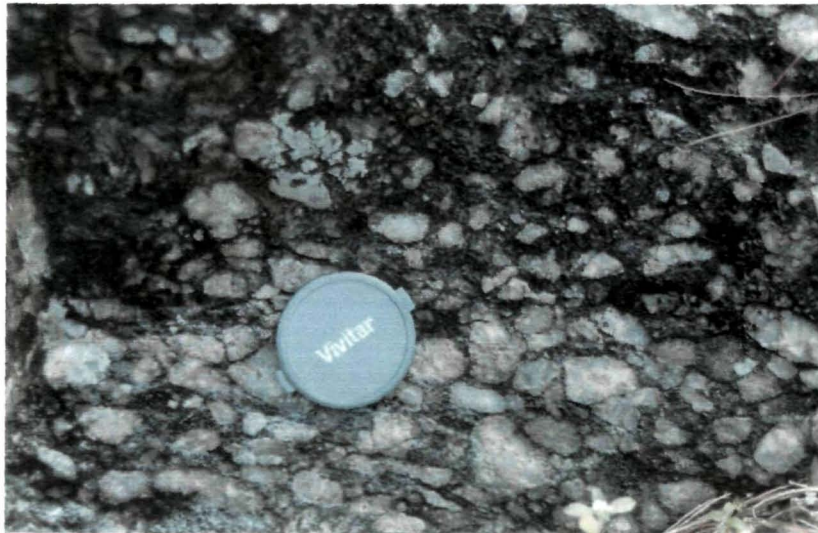


Figure 3.2: Basal conglomerates comprising of pebbles of quartz exposed in west of Union Christian College, Barapani.

i. Quartzites

The most dominant constituent of the Shillong Group of rocks within SMPA is represented by quartzites (Figure 3.1). They are seen exposed in the road cuttings, quarry and nala sections around Shillong township, Upper Shillong, Mawpat, Laitkor and Happy Valley areas. From field observation it is seen that quartzites vary in

nature and include: grayish white, milky white and dark grey fine grained, compact and massive type. Along the road cutting and quarries of Mawdiangdiangand around Laitkor areas they are pinkish white to yellowish white in colour with soft friable and coarse granular quartzites. Coarse granular quartzites laterally grade into fine grained compact meta-quartzite. At places they are highly weathered and ferruginous in nature. Thin beds of pale greenish grey to purple coloured phyllite partings are common in the quartzites (Figure 3.3). Along the quarry section in the eastern part of Pamlakrai, road section south of Mawpat and north of Shillong Peak beds of phyllite measuring around 10-20 cm are exposed. Dark grey, tough and compact quartzites are seen exposed in the road section north of Laitkor Peak. It has been observed that well preserved sedimentary structures with signature of folding, flexures and small scale faulting are common within Shillong Group of quartzite.

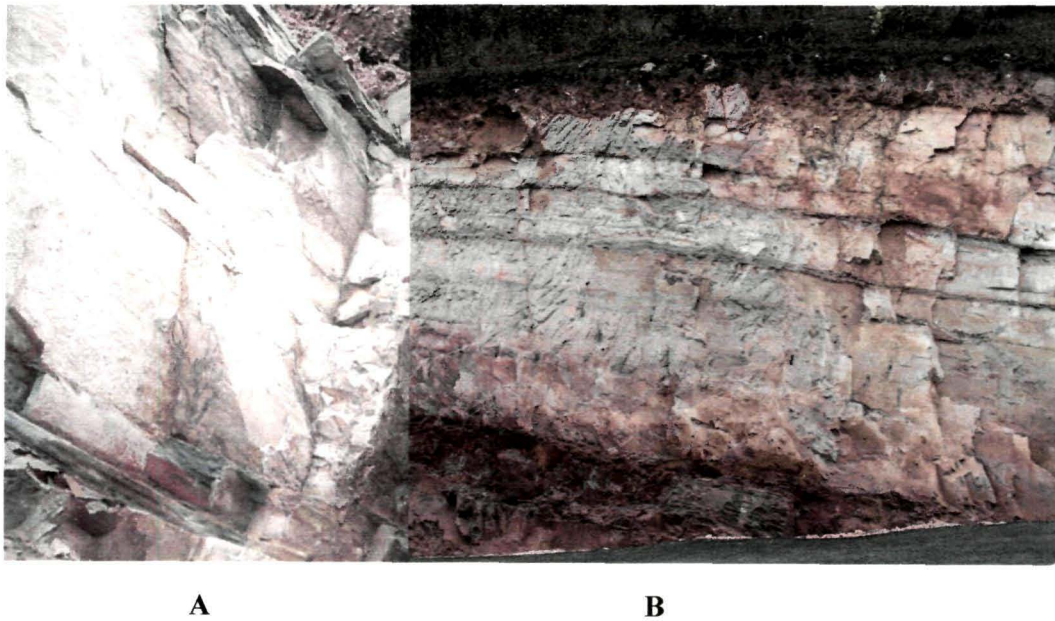


Figure 3.3: Exposure of Quartzite (A) and well bedded Phyllite (B) of lower Shillong Group

Large scale planar cross stratification are commonly found as internal bedding structures. They are however, obliterated at places due to recrystallitation.

ii. Intra-formational conglomerate

Thin impersistent conglomerates interlayered with the quartzite beds and thick beds of conglomerates are found within the Shillong Group. They consist of sub-rounded to well rounded and flat pebbles and cobbles, predominantly of quartz and occasional quartzites set in siliceous-phyllitic matrix. Along Wah Umshirpi west of Mawprem a conglomerate horizon measuring about 2 km in strike length and as much as 50 m in thickness has been encountered. Discontinuous band of this conglomerate also occurs southwest of Umlynka and north of Phudmawri in the same strike continuity.

iii. Phyllites

Phyllites display wide variation in composition from soft and shaly type to shale with varying proportion of siliceous matter. The lower part of the Shillong Group is largely argillaceous that form mostly phyllites towards northeastern part of the study area. They are greenish grey, reddish brown, pinkish to purple coloured fine grained rocks often micaceous with well preserved foliation and schistosity. Good exposures of phyllites with various degree of deformation are found along NH 40 between Umiam lake and Mawlai. Near Barapani-shearzone north of Mawiong, phyllites have become siliceous imparting a quartzitic look. White to greenish grey phyllites is seen interbedded with quartzites in a quarry section west of Umlynka.

In the north as well as south of the study area, quartz schists and quartz-sericite-schists are well exposed in the road sections. They are well foliated, light gray to white coloured rock and exhibit axial plane schistosity making an acute angle with the primary foliation in the direction of dip of the strata (Figure 3.4). Impressions and

signatures of the structural elements viz., pucker, lineations, slickensides are perfectly preserved.

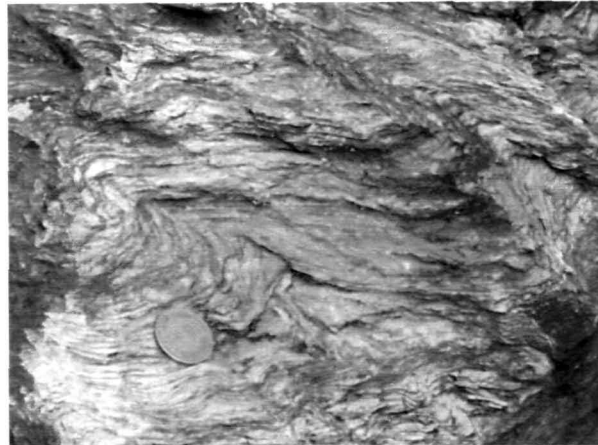


Figure 3.4: Highly deformed quartz-sericite-schists from the barapani shear zone.

Basic intrusive

The Shillong Group of rocks is intruded by basic dykes and sills which subsequently underwent regional metamorphism of amphibolites facies. These are locally known as the Khasi greenstone and are mostly exposed as linear to curvilinear bodies parallel to the strike of the country rock. Usually they are emplaced along the planes of weakness and at places they occur as sills. The rocks are generally massive, fine to medium and coarse grained, greenish to black gray in colour and doloritic to amphibolitic and epidioritic in composition. In the area of mapping three such basic intrusives trending NE-SW and emplaced mainly along the strike of the country rocks occur south of Happy Valley, Mawdiangdiang and west of Mawprem. They occur at higher elevation in the southwest to lower elevation in the northeast and show concordant relationship with the country rock at their southwestern extremity, SW of Umlynka. At Mawdiangdiang these rocks are highly jointed and at places well developed columnar joints can also be seen (Figure 3.5). Offshoots of intrusive body

emplaced along the ENE-WSW and NW-SE trending joints, are also seen exposed south of Happy Valley. At places the rocks have undergone spheroidal weathering.



Figure 3.5: Khasi greenstone with columnar joints

Basic dykes are exposed at west of Mawprem and occurs in discontinuous patches for a strike length of more than 5 kms from west of Upper Shillong along Wah Undiengmet west of Phudmawri. This body is exposed all along Umshirpi stream in contact with the intraformational conglomerate parallel to the strike. In southwest of Umlyngka, it is emplaced along the bedding plane in contact with the conglomerate. It is doleritic to epidioritic in composition. A narrow linear intrusive body trending NE-SW is also seen exposed in the Umshirpi stream near the iron bridge of cantonment area. One more intrusive body, exposed in the vicinity of the study area trending NE-SW and running for a strike length of more than 3 km is exposed along the stream beds around Umroi area. It is generally massive, doleritic and epidioritic in composition and show a sharp contact with the surrounding country rocks. None of the basic intrusive of the area has been found to share the fold deformation of the Shillong Group of rocks, suggesting their post deformational status.

Acid Intrusive

Acid Intrusive namely porphyritic granitic bodies of various dimensions occur as pluton, locally known as Myllem Pluton, is found in the study area (Figure 3.6). This rock type occupies a small part in the SW of the study area. The granites are intrusive dominantly into the metasediments of the Shillong Group. These are pink to light grey, coarse grained, porphyritic, rich in K-feldspar and occur as phenocrysts. Xenoliths of quartzites are encountered within the Myllem granites indicating a later emplacement history of these acidic intrusives into the quartzite (Figure 3.7). The general alignment of the granite bodies is E-W to NE-SW conformable with the tectonic axis or the major lineaments (ENE-WSW) of the Shillong plateau. At Myllem they are found to be cutting across the regional schistosity. These rocks are jointed and have been subjected to spheroidal weathering of various intensities.

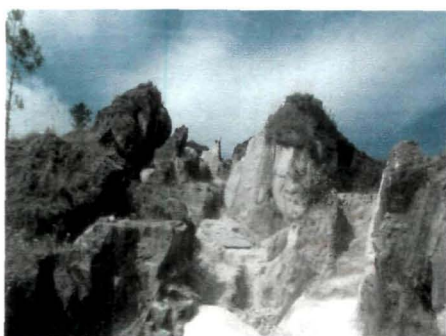


Figure 3.6: Grey porphyritic Myllem Granite



Figure 3.7: Xenolith 'X' of quartzite in Myllem Granite

i. Quartz Veins

In the area of mapping the quartzites of Shillong Group and Khasi greenstone are affected by numerous cross cutting quartz veins, which mark a post deformational phenomenon. These quartz veins trends along NNE-SSW, NW-SE and NE-SW and range in width from less than 1 cm to more than 30 cm (Figure 3.8). They have been emplaced along the joint planes.

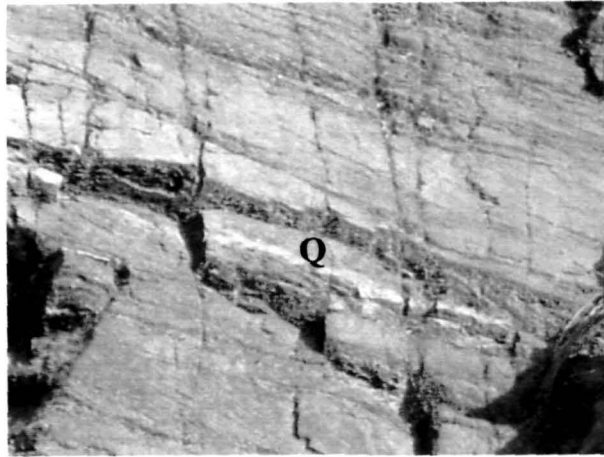


Figure 3.8: Quartz veins 'Q' within quartzite

In Happy Valley, Khasi greenstone is also traversed by numerous NNE-SSW to NE-SW quartz veins trending parallel to sub-parallel and ranging in width from 10 cms to 50 cms. Some of the quartz veins are mineralized containing ferruginous band.

Quaternary sediments

Intermontane valleys in the study area are filled with colluviums. Alluvial valley fills are also found along few restricted zones viz., Wah Umkhrah valley.

i. Colluvial hill wash sediments

Boulder, pebbles and cobbles with moderate to high angularities as well as occasionally sub-rounded fragments are found embed in a sandy ferruginous matrix. Such deposits are found locally at the base of laitkor range. Colluvium, overlying ferruginous compact quartzites, is also seen exposed near Sericulture Farm (Figure 3.9). It varies in thickness from 1.5 m to 3.0 m.



Figure 3.9: Colluvial debris comprising of pebbles of quartz embedded in semi-consolidated ferruginous matrix exposed in a road section near Sericulture Farm

ii. Alluvial valley fills

Recent alluvial sediments of Wah Umkhrach comprising of yellowish to brownish grey coloured silt and clay form a narrow alluvial tract in Polo ground and Pynthorumkhrach areas and form a 1.5 to 2.0 m high bank along Wah Umkhrach (Fig 3.10). Narrow valley fills have also been found along Wah Umshing, Wah Umkhrach, SW of Umlyngka, Wah Umkhen, south of Happy Valley by the deposition of recent sediments. Minor valley fills of limited extension composed of grayish brown to yellowish brown coloured sticky clay have been observed in Laithumkhrach, Dhankheti, Nongrim Hills and Umpling.



Figure 3.10: Narrow alluvial tract in Polo ground

Structure

i. Non – diastrophic structure

The primary sedimentary structures like bedding plane, current bedding and ripple marks (mostly symmetrical and sharp crested) are well preserved in the arenaceous member of Shillong Group of rocks. Well developed current bedding in the quartzites form internal bedding features strike NE-SW direction. In conglomerates, bedding is revealed by pebble free layer. In less metamorphosed siltstone, lenses and channel fills are seen. Cross bedding are well exposed in the Happy Valley (Figure 3.11) along Nongthymmai-Laitkor peak road section and along Wah Umpling and Wah Umkhrah. Small scales thinly laminated cross beds are more common. The foreset laminae of cross bed dip at an angle of 20° - 30° and point to a southerly transport direction. Ripple marks have been noticed in the quartzites along Wah Umkhrah in the west of Mawlai.



Figure 3.11: Shillong Quartzites with medium scale cross stratification as internal bedding structure.

ii. Diastropic structure

The Shillong Group of rocks show a persistent NE-SW trend. Bedding, cleavage and schistosity all have a persistent north-easterly strike with minor swings. The quartzites have a regional strike of NE-SW with dip varying between 32°-60° towards SE. More than one set of folding has led to complex fold geometry. Structurally, these rocks are deformed to various degrees forming both plunging and non-plunging folds and show a combination of monocline and homoclines. The type of folding in the area is termed as the "Intermediate crest like folding" (Belousov, 1962). Mazumdar (1976) opined that this structural set-up may be due to reactivation along fractures in the basement particularly below the zones of steep dips which can explain the numerous monoclinal bends in Shillong Group of rocks. Individual folds are open and practically non-plunging but, generally of monoclinal or asymmetric types with abrupt steepening of beds. Open folds and flexures are seen well exposed in the road sections opposite St. Edmund's College, Pine Wood Hotel and Mawpat-Mawlenrei road sections. Asymmetric folds with fold axis trending NNE-SSW are well exposed near junction of Tynring and Mawpat roads along nala north of Spread Eagle falls and quarry section east of Pamalakrai (Figure 3.12). Asymmetric folds and abrupt steepening (Figure 3.13) of strata is seen in the road section near Mawlai, Mawdiangdiang, Nongthymmai and quarry section along Wah Umkhrah, north of Spread Eagle falls.



Figure 3.12: Open fold in Shillong quartzites underlying rounded hillock

The quartzites are affected by three sets of joints making them splintery at places where all the sets are intensely developed. The joint sets are found trending in the NNE-SSW (sub-vertical dips); ENE-WSW (30° NW); NW-SE ($65^{\circ} - 75^{\circ}$ SW). Minor local faults and shears can be deciphered from the evidences of brecciation within quartzites exposed on a denudational hill near Mawpat. Crushing effect on the rocks with sharp angular fragments striated and polished surface of quartzites exposed in a stream section east of Laitkor Peak.



Figure 3.13: Steep dipping rocks showing folding exposed at road section in Mawdiangdiang

No major fault or thrust could be identified within the study area. However, a number of prominent lineaments and a major shear zone known as Tyrsad-Barapani shear occur in the northern part having NE-SW trend. The shear zone has affected the phyllites which can be very well seen near Tyrsad area and between Mawiong and Umiam along the NH-40. It is a narrow zone of intensely sheared phyllites with nearly vertical foliation plane and characterized by kink bands in the inter foliation zones. Sulphur leaching is prominently seen at some places within this shear zone. The weak zone is expected to act as a conduit for mineralized fluid movement.

iii. Lineaments

More than 56 lineaments of >1km length have been traced within the study area (Figure 3.14). However, most of the major lineaments are of 3 –10 km in length with a maximum of ~ 13 km. Majority of the lineaments are rectilinear while a few are curvilinear. Most of them occur in intersecting sets. Average lineament density for the whole study area is found to be 0.4 - 3 km⁻¹ (Figure 3.15) with lineament frequency as 3.3 – 0.7 km⁻². Statistical analysis shows that most of the prominent lineaments in the study area show NE-SW trend (Figure 3.16) conforming to the general structural trend. These linear structures have played a significant role in guiding the drainage pattern.

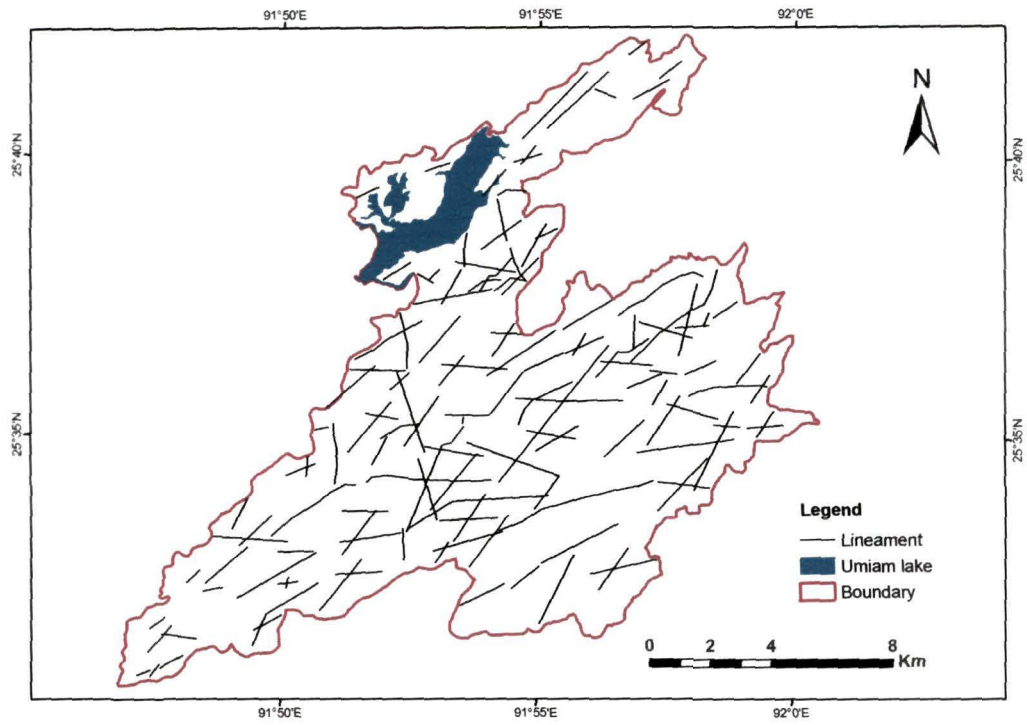


Figure 3.14: Lineament map of the study area

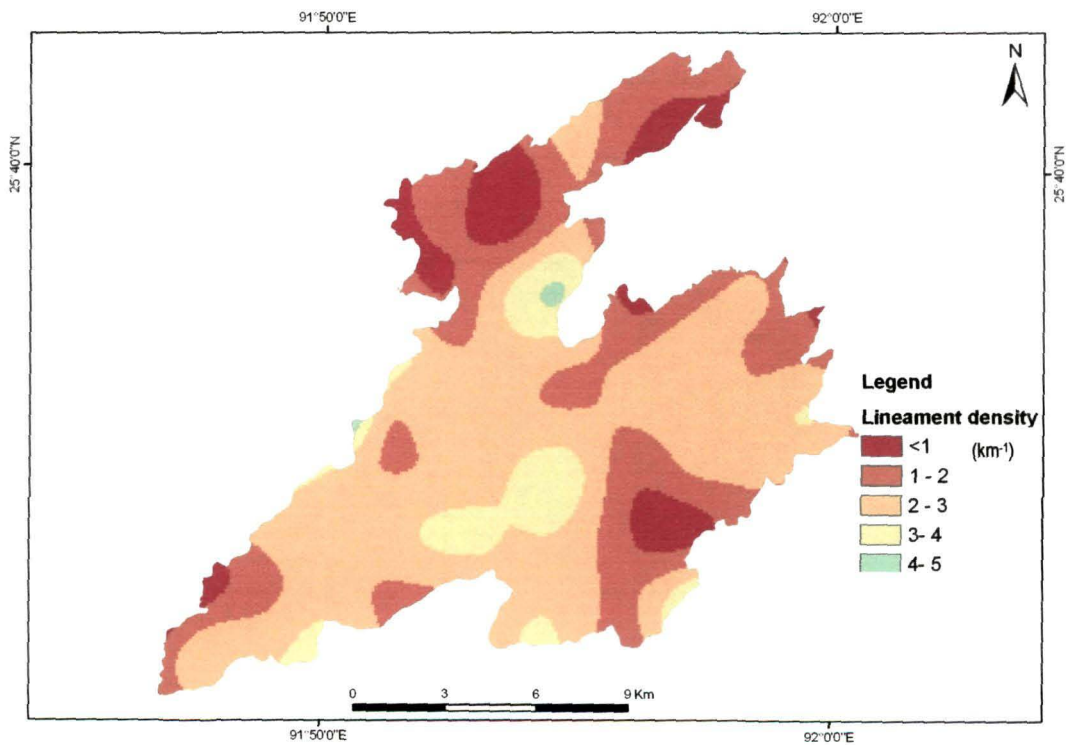


Figure 3.15: Lineament density map of the study area generated through interpolation of lineaments extracted from DEM and satellite

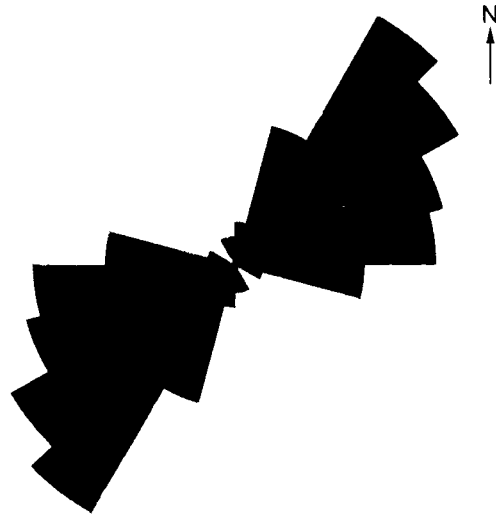


Figure 3.16: Rose diagram showing the Lineament trends

Metamorphism

The Shillong Group of rocks have attained a very low to low grade of metamorphism under green schist facies condition. Although, sedimentary structures are fully retained in these rocks, the grade of metamorphism responsible for metaclastic texture of quartzites is of some interest. Basic intrusive also share weak metamorphism of Shillong Group of rocks. Primary minerals have been mostly eliminated, due to metamorphism, however the texture remains unchanged.

Geomorphology

The study area fall on the central upland zone of the Meghalaya Plateau named Shillong plateau which is a dissected plateau with intervening V-shaped narrow valleys. The elevation of Shillong Master Plan Area varies from 1400 – 1900 meter above mean sea level. A gently undulating plateau top, the Laitkor range trending East-West direction with an average elevation of 1900 m above msl, is a prominent landmark in the southern extremity of the Shillong town. The Shillong Peak (1964 m)

and Laitkor peak (1960 m) form the highest points in the area of mapping. The main urban growth center of Shillong Master Plan Area is situated on a broad topographic low with several flat topped low relief hillocks and gently undulating valleys. Pologround or Umkhrach valley skirts the northern edge of the town and is situated at a much lesser height.

The present day landscape of the study area is the result of a competing interaction of lithology and structure as well as climatic factors. Mass movements have played a major role in evolution of the numerous hillslopes while geomorphic work by high gradient rivers is evidently a controlling factor for the present day landscape development. Because of effective transfer of eroded debris, both from fluvial erosion and mass movement, the valleys are deeply incised bordered with cliff faces. Sheet erosion due to non-channel overland flow is very effective in the study area particularly during monsoon when precipitation may be as high as >10000mm.

Broadly the geomorphology of Shillong Master Plan Area can be subdivided into two major geomorphic domains viz., plateau landform and fluvio denudational landforms. Almost the entire area comprises erosional landform which can be further subdivided into three categories viz., highly dissected, moderately dissected and less dissected. The fluvio denudational landforms can be further subdivided into sub-domains namely, the narrow infilled valleys and the terraces. Narrow valley fills and recent terraces have been deposited along the main streams cutting through the erosional surfaces.

The five major geomorphic units delineated in the study area are: the structural hills, recent terraces, residual hills, alluvial valleys and large static water bodies. The structural hills can be further differentiated into three categories viz., highly dissected,

moderately dissected and less dissected (Figure 3.17). Other geomorphic features include ridge crest, cliff and spot height.

Structural hills

The area is characterized by a number of structural hills and alternate valleys with various degree of erosional dissection. Structural hills composed of Shillong Quartzites and phyllites form the dominant geomorphic unit covering ~92% of the Shillong Master Plan Area (Figure 3.18, Table 3.3). These hills show well developed structural lineaments with a clear NE–SW trend that conforms to the general strike of the Precambrian terrain and the V–shaped narrow valleys were controlled by NE-SW and NW-SE trending joints.

Table 3.3: Areal coverage of different geomorphic domain

Geomorphic domain	Area (km²)	Area %
Alluvial valley	3.52	1.69
Highly dissected	29.56	14.20
Moderately dissected	109.8	52.74
Less dissected	52.88	25.40
Umiam lake	8.9	4.28
Residual hill	1.41	0.68
Recent terrace	2.11	1.01

The predominant trend of erosional dissection is along NE-SW. A set of offset faults cross cutting this general trend has affected the structural hills particularly towards north. These faults have an important bearing in the drainage behavior of the region since it is found that a number of falls have developed following the same viz., the Elephant falls, Bedon and Bishop falls, Gunner falls in the SW side and Sweet falls in the SE.

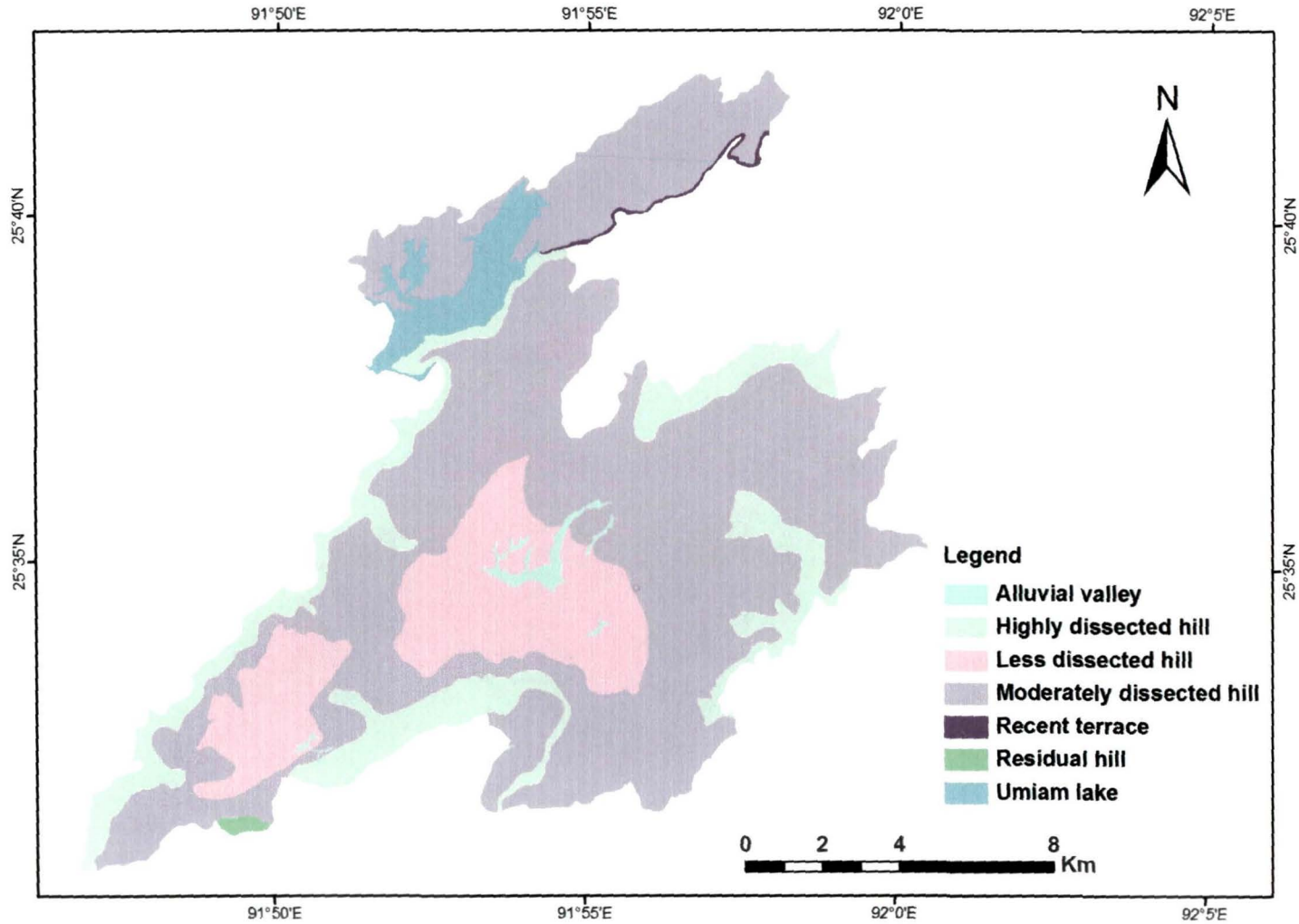


Figure 3.17: Geomorphology of the study area

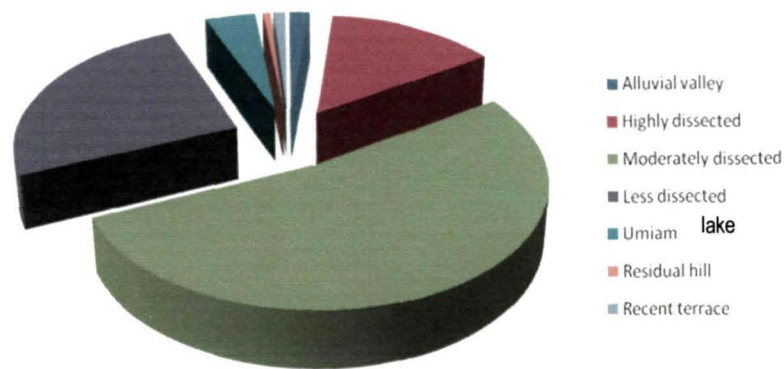


Figure 3.18: Areal coverage by major geomorphic units

Accordingly, the three categories viz., highly dissected, moderately dissected and less dissected can be differentiated in the area. The highly dissected hills extending from east-west trending Laitkor range with an average elevation of 1900 m above m.s.l. in the south to Mawpat range a NE-SW trend of 1600m elevation above m.s.l. in the northeast. Shillong Peak and Laitkor Peak the highest points of the study area are also located within this category and constitute the plateau top which is a gently undulated terrain with flat round hummocks. The Laitkor range slopes gently towards south while its northern slopes are very prominent and forms a rain shadow, forested zone which descends at 15° to 25° slope angle to form less dissected slope. Towards its lower reaches slope are gently undulating and inhabited. The southern slopes are sparsely forested and characterized by flat rounded and moderately crested ridges and NE-SW trending strike ridges while northern slopes are characterized by moderately to sharp crested ridges and NE-SW trending strike ridges. It is also observed that towards the northern slopes rills and gullies and lateritic crust has developed. The Mawpat range slopes both towards south and north at an angle varying from 5° to 15° and towards south it merges with the northern slopes of Laitkor range. The highly dissected hills particularly towards southeast are dotted with numerous erosional

scarp faces (Figure 3.19) and small geomorphic feature like sandstone cave developed by the action of running water (Figure 3.20).



Figure 3.19: Erosional scarp face developed along joints



Figure 3.20: A cliff face by the side of a narrow gorge developed along Wah Umkhen due to deeper down cutting.

In the moderately dissected areas however, the topography show high erosional dissection following the bedding planes (Figure 3.21). In the less dissected types the topography is characterized by flat topped rolling hills and valleys (Figure 3.22) with relief varying from 20 m to 80 m. It is observed that flat topped, low relief hillocks undulating with gently sloping valleys and moderate relief hills have steep slopes on

the two sides. The long continuous strike ridge developed in this area have moderate to high dips. Areas within the surface depicting rolling topography have low and rolling dips.

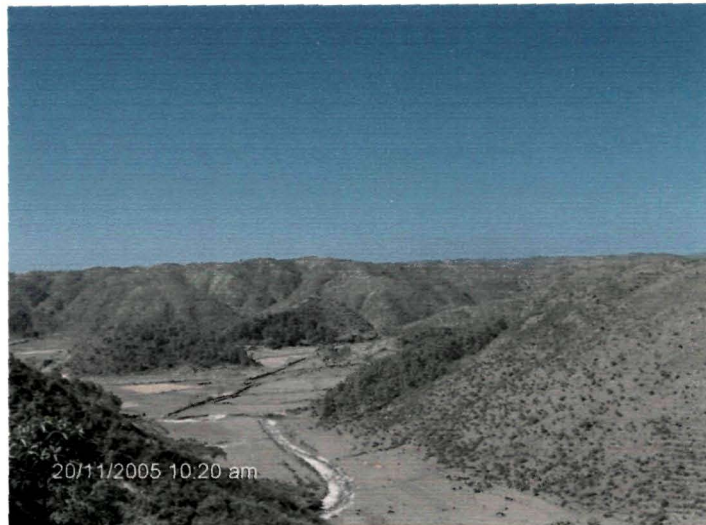


Figure 3.21: A typical landscape along the Shillong City. Small elongate intermontane valleys have developed within moderately dissected plateau terrain. The valley is extensively used for cultivation. Sparse vegetation is due to poor development of soil profile



Figure 3.22: Erosional Pre-Cambrian hills interspersed with narrow valleys.

Alluvial valleys

The town is mainly situated on hills and hills slopes with small and intermontane valleys (Figure 3.23). A conspicuous geomorphic feature in the central part of the

study area is the presence of a distinct topographic low (Figure 3.24) along the Wah Umkhras River around Polo Ground. This valley skirts the northern edge of the town and is situated at a much lesser height than the Shillong plateau.



Figure 3.23: An intermontane valley filled used for cultivation and settlements near ICAR complex, Barapani.

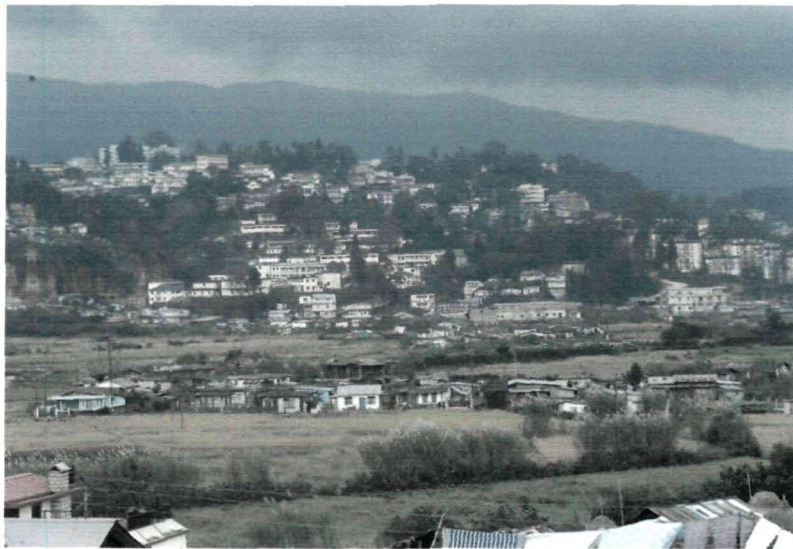


Figure 3.24: A well developed valley along the Wah Umkhras in Polo Ground area

This valley gently slopes to the Wah Umkhras and the hills are gently rounded in nature compared to the steep hills in their neighborhood. This valley is bounded on west and east by hills and is abutted by the Pynthorumkhras hills. But the valley has

three fingers like extension on the sides of the two localities of Pynthorumkhrah area. The first two extensions are on both sides of the golfground and the third and the eastern most extension is along the Wah Lankarding River. Of the three extensions, the last one is the most widely developed. Over the years, it has been filled by sediments both colluviums and alluvium. Reworking of these sediments by the river during flood and concentration of high humus has made it a fertile ground for agricultural activities.

Residual hills

A residual hill located in the south western corner of the study area has developed from deep weathering of the Myllem granite intrusive. Weathering is facilitated by the well developed joints leading to spheroidal weathering. The dismembered granite boulders impart a very rugged appearance to this part of the study area.

Recent terraces

Recent terraces are confined by and large along the northern fringe of the Umiam lake downstream of a concrete dam across the Wah Umiam river. They are composed of sand and largely angular gravels. At places top of the terraces shows gully erosion.

Drainage network, water bodies and waterfalls

The drainage patterns in the study area are well developed and are of dendritic, sub-dendritic, trellis and rectangular type (Figure 3.25). The major trend of rivers synchronizes with the major structural trend of the region which is NE-SW, while a set of tributaries have developed as a result of erosional dissection across the structural trend and also following offset faults and joints across this trend.

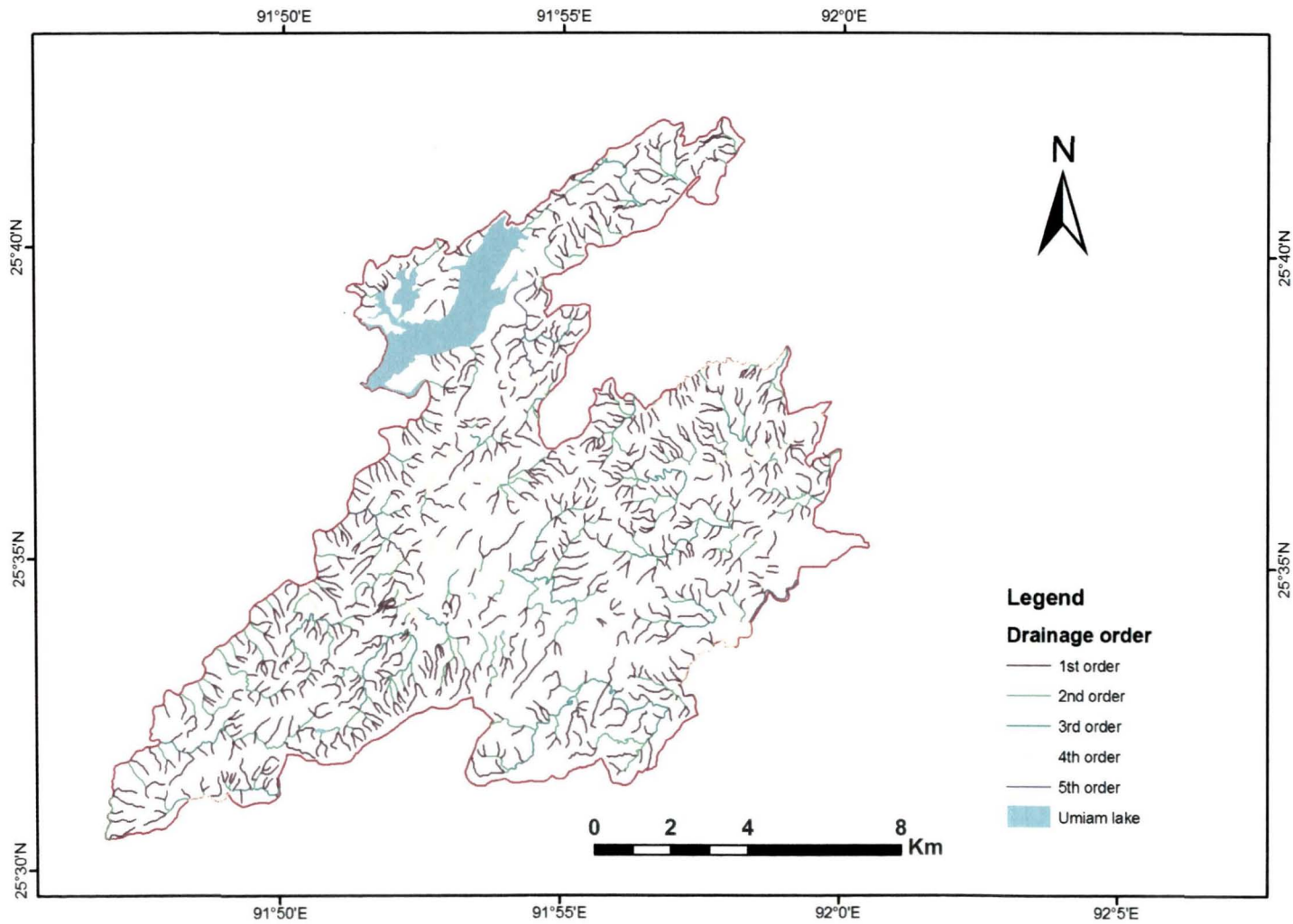


Figure 3.25: Drainage network of the study area

Dendritic pattern is mostly developed in the sediment filled gently sloping central and moderately dissected southwestern part of the terrain. Steep hill slopes of the Laitkor range and Mawpat ridge are characterized by dendritic drainage with very high drainage density. Towards north and northwest, trellis pattern of drainage is developed due to structurally controlled erosion. The trunk channel follows the structural trend of the quartzites of Shillong Group while the tributaries join it following erosional dissecting across this trend. The lower plateau region in the central part of the area is characterized by moderately high drainage density with subdendritic to trellis type of drainage pattern. Wah Umkhen is the main streams on the southern side of the study area and is also joint controlled and show trellis type of drainage pattern. The study area is characterized by two sets of well developed joints viz., one along NE-SW and the other trend NW-SE. Streams are developed following these trends in some parts towards north. It is found that many channels in their courses take the rectangular paths following these two trends of joints streams flows following the strike and joints and form the rectangular pattern. The main drainage of Shillong town is constituted by northwesterly flowing Wah Umkhrah and Umshirpi streams which are joint control. These two streams join near Beadon and Bishop falls to form the westerly flowing Wah Ro-Ro, a joint controlled deep gorge and a tributary to Umiam lake.

Two major static water bodies within the study area viz. the Umiam lake and the Wards lake (Figure 3.26 and 3.27) occupy about 5% of the total area. The Umiam lake is located by the side of Shillong-Guwahati Road about 12 Kms from Shillong. It is the major storehouse of freshwater and has a surface area of over 8 sq km. A dam has been constructed across this river to divert the main flow of water into Wah Umtrew for electric generation. The principal tributaries flowing into the reservoir

are: the Umshyrpi, the Umjasai and the Wah Umkhrach which have their sources near Shillong Peak and flow through Shillong city.



Figure 3.26: Umiam lake



Figure 3.27: Wards lake

The terrain lends itself to the formation of magnificent waterfalls and cataracts in all the rivers and streams. They are seen precipitating over cliffs several metres in depth (Figure 2.28). Within the city centre there are several falls namely, the (1) Kshaid Umrisa or Crinoline Falls (2) Kshaid Umshyrpi or Bishop's Falls (3) Kshaid Sunapani or Beadon Falls further away are the (4) Kshaid Um-diengpun or Elephant's Falls (5) Kshaid Wei Tdem or Sweet Falls (6) Kshaid 'Wei-sup or Gunner Falls (7) Kshaid Um-ka-liar or Spread-Eagle Falls.



Figure 3.28: A water fall formed across general strike

Digital Elevation Model (DEM)

A 30m DEM was generated for the study area by extracting elevation contours from Survey of India topomaps in 1:50000 scale (Figure 3.29). For the present study eleven profiles were extracted from the DEM out of which four in the NS direction and seven in the EW direction . The characteristics of the profiles are describe below:

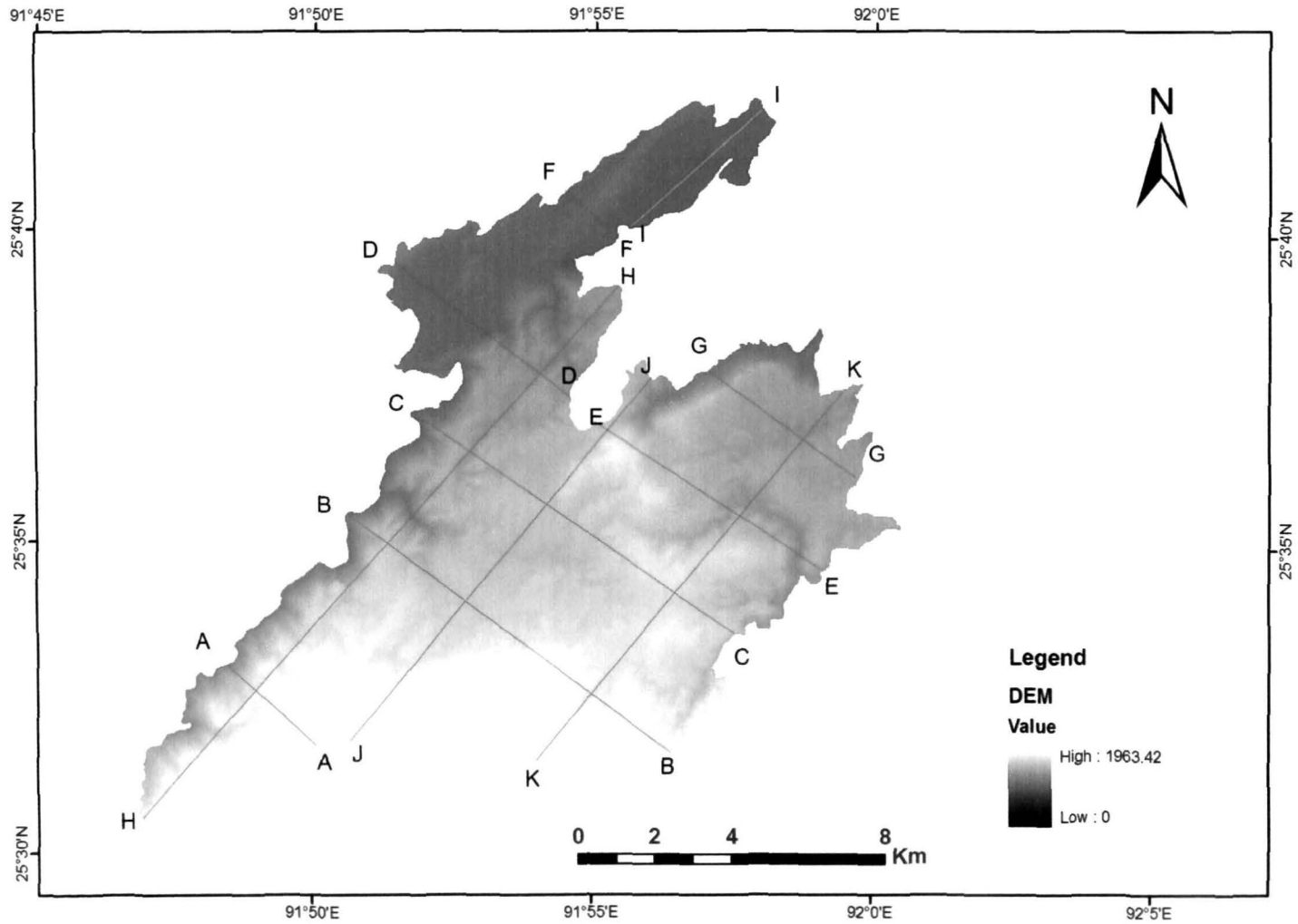


Figure 3.29: DEM derived from Survey of India elevation contours at 20m interval



Figure 3.30: DEM profile along AA'

The topographic profile AA' (Figure, 3.30) lies in between points $91^{\circ}47'43.35''E - 25^{\circ}32'28.28'' N$ and $91^{\circ}49'33.45''E - 25^{\circ}31'06.92''N$ with maximum elevation of 1817m and minimum elevation of 1200m. The profile slopes towards northwestern part of the study area, in the southeastern corner due to change in lithology. The profile shows an increase of slope which results into a residual hill. The valley section is controlled by Umiam River flowing along the strike direction of the area. Myllem Granite is found in the residual hill whereas the entire valley area is dominated by Shillong Group of rocks.

Places of urban settlements like Sadew, Baniun and Nonglyer are found concentrating in the low flat area of the profile. The corrugation in the profile section towards NW is structurally controlled where weathering is taking place in the weak zone giving rise to a highly and moderately dissected slope.

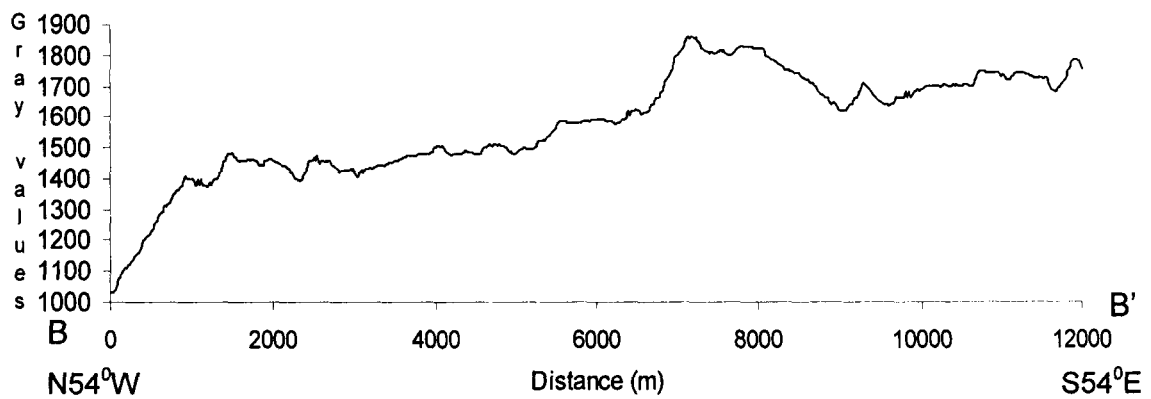


Figure 3.31: DEM profile across BB'

The topographic profile BB' lies in between points $91^{\circ}50'34.95''E - 25^{\circ}35'28.10''N$ and $91^{\circ}56'20.75''E - 25^{\circ}31'35.90''N$ with maximum elevation of 1880m and minimum elevation of 1040m. Places of settlements like Laitkor, Umphyrnai, Mawlynghat, Malki, Laban, Lumparing, Lawsohtun, Mawprem, Cantonment and Umlynka are found concentrating in the lower elevated section of the profile. The profile across the middle part of the Shillong Master Plan Area shows a prominent peak at the mid part identified as laitkor peak with spot height of 1880m. Rock types found are: intrusion of Khasi greenstone and Shillong Group of rocks.

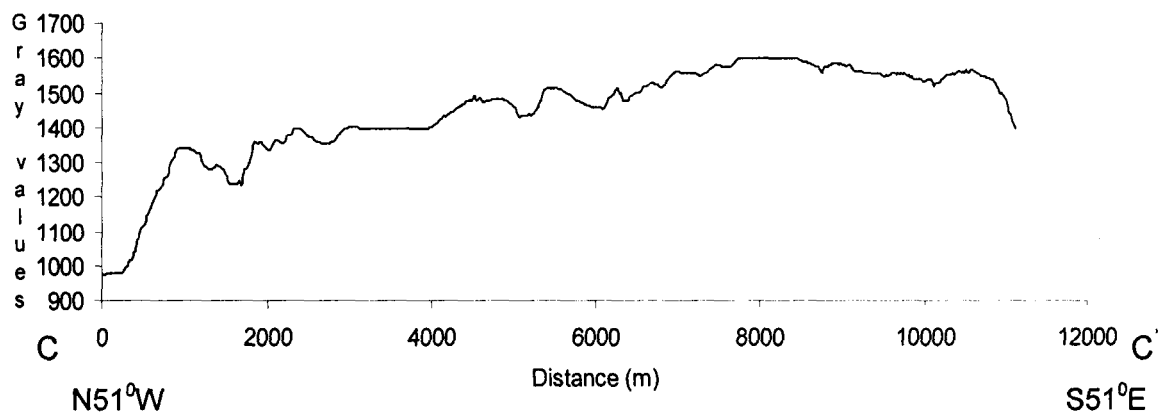


Figure 3.32: DEM profile across CC'

The topographic profile CC' lies in between points $91^{\circ}52'15.74''\text{E} - 25^{\circ}37'17.3''\text{N}$ and $91^{\circ}57'26.24''\text{E} - 25^{\circ}33'30.51''\text{N}$ with maximum elevation of 1600m and minimum elevation of 1240 m and elevation increases towards the SE part. The profile transects through Shillong Group of rocks while towards the southeastern corner the area is intruded by Khasi greenstone. The profile pass through the highly and moderately dissected plateau and towards the central part the depression in the profile is occupied by valley filled sediments of Wah Umkhrah. Area of Mawlai, Mawiong, Langkarding, Rynjah, Nongrah and Happy Valley are found along this profile section.

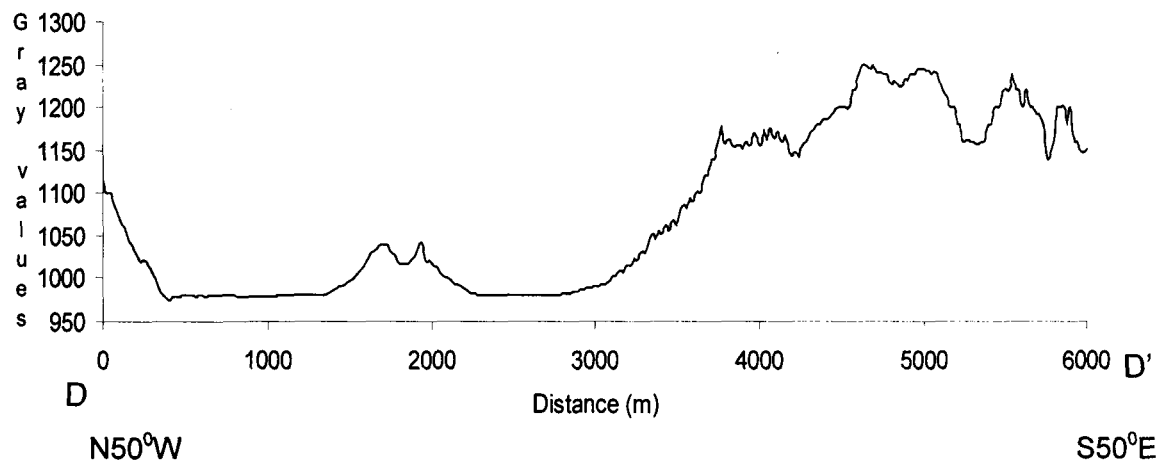


Figure 3.33: DEM profile across DD'

Topographic profile DD' lies in between points $91^{\circ}51'51.70''\text{E} - 25^{\circ}39'48.36''\text{N}$ and $91^{\circ}51'43.89''\text{E} - 25^{\circ}37'41.95''\text{N}$ with maximum elevation of 1600m and minimum elevation of 1240m. The profile transects through Barapani, Union Christian College and Mawiong. The two depressions within the profile are occupied by Umiam lake. Towards SW extremity the elevation increases and profile is characterized by hilly terrain with elevation over 1245m. The underlying lithology for the whole profile section is Shillong Group of rocks

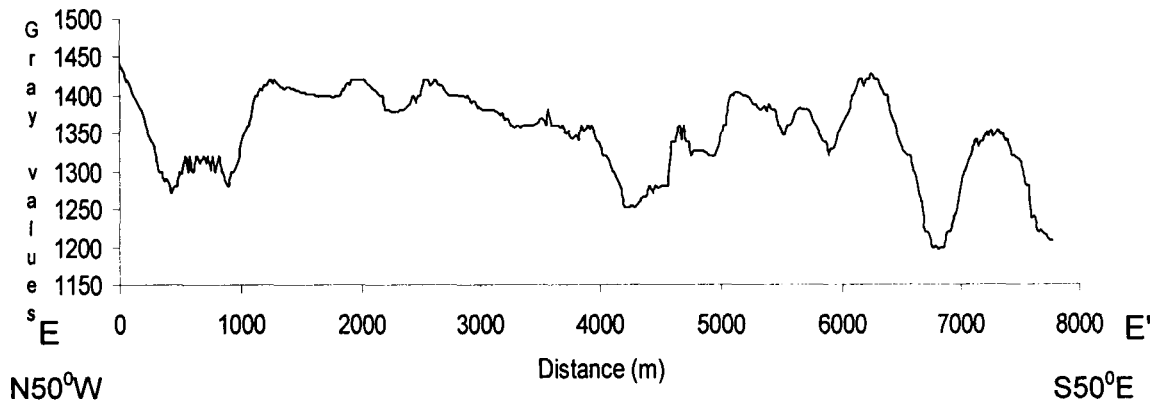


Figure 3.34: DEM profile across EE'

Topographic profile EE' lies in between points $91^{\circ}55'28.25''\text{E} - 25^{\circ}37'10.25''\text{N}$ and $91^{\circ}59'04.67''\text{E} - 25^{\circ}34'31.00''\text{N}$, with maximum elevation of 1440m and minimum elevation of 1220m. The corrugation for the entire profile section is due to the presence of highly and moderately erosional dissected hills controlled structurally by fracture pattern. Towards the two corner of the profile are the highly erosional dissected hills with moderately erosional dissected hills in the middle. The underlying lithology for the whole profile section is Shillong Group of rocks with intrusion of Khasi greenstone at Mawdiandiang area, places of Mawpat, Lankerding, and Diengiong.



Figure 3.35: DEM profile across FF'

Topographic profile FF' lies in between points $91^{\circ}54'30.67''\text{E} - 25^{\circ}41'40.17''\text{N}$ and $91^{\circ}55'25.62''\text{E} - 25^{\circ}39'55.23''\text{N}$ with maximum elevation of 1040m and minimum elevation of 940m. Tableland landform has developed in this section. The underlying lithology for the whole profile section is Shillong Group of rocks

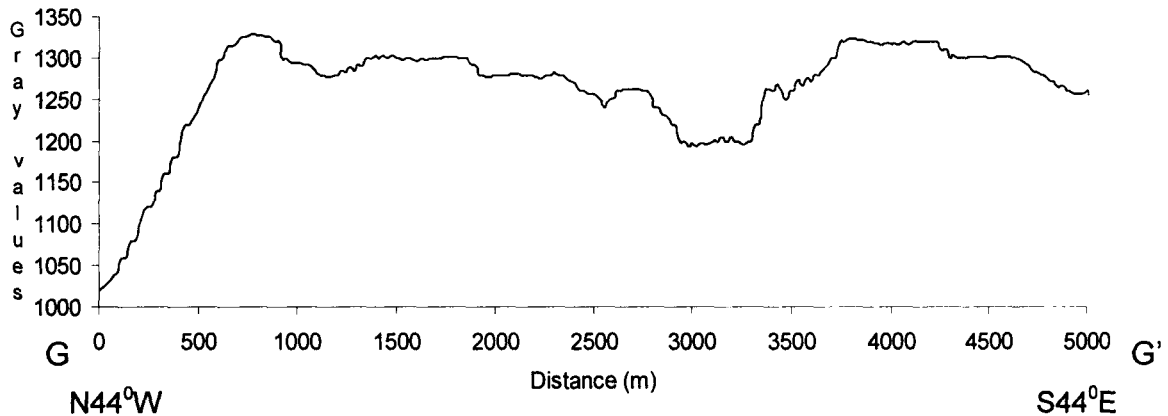


Figure 3.36: DEM profile across GG'

Topographic profile GG' lies in between points $91^{\circ}57'25.22''\text{E} - 25^{\circ}38'03.21''\text{N}$ and $91^{\circ}59'38.33''\text{E} - 25^{\circ}35'58.82''\text{N}$ with maximum elevation of 1320m and minimum elevation of 1020m. The underlying lithology for the whole profile section is Shillong Group of rocks. The corrugation for the entire profile section is due to the presence of highly and moderately erosional dissected hills controlled structurally by fracture pattern. The NW corner of the profile is dominated the highly erosional dissected hills with moderately erosional dissected hills covering the whole profile section.



Figure 3.37: DEM profile along HH'

Topographic profile HH' lies in between points $91^{\circ}46'50.82''\text{E} - 25^{\circ}30'32.13''\text{N}$ and $91^{\circ}54'55.55''\text{E} - 25^{\circ}39'04.29''\text{N}$ with maximum elevation of 1730m and the minimum elevation of 1080m. The characteristics of the profile show a rugged topography landscape. The underlying lithology for the whole profile section is Shillong Group of rocks. Higher elevation is seen towards southwestern part with decreasing order towards NE. The profile transecting the moderately dissected plateau reflects mostly hilly terrain.



Figure 3.38: DEM profile along II'

Topographic profile II' lies in between points $91^{\circ}55'56.14''\text{E} - 25^{\circ}40'08.07''\text{N}$ and $91^{\circ}57'55.10''\text{E} - 25^{\circ}42'09.27''\text{N}$ with maximum elevation of 982m and the minimum elevation of 900m. The middle part of the profile shows a prominent hill at the mid part with spot height of 982m, within an otherwise gentle sloping terrain. The underlying lithology for the whole profile section is Shillong Group of rocks

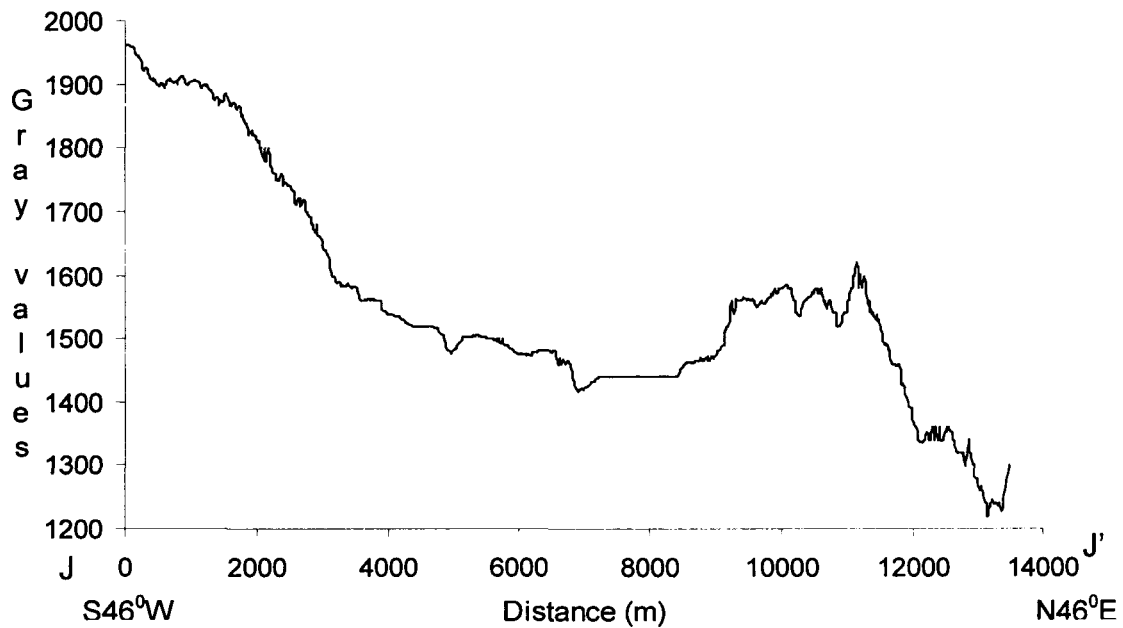


Figure 3.39: DEM profile along JJ'

Topographic profile JJ' in between points $91^{\circ}51' 09.98''\text{E} - 25^{\circ}31'48.91''\text{N}$ and $91^{\circ}56' 02.51'' \text{E} - 25^{\circ}37' 37.59''\text{N}$ with maximum elevation of 1964m and the minimum elevation of 1220m. The underlying lithology for the whole profile section is Shillong Group of rocks. Profile sections from Shillong peak to Pologround present a step wise profile. The general altitude of Shillong city varies from about 1480 meters to 1580 meters above m. s. l., that of Pologround is about 1440 meters and the altitude of Laitkor range is around 1920 meters, the highest peak of the area, the Shillong Peak, having a height of 1964m meters is located south of Shillong Master Plan Area and forms part of Shillong range. The underlying lithology for the whole profile section is Shillong Group of rocks. Towards the southwestern corner the profile transects through highly dissected hills preceding further the profile enters less dissected hills where Shillong city is concentrated with Mawpat ridge on the northeastern corner of the profile section. In the northeastern corner prominent range in the profile is the Mawpat range, the surface is characterized by

denudational/structural hills with alternate valleys. Within the less dissected hills a more or less flat depression is seen in the profile which is occupied by valley filled sediments.

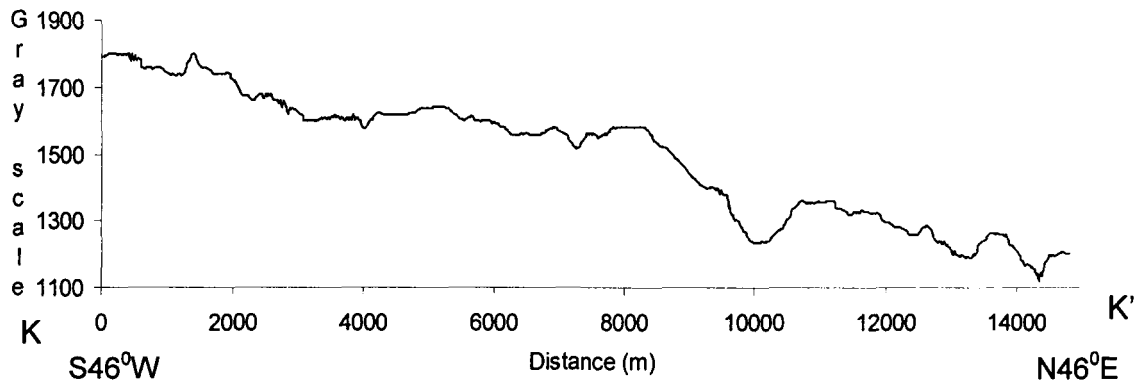


Figure 3.40: DEM profile along KK'

Topographic profile KK' lies in between points $91^{\circ}54' 04.45''$ E- $25^{\circ}31' 25.17''$ N and $91^{\circ}59' 47.36''$ E - $25^{\circ}37' 36.66''$ N with maximum elevation of 1800m and the minimum elevation of 1100m. The underlying lithology for the profile section is Khasi greenstones towards the SW part and the rest of the area with the Shillong Group of rocks. The corrugation for the entire profile section is due to the presence of highly and moderately erosional dissected hills controlled structurally by fracture pattern.

Slope

A total of seven classes of slope categories (Figure 3.41) have been derived for Shillong Master Plan Area. They are level to gentle ($0^{\circ} - 2^{\circ}$), gentle ($2^{\circ} - 5^{\circ}$), moderate ($5^{\circ} - 15^{\circ}$), moderately steep ($15^{\circ} - 25^{\circ}$), steep ($25^{\circ} - 35^{\circ}$), very steep ($35^{\circ} - 55^{\circ}$) and precipitous to vertical ($>55^{\circ}$).

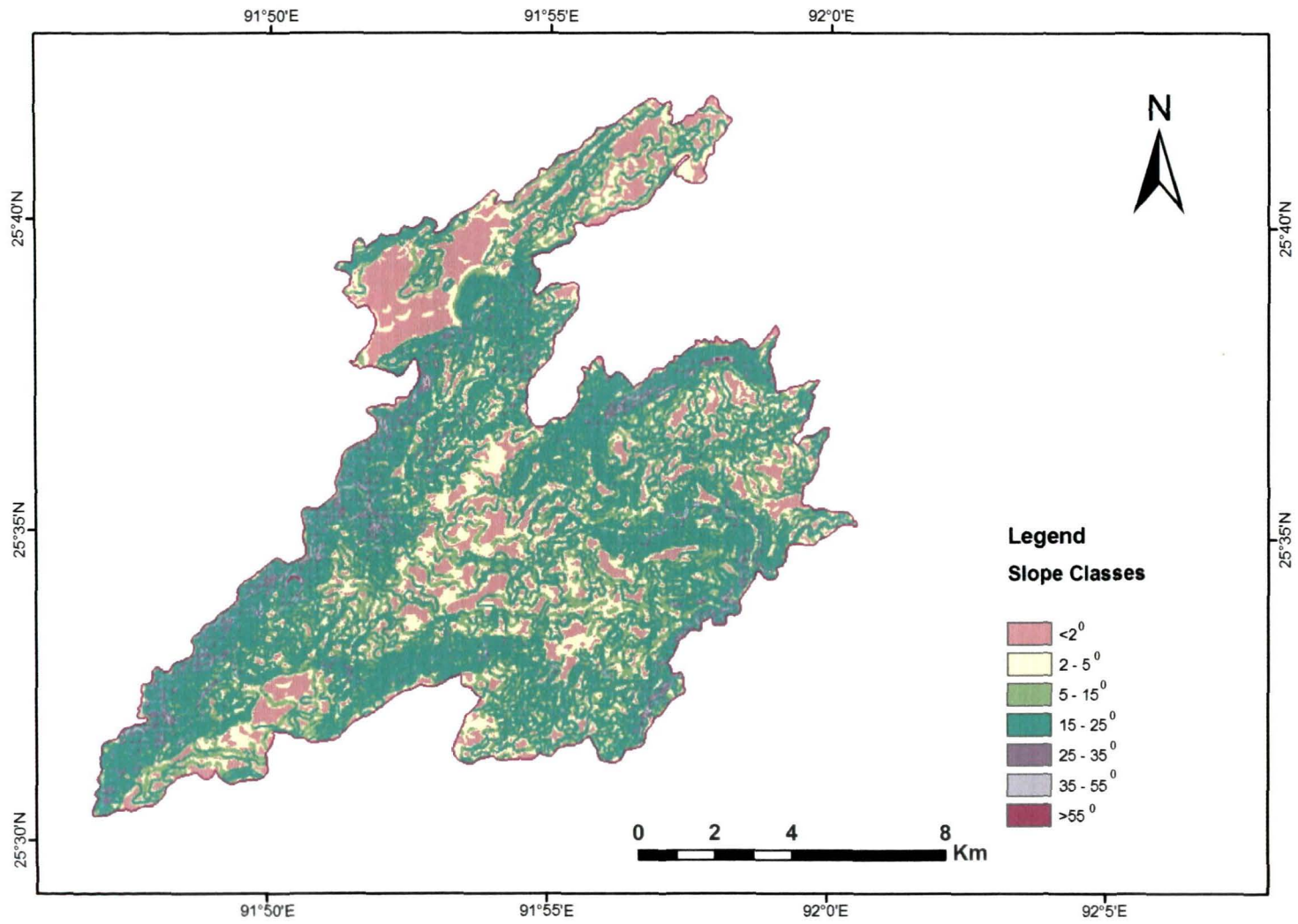


Figure 3.41: Slope map of the study area

Slope Class: 0° - 2°

It represents a plain to slightly sloping area. Valley filled areas of Pologround, Pasture, Wards Lake, Barabazaar, Golfink, Pynthorumkhrah, Lankerding, Umsawti, Umlynka, Mawshbuit, Umroi and Plateau top areas of Mawlenrei, Tynring and Mawkasiang fall in this category. These areas are suitable for agricultural use and permanent settlements. This slope range is locally available on hills tops also.

Slope Class: 2° - 5°

It is a gentle slope category and occurs in the top of Laitkor range and its southern slopes. Settlements of Upper Shillong, Happy Valley, Nongrah and most of the rural settlements of Shillong situated in Umniuh, Nongsder, Umroi, Mawdiangdiang, Tynring, Nonglyer and Umphyrnai also falls in this category. On the lower Shillong surface, this slope category occurs in Pynthorumkhrah, Phudmawri, Mawroh, Umshing and Lankerding areas. It is also available in limited areas in Laitumkhrah, around Wards Lake, Laban, Jailroad, Police Bazaar, Nongmynsong, Bishnupur, Lachumiere, Refugee colony, top of the low relief hillocks in lower Shillong areas also fall in this slope category. A large part of the area near Rangmen, Mawkhasiang and Mawlong also falls in this slope category. This slope range is suitable for agricultural use and permanent heavy structure settlements.

Slope Class: 5° - 15°

This is the most dominant slope category in the study area and represents undulating uplands. It includes pediments and hill slopes. Rocky surface with thin soil cover are main features in this category. Much of the area on the north as well as in the south in the Greater Shillong falls within this slope category i.e., Umladew, Union Christian College, Mawlendep, Barapani, Mawiong, Lumdawblei, Nongkseh, Umjajew,

Mawkenroh, Shyrwat, Mawpat, Mawjer, Mawlenrei, Lummawsiang, Laitkor, Umphyrnai, Mawlyngad, Nongumlong, Sadew, Baniun, Laitjem, Mawklot and Shillong peak . A large part of Lower Shillong surface falls in this category namely, Nongarh, Rynjah, Mawkhar, Jaiaw, Nongthymmai, Farm, Lumparing, Rait Laban, Jhalupara, Kyntonmasar, Phudmawrie, Umpling, Mawdetbaki, Langkerding, Happy Valley, Malki, Kenchestrace, Upper Shillong and Madanriting. This slope category is still favorable for agricultural use and construction of settlements. This slope is difficult for road development with favorable gradient and needs deep cuts on slopes involving removal of toe and lateral support which induces slope in-equilibrium and slides. Landslides are observed in Malki, Laban, Lawsohtun, Nongthymmai, GS Road Mawiong. Slope category $<15^{\circ}$ is suitable for construction of lighter structure while 15° slope marks the limit for difficult road building. Development of these slopes for housing and other construction activities involves extensive earth cutting and leveling of the ground which results in siltation of down slope streams besides promoting gully erosion.

Slope Class: $15^{\circ} - 25^{\circ}$

This category represents moderately steep slope and occupies areas between Laitkor range and Shillong town and other hill slope areas on eastern, western and northern sides of Shillong namely, Barapani, Mawiong, Umjajew, Mawpat, Laitkor and Nongpiur. These slopes are forested and drained by 2nd and 3rd order streams. Deforestation of such slopes is resulting in increased run off and intensive soil erosion which is evidenced by development of rills and gullys on such slopes. Urban invasion of such slopes is causing slope failures and slides as observed along GS Road in Barapani area. The gradient is a formidable obstruction in road development.

Slope Class: 25° -35°

This represents a steep slope category and occupies valley slopes of Wah Umiam and Wah Umkhen nasals. In the Shillong town such slopes have been observed locally along Laitkor range, valley slopes of Wah Umkhrah, Wah Umshirpi streams and their tributaries. Loss of vegetation cover on such slopes leads to high degree of erosion and soil loss. Steep slope ranging 15°-35° can be utilized for terrace cultivation, horticulture and afforestation.

Slope Class: 35° – 55°

This represents vertical steep slope and any development activities will lead to intensive denudation and sliding. This slope category is locally available along Raid Laban, Umlyinka, Mawiong, Mawpat ridge, Wah Umiam, Wah Ro-Ro, Wah Shella and Wah Umkhen. Precipitous slope above 35° should not be disturbed.

Slope Class: >55°

This slope category represents precipitous to vertical slope and observed in the areas locally along deep gorges of Mawiong, Mawpat ridge, Wah Umiam, Wah Ro-Ro and Umkhen. Intensive denudation, sliding, rockfall are the characteristic features of this category.

It is evident from the data in Table 3.4 and Figure 3.42 that most of the study area is under 2° -35° i.e., gentle, moderate, moderately steep and steep slope. The main urban agglomeration of the city is developed in and around this slope category with 23.31% of the total area falling under moderately slope followed by steep and moderate slope with 21% and 17.51%, 15.26% by gentle slope and 13.72% by level to gentle slope.

Table 3.4: Slope classes of the study area

Slope classes	Categories	Area in km ²	Area%
0 ⁰ - 2 ⁰	Level to gentle	27.62	13.72
2 ⁰ - 5 ⁰	Gentle	31.76	15.26
5 ⁰ - 15 ⁰	Moderate	36.44	17.51
15 ⁰ - 25 ⁰	Moderately steep	52.69	23.31
25 ⁰ - 35 ⁰	Steep	43.71	21.00
35 ⁰ - 55 ⁰	Very steep	9.39	4.51
>55 ⁰	Precipitous to vertical	6.54	3.14

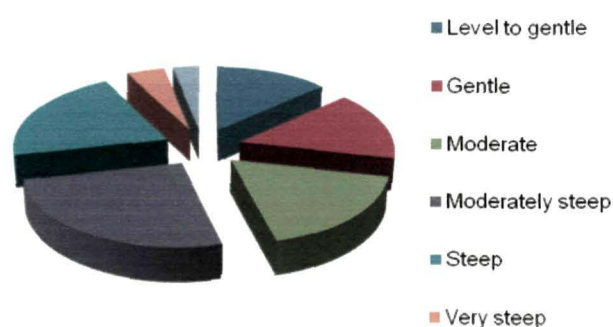


Figure 3.42: Aerial extent of slope classes in the study area

Aspect

Aspect map showing the direction in which the slopes are facing is presented in Figure 3.43. Area under eight aspect classes one for each of the main compass directions N, NE, E, SE, SW, W and NW are given in Table 3.5. The pie representation (Figure 3.44) of the aspect attributes shows that maximum slope faces are directed towards NNW (18.87%), followed by WNW (14.66%), NNE (13.66%), ESE (12.19%), ENE (11.68%), SSE (12.18%), SSW (8.87%) and WSW (7.90%). The frequent change in aspect values can be attributed to infinite irregularities in a slope surface.

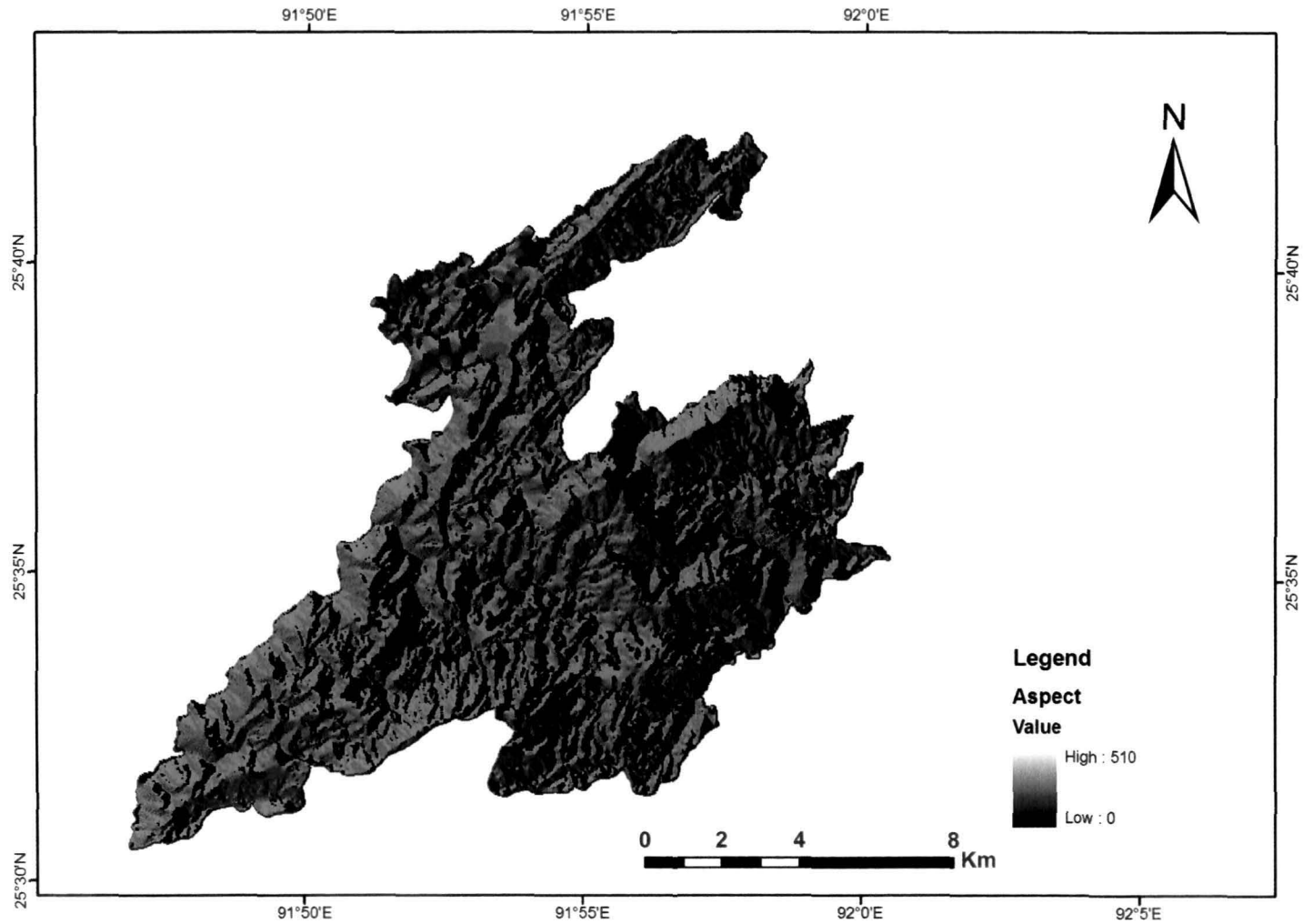


Figure 3.43: Aspect map derived from a 30m DEM

Table 3.5: Aspect classes of the study area

Direction	Area(sq km)	Area%
NNE	28.44	13.66
ENE	24.32	11.68
ESE	25.38	12.19
SSE	25.35	12.18
SSW	18.46	8.87
WSW	16.44	7.90
WNW	30.51	14.66
NNW	39.28	18.87

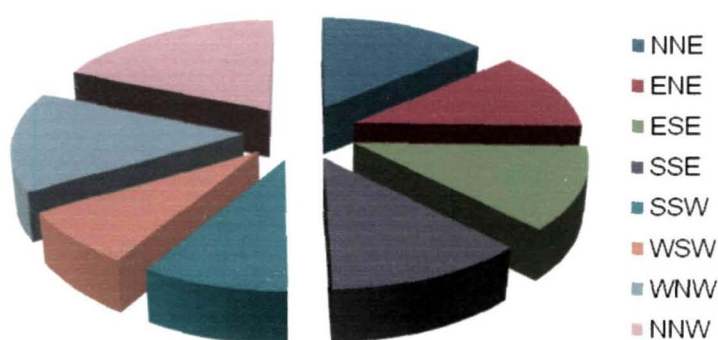


Figure 3.44: Aerial extent of aspect of the study area

Shaded Relief

The fine texture in the shaded relief map (Figure 3.45) indicates smooth topography while the prominent geomorphic units are the highly and moderately dissected hills. The structural trends seen in the map indicates that the hills are aligned in a NE-SW trend.

Elevation Map

An elevation map generated from 30m DEM shows that the range of elevation varies between 880m to 1960m (Figure 3.46). The general overview of the area

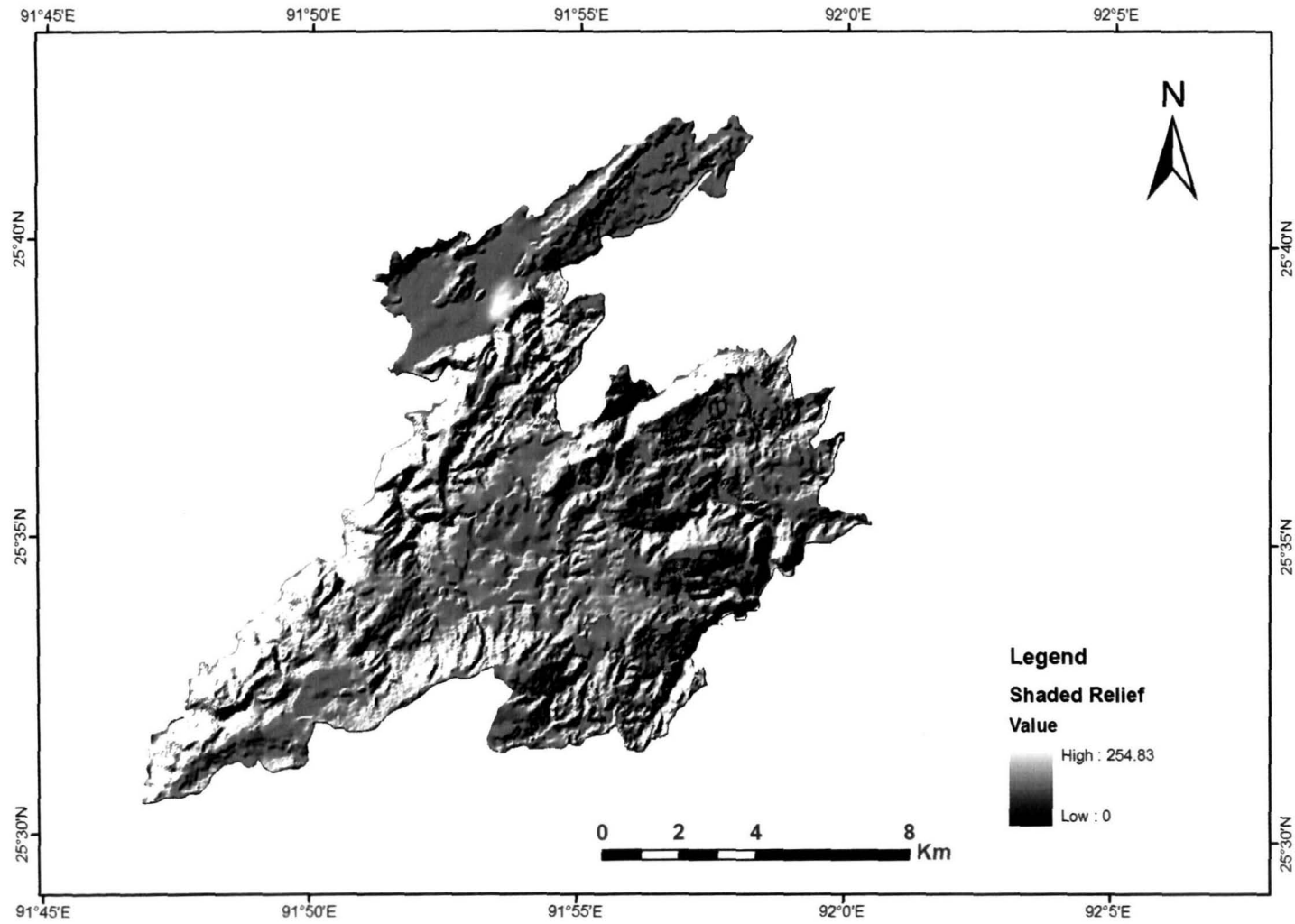


Figure 3.45: Shaded Relief derived from a 30m DEM

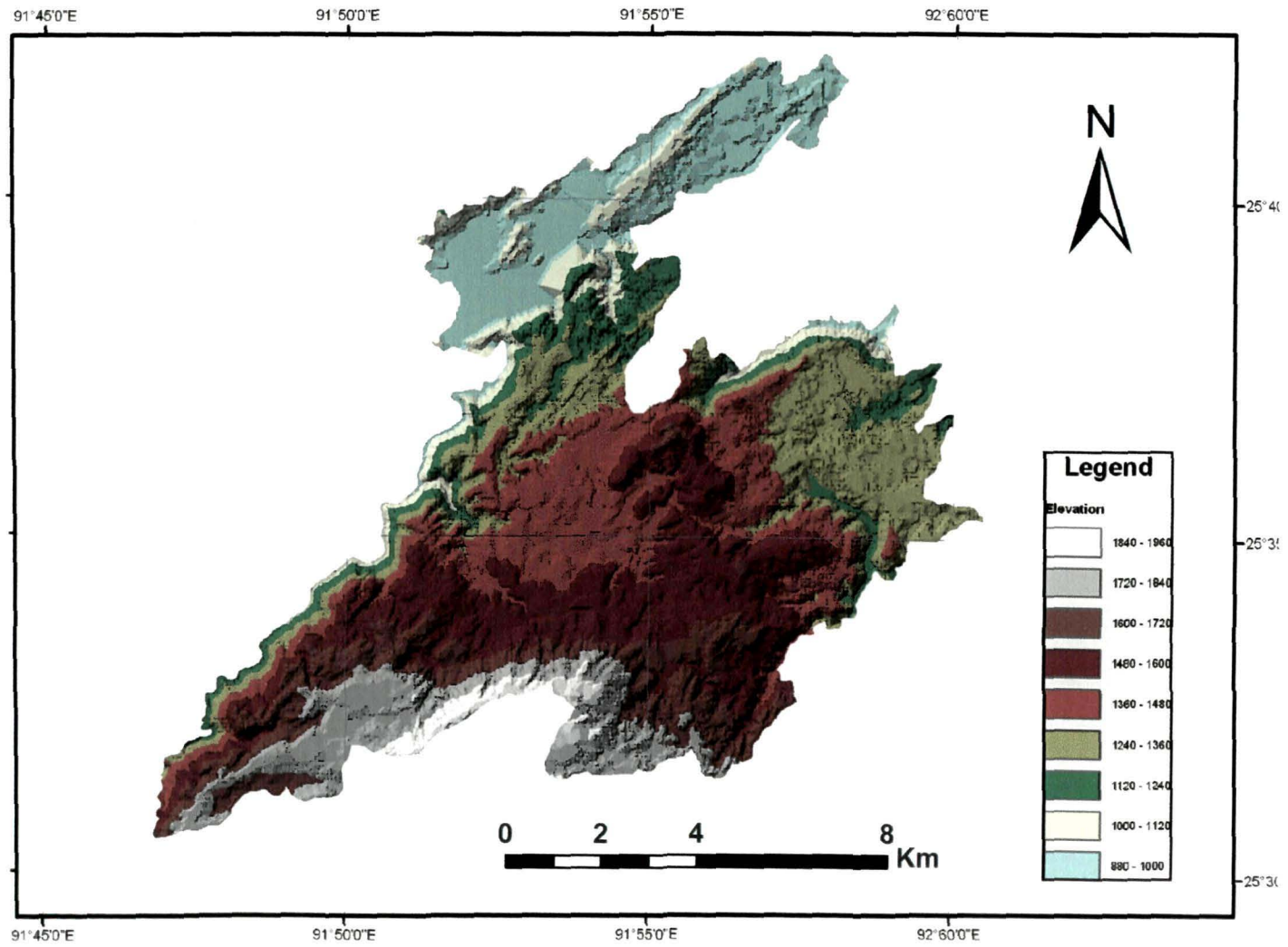


Figure 3.46: Elevation map derived from a 30m DEM

shows that elevation of the area decreases gradually towards the north with highest elevation concentrated towards south.

Soil

Three main order of soil (Table 3.6) can be seen in the study area. The soil consist of, Inceptisol and Ultisol according to NSSB-LUP. Entisols have also been observed through field study which is found on very recent geomorphic surfaces. The diversity in climate and physiographic division are responsible for variation in soil types in the study area. Temperature with igneous and metamorphic rocks in different stages of weathering largely governs the nature and extends of soil occurring, therefore the overall soil development is Ultisols with Inceptisols occurring in places where local amphibolites are emplaced. The soils developed on the hills sides and/or escarpments are moderately shallow to deep, loamy skeletal to fine, excessively drained and subjected to moderate to very severe erosion hazards. These soils have structural to well developed textural B horizon and are of Umbric Dystrochrepts, Typic Kandihumutls and Typic Kandiudutls sub group .

Table 3.6: Soil type in and around Shillong Master Plan Area (NSSB-LUP publ. 52)

Mapping unit	Sub group	Great group	Sub order	Order
01	Typic Kandiudutls	Kandiudults	Udults	Ultisol
04	Typic Kandihumutls	Kandihumults	Hamults	Ultisol
05	Typic Kandihumutls	Kandihumults	Hamults	Ultisol
07	Umbric Dystrochrepts	Dystrochrepts	Ochrepts	Inceptisol

Ultisols are characterized by acidic B horizon and occurs on the hills slope. It is normally reddish or yellow subsurface ferruginous clay mass formed due to weathering and chemical leaching of ferruginous quartzites with evidence of accumulation of iron oxides (Figure 3.47). The principal processes involved in forming Ultisols in the study area are clay minerals weathering, translocation of clay to accumulate in an argillic or kandic horizon, and leaching of base-forming cation from the profile.



Figure 3.47: Partial weathered soil of B horizon overlying bed rock (Quartzites).

Humus in A horizon is very thin and supports less vegetation.

The development of soil profile is very irregular. Towards north of the study area the soil is comparatively better developed than the southern side. The Shillong Group of rocks is highly weathered in nature and the degree of weathering is found to be more in topographic depressions. The development of soil cover is highly irregular and range in thickness from a thin veneer to more than 10 m at places. In areas which are characterized by flat topography, the thickness of soil cover ranges from 1.0 to 3.0 m.

Inceptisols comprising yellowish brown to greyish brown silt, and clay occurred mainly on the plateau top with thickness varying from 2.0 to 6.0 m and are the beginning of B horizon. Since metabasics are more prone to weathering than the quartzites, the areas around Happy Valley, Mawdiangdiang, Phudmawri and Mawlai where metabasics are emplaced in the quartzites, an acute tendency of oxidation is seen in the quartzite and they are overlain by a thick laterite capping.

Beside the above soil types it has been observed from field study that entisols are found on very recent geomorphic surfaces. It is brownish grey to dark coloured sandy clay loam, found on valley fills along Umkhrah river and its tributary in the Polo ground area and the minor valley fills in the area. Entisols have no diagnostic pedogenic horizons. The soil productivity is high and fertile, poorly drained and seasonally flooded. These valley fills are heavy loams and contain larger amount of organic matter. It is found that this soil, with their level topography, proximity for water for irrigation, and periodic nutrients replenishment by flood water sediments, can support agricultural activities in the valley filled areas.

The chemical analysis of soils reveals that all the soils are mildly acidic in nature with pH ranging from 4.8 to 6.2. Electrical conductivity is well within normal limits. Organic carbon is usually high but the soils have been found to be poor in phosphorous and potash. Alluvial fills having loam contain higher organic matter and retain good amount of moisture which make it good for paddy cultivation.

Although snapshots on geological framework of Shillong Master plan Area are found in published literature (Roy et.al., 1988) detailed geological map in 1:50,000 scale is not available in this context. The present study has brought out the minor details for example the presence of basic dykes (Khasi greenstones). On the other hand information on the comprehensive geomorphological parameters and landscape development was almost non-existent. The present study will help to fill in this information gap and enhance the understanding of landscape development in Shillong Master Plan Area.

CHAPTER 4

MORPHOMETRIC ANALYSIS

Introduction

Morphometric analysis refers to the measurement and mathematical evaluation of the configuration of the earth surface and the shape and dimension of the landforms. It incorporates quantitative study of the area, altitude, volume, slope and profile of the land and the drainage basin characteristics of the area concerned. Drainage basin may be used to subdivide the landscape of the area. The drainage basin is most commonly analyzed in morphometry as they form ideal aerial units for interpretation and analysis of fluvially originated landforms where they exhibit an example of an open system of operation with its various components such as, stream segments, basin length, basin parameter and basin area which indicates the nature of development of the basin. Studies on development of drainage basin and sub-basin help in interlocking the evolution and shaping of a landscape. As a quantitative measure of drainage network, morphometric analysis gives a foundation for hydrological study. Pioneer works of Strahler (1952, 1957), Horton (1932, 1956) are the basic foundation for morphometric analysis. Subsequently Bloom (2002) and Keller and Pinter (1996) have further propagated the morphometric analysis. Stream profile analysis and stream gradient index by Hack (1973) was another milestone in morphometric analysis. Many workers have used the principles developed by these pioneers to quantitatively study the drainage basin as a tool for landscape analysis.

(Sharma, 1987, Raj et. al., 1999, Awasthi, 2001). Drainage basins form the fundamental unit of morphometric analysis for quantitative evaluation of the form characteristics of a particular unit of landform. A quantitative analysis of the drainage basin in terms of various morphometric parameters is necessary to understand the relationship between forms and the processes.

Horton (1945) applied quantitative morphological analysis or morphometry in the study of the erosional development of streams and their drainage basins. Since then, methods of morphometrical analyses of drainage basins were further developed by several geomorphologists among these are: Strahler (1952, 1954), Schumm (1956), Morisawa (1957, 1958), Scheidegger (1965), Shreve (1967), Gregory (1966, 1968), Selby (1968), Smart (1967, 1969), Gregory and Walling (1973). Morphometric analysis provides quantitative description of the basin geometry and helps to understand initial slope or inequalities in the rocks hardness, structural controls, recent diastrophism, geological and geomorphic history of drainage basin (Strahler, 1964). Landforms are created via erosional and depositional processes, the geometry of which is controlled by the processes that shape them. Therefore morphometric analysis provides data that yield insights into these processes. Morphometric analyses require measurement of linear features, gradient of channel network and contributing ground slopes of the drainage basin (Nautiyal, 1994). The morphometric analysis for individual sub-basins has been achieved through measurements of linear, aerial and relief aspect of the basin and slope contribution (Nag and Chakraborty, 2003). Whereas the first two categories of measurement are planimetric, the third category treats the vertical inequalities of the drainage basin forms.

The study presents the results of detailed morphometric analysis of the fourth-order drainage basins and discusses their features and characteristics. The study also probes the stages of geomorphic development of the sub-basin drainage with the help of different morphometric parameters viz., stream order, stream number, stream length, mean stream length, bifurcation ratios, elongation factor, circularity index, shape factor, drainage density, stream frequency, texture ratio, relief ratio, length of overland flow, constant channel maintenance, infiltration number, hypsometric curve and index and longitudinal profiles.

Review of literature

During a study of stream profile and streambed materials in the Shenandoah Valley, Hack (1957) found that a simple logarithmic graph of the stream profile provides the basis for a useful system of analysis. In this graph, the origin of the graph is at the drainage divide, which forms the source of the stream. The vertical coordinate is an arithmetic scale and represents the altitude or height above a datum. The horizontal coordinate is a logarithmic scale and represents the stream length or distance from the source. Hack (1960) stated that in an erosionally graded landscape, the longitudinal profile of a stream is a property of stream geometry that can provide clue to the underlying materials as well as an insight into geologic processes and the geomorphic history of the area. Hack (1973) devised a method of analyzing the longitudinal profile and developed a new unit of measurement called the stream-gradient index. The index serves as an aid to geological mapping, as it permits comparisons to be made of stream of different sizes, analogous to data on magnetic intensities.

Hypsometric analysis is the study of the distribution of ground surface area or horizontal cross sectional area of a landmass with respect to elevation (Strahler, 1957b). The elevation characteristics of drainage basins are best depicted in and analyzed by hypsometric curves that are non-dimensional measure of the proportion of the catchment area above a given elevation (Strahler, 1952, 1957). The important elements for analyzing the landscape are the hypsometric curve and hypsometric integral values. The integral is a numerical index which may be used in the classification and in the comparison of different landscapes (Strahler, 1952).

Different workers have used the hypsometric curves for different purposes. Schumm (1956), Strahler (1964), Leopold et al. (1964) and Hurterz et al. (1999) have suggested that hypsometric curve are related to geomorphic and tectonic evolution of drainage basins. Hutchinson and Dowling (1991) and Wyatt (1993) used hypsometry to study the regional altitude frequency of continents in order to estimate the erosion-related sediments yields. The significances of the shape of the hypsometric curves has been recognized by Strahler (1952, 1957, 1964) who on the basis of hypsometry identified three types of landforms, namely, young, mature and monadock. Recently, Sinha-Roy (2002) derived an empirical relationship involving the mean elevation and the hypsometric integral to determine the relative tectonic uplift of the sub-catchments of Banas drainage basin. He concluded that the tectonic uplift deduced from hypsometry is relatively greater in the SW part of the Banas drainage basin than in the N and NW parts, which was due to differential vertical movements of several tectonic sub-blocks.

The longitudinal profile is a graph of distance versus elevation. The construction of longitudinal profile provides an interpretation of the surface history as they are the erosional curves and the river course flows from the source to mouth at any stage of evolution (Kumar and Pandey, 1981). Stream networks have regular geometric properties that can be quantitatively described. In an erosionally graded landscape, the longitudinal profile of a stream is a property of stream geometry that can provide clues to underlying materials as well as insight into geologic processes and the geomorphic history of the area (Hack, 1960). The longitudinal profile is the least transient expression of fluvial processes reflecting geological influences such as the available relief or tectonic history and base level changes on the processes of erosion and deposition and of the distribution of outcrops of different lithology (Richards, 1982). Long profile (gradient) adjustments are emphasized as being necessary to maintain sediments transport with the available discharge and given channel characteristics (Mackin, 1948).

Longitudinal profiles of streams channels are due to increase of discharge (Gilbert, 1877) and the decrease of bed material grain size due to abrasion during transportation downstream (Chorley, 1969). The nature of the channel or of the deposits in which it is excavated may also exercise some influence on the shape of the longitudinal profile. The longitudinal profile also reveals the gradient required by the river to transport its normal bed load. Hack (1957) has shown that the change of slope downstream (concavity) is influenced by change in size of debris downstream. The more quickly the bed materials decrease in size downstream, the more concave is the longitudinal profile. Conversely, where particle size increases downstream, the profile has a small concavity. If the rate of increase of particle size downstream is large enough, the profile is a straight line or may

be convex to the sky. The flattening of the profile downstream is undoubtedly related to the increase in volume, which goes with increase in drainage area. The uniform / graded up-concavity of the profile shape is indicative of absence of across channel structural lineament. A stream profile marked by abrupt change in gradient is called an interrupted profile. Sharp inflections in the interrupted profile are called knickpoints. The behavior of the knickpoints or the point at which the abrupt break in slope occurs is governed by the discharge regimen and by the structure across channel and composition of the bed and bank material of the river (Leopold, 1964). While working on the river profiles along the Himalayan arc, Seeber and Gornitz (1983) concluded that in a steady state condition, when climate and the rate of uplift is equal to the rate of incision, the longitudinal profile of the river would be graded.

Remote sensing techniques using satellite images are a convenient tool for morphometric analysis. Many workers have carried out morphometric analysis using remote sensing techniques. Srivastava (1997) studied the drainage pattern of Jharia coalfield (Bihar) using remote sensing technology. Nag (1998) carried out morphometric analysis of Chaka subbasin in Purulia district, while Nag and Chakraborty (2003) deciphered the influence of rock types and structures in the development of drainage network in hard rock area. Biswas et.al. (1999) studied part of Nayagram Block in the Midnapore District, West Bengal in terms of the morphometric parameters viz., stream length, bifurcation ratio, drainage density, stream frequency, texture ratio, form factor, circularity ratio and elongation ratio for prioritization of sub-watersheds of the area. Srinivasa-vittala et.al. (2004) used remote sensing and GIS techniques in morphometric analysis of sub-watersheds in Pawagada area of Tumkur district, Kanataka. Recently, Chopra et.al.

(2005) carried out morphometric analysis using remote sensing data, GIS techniques in Bhagra-Phungotri and hara Maja sub-watersheds of Gurdaspur district, Punjab. They found out that both sub-watersheds show dendritic to sub dendritic drainage pattern having moderate drainage texture, high burfication ratio and low drainage density indicating that the area is underlain by resistant permeable rocks with strong structural control on the drainage. Ratnam et.al. (2005) identified twenty-four suitable sites for check dam construction based on micro-watershed prioritization by using remote sensing data, GIS techniques and also through morphometric studies of Tarafeni watershed in Midanpur district, West Bengal. Their findings show that integrated study of Sediment Yield Index model and morphometric analysis yield good result in prioritization of watersheds. Al-Sulaimi et.al. (1997) concluded a detailed morphometric analysis of the endoeric drainage basins in Kuwait and discussed their genesis and impact on the present day arid environmental conditions. The role of the studied drainage systems in the occurrence of mobile sand and sand dunes, rainwater harvesting, and land capability was also emphasised. Morphometric analysis at sub-watershed level was carried out by Srinivasa Vittala et al. (2004). They concluded that the terrain exhibited dendritic to sub-dendritic drainage pattern.

Results and Discussion

Eleven fourth-order drainage (Figure 4.1 and Table 4.1) basins were used as a statistical sample in the processing of the morphometric parameters analyses, with the distribution of the lithological units for each fourth order drainage basin (Table 4.2). The morphometric analysis for the individual fourth-order drainage basins have been carried out using the mathematical formula and their results are summarized in Table 4.3- 4.13.

Table 4.1: Fourth-order drainage sub-basins of the study area

Index No.	Name of the sub basin
D1	Um Baniun
D2	Wah Umiam (tributaries)
D3	Umshirpi
D4	Wahumkhrah
D5	Wah Umkhen
D6	Wah Umkhen (tributaries)
D7	Wah Umbah
D8	Wah Shella (tributaries)
D9	Wah Tamdong
D10	Phud-Umsning (tributaries)
D11	Phud Mawiong

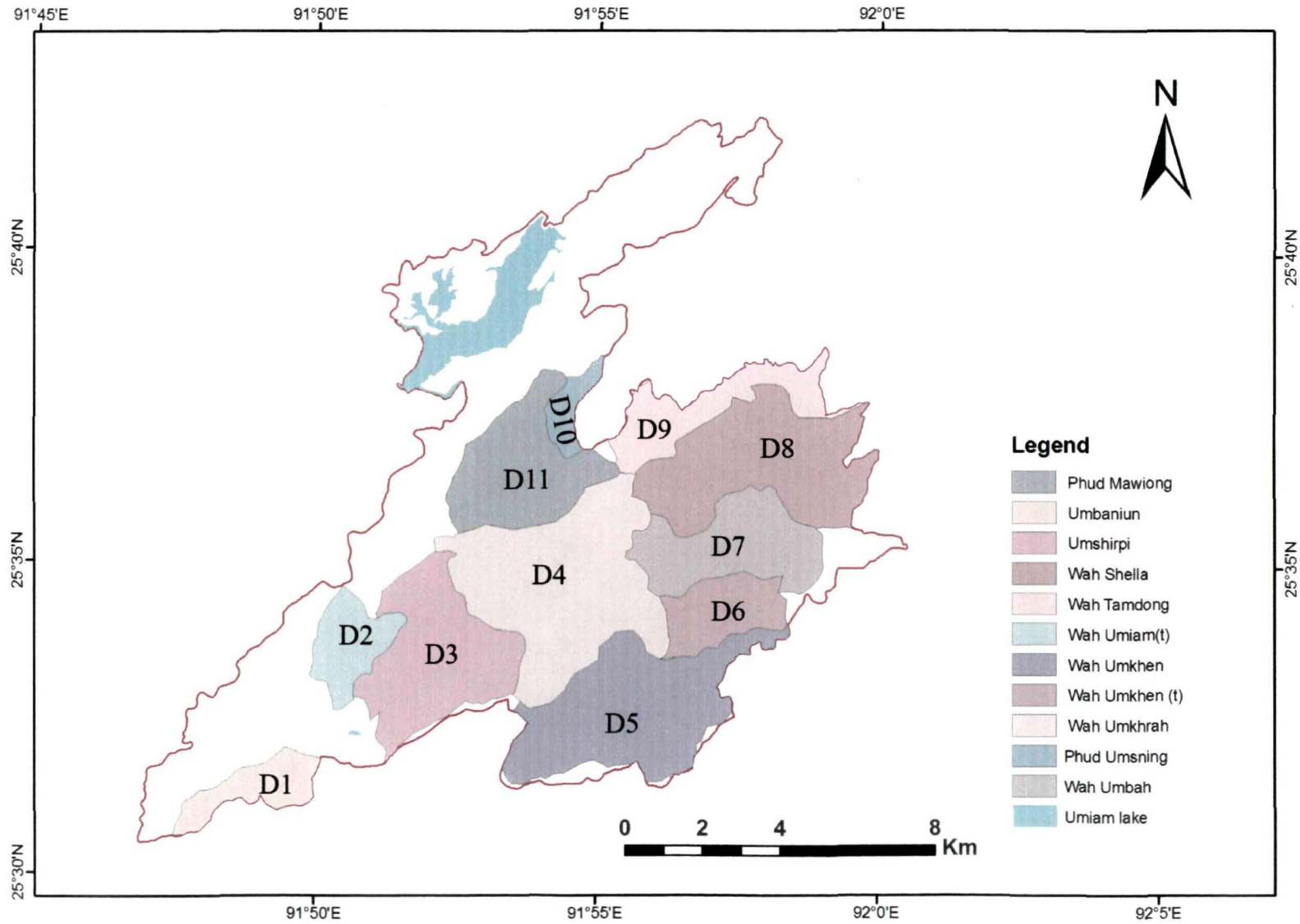


Figure 4.1: Fourth-order drainage sub-basins in the study area

Table: 4.2: The lithological units of the fourth-order drainage sub-basin.

Basin index	Sub basin	Lithological units
D1	Um Baniun	Mostly quartzite with intrusion of porphyritic granite.
D2	Wah Umiam (tributaries)	Mostly quartzite with subordinate amount of amphibolites (Khasi greenstone), conglomerates, weathered mantle and laterite soil cover.
D3	Umshirpi	Mostly quartzite with subordinate amount of amphibolites (Khasi greenstone), conglomerates and weathered mantle.
D4	Wah Umkhras	Valley filled sediments and quartzite occupies a large area with subordinate amount of amphibolites (Khasi greenstone), weathered mantle, conglomerates, brecciated quartzite and laterite soil cover.
D5	Wah Umkhen	Mostly quartzite with intrusion of amphibolites (Khasi greenstone), and subordinate amount of weathered mantle and valley filled sediments.
D6	Wah Umkhen (tributaries)	Quartzite
D7	Wah Umbah	Mostly quartzite with scattered intrusion of amphibolites (Khasi greenstone).
D8	Wah Shella (tributaries)	Mostly quartzite with scattered intrusion of amphibolites (Khasi greenstone).
D9	Wah Tamdong	Quartzite
D10	Phud-Umsning (tributaries)	Quartzite
D11	Phud Mawiong	Mostly quartzite with subordinate amount of amphibolites (Khasi greenstone), conglomerates, weathered mantle and laterite soil cover.

Linear aspects

i. Stream Order (U)

Almost 80% of the area under study is covered by fourth-order drainage basins with negligible interfluvial areas. It is observed that basin area is not the controlling factor in drainage development. Elongated fourth-order drainage basins with smaller areas have developed towards north viz., basin D9 and southwest viz., D1. However, in the central part of the area the fourth-order drainage basins, D4 are developed occupying larger

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basinal area and take nearly circular form. The variation in size of the fourth-order drainage basin is largely due to physiographic and structural conditions prevailing in these drainage basins.

Table 4.3: Morphometric analysis: linear and aerial aspects for the sub-basin D1

Sl. No	D1-Um Baniun							Scale: 1:50,000	
	Stream Order	Stream Number	Bifurcation Ratio	Stream Length	Maximum Basin Length	Mean Stream Length	Basin Perimeter		
	U	Nu	Rb	Lu(km)	Lb(km)	Lu	P(km)		
LINER ASPECT	1	51	4.25	24.321					
	2	12	4.00	5.356					
	3	3	3.00	3.327	6.530	1.109	17.258		
	4	1		4.511		4.511			
		$\Sigma Nu=67$		$\Sigma Lu=37.515$					

AREAL ASPECT	Drainage Area	Shape Parameter			Drainage Density	Stream Frequency	Infiltration No.	Length of Overland Flow	Constant of channel maintenance
		Elongation Ratio	Circularity Ratio	Form Factor					
	Au(km ²)	Re	Rc	Rf	D (km.km ⁻²)	Fs(km ⁻¹)	If(km ⁻²)	Lg(km)	C(km ⁻² .km ⁻¹)
	11.410	0.584	0.481	0.268	3.288	5.872	19.307	0.152	0.304

Table 4.4: Morphometric analysis: linear and aerial aspects for the sub-basin D2

Sl. No	D2 - Wah Umiam (tributary).							Scale: 1:50,000	
	Stream Order	Stream Number	Bifurcation Ratio	Stream Length	Maximum Basin Length	Mean Stream Length	Basin Perimeter		
	U	Nu	Rb	Lu(km)	Lb(km)	Lu	P(km)		
LINER ASPECT	1	30	4.29	12.325					
	2	7	3.50	5.125	3.660	0.7322	10.749		
	3	2	2.00	2.657		1.3283			
	4	1		1.086		1.0863			
		$\Sigma Nu=40$		$\Sigma Lu=21.193$					

AREAL ASPECT	Drainage Area	Shape Parameter			Drainage Density	Stream Frequency	Infiltration No.	Length of Overland Flow	Constant of channel maintenance
		Elongation Ratio	Circularity Ratio	Form Factor					
	Au(km ²)	Re	Rc	Rf	D (km.km ⁻²)	Fs(km ⁻¹)	If(km ⁻²)	Lg(km)	C(km ⁻² .km ⁻¹)
	5.322	0.711	0.579	0.397	3.982	7.516	29.929	0.126	0.211

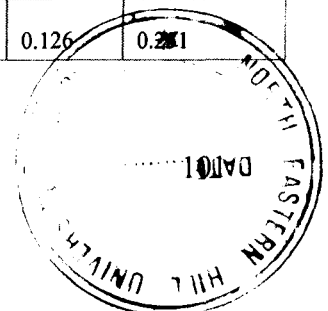


Table 4.5: Morphometric analysis: linear and aerial aspects for the sub-basin D3

Sl. No	D3 - Umshirpi							Scale: 1:50,000
	Stream Order	Stream Number	Bifurcation Ratio	Stream Length	Maximum Basin Length	Mean Stream Length	Basin Perimeter	
	U	Nu	Rb	Lu(km)	Lb(km)	Lu	P(km)	
LINER ASPECT	1	84	4.00	39.255		0.4683		
	2	21	7.00	15.046		0.7165		
	3	3	3.00	7.335	6.484	2.4451	20.848	
	4	1		3.635		3.6354		
		$\Sigma Nu=109$		$\Sigma Lu=65.272$				

AREAL ASPECT	Drainage Area	Shape Parameter			Drainage Density	Stream Frequency	Infiltration No.	Length of Overland Flow	Constant of channel maintenance
		Elongation Ratio	Circularity Ratio	Form Factor					
	Au(km ²)	Re	Rc	Rf	D (km.km ⁻²)	Fs(km ⁻¹)	If(km ⁻²)	Lg(km)	C(km ⁻² .km ⁻¹)
	15.842	0.693	0.458	0.377	4.120	6.880	28.349	0.121	0.243

Table 4.6: Morphometric analysis: linear and aerial aspects for the sub-basin D4

Sl. No	D4 - Umkhrah							Scale: 1:50,000
	Stream Order	Stream Number	Bifurcation Ratio	Stream Length	Maximum Basin Length	Mean Stream Length	Basin Perimeter	
	U	Nu	Rb	Lu(km)	Lb(km)	Lu	P(km)	
LINER ASPECT	1	78	5.20	38.722		0.496		
	2	15	5.00	14.313		0.954		
	3	3	3.00	7.358	7.750	2.453	26.810	
	4	1		5.144		5.144		
		$\Sigma Nu=97$		$\Sigma Lu=65.537$				

AREAL ASPECT	Drainage Area	Shape Parameter			Drainage Density	Stream Frequency	Infiltration No.	Length of Overland Flow	Constant of channel maintenance
		Elongation Ratio	Circularity Ratio	Form Factor					
	Au(km ²)	Re	Rc	Rf	D (km.km ⁻²)	Fs(km ⁻¹)	If(km ⁻²)	Lg(km)	C(km ⁻² .km ⁻¹)
	25.077	0.729	0.438	0.418	2.613	3.868	10.109	0.191	0.383

Table 4.7: Morphometric analysis: linear and aerial aspects for the sub-basin D5

Sl. No	D5 - Umkhen							Scale: 1:50,000	
	Stream Order	Stream Number	Bifurcation Ratio	Stream Length	Maximum Basin Length	Mean Stream Length	Basin Perimeter		
	U	Nu	Rb	Lu(km)	Lb(km)	Lu	P(km)		
LINER ASPECT	1	74	5.29	37.930		0.5126			
	2	14	7.00	13.952		0.9966			
	3	2	2.00	9.638		4.8191			
	4	1		4.575		4.5754			
		$\Sigma Nu=91$		$\Sigma Lu=66.096$	9.662				25.545

AREAL ASPECT	Drainage Area	Shape Parameter			Drainage Density	Stream Frequency	Infiltration No.	Length of Overland Flow	Constant of channel maintenance
		Elongation Ratio	Circularity Ratio	Form Factor					
	Au(km ²)	Re	Rc	Rf	D (km.km ⁻²)	Fs(km ⁻¹)	If(km ⁻²)	Lg(km)	C(km ⁻² .km ⁻¹)
	23.340	0.564	0.449	0.250	2.832	3.899	11.041	0.177	0.353

Table 4.8: Morphometric analysis: linear and aerial aspects for the sub-basin D6

Sl. No	D6 - Umkhen (tributary)							Scale: 1:50,000	
	Stream Order	Stream Number	Bifurcation Ratio	Stream Length	Maximum Basin Length	Mean Stream Length	Basin Perimeter		
	U	Nu	Rb	Lu(km)	Lb(km)	Lu	P(km)		
LINER ASPECT	1	19	3.80	11.499		0.605			
	2	5	2.50	3.027		0.605			
	3	2	2.00	2.767		1.384			
	4	1		1.124		1.124			
		$\Sigma Nu=27$		$\Sigma Lu=18.417$	4.154				11.416

AREAL ASPECT	Drainage Area	Shape Parameter			Drainage Density	Stream Frequency	Infiltration No.	Length of Overland Flow	Constant of channel maintenance
		Elongation Ratio	Circularity Ratio	Form Factor					
	Au(km ²)	Re	Rc	Rf	D (km.km ⁻²)	Fs(km ⁻¹)	If(km ⁻²)	Lg(km)	C(km ⁻² .km ⁻¹)
	6.257	0.679	0.603	0.363	2.944	4.315	12.703	0.170	0.340

Table 4.9: Morphometric analysis: linear and aerial aspects for the sub-basin D7

Sl. No	D7 - Wah Umbah						Scale: 1:50,000	
	Stream Order	Stream Number	Bifurcation Ratio	Stream Length	Maximum Basin Length	Mean Stream Length	Basin Perimeter	
	U	Nu	Rb	Lu(km)	Lb(km)	Lu	P(km)	
LINER ASPECT	1	47	3.92	22.347		0.475		
	2	12	6.00	6.000		0.500		
	3	2	2.00	4.111	5.884	2.055	17.812	
	4	1		2.663		2.663		
		$\Sigma Nu=62$		$\Sigma Lu=35.121$				

AREAL ASPECT	Drainage Area	Shape Parameter			Drainage Density	Stream Frequency	Infiltration No.	Length of Overland Flow	Constant of channel maintenance
		Elongation Ratio	Circularity Ratio	Form Factor					
	Au(km ²)	Re	Rc	Rf	D (km.km ⁻²)	Fs(km ⁻¹)	If(km ⁻²)	Lg(km)	C(km ⁻² .km ⁻¹)
	11.525	0.651	0.456	0.333	3.047	5.380	16.394	0.164	0.328

Table 4.10: Morphometric analysis: linear and aerial aspects for the sub-basin D8

Sl. No	D8 - Wah Wah Shella						Scale: 1:50,000	
	Stream Order	Stream Number	Bifurcation Ratio	Stream Length	Maximum Basin Length	Mean Stream Length	Basin Perimeter	
	U	Nu	Rb	Lu(km)	Lb(km)	Lu	P(km)	
LINER ASPECT	1	67	3.722	31.2		0.466		
	2	18	3.6	8.7		0.483		
	3	5	5	4.9	7.05	0.98	19.35	
	4	1		5.65		5.65		
		$\Sigma Nu=91$		$\Sigma Lu=50.45$				

AREAL ASPECT	Drainage Area	Shape Parameter			Drainage Density	Stream Frequency	Infiltration No.	Length of Overland Flow	Constant of channel maintenance
		Elongation Ratio	Circularity Ratio	Form Factor					
	Au(km ²)	Re	Rc	Rf	D (km.km ⁻²)	Fs(km ⁻¹)	If(km ⁻²)	Lg(km)	C(km ⁻² .km ⁻¹)
	14.873	0.617	0.499	0.299	3.392	6.118	20.754	0.147	0.295

Table 4.11: Morphometric analysis: linear and aerial aspects for the sub-basin D9

Sl. No	D9 - Wah Tamdong							Scale: 1:50,000
	Stream Order	Stream Number	Bifurcation Ratio	Stream Length	Maximum Basin Length	Mean Stream Length	Basin Perimeter	
	U	Nu	Rb	Lu(km)	Lb(km)	Lu	P(km)	
LINER ASPECT	1	71	4.73	33.624		0.474		
	2	15	3.00	5.779		0.385		
	3	5	5.00	4.672	7.858	0.934	24.266	
	4	1		7.123		7.123		
		ΣNu=92		ΣLu=51.198				

AREAL ASPECT	Drainage Area	Shape Parameter			Drainage Density	Stream Frequency	Infiltration No.	Length of Overland Flow	Constant of channel maintenance
		Elongation Ratio	Circularity Ratio	Form Factor					
	Au(km ²)	Re	Rc	Rf	D (km.km ⁻²)	Fs(km ⁻¹)	If(km ⁻²)	Lg(km)	C(km ⁻² .km ⁻¹)
	12.951	0.517	0.276	0.210	3.953	7.104	28.083	0.126	0.253

Table 4.12: Morphometric analysis: linear and aerial aspects for the sub-basin D10

Sl. No	D10 - Phud Umsning (tributary)							Scale: 1:50,000
	Stream Order	Stream Number	Bifurcation Ratio	Stream Length	Maximum Basin Length	Mean Stream Length	Basin Perimeter	
	U	Nu	Rb	Lu(km)	Lb(km)	Lu	P(km)	
LINER ASPECT	1	20	4.00	11.741		0.587		
	2	5	2.50	3.828	3.534	0.766	12.065	
	3	2	2.00	0.626		0.313		
	4	1		0.977		0.977		
		ΣNu=28		ΣLu=17.173				

AREAL ASPECT	Drainage Area	Shape Parameter			Drainage Density	Stream Frequency	Infiltration No.	Length of Overland Flow	Constant of channel maintenance
		Elongation Ratio	Circularity Ratio	Form Factor					
	Au(km ²)	Re	Rc	Rf	D (km.km ⁻²)	Fs(km ⁻¹)	If(km ⁻²)	Lg(km)	C(km ⁻² .km ⁻¹)
	4.905	0.744	0.468	0.434	3.167	5.164	16.354	0.158	0.316

Table 4.13: Morphometric analysis: linear and aerial aspects for the sub-basin D11

Sl. No	D3 - Phud Mawiong.						Scale: 1:50,000	
	Stream Order	Stream Number	Bifurcation Ratio	Stream Length	Maximum Basin Length	Mean Stream Length	Basin Perimeter	
LINER ASPECT	U	Nu	Rb	Lu(km)	Lb(km)	Lu	P(km)	
	1	46	4.60	23.026		0.501		
	2	10	5.00	5.913		0.591		
	3	2	2.00	1.125	5.683	0.562	17.402	
	4	1		9.921		9.921		
		$\Sigma Nu=59$		$\Sigma Lu=39.985$				

AREAL ASPECT	Drainage Area	Shape Parameter			Drainage Density	Stream Frequency	Infiltration No.	Length of Overland Flow	Constant of channel maintenance
		Elongation Ratio	Circularity Ratio	Form Factor					
	Au(km ²)	Re	Rc	Rf	D (km.km ⁻²)	Fs(km ⁻¹)	If(km ⁻²)	Lg(km)	C(km ⁻² .km ⁻¹)
	12.516	0.702	0.519	0.388	3.195	4.714	15.060	0.157	0.313

i. Stream Number (Nu)

It was observed that the number of stream segment increases with decreasing stream order in all the sub-basins. Graphical semi log plot of stream number vs. stream order yielded straight lines (Figure 4.2). For ideal condition, as stated by Strahler (1969) the relationship between order and number the regression equation showed negative correlation thus conforming to the prevalent law of stream number.

i. Bifurcation Ratio (Rb)

Bifurcation ratio gives a measure of drainage development in a basin. Horton (1945) considers the bifurcation ratio as an index of relief and dissection. Studies of many stream network confirms the principle that in a region of uniform climate, rock type, and stage of development, the bifurcation ratio tends to remain constant from one order to the next, except where powerful geological control dominates (Strahler, 1968).

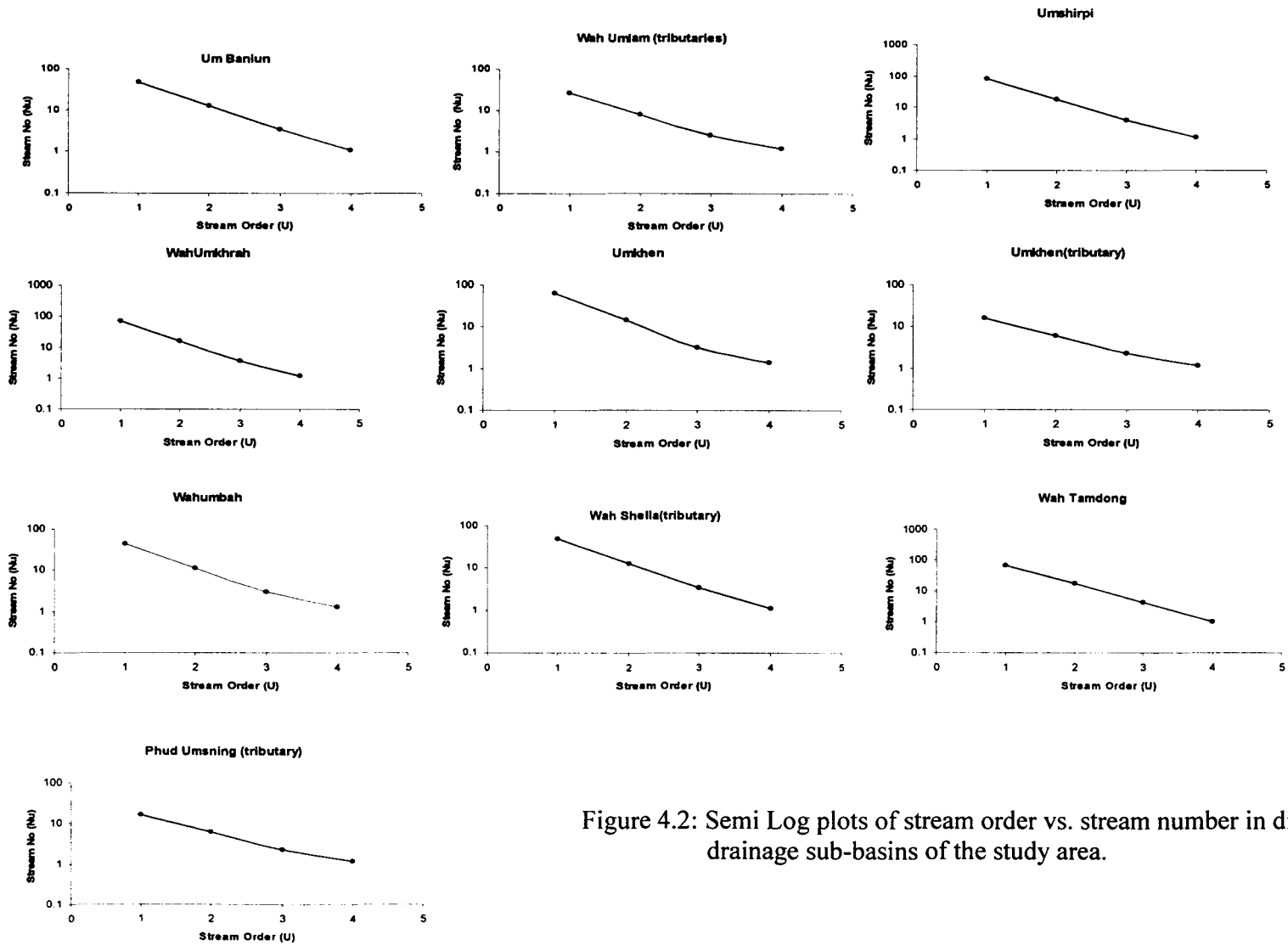


Figure 4.2: Semi Log plots of stream order vs. stream number in different drainage sub-basins of the study area.

The bifurcation ratio is of fundamental importance in drainage basin analysis as it is the foremost parameter to link the hydrological regime of a watershed under topological and climatic regime (Raj et. al., 1999). This parameter is important in understanding the shape of the basin and also helps in deciphering the runoff behavior. Lower bifurcation ratio values of the watersheds show that the drainage pattern is not distorted (Nag, 1998). In case of the present study as seen from the data in Table 4.3- 4.13 this ratio is not uniform from one order to the next. According to Schumm (1956), because of chance of irregularities, bifurcation ratio between the successive pairs of orders differs within the basin even if a general trend of geometric series exists.

The mean bifurcation ratio (R_b) varies from a minimum of 2 in a flat or rolling drainage basin to 3 or 4 in mountainous or highly dissected drainage basins (Horton, 1945). For the present study mean bifurcation ratio for all fourth-order drainage basins range between 4.76 of Wah Umkhen to 2.63 (Phud-Umshing) (Table 4.14) i.e. the variation of bifurcation ratio of different orders over a mean value is rather small, indicating variation in lithology, strong structural control and stage drainage development. The calculated weighted mean ranges from 3.07 for Phud-Umshing to 5.45 for Wah Umkhen. Structural effects cause basin elongation (Chorley, 1969) as apparent from the tabulated values, the higher values of bifurcation ratio are found for the elongated drainage basins dominated by Khasi greenstone, quartzites, weathered mantle and valley filled sediments, covering the hilly terrain with strong structural effects mostly in the south and southwestern part. On the other hand the lower values are shown by the drainage basins that drain through pure quartzitic area. Thus these variations in bifurcation ratio are dependent upon the lithological and geological development of drainage basin (Strahler, 1971). The elongated

watershed, which comprises higher Rb would result into a lower but extended peak flow, while round watershed with low Rb produces sharp peak flow.

Table 4.14: Bifurcation Ratio and Weighted Mean Bifurcation Ratio of fourth-order drainage sub-basin.

Index	Sub-basin	Mean bifurcation ratio	Weighted mean bifurcation ratio
D1	Um Baniun	3.75	4.14
D2	Wah Umiam (tributaries)	3.26	4.00
D3	Umshirpi	4.67	4.15
D4	Wah Umkhrah	4.40	5.09
D5	Wah Umkhen	4.76	5.45
D6	Wah Umkhen (tributaries)	2.77	3.37
D7	Wah Umbah	3.97	4.22
D8	Wah Shella	4.11	3.76
D9	Wah Tamdong	4.24	4.44
D10	Phud-Umsning (tributaries)	2.63	3.07
D11	Phud Mawiong	3.07	4.56

ii. Stream Length (Lu)

Graphical representation of the total stream length against stream order was also prepared in a semi-log plot as suggested by Strahler (1957). The general logarithms of the number of stream of a given order, when plotted against the stream order, the points lie on a straight line (Horton, 1945). Bivariant plot between stream order and total stream length shows negative exponential functions, indicating that the total stream length decreases with increase in stream order indicating that development of drainage is higher for the lower order (Figure 4.3). However, the drainage basin D10 shows slight deviation from the straight line. Deviation from its general behavior indicates that the terrain is

characterized by high relief and/or moderately steep slopes, underlain the various lithology and probable uplift across the basin (Singh and Singh 1997).

iii. Mean stream length (Lu)

The mean stream length of a channel is a dimensional property and reveals the characteristic size of drainage network components and its contributing basin surfaces (Strahler, 1964). The values of mean stream length are plotted against respective stream order (Figure 4.4). These line diagrams show the relationship between mean stream length and the stream order for each drainage basin. The relationship reveals more or less a straight line regression of positive exponential form as postulated by Strahler (1971).

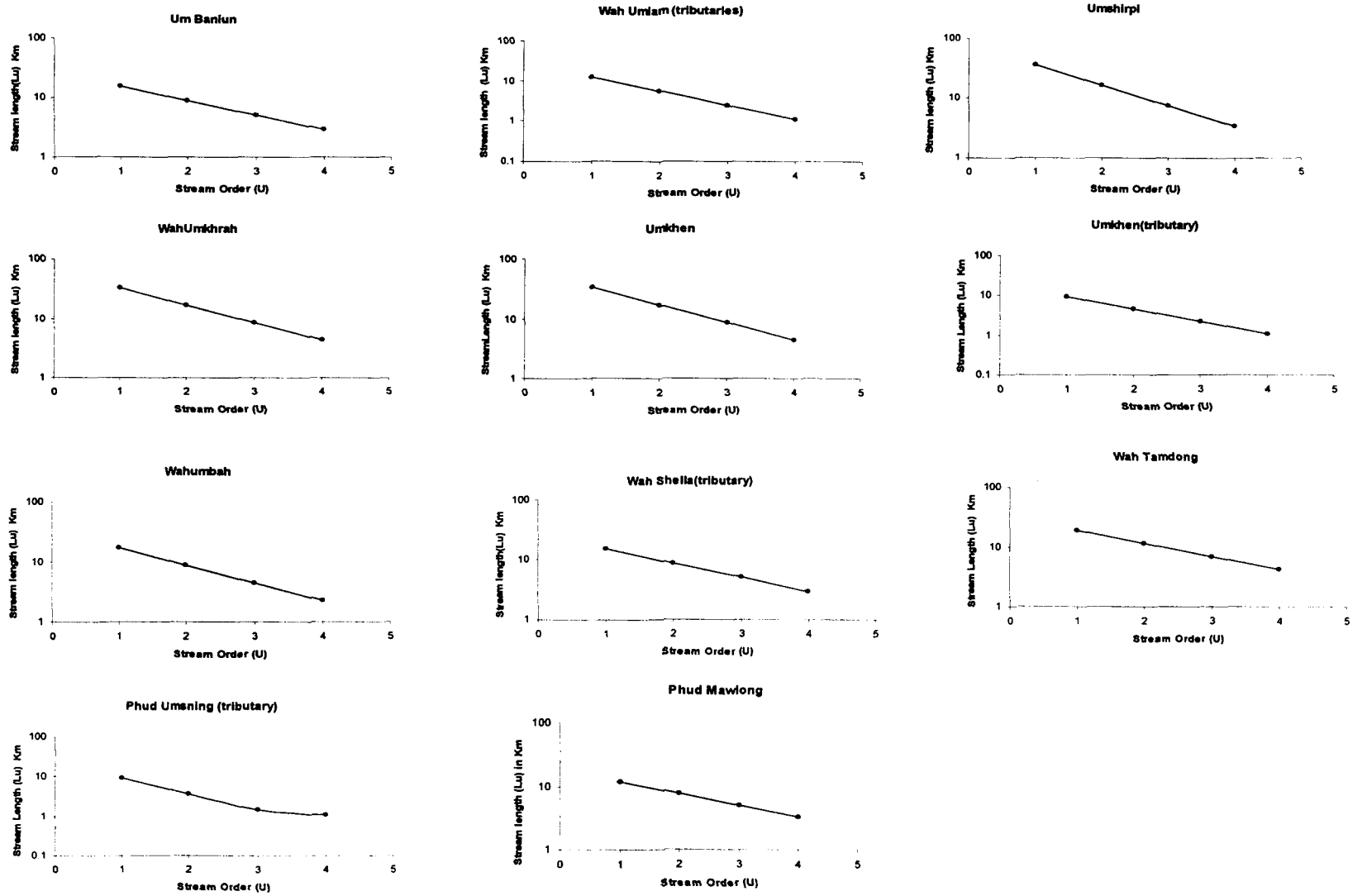


Figure 4.3: Semi Log plot of stream order vs. stream length for various drainage sub-basins of the study area.

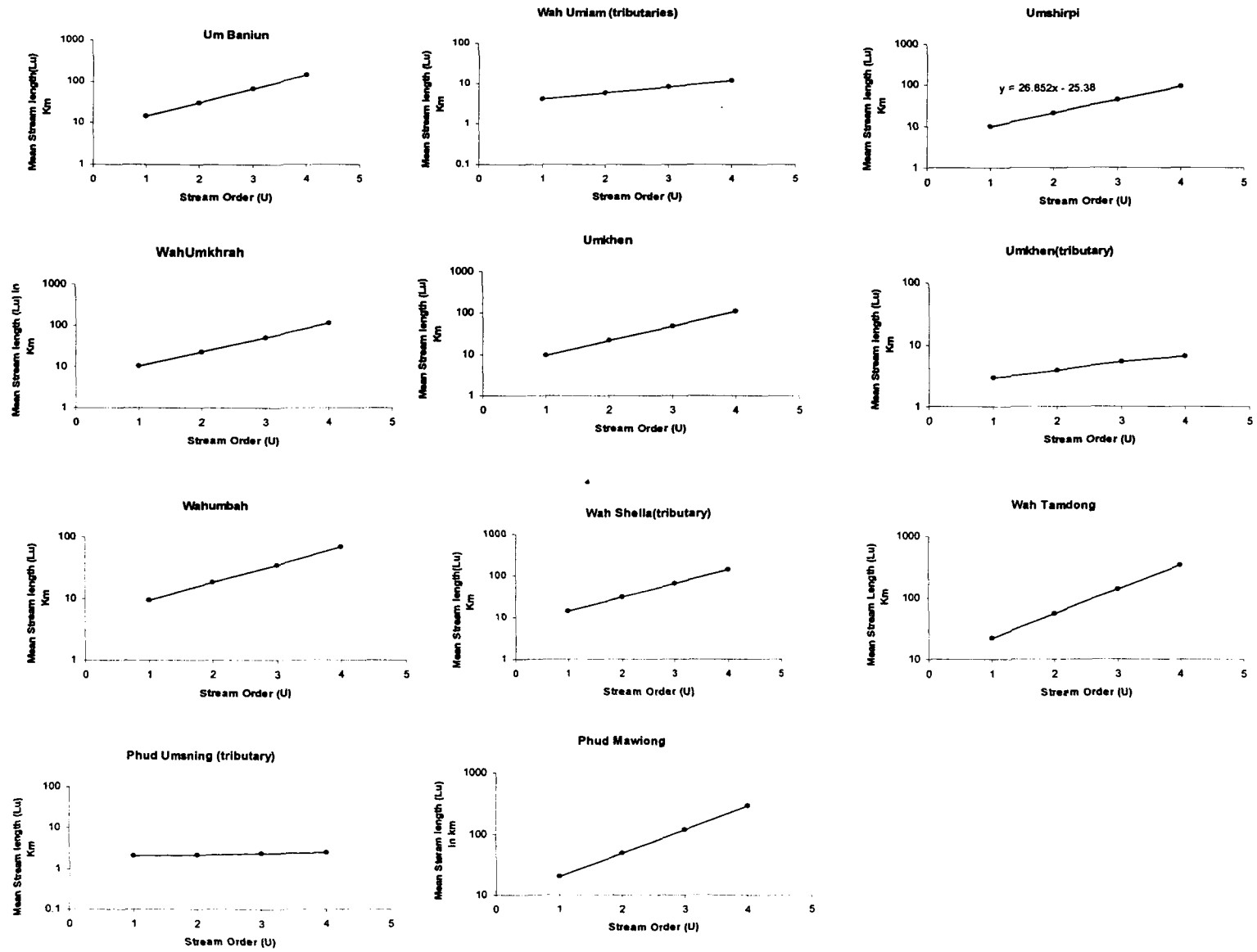


Figure 4.4: Semi Log plot of stream order vs. mean stream length for various drainage sub-basins of the study area.

Aerial aspects

i. Drainage area

Basin area is hydrologically important because it directly affects the size of the storm hydrograph and the magnitude of peak and mean runoff (Chorley, 1969). The maximum flood discharge per unit area is inversely related to size of the basin, because the most intense storms are usually of the smallest size (More, 1967). The computed data, tabulated basin wise (Table 4.15) shows that the maximum basin area of about 25.08 km² was found for the drainage basin D4 while the drainage basin D10 covers the minimum basin area of 4.91km². As such it is expected that the D4 basin will produce a smaller peak flood flow than that of D10 if magnitude and intensity of rainfall along with other factors remain same. In the study area Wah Umiam is the main outlet in the western part, Wah Umkhen in the southeastern part and Wah Shella and Wah Tamdong are the main outlets in northeastern part.

In order to find out the relationship between the basin area and the total stream length for the respective basins, a regression line was constructed using a double-log graph paper. It was found that the drainage area bears a power function relationship with total stream length, which is shown in Figure 4.5. The relationship of stream length to basin area is important because plots of basin area draining into various locations along the main stream (i.e., area-distance curve) give an idea of pattern of runoff and also because the relationship of total stream lengths of all orders to basin area is one of the most sensitive and variable morphometric parameter and one which controls the texture of landscape dissection and the spacing of stream (Chorley, 1969).

Table 4.15: Stream length and basin area of fourth-order drainage sub-basins.

Index	Sub-basin	Basin area (km ²)	Stream length (km)
D1	Um Baniun	11.41	37.51
D2	Wah Umiam (tributaries)	5.32	21.19
D3	Umshirpi	15.84	65.27
D4	Wah Umkhrah	25.08	65.54
D5	Wah Umkhen	23.34	66.10
D6	Wah Umkhen (tributaries)	6.26	18.42
D7	Wah Umbah	11.53	35.12
D8	Wah Shella	14.87	50.45
D9	Wah Tamdong	12.95	51.20
D10	Phud-Umsning (tributaries)	4.91	17.17
D11	Phud Mawiong	12.52	39.98

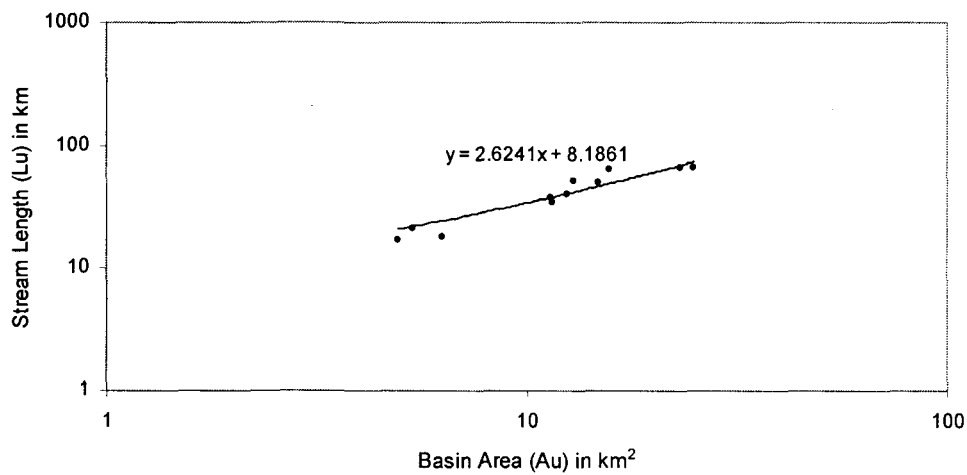


Figure 4.5: Log-Log plot of basin area (Au) vs. stream length (Lu)

ii. Drainage Density (Dd)

Drainage density has long been recognized as a topographic characteristic of fundamental significance as it is a parameter which in many ways provides the link between the form

attributes of the basin and the processes operating along the stream course (Gregory and Welling, 1973). It reflects the landuse and affects infiltration and the basin response time between precipitation and discharge. It is also of geomorphological interest particularly for the development of slopes. Drainage density affects the runoff pattern, in that a high drainage density removes surface runoff rapidly, decreasing the lag time and increasing the peak of the hydrograph (Chorley, 1969). It is observed in the regions of impermeable subsurface material with mountainous relief. Higher drainage density is characteristics of impermeable but erodable lithology of the basin. On the other hand, low drainage densities indicate that most rainfall infiltrates the ground and fewer channels are required to carry the runoff. Low drainage densities are observed in regions underlain by permeable material with low relief.

The value of drainage density thus obtained shows that drainage density of fourth-order drainage basins of the study area range between 4.12 to 2.61km.km⁻² (Table 4.16). Almost uniform drainage density with small standard deviation (± 0.45) for the given drainage basins indicates common geological control on drainage development in the area. That lithology is a controlling factor is apparent from the fact that the drainage basin D4 showing lowest drainage density drains the central part of the study area and is characterized by unconsolidated sediment fills while D3 showing the highest drainage density drains through amphibolites (Khasi greenstones) and Precambrian metasediments (Shillong quartzite). The higher value indicates the more runoff than infiltration from precipitation, which also indicates the hilly terrain of consolidated material.

Table 4.16: Drainage density, drainage texture and drainage frequency of fourth-order drainage sub-basin.

Index	Sub-basin	Drainage density (km.km ⁻²)	Drainage frequency (km ⁻¹)	Drainage texture (km ⁻¹)
D1	Um Baniun	3.29	5.87	3.88
D2	Wah Umiam (tributaries)	3.98	7.52	3.72
D3	Umshirpi	4.12	6.88	5.23
D4	Wah Umkhras	2.61	3.87	3.62
D5	Wah Umkhen	2.83	3.90	3.56
D6	Wah Umkhen (tributaries)	2.94	4.32	2.37
D7	Wah Umbah	3.05	5.38	3.48
D8	Wah Shella	3.39	6.12	4.70
D9	Wah Tamdong	3.95	7.10	3.79
D10	Phud-Umsning (tributaries)	3.17	5.16	2.32
D11	Phud Mawiong	3.20	4.71	3.39

iii. Stream Frequency (Fs)

In the present study stream frequency ranges from 3.87 to 7.52. Stream frequency may be directly related to the lithological characteristics, since higher values were found in area occupied by consolidated and somewhat impervious quartzite of Shillong Group. Like the drainage density, stream frequency is a similar measure of stream network of a drainage basin. Table 4.16 shows close correlation between stream frequency with drainage density indicating the increase in stream population with respect to increase in drainage density. To evaluate the relationship between drainage density and stream frequency, a log-log plot of drainage density vs stream frequency is prepared. The regression line indicates the existence of direct relationship between the two parameters (Figure 4.6).

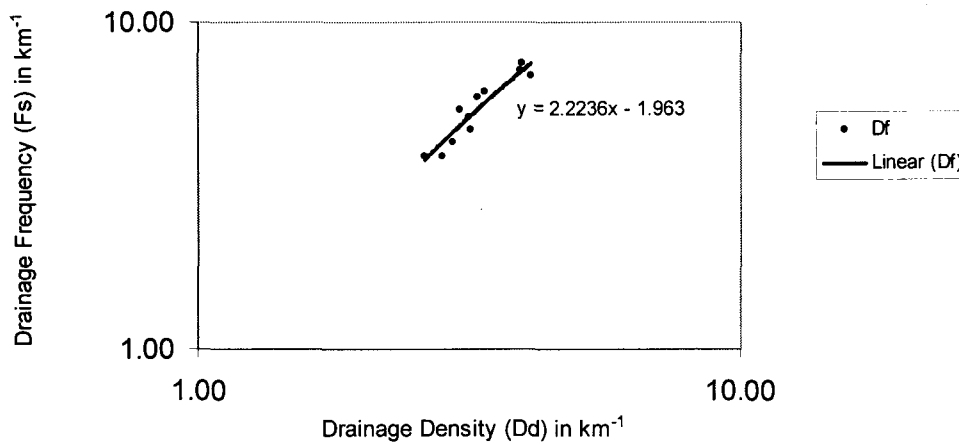


Figure 4.6: Log - Log plot of drainage density vs stream frequency

iv. Drainage Texture (Rt)

Horton (1945) recognized infiltration capacity as the single important factor which influences drainage texture and recommended the drainage texture to be included with drainage density and stream frequency. Smith (1950) has classified drainage density into five different textures i.e. very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8). In the present study all the drainage basins have coarse drainage texture except D3 which has moderate drainage texture (Table 4.16).

v. Shape parameters

Basin shape controls the geometry of the stream network and the basin shape itself is largely controlled by geological structure. The shape of the basin mainly governs the rate at which the water is supplied to the main channel. The evaluation of basin shape helps to predict the stream-discharge characteristics. Hydrograph characteristics to a large extent depend on the shape of the basin. The common shape measures viz., elongation ratio(Re),

circularity ratio(R_c), and form factor (R_f) are used for characterizing drainage basin shape which is an important parameter from hydrological point of view (Table 4.17). Unless pronounced structural control is present, drainage basins differ relatively little in shape, although they tend to become more elongated with strong relief and steep slopes (Chorley, 1969). Mutual relationship of these parameters can be evaluated from the plot as shown in Fig. 4.7. It is found that for a given drainage basin the elongation ratio, circularity ratio and form factor show a relationship of decrease in values the order being elongation ratio > circularity ratio > form factor. The three measures thus are conformable and suitable for defining basin shape.

Table 4.17: Shape parameters of forth-order drainage sub-basin

Index	Sub-basin	Elongation ratio (R_e)	Circularity ratio (R_c)	Form factor (R_f)
D1	Um Baniun	0.58	0.48	0.27
D2	Wah Umiam (tributaries)	0.71	0.58	0.40
D3	Umshirpi	0.69	0.46	0.38
D4	Wah Umkhrach	0.72	0.44	0.42
D5	Wah Umkhen	0.56	0.45	0.25
D6	Wah Umkhen (tributaries)	0.67	0.60	0.36
D7	Wah Umbah	0.65	0.46	0.33
D8	Wah Shella	0.61	0.50	0.29
D9	Wah Tamdong	0.51	0.28	0.21
D10	Phud-Umsning (tributaries)	0.74	0.47	0.43
D11	Phud Mawiong	0.70	0.52	0.39

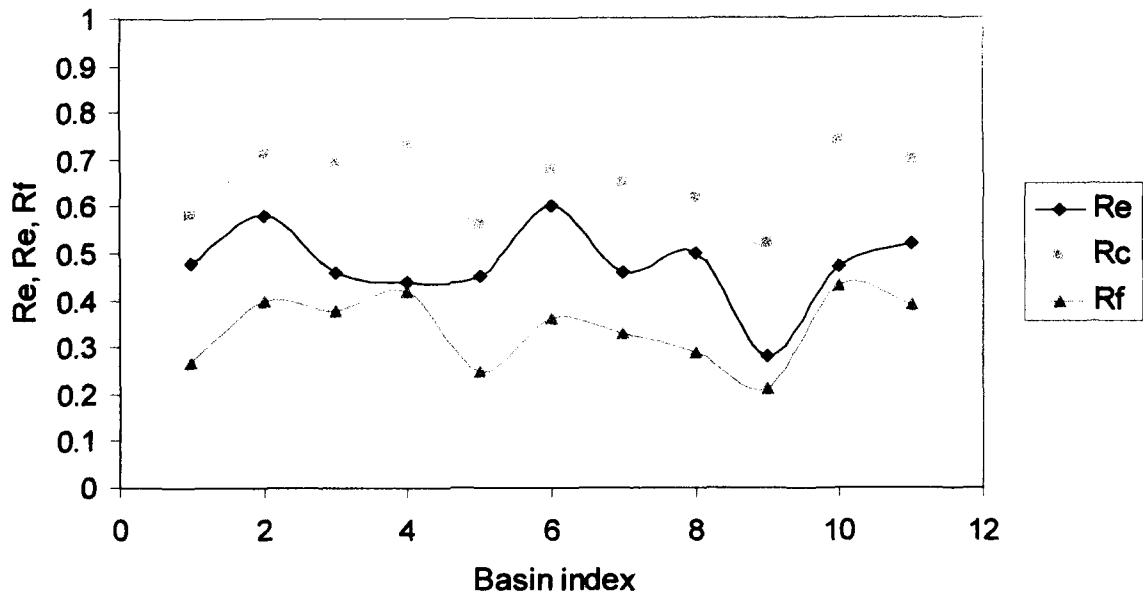


Figure 4.7: Relation between different shape parameters

Elongation Ratio (Re)

In general the elongation ratio values vary between 0 and 1.57. The value 1.57 represents a basin of an ideal circular shape, while the zero value describes a fully elongated basin. Values higher than 0.8 refer to basins that show a low relief, while values lower than 0.8 are associated with basins of a steep relief (Fairbridge, 1968). A circular basin is more efficient in run-off discharge than an elongated basin (Singh and Singh, 1997). The value of elongation ratio of 0.6 to 1.0 is associated with a wide variety of climate and geology. Values close to 1.0 are typical of regions of very low relief whereas that of 0.6 to 0.8 are associated with high relief and steep ground slope (Strahler, 1964). These values can be grouped into three categories, namely circular (>0.9), oval (0.8-0.9) and less elongated (<0.7).

The calculated values of elongation ratio for the fourth-order basins range from 0.51 to 0.74 (Table 4.17) and suggest an intermediate shape with a tendency to elongation associated with strong relief and steep slope. In the southeastern part the basins show a fully elongated shape. The basins in the central part show a stronger tendency to circular shape, while the northern basins show a slight tendency to circularity. It is remarkable that in southwestern part the basins show an intermediate shape with a tendency to elongation. This indicates that in the present situation, the elongation ratio values are mainly controlled by structural conditions and lithology. The elongated shape of the basins indicates a young stage of evolution while the intermediate shape with a tendency to circularity suggests an early mature stage.

Circulatory Ratio (R_c)

The value of circularity ratio (R_c) for quadrangular basins is approximately 0.8 and it decreases as the shape becomes more elongated. In the fourth order drainage basins under study the values of circularity ratio was found to vary between 0.28 (D9) to 0.6 (D6). The shape of the basins can be approximated by an intermediate one with a tendency to elongation. The observed combination of high elongation ratio and circularity values, especially in the southwestern and southeastern part, can be explained by the complicated shape of the basins. The complicated shape is the result of the presence of a combination of lithological formations, leading to differential erosion and consequently to watershed displacement. The circularity ratio shows somewhat lower values for the basins in northern part of the study area where there is strong structural control on the drainage development. Therefore, the structural control of drainage is probably responsible for the

low values of circularity ratio. To understand the relationship between bifurcation ratio and elongation ratio a regression line is constructed using these parameters which show a linear negative regression i.e. with increase of elongation ratio, bifurcation ratio decreases (Figure 4.8).

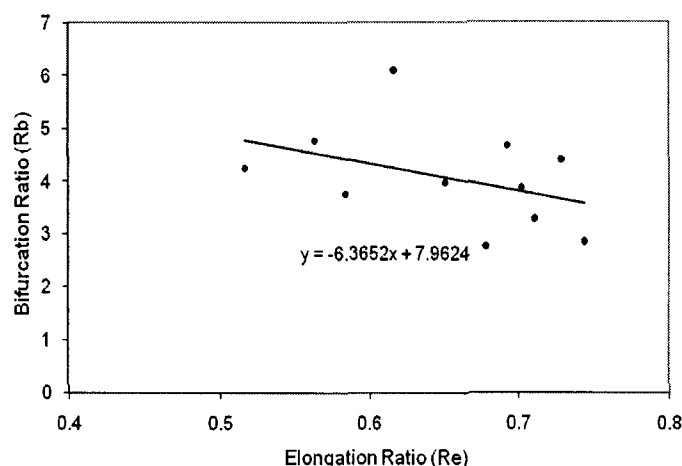


Figure 4.8: Graphical plot of elongation ratio vs. bifurcation ratio.

Form Factor (Rf)

Form factor is the numerical index commonly used to represent different basin shapes. The value of form factor would always be less than 0.78. Smaller the value of form factor, more elongated will be the basin. The basins with high form factors have high peak flows of shorter duration, whereas, elongated drainage basin with low form factors have lower peak flow of longer duration. It is observed that as the value of form factor decreases, the time base of hydrographs increases lowering the peak discharge value. Thus a drainage basin having low form factor is less likely to experience floods. Table 4.17 shows that the value of Rf varies from 0.21(D9) to 0.43 (D10). The values indicate

the drainage basin to be elongated in shape and suggest flatter peak flow for longer duration. Flood flows of such elongated basins are easier to manage than those of the circular basin. However, most of the basins are having low to very low form factor which is largely due to structural control on the drainage.

vi. Infiltration Number (If)

The higher the infiltration number the lower will be the infiltration and consequently, higher will be run off. This leads to the development of higher drainage density. It gives an idea about the infiltration characteristics of the basin. Table 4.18 shows that Wah-Umiam (t), has the highest infiltration number of 29.93 km⁻² indicating relatively lower infiltration and hence higher drainage density. Thus by inference, it may be said that high infiltration number will indicate high drainage density. It is observed that the minimum infiltration number (10.11 km⁻²) indicating maximum infiltration experienced by drainage basin D4 since it drains through valley filled sediments, while the sub basins draining the metasediments of Shillong Group show an invariably higher infiltration number.

Table 4.18: Computed values of infiltration number (If), length of overland flow (Lg), constant of channel maintenance (C) and Drainage density of fourth-order drainage sub-basin.

Index	Sub-basin	If (km ⁻²)	Lg (km)	C (km ⁻² .km ⁻¹)	Drainage density (km.km ⁻²)
D1	Um Baniun	19.31	0.15	0.30	3.29
D2	Wah Umiam (tributaries)	29.93	0.13	0.25	3.98
D3	Umshirpi	28.35	0.12	0.24	4.12
D4	Wah Umkhrah	10.11	0.19	0.38	2.61
D5	Wah Umkhen	11.04	0.18	0.35	2.83
D6	Wah Umkhen (tributaries)	12.70	0.17	0.34	2.94

D7	Wah Umbah	16.39	0.16	0.33	3.05
D8	Wah Shella	20.75	0.15	0.30	3.39
D9	Wah Tamdong	28.08	0.13	0.25	3.95
D10	Phud-Umsning (tributaries)	16.35	0.16	0.32	3.17
D11	Phud Mawiong	15.06	0.16	0.31	3.20

i. Length of overland flow (L_g)

It is an important independent variable, which greatly affect the quantity of water required to exceed a certain threshold of erosion. This factor relates inversely to the average slope of the channel and is quite synonymous with the length of sheet flow to a large degree. The length of overland flow bears an effective relationship with the drainage density and constant channel maintenance. Low drainage density indicates relatively long overland flow of surface water and possibilities of higher recharge. In the present study D4 has highest length of overland flow of 0.19 km, which has low drainage density and D3 the minimum value of length of overland flow of 0.12 km. In general, most of the elongated sub basins viz., D2, D3 and D9 show low value of length of overland flow (Table 4.18). Smaller the value of overland flow the quicker surface runoff will enter the streams. Therefore, in a relatively homogeneous area less rainfall is required to contribute a significant volume of surface runoff to stream discharge when the value of overland flow is small than when it is large.

ii. Constant of Channel Maintenance (C)

Schumn (1956) has used the inverse of the drainage density having the dimension of length as a property termed constant of channel maintenance. In drainage basins having

higher values of this parameter, there will be lower value of drainage density. Table 4.18 shows that Wah Umkharh has high constant channel maintenance of $0.38 \text{ (km}^{-2}.\text{km}^{-1}\text{)}$, which has the least drainage density, while Umshirpi has lowest constant channel maintenance of $0.38 \text{ (km}^{-2}.\text{km}^{-1}\text{)}$ which has the highest drainage density.

Relief aspects

i. Channel Gradient

The total drop in elevation from the source to the mouth of the trunk channels in each drainage basin were measured along the channels and tabulated in Table 4.19. As evident from the basin relief, the maximum ground slope of 120 m/km was found for the sub-basin D3 while D1 has the lowest gradient of 49 m/km.

Table: 4.19: Relief parameters of fourth-order drainage sub-basin.

Index	Sub-basin	Elevation of highest point on basin perimeter m	Elevation of lowest point at the mouth. m	Maximum basin relief. (H) m	Maximum basin length (Lb) km	Relief ratio (Rh)
D1	Um Baniun	1960	1640	320	6.53	0.04
D2	Wah Umiam (tributaries)	1780	1060	720	3.66	0.19
D3	Umshirpi	1960	1180	780	6.48	0.12
D4	Wah Umkrah	1700	1180	520	7.75	0.06
D5	Wah Umkhen	1880	1220	660	9.66	0.06
D6	Wah Umkhen (tributaries)	1680	1220	460	4.15	0.11
D7	Wah Umbah	1620	1120	500	5.88	0.08
D8	Wah Shella	1610	1160	450	7.03	0.06
D9	Wah Tamdong	1680	960	720	7.86	0.09

D10	Phud-Umsning (tributaries)	1640	1140	500	3.35	0.14
D11	Phud Mawiong	1680	1140	540	5.68	0.09

ii. Relief Ratio (Rh)

It measures the overall steepness of a drainage basin and is an indicator of intensity of erosion processes operating on the slope of the basin. Relief ratio normally increases with decreasing drainage area and size of a given drainage basin (Gottschalk, 1964). The relief ratio / mean surface slope of the fourth-order drainage basins vary between the values of 0.04 to 0.19 (Table 4.19). Basins consisting of Khasi greenstone, conglomerates, quartzite, weathered mantle and laterite soil cover show high values of relief ratio, while basins made up of quartzite and porphyritic granite show low values. The lowest values were observed in drainage basins with quartzite and porphyritic granite indicating that erosional processes took place. The high values of relief ratio in the southwestern part can be explained by the presence of highly resistant rocks underlying the basin.

iii. Ruggedness Number (HD)

Strahler (1968) described ruggedness number (HD) as the product of maximum basin relief and drainage density and it usefully combines slope steepness with its length. Extremely high values of ruggedness number occur when slopes of the basin are not only steeper but long, as well. For the present sub basins, the ruggedness number varies from 1.05 for D1 with moderate sloping area to 3.21 for D3 having higher elevation with gradual change in slope of uniform nature (Table 4.20).

Table: 4.20: Ruggedness numbers of fourth-order drainage sub-basin.

Index	Sub-basin	Maximum basin relief. (H) m	Drainage density (km.km⁻²)	Ruggedness no (HD)
D1	Um Baniun	320	3.29	1.05
D2	Wah Umiam (tributaries)	720	3.98	2.86
D3	Umshirpi	780	4.12	3.21
D4	Wah Umkhras	520	2.61	1.35
D5	Wah Umkhen	660	2.83	1.86
D6	Wah Umkhen (tributaries)	460	2.94	1.35
D7	Wah Umbah	500	3.05	1.52
D8	Wah Shella	450	3.39	1.40
D9	Wah Tamdong	720	3.95	2.84
D10	Phud-Umsning (tributaries)	500	3.17	1.58
D11	Phud Mawiong	540	3.20	1.72

Hypsometric analysis and its significance

The general classification of hypsometric curve has been carried out and a series of paired values, h/H and a/A has been obtained. The hypsometric curves have been drawn for all sub-basins (Figure 4.9-4.19). The values of the hypsometric parameters are given in (Table 4.21-4.31).

Table 4.21: Data used for drawing of hypsometric curve shown in Figure 4.9 (after Schumm, 1956)

D1: Um Baniun							
Highest point (m)	Lowest point (m)	Basin relief (H), m	basin area (A), km ²	Contour m	Area (a) km ²	Relative area (a/A)	Relative height (h/H)
1960	1640	320	11.41	1900	0.06	0.01	0.81
				1800	1.06	0.09	0.50
				1700	8.21	0.72	0.18
				1640	11.41	1	0

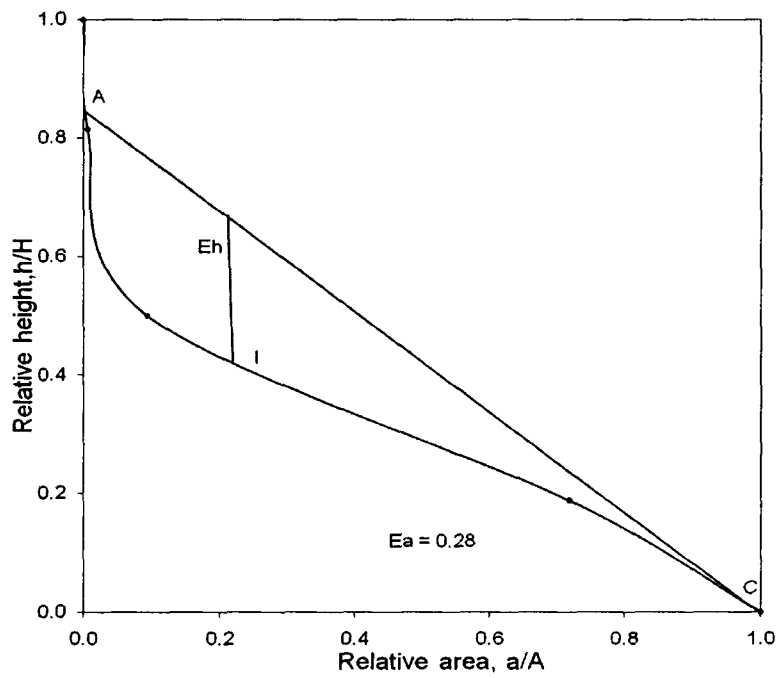


Figure 4.9: Hypsometric curve of Um Baniun sub-basin.

Table 4.22: Data used for drawing of hypsometric curve shown in Figure 4.10 (after Schumm, 1956)

D2: Wah Umiam (tributaries)							
Highest point (m)	Lowest point (m)	Basin relief (H), m	basin area (A), km ²	Contour m	Area (a) km ²	Relative area (a/A)	Relative height (h/H)
1780	1060	720	5.322	1700	0.62	0.11	0.88
				1600	2.20	0.41	0.75
				1500	4.59	0.86	0.61
				1400	4.99	0.93	0.47
				1300	5.13	0.96	0.33
				1200	5.25	0.98	0.19
				1100	5.31	0.99	0.05
				1060	5.32	1	0

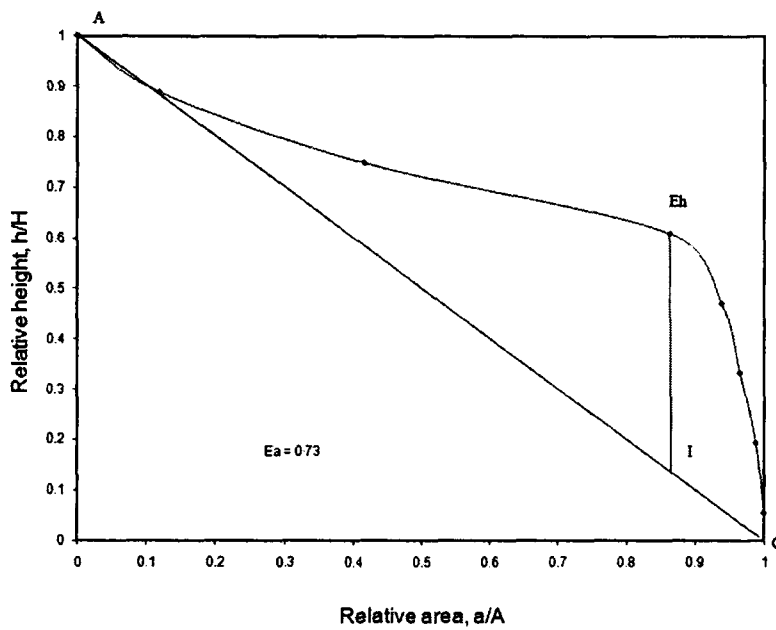


Figure 4.10: Hypsometric curve of Wah Umiam (t) sub-basin.

Table 4.23: Data used for drawing of hypsometric curve shown in figure 4.11 (after Schumm, 1956)

D3:Umshyrpi							
Highest point (m)	Lowest point (m)	Basin relief (H), m	basin area (A), km ²	Contour m	Area (a) km ²	Relative area (a/A)	Relative height (h/H)
1960	1180	780	15.842	1900	0.44	0.02	0.92
				1800	2.55	0.16	0.79
				1700	4.38	0.27	0.66
				1600	6.99	0.44	0.53
				1500	12.78	0.80	0.41
				1400	15.15	0.95	0.28
				1300	15.72	0.99	0.15
				1200	15.82	0.99	0.02
				1180	15.84	1	0

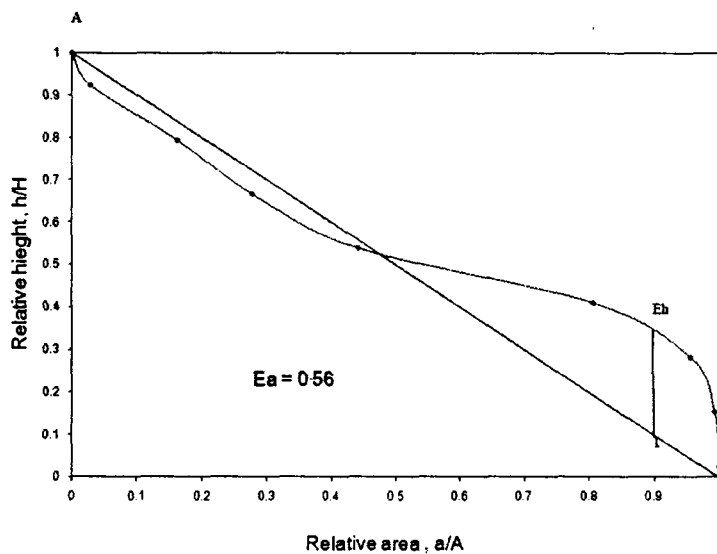


Figure 4.11: Hypsometric curve of Umshirpi sub-basin

Table 4.24: Data used for drawing of hypsometric curve shown in figure 4.12 (after Schumm, 1956)

D4:Wah Umkhrach							
Highest point (m)	Lowest point (m)	Basin relief (H), m	basin area (A),km ²	Contour m	Area (a) km ²	Relative area (a/A)	Relative height (h/H)
1700	1180	520	25.077	1600	0.33	0.01	0.80
				1500	10.47	0.41	0.61
				1400	24.66	0.98	0.42
				1300	25.01	0.99	0.23
				1200	25.02	0.99	0.03
				1180	25.07	1	0.00

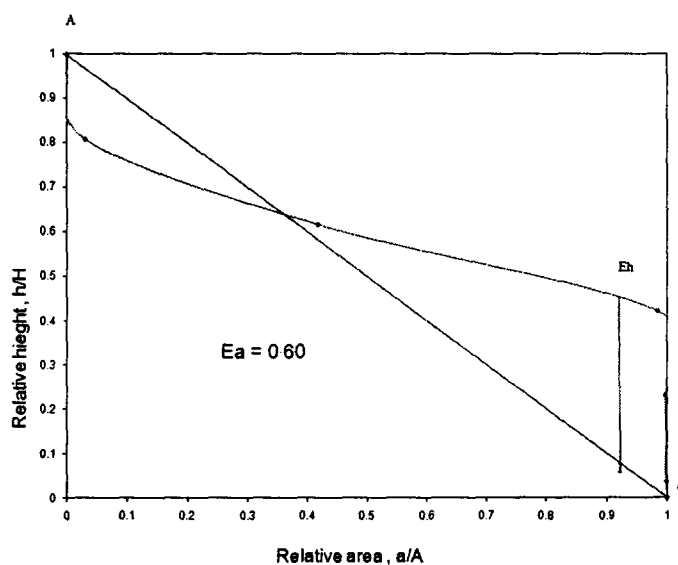


Figure 4.12: Hypsometric curve of Wah Umkhrach sub-basin

Table 4.25: Data used for drawing of hypsometric curve shown in figure 4.13 (after Schumm, 1956)

D5: Wah Umkhen							
Highest point (m)	Lowest point (m)	Basin relief (H), m	basin area (A), km ²	Contour m	Area (a) km ²	Relative area (a/A)	Relative height (h/H)
1880	1220	660	23.340	1800	3.12	0.13	0.87
				1700	7.276	0.31	0.72
				1680	15.34	0.65	0.57
				1500	20.10	0.86	0.42
				1400	22.07	0.94	0.27
				1300	22.93	0.98	0.12
				1220	23.34	1	0

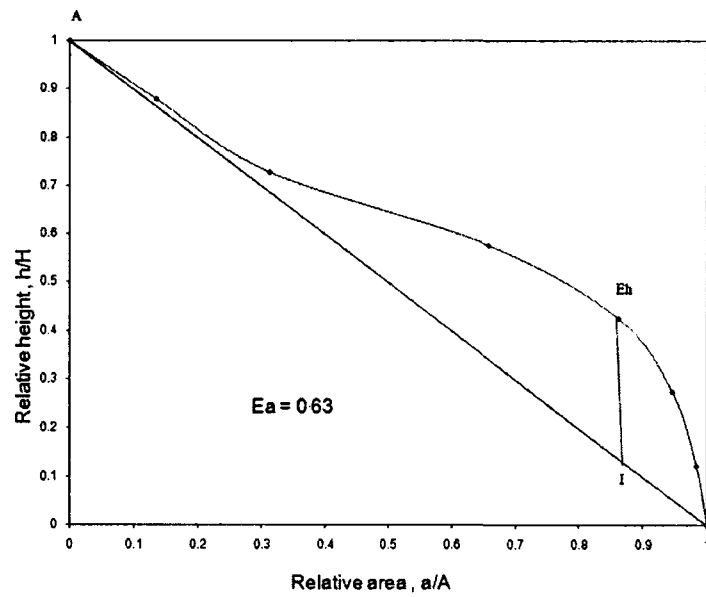


Figure 4.13: Hypsometric curve of Wah Umkhen sub-basin

Table 4.26: Data used for drawing of hypsometric curve shown in figure 4.14 (after Schumm, 1956)

D6: Um Khen(tributaries)							
Highest point (m)	Lowest point (m)	Basin relief (H), m	basin area (A), km ²	Contour m	Area (a) km ²	Relative area (a/A)	Relative height (h/H)
1680	1220	460	6.257	1600	0.64	0.10	0.82
				1500	3.56	0.57	0.60
				1400	5.51	0.88	0.39
				1300	6.14	0.98	0.17
				1220	6.25	1	0

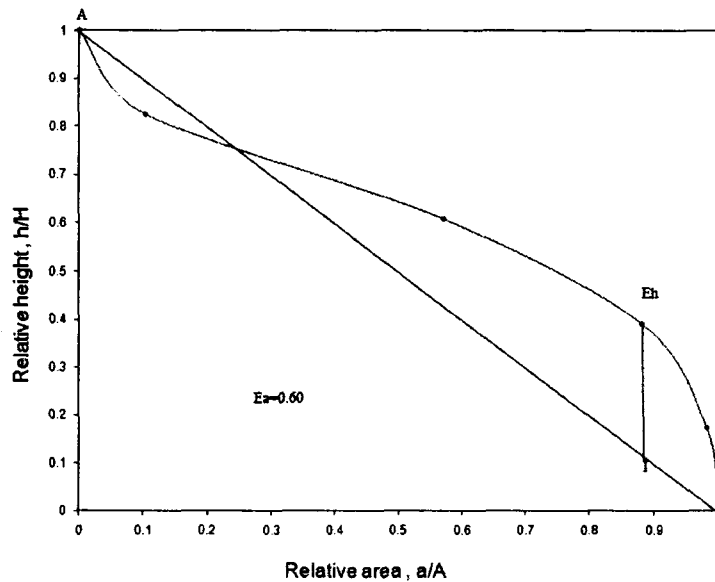


Figure 4.14: Hypsometric curve of Wah Umkhen(t) sub-basin

Table 4.27: Data used for drawing of hypsometric curve shown in figure 4.15 (after Schumm, 1956)

D7 - Wah Umbah							
Highest point (m)	Lowest point (m)	Basin relief (H), m	basin area (A), km ²	Contour m	Area (a) km ²	Relative area (a/A)	Relative height (h/H)
1620	1120	500	11.525	1600	0.22	0.01	0.96
				1500	2.62	0.22	0.76
				1400	5.16	0.44	0.56
				1300	9.10	0.79	0.36
				1200	11.21	0.97	0.16
				1120	11.52	1	0

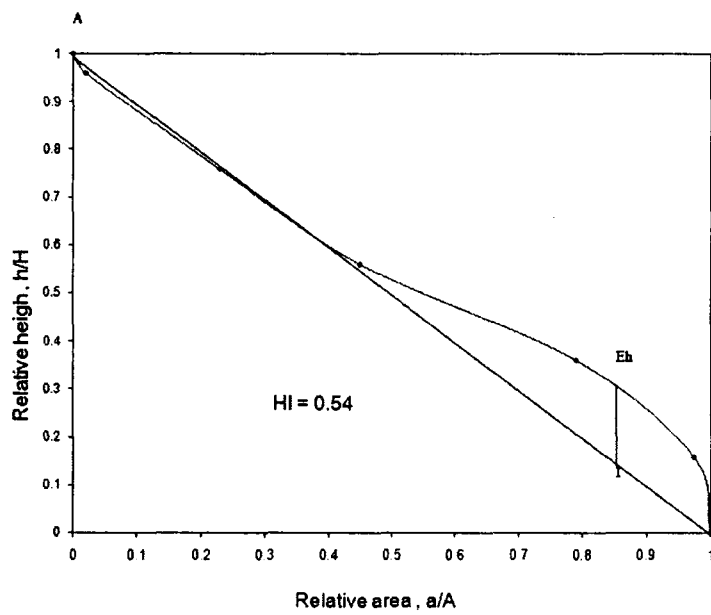


Figure 4.15: Hypsometric curve of Wah Umbah sub-basin

Table 4.28: Data used for drawing of hypsometric curve shown in figure 4.16 (after Schumm, 1956)

D8:Wah Shella							
Highest point (m)	Lowest point (m)	Basin relief (H), m	basin area (A), km ²	Contour m	Area (a) km ²	Relative area (a/A)	Relative height (h/H)
1610	1160	450	14.873	1600	0.25	0.01	0.97
				1500	0.82	0.05	0.75
				1400	3.62	0.24	0.53
				1300	9.07	0.61	0.31
				1200	14.65	0.98	0.08
				1160	14.87	1	0

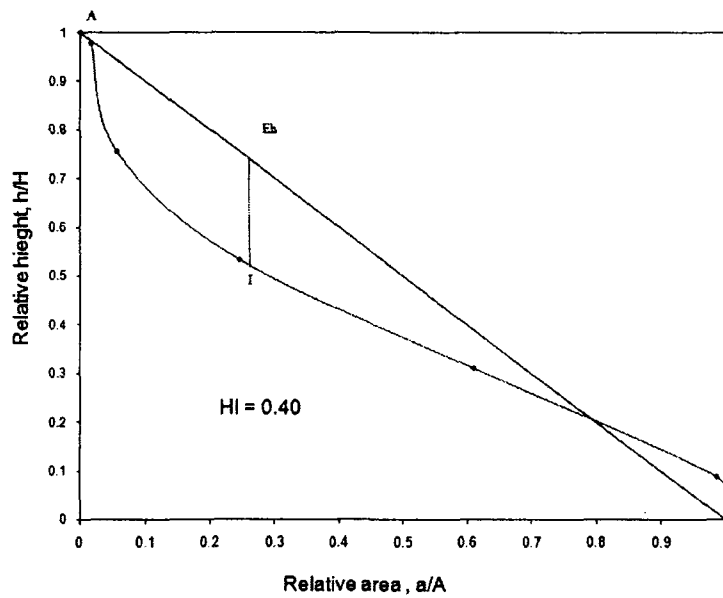


Figure 4.16: Hypsometric curve of Wah Shella sub-basin

Table 4.29: Data used for drawing of hypsometric curve shown in figure 4.17 (after Schumm, 1956)

D9: Wah Tamdong							
Highest point (m)	Lowest point (m)	Basin relief (H), m	basin area (A), km ²	Contour m	Area (a) km ²	Relative area (a/A)	Relative height (h/H)
1680	960	720	12.951	1600	0.14	0.01	0.88
				1500	0.42	0.03	0.75
				1400	1.56	0.12	0.61
				1300	3.23	0.25	0.47
				1200	5.51	0.42	0.33
				1100	7.59	0.58	0.19
				1000	10.07	0.77	0.05
				960	12.95	1	0

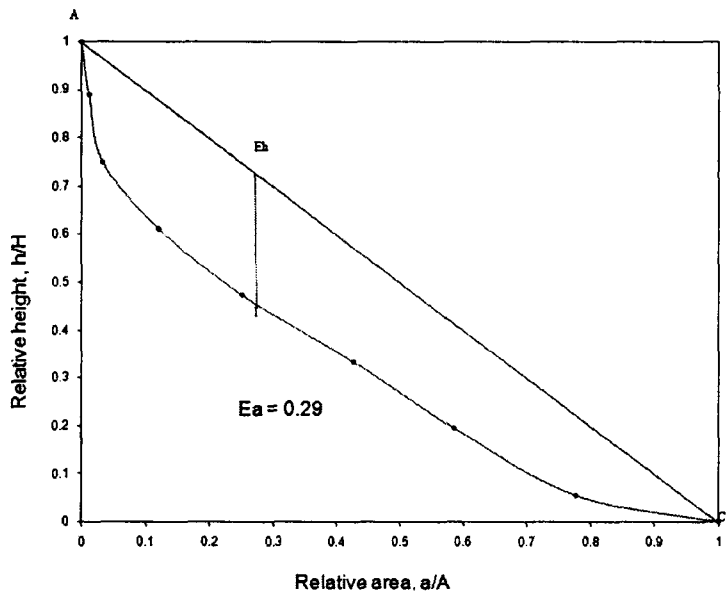


Figure 4.17: Hypsometric curve of Wah Tamdong sub-basin

Table 4.30: Data used for drawing of hypsometric curve shown in figure 4.18 (after Schumm, 1956)

D10-Phud-Umsning (tributaries)							
Highest point (m)	Lowest point (m)	Basin relief (H), m	basin area (A), km ²	Contour m	Area (a) km ²	Relative area (a/A)	Relative height (h/H)
1640	1140	500	5.422	1600	0.01	0.02	0.92
				1500	0.06	0.01	0.72
				1400	0.96	0.17	0.52
				1300	3.02	0.55	0.32
				1200	5.07	0.93	0.12
				1140	5.42	1	0

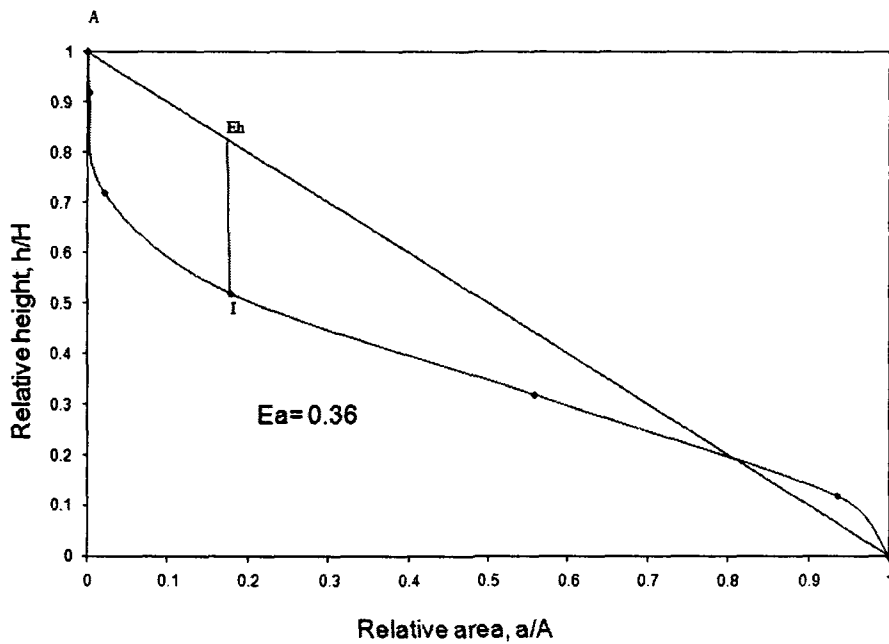


Figure 4.18: Hypsometric curve of Phud-Umsning (t) sub-basin

Table 4.31: Data used for drawing of hypsometric curve shown in figure 4.19 (after Schumm, 1956)

D11: Phud Mawiong							
Highest point (m)	Lowest point (m)	Basin relief (H), m	basin area (A), km ²	Contour m	Area (a) km ²	Relative area (a/A)	Relative height (h/H)
1680	1140	540	12.516	1600	0.14	0.01	0.85
				1500	0.71	0.05	0.66
				1400	4.21	0.33	0.48
				1300	9.73	0.77	0.29
				1200	12.31	0.98	0.11
				1140	12.51	1	0

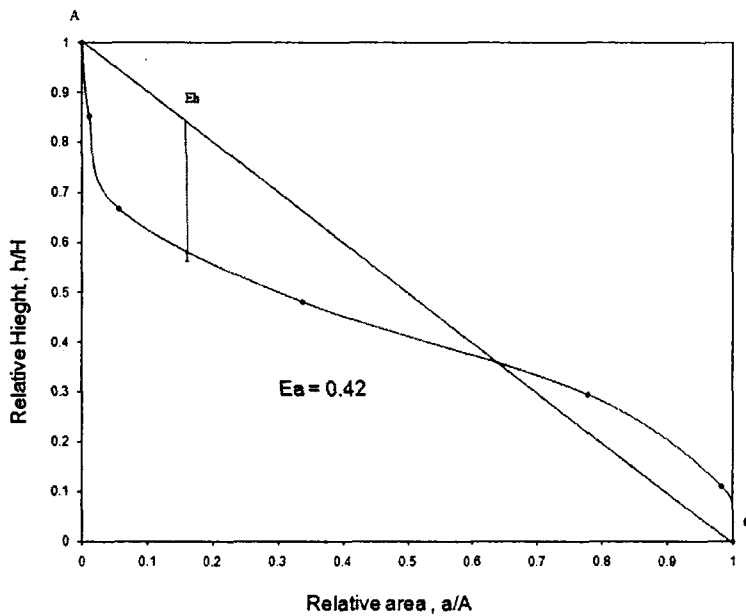


Figure 4.19: Hypsometric curve of Phud Mawiong sub-basin

Hypsometric parameters and their relation to landform evolution

Schumm (1958) described the stages of geomorphic development on the basis of hypsometric integral and classified them into three broad categories: youthful stage (60--100%), mature stage (35-59%), and old stage (below 35%). The hypsometric integral value is high in the youthful stage, it decreases as the landscape is denuded towards a stage of maturity and old stage. High values of the hypsometric integral indicate that most of the topography is high relative to the mean, such as smooth upland surface cut by deeply incised streams. Intermediate to low values of the integral are associated with more evenly dissected drainage basins (Keller and Pinter, 1996). The relationship between the hypsometric integral and the degree of dissection is used as an indicator of a landscape's stage in the cycle of erosion.

The hypsometric integral calculated for the fourth-order drainage basins varied from 0.28 to 0.73 (Table 4.32). This suggests an unevenly distributed dissection of the drainage basins. The nature of the hypsometric curves and relation between the hypsometric integral and degree of dissection indicates that the study area represent a youthful stage approaching to an early mature stage of evolution. The high hypsometric integral values of sub basins D2, D4, D5 and D6 represent the deep incised and high down cutting as well as the younger stage of development. The hypsometric integral is therefore a numerical description which may be used in the classification, and in the comparison of different landscapes. The values of hypsometric integrals and the form of the hypsometric curves taken together help to identify the stage of basin development.

Table 4.32: Hypsometric integral of fourth-order drainage sub-basins

Index	Sub-basin	Hypsometric integral (HI)	Hypsometric integral (%)	Remarks
D1	Um Baniun	0.28	28.25	Old stage
D2	Wah Umiam (tributaries)	0.73	73.75	Youthful stage
D3	Umshirpi	0.56	56.25	Mature stage
D4	Wah Umkhrah	0.60	60.25	Youthful stage
D5	Wah Umkhen	0.63	63.00	Youthful stage
D6	Wah Umkhen (tributaries)	0.60	61.00	Youthful stage
D7	Wah Umbah	0.54	54.00	Mature stage
D8	Wah Shella	0.40	40.00	Mature stage
D9	Wah Tamdong	0.29	29.00	Old stage
D10	Phud-Umsning (tributaries)	0.36	36.00	Mature stage
D11	Phud Mawiong	0.42	42.50	Mature stage

The shape of the hypsometric curve for the fourth-order drainage basins is variable. The sub-basins D7, D8, D10 and D11 have the shape of mature landform, sub-basins D1 and D9 approach monadnock type, while the curve of sub-basins D2, D3, D4, D5 and D6 show concave-down. Most of the resulted hypsometric curves show mature equilibrium stage namely, Umshirpi, Wah Umbah, Wah Shella (tributaries), Phud-Umsning (tributaries) and Phud Mawiong, whereas Wah Umiam (tributaries), Wah Umkhrah, Wah Umkhen and Wah Umkhen (tributaries) show relatively youthful stage with Um Baniun and Wah Tamdong approaching to Monadnock stage (i.e. old stage) of geomorphic development.

Table 4.33: Hypsometric parameters of fourth order drainage sub-basin

Index	Name of Sub-basin	Area (km ²)	Eh	Ea	I coordinate		Curve shape parameter				hm	U
					a*	h*	h(0.2)	h(0.5)	h(0.8)	h(0.9)		
D1	Um Baniun	11.41	.16	.28	.09	.5	.43	.28	.14	.07	.08	.80
D2	Wah Umiam (tributaries)	5.32	-.44	.73	.8	.2	.87	.73	.64	.1	.52	.79
D3	Umshirpi	15.84	-.25	.56	.85	.15	.74	.52	.43	.34	.43	.87
D4	Wah Umkhrach	25.07	-.40	.60	.95	.44	.70	.57	.49	.46	.32	.72
D5	Wah Umkhen	23.34	-.28	.63	.80	.20	.79	.63	.46	.35	.45	.82
D6	Wah Umkhen (tributaries)	6.25	-.29	.60	.85	.13	.78	.64	.45	.36	.32	.72
D7	Wah Umbah	11.52	.21	.54	.8	.18	.78	.52	.36	.25	.20	.66
D8	Wah Shella	14.87	.23	.40	.2	.57	.57	.37	.21	.15	.18	.78
D9	Wah Tamdong	12.95	.16	.29	.1	.51	.51	.27	.04	.01	.29	.90
D10	Phud-Umsning (tributaries)	5.42	.32	.36	.2	.5	.49	.34	.19	.13	.19	.83
D11	Phud Mawiong	12.51	.21	.42	.2	.62	.56	.4	.27	.19	.24	.82

Ea: hypsometric integral; Eh: hypsometric curve; U: uplift; hm: mean elevation.

The controlling factor for the shape of the hypsometric curve are hypsometric integral (Ea) and the concavity of the hypsometric curve (Eh). The curve provides clues to landform evolution (Sinha-Roy, 2002). The values for hypsometric integral and hypsometric curve vary for the sub-basins (Table 4.33). The Ea values of the sub-basin have been categorized into three groups based on the obtained values namely: Group 1 (average Ea = 0.62, for sub-basin D2, D3, D4, D5 and D6), Group 2 (average Ea = 0.43, for sub-basin D7, D8, D10 and D11) and Group 3 (average Ea = 0.028, for sub-basin D1 and D9). For matured and old landforms Eh is positive, but in immature and young landforms Eh is negative (Sinha-Roy, 2002). It was found that the sub-basin grouped on the basis of Ea corresponds exactly to those grouped on the basis of Eh. Group 2 and Group 3 sub-basin show average Eh values of 0.22 and 0.16 respectively, while Group 1

curves are concave – down showing negative Eh values. These values suggest that sub-basins D2, D3, D4, D5 and D6 are least incised, and sub-basin D7, D8, D10 and D11 are least eroded with most erosion prevails in sub-basins D1 and D9.

The position of the slope inflection point (I) for the sub-basins are given by a^* and h^* on the hypsometric curves. The hypsometric parameter a^* reflects the erosion characteristics of the catchment such that lower the value of a^* greater is the extent of subdued topography approaching Davisian style peneplain (Sinha-Roy, 2002). Also, lower the value of h^* higher is the degree of peneplanation. The obtained value for a^* and h^* on the hypsometric curves shows variation, which indicates a variability in the landform pattern and their evolution within the sub-basin. Therefore, the sub-basins are grouped on the basis of a^* values, namely Group 1 (average $a^* = 0.85$, for sub-basins D2, D3, D4, D5, D6 and D7), Group 2 (average $a^* = 0.2$, for sub-basins D8, D10 and D11) and Group 3 (average $E_a = 0.095$, for sub-basins D1 and D9). The degree of peneplain is highest in Group 3 followed by Group 2 with least in Group 1 sub-basin. Therefore, the value suggest that sub-basins D1 and D9 are in a state of declining equilibrium caused by strong erosion and formation of vast pediplain, hence suggest Davisian style peneplain of the sub-basin landscape referring to their lower h^* value .

The shape of the hypsometric curve has been analyzed by calculating the values of h (0.2), h (0.5) and h (0.8) (Table 4.33). Higher the value of h (0.2) i.e., higher hypsometric head indicates greater influence of diffusive processes at the upper reaches of the sub-catchment. On the other hand, the higher the value of h (0.8) the greater is the mass accumulation at the subcatchment mouth derived mainly through fluvial (advective)

transport (Sinha-Roy, 2002). It is observed that from the derived values for h (0.2), h (0.5) and h (0.8) Table 3.16, it is found that sub-basins D1 and D9 show the least effect of diffusive process with average value of 0.47 for h (0.2) and fluvial erosion has added minimum mass at the respective sub-basin with average value of 0.09 for h (0.8). Conversely for sub-basins D7, D8, D10 and D11 with average value of 0.06 for h (0.2) show moderate diffusive erosion in the upstream segments and consist large mass accumulation at the sub-basin mouth with average value of 0.26 for h (0.8).

The calculated empirical relation between uplift (U), mean elevation (hm) and the hypsometric integral (E_a) gives the value of the relative uplift parameter for the sub-basin (Table 3.16). The resulted values of U for the sub-basins range from 0.66 to 0.90 suggesting moderate to low uplift of the terrain and a spatial variation in neotectonically controlled uplift magnitude. Uplift is a parametric measure of the elevation increase in excess of denudation since the time the present drainage system came into existence and that it does not indicate the absolute magnitude of tectonic uplift (Sinha-Roy, 2002). The value of U varied from 0.78 to 0.90 (Table 4.33). Most of the basins fall on the SW and SE corner of the study area covering a large part of Shillong peak and Laitkor range suggesting that uplift in the SW and SE corner is the highest. Sub-basins D4, D6 and D7 have low range of U value (0.66 – 0.72) suggesting low uplift or mild subsidence, these sub-basins are located towards the NE corner of the study and the basins are located in the valley filled areas. Therefore, it can be concluded that the SW and SE part of the area is the major uplift block while the NE segment has generally subsided.

Longitudinal Profile of the River Channel

Longitudinal profile constructed for each basin under the study area is shown in Figure 4.20. In the present study Um Baniun shows long profile of low concavity indicating increase of bed size materials downstream (Hack, 1957). The differences are caused by the difference in lithology of the tributaries stream as the area is underlain by Shillong quartzite and Myllem granite. In the upstream reaches Shillong quartzite makes up only a small part of the bedload and downstream the major part is constituted by Myllem granite. The long profile of Wah Umiam (t) shows an interrupted profile marked by rapids and waterfall. In the upper reaches the profile is of smooth and uniform nature as in this part the river flows through an area of Shillong quartzite. But after 3.85 km there is knickpoint where the channel slope has steepened abruptly marked by a waterfall of about 37 m and the main stream is intersecting a linear feature at this point. The knickpoint is developed as a result of accelerated erosion at structurally weak zones. From this point besides Shillong quartzite, the main stream is also fed by eroded materials of Khasi greenstone from the tributaries stream. Umshirpi, one of the principal streams draining Greater Shillong are originates from Shillong peak. The longitudinal profile of the river reflects accelerated rate of erosion in the upper and middle reaches and the lower reach is adjusted to the geology of the area. The upper and middle reaches are underlain by Shillong quartzite. From Shillong Peak it shows gradual change in slope with uniform nature but near Raid Laban reserve forest it flows through a scarp face demarcated by a knickpoint and on reaching Shillong town it flows in a gentle slope. The upper course has been affected by changes in the base level during the geologic history of the river. This is due to the headward limits of successive period of base leveling in

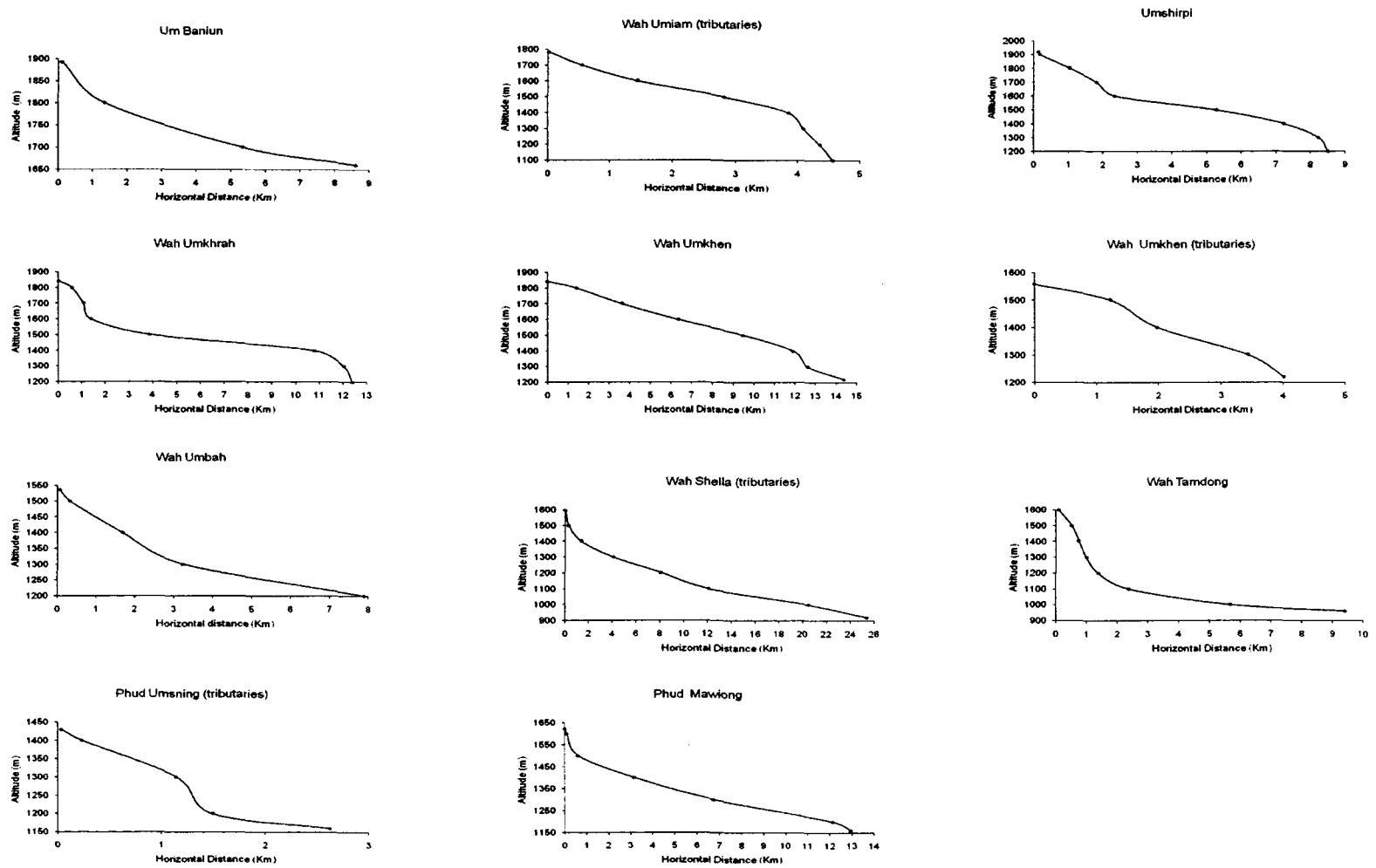


Fig 4.20: Longitudinal profile of fourth order sub-basins of the study area.

multicyclic valleys of homogenous rocks (Thornberry, 1973). In the lower end the profile steepens abruptly and becomes a series of rapids and falls namely, the Gunner falls of about 24m and the Bishop falls of 122m, which is an offset fault across the general strike. In this reach the river passes through the resistance of Khasi greenstone and conglomerates of the Shillong group of rocks. Major differences in the materials along the course of a stream commonly cause an abrupt change in the profile as seen in Wah Umkhrah. In its upper reaches the river is floored by Shillong quartzite, a knickpoint in the upper end represents the Spread Eagle falls (20 m) near Umpling. At 3.5 km it enters the valley filled sediments area and the profile abruptly changes in character gradually become flat. In this part the river flows through the Shillong town up to Mawlai. At 10.85 km at Mawlai the river again enters Shillong quartzite and again the profile abruptly changes and shows a steep slope. At this point the river is also offset by a fault. At 12.2 km the river is floored by Khasi greenstone and conglomerates of the Shillong group where it joins Umshirpi river and meets the main tributary Phud-Ro Ro river through the Beadon falls. Wah Um Khen profile is close to a straight line with gentle slope in the upper and middle reaches and characterized by knickpoint in the lower reach. Throughout the course, Shillong quartzite is brought in by the tributaries to make the bed material of the river. In between Laitkor and Madanriting, Khasi greenstone crops out at few places in the stream and makes up a small portion of the bed materials. The river flows through an area of hard rock terrain of Khasi greenstone and Shillong quartzite. The river Um Khen flows through an axis of a fold. Throughout this course, cobbles and pebbles of Khasi greenstone and Shillong quartzite are brought in by tributaries to make up the bed materials. Due to down cutting of the river course, the scarp faces are developed in the both side of the

river. The knickpoint in the lower end of the profile is represented by the Sweet falls (199m).

In contrast, the profile of Wah Um Khen (t), shows upconvexity. There is no apparent change in lithological condition from the neighboring basins. Any significant structural anomaly is also not recorded. The upconvexity can be explained by increase in the rate of particle size downstream (Hack, 1957). The river long profile for the trunk channels of Wah Umbah and Wah Shella shows smooth up-concavity. Due to the downstream increases in the channel's width and depth and the general tendency of decrease in of the bed-particles size, the gradient generally flattens (Leopold, 1964). Therefore, the longitudinal profile of Wah Umbah and Wah Shella is concave to the sky. These rivers are structurally controlled and flow along the main structural trend and are not subjected to offset in their courses. Besides, the basin is underlain by uniform lithology throughout the course characterized by Shillong quartzite. The Wah Tamdong and Phud Mawiong trunk channel show smooth upconcavity profile. Both rivers flow in a strike valley jointed by tributaries draining Shillong quartzites area. Along its course the tributaries provide a continuous source of uniform size of bed materials downstream. The uniformity in size of the bed materials suggests that the stream has uniform competency along the course because of bed rock geology of the basin. Phud-Umsning (t) river is characterized by a knickpoint, which represents a scarp face at a distance of about 1.2 km from the point of origin. From the field verification it is clear that the scarp face is developed due to the offset faulting across the strike of the beds. In general the longitudinal profiles of the study area shows major structural controls. Most of the rivers show knickpoints, waterfalls suggestive of profile adjustments. This may be attributed to the continuous tectonic activities.

CHAPTER 5

WATER RESOURCES

Introduction

Water is essential for sustenance of life on earth. Its sustained supply is needed for socio-economic development and for maintaining healthy ecosystems. The water resources can be divided into two categories: surface water and sub-surface water. Surface water encompasses rivers, streams and lakes and sub-surface water includes spring and ground waters. As population increases and development calls for an increased allocations of groundwater and surface water for the domestic, agriculture and industrial sectors. The increasing stress on freshwater resources brought about by ever rising demand as well as by growing pollution worldwide, is of serious concern. Water use has been growing at more than twice the rate of population increase in the last century. Most countries in the Near East and North Africa suffer from acute water scarcity, as do countries such as Mexico, Pakistan, South Africa, and large parts of China and India (UN-Water,2006). In order to sustain their needs, these countries need to focus on the efficient use of all water sources groundwater, surface water and rainfall. Good city water management is complex and tedious to achieve. It requires an integrated management of water supplies for domestic and industrial needs, the control of pollution and the treatment of wastewater, the management of rainfall runoff (including stormwater) and prevention of flooding, and the sustainable use of water resources. To maintain the availability of water all needful efforts are being made in the field of research and development to meet the demand for domestic,

agricultural and industrial uses (Bhaisare and Goel, 1992). Remote sensing helps in management of water resources in view of their availability (qualitative and quantitative) and its ever-increasing demand for drinking, irrigation and industrial sectors (Trivedi et.al. 2005). Earlier studies indicate that remotely sensed data and GIS techniques are vital tools for delineation and evaluation of surface water and groundwater potential zones of an area (Chaterjee and Bhattacharya, 1995; Krishnamurthy and Srinivas, 1995; Krishnamurthy et al., 1996; Tiwari and Rai, 1996; Ravindran and Jeyaram, 1997; Saraf and Choudhary, 1998; Srivastava and Bhattacharya, 2000; Sarkar et al., 2001; Khan and Moharana, 2002, and Sankar, 2002).

The present study is an attempt to account the quantity of water supply from ground water and surface water based on limited secondary data available and also to check the qualitative aspects of the available water sources for domestic purposes. An attempt is made to develop a ground water prospect zone map through the convergence of evidence method by integrating collateral data, satellite image analysis and field inputs.

Review of Literature

Gupta and Ganesh Raj (1992) have carried out groundwater prospective zone mapping of the entire Pavagada taluk covering 1,350 km² area in Tumkur district (Karnataka) on 1:63,360 scale using Landsat TM and have delineated various hydromorphogeologic units through visual interpretation and possibilities of quantification of yield estimates based on borewell data of these zones. Their study indicated that valley fill zone is the best groundwater potential zone and pediplains in

general have poor yield potential in the area. Study on geological, geomorphological and hydrochemical analysis to understand the hydrogeomorphological conditions and hydrochemistry of Ghoradongri watershed of Betul district of Madhya Pradesh was carried out by Trivedi et.al. (2005). The occurrence of groundwater in the hard rock terrain was found confined to secondary permeable structures, i.e. fractures and weathered zone and in upper unconsolidated materials (Srinivasa Vittala et.al. 2005). Exploration and utilization of groundwater especially in hard rock terrain, requires thorough understanding of geology, geomorphology and lineaments of an area, which directly or indirectly controls the terrain characteristics (Pradeep, 1998). Delineation and characterization of groundwater potential zones of nine sub-watersheds of North Pennar basin, Tamkur district, Karnataka was carried out by Srinivasa Vittala et.al. (2005) using remote sensing and GIS techniques based on slope, lithology, hydrogeomorphology, lineament and borewell data parameters. They concluded that nearly level, very gentle and gentle sloping areas are better than the much steeper hilly areas from the groundwater point of view. Groundwater is dynamic and replenishable natural resource but in hard rock terrain availability of groundwater is of limited extent and its occurrence is essentially confined to fractured and weathered zones (Saraf and Choudhury, 1998). Singh et.al. (1997) delineated the aquifer in a micro-watershed in a granitic terrain through detailed hydrogeological investigations and found that in the granitic terrain, groundwater occurs in shallow weathered and fractured zones. Lokesha et. al. (2005) made a quantitative evaluation of groundwater potential zones in the Cauvery and Kabini rivers valleys in Mysore district, using IRS data and GIS techniques in relation to field surveys. They concluded that factors such as geomorphology, lineaments, drainage density, lithology and surface water bodies directly influence the ground water conditions. Good ground water prospect was

found in the valley region compared to the remaining area whose yield was moderate to poor. Baruah et. al. (1993) conducted a hydrogeomorphological study in parts of Goalpara district, Assam. They discussed the geomorphic forms and their relevance to groundwater occurrences, and suggested that tea plantation areas and valley fills should be taken for exploratory drilling. Nag (2005) conducted a study on the hydrogeomorphology and lineament using remote sensing and GIS technique, for detecting the most suitable zone for groundwater occurrence in the Baghmundi Block, Purulia district, West Bengal. From the suitability map excellent groundwater potential zone was found around Ayodhya village due to presence of planation surface along valley fill within this area. Ray et.al. (1993) demonstrated the potential of GIS techniques in integrating remote sensing and field inputs for hydrological investigation in a drought prone area of Eastern Singhbhum. They opined that the methodology can be accepted as a standard for hydrological investigations targeting prospective zones. Burman (1993) highlighted the contribution of remote sensing techniques as an integral part of hydrogeological investigation in the greater Guwahati area for delinating most prospective ground water potential belts as well as surface water sources for augmentation of urban water supply. Subba (2001) reported that hill towns in the Darjeeling and Shillong located in the wettest corner of the Indian subcontinent, face water scarcity all year round. Ravindran and Manchanda (1993) evaluated groundwater and surface water potentials in JNU campus, New Delhi using remote sensing technique in conjunction with ground surveys to locate the sites for ground water exploration and rain water harvesting. The study recommended long term and short term measures for better management of water within the campus. Merz et. al. (2004) documented qualitative and quantitative aspects of the public water supply for domestic purposes in the Jhikhu Khola and Yarsha Khola watersheds

and related the issues to other watersheds in the Hindu Kush–Himalayan region. They found that the water quantity and quality concerns in the two watersheds of Nepal were not isolated cases but similar problems were reported from other watersheds in China, India and Pakistan.

In urban areas, most impairment of water resources are the direct results of local human activities such as water consumption, waste production, construction of building and traffic system, and the engineering of rivers. Wagner et. al. (2002) identified the most relevant sustainability deficits and derived general vectors for more sustainable water management based on the results and observations of watershed case studies, in Japan, United States, Switzerland and Brazil. They found that differing historical and cultural backgrounds, extent of development, varying perception of water management activities, and differing uses of natural ecosystems have necessitated formulation of different social, political and economic strategies to handle water issues. Huang and Ferng (1990) studied seventy eight third order watersheds and grouped them into five watershed zones representing varied assimilative capacities and relative societal priorities of water quality management. In order to prioritize potential source of ground water pollution in Idaho, water quality planners in the state developed a decision analysis technique which numerically identified the most important pollution sources. The results of this process were subsequently used as a starting point to develop and implement the groundwater protection programs of the state (Shook and Grantham, 1993). Srinivasa Rao. et.al, (1997) used multiple regression analysis to assess the groundwater quality in relation to agricultural and domestic uses in a part of the Peninsular Archean granite and gneissic complex of India. They found that the groundwater is suitable for both agricultural and domestic uses, with high concentration of nitrates observed in some

of the wells that are affected by the impact of industrial effluents. Joji et. al. (2001) worked on geomorphology and terrain characteristics of Vamanapuram river basin, southern Kerala, India with special reference to ground water potential zones in the basin. The qualitative studies revealed that ground water in the different geomorphic units contain chemical constituents that were within the maximum permissible limit prescribed by the WHO and Bureau of India Standards, and the water was suitable for drinking purposes. According to Sim and Balamurugan (1991) the urban water problems in southeast Asian cities are viewed as the consequences of rapid and uncontrolled urbanization and unsustainable development. In the long term, given the ever-increasing urbanization and population growth, the urban water problems in southeast Asia are expected to escalate rather than attenuate unless serious planning and management are carried out. Land classification, based on integrated land and water quality, has been found to be a useful tool for land management practices aimed at enhancing surface water quality. Multi-variate techniques (factor analysis, cluster analysis, discriminate analysis) have been used for taxonomic land classification based on watershed units (Wang, 2001).

Results and Discussion

Scenario of water supply and production in Greater Shillong Planning Area (GSPA)

Greater Shillong Planning Area (GSPA) is a rapidly growing urban centre. Water scarcity is common across the urban complex even though it receives a very high rain fall of the order of 2400mm/ year. GSPA has been exclusively relying on surface water, but during recent years it has started using groundwater to meet the requirements of growing population. The total potable water supply quantum is obtained from numerous springs and a few low discharge streams, formed due to seepage of inland water. Besides private bore wells or hand pumps are also being used extensively for water supply in the area. These water sources are controlled and taken care by several institutions such as the Shillong Municipal Board (SMB), Public Health Engineering Department (PheD), Shillong Cantonment Board (SCB) and local Dorbars, who are responsible for providing the water supply service. The SMB and PheD provide the bulk of the water supply services. In order to meet long-term projection of water demand, a dam was constructed under Greater Shillong Water Supply Scheme (GSWSS) in 1978 to divert water from Umiew River located 25 km from the main city.

The Shillong Municipal Board (SMB) obtains water supply from several surface water sources such as springs and streams which were identified long back probably when the town was established. These surface water sources include Wahrisa, Wahjalynoh, Umjasai, Crinoline, Madan Laban, Patta Khanna and Wahdienglieng. For example the water supply scheme from Umjasai stream was undertaken in the year 1958 and since then water is being distributed in the municipal area without any treatment. It was observed that these sources are utilized for water supply either by

construction of a pumping station and thereby supplying water through the pipes, or by inserting the pipe directly into the spring source. The former method is adopted where there is conspicuous discharge of the spring. The quantity of water produced from these sources for pre-monsoon and monsoon period is given in Table 5.1.

Table 5.1: Quantity of discharge from SMB sources

Sl. No.	Name of the Source	Discharge	
		Premonsoon (mld)	Monsoon (mld)
1	Wah Risa	0.45	0.64
2	Wah Jalynoh	0.45	0.64
3	Umjasai	0.91	1.14
4	Crinoline	0.36	0.5
5	Madan Laban	0.23	0.36
6	Patta Khanna	0.11	0.23
7	Wahdienglieng	0.23	0.29
	Total	2.74	3.8
	Average	3.27 mld	

Source: Shillong Municipal Board

The average quantity of water produced per day is 3.27 mld (million liter per day) from these sources and it is distributed within Shillong Municipality area. Table 5.2 gives the names of the localities covered by each source.

Table 5.2: Names of Localities covered by different water sources

Sl. No.	Water Source	Localities Covered
1	Wah Risa	Malki, Dhankheti, Secretariat Hill, Keating Road and Lumparing
2	Wah Jalynoh	Bishnupur, Rilbong, Kench's Trace & Oxford Hills
3	Umjasai	Mawkhar, Mawprem, Jaiaw, Umsohsun, Qualapatty, Lamavilla, Dymmiew, Mission, Wahingdoh, Riatsamthiah, Mawlai Nongmali, Forest Colony and Sunny Hills .
4	Madan Laban	Greater Laban
5	Crinoline	Nongmalki, Secretariat Hills, Sweeper Line, Robert Hospital,

		T.B. Hospital and Civil Hospital
6	Pata Khana	Madan Laban and some parts of Laban area
7	Wahdienglieng	Lummawrie, Cleve Colony and part of Nongrim Road

Source: Shillong Municipal Board

Sources of water supply which were implemented and maintained by PheD or implemented by PheD but maintained by the local committee are given in Table 5.3. These sources provide water only for townships viz., Shillong Cantonment, Nongthymmai, Mawlai, Madanrting, Pynthorumkhrah and Nongmynsong. Average production from these sources is 5.69 mld out of which 3.64 mld is contributed by surface sources and 2.05 mld from underground sources.

Table 5.3: Quantity of water supplied by PheD under various water supply schemes

Sl. No.	Name of the Scheme	Quantity (mld)
1	Mawlai Umsohlang WSS	1.95
2	Pynthor Umkhrah DTW WSS	0.65
3	Pynthorbah Lum Shiap DTW WSS	0.75
4	Umkhen WSS	0.99
5	Lawjynrew, Lumiawblot, Pohkseh, Demthring WSS	0.50
6	St Edmunds(Lumawrie) DTW WSS	0.04
7	Madanrting WSS	0.20
8	Wahdingdoh(Jingthangbriew) DTW WSS	0.08
9	Jaiaw Laitdom DTW WSS	0.16
10	Nongmynsong DTW WSS	0.24
11	U Tirot Singh Nagar-Lumshngain DTW WSS	0.13
	Total	5.69

Source: Public Health Engineering Department

In areas beyond the SMB and PheD networks water supply service is being provided by the local dorbar by implementing small water schemes supplying through stand posts such as localities of Nongpuir, Lumpyngngad, Demthring, Lumdiengsoh, Wahdienglieng and Madanrting. Small local springs also serve as source of water

supply used by nearby residents in Pynthorbah, Mawlyngngad and Itshyrwat. Households without access to institutional services depend upon supply made by water tankers or purchase water from private vendors/ operators or draw water from private bore wells or hand pumps.

Accounts of water

The revised guidelines/norms on water supply by the Govt. of India, prescribes supply of 135 lpcd and 40 lpcd for the urban and rural population. According to this guideline 51.70 mld is required for a population of 382986 (Phed, 2006). SMB and PheD water supply accounts for 8.96 mld, thus the town has a net deficit of 42.74 mld. This deficit is compensated by balancing through imports from Umiew river through Greater Shillong Water Supply (GWSS). The average production capacity of the dam is 31.78 mld out of which 19.72 mld is supplied to GSPA (Phed, 2006). At present a total of 28.68 mld (Table 5.4) is being supplied to the consumers which is hardly sufficient to meet the growing demands of water. Therefore the total water production from GSPA is around 24.09% from surface water and 07.16% is pumped from groundwater and remaining 68.75% is imported from Umiew river (Figure 5.1). GSPA reliance on Umiew river water source is evident. Without this external source, the city's rapid development would have been impossible, since consumption has exceeded total local water supply. Besides the supply from Umiew river a deficit of 14.06 mld is experienced or in other words 70 lpcd is available to the consumers which is very much below the required norms. With the current trend of reduction of discharge of the water sources as reported by local residents during interviews, the small spring sources are likely to be dried up thus reducing the yield considerably in the coming decades. In such situation there will be almost total dependence on Umiew river.

Table 5.4: Water availability in Greater Shillong Planning Area

Sl. No	Source	Discharge (mld)	%
1	Surface water from sources within city	6.91	24.09
2	Ground water from sources within city	2.05	07.16
3	Umiew River	19.72	68.75
	Total	28.68	

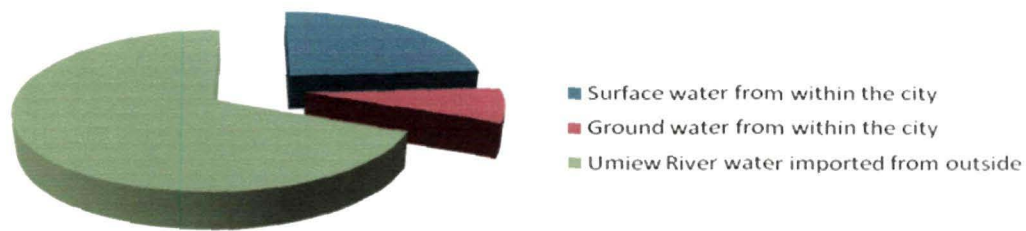


Figure 5.1: Total water availability for Greater Shillong Planning Area

Groundwater prospective zones in the study area

Geological and geomorphological studies indicate that occurrence and distribution of surface water and ground water of Shillong Master Plan Area is not uniform due to inhomogeneity of lithology and degree of weathering as well as soil profile development. The Shillong group of rocks is characterized by quartzites with some metabasic intrusive of low interstitial porosity but high fracture porosity. The rocks are widely weathered and the degree of weathering is found to be more in the topographic depression than in other areas. The metabasic rocks are more prone to weathering than the quartzitic rocks. The thickness of weathered zones varies from a thin veneer to more than 10-15 m at places. The NE-SW direction of lineaments coincides with the strike direction of the rocks and has well developed joint direction,

and therefore it will be more conducive for ground water storage and circulation. However, hydrologically, the intersection point of various lineaments in the area are very important, as they indicate the places where there will be several source of ground water circulation and the ground water withdrawal, therefore bore well/tube well located at such places will have a good supply of water. Geomorphologically, landform varies from highly dissected hills and hills slope with small and narrow intermontane valleys. The high relief areas of the southern and south-eastern corner occupied by Laitkor range and Shillong peak with steep topographic slope, and characteristic geological set-up offer high run-off and little scope for rain water infiltration. The discharge at this level is meager to very little in several of the streams which are mostly of low order. The ground water potential therefore in these terrains is limited to intermontane valleys.

The hydrogeological data indicate that groundwater occur both under artesian as well as in water table condition (Table 5.5). Occurrence of ground water in Shillong group of rocks is under water table condition in the weathered zones of underlying hard rocks, which is unconsolidated and consists of loose porous medium with well developed secondary porosity composed of cracks, fissures and joints. Ground water in the consolidated rocks occur under semi-confined condition. Hydrogeological data shows that depth of water level is shallower in topographic depression than in the upland areas or slopes. It varies from 4 m to 8 m in topographic depressions whereas in upland areas it is about 55 meters.

Table 5.5: Hydrogeological data of wells in Shillong Master Plan Area

Sl. No	Village	Borewell Diameter (mm)	Borewell Depth (m)	Casing Depth (m)	Yield (l/m)	Static Water Level (m)	Draw down (m)
1	Auxillium	150	130		18	21.8	NA
2	12 mile	100	60	18	153.9	7.5	NA
3	Umpling	56	18.75	4	NA	27	NA
4	Umpling	62	12.5	6.25	NA	10	NA
5	Umpling	68.75	10	Artesian	NA	15.4	NA
6	Rynjah	62.5	15	3	NA	27	NA
7	Rynjah	87.5	15	Artesian	NA	27	NA
8	Rynjah	87.5	NA	NA	NA	NA	NA
9	Rynjah	66.25	22	10	NA	55	NA
10	Rynjah	68.75	18.75	28	NA	55	NA
11	Rynjah	66.25	20	26	NA	55	NA
12	Umtyngar	100	45.45	20	10	4.5	NA
13	Mawtawar	150	107	31	27	NA	NA
14	Umshing, Mawkynroh	150	100	8	30	8.4	NA
15	Mawlai Umshing	150	100	15	27.5	15	NA
16	Mawlai Umshing	150	100	23	27.5	18	NA
17	Mawiong	150	101	36.5	45	27	NA
18	Tynring-111	150	134	12	153	31.53	NA
19	Tynring-1	150	129	10	120	33	NA
20	Mawlynghat	150	72	30	40.36	19	NA
21	Umphyrnai-111	150	81	16.15	97.65	9	NA
22	Umphyrnai-11	150	60	12	40	17.5	NA
23	Umphyrnai-1	150	60	12	55.8	12	NA
24	Kynton-U-Mon	125	81	33	97.65	3.6	NA
25	Nongmysong DTW (w/s/s)- 1	150	100	6.25	262.5	Artesian	18
26	Nongmysong DTW (w/s/s)- 2	200	100	30	371	8	60
27	Nongmysong DTW (w/s/s)- 3	200	100	30	614	4	50
28	Mawpat DTW (w/s/s)	150	152	26	315	Artesian	25
29	Pynthorbah DTW (w/s/s)- 1	150	67	6.25	265	15	24
30	Pynthorbah DTW (w/s/s)- 2	150	60	6.9	155	27	20
31	Mawlai-Mawroh DTW (w/s/s)- 1	200	109.5	30.85	132	21	60
32	Mawlai-Mawroh DTW (w/s/s)- 2	200	100.5	6.2	483	15	50
33	Mawlai-Umsaw Umkhiew - 1	110	61.64	22	NA	24.72	30
34	Mawlai-Umsaw Umkhiew - 2	110	60	32.12	NA	30.44	38
35	Mawlai-Umsaw Umkhiew - 3	110	60	32	NA	30	3.8
36	Permanent Campus, NEHU	250	89.67	30	6	20.2	50

Source: Public Health Engennering Department, Government of Meghalaya

The water level towards the SW is shallow (within 10 meters) while it is deeper towards NW side (Figure 5.2). It is also observed that the depth of water level is comparable in different litho- units. The tube wells constructed between the depth range of 100 m to 152 m yield 132 to 614 liters per minute for a drawdown of about

3.8 m to 60 m. The overall yield capacity of the tube wells indicate moderate to high yield potentiality. Some deep tube wells for example, Nongmynsong DTW indicates high yield of about 614 liter/minute. In spite of this, Shillong Agglomeration depends mostly on the surface water such as rivers, streams and few springs for water supply. Ground water extraction for public use is insignificant.

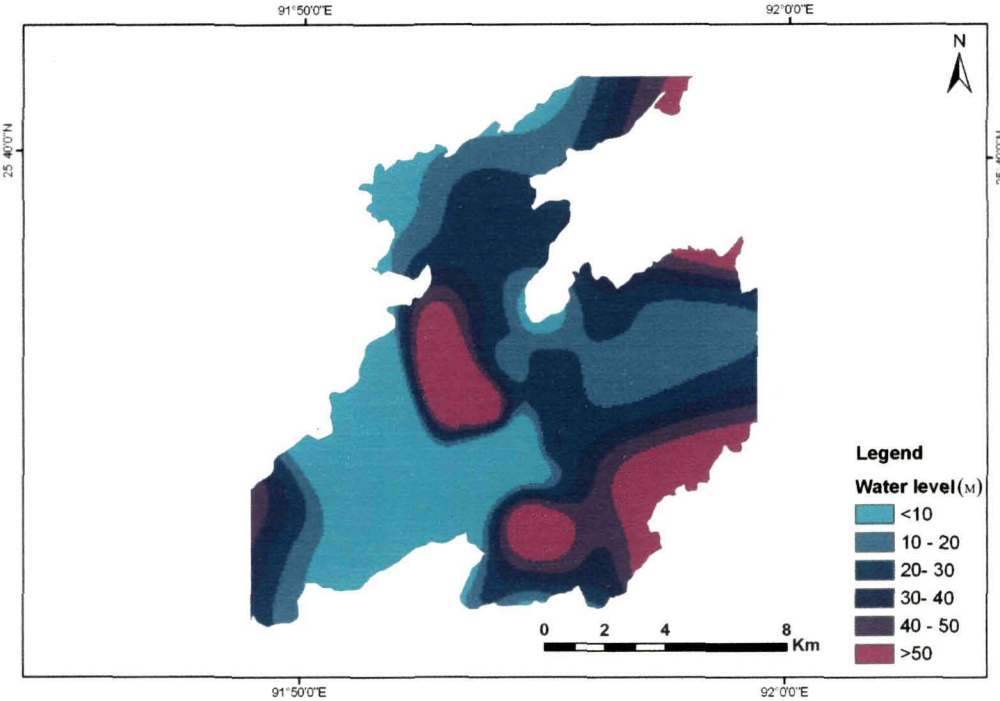


Figure 5.2: Water level map of Shillong Master Plan Area

Water quality

The data relating to chemical analysis of water supplied for domestic use is given in Appendix I and summarized in Table (5.6).

Table 5.6: Chemical analysis of drinking water in the study area

Parameters	Value	WHO Standards (1992)/ ISI (1991)
pH	5 – 7.4	6.5 – 8.5
Turbidity (NTU)	1.88 – 30.1	5
Nitrate (mg/l)	Traces – 7.2	45 - 100
Iron (mg/l)	0.1 – 3.5	0.3
Chloride (mg/l)	0.16 – 46.8	250 - 1000
Fluoride (mg/l)	0.02	1.0 – 1.5
Total Hardness (mg/l)	0.04 – 62.4	300 - 600

Although pH usually has no direct impact on consumers, it is one of the most important operational water quality parameters. It is observed that the water pH value ranged from 5–7.4 while as per WHO/ISI standard the range is 6.5–8.5. The average value for pH for most of the samples constituting above 85% showed that the values ranged from 6.8–7 indicating mildly acidic reaction. The spring water and well water were slightly acidic in most of the sample whereas surface water was slightly acidic to neutral, but few of them were mildly alkaline in nature. The water from deep tube well of Fire Brigade station have a pH value of 6.3 which is likely to be corrosive in nature. Therefore, any failure to minimize corrosion can result in the contamination of drinking-water and in adverse effects on its taste and appearance. The extrapolated map for pH values shows high pH in the central part of the study area (Figure 5.3).

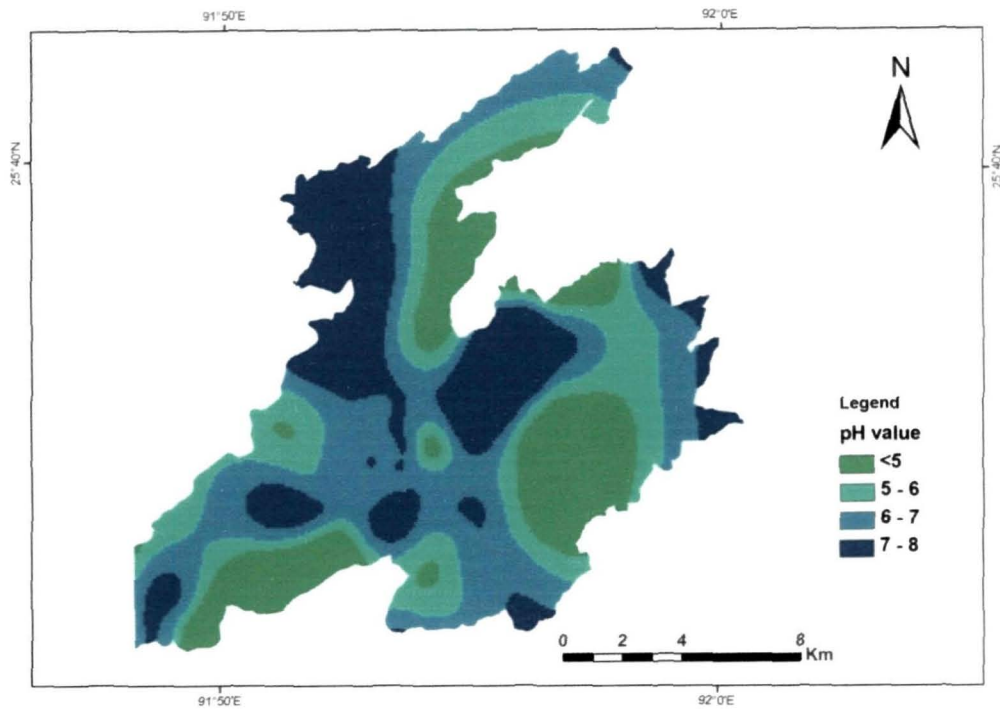


Figure 5.3: The extrapolated map of pH value of water in the study area

The ground water is characterized by an acidic reaction and is very slightly mineralized. It probably indicates that rain water which is the principal source of ground water in the area is not much mineralized. This may be because either it does not infiltrate much into the rocks before being discharged inhibiting thereby a long contact, or because the rocks themselves are not very mineralized. The latter reason may be responsible to a large extent, as most of the rock types developed in the study area consist of quartzite.

The concentration of chloride varied from 0.16 – 52.05 mg/l, the permissible and recommended limit for chloride concentration by both WHO and ISI is 250 mg/l for domestic use. Figure 5.4 shows the distribution of chloride with high concentration in the NE corner and low concentration in the S, SW and SE corner.

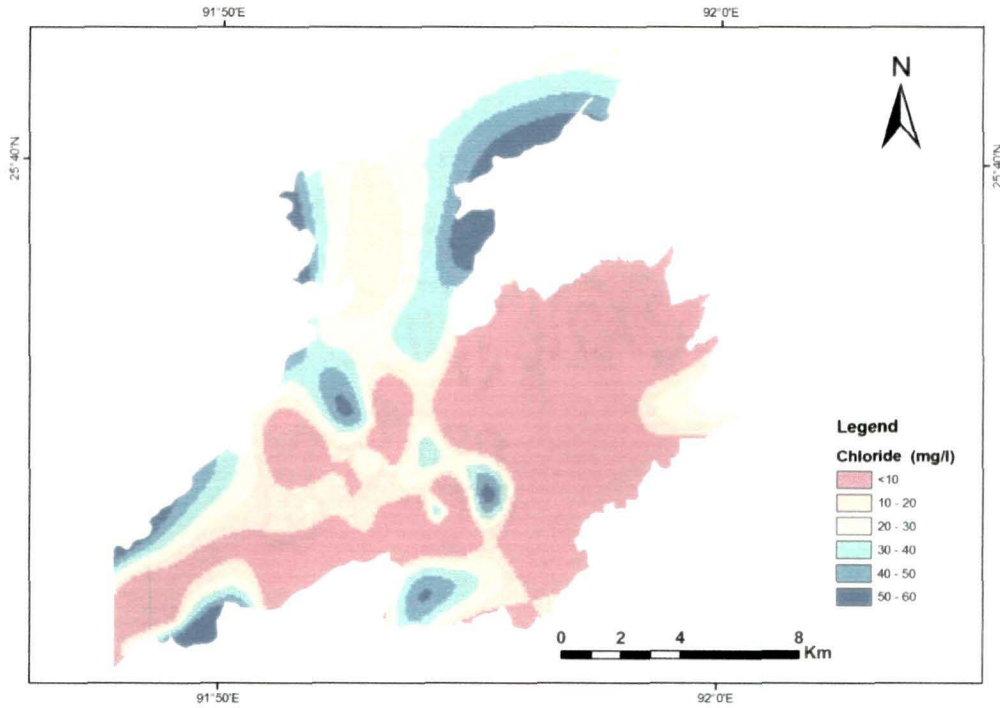


Figure 5.4: Distribution of Chloride content (mg/l) in the water of the study area

The safe limit of iron for drinking purpose by WHO is upto 1.0 mg/litre. Iron content varied from 0.1 to 3.5 mg/litre. In some locations the Iron content is high and even exceeds the permissible limit of 1.0 mg/litre, for example, the tube wells and hand pumps of forest colony, mawlai mawroh, A G Complex and deep tube wells of Auxillium, Umpling tribal colony, south-west of Laban and Ishrwat which markedly impairs the potability of the water (Figure 5.5). As such water is not safe for drinking purposes as excessive iron causes constipation and staining of teeth. Stomach disorder and constipation is the common diseases of the area. Excess iron if taken is flushed out of the body as the body does not retain iron more than its requirement.

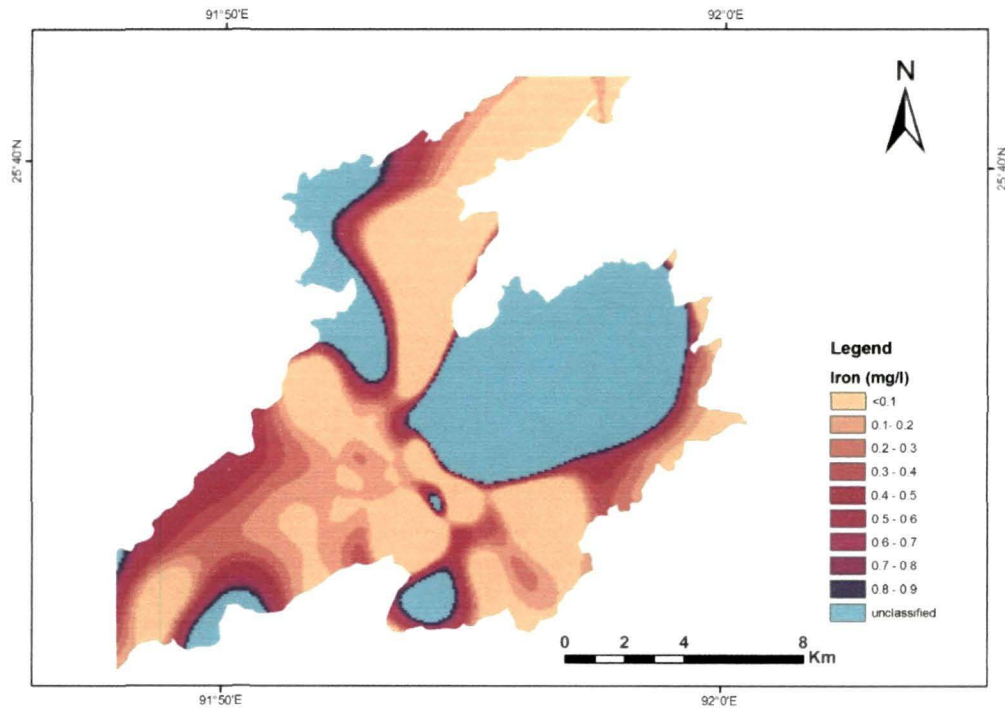


Figure 5.5: Distribution of Iron content (mg/l) in the water of the study area

Total hardness of water varies from 0.04 to 62.4 mg/litre indicating that the water of this area is very soft. The concentration of fluoride in the water of the study area was 0.02 mg/litre. It is lower than the recommended value 1.5 mg/litre (WHO), it is safe for drinking purposes as low concentrations provide protection against dental caries, both in children and in adults. Exceptions include fluoride, and declining dental health has been reported from populations consuming desalinated water with very low fluoride content where there is a moderate to high risk of dental caries (WHO, 2003).

The value for turbidity ranged from 1.88 NTU to 30.1 NTU. The appearance of water with a turbidity of less than 5 NTU is usually acceptable to consumers (WHO, 2003). It is found that fifty percent of the sample areas have turbidity more than the permissible limit. Figure 5.6 shows the turbidity distribution for the study area.

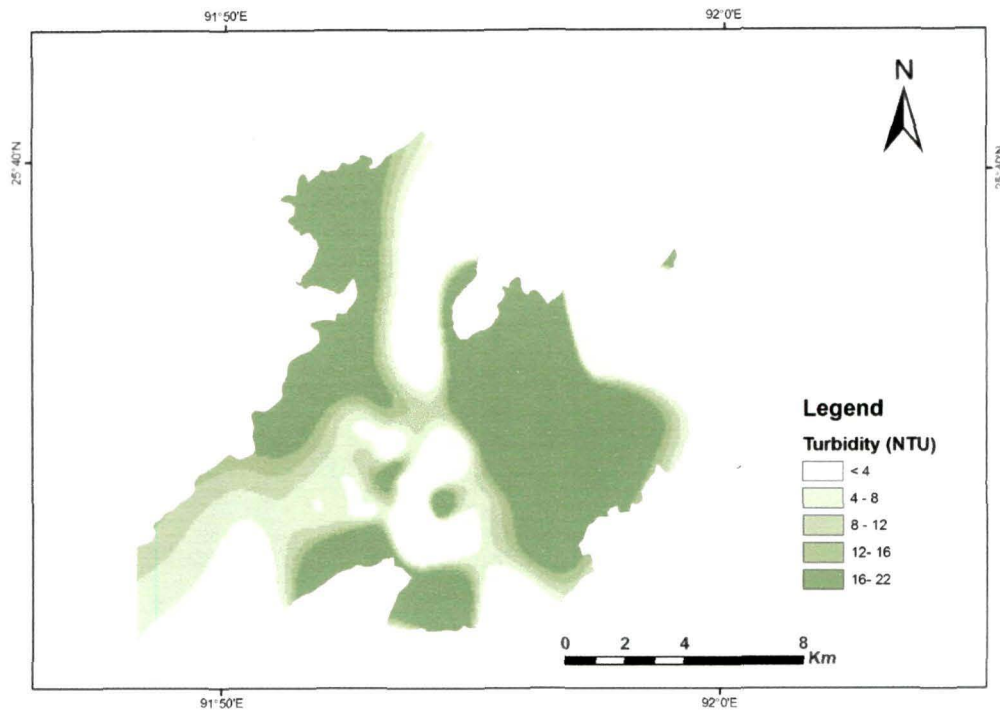


Figure 5.6: Distribution of Turbidity (NTU) in the water of the study area

The tube well of AG Complex have a higher value 16.68 NTU with Fire Brigade deep tube well of 30.1 NTU. The turbidity may be due to the presence of inorganic particulate matter in some groundwaters or sloughing of biofilm within the distribution system. Even the drinking water obtained from Greater Shillong Water Supply Scheme have higher value of turbidity, this shows that the turbidity in drinking-water is caused by particulate matter that may be present from source water as a consequence of inadequate filtration or from resuspension of sediment in the distribution system.

The concentration of Nitrate ranged from traces to 7.2 mg/litre with few exceptions. Nitrates are considered to be the index of pollution due to sewage disposal. From the available data it is clear that the quality of water is generally not affected due to nitrate contamination. However Mawpdang spring, Police Bazar and Umtrew river

shows higher values indicating the beginning of pollution of the water resources. Presence of Nitrate at Fire Brigade indicates sewage contamination of ground water. In general, the water is suitable for domestic use and the quality of groundwater and surface water is affected primarily by anthropogenic activities.

CHAPTER 6

LAND USE /LAND COVER ANALYSIS

Introduction

The land use/land cover pattern of a region is an outcome of natural and socio – economic factors and utilization of land resources by man in time and space. Land is becoming a scarce resource due to immense agricultural and demographic pressures. Hence, information on land use / land cover and potentials for their optimal use is essential for planning and implementation of land use schemes to meet the increasing demands of land resources for basic human needs and welfare. Land use and land cover change has become a central component in current strategies for managing natural resources and monitoring environmental changes. The major procedure in analysing the temporal variations of land use is through the application of remote sensing data, which provide a reliable database for planning, evaluation and monitoring the temporal dynamics in a GIS environment.

In this chapter land use/ land cover change of the study area between 2000 and 2005 has been analysed with a view to detect the changes taking place and to identify the areas that are experiencing faster rate of change in the land use.

Review of literature

Ever since the launch of the first Indian remote sensing satellite (Landsat-1) in 1972, land use and land cover studies have been carried out on different scales for different users. For instance, waste land mapping of India was carried out on 1:1 million scales by NRSA using 1980 – 82 landsat multi spectral scanner data and it was estimated that about 16.2% of country's land mass was covered by wastelands. It has been noted over time through series of studies that Landsat Thematic Mapper is adequate for general extensive synoptic coverage of large areas. In 1985, the U.S Geological Survey carried out a research program to produce 1:250,000 scale land cover maps for Alaska using Landsat MSS data. Shosheng et. al. (1994) emphasised the advantages of remote sensing techniques in relation to field surveys in providing a regional description of vegetation cover. The results of their research were used to produce four vegetation cover maps that provided new information on spatial and temporal distributions of vegetation and allowed regional quantitative assessment of the vegetation cover. Mohanty (1994) analysed the urban land use change of north Bhubaneswar, Orissa using aerial photographs and satellite data. Singh (1995) analyzed the land use management and urban planning in Bhilai, an industrial complex, and suggested land use for the expected population by the year 2001 AD. An analysis of land use and land cover changes was done using the combination of MSS Landsat and land use map of Indonesia by Dimiyati (1995). Using land use land cover images of 1972, 1984 and land use maps of 1990, he calculated the index of change. This was done to analyze the pattern of change in the area, which was rather difficult with the traditional method of surveying as noted by Olorunfemi (1983) when he was using aerial photographic approach to monitor urban land use in developing countries with Ilorin in Nigeria as the case study. Lalianthanga and

Goswami (1997) applied IRS-1B (F) Data on 1:50,000 scale for studying land use of Serchip rural development block of Aizawl district.

MENRIS (1997) studied the land use changes in Pranmati watershed Garhwal Himalayas using IRS- IB and inferred that cultivated land increased significantly at the expense of forest and pasture land. Uttarwar (1999) studied the usefulness of aerial photographs at pre-planning stage in urban fringes. The data generated from the study was made available to the physical planners to monitor and periodically evaluate the land available with them for urban extension. Ramesh and Goel (1999) used aerial photographs to make an inventory of land use types and to appraise the development plan–2001 with the existing land-use. Rashid (1999) located and assessed the suitable vacant land in Bardez along the national highway between Panaji and Mapusa for urban development using aerial photographs. Bisht and Sokhi (1999) studied the growth of Saharanpur city and analyzed the functional characteristics and structural pattern using remote sensing data. Bhargava and Sokhi (1999) identified the deviations from the master plan proposals of Noida, a new town near Delhi by using Remote Sensing Technique and GIS software. Singh and Vatsavia (1999) utilized digital mapping technique using spot data for information generation pertaining to urban/sub-urban environment of Dehradun.

Vivekanand et.al. (1999) created spatial database of various resources such as land use/land-cover, drainage, soil, and slope data by using universal soil loss equation (USLE) to identify erosion prone areas and site suitability analysis for afforestation. Adeniyi. el. al. (1999) delineated the land use /land cover change evaluation in Sokoto – Rima Basin of North – Western Nigeria based on Archival Remote Sensing and GIS techniques, used aerial photographs, Landsat MSS, SPOT XS/Panchromatic image

Transparency and Topographic map sheets to study changes in Sokoto and Guroyo dams between 1962 and 1986. The work revealed that land use land cover of both areas was unchanged before the construction while settlement alone covered most part of the area. However, during the post-dam era, land use /land cover classes changed with settlement still remaining the largest. Marceau. et.al. (2001) linked temporal and spatial information into a GIS database structure to investigate the land use changes in a rural urban region over a thirty-five year period, where information such as rate of change of land use and zoning regulations and land–use successions were extracted from the database. They concluded that the approach represents a flexible and performing tool for scientists and planners who need to efficiently capture essential spatial-temporal information required for geographical inquiry and decision-making. Cievo et. al. (2002) in their comparison of land use land cover change detection methods, made use of 5 methods viz., traditional post-classification cross tabulation, cross correlation analysis, neural networks, knowledge-based expert systems, and image segmentation and object-oriented classification. A combination of direct T1 and T2 change detection as well as post classification analysis was employed. Nine land use land cover classes were selected for analysis. They observed that there are merits to each of the five methods examined, and that at the point of their research no single approach can solve the land use change detection problem.

Chauhan et. al. (2003) used aerial photographs of 1976 and IRS –IC LISS III satellite data of 1999 to carry out change detection in Sal forest of Deradhun Forest Division

Mahajan and Panwar (2005) carried out a study on land use change in Aswani Khan Watershed using GIS techniques. They observed that over a span of twenty years, the agriculture area in the watershed has increased whereas the forest area and waste land area has decreased. Their topographic analyses indicated that the wastelands in the

mid altitudes and mid-slopes suitable for agriculture purpose were brought under cultivation. On the other hand at relatively higher altitude and moderate slopes, a decrease in forest area was observed due to encroachment for settlements and cultivation. Pandey and Nathawat (2006) carried out a study on land use land cover mapping of Panchkula, Ambala and Yamunangar districts of Haryana, India. They observed that the heterogeneous climate and physiographic conditions has resulted in development of varied land use land cover in these districts. An evaluation by digital analysis of satellite data indicated that majority of areas in these districts are used for agricultural purpose. The hilly regions exhibit fair development of reserved forests. It was inferred that land use land cover pattern in the area were generally controlled by agro-climatic conditions and groundwater potential. Mahajan et.al. (2001) studied the land use status of Ashwani Khad watershed using IRS-ID satellite data and carried out topographic analysis using GIS techniques to show that altitude, slope and aspect affected the land utilization pattern. Thakur and Goswami (1993) prepared urban sprawl map and land suitability map of Guwahati city using multivariate SOI topographical maps and satellite data and identified areas suitable for construction and conservation. The study indicated that by analyzing satellite data it was possible to detect the growth of the city over the period of time and also to evaluate the suitability of land for urban development.

Results and Discussion

Land use /land cover distribution

The land use/land cover distribution for the two years is presented in Figure 6.1 and 6.2. Six land use classes have been identified namely, built up land, dense forest, open forest, scrub, agricultural crop land and water bodies. Table 6.1 gives the area wise distribution of landuse/landcover class. For the year 2000, built up land occupies 8.96 % of the study area and includes urban and rural habitation and settlement. Water bodies cover 4.28 % of the area and is mainly represented by the Umiam lake and wards lake. Agricultural crop land, usually bun cultivation, covers 6.58 %, with scrubs occupying 10.03 % of the study area. The area under pure pine and pine with broad leaved trees has been classified as dense forest and occupies 50.92 % with open forest covering 19.23 % of the study area. Similarly, for the year 2005, built up land, dense forest, open forest, scrub, agricultural crop land and water bodies covered 9.35%, 50.04 %, 18.90 %, 10.15 % and 6.93 % and 4.28% respectively.

Table 6.1: Distribution of area under different land use classes during years 2000 and 2005

LULC Class	2000		2005	
	km ²	%	km ²	%
Built-up area	18.66	8.96	19.46	9.35
Dense forest	106.01	50.92	104.18	50.04
Open forest	40.02	19.23	39.34	18.90
Scrub	20.88	10.03	21.88	10.15
Agricultural Crop land	13.71	6.58	14.42	6.93
Water bodies	8.90	4.28	8.90	4.28

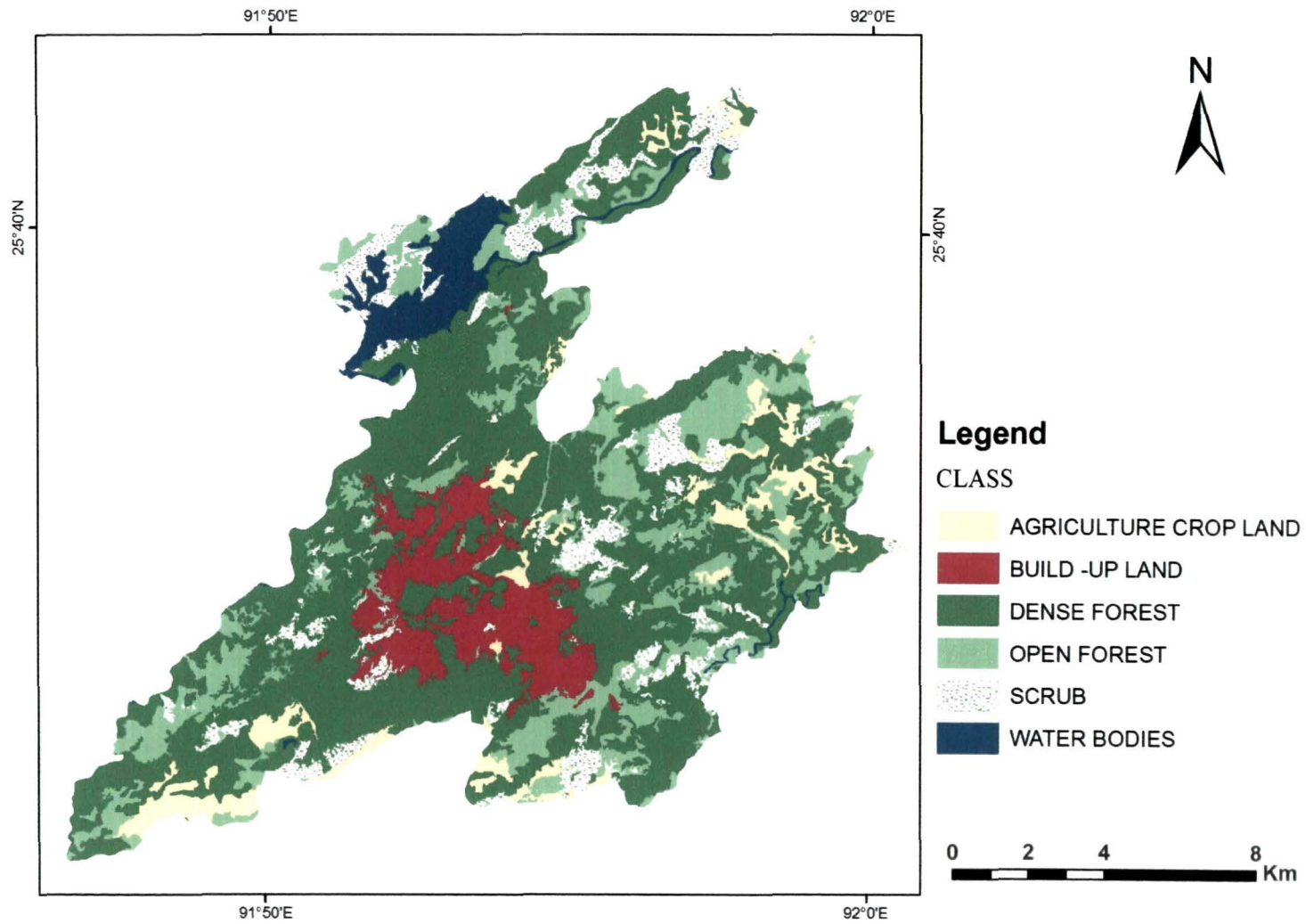


Figure 6.1: Land use map of the study area for the year 2000

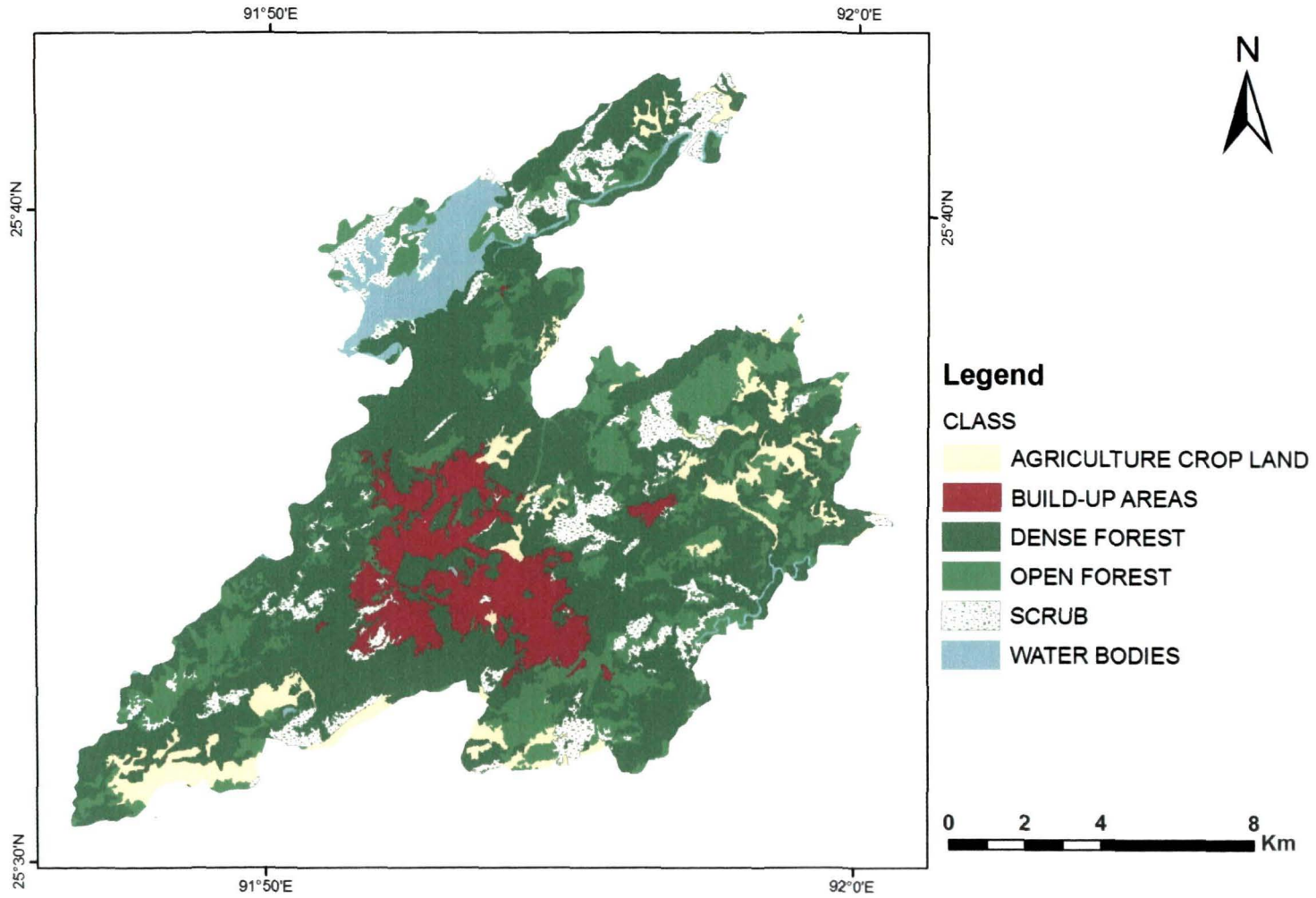


Figure 6.2: Land use map of the study area for the year 2005

Reserved and Protected forest cover

The reserved and protected forests form almost a complete ring around Shillong (Figure 6.3). Shyrwat reserved forest lies north of the study area with Laitkor protected forest, Raid Laban reserved forest and Upper Shillong protected forest running in an east-west direction lies south and Riat Khwan reserved forest border the study area in the west.

The area of Reserved and Protected forests are given in Table 6.2. The localities adjoining or falling within the Reserved and Protected forests are listed in Table 6.3. The total area calculated for reserved and protected forest is 21.59 km² which comprise around 12.26 % of the total study area. The natural forests conform to sub-tropical pine forest which covers most forested areas except in few places where it is mixed with broad leaved species. The broad leaves forests generally occur in long strips of varying depths along the streams and ravines where area is very moist. The principal tree species met with are the Oaks. Along with these trees of Uriam, Chapa, Kroi, Am, Nodar can also be found.

Table 6.2: Area covered by Reserved and Protected Forests

Sl. No	Reserve forest/ Protected Forest	Area (km²)
1	Laitkor Protected Forest	2.41
2	Raid Laban Reserved Forest	2.05
3	Upper Shillong Protected Forest	12.78
4	Shyrwat Reserved Forest	0.44
5	Riat Khawan Reserved Forest	3.91
	Total	21.59

Table 6.3: List of localities and villages adjoining/falling under Reserved and Protected forests

Sl no	Forests	Villages and localities	
1	Shyrwat Reserved Forest	Shyrwat Village	
		North	Mawroh
2	Laitkor Protected Forest	North	Lumparing, Malki, Cleave Colony, Risa Colony, Lumdiengsoh, Lumpngad
		West	Lumparing
		South	Air Force Area
		East	Green Block II
3	Riat Laban Reserved Forest	South	Air Force Area
		North	Laban, Madan, Laban, Lawsotun, RiatLaban
4	Upper Shillong Protected Forest	North	Cantonment
		NW	Nongkseh, Lummawbah
		West	3 rd Mile, 4 th mile, Nongpiur, Mawklot
		South	Sadew, Baniun, Easter Air Command, 7 th Mile (Mawrasai)
		East	Part of Lawsotun
5	Riat Khwan Reserved Forest	East	Mawiong
		South	Umjajew

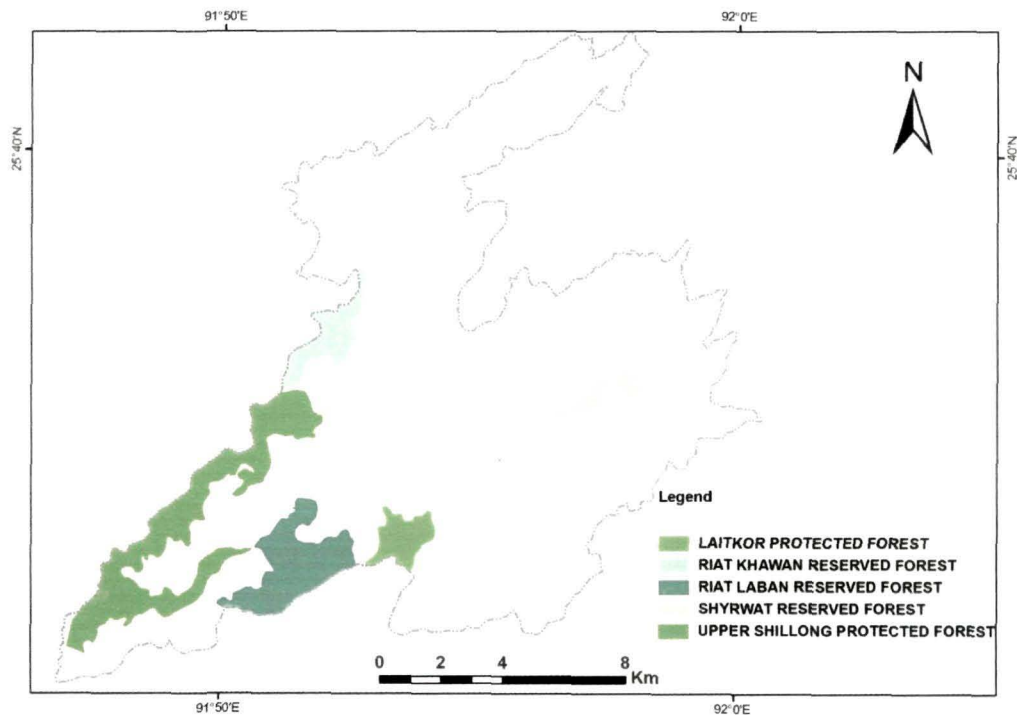


Figure 6.3: Location of Protected and Reserved forests in the study area

It was observed that reserved forests and protected forests are the major catchment areas of seven municipal sources and other water sources tapped by PHeD for water supply to the Shillong Municipality, Shillong Cantonment and to the reservoir of Umiam Hydel Project. Raid Laban reserved forest, Laitkor and Upper Shillong protected forest forms the catchment areas for water supply to Shillong Municipality and Cantonment areas. These forests have numerous springs that feed the Umshirpi river which drains into the Umiam Lake. The forests act as lungs to the Shillong agglomeration comprising of Shillong Municipality, Shillong Cantonment, townships as well as other localities around SMPA which are encircled by these forests. It has been observed that several water sources have dried mainly due to rapid expansion of the city into these forests which once skirted the town.

Land use change detection

In order to put any change into a proper perspective, it is useful to establish the state of the environment in the selected base year. The trend of change in land use category for both the years was then analyzed. From the analysis it has been observed that there has been a change in vegetation and land cover types within a span of five years (Figure 6.4). The land use statistics giving percentage of area under different class of land use for both years are presented in Table 6.4.

Area under dense forest has reduced and it has been replaced by open forest, scrubs, agriculture and built up areas. In 2000 area under dense forest and open forest was 106.01 and 40.02 km² (50.92 and 19.23% of the total area) and it decreased to 104.18 and 39.34 km² (50.04 and 18.90 %) in 2005.

Table 6.4: Land use changes in 2000-2005.

LULC Class	2000 - 2005	
	Area (km ²)	Change Percent
Built-up area	0.80	0.38
Dense forest	-1.83	-0.88
Open forest	-0.69	-0.33
Scrub	1.01	0.48
Agricultural Crop land	0.71	0.34
Water bodies	-	-

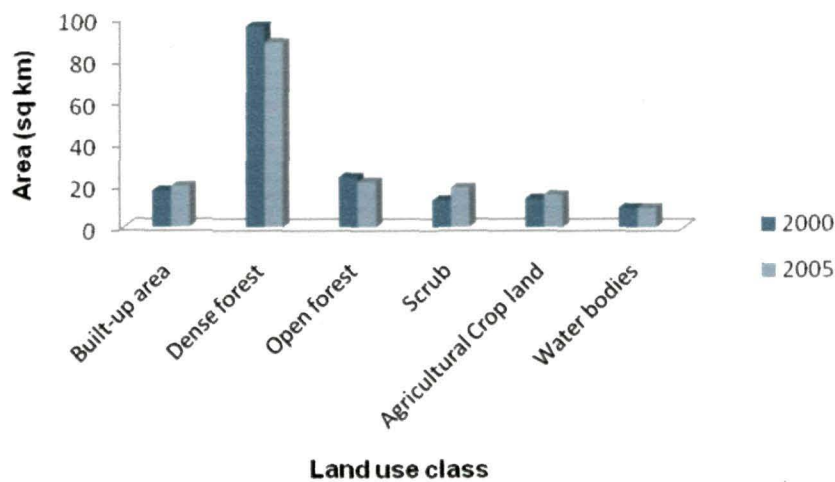


Figure 6.4: Landuse / landcover change during the period 2000–2005

A decrease of 1.83 and 0.69 km² in the forest vegetation was largely caused by increasing rate of deforestation due to unsustainable extraction of timber, agricultural activities and urbanization. Although agriculture area has increased from 13.71 km² (6.58% of the total area) to 14.42 km² (6.93%) i.e, an increase of 0.71 km² with faulty cultivation practice (bun cultivation) which can create severe erosion problem in future. Built up land class has increased by 0.80 km², this is due to expansion over the years where the town has spread to the forests areas which once skirted the town.

Built up land have expanded especially towards north-eastern part of the study area, this is a new township located nearly 13 kms from the main city accessible by a motorable road. The new township includes ten villages viz., Mawdiangdiang, Umroh, Mawlong, Diengiong, Umsawli, Mawkasiang, Madansaisiej, Mawpdang, Siejiong and Tynring.

CHAPTER 7

LANDSLIDE AND FLASHFLOOD

Introduction

The geoenvironmental hazards in the study area include both natural hazards as well as man-made hazards. These are: landslide, flashflood, siltation of river due to quarrying and loss of top soil. Landslide hazard was defined by Varnes (1984) as the probability of occurrence of a potentially damaging landslide phenomenon within a specified period of time and within a given area. The factors that determine the landslide hazard of an area may be grouped into two categories: (1) the intrinsic variables that contribute to landslide susceptibility, such as geology, slope gradient, slope aspect, elevation, soil geotechnical properties, vegetation cover, and long-term drainage patterns; and (2) the extrinsic variables that tend to trigger landslides in an area of given susceptibility, such as heavy rainfall, and earthquakes (Wu and Sidle 1995; Atkinson and Massari 1998). Therefore, the probability of landslide occurrence depends on both the intrinsic and extrinsic variables. However, the extrinsic variables may change over a very short time span, and are thus very difficult to estimate. If extrinsic variables are not taken into account, the term “susceptibility” could be employed to define the likelihood of occurrence of a landslide event. The spatial distribution of the intrinsic variables within a given area determines the spatial distribution of relative landslide susceptibility in that region (Carrara et.al. 1995).

A variety of techniques have been developed to assess landslide susceptibility. Geographical information systems (GIS) have become an important tool for landslide susceptibility mapping. GIS is a general-purpose computer based technology designed to capture, store, manipulate, analyze and display diverse sets of spatial or geo-referenced data. The overlay operation commonly applied within the GIS is useful in both heuristic and statistical approaches (Gupta and Joshi 1989; Carrara et.al. 1991, 1995; Wang and Unwin 1992; Mark and Ellen 1995; Van Westen et.al. 1997; Fernandez et.al. 1999).

Landslides and flash flood are recurrent problem throughout most of Shillong Master Plan Area, where they cause extensive damage to property and occasionally result in loss of life. Landslides and flash flood are triggered by heavy rainfall. Very few attempts have been made to study the landslides and flashflood in the state of Meghalaya in general and Shillong in particular (Agarwal, 1994). In view of this landslide inventory and identification of vulnerable areas with respect to landslides and flashflood assumes significance. This study utilizes GIS and employs overlay analysis and statistical analysis to define the physical parameters contributing to the causal factors of landslides and flash flood for a similar geo-environmental condition. Such effort will be useful in proper landuse planning, designing civil structures and urban drainage.

Review of Literature

Dai et.al. (2001) presented a method that utilizes GIS and employs statistical analysis to define the physical parameters contributing to the occurrence of landslides and classified their study area into five classes of relative landslide susceptibility, namely, very low, low, moderate, high, and very high. Mckean et.al. (1991) used the remote sensing and Geographic Information System (GIS) to assess landslide hazards. Prabhu et. al. (2009) used artificial neural network approach to estimate areas susceptible to landslide using a spatial database and also analyzed the socio-economic impact of the Nilgiris landslide. A susceptibility map was created and it was found that by this method, landslide occurrence can be assessed, and the method proved to be an efficient tool for analyzing landslide susceptibility compared to the conventional methods of landslide mapping. Gupta, et. al. (2009) developed a model to generate a hazard map for predicting the landslide hazards along NH 31A between Rangpo and Singtam using aggregation method. They found that the proposed methodology can be used in landslide hazards zonation prediction. Narasimha (2001) prepared thematic maps on slope morphometry, geomorphology and landuse-land cover for Niligiri hills, and studied their influence over the landslides incidence. He found that slope, geomorphology and landuse have a conspicuous influence on the occurrence of landslides. Jagannathan and Kameswar (2001) found that besides others parameters like slope and landuse, the pattern of rainfall and condition of ground and surface water regulated the initiation of slides in the Western Ghats. They observed that the high rainfall causes saturation of soil and poor pressure thereby decreasing the cohesive strength and angle of internal friction, causing landslide. Varnes (1984) reported that landslides occurred where the maximum daily rainfall exceeded 188.8 mm, with a maximum hourly rainfall of 90 mm. Metrotra et. al. (1993) carried out a

terrain evaluation to understand the relationship of lineament with lithology, drainage pattern and the existing landslide in the parts of Alakanda valley of Garhwal, Himalaya with the help of remote sensing data and field investigation. They found that landslides occur, in zones of closely spaced intersecting lineaments, and in the phyllitic rocks having low drainage density. Krishnaswami (1980) adopted the three-fold geomorphic division of India into Peninsula, the Indo-gangetic Plain and the Extra-Peninsula as the basis for evaluating the relative incidences of landslides. He found that the different geological history, the varying character of the geological formations and the contrasting physiographic make-up of the three geomorphic divisions define the pattern and quantum of incidences of landslides. Sharma et. al. (2009) made a detailed survey of the importance of various soil parameters with respect to their influence on slope instability and landslide vulnerability. From the study it was deduced that the soil depth was the most influencing soil parameter determining the slope instability.

In northeast a number of studies have been conducted. Raju (2001) highlighted the role of rainfall and seismicity, particularly their combined effect in inducing extensive landslides in Mizoram. He concluded that the extensive landslides that occurred within a short span of time in May, 1995 might have been triggered by earthquake along with a heavy rainfall. He also suggested that the tremors during or immediately after continuous rainfall can possibly cause extensive landslide. Borah et. al. (2001) found that the landslide in Guwahati are either due to rapid downward movement of rock mass, soil cum rock mass or sudden spreading of soil. The factors controlling the stability of slopes include high intensity rainfall, disturbances of natural drainage, hills cutting, deforestation, structural features of rocks units, lithology, high degree of rock weathering, building structures on the slope and slope angles. They concluded

that the ability to control landslide could be enhanced by adoption of appropriate landslide management techniques. Chopra and Srivastava (2001) identified the major geological hazards of Assam viz., landslide, earthquake and floods, besides minor hazards that include water logging, soil erosion, land subsidence, drainage congestion, land degradation and groundwater pollution. For proper mitigation of the geological hazards, they suggested that a disaster management authority with full autonomy at the state and district levels should be set up under the technical control of experts in the related field. This authority should be in command at the time of disaster mitigation and all administrative and logistic support should be binding on the district authorities. Hiese and Reddy (2001) studied the existing land use pattern of Kohima area, Nagaland with special reference to the evaluation of landslides and a change in the land use pattern for two years with the help of remote sensing. They observed there has been a rapid change in the land use pattern which has caused serious consequences on the environment as well as climatic conditions. They suggested that reasonable geotechnical measures using remote sensing could be used for identifying large landslides. Awasthy (2001) made a site specific geotechnical appraisal of few disastrous landslides of Mizoram. He emphasized on the need for development of new satellite township near Aizawl. On the basis of landslide incidences, physical characteristics of geological materials and slope characterization a revised landslide hazard zonation map for Mizoram terrain was prepared. Ghose and Mitra (2001) prepared a landslide hazard (Macro) zonation (LHZ) map on 1:25,000 scale following the landslide hazard evaluation factor (LHEF) rating scheme proposed by the Indian Bureau of Standards for the area between Singtam and Ranipul sector of East Sikkim District. They did not observe any definite pattern of distribution of the various zones in the LHZ map and reported that the maximum area was covered under high hazard

zone followed by moderately hazard zone. Tiwari et. al. (2001) prepared a landslide hazard zonation map along the path of NH-54 in a stretch of 55 km between North Tawipui and Thingfal in the Lunglei district of Mizoram in 1:50,000 scale. Khullar (2001) reported that the geoenvironmental factors, viz., geomorphology, lithology, structure, climate and rainfall, drainage, seismicity and anthropogenic factors were responsible for extensive landslide in Mizoram. He highlighted the main causative factors of extensive landslides in Mizoram and spelled out a generalized mitigation measures.

Results and Discussion

Inventory and characterization of landslide

As many as 60 minor and major landslides have been documented through on site inventories during 2003 and 2004 within the city, some of which were of recurring type while most of them were found in new localities. Their distribution is predominantly along NH-40 apart from those in thickly populated urban areas. Table 7.1 gives a detailed inventory of the different landslides occurred in Shillong Master Plan Area. Landslide locations were documented by field observation using GPS. Inventories of individual landslides were carried out in the field and the salient features were documented. Figure 7.1 shows the locations of recent landslides that occurred during 2003 and 2004 which were physically verified, and this was used to evaluate the frequency and distribution of landslide in the area. Most of the slides include slumping, debris fall and flow and the factors that have a direct bearing on the stability of the study area are: changes in the slope gradient both natural and man-made, changes in antecedent moisture content, vegetation, lithology etc. Most of the



Figure 7.2: Debris fall and slumping

Rains set new record
By Our Reporter

SHILLONG: Heavy downpour continued to make new records in the State everyday.
Friday's rainfall measuring 262.0mm recorded till 8.30am is the highest one day record in the past sixteen years.
The highest rainfall since 1970 has been recorded on June 7, 1989, with 272.1 mm.

Rains, landslides claim seven more in State
By Our Reporter

SHILLONG: Incessant rain continued to batter the State's

rushed to the Military Hospital.
She was, however, declared brought dead. Later the body

Oct 9, 2004

Incessant rains for the past few days in the city has resulted in landslides in many places including that of (L) Kharmalki and (R) Lawsotun Block I which claimed two lives. A 24-year old man, Ariston Khardewsaw died on Thursday when a wall collapse on him. On Friday morning, a middle aged lady died on the spot when loose soil swept the kitchen where she was working.

Figure 7.3: Newspaper clipping, The Shillong Times dated 9th October 2004

Table 7.1: Inventory and characterization of landslides in the study area

Slide No.	Location of landslide		Type of movement	Materials involved	Formation	Probable cause	
0	N25°38.736'	E91°53.497'	Slumping	Regolith overlying the parent rocks	Well-bedded and jointed phyllites with high fissibility	Road cutting which left high angle slopes. Rainfall	
1	N25°38.613'	E91°53.452'	Flow	Weathered phyllites , clay, top soil	Well-bedded and jointed phyllites with high fissibility,	The phyllites are oversaturated with water thereby decrease the cohesiveness leading to plastic flow.	
2	N25°39.154'	E91°53.925'					
3	N25°39.112'	E91°53.974'	Slumping	Regolith overlying the parent rocks	Well-bedded and jointed phyllites with interbedded quartzites	Having steep road cuttings exposing the weathered regolith that cap over the parent rock.	
4	N25°39.120'	E91°53.973'					
5	N25°39.134'	E91°53.960'					
6	N25°39.039'	E91°53.959'					
7	N25°39.005'	E91°53.601'				Overburden is already saturated after a high intensity of rain.	
8	N25°38.973'	E91°53.598'					
9	N25°38.475'	E91°53.500'					
10	N25°38.491'	E91°53.476'					
11	N25°37.957'	E91°53.504'	Debris fall	Regolith overlying the parent rocks and phyllites	Well-bedded and jointed phyllites with interbedded quartzites	During rains when the pore water pressure increases weathered rocks easily fail along fissile surface like bedding, foliation or joints of phyllitic rocks	
12	N25°37.937'	E91°53.501'					
13	N25°37.881'	E91°53.483'					
14	N25°37.969'	E91°53.506'					
15	N25°38.027'	E91°53.524'	Slumping	Regolith overlying the parent rocks	Quartzites	Having steep road cuttings exposing the weathered regolith that cap over the parent rock.	
16	N25°39.158'	E91°53.932'					
17	N25°39.093'	E91°53.998'					
18	N25°38.924'	E91°53.929'				Take place when load is released due to cutting of slopes.	
19	N25°38.907'	E91°53.824'					
25	N25°38.854'	E91°53.560'					
26	N25°38.735'	E91°53.496'					
27	N25°38.608'	E91°53.447'					Overburden is already saturated after a high intensity of rain.
28	N25°38.939'	E91°53.581'					
29	N25°38.445'	E91°53.526'					
30	N25°38.436'	E91°53.526'					
31	N25°38.428'	E91°53.527'					
32	N25°38.409'	E91°53.529'					
33	N25°38.368'	E91°53.564'					
34	N25°38.242'	E91°53.593'					
35	N25°38.173'	E91°53.573'					
36	N25°38.162'	E91°53.569'					

37	N25°38.082'	E91°53.538'				
39	N25°37.845'	E91°53.440'				
40	N25°37.839'	E91°53.426'				
41	N25°37.807'	E91°53.397'				
42	N25°37.720'	E91°53.342'				
43	N25°37.717'	E91°53.334'				
44	N25°37.683'	E91°53.302'				
45	N25°37.143'	E91°52.804'				
46	N25°37.119'	E91°52.769'				
47	N25°37.101'	E91°52.735'				
48	N25°37.094'	E91°52.722'				
49	N25°36.990'	E91°52.603'				
50	N25°36.723'	E91°52.422'				
51	N25°36.721'	E91°52.425'				
52	N25°36.611'	E91°52.421'				
	N25°36.607'	E91°52.420'				
20	N25°39.000'	E91°53.993'	Debris fall	Regolith overlying the parent rocks and quartzites	Quartzites	Having steep road cuttings exposing the weathered regolith that cap over the parent rock.
21	N25°39.024'	E91°54.002'				
22	N25°38.956'	E91°53.938'				
23	N25°38.941'	E91°53.834'				
24	N25°38.942'	E91°53.818'				Overburden is already saturated after a high intensity of rain.
53	Nongthymmai		Debris fall	Regolith overlying the parent rocks and weathered quartzites	Quartzites	Take place under the load pressure of civil structures like residences
54	Malki					
55	Laban					
56	Lawsotun					Overburden is already saturated after a high intensity of rain. High slope angle
57	Lumparing		Debris fall	Regolith overlying the parent rocks and weathered quartzites	Quartzites	Overburden is already saturated after a high intensity of rain.
58	Upper Shillong					High slope angle
59	Umlynka		Debris fall	Weathered phyllites , clay, top soil	Quartzites	Take place under the load pressure of civil structures like residences Overburden is already saturated after a high intensity of rain. Falling of retention wall.

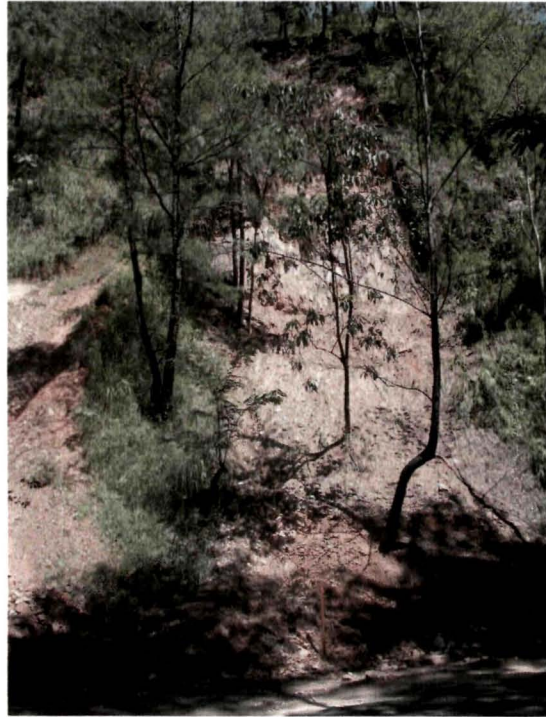
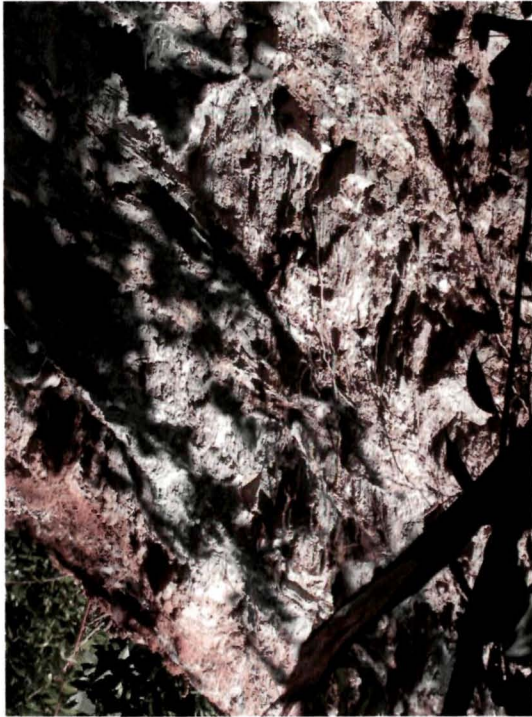


Figure 7.4: Glimpses of Landslides in Shillong Master Plan Area.

Casual factors for landslides

In the study area, the landslides were mainly debris flow and slumping that occurred during 3-4 hours of high intensity rainfall, or shortly after. The landslides occurred where the maximum daily rainfall exceeded 188.8 mm, with a maximum hourly rainfall of 90 mm. Damages in 2003 and 2004 was particularly higher and frequently the Shillong town remained cut off from the rest of the country for several hours when a series of landslides blocked the NH-40 highway during this time.

Landslides are difficult to predict and their causes vary from place to place. An integrated study of the causal factors using remote sensing data analysis, GIS and field investigation in respect of geological, geomorphological and meteorological parameters suggest that a multiple of factors are responsible for landslide in the study area. The geoenvironmental factors responsible for landslides in the study area include geomorphology, lithology, structure, climate and rainfall, drainage, slope and anthropogenic factors. The influences of these factors in triggering landslides are discussed below.

i. Landslide and landuse pattern

It will be essential to mention that indiscriminate cutting of slopes for construction of roads and urban settlements have also promoted slope failure. Most of the landslides are confined in the national highways and urban areas. Landslide prone areas within urban areas are mostly debris fall (Table 7.2 and Figure 7.5) and are located on steep hill slopes where the settlements have come up in a haphazard and unplanned manner and landslides take place under the load pressure of civil structures like residences (Figure 7.6). Areas affected include Malki-Dhanketi, Upper Shillong, Laithumkhrah and Lawsohtun, Laban, Nongrim Hills and Umlynka were ravaged by landslides most

of which were triggered by incessant monsoon rainfall. In the urban areas the processes get accelerated due to human interference in the landslide prone areas. Landslides are mostly encountered along the NH 40 that cause frequent disruption of vehicular traffic. The affected areas include Umiam, Umtrew, Umsalem, Ryndangbriew, and Mawiong. The area between Mawlai and Summer along NH 40 shows conspicuously frequent incidence of landslides. Majority of the recent failures along the NH 40 are characterized by slumps with an average width of about 30 m and a length of 50 m from the toe to the highest back scarp.

Table 7.2: Distribution of Landslides in different land use classes.

Sl. No	Land use class	No of landslides	Type of landslide
1	Open forest	5	Slumping, Debris fall.
2	Dense forest	47	Flow, Debris fall and Slumping
3	Scrub	3	Slumping
4	Agriculture crop land	-	-
5	Urban areas	5	Debris fall.
6	Water bodies	-	-

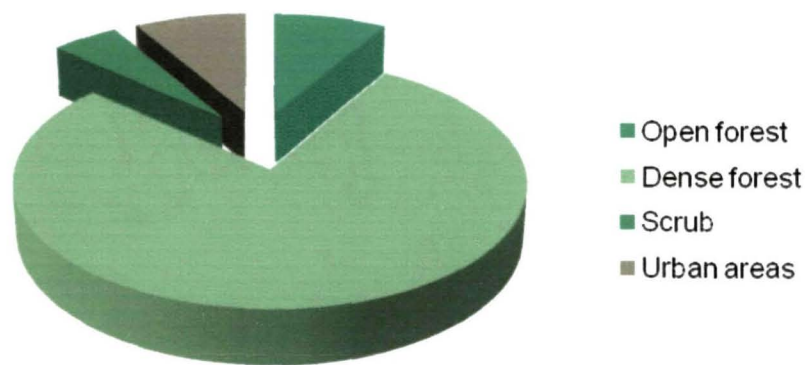


Figure 7.5: Distribution of landslide in different land use classes.

In most areas slumps have met at the toe or crown. Toe removal through unscientific method has been attributed as the main causative factor for these slides. Normally the calamity is triggered by a sufficiently strong mechanism which overcomes the natural stability of a segment i.e. the shear resistance threshold is exceeded. The landslide occurrence values are higher in dense forest areas and lower in open forest and scrub. The dense forests along the NH 40 have smaller diameter pines trees compared to the other areas with larger diameter. This factor might also accelerate the cause for sliding since larger diameter trees have more roots, and so have the capacity to maintain the water and soil pore pressure in heavy rains. The undisturbed forest, natural grass lands and forest plantations have not witnessed any remarkable slide.



Figure 7.6: Breakage of the retaining wall in umlynka after heavy incessant rainfall where three people died on the spot.

ii. Landslide and drainage pattern

The drainage density was found to be $0.35-5.43 \text{ km km}^{-2}$. Most of the slides were concentrated on drainage density of $1-3 \text{ km km}^{-2}$ (Table 7.3) and are of debris fall and slumping type in nature. The landslide occurrence (Figure 7.7) is higher when the

drainage is good. From the overlay analysis of drainage map with landslide map it was observed that most of the slides occurred in areas where dominating drainage pattern show a trellis pattern, locally dentritic. The trunk channel follows the structural trend of the quartzites of Shillong Group while the tributaries join it following erosional dissecting across this trend. The streams and rivulets descending the high slopes incise their channel deep into the thick overburden and intensely deformed soft sediments inducing instability to the hill slopes (Figure 7.8). Drainage characterization in the study area reflects the slope evolution of an area and an indicator of the mass wasting and related erosional aspects. Thus it may be concluded that zones with the parallel pattern of drainage associated with strong slope control is the most probable situation for landslides.

Table 7.3: Landslide frequency in different Drainage density classes

Sl. No	Drainage density (km km ⁻²)class	No of landslide	Type of landslide
1	<1	-	-
2	1 – 2	17	Slumping and flow
3	2 – 3	36	Flow, Debris fall and Slumping
4	3 – 4	3	Debris fall and Slumping
5	4 – 5	3	Debris fall

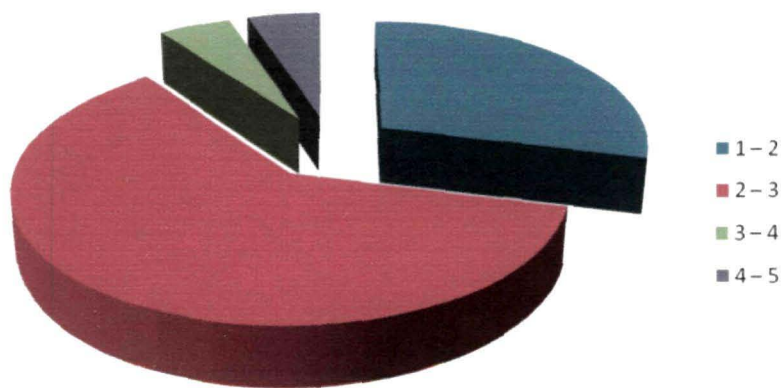


Figure 7.7: Distribution of landslide in different Drainage density classes



Figure 7.8: a. Breakage of the retention wall by the stream side during flash flood
 b. Debris fall near the stream at 4th mile, Upper Shillong.

iii. Landslide and Slope

In the case of slope, the steeper the slope the greater the landslide susceptibility (Table 7.4). Below 5° , slope number of slide is very low, but greater the angle from 5° to 35° , the number of slide increases. It means the landslide susceptibility increases according to slope angle. It was observed that at slope angle higher than 15° highest density of active landslides was found (Figure 7.9). Landslide recurrence was observed in areas with slope $<35^{\circ}$ and mostly within a buffer of 0-10m from the nearest road. Landslides take place under the load release due to cutting of slopes. The artificial hillside cut and construction activity on steep slope give rise to slope failure. Urbanization of steep hill slopes involving development of roads, expansion of habitation and new commercial establishments around localities of Mawpat, Lumparing, Risa colony, Bishnupur, Upper Nongthymmai, Madanriting, Lower New Colony, Tynring and Mawlai including several defence establishments on the hills of Mawpat, Lawsohtun and Rynjah areas have come up in a haphazard way. The slope

angle is an essential component of slope stability analysis. This is because as the slope angle increases, sheer stress in soil or other unconsolidated materials generally increases as well which leads to sliding of the materials. On the other hand low frequency of landslide was observed in gentle slope because of lower sheer stress associated with low gradient. On average, the frequency of landslides was greater on steep slopes than on gentle slopes. Further, an increase in landslide possibility was seen in such slopes which are oriented towards the NNW and NNE facing hills slopes.

Table 7.4: Landslide distribution in various slope classes

Sl. No	Slope class (Angle °)	No of landslides	Type of landslide
1	<2	1	Slumping
2	2 - 5	1	Slumping
3	5 – 15	11	Flow, Debris fall and Slumping
4	15 – 25	34	Flow, Debris fall and Slumping
5	25 – 35	13	Debris fall and Slumping

The study suggests that high positive pore pressure developed in the fissile rocks and thin soil cover overlying bedrocks and seepage of water from continuous precipitation were the triggering factors for slope failure.

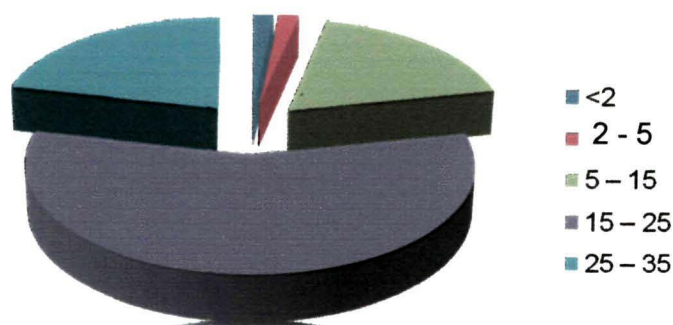


Figure 7.9: Distribution of landslides in various slope classes

iv. Landslide and lithology

The study area is beset with low grade metamorphic rocks of Shillong group of rocks comprising of quartzites with sub-ordinate phyllite of high fissibility and slates (in the northern extremity) and conglomerate. The rocks are highly weathered with soil cover ranging in thickness from less than 1 m to about 10 m at places. The relationship between landslide and lithology (Table 7.5) shows that landslide occurrence is higher in quartzite and phyllite in contrast to rainfall-triggered landslides in valley fill area which is negligible. This result is related to lithology and topography. Agarwal (1994) studied the landslide along NH 40 and found that the slides are confined to Shillong group of rocks and are more frequent where development activities have altered the slope profile. Incidentally all the active landslides that took place during the monsoon period in the study area were encountered along the NH-40, in the stretch characterized by well-bedded and jointed phyllite and the type of slide was mostly debris fall (Table 7.5). Therefore, it can be concluded that the potential stability problem along NH-40 was caused by steep slope excavations exposing the weathered regolith that cap over the parent rock in weak strata dominated by phyllite.

Table 7.5: Landslide distribution in lithology

Sl. No	Lithology	No of landslide	Type of landslide
1	Phyllites	6	Debris fall
2	Quartzites	54	Flow, Debris fall and Slumping

v. Landslide and structure

Most of the rock formations encountered in the study area were weathered to varying degrees, heavily jointed and intercalated with phyllite. Three discontinuity sets of joints have been encountered in the quartzites which have rendered them

splintery at places where all the sets are intensely developed. During rains when the pore water pressure increases weathered rocks easily fail along fissile surface like bedding, foliation or joints of phyllitic rocks. Along these joint planes the rocks fall and give rise to landslide mostly of debris fall. Major shear zone known as Tyrsad-Barapani shear occur in the near vicinity having NE-SW trend was found to affect the phyllites between Mawiong and Umiam along NH 40 which may also be another factor inducing slope failure.

Table 7.6: Landslide distribution and lineament density

Sl. No	Lineaments density class	No of landslides	Type of landslide
1	<1	9	Flow and Slumping
2	1 – 2	23	Debris fall and Slumping
3	2 – 3	18	Debris fall and Slumping
4	3 – 4	10	Debris fall

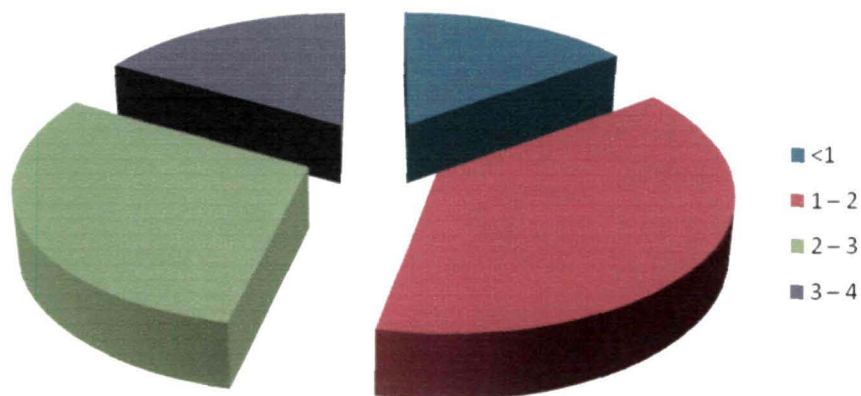


Figure 7.10: Distribution of landslide in various lineaments density classes

The analysis of relationship between landslide and lineaments density (Table 7.6, Figure 7.10), shows that most slides are confined to lineament density (1–3 kmkm⁻²) having NE-SW trend conforming to the structural trend of the area. Therefore, it may be concluded that the NE-SW trending Shillong Group of rocks, in general steeply

dipping with dip varying between 32°-60° towards SE, induce frequent slope failure. The area was also found to be susceptible to slope instability as the dip of the strata is in the same direction as the slope, although at places the bedding planes dipped unfavourably out of the slopes in many instances. Asymmetric folds and abrupt steepening of strata was seen in the road section near Mawlai

vi. Meteorological factors

The Shillong city witnesses strong monsoon precipitation during June to October with an average of 22 rainy days in a month and an average annual rainfall of about 2100mm. Rainfall intensity is however, variable in different parts of Greater Shillong area with a maximum of rainfall concentrated towards southwestern part. Figures 7.11 and 7.13 show monthly and annual variation of rainfall. An unusually high rainfall was recorded on October 8, 2004 measuring 262 mm as the highest one-day record in the past sixteen years. The highest rainfall since 1970 has been recorded on June 25, 1988 with 273.1 mm. As can be seen from the Figure 7.12 the years 2003 and 2004 received the maximum monthly rainfall particularly during October. It is interesting to note that during these two years the landslides were found to have closely followed the maximum rainfall days in October. The study indicates that, rather than simply in periods of high rainfall, landslides are more common when precipitation is continuous and exceeds the field capacity of the soil which may result in a rapid buildup of pore water pressure. In addition, even when high amounts of intense rainfall were involved, landslides were more likely if this has been preceded by a period of light but incessant precipitation. Light precipitation may infiltrate downwards and increase the soil moisture whereas heavy rainfall can flow on the surface in the form of runoff. Hence landslides occur when a high intensity rain follows a prolonged steady rainy season i.e. when the over burden is already

saturated. If the rainfall is not continuous, the soils lose their moisture and regain their strength within only a few days, while a much longer period is required before they become saturated again.

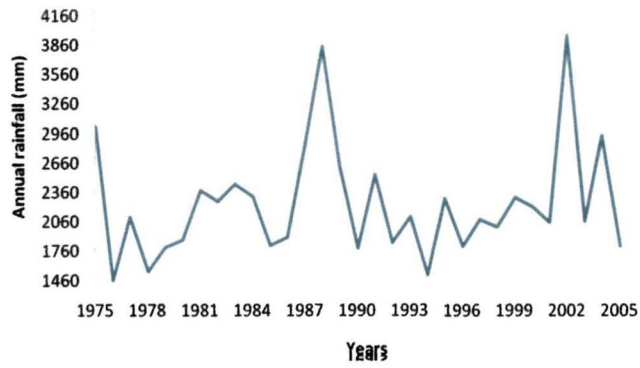


Figure 7.11: Variation in mean annual rainfall

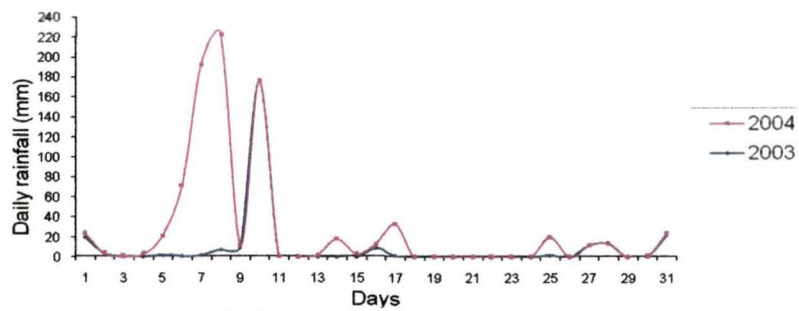


Figure 7.12: Daily variation in rainfall for the year 2003 and 2004

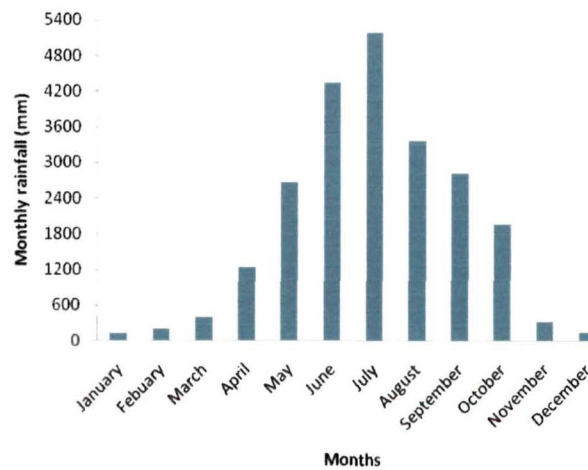


Figure 7.13: Monthly average rainfall for the last 30 years (1975 to 2005)

As a consequence, in the study area landslides occur more frequently in monsoon season. This phenomenon, together with the effect of surface erosion around the lower parts of the slopes and an increase in bulk density at the top, is likely to give rise to sudden and catastrophic failures. Frequently, such slope instabilities are followed by slumps until the equilibrium is re-established. It is surmised that heavy rainfalls during a continuous steady rains induce landslides in critical areas.

Flash flood

In the study area flashfloods are triggered by high intensity rainfall particularly along topographic lows around rivers. The problem has been aggravated by an overall reduction in river capacity and competence mostly due to human interference. Deforestation in the catchment areas of all the major rivers is very pronounced which has led to high sediment dispersal into the rivers. Extensive quarrying of the Shillong Group of rocks as building blocks and stone chips or sand mining mostly along step slopes bordering rivers has perceptibly silted up the river beds. Of the two main streams Wah Umkhrah and Umshirpi that drains through Shillong Master Plan Area, Wah Umkhrah has a larger catchment area and forms a floodplain. The Wah Umkhrah valley is deep and narrow in its upper reaches, which abruptly becomes wider and forms the floodplain in Pologround area. Recurring flash floods have been recorded mainly in this part of the valley. The load carrying capacity of the stream is also greatly reduced by rampant encroachment of the narrow valley right down to the channel itself (Figure 7.14). The flood hazard in this part is expected to grow further because of ongoing accelerated destruction of forest in the catchment area of Wah Umkhrah to accommodate the ever increasing demand for settlement areas.

In the absence of integrated drainage and sewage system the domestic sewage is being discharged directly to the streams (Figure 7.15) in the congested areas like Bara Bazar, Police Bazar, Garikhana, Laban and Mawprem, where the stream gets loaded with sewage and garbage resulting in decrease of the water carrying capacity of Wah Umkhrah. Records show that during recent past flashflood (Figure 7.16) along Wah Umkhrah submerged the areas viz., Pynthorumkhrah, Polo, Mawlai-Nongpdeng, Lawmali, 4th and 5th Furlong, Nongmynsong and Parmaw near Lumparing thereby resulting in damage of many houses.



Figure 7.14: Encroachment of the settlement areas towards the river bank



Figure 7.15: Dumping of garbage directly into river



Figure 7.16: Inundation due to flash floods along Wah Umkhrach river affecting life and properties

Many quarry sites in the study area are exploited for sand and aggregates utilized for construction purposes (Figure 7.17). It is interesting to note that detrimental quarrying procedures on the quarries sites are located by the sides of the streams (Figure 7.18). The principal problem related to the generation of silt from the quarry sites and deep excavations is sedimentation of rivers and streams.



Figure 7.17: Quarry sites of quartzite and amphibolites for sand and aggregates

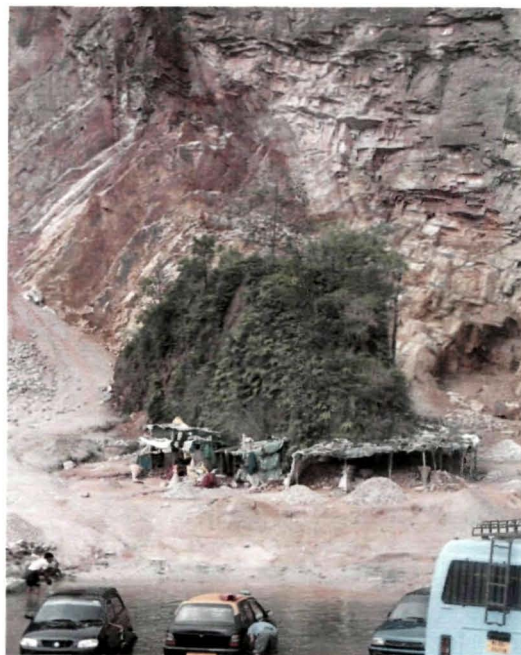


Figure 7.18: Huge quantum of silt is generated from the quarries that find their way to the nearest river. The photograph shows heavy siltation of Wah umkrah at the quarry sites. The siltation reduces the channel capacity and aid in flash flood.

Deforestation of lands and the subsequent use of land for urbanization and poor cropping management in the study area result into increased erosion and soil loss thereby increased downslope sedimentation and silting of water course and reservoir. Shifting cultivation “bun” methods of potato cultivation and cultivation on slopes with contour bunding are widely practiced in the study area which also results in excessive soil erosion (Figure 7.19). Soil erosion as a result of these activities is quite alarming but often it goes unnoticed as the eroded material is efficiently transported to drainage system due to rugged nature of terrain. Activities such as agricultural practice, timber logging and quarrying have come out at the expense of forest clearing around area extending from extending from Barapani, Umlynka, Mawpat, Tynring and Mawpdang.



a

b

Figure 7.19: a. Forest clearing for cultivation in rural fringe
b. Bun method of potato cultivation located near the stream

CHAPTER 8

URBAN METABOLISM

Introduction

The philosophy of modern cities is characterized by their routine use of energy as a driving force for power production, transportation of goods, construction of building and infrastructure as well as domestic comforts. In order to sustain themselves the cities rely on the ecosystems beyond the city limits for more resource and at the same time accumulate large amounts of materials within themselves. From the point of view of system ecology, cities are self-regulating system and may be seen as superorganism created for the benefit of human beings and for sustaining their livelihood (Huang and Hsu, 2003).

In an innovative thinking, taking the cue of metabolism which signify the chemical process by which food is built up into living matter or by which living matter is broken down into simpler substances, in the year 1965, Wolman brought forward the concept of urban material metabolism. He viewed the operation of urban ecosystem as a metabolic process. In recent years, ecologists have begun to model hybrid economic and ecological systems such as cities as if they were “superorganisms”, with their own metabolic processes (Zhang et.al. 2008). Such research on urban metabolism can contribute to solving of urban ecological and environmental problems by highlighting the demands placed by the urban metabolic system on various resources and the pressure of its discharged wastes on the environment (Sahely et al. 2003; Zhang et al. 2006). Urban metabolism has been extensively applied to explore resource consumption, material flows, asset accumulation and waste emissions in socio-

economic systems since the concept was first extended from biological science by social scientists to analyze human systems (Wolman, 1965). The metabolism of a city can be seen as the process of transforming all the materials and commodities for sustaining the city's economic activity. Extending from the concept of urban metabolism, the requirements to sustain the city include even the construction materials needed to build the city's structure over a period of time. Lawson and Douglas (1998) have suggested that deliberate human activity, in terms of excavating and filling of sectors of the earth's surface has become the most efficient geological agent on the earth at present.

The major environmental problems and associated social costs of an urban ecosystem are related to the rapid increase of resource inputs for urban consumption and the disposal of construction wastes, which are of nuisance to urban dwellers. To make urbanization sustainable, we must first understand how our cities function in the context of resource consumption. Like human metabolism, the physical and biological processes of a city system transform inflows of energy and materials into useful products, services and wastes. They are based on the laws of thermodynamics and a balance sheet of inputs and outputs can be analyzed. Material flow analysis can provide a framework for analyzing the urbanization process and the way cities are transforming the earth's ecosystems as a consequence of human activities. Rapid transfer of materials from the natural environment to the urban and industrial environment will change both geomorphology and urban morphology. Lawson and Douglas (1998) suggested that the account and quantification of material flow, reuse and recycling should be important components in the development of indicators that would help in identifying as to which country or city is becoming more sustainable in its behaviour.

This study is an attempt to understand the metabolism of Shillong Urban Agglomeration using the data on consumption of construction materials and discharge of waste and by preparing a flow diagram for the same.

Review of literature

The metabolism of an ecosystem has been defined by ecologists as the production (via photosynthesis) and consumption (by respiration) of organic matter, typically expressed in terms of energy (Odum, 1971). Kennedy et.al. (2007) defined urban metabolism as the sum total of the technical and socioeconomic processes that occur in cities, resulting in growth, production of energy and elimination of waste. Although metabolism is purely a biological concept, it can be applied by way of analogy to cities because the urban metabolic system is also a mechanism for processing resources and producing waste.

In the wake of rapid urban expansion, Abel Wolman published a pioneering article on the metabolism of cities (Wolman, 1965). He developed the urban metabolism concept in response to deteriorating air and water quality in American cities - issues still recognized today as threatening sustainable urban development. Wolman analyzed the metabolism of a hypothetical American city, quantifying the overall fluxes of energy, water, materials, and wastes into and out of an urban region of 1 million people. Since Wolman's work, a handful of urban metabolism studies have been conducted by a number of scholars based on Wolman's idea by treating city as if they were organisms and analyzing the processes and mechanisms that formed their metabolism in urban regions around the globe.

In the year 1995, Tjallingii put forward an opinion that a city, as an ecosystem, needed the imports of materials and energy for maintaining the function of the

ecosystem normally, and at the same time these imports would also bring about economic cost and environment problems. He held that the eco-efficiency of urban materials metabolism could be improved through utilizing administrative and technologic measures to restore the urban metabolic processes. Lyle (1996) reviewed the ecological researches on cities and emphasized about the importance of cities in the global ecology and suggested to put aside the classical image of cities and to consider the ecological functions of cities. Satterthwaite (1997) outlined a framework for assessing the environmental performance of cities in regard to their meeting of sustainable development goals and stressed on the importance of taking into account the environmental costs generated or imposed by city-based activities on people or ecological resources outside city boundary or displaced into the future. Newman (1999) expanded the concept of urban metabolism to include aspects of livability for demonstrating the practical meaning of sustainability. Mani and Varghese (1999) discussed the ongoing effort in developing a system to assist planners in taking decisions conducive to sustainable development and progress, where system design is generic and can be adopted to other areas such as urban planning, defense, agriculture, population studies etc.

Newman (1999) proposed that the process of urban materials metabolism, such as a biological system operation, was about the inputs of resources and the output of production and waste. Newcombe et.al. (1978) studied the metabolic process in Hong Kong to determine inflows and outflows of construction materials and finished goods based on the theory of materials metabolism. Warren-Rhodes and Koenig (2001) studied the resource consumption, waste generation and its reuse in Hong Kong. Their results showed that per capita food, water, and materials consumption had increased by 20%, 40%, and 149%, respectively from 1971 to 1997. Sahely et. al. (2003) found

that although most inputs to Toronto's metabolism were constant or increasing, some per capita outputs, notably residential solid waste had decreased between 1987 and 1999. Newman et.al. (1996) studied the material metabolism in Sydney in 1970. Folke et.al. (1997) reported that Hong Kong relies upon, and appropriates heavily from natural ecosystem to produce food, water and other resources and to process wastes. Similar to other cities, it significantly augments and alters material flow and energy cycling through the environment. Huang (1998) focused on quantifying the embodied energy in cities by applying thermodynamics methods on urban material metabolism in Taipei. Louise (1998) focused on the urban metabolism to quantify the inflow and stock of heavy metals (Cd, Cr, Cu, Pb, Hg, Ni, and Zn) in goods in the anthroposphere of Stockholm, Sweden. The study showed the importance of stock which will help the planners to understand and predict future problems that may arise from metal containing goods and to implement a more sustainable use of metals. Hansen and Lassen (1998) developed an application of the database for a substance flow analysis of aluminium at the national level in Denmark, where the database has proven to be extremely useful in improving the environmental characteristics of different types of industrial products like copper and nickel. The ESPROMUD project (2008) examined the ways mining and urbanization change the rates and magnitude of the transformation of the earth's surface by geologic and geomorphic processes. It sets out to establish the total quantities of material shifted by extractive industries and in the building and operation of towns and cities and their supporting infrastructure. The findings of the project suggest that there is a need of scale-linked feedback from global climate and biogeochemical cycles to the local deliberate material flow and land surface modifications that will determine how those global changes impact upon individual cities and communities. Huang and Hsu (2003) applied material flow and

ecological energetic analyses to investigate Taipei area's urban sustainability in the context of urban construction. The material flows (sand and gravel, cement, asphalt, and construction waste) for constructing major urban engineering projects such as roads, bridge, MRT, flood prevention projects, storm drainage and sewerage pipes, and buildings have been analyzed for Taipei metropolis. It concentrates on the analysis of materials flows and evaluation of indicators. Lawson and Douglas (1998) concluded that the demands of cities for earth materials for construction have caused so much movement of rock and sedimentary matter that its rate is higher by two or three-orders than magnitude of the rates of erosion and sedimentation.

In India, literature on approaches towards urban metabolism is very rare. Learnmoth and Simmons (1997) viewed the metropolian area of Greater Calcutta as an ecosystem where functions of the city and system model of Calcutta has been worked out. They concluded that there is an overall ecological "envelope" which sets limits to human endeavour and all the adjustments within it have to be made through the medium of human culture in all its diversity. Chatterjee and De (1999) critically analyzed the present crisis faced by the society in managing the environmental problems, which are due to the absence of the systematic analysis and synthesis (system approach) of the environment. They emphasized that each and every environmental system is to be examined and understood in terms of its structure and behavior and at the same time interaction among them are to be determined. This will lead to a fruitful and sustainable management of environment and resources.

Results and Discussion

During the recent past, Shillong Urban Agglomeration (SUA) has experienced a rapid growth in expansion of urban areas with high rates of per capita consumption. As a result of rapid urbanization, currently, nearly 80% of the population in Shillong Master Plan Area lives in SUA which has become a visibly unsustainable environment. Despite a great expansion of the commercial sectors in SUA more investment in urban infrastructure is needed for sanitation and improving transportations. The examination of the demands on resources and disposal of urban wastes is critical to the evaluation of trends towards future sustainability.

A total of 503316 m² plinth area has been constructed between 2005-2008. Data on building construction for these years revealed that there is an increase of total plinth area of buildings per annum in SUA mainly in response to the rapid urbanization during the study period (Table 8.1).

Table 8.1: Summary of urban construction in Shillong Urban Agglomeration

Year	Category			
	Building (m ²)	Road (m ²)	Storm drainage (m)	RCC slab bridge (m ²)
2005-2006	106076.69	1040	1680	Nil
2006-2007	132080.31	1313	1749	Nil
2007-2008	265159.21	412	674	12.80
Total	503316	2765	4103	12.80

Road construction has been a major civil engineering project in SUA, since 1972 to 2008 total roads length is 189256 m² out of which 177766 m² is black topped and 1149 m² is concrete cement roads. During the period of three years a total length of 2765m² of new black topped roads has been built (Table 8.1). This has contributed to

the improvement of transport infrastructure in SUA. Since the area receives heavy rainfall, the construction of storm water drainage was also considered as major civil engineering project in SUA. The total length of storm water drainage built since 1972 was 33774m, in these three years of study the total length was 4103m which corresponds to 12.15 % of the total length since 1972. These constructions are leading to one-way traffic of energy and materials from rural areas to urban area (SUA) which is causing depletion of resources and degradation of the environment.

Resource flow

Calculation of the earth moving involved in all the urban construction was difficult as each individual project involves a different set of structural and resource requirements. Per unit requirements of materials for each type of construction has been used as a basis for estimating material flows during the past three years (Table 8.2).

Table 8.2: Per unit requirements of construction materials.

Category	Materials			
	Stone aggregates	Sand	Cement	Bitumen
Building	0.86 m ³ /m ²	0.5 m ³ /m ²	330 kg/m ²	0.0
Road	0.027 m ³ /m ²	0.0	0.0	2.64 kg/m ²
Storm water drainage	0.90 m ³ /m ²	0.5 m ³ /m ²	320 kg/m ²	0.0
RCC bridge	0.86 m ³ /m ²	0.50 m ³ /m ²	400 kg/m ²	0.0

Source: Public Works Division, Government of Meghalaya

Total consumption of stone aggregates and sand in three years was 6047.95 Mt (Table 8. 3) out of which 5999.31 Mt was consumed for construction of engineering projects such as buildings. An overall increase in year wise consumption was observed for stone aggregates and sand. The total consumption of cement in SUA for

three years was 918.22 Mt and the major consumption of cement was for construction of buildings (913.51Mt) with a maximum of 482.35 Mt in 2007-2008. As for bitumen, the major use was in road construction with 0.27 Mt for three years, and there is a tendency of decrease in the volume of consumption. This was mainly because most of the road constructions within the urban areas were nearly completed. In summary, sand and gravel are the major materials required for urban construction, which amounts to approximately 85.69 % of the total demand and are used mostly for buildings. The overall materials consumption for construction projects such as buildings are still increasing which indicates that urban expansion is taking place rapidly.

Table 8.3: Trends of resource consumption for urban construction in SUA

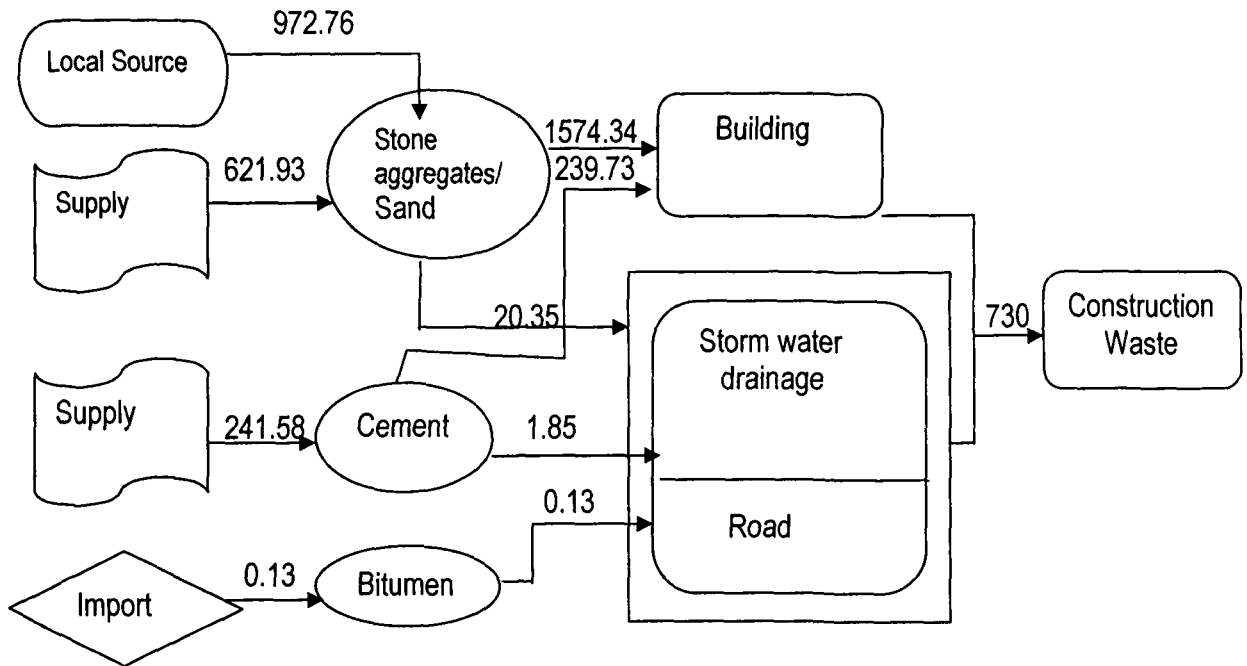
Category	Materials((Mt per year)		
	Stone aggregates and sand	Cement	Bitumen
2005-2006	1283.28	194.29	0.1
2006-2007	1594.69	241.58	0.13
2007-2008	3169.97	482.35	0.04
Total	6047.9	918.22	0.27

Data on construction waste are inevitably incomplete due to the lack of site for dumping and illegal fly tipping (illegal dumping). The most recent estimate of construction waste in SUA shows production of 730 Mt per annum for the year 2006-2007 which comes to 39.75 % of the resource consumed for construction. Although data for construction waste is not available for the year 2007-2008 the same was computed, assuming that the percent of waste during 2007-2008 remain the same as that of the year 2006-2007. Thus the construction waste for the year 2007-2008 was found to be 1451.81 Mt. Huang and Hsu (2003) reported that in Taipei city the

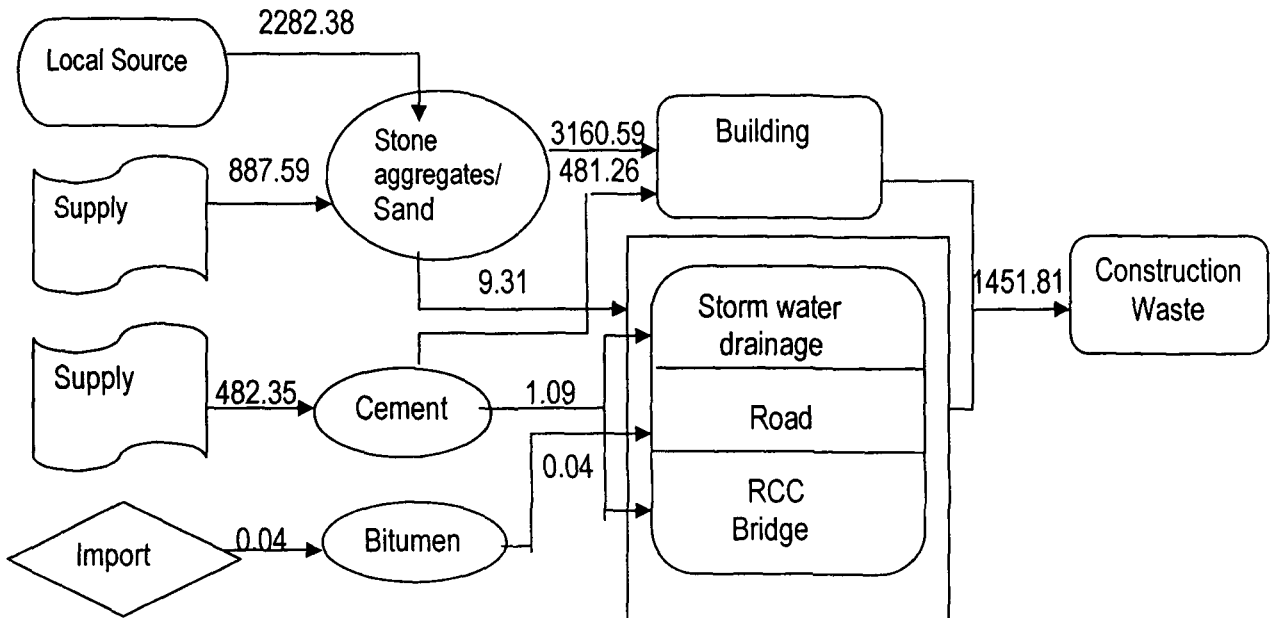
construction waste accounts to about 30 to 40%. This shows that the production of waste in the case of Shillong is similar to bigger cities situated in economically developing countries. Figure 8.1 summarised the comparison of materials flows for the year 2006-2007 and 2007-2008. The total amount of stone aggregates and sands consumption for these two years was 1594.69 Mt and 3169.97 Mt, out of which 612.93 Mt (39%) and 887.59 Mt (28%) come from supply outside the study area, 972.76 Mt (61%) and 2282.38 Mt (72%) come from local source supply. For 2006-2007, the total consumption of construction materials such as stone aggregates, sands, cement and bitumen amounts to 1836.40 Mt out of which 1574.34 Mt of stone aggregates and sands is utilized for building and 20.35 Mt for storm water drainage and roads. Out of 241.58 Mt of cement, 239.73 Mt is consumed for buildings and 1.85 Mt for storm water drainage. For road construction 0.13Mt of bitumen has been consumed. Similarly for the year 2007-2008, the total consumption of construction materials such as stone aggregates, sands, cement and bitumen amounts to 3169.97 Mt out of which 3160.59 Mt of stone aggregates and sands is utilized for building and 9.31 Mt for storm water drainage, roads and RCC bridges. Out of 482.35 Mt of cement, 481.26 Mt is consumed for buildings and 1.09 Mt for storm water drainage and RCC bridges. Road construction consumed 0.04 Mt of bitumen. The total consumption of stone aggregates and sands in 2007-2008 has increased to 66.53%, with an increase of production of about 10% from the hinterland, due to increase of building structures. As for the resource flows for building in 2007-2008, the consumption of stone aggregates and sands has increased by 66.75 %, and consumption of cement increased by 33.27 % due to the requirement of RCC buildings. However, the consumption of bitumen has decrease by 25.53 % as compared to 2006-2007. In addition to local source, the supply of stone aggregates

and sands has to rely on supply from outside Shillong city. The source of cement is from supply and for bitumen the city relies on import.

2006 - 2007



2007 - 2008



Units: Mt

Figure 8.1: Summary of resource flow of SUA urban construction.

The extraction of stones aggregates and sand is the most significant human contribution through material production to the geomorphic change in Shillong city landscape. From the limited study carried out during last few years it is found that the production of stone aggregates and sand has increased substantially and has become the largest source of primary aggregates used in Shillong city. The quarries located within the study area are worked as small enterprises and produce 61% and 72% of stones aggregates and sand consumed respectively for construction projects. This is because people seeking stone aggregates, sand and gravel tend to procure these materials that they need from the nearest and most convenient place. Active quarries or former quarries are not yet reclaimed due to which the scar faces of these extractive activities are vividly visible in the landscape. Such direct landform reshaping by such activities is high in areas of Nongthymmai, Laitkor, Pynthorumkhrah, Mawdiangdiang, Mawlai, Mawpat, Umroi and Umlynka. Out of 730 Mt of construction waste produced, a considerable part of this dumping of waste may be seen as a massive human contribution to changing the geomorphology of Shillong city through material aggregates extraction in some of the localities.

Increase in local production of stone aggregates and sand for consumption by different engineering projects in Shillong city, has raised the amount of siltation in the streams located near the quarry sites viz., Wah Umkhrah, Umshirpi and creating new level land which have been landfilled raising the height of the ground surface which is seen mainly in the area along NH 40. This material transfer is modifying the landscape at a rapid pace, particularly at the sites of extraction and waste disposal. With the present pace of urban growth, the waste materials are bound to increase. The rapid growth of urban areas with relatively weak planning and environmental controls

means that the geomorphic changes related to urban ecology are likely to become more extensive in the near future.

Materials flow accounting and quantification of the urban metabolism has helped in the development of indicators of the degree to which the Shillong city is becoming more susceptible in its behaviour vis-à-vis the geoenvironmental setup. The study suggests recycling of construction materials to reduce the rate of geomorphic transformation by construction material use and disposal is the need of the hour. The examination of geomorphic consequences of urban growth activities confirms the importance of looking at and encouraging of re-use of materials everywhere. It is important to identify the key areas of intervention to reduce off-site impacts and cost.

In terms of land consumption, both material extraction and dumping of wastes continues at present rate, the demand for large areas of land for such activities will grow. Since these areas have become unsuitable for other productive use and agriculture, the pressure will mount on the fringe areas to feed the city or for housing and infrastructure development which is bound to be unsustainable in the long run. The excavations of materials for major developments requiring substantial earth removal and relocation needs to be examined to find ways and means for more balanced use of earth resources.

The study, though very preliminary demonstrates that the city is growing at a very rapid pace and production of the construction waste is very high. There is a scope of reduction in urban waste through reuse as has been done in developed countries viz., (Bell, 1997).

CHAPTER 9

GENERAL DISCUSSION

Shillong Master Plan Area is a Precambrian terrain with low grade metamorphic rocks occupying more than 90% of the total area. The rocks are dominantly quartzites with sub-ordinate phyllites and slates, quartz-sericite schist and conglomerate. These rocks are intruded by mafic sills and dykes comprised of epidiorite, dolerite, amphibolites, pyroxenite rocks known as Khasi greenstones which occur mostly as sills concordant with the formation and acid intrusive such as Myllem granite. A part of the southwestern fringe of the study area is covered by Myllem granite, which is a batholithic intrusive body.

The oldest lithounit of the study area is composed of granite gneiss, forming part of the Basement Gneissic Complex. They are overlain by the Shillong Group of metasediments following an intervening hiatus marked by a conglomerate horizon. These sediments were deposited in a Proterozoic intracratonic basin under fluvial environment. Stratigraphically older horizon within the Shillong Group is mainly argillaceous, which are well exposed in northern and southern part of the basin, while the upper horizons are predominantly arenaceous with intermittent argillaceous and impersistent conglomerate beds. The Shillong Group of rocks are intruded by mafic sills and dykes which have undergone amphibolite facies metamorphism. They are now found as discontinuous bodies exposed at places as well as under a thin veneer of quartzites and locally known as Khasi greenstones. The youngest event of the

Precambrian sequence in Shillong Plateau is marked by emplacement of acid intrusives which form batholiths, stocks and bosses. A small part of a batholithic porphyritic granite known as Myllem granite is exposed in the western part of the study area. The quartzites of Shillong Group of rocks and Khasi greenstones are affected by numerous cross cutting quartz veins, which mark a post deformational phenomenon. These quartz veins trend along NNE-SSW, NW-SE and NE-SW and range in width from less than 1 cm to more than 30 cm.

Colluvial hill wash and a few patches of alluvium constitute the Quaternary sediments of the area which locally occur along the hill slopes and in intermittent valleys. They are seen as poorly sorted debris composed of cobble to boulder size sub-angular to angular pieces of tough massive quartzites and ferruginous quartzite embedded in semi-consolidated sandy ferruginous matrix and varies in thickness from 1.5 m to 3.0 m. Yellowish to brownish grey alluvium composed of silt and clay form a narrow alluvial tract in Polo ground and Pynthorumkhrah areas and form a 1.5 to 2.0 m high bank along Wah Umkhrah river. Minor valley fills of limited extension composed of grayish brown to yellowish brown coloured sticky clay have also been observed.

Both diastrophic and non-diastrophic structures are recorded in the study area. Non-diastrophic structures include primary sedimentary structures like bedding plane, current bedding and ripple marks, mostly symmetrical and sharp crested, which are well preserved in the arenaceous member of the Shillong Group. Well developed current bedding with foreset laminae dipping 20° - 30° form internal bedding structures in quartzites. In conglomerates crude bedding is revealed by presence of intermittent pebble free layers. In less metamorphosed areas siltstone lenses and channel fills are seen.

Deformation structures are well developed in Shillong Group of rocks which include at least three phases of folding resulting in both plunging and non-plunging types. Individual folds are open and mostly non-plunging and asymmetric types. Three sets of joints trending NNE-SSW (sub-vertical dips), ENE-WSW (30° NW) and NW-SE ($65^{\circ} - 75^{\circ}$ SW) have been encountered in the quartzites. Minor local faults and shears can be deciphered from brecciation within quartzites at some places.

Lineaments trending NE-SW conforming to the structural trend of the area are commonly found in higher frequency towards north. Average lineament density is $0.4 - 3 \text{ km}^{-2}$ while lineament frequency varies between $\sim 3.25 - 0.7 \text{ km}^{-1}$. Major drainage control in the area is found to be due to the predominant NE-SW trending lineaments. A major shear zone known as Tyrsad-Barapani shear trending NE-SW occur in the northern part that affect mainly the Phyllites of Shillong Group near Tyrsad and between Mawiong and Umiam along the G.S. Road.

The Shillong Master Plan Area is part of the central upland of the greater Shillong Plateau with elevation varying between 1400–1900m amsl. A gently undulating plateau top, the Laitkor range trending East-West direction with an average elevation of 1900 m above msl, is a prominent landmark in the southern extremity of the Shillong town. The Shillong Peak (1964 m) and Laitkor peak (1960 m) forms the highest points in the area of mapping. The main urban growth center of Shillong Master Plan Area is situated on a broad topographic low with several flat topped low relief hillocks and gently undulating valleys. Polo ground or Umkhrah valley skirts the northern edge of the town and is situated at a much lesser height.

The present day landscape of the study area is the result of a competing interaction of lithology and structure as well as climatic factors. Mass movements have played a major role in evolution of the numerous hillslopes while geomorphic work by high gradient rivers is evidently a controlling factor for the present day landscape development. Because of effective transfer of eroded debris, both from fluvial erosion and mass movement, the valleys are deeply incised bordered with cliff faces. Sheet erosion due to non-channel overland flow is very effective in the study area particularly during monsoon when precipitation may be as high as >1000 mm.

Broadly the geomorphology of Shillong Master Plan Area can be subdivided into two major geomorphic domains viz., plateau landform and fluvio denudational landforms. Almost the entire area comprises erosional landform which can be further subdivided into three categories viz., highly dissected, moderately dissected and less dissected. The fluvio-denudational landforms can be further subdivided into sub-domains namely the narrow infilled valleys and the terraces. Narrow valley fills and recent terraces have been deposited along the main streams cutting through the erosional surfaces.

DEM profiles shows that the area is having an undulating topography within the plateau domain with various degree of erosional dissection imparting the corrugation. Slopes vary between 2° - 35° . The main urban agglomeration of the city is developed in and around the moderate slope category which form ~28% of the total area. Out of the eight aspect classes representing direction of slope viz., NNW (18.87%), WNW (14.66%), NNE (13.66%), ESE (12.19%), ENE (11.68%), SSE (12.18%), SSW (8.87%) and WSW (7.90%), the maximum of slopes are found to be sloping towards NNW.

Dentritic, sub-dentritic, trellis and rectangular type drainage could be delineated in the study area. The main drainage of Shillong town is constituted by northwesterly flowing Wah Umkhrah and Umshirpi streams which are following the general strike of the area. These two streams join near Beadon and Bishop falls to form the westerly flowing Wah Ro-Ro, a joint controlled deep gorge and a tributary to Wah Umiam. The major trend of rivers synchronizes with the major structural trend of the region which is NE-SW, while a set of tributaries have developed as a result of erosional dissection across the structural trend and also following offset faults and joints across this trend. The lower plateau region in the central part of the area is characterized by moderately high drainage density with subdendritic to trellis type of drainage pattern. Rectangular drainage developed at many places is directly controlled by the two dominant joint patterns viz. NE-SW and NW-SE.

The development of soil cover in the study area is highly irregular and range in thickness from a thin veneer to more than 10 m at places. Inceptisol, and ultisols are the two major soil types of the study area. Ultisols are found in places dominated by quartzites and inceptisols occur in places where amphibolites are emplaced. The soils developed on the hills sides and/or escarpments are moderately shallow to deep, loamy skeletal to fine, excessively drained and subjected to moderate to very severe erosion hazards. These soils have well developed B horizon. Ultisols are reddish or yellow subsurface ferruginous clay mass with very irregular soil profile and formed due to weathering and chemical leaching of ferruginous quartzites. Towards north of the study area soil is comparatively better developed than the southern side. Areas which are characterized by flat topography, thickness of soil cover ranges from 1.0 to 3.0 m. Inceptisols comprising yellowish brown to greyish brown silt and clay occur mainly on the plateau top with thickness varying from 2.0 to 6.0 m. Oxidation is

prevalent in the areas where metabasics are emplaced in the quartzites and they are overlain by a thick laterite capping. Entisols have also been observed on very recent geomorphic surface along Wah Umkhrah and its tributary in the Polo ground area and the minor valley fills in the area. It is brownish grey to dark coloured sandy clay loam. They are fertile, poorly drained and seasonally flooded. These valley fills are heavy loams and contain larger amount of organic matter. It is found that this soil, with their level topography proximity for water for irrigation, and periodic nutrients replenishment by flood water sediments, supports agricultural activities in the valley filled areas.

The fourth-order drainage basin is occupied by diverse lithological unit and covers almost 80% of the area under study. The variation in size of the fourth-order drainage basins is largely due to physiographic and structural conditions prevailing in these drainage basins. Higher drainage development giving high mean bifurcation ratio is found in highly dissected drainage basins with strong structural control while elongated basins with high value of weighted mean bifurcation ratio shows variation in lithology dominated by Khasi greenstones, quartzites, weathered mantle and valley filled sediments, while lower values drain through pure quartzitic area. Higher drainage development giving high drainage density and stream frequency is characteristically found in the quartzite dominated terrain while lowest drainage development is found in the area occupied by the valley filled sediments. Values of elongation ratio range from 0.5 to 0.7 and circulatory ratios vary from 0.3 to 0.6. High values of elongation ratio and circularity values, especially in the south-western and south-eastern part is due to the combination of lithology and structural control and suggest an intermediate shape with a tendency to elongation associated with strong relief and steep slope. In the southeastern part the basins show a fully

elongated shape, the central basin show a stronger tendency to circular shape, the northern basins show a slight tendency to circularity and the southwestern basins show an intermediate shape with a tendency to elongation. The elongated shape of the basins indicates a young stage of evolution, while the intermediate shape with a tendency to circularity suggests an early mature stage. Lower values of the basins in northern part may be due to strong structural control on the drainage development. Minimum infiltration number shown by the Wah Umkhrah basin is possibly due to its lower catchment being in valley fill sediments, while the sub-basins draining the metasediments of Shillong Group show an invariably higher infiltration number.

The high hypsometric integral values of Wah Umiam (tributaries), Wah Umkhrah, Wah Umkhen, Wah Umkhen (tributaries) represent younger stage of development with deep incised and high down cutting with concave-down hypsometric curve, while Um Baniun and Wah Tamdong shows lower values with hypsometric curve approach monadock stage (i.e. old stage) of geomorphic development and Umshirpi, Wah Umbah, Wah Shella (tributaries), Phud-Umsning (tributaries) and Phud Mawiong has the shape of mature landform. Concavity of the hypsometric curve (Eh) shows that sub-basin D2, D3, D4, D5 and D6 are least incised, and sub-basin D7, D8, D10 and D11 are least eroded while most erosion prevails in sub-basin D1 and D9. From the position of the slope inflection point, a^* and h^* it is found that degree of peneplanation caused by strong erosion is highest in D1 and D9 followed by D8, D10 and D11 with least in D2, D3, D4, D5, D6 and D7. D1 and D9 sub-basin shows least effect of diffusive process, while those of D7, D8, D10 and D11 shows moderate diffusive erosion in the upstream segments and consist large mass accumulation at the sub-basin mouth.

A measure of a relative terrain uplift varying from 0.78 to 0.90 indicates high upliftment in the SW and SE sides compared to the NE corner. In general the longitudinal profiles of the trunk channels shows major structural controls. Differences in the materials along the course of a stream commonly caused an abrupt change from low concave to flat profile. The longitudinal profiles of most of the trunk channels shows the presence of one or more knick points which is related to offset faults in the region and a number of waterfalls dotting the study area are found to have been formed following these offset faults across the general strike in the Shillong quartzite, thus suggestive of profile adjustments to the continuous tectonic activities. The analysis of morphometric parameters of the drainage network shows that drainage development is largely controlled by structure and lithology.

Shillong Municipal Board (SMB) and Public Health Engineering Department (PHeD) provide the bulk of the water supply services to Shillong city. In order to meet long-term projection of water demand, a dam was constructed under Greater Shillong Water Supply Scheme (GSWSS) to divert water from Umiew River located 25 km from the main city. The Shillong Municipal Board obtains water supply from several surface water sources such as springs and streams amounting to 3.27 mld per day and it is distributed within Shillong Municipality area. Whereas water supply by PheD amounts to 5.69 mld out of which 3.64 mld is contributed by surface sources and 2.05 mld from underground sources and is supplied mainly to township. In areas beyond the SMB and PheD networks water supply service is being provided by the local dorbar by supplying water through stand posts.

SMB and PheD water supply accounts for 8.96 mld. 28.68 mld water is supplied by GWSS. The total water production from Greater Shillong Plannig Area is around

24.09% from surface water and 07.16% is pumped from groundwater and remaining 68.75% is imported from Umiew river. Besides the supply from Umiew river a deficit of 14.06 mld is experienced. Thus only 70 lpcd water is available to the consumer which is very much below the Government of India norms (130 lpcd for urban area).

Geological and geomorphological studies indicate that occurrence and distribution of surface water and ground water of Shillong Master Plan Area is not uniform due to inhomogeneity of lithology and degree of weathering as well as soil profile development. Hydrologically, tube wells/bore wells located at the intersection point of various lineaments in the area will have a good supply of water. Geomorphologically the ground water potential is limited to intermontane valleys.

Limited hydrological data used in this study indicates that groundwater occur both under artesian as well as water table condition with moderate to high yield. Occurrence of ground water in Shillong group of rocks is under water table condition in the weathered zones of underlying hard rocks where as in consolidated rocks it occurs under semi-confined condition. In general depth of water level is shallower in topographic depression than in the upland areas or slopes. The water of the area is mildly acidic to alkaline, soft and poorly mineralized. The elements present in the water are far less than the toxic limit excepting Fe which shows concentration more than 0.3 mg/litre. Average chemical health of the water sources is within safe limits as per national and WHO certified values. However, a higher degree of mineralization would have made the water more suitable to public health. The near deficiency of vital elements is due to non-availability of these elements in the Shillong group of rocks. Further, due to higher gradient, available elements are also washed away during heavy precipitation.

Six land use classes have been identified namely, built up land, dense forest, open forest, scrub, agricultural crop land and water bodies. For the year 2000, built up land occupies 8.96 % of the study area consist of urban and rural habitation and settlement. Water bodies cover 4.28 % of the area and are mainly represented by the Umiam lake and Wards lake. Agricultural crop land usually bun cultivation covers 6.58 %, with scrubs occupying 10.03 % of the study area. The area covered under pure pine and pine with broad leaf trees has been classed as dense forest which occupies 50.92 % with open forest consisting 19.23 % of the study area. Similarly, for the year 2005, built up land, dense forest, open forest, scrub, agricultural crop land and water bodies cover 9.35 %, 50.04 %, 18.90 %, 10.15 % and 6.93 % and 4.28 % respectively. From the analysis it has been observed that there has been a change in the landuse/landcover pattern within a span of five years. Area under dense forest has reduced to 7.74 km² which is replaced either by open forest, scrubs and agriculture and urbanization. A decrease of 2.28 km² is observed in open forest mainly due to deforestation, agricultural activities and urbanization. The reserved and protected forest forms almost a complete ring around Shillong comprises around 12.26 % of the total study area. Although agriculture area has increased by 0.71 km² mainly due to bun cultivation, this can create severe erosion problem and increase of siltation rate. Built up land class has an increase of 0.80 km², this is due to rapid expansion over the years where the town has spread to the forests areas which once skirted the town. Built up land have expanded especially towards northeastern part of the study area, this is a new township located nearly 13 km from the main city.

The twin hazards of landslides and flashfloods are recurrent geoenvironmental hazards causing loss of life and extensive damage of properties along certain sectors

of the city and adjacent areas. With growing anthropogenic activities and urban development, these twin problems have become more acute over the study years. As many as 60 minor and major landslides have been documented through on site inventurisation during the study years within the city, some of which are recurring type while most of them being found in new localities. Their distribution is predominantly along NH-40 apart from those in thickly populated urban areas. Most of the slides include slumping, debris fall and flow and the factors that have a direct bearing on the stability of the study area are the result from changes in the slope gradient both natural and man-made, changes in antecedent moisture content, vegetation and lithology. Most of the slides in the study area are confined to the regolith overlying the parent rocks. An integrated study of the causal factors using remote sensing data analysis, GIS and field investigation in respect of geological, geomorphological and meteorological parameters suggest that a multiple of factors are responsible for landslide in the study area.

Most of the landslides are confined in the national highways and urban areas. Landslide prone areas within urban areas are mostly debris fall and are located on steep hill slopes where the settlements have come up in a haphazard and unplanned manner and landslides take place under the load pressure of civil structures like residences. Unnatural load imposed on the rocks by the haphazard civil structures without slope management is another triggering factor. Landslides are mostly encountered along the NH 40 that cause frequent disruption of vehicular traffic. Majority of the recent failures along the NH 40 are characterized by slumps with an average width of about 30 m and a length of 50 m from the toe to the highest back scarp. Toe cutting through unscientific method has been attributed as the main causative factor for these slides. The landslide occurrence values are higher in dense

forest areas and lower in open forest and scrub areas. In these dense forests have smaller diameter pines trees with less roots, and have little capacity to maintain the water and soil pore pressure during heavy rains. Landslide recurrence is observed in areas with slope $<35^{\circ}$ and mostly in areas of toe cutting of slopes. The study suggests that high positive pore pressure developed in the fissile rocks and thin soil cover overlying bedrocks due to seepage of water from continuous precipitation is the triggering factor for slope failure. Landslide occurrence is higher in quartzite and phyllite. Incidentally all the active landslides that took place during the monsoon period in the study area are encountered along the NH-40, in the stretch characterized by well-bedded and jointed phyllite and the type of slide is mostly debris fall. Correlation of landslide frequency with respect to lineament density shows that most of the slides are confined to areas with lineament density $1-3\text{km}^{-1}$ having NE-SW trend conforming to the structural trend of the area. Flashfloods have been recorded in recent years in few localities particularly the topographic lows around Pologround areas. The immediate cause of flashfloods is however, constriction of the floodplain of Wah Umkhrah river by settlement, uncontrolled input of debris from the surrounding cliffs following high intensity rain and high relief of the terrain.

Siltation, though not a major cause of concern as of now, is slowly showing the sign of becoming a major problem in near future. Numerous rock and sand quarry sites are located along streams in and around the Shillong town. These quarries discharge huge quantum of silt on regular basis to the streams which is beyond the capacity and competence of the rivers to dissipate downstream. This results in aggradations of riverbeds and many a times leads artificial damming that becomes a cause of flashflood during rainy season. Urbanization of steep hill slopes involving development of roads, expansion of habitation and new commercial establishments

have come up in a haphazard way at the expense of forest. This also has contributed to enormous silt generation in the study area.

Shifting cultivation (bun methods of potato cultivation) and cultivation on the slopes with contour bunding are widely practiced in the study area which also results in excessive soil erosion. Soil erosion as a result of these activities is quite alarming but often it goes unnoticed as eroded material is efficiently transported to drainage system due to rugged nature of terrain. Deforestation of lands and the subsequent use of land for urbanization and poor cropping management in the study area result into increased erosion and soil loss thereby increased downslope sedimentation and silting of water course and reservoir. Anthropogenic activities such as deforestation and unplanned urbanization are the two most important factors responsible for environmental degradation leading to excessive soil erosion, lost of soil fertility, siltation of water courses, landslide, flood hazards and general desecration of landscape.

The extraction of stones aggregates and sand is the most significant human contribution through material production to the geomorphic change in Shillong city landscape. From the limited study carried out during last few years it was found that the production of stone aggregates and sand has increased substantially and has become the largest source of primary aggregates used in Shillong city. The quarries located within the study area are worked as small enterprises and produce 61% and 72% of stones aggregates and sand consumed respectively for construction projects. This is because people seeking stone aggregates, sand and gravel tend to procure these materials that they need from the nearest and most convenient place. Active quarries or former quarries are not yet reclaimed due to which the scar faces of these extractive activities are vividly visible in the landscape. Such direct landform reshaping by such

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The present study takes a holistic look into the geoenvironmental status of the Shillong urban agglomeration and its adjoining areas. The urban ecosystem has been analysed with the concept of urban material metabolism and it has been tried to find a link between the physical and biological parameters vis-à-vis their spatio-temporal variability. Lithological units, landforms and prevalent geomorphic setting are focused as platform to understand the urban ecosystem. This study has brought out a set of baseline data pertaining to the physical attributes which is expected to fill an information gap and be useful as future reference to understand and manage their spatio-temporal variability vis-à-vis changing status of the urban ecosystem in a scenario of ever increasing human interference with the natural systems. The study however, can be treated as the first approximation considering the resolution of mapping adopted. A further high resolution study, taking advantage of advanced technology available, both in temporal and spatial contexts and with direct field measurement of attributes to calibrate the changes imposed, will be the next step in right direction.

SUMMARY

Geoenvironment has been a key area of concern particularly during the last few decades due to increasing manifestation of adverse impact of anthropogenic forces on most parts of the earth. The top stratum of the earth's crust with diverse geological and geomorphic setting as well as under different climate regime, having interface with the hydrosphere, atmosphere and biosphere has borne the brunt of exploitation of earth's resources throughout the human civilization, more so in the post industrial era. The resultant impact on the structure and function of earth ecosystem is now all too apparent. It is often felt that there is a need for continuous evaluation and appraisal of the environment in terms of the physical parameters of the earth system vis-a-vis the man made ecosystems. Geoenvironmental study in combination with metabolism analysis in spatio-temporal context can be a very effective tool for rational evaluation of changing status of the environment and overall functioning of the ecosystem.

The geoenvironmental view of resource exploitation takes into account both the mass of minerals produced and the masses of overburden, wastes and by-products created. This view lead to a recognition that the material flows driven by human activities can be seen as part of a broader anthropogenic transformation of the earth's surface which has implications not only for supplies and environmental costs of materials, but also for the nature of the lands on which we live and the landscapes surrounding our daily lives. Materials flow accounting and quantification of the urban metabolism can help in the development of indicators of the degree to which a city is becoming more

sustainable in its behavior. Integrated appraisal of geoenvironment together with urban metabolism is an emerging field of applied research which has received ample attention of researchers in recent times. In a number of cities world over, the planners and researchers are engaged in evolving a holistic model of urban development based on modern ecological principles.

Shillong, the capital city of Meghalaya, is a growing urban centre with three and half lakh population, covering about 208 km² land. The growth has caused an immense pressure on the available resources and environment resulting into an imbalance in the city ecosystem. Therefore there is a need of regular monitoring of environment and inventorisation of the resources for proper planning and management of the city ecosystem. In doing so the status of geoenvironment has to be known for present and future development activities. In absence of a comprehensive base line data on the different geoenvironmental parameters it is difficult to comprehend any change that has taken place in terms of quantum and rate. Present study aims to fill in this gap in our knowledge on the dynamics, structure and function of Shillong city ecosystem. This study also intends to generate the base line data on Geoenvironment and Metabolism of Shillong city which can be used for monitoring of change and in planning for sustainable development of the city.

With availability of high resolution satellite data with repetitive coverage of the earth, development in location based technology viz., Global Positioning System (GPS) and enhanced capability of value addition to geospatial database in Geographic Information System (GIS) platform, have proved to be a valuable tool for evaluation of resources, appraisal of geoenvironmental status of a region as well as for assessing their spatio-temporal variability. Therefore, for the present study basic spatial data

was generated based on satellite data (IRS LISS III, FCC) and Survey of India (SoI) topomaps in 1:50000 scale. Preprocessing of topomaps and satellite data was done in GIS environment using the Orthoengine module of Geomatica 9.1 giving input of same projection parameters as earth model. Extensive fieldwork was carried out, both along and across strike for identifying the geological and geomorphological attributes. Satellite images (IRS LISS III, FCC) and DEM were studied for identifying the susceptible areas for landslides. On-site investigation and documentation of the existing landslides were carried out to develop an inventory. Flash flood prone areas were identified based on their record in news media and the actual events that happened during the year 2003 and 2004. The prefield maps were edited and finalized based on the field inputs and a spatial database was generated in GIS environment. Morphometric analysis was carried out based on the drainage segments and elevation contours extracted from Survey of India topomaps in 1:50000 scale. The LULC thematic mapping was done through standard visual interpretation techniques. Different thematic layers were prepared after digitizing and their attributes were entered accordingly. Thematic information gathered from laboratory analysis and fieldwork has been brought to GIS platform for further processing and analysis. Published geological maps, soil map, boundary map, municipal ward and township map, meteorological data, water sources location, water supply and production pattern, ground water level, water quality and consumption of construction materials data were used as collateral data. The GIS database generated in the form of raster, vector and attribute data was integrated for generation of composite data sets and queries buildings.

Shillong Master Plan Area is a Precambrian terrain with low grade metamorphic rocks occupying more than 90% of the total area. The oldest lithounit of the study area is

composed of granite gneiss, forming part of the Basement Gneissic Complex. They are overlain by the Shillong Group of metasediments following an intervening hiatus marked by a conglomerate horizon. These sediments were deposited in a Proterozoic intracratonic basin under fluvial environment. Stratigraphically older horizon within the Shillong Group is mainly argillaceous, which are well exposed in northern and southern part of the basin, while the upper horizons are predominantly arenaceous with intermittent argillaceous and impersistent conglomerate beds. The Shillong Group of rocks are intruded by mafic sills and dykes which have undergone amphibolite facies metamorphism. They are now found as discontinuous bodies exposed at places as well as under a thin veneer of quartzites and locally known as Khasi greenstones. The youngest event of the Precambrian sequence in Shillong Plateau is marked by emplacement of acid intrusives which form batholiths, stocks and bosses. A small part of a batholithic porphyritic granite known as Myllem granite is exposed in the western part of the study area. The quartzites of Shillong Group of rocks and Khasi greenstones are affected by numerous cross cutting quartz veins, which mark a post deformational phenomenon. Colluvial hill wash and a few patches of alluvium constitute the Quaternary sediments of the area which locally occur along the hill slopes and in intermittent valleys.

Both diastrophic and non-diastrophic structures are recorded in the study area. Non-diastrophic structures include primary sedimentary structures like bedding plane, current bedding and ripple marks, mostly symmetrical and sharp crested, which are well preserved in the arenaceous member of the Shillong Group. Deformation structures are well developed in Shillong Group of rocks which include at least three phases of folding resulting in both plunging and non-plunging types. Three sets of joints trending NNE-SSW, ENE-WS and NW-SE have been encountered in the

quartzites. Minor local faults and shears can be deciphered from brecciation within quartzites at some places. Lineaments trending NE-SW conforming to the structural trend of the area are commonly found in higher frequency towards north. Average lineament density is $0.4 - 3 \text{ km}^{-2}$ while lineament frequency varies between $\sim 3.25 - 0.7 \text{ km}^{-1}$. Major drainage control in the area is found to be due to the predominant NE-SW trending lineaments. A major shear zone known as Tyrsad-Barapani shear trending NE-SW occur in the northern part that affect mainly the Phyllites of Shillong Group near Tyrsad and between Mawiong and Umiam along the GS Road. The Shillong Master Plan Area is part of the central upland of the greater Shillong Plateau with elevation varying between 1400–1900m amsl. A gently undulating plateau top, the Laitkor range trending East-West direction with an average elevation of 1900 m above msl, is a prominent landmark in the southern extremity of the Shillong town. The Shillong Peak (1964 m) and Laitkor peak (1960 m) forms the highest points in the area of mapping. The main urban growth center of Shillong Master Plan Area is situated on a broad topographic low with several flat topped low relief hillocks and gently undulating valleys. Polo ground or Umkhrah valley skirts the northern edge of the town and is situated at a much lesser elevation.

The present day landscape of the study area is the result of a competing interaction of lithology and structure as well as climatic factors. Mass movements have played a major role in evolution of the numerous hillslopes while geomorphic work by high gradient rivers is evidently a controlling factor for the present day landscape development. Because of effective transfer of eroded debris, both from fluvial erosion and mass movement, the valleys are deeply incised bordered with cliff faces. Sheet erosion due to non-channel overland flow is very effective in the study area particularly during monsoon when precipitation may be as high as $>1000 \text{ mm}$.

Broadly the geomorphology of Shillong Master Plan Area can be subdivided into two major geomorphic domains viz., plateau landform and fluvio denudational landforms. The entire area comprises mostly of erosional landform which can be further subdivided into three categories viz., highly dissected, moderately dissected and less dissected. The fluvio-denudational landforms can be further subdivided into sub-domains namely, the narrow infilled valleys and the terraces. Narrow valley fills and recent terraces have been deposited along the main streams cutting through the erosional surfaces.

DEM profiles shows that the area is having an undulating topography within the plateau domain with various degree of erosional dissection imparting the corrugation. Slopes vary between 2° - 35° . The main urban agglomeration of the city is developed in and around the moderate slope category which form ~28% of the total area. Out of the eight aspect classes representing direction of slope viz., NNW (18.87%), WNW (14.66%), NNE (13.66%), ESE (12.19%), ENE (11.68%), SSE (12.18%), SSW (8.87%) and WSW (7.90%), the maximum of slopes are found to be sloping towards NNW.

Dentritic, sub-dentritic, trellis and rectangular type drainage could be delineated in the study area. The main drainage of Shillong town is constituted by northwesterly flowing Wah Umkhrah and Umshirpi streams which are following the general strike of the area. These two streams join near Beadon and Bishop falls to forms the westerly flowing Wah Ro-Ro, a joint controlled deep gorge and a tributary to Wah Umiam. The major trend of rivers synchronizes with the major structural trend of the region which is NE-SW, while a set of tributaries have developed as a result of erosional dissection across the structural trend and also following offset faults and

joints across this trend. The lower plateau region in the central part of the area is characterized by moderately high drainage density with subdendritic to trellis type of drainage pattern. Rectangular drainage developed at many places is directly controlled by the two dominant joint patterns viz. NE-SW and NW-SE.

The development of soil cover in the study area is highly irregular and range in thickness from a thin veneer to more than 10 m at places. Inceptisol, and ultisols are the two major soil types of the study area. Ultisols are found in places dominated by quartzites and inceptisols occur in places where amphibolites are emplaced. The soils developed on the hills sides and/or escarpments are moderately shallow to deep, loamy skeletal to fine, excessively drained and subjected to moderate to very severe erosion hazards. These soils have well developed B horizon. Entisols have also been observed on very recent geomorphic surface along Wah Umkhrah and its tributary in the Polo ground area and the minor valley fills in the area.

The fourth-order drainage basin is occupied by diverse lithological units and covers almost 80% of the area under study. The variation in size of the fourth-order drainage basins is largely due to physiographic and structural conditions prevailing in these drainage basins. Higher drainage development giving high mean bifurcation ratio is found in highly dissected drainage basins with strong structural control while elongated basins with high value of weighted mean bifurcation ratio shows variation in lithology dominated by Khasi greenstones, quartzites, weathered mantle and valley filled sediments, while lower values drain through pure quartzitic area. Higher drainage development giving high drainage density and stream frequency is characteristically found in the quartzite dominated terrain while lowest drainage development is found in the area occupied by the valley filled sediments. Values of

elongation ratio range from 0.5 to 0.7 and circulatory ratios vary from 0.3 to 0.6. High values of elongation ratio and circularity values, especially in the south-western and south-eastern part is due to the combination of lithology and structural control and suggest an intermediate shape with a tendency to elongation associated with strong relief and steep slope. In the southeastern part the basins show a fully elongated shape, the central basin show a stronger tendency to circular shape, the northern basins show a slight tendency to circularity and the southwestern basins show an intermediate shape with a tendency to elongation. The elongated shape of the basins indicates a young stage of evolution, while the intermediate shape with a tendency to circularity suggests an early mature stage. Lower values of the basins in northern part may be due to strong structural control on the drainage development. Minimum infiltration number shown by the Wah Umkhrah basin is possibly due to its lower catchment being in valley fill sediments, while the sub-basins draining the metasediments of Shillong Group show an invariably higher infiltration number.

The high hypsometric integral values of Wah Umiam (tributaries), Wah Umkhrah, Wah Umkhen, Wah Umkhen (tributaries) represents younger stage of development with deep incised and high down cutting with concave-down hypsometric curve, while Um Baniun and Wah Tamdong show lower values with hypsometric curve approach monadock stage (i.e. old stage) of geomorphic development and Umshirpi, Wah Umbah, Wah Shella (tributaries), Phud-Umsning (tributaries) and Phud Mawiong have the shape of mature landform. Concavity of the hypsometric curve (Eh) shows that sub-basin D2, D3, D4, D5 and D6 are least incised, and sub-basin D7, D8, D10 and D11 are least eroded while most erosion prevails in sub-basin D1 and D9. From the position of the slope inflection point, a^* and h^* it is found that degree of peneplanation caused by strong erosion is highest in D1 and D9 followed by D8, D10

and D11 with the least in D2, D3, D4, D5, D6. D7, D1 and D9 sub-basin show least effect of diffusive process, while those of D7, D8, D10 and D11 show moderate diffusive erosion in the upstream segments and consist large mass accumulation at the sub-basin mouth.

Morphometric studies show differential tectonic upliftment in the study area which is reflected in the hypsometric parameters. A measure of a relative terrain uplift varying from 0.78 to 0.90 indicates high upliftment in the SW and SE sides compared to the NE corner. In general the longitudinal profiles of the trunk channels shows major structural controls. Differences in the materials along the course of a stream commonly caused an abrupt change from low concave to flat profile. The longitudinal profiles of most of the trunk channels show the presence of one or more knick points which is related to offset faults in the region. A number of waterfalls dotting the study area are found to have been formed following these offset faults across the general strike in the Shillong quartzite, suggestive of profile adjustments to the continuous tectonic activities. The analysis of morphometric parameters of the drainage network showed that drainage development is largely controlled by structure and lithology.

Limited hydrological data used in this study indicates that groundwater occur both under artesian as well as water table condition with moderate to high yield. Occurrence of ground water in Shillong group of rocks is under water table condition in the weathered zones of underlying hard rocks whereas in consolidated rocks it occurs under semi-confined condition. In general depth of water level is shallower in topographic depression than in the upland areas or slopes. The water of the area is mildly acidic to alkaline, soft and poorly mineralized. The elements present in the water are far less than the toxic limit excepting Fe which shows concentration more

than 0.3 mg/litre. Average chemical quality of the water sources is within safe limits as per national and WHO certified values. However, a higher degree of mineralization would have made the water more suitable to public health. The near deficiency of vital elements is due to non-availability of these elements in the Shillong group of rocks. Further, due to higher gradient, available elements are also washed away during heavy precipitation.

Six land use classes have been identified namely, built up land, dense forest, open forest, scrub, agricultural crop land and water bodies. For the year 2000, built up land occupies 8.96 % of the study area. Water bodies cover 4.28 % of the area and are mainly represented by the Umiam lake and Wards lake. Agricultural crop land usually bun cultivation covers 6.58 %, with scrubs occupying 10.03 % of the study area. The area covers under pure pine and pine with broad leaf trees has been classed as dense forest which occupies 50.92 % with open forest consisting 19.2 % of the study area. Similarly, for the year 2005, built up land, dense forest, open forest, scrub, agricultural crop land and water bodies cover 9.35 %, 50.04 %, 18.90 %, 10.15 % and 6.93 % and 4.38 % respectively. From the analysis it has been observed that there has been a change in the landuse/ landcover pattern within a span of five years. Area under dense forest has reduced to 7.74 km² which is replaced either by open forest, scrubs and agriculture and urbanization. A decrease of 2.28 km² is observed in open forest mainly due to deforestation, agricultural activities and urbanization. The reserved and protected forest forms almost a complete ring around Shillong comprises around 12.26 % of the total study area. Although agriculture area has increased to 0.71 km² mainly due to bun cultivation, this can create severe erosion problem and increase of siltation rate. Built up land class has an increase of 0.80 km², this is due to rapid expansion over the years where the town has spread to the forests areas which

once skirted the town. Built up land have expanded especially towards northeastern part of the study area.

The twin hazards of landslides and flash floods are recurrent geoenvironmental hazards causing loss of life and extensive damage of properties along certain sectors of the city and adjacent areas. With growing anthropogenic activities and urban development, these twin problems have become more acute over the study years. As many as 60 minor and major landslides have been documented through on site inventerisation during the study years within the city, some of which are recurring type while most of them being found in new localities. Their distribution is predominantly along NH-40 apart from those in thickly populated urban areas. Most of the slides include slumping, debris fall and flow. The factors that have a direct bearing on the stability of the study area are: the changes in the slope gradient both natural and man-made, changes in antecedent moisture content, vegetation and lithology. Most of the slides in the study area are confined to the regolith overlying the parent rocks. An integrated study of the causal factors using remote sensing data analysis, GIS and field investigation in respect of geological, geomorphological and meteorological parameters suggest that a multiple of factors are responsible for landslide in the study area.

Landslide prone areas within urban areas are mostly debris fall and are located on steep hill slopes where the settlements have come up in a haphazard and unplanned manner. Unnatural load imposed on the rocks by the haphazard civil structures without slope management is another triggering factor. Landslides are mostly encountered along the NH 40 that cause frequent disruption of vehicular traffic. Majority of the recent failures along the NH 40 are characterized by slumps with an

average width of about 30 m and a length of 50 m from the toe to the highest back scarp. Toe cutting through unscientific method has been attributed as the main causative factor for these slides. The study suggests that high positive pore pressure developed in the fissile rocks and thin soil cover overlying bedrocks due to seepage of water from continuous precipitation is the triggering factor for slope failure. Landslide occurrence is higher in quartzite and phyllite. Correlation of landslide frequency with respect to lineament density shows that most of the slides are confined to areas with lineament density $1-3\text{km}^{-1}$ having NE-SW trend conforming to the structural trend of the area. Flash floods have been recorded in recent years in few localities particularly the topographic lows around Polo ground areas. The immediate cause of flash floods is however, constriction of the floodplain of Wah Umkhrah river by settlement, uncontrolled input of debris from the surrounding cliffs following high intensity rain and high relief of the terrain.

Siltation, though not a major cause of concern as of now, is slowly showing the sign of becoming a major problem in near future. Numerous rock and sand quarry sites are located along streams in and around the Shillong town. These quarries discharge huge quantum of silt on regular basis to the streams which is beyond the capacity and competence of the rivers to dissipate downstream. This result in aggradations of riverbeds and many a times leads artificial damming that becomes a cause of flashflood during rainy season. Urbanization of steep hill slopes involving development of roads, expansion of habitation and new commercial establishments have come up in a haphazard way at the expense of forest. This also has contributed to enormous silt generation in the study area.

The extraction of stones aggregates and sand is the most significant human contribution through material production to the geomorphic change in Shillong city landscape. From the limited study carried out during last few years it is found that the production of stone aggregates and sand has increased substantially and has become the largest source of primary aggregates used in Shillong city. The quarries located within the study area are worked as small enterprises and produce 61% and 72% of stones aggregates and sand consumed respectively for construction projects. This is because people seeking stone aggregates, sand and gravel tend to procure these materials that they need from the nearest and most convenient place. Active quarries or former quarries are not yet reclaimed due to which the scar faces of these extractive activities are vividly visible in the landscape. Such direct landform reshaping by such activities is high in areas of Nongthymmai, Laitkor, Pynthorumkhrah, Mawdiangdiang, Mawlai, Mawpat, Umroi and Umlynka. Out of 730 Mt of construction waste produced during the year 2006-2007, a considerable part of this dumping of waste may be seen as a massive human contribution to changing the geomorphology of Shillong city through material aggregates extraction in some of the localities.

Increase in local production of stone aggregates and sand for consumption by different engineering projects in Shillong city, has raised the amount of siltation in the streams located near the quarry sites viz., Wah Umkhrah, Umshirpi and creating new level land which have been landfilled raising the height of the ground surface. This material transfer is modifying the landscape at a rapid pace, particularly at the sites of extraction and waste disposal. With the present pace of urban growth, the waste materials are bound to increase. The rapid growth of urban areas with relatively weak

planning and environmental controls means that the geomorphic changes related to urban ecology are likely to become more extensive in the near future.

Materials flow accounting and quantification of the urban metabolism has helped in the development of indicators of the degree to which the Shillong Master Plan Area is becoming more susceptible in its behaviour vis-à-vis the geoenvironmental setup. The study suggests recycling of construction materials to reduce the rate of geomorphic transformation by reuse and disposal of construction material. The examination of geomorphic consequences of urban growth activities confirms the importance of looking at and encouraging of re-use of materials everywhere. It is important to identify the key areas of intervention to reduce off-site impacts and cost.

In terms of land consumption, both material extraction and dumping of wastes if continues at present rate, the demand for large areas of land for such activities will grow. Since these areas have become unsuitable for other productive use and agriculture, the pressure will mount on the fringe areas to feed the city or for housing and infrastructure development which is bound to be unsustainable in the long run. The excavations of materials for major developments requiring substantial earth removal and relocation needs to be examined to find ways and means for more balanced use of earth resources.

The present study takes a holistic look into the geoenvironmental status of the Shillong urban agglomeration and its adjoining areas. The urban ecosystem has been analysed with the concept of urban material metabolism and it has been tried to find a link between the physical and biological parameters vis-à-vis their spatio-temporal variability. Lithological units, landforms and prevalent geomorphic setting are focused as platform to understand the urban ecosystem. This study has brought out a

set of baseline data pertaining to the physical attributes which is expected to fill an information gap and be useful as future reference to understand and manage their spatio-temporal variability vis-à-vis changing status of the urban ecosystem in a scenario of ever increasing human interference with the natural systems. The study however, can be treated as the first approximation considering the resolution of mapping adopted. A further high resolution study, taking advantage of advanced technology available, both in temporal and spatial contexts and with direct field measurement of attributes to calibrate the changes imposed, will be the next step in right direction.

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APPENDICES

Appendix I: Chemical analysis of drinking water (2003)

Sl. No	Name	Source	pH	Hardness (mg/l)	Fe (mg/l)	Chloride (mg/l)	Bacteriological (MPN)	Turbidity (NTU)	Fluoride (mg/l)	Nitrate-N (mg/l)
0	Jaiaw Robert Hospital	Gravity	6.80	0.20	0.1	18.00	<2	3.16	NA	NA
1	4 1/2 Mile Tank	Gravity	7.64	0.51	0.1	16.41	<2	6.25	NA	NA
2	AG Complex Tube Wells	Tube Wells	6.50	0.40	0.6	32.03	<2	16.68	NA	NA
3	Assembly (Oakland)	Gravity	6.79	0.27	0.1	12.44	<2	8.02	NA	NA
4	Bara Bazar area (Public tap)	Gravity	6.60	0.40	0.2	13.50	NA	NA	NA	NA
5	Barapathar Tank	Gravity	6.39	0.19	0.1	7.35	<2	7.91	NA	NA
6	Chief Secretary Quarter(Oxford)	Gravity	6.91	0.55	0.1	17.67	9.2	5.47	NA	NA
7	Forest Colony	Hand Pump	7.00	4.18	0.8	0.16	NA	NA	NA	NA
8	Sdb Mawlai Mawroh	Well	6.78	0.64	0.6	17.05	<2	3.55	NA	NA
9	Greater Mawiong	Gravity	7.30	0.24	0.2	18.00		8.04	NA	NA
10	Harisava Tank	Gravity	6.82	0.48	0.1	16.50	5.1	4.39	NA	NA
11	Iewduh	Gravity	6.78	0.33	0.1	8.64	<2	6.01	NA	NA
12	Jaiaw	Gravity	6.80	0.29	0.1	10.84	<2	8.30	NA	NA
13	Karim Tank	Gravity	6.90	0.48	0.1	16.75	5.1	4.81	NA	NA
14	Kynton-u-mon w/s/s	Gravity	6.80	0.32	0.1	16.00	<2	4.16	NA	NA
15	Lachumere Municipal Tank	Gravity	6.94	0.50	0.1	16.99	<5.1	6.32	NA	NA
16	Lachumere PHE Tank	Gravity	6.61	0.46	0.1	15.32	<9.2	5.60	NA	NA
17	Laithumkhrah	Gravity	6.86	0.49	0.1	8.22	<2	6.63	NA	NA
18	Laitkor	Gravity	5.00	0.26	0.1	14.00	<2	3.04	NA	NA
19	Lamavilla (Public Tap)	Gravity	6.80	0.80	0.1	14.00	NA	NA	NA	NA
20	Lamlyer w/s/s	Gravity	6.50	0.32	0.1	12.00	2	3.32	NA	NA
21	Mawbyinna Madanlaban (St John)	Gravity	6.50	0.29	0.1	16.67	<2	3.52	NA	NA
22	Lumparing RCC Tank PHE	Gravity	6.93	0.53	0.1	15.83	2.2	10.78	NA	NA

23	Mawkhariah and Nongriem Sadew	Gravity	6.40	0.04	0.1	2.84	NA	NA	NA	NA
24	Mawklot	Gravity	6.40	0.12	0.2	11.30	NA	NA	NA	NA
25	Mawkhar	Gravity	6.84	0.44	0.1	11.51	<2.2	5.58	NA	NA
26	Mawlai Tank	Gravity	6.84	3.08	0.1	13.24	<2	6.01	NA	NA
27	Mawprem	Gravity	6.78	0.28	0.1	9.67	<2	4.82	NA	NA
28	Mawreng	NA	6.50	0.08	0.1	28.36	NA	NA	NA	NA
29	Nongpdeng Spring	Spring	6.90	0.40	0.1	10.00	NA	6.68	NA	NA
30	Nongpiur	NA	6.50	0.12	0.1	5.67	NA	NA	NA	NA
31	Nongthymmai Rum	NA	6.80	0.24	0.1	5.67	NA	NA	NA	NA
32	Nongthymmai Tank	Gravity	6.70	0.60	0.1	12.00	<2	2.04	NA	NA
33	Oxford Dulan Compound tank	Gravity	6.81	0.53	0.1	16.77	5.1	5.38	NA	NA
34	Oxford Mission Tank	Gravity	6.70	0.46	0.1	18.91	<2	6.47	NA	NA
35	Oxford Risa Tank	Gravity	6.84	0.53	0.1	17.82	2.2	5.20	NA	NA
36	Pomlum and Banium	Gravity	6.50	0.28	0.1	23.36	NA	NA	NA	NA
37	R.P.Shaha	Gravity	7.00	0.24	0.1	7.00	NA	6.84	NA	NA
38	Pasture Hills Tank	Gravity	6.46	0.43	0.1	15.34	<2	6.43	NA	NA
39	Pine wood Hotel	Gravity	6.93	0.49	0.1	17.83	<9.2	5.33	NA	NA
40	Raj Bhavan Tank	Gravity	6.86	0.49	0.1	18.18	5.1	6.27	NA	NA
41	Robert Hospital	Gravity	6.80	0.20	0.1	0.19	2	2.60	NA	NA
42	S A Nongrum Oxford	Gravity	6.80	0.32	0.1	10.00	<2	2.56	NA	NA
43	Sadew	Gravity	6.50	0.08	0.1	5.67	NA	NA	NA	NA
44	Sohrynkham	Gravity	6.80	0.40	0.1	12.00	<2	3.48	NA	NA
45	Raid Laban SMB Tank	Gravity	6.50	0.32	0.1	10.00	<2	1.88	NA	NA
46	SV School Tank (Madan laban)	Gravity	6.81	0.50	0.1	15.08	2.2	4.90	NA	NA
47	Synnai Nongthymmai	Gravity	7.10	0.24	0.1	23.00	<2	4.20	NA	NA
48	Umphyrnai w/s/s	Gravity	6.90	0.32	0.1	16.00	<2	4.76	NA	NA
49	Lumiawblot nongthymmai	Dug Well	6.90	1.36	0.1	48.05	NA	6.32	NA	NA
50	Traditional spring Lumiawblot	Spring	6.50	1.56	0.2	52.05	NA	10.88	NA	NA
51	Um Lawjynrew 1 Nongthymmai	NA	6.80	0.32	0.1	26.00	NA	7.68	NA	NA
52	Um Lawjynrew 2	NA	6.50	0.44	0.1	24.00	NA	8.44	NA	NA
53	GAD Quarter Tank	Gravity	6.64	0.49	0.1	15.02	6.9	5.92	NA	NA

54	Marbaniang w/s/s Mylliem	Gravity	6.70	0.22	0.1	12.00	<2	4.00	NA	NA
55	Mawpdang w/s/s New Shillong	Gravity	6.70	0.32	0.1	13.00	3	3.40	NA	NA
56	Oakland	Gravity	6.75	0.18	0.1	4.54	2	3.40	NA	NA
57	Fire Service Station Bore (I)	DTW	6.3	30	1.3	15	170	30.1	0.02	Trace
58	Rynjah	DTW	NA	NA	0.2	NA	NA	NA	0.02	0.1
59	Auxillium	DTW	NA	NA	3.5	NA	NA	NA	0.02	0.4
60	Umpling Tribal Colony	DTW	NA	NA	1.4	NA	NA	NA	0.02	0.1
61	Ishyrwat	DTW	NA	NA	2	NA	NA	NA	0.02	0.3
62	Umiam Lake	Lake	7.6	22	NA	16	NA	22	NA	1.4
63	Wards Lake	Lake	7.2	18	NA	10	NA	21	NA	2
64	Police Bazar	Spring	6.8	50.5	NA	25	NA	10	NA	7.2
65	Mawpdang (Mawlai)	Spring	7	62.4	NA	46.8	NA	14	NA	5

Source: PHeD Department, Meghalaya State Pollution Control Board; Government of Meghalaya, Shillong.

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