Drainage Network Analysis: Implication to Tectonic Interpretation of Sarawak

by

Nur'Azri Nabilah Binti Dahalan
13961

Dissertation submitted in partial fulfilment of the requirements for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the Petroleum Geosciences Programme
Universiti Teknologi PETRONAS in partial fulfilment of the requirements for the
BACHELOR OF TECHNOLOGY (Hons)
(PETROLEUM GEOSCIENCES)

Approved by,

____

AP Dr David Menier

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NUR'AZRI NABILAH BINTI DAHALAN

ABSTRACT

Landforms in Sarawak are results of a complex tectonic evolution. The tectonics in this region has greatly influenced the drainage system. Sarawak which is made up of complex geological and structural settings due to the multiple tectonic events is an ideal study area to investigate the tectonic activities that shaped the landforms of Sarawak besides the fact that there has been lack of regional scale study conducted in the area because of the dense forest. Digital elevation model (DEM) of Shuttle Radar Topographic Mission (SRTM) is the primary data that is used to perform the analysis. Based on the stream order analysis, the drainage networks in Sarawak are characterized into the first until the sixth order, based on the Horton-Strahler scheme. Watershed basin analysis is performed by identifying the area drained by a stream section and its tributaries and a total of 97 watershed basins are characterized. Based on the results from watershed analysis, drainage basin area which refers to the area of a given watershed is calculated. The density of the drainage basin is also calculated to study the sum of the drainage lengths divided by basin area. The tectonic interpretation is performed by generating profiles of certain drainage networks. The irregularities and anomalies identified on the drainage longitudinal profiles give the information required to study the tectonic processes that occurred in Sarawak. The findings from the profiles are further supported by more analysis and evidences obtained from the cross section of the drainage network as well as from field observations.

ACKNOWLEDGEMENT

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Geomorphology is a part of geology that deals with the study of landforms, including their description and genesis (Gupta, 2003). Rather than in the field, landform features are better studied and analysed on a regional scale using synoptic coverage provided by aerial photographs and satellite images (Gupta, 2003). Studying surface features of the Earth using these data, geomorphological investigations can be carried out easily as it provides direct information on the landscape (Gupta, 2003). These factors have brought about the importance and significance of Geographic Information System (GIS) and Digital Elevation Model (DEM) in many aspects of geological study. Both DEM and GIS have brought about a huge contribution in various fields in geology. This is proven by the increasing number of geological studies done using DEM and GIS (Kuterdem & Dirik, 2007; Singh, Sarangi, & Sharma, 2008; Rossetti, Valeriano, & Furini).

Geomorphological study requires one to consider all possible aspects that contribute to the formation of the landforms of the area. The study may require one to consider, not only the geomorphological parameters, but also drainage characteristics that make up the area in order to understand the tectonic behaviour of the region (Mohanty, Baral, & Malik, 2004). Drainage networks, drainage basin or watershed can be delineated easily by utilizing elevation data and GIS software. This in turn allows analysis on hydrological parameters and characteristics to be performed more efficiently in shorter time and less expenses. Figure 1 shows a drainage basin with the main river that is delineated from elevation data in GIS environment.

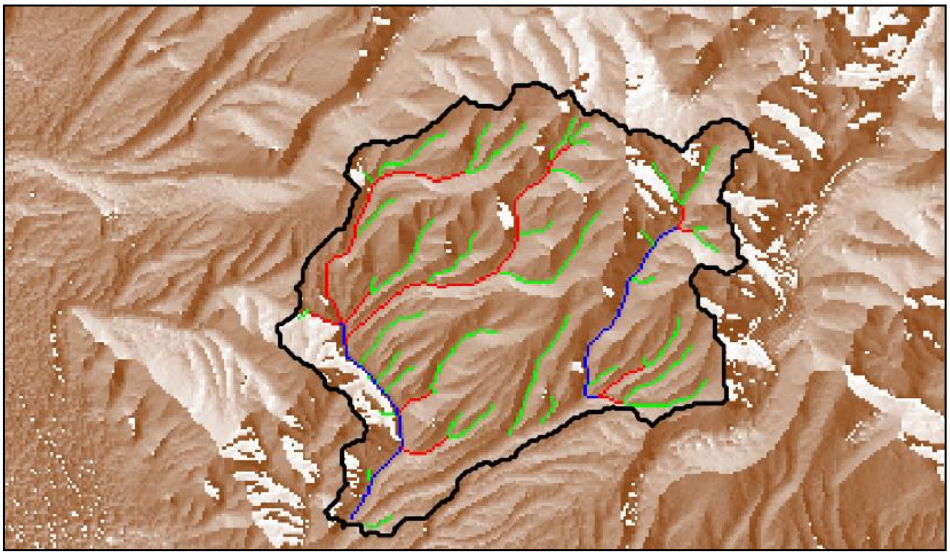


Figure 1: A drainage basin with the main river that is delineated in GIS environment. (MAPWINDOW, 2011)

Shuttle Radar Topographic Mission (SRTM) is an extensive DEM data is favoured by many researchers as they are consistent and comparable across large areas, compared to other high resolution DEMs (Mohanty, Baral, & Malik, 2004).

Geological features such as fault, fold and stream can be mapped out using DEM and for geologists, the information gathered from DEM is sufficient for them to carry out further study, particularly when no other data are available. This is common especially when the area is remote and inaccessible such that field work or other conventional methods are time-consuming and costly. Sarawak which is mostly made up of densely forested area is an appropriate area to carry out DEM based geomorphological studies due to the inaccessibility of onshore part.

Since Sarawak covers a relatively large area of the Borneo Island, the area of study is specified as shown in Figure 2.

Apart from that, Sarawak has been subjected to complex and massive tectonic evolution that contributed to the formation of its landforms that include the orogenic landform features in the Rajang Accretionary Complex. This makes Sarawak as an ideal laboratory to investigate the relative tectonic activity resulting from the tectonic evolution.

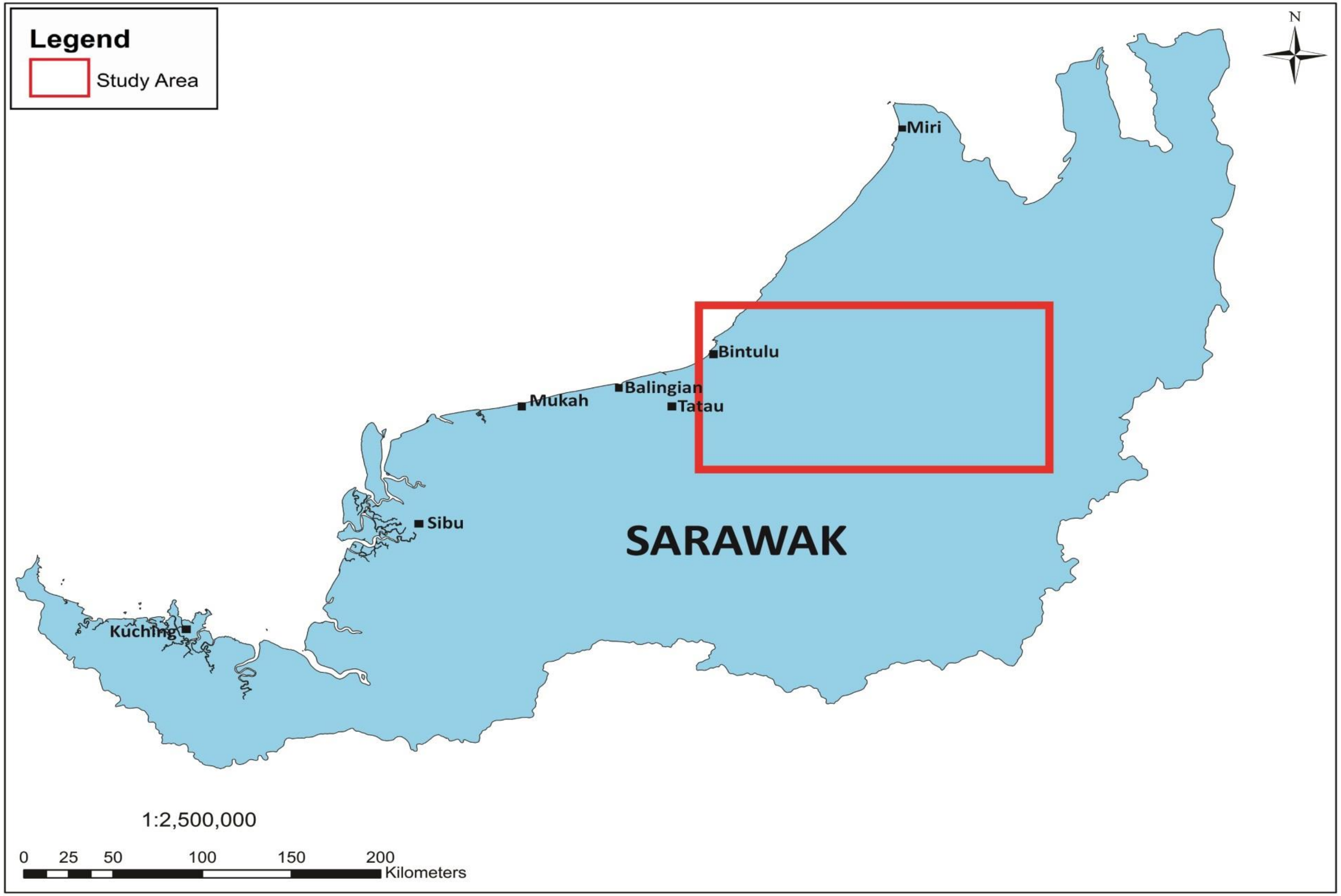


Figure 2: Location of Study Area in Sarawak.

1.2 PROBLEM STATEMENT

Sarawak comprises of densely forested area and it is hardly accessible for geologic study through field work. Consequently, there is a lack of information available to study the regional geology and tectonics of the area. In order to provide the needed geological information of the remote and large area of Sarawak, DEM and GIS is utilized to map out the geological features, which can give information on the tectonics of the area that shaped its landforms.

1.3 OBJECTIVE AND SCOPE OF STUDY

Objectives

a. To delineate drainage network in Sarawak using DEM

b. To define watershed basins for the entire drainage system of Sarawak and calculate their corresponding indices

c. To perform qualitative interpretation on tectonics based on drainage network

Scope of Study

The central focus of this study would be on geomorphological studies that emphasize on the drainage system based on the information obtained from DEM data. DEM is used to delineate drainage network and watershed basins. Further analysis on stream order, stream pattern, drainage network length, drainage anomaly, watershed basin area and density are performed based on the drainage network and watersheds.

Drainage network that is delineated using DEM will be used to relate the geomorphology of Sarawak with tectonic processes that formed the surface and structures of the area. Specifically, longitudinal profiles of selected drainage networks delineated within the study area will be generated and used to analyse the tectonics. The results from the geomorphological study will not be interpreted with respect to the sedimentology and stratigraphy associated with the area.

CHAPTER 2

LITERATURE REVIEW

2.1 Tectonic & Geological Background of Sarawak

Sarawak, occupying the north-western part of Borneo has undergone a complex tectonic evolution. The tectonic evolution of the area was recorded to have started in the late Cretaceous. This was supported by the deposition of shale, sandstone and chert that were found exposed in the Batang Lupar Valley (About Sarawak, 2011). During Middle Tertiary, the area was reported to have been subjected to various tectonic events such as uplifting, folding and faulting due to the fact that there was hiatus period of sedimentary rock deposition. This was further analysed and studied by Madon (1991).

Based on the research that has been conducted in the area, Madon (1991) came into conclusion that the oldest rock found in the area was deposited during the Late Mesozoic. He also stated in his study that the deposition of various lithologies in the area was getting younger in the direction from south to north and from west to east. He also found that the structural and stratigraphic complexity is decreasing toward the east part of Sarawak.

The tectonic evolution of the Borneo Island is very much associated to the rifting and sea floor spreading of South China Sea (Holloway, 1982). This is supported by and (James, 1984) as well as Tan and Lamy (1990). The former provide the explanation of the evolution using model, showing Central Luconia located in offshore of Sarawak being underlain by rifted South China Sea crust. The latter suggested that due to the rifting of South China Sea, collision occurred between the tectonic blocks with the island. These tectonic events are supported by Sorkhabi (2012) in his paper and he further stated that these events led to the formation of Rajang accretionary complex.

There were also tectonic processes involving uplifting and closing or proto-South China Sea or the Rajang Group (Mazlan, 1999). He further claimed that due to the uplifting and closing of the proto-South China Sea, Sarawak Basin formed and it is known as post-orogenic foreland basin. Normal faulting which occurred during Middle to Late Eocene had caused extension of the tectonic blocks in the area, resulting in formation of half-graben in the Balingan and Tatau provinces (Ismail and Swarbrick, 1997; Madon, 1999; Sim and Jaegar, 2003). This also had led to the formation of rift basin onshore of Sarawak, extended to Kalimantan (Pieters et al., 1987; Taib, 2010; Setijadji et al., 2010).

Onshore region of west Sarawak and Kalimantan was also subjected to extensional force that was associated to post-subduction event (Moss, 1998). ‘Second rifting’ that occurred during Late Oligocene to early Miocene had caused the sea floor in South China Sea marginal basin (Cullen, 2010).

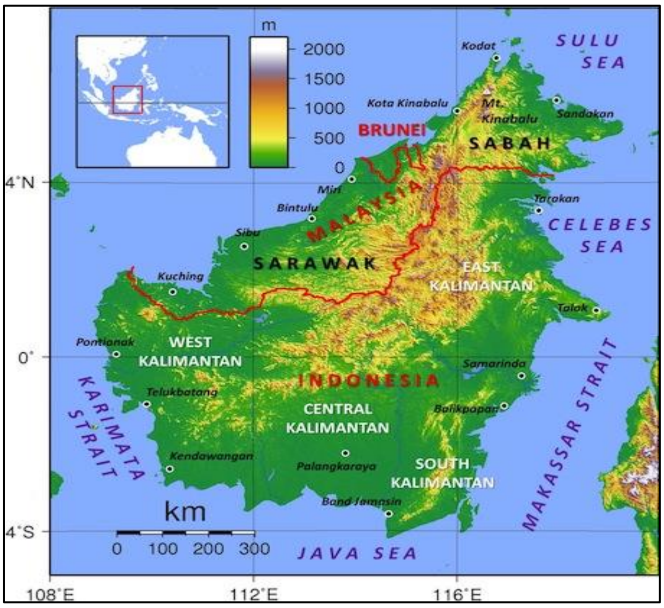


Figure 3: Rajang Accretionary Complex in Borneo. (Sorkhabi, 2012)

One of the important geological features that formed due to the tectonic evolution in Sarawak is the Rajang Accretionary Complex. Figure 3 shows the Rajang Accretionary Complex in the Borneo. The Rajang Accretionary Complex is generally southward, while the complex as a whole becomes younger northward (Honza, John, & Banda, 2000). They further stated in their study that the complex is interpreted as a series of thrust slices formed by accretion at a subduction trench as shown in Figure 4. In the Late Eocene, the subduction of the tectonic block stopped due to the collision of Balingian-Luconia Continent with the Rajang Accretionary Complex, initiating the Sarawak Orogeny (Honza, John, & Banda, 2000).

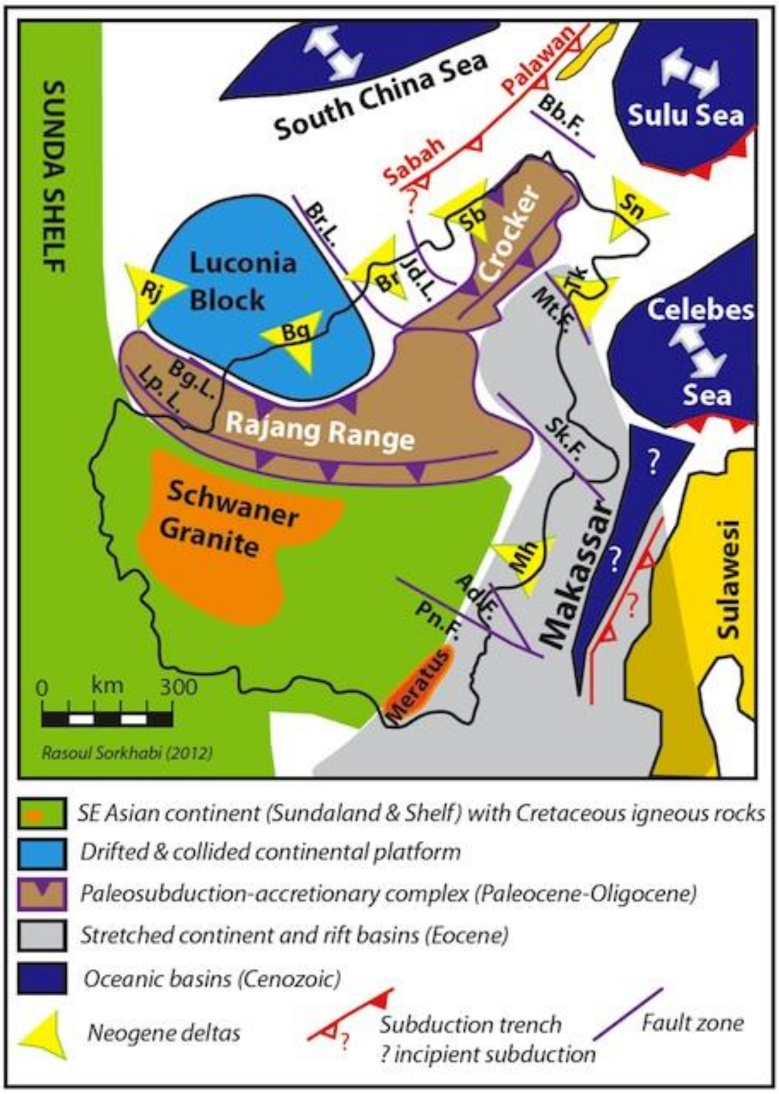


Figure 4: Sketched Map Showing Main Tectonic Features of Borneo. (Sorkhabi, 2012)

A summary on the tectonic evolution in Sarawak and the subsequent related processes and events are provided in Figure 5.

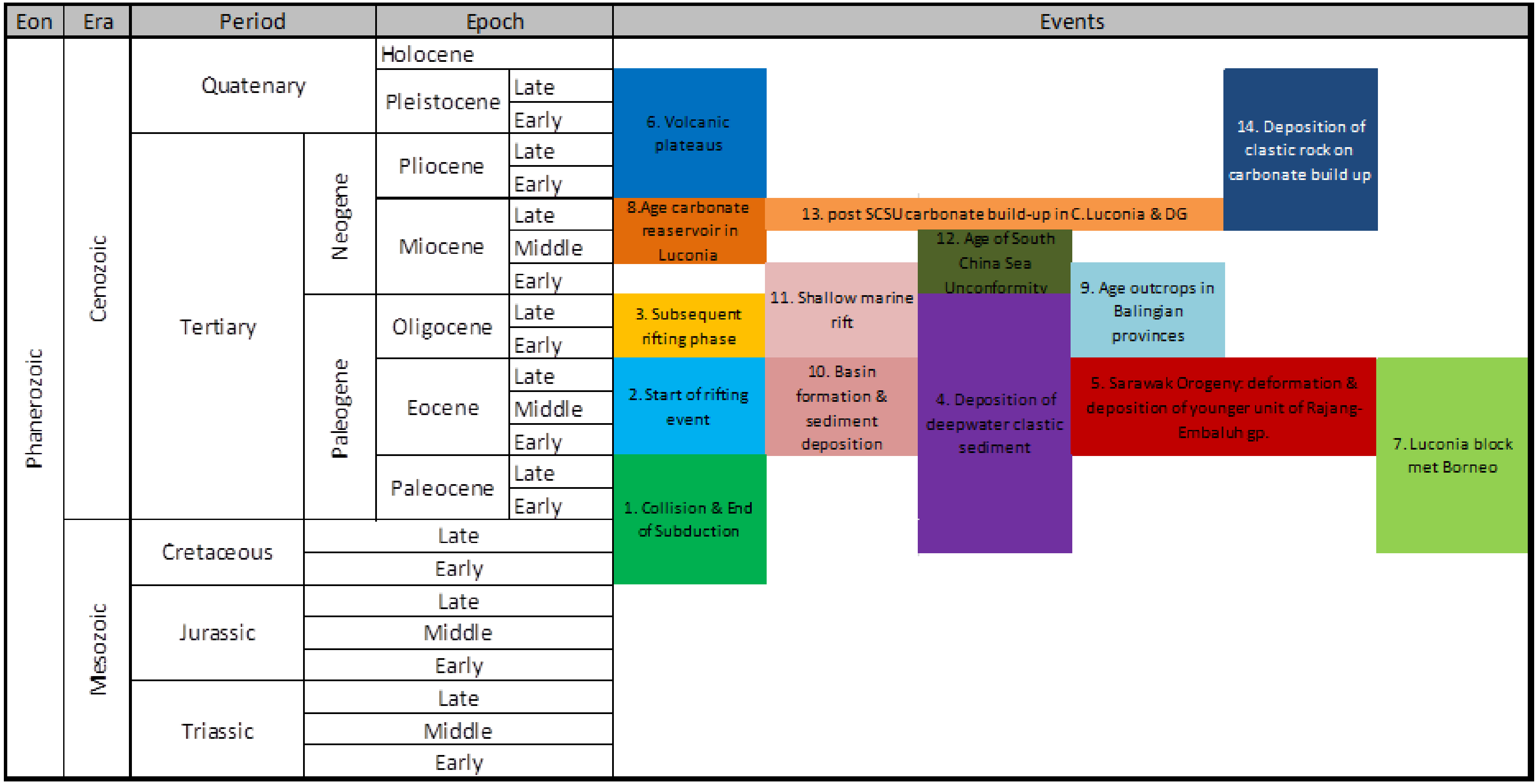


Figure 5:Tectonic evolution in Sarawak and the subsequent related processes and events

2.2 Drainage System

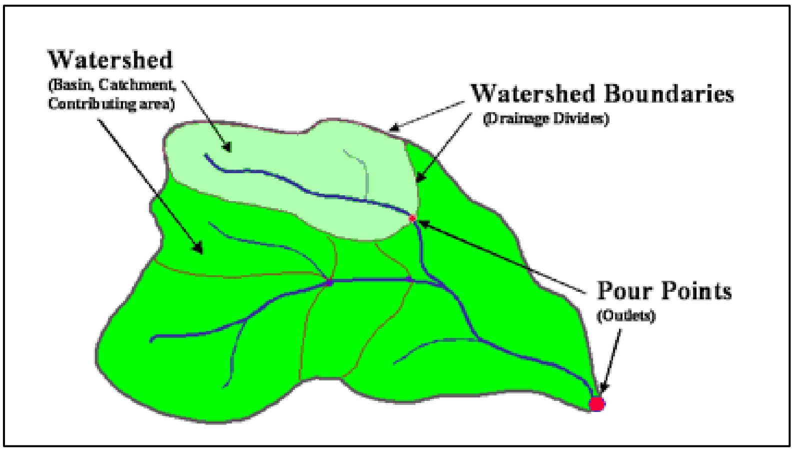


Figure 6: A Drainage System. (Esri, 2012)

Figure 6 shows a drainage system. Drainage sytem is defined as the area upon which water falls and the network through which it travels to an outle (Esri, 2012). Flow of water through a drainage system makes up the hydrologic cycle which also comprises of precipitation, evapotranspiration, and ground wate (Esri, 2012). An area that drains water and other substances to a common outlet is referred to as a drainage basin (Esri, 2012). Drainage basin can also be defined as the total area of land drained by a stream and all of its branches or tributaries or feeeders (RESOURCES FOR PHYSICAL GEOLOGY & HISTORICAL GEOLOGY). Ersi (2012) also stated that other common term for a drainage basin are watershed, basin, catchment, or contributing area. This area is normally referred to as the total area flowing to a given outlet, or pour point (Esri, 2012). A pour point is the point at which water flows out of an area, which is also the lowest point along the boundary of the drainage basin (Esri, 2012). Drainage divide or also known as watershed boundary is the boundary betweem two basins (Esri, 2012).

2.3 Geographic Information System (GIS), Digital Elevation Model (DEM) and Drainage Analysis

GIS is a tool that is developed to process, analyse and integrate spatial data sets (Gupta, 2003). Gupta (2003) also stated that GIS is a higher-order computer-based system which permits storage, manipulation, display and output of spatial information.

DEM is digital elevation set recording the topographic surface expression of any area (Chenrai, 2012). It also can be referred to as a form of digital terrain data (Mohanty, Baral, & Malik, 2004). DEM can also be defined as a raster representation of continuous surface, usually referencing the surface of the earth (Esri, 2012). The accuracy of DEM is influenced by the resolution, data type and actual sampling of the surface when creating the original DEM (Esri, 2012). Most studies involving DEM use SRTM data. Extensive data from a single source as with SRTM is particularly desirable due to the consistency and comparability across large areas, compared to other high resolution DEMs derived from variable sources like individual satellite images (Mohanty, Baral, & Malik, 2004).

Both GIS and DEM have been widely used in the study of morphology and tectonic (Kuterdem & Dirik, 2007). It is very useful in detecting, delineating and interpreting geological and structural features (Pirasteh, Pradhan, Safari, & Ramli, 2011). Specifically, this particular advantage of DEM data plays an important role when studying the geology of an area on a regional scale (Chenrai, 2012).

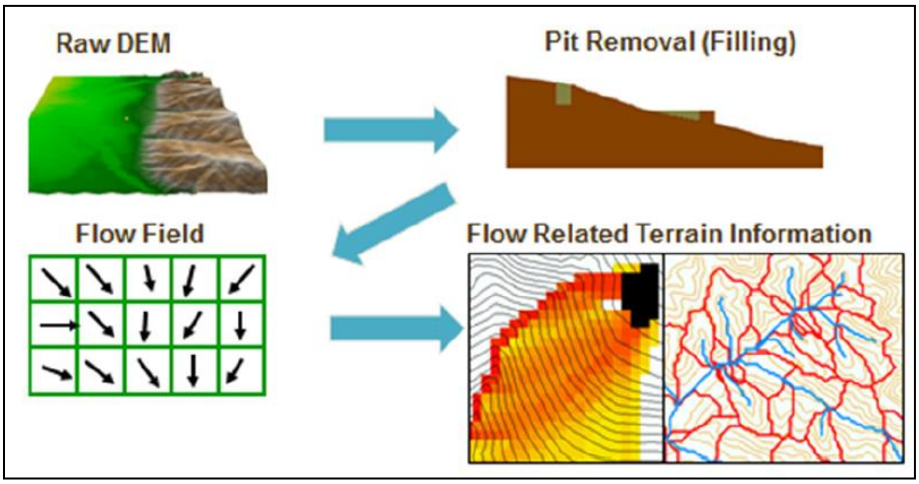


Figure 7: Workflow to obtain a depressionless DEM. (Tarboton, 2006-2013)

According to Esri (2012), an analysis on drainage system should start with elevation model. However, DEM usually contains errors that are termed as sinks or pits (Esri, 2012). Sink refers to cell that has elevation lower than the surrounding cells and it will lead to error in calculating flow direction (Tarboton, 2006-2013). A sink has to be removed in order for the depressionless DEM that is hydrologically correct and thus, can be used to calculate flow directions for each grid cell (Esri, 2012; Tarboton, 2006-2013). The flow field from which flow related terrain information such as watersheds and stream network is derived will be calculated once the flow directions have been quantified (Tarboton, 2006-2013). Figure 7 shows the workflow to obtain a DEM that its pits removed and can be used for drainage analysis.

Strahler (1957) stated in his paper that the first step in drainage analysis is order designation. He modified the order proposed by Horton in 1945. The designation of stream order then is known as Horton-Strahler scheme, which is shown in Figure 8. Based on the proposed method, streams are indexed with increasing numbers from source to outlet (Dombradi, Timar, Bada, Cloeting, & Hovarth, 2007).

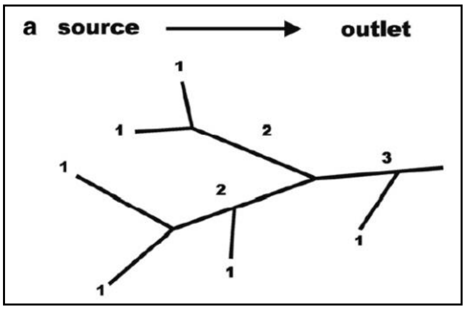


Figure 8: Illustration of hierarchical designation of stream order following Horton-Strahler scheme. Streams are indexed with increasing numbers from source to outlet. (Dombradi, Timar, Bada, Cloeting, & Hovarth, 2007)

Another drainage parameters studied by Strahler (1957) is drainage basin areas which he defined as area of a given watershed or drainage basin. Analysis on drainage system with respect to the basin areas has to be performed by comparing basins of the same order of magnitude i.e. area of a second order basin can only be compared with the area of another second order basin (Strahler, 1957).

Drainage density is defined as the sum of channel lengths divided by basin area. It is an indicator of the linear scale landform elements in a drainage basin (Strahler, 1957).

Howard (1967) conducted analysis on drainage system by considering few aspects such as drainage patterns, individual stream patterns and drainage anomalies.

Maps of drainage network can be produced in order to study and analysed the distribution of the drainage systems of an area (Markose & Jayappa, 2011). Figure 9 shows a drainage network with designated stream order.

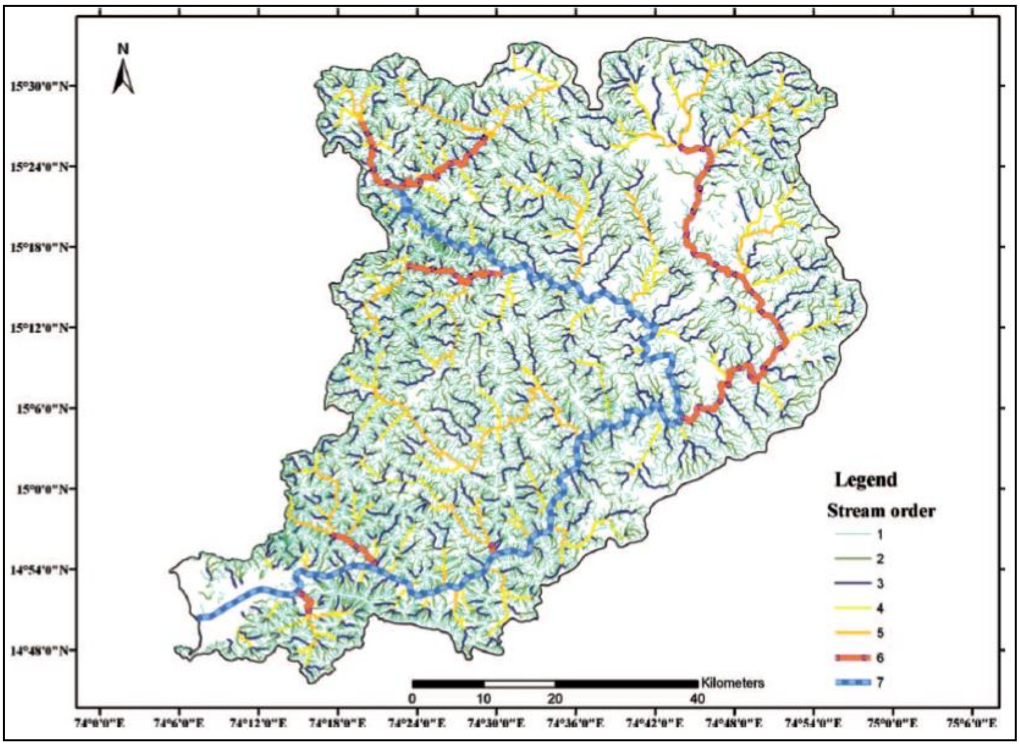


Figure 9: Map of drainage network with designated stream order. (Markose & Jayappa, 2011)

Apart from analysing drainage system based on these parameters, drainage which is a linear feature in GIS database can be analysed by measuring the azimuth. However, traditional methods which may include network delineation by stereoscopic vision of aerial photographs, tracing drainage system from topo map and calculation of basin parameters using planimeter, to mesure a large number of linear data are time-consuming and costly (Dinesh, Markose, & Jayappa, 2012).

2.4 Tectonic Interpretation Based on Drainage Networks

Studying the drainage systems can lead to the tectonics interpretation of an area as tectonics, according to Mahmood & Gloaguen (2012), in a particular area heavily influence its drainage systems and geomorphic expressions. They further stated in their paper that using DEM derived network, evaluation on the tectonics can be performed in order to study about the uplift rate associated with the area. This is also supported by Mohanty, Baral, & Malik (2004) who stated that there is an intimate link between uplift rates and geomorphology of an area. The evidence of tectonic activities can be found through various geomorphic signatures that can be studied using geology such as lithology, proximity to active faults and lineament density as well as geomorphological aspects such as landform, slope, lateral erosion by streams, drainage texture, elevation differences between adjacent valleys, altitude and relief (Mohanty, Baral, & Malik, 2004).

In the study conducted by Chen (n.d.), he stated that river profile provides information, not only on the association between erosion, lithology and accumulation, but also about tectonic events. He further stated that under certain conditions river profile furnishes evidence for tectonic deformation. Chen (n.d.) also stated that a typical river profile exhibits a characteristic shape as shown in Figure 10. However, there are several factors that can cause changes on the entire fluvial system, hence causing the system to adjust itself to achieve the typical river profile (Chen, n.d.). The factor include tectonic movements such as uplift or subsidence which can induce vertical changes to a given river profile.

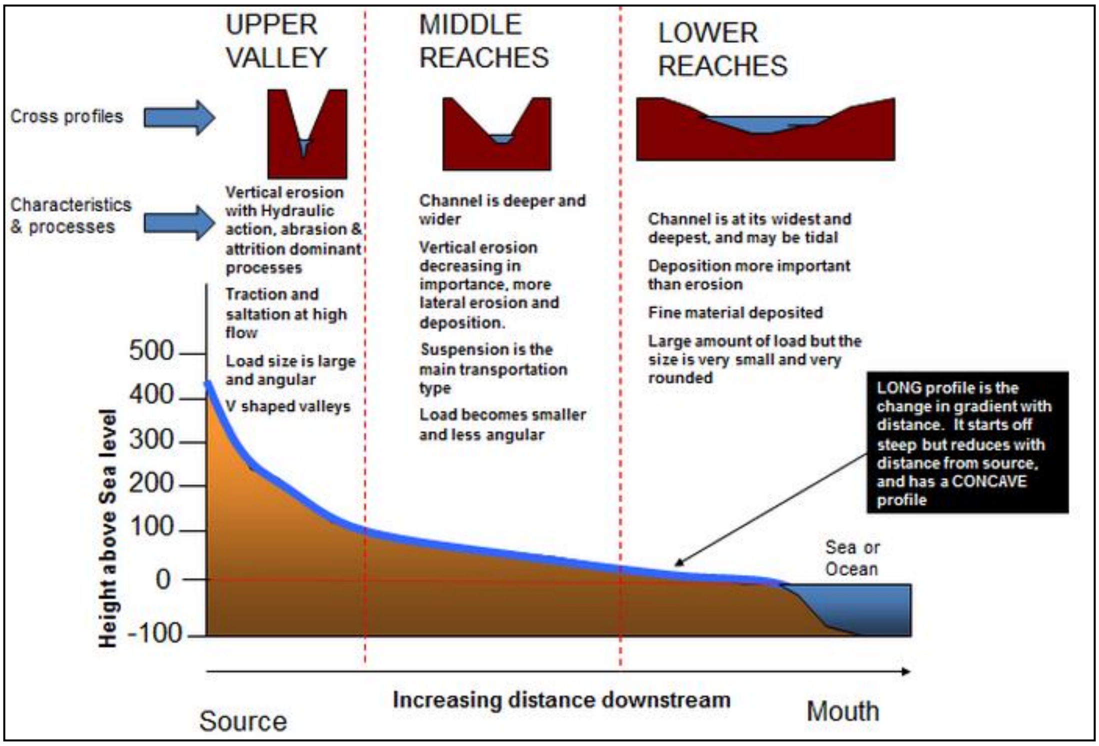


Figure 10: Profile of typical river and the corresponding valley shapes found at respective sections along the profile. (coolgeography.co.uk)

There is also another study conducted by Schumm (1993), who stated that the change on fluvial system is influenced by the baselevel. He further stated that there are another variables contributed to the change in the fluvial system. The variables are grouped into baselevel controls, which include direction, magitude, rate and duration; geologic controls, such as lithology, structure and nature of valley alluvium; and geomorphic controls which refer to the inclination of exposed surfaces, valley morphology, and river morphology and adjustability (Schumm, 1993).

CHAPTER 3

METHODODOLOGY

3.1 Field work

- Field work will be conducted at certain locations within the study area.
- The data and information that are collected from field work can be integrated with the analysis on the drainage system.

3.2 DEM data acquirement

- Data that will be used are DEM of Shuttle Radar Topography Mission (SRTM).
- The data are provided by United State Geological Survey (USGS).

3.3 Drainage analysis using DEM data

- Analysis will be performed using GIS software
- The stream order will be designed based on Horton-Strahler scheme.
- Anomalies in the drainage system of area of interest will be analysed
- Stream length, drainage basin area and density will be calculated.
- Maps of drainage network will be produced to analyse the drainage system.

3.4 Tectonic Interpretation

- Qualitative interpretation on the tectonic processes that shaped the landform and morphology of the area based on drainage network

The workflow for the study is shown in Figure 11.

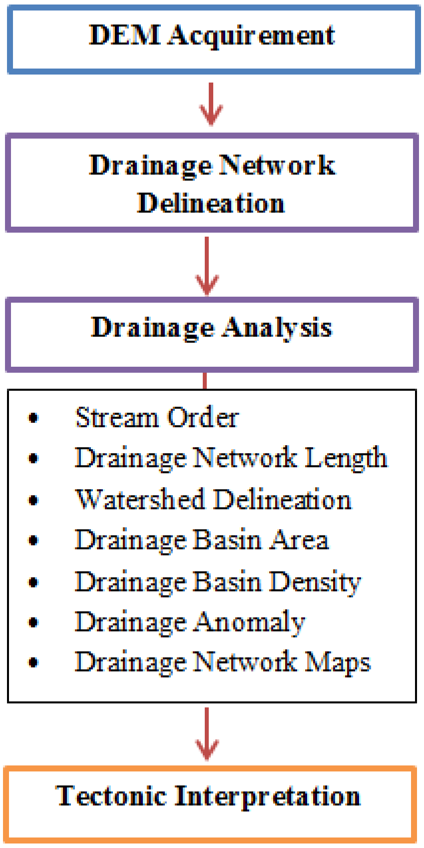
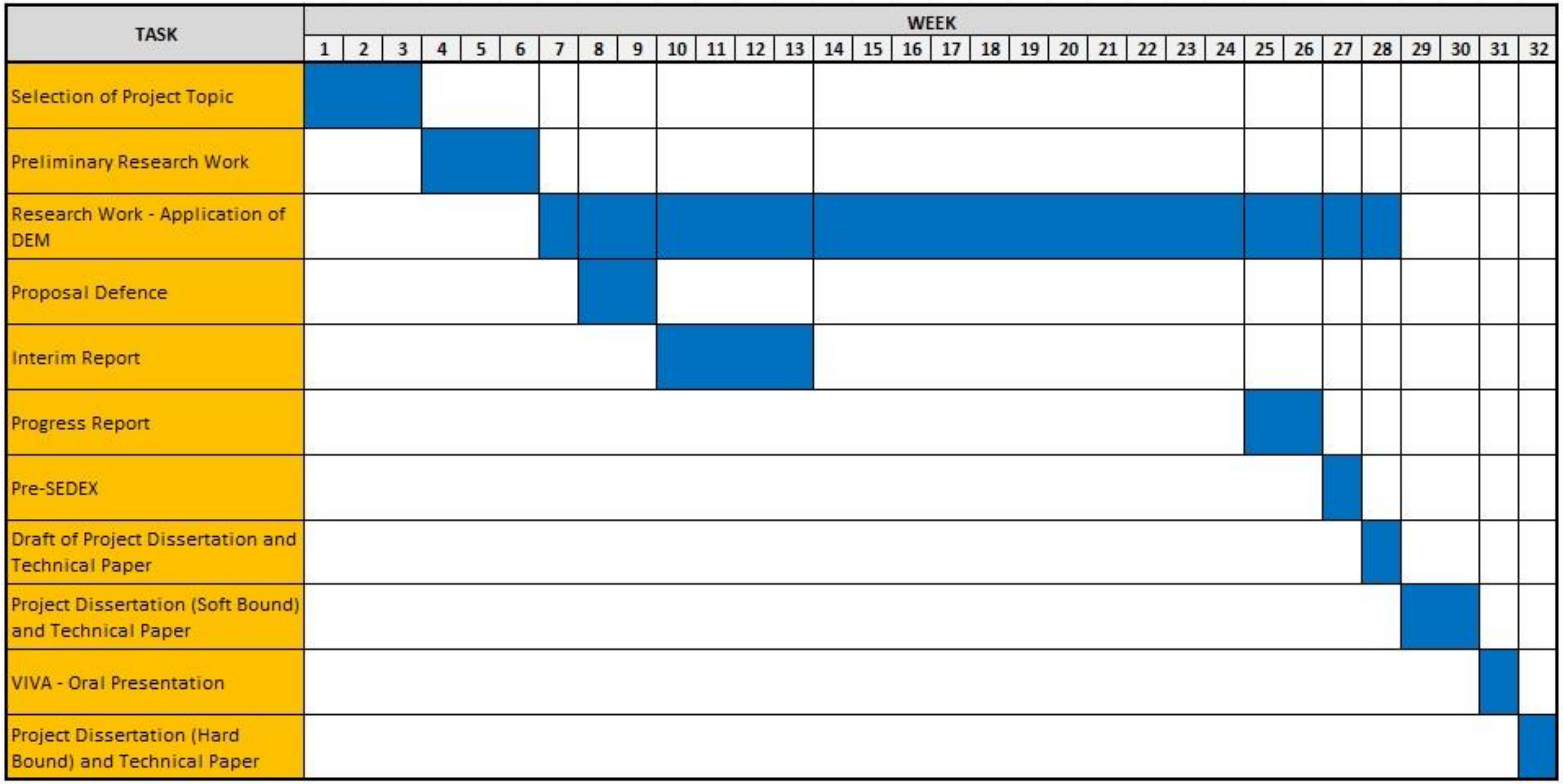
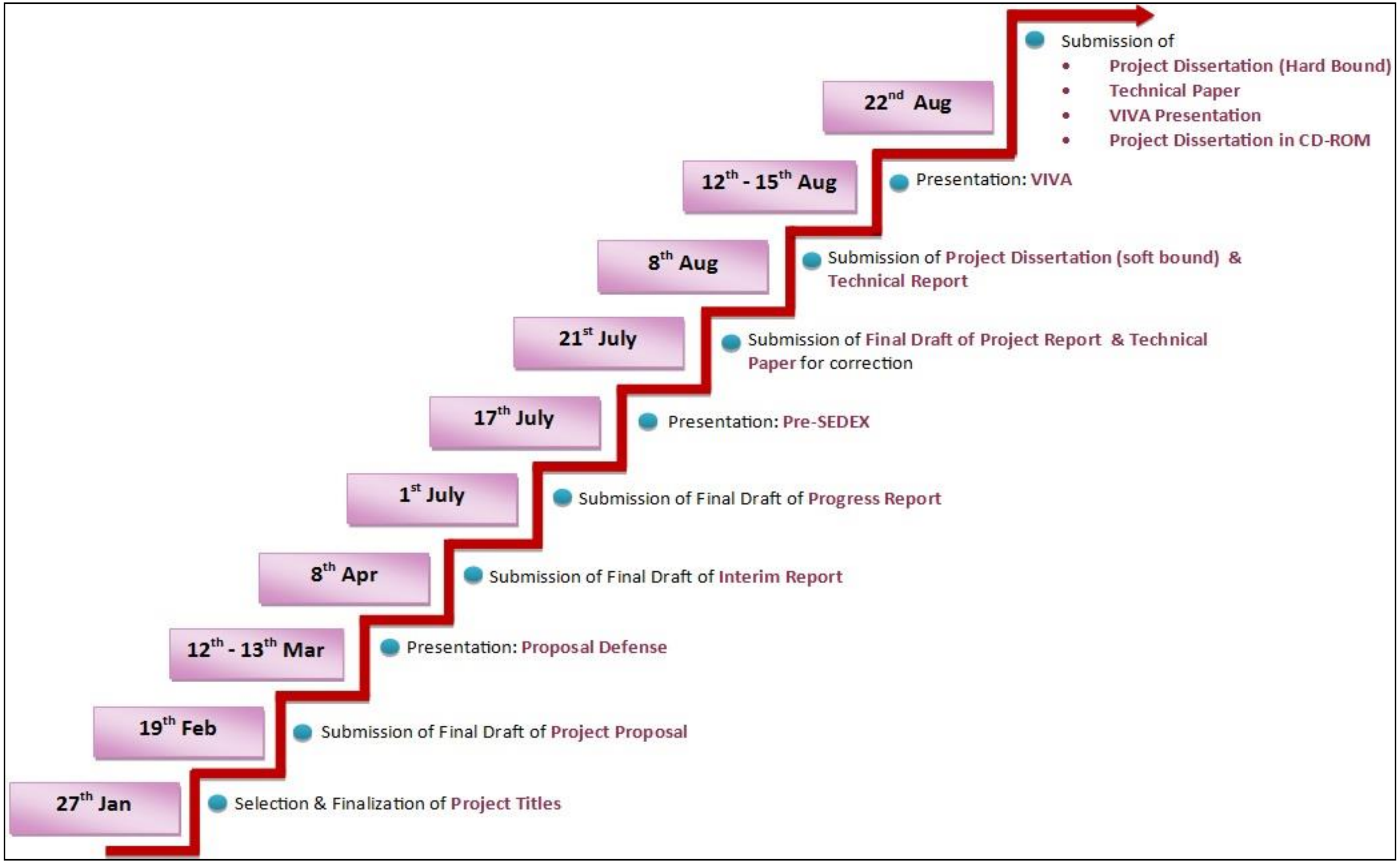


Figure 11: Workflow of the project.

3.6 Project Gantt Chart



3.7 Key Milestone



CHAPTER 4

RESULTS & DISCUSSION

For this project, there are two different sets of data have been acquired. The first dataset has the resolution of 30 arc-second which is equivalent to approximately 1 km at the equator. This dataset comprises of conditioned DEM, flow direction and flow accumulation in raster format. It also consists of vector data set of river network and drainage basin. Figure 27, Figure 28, Figure 29, Figure 30 and Figure 31 in Appendix II shows these datasets.

The second data set has a resolution of 3 arc-second, which is equivalent to approximately 90 m at the equator. The data set comprises of void filled and conditioned DEM in raster format. Figure 32 and Figure 33 in Appendix III shows the conditioned DEM with 90 m resolution.

All of these data are derived from Digital Elevation Model of Shuttle Radar Topographic Mission (SRTM), provided by United State Geological Survey (USGS).

Using these datasets, drainage network in Sarawak is delineated. Figure 12 shows the drainage network that has been succesfully delineated using the DEM. Based on the results, the whole Sarawak region is covered by a total of 1620 streams.

The streams of the drainage network are characterized into stream order of Horton-Strahler scheme. Figure 13 shows the drainage network with the streams characterized into stream order. Based on this analysis, the sixth order is the highest stream order of the drainage network in Sarawak.

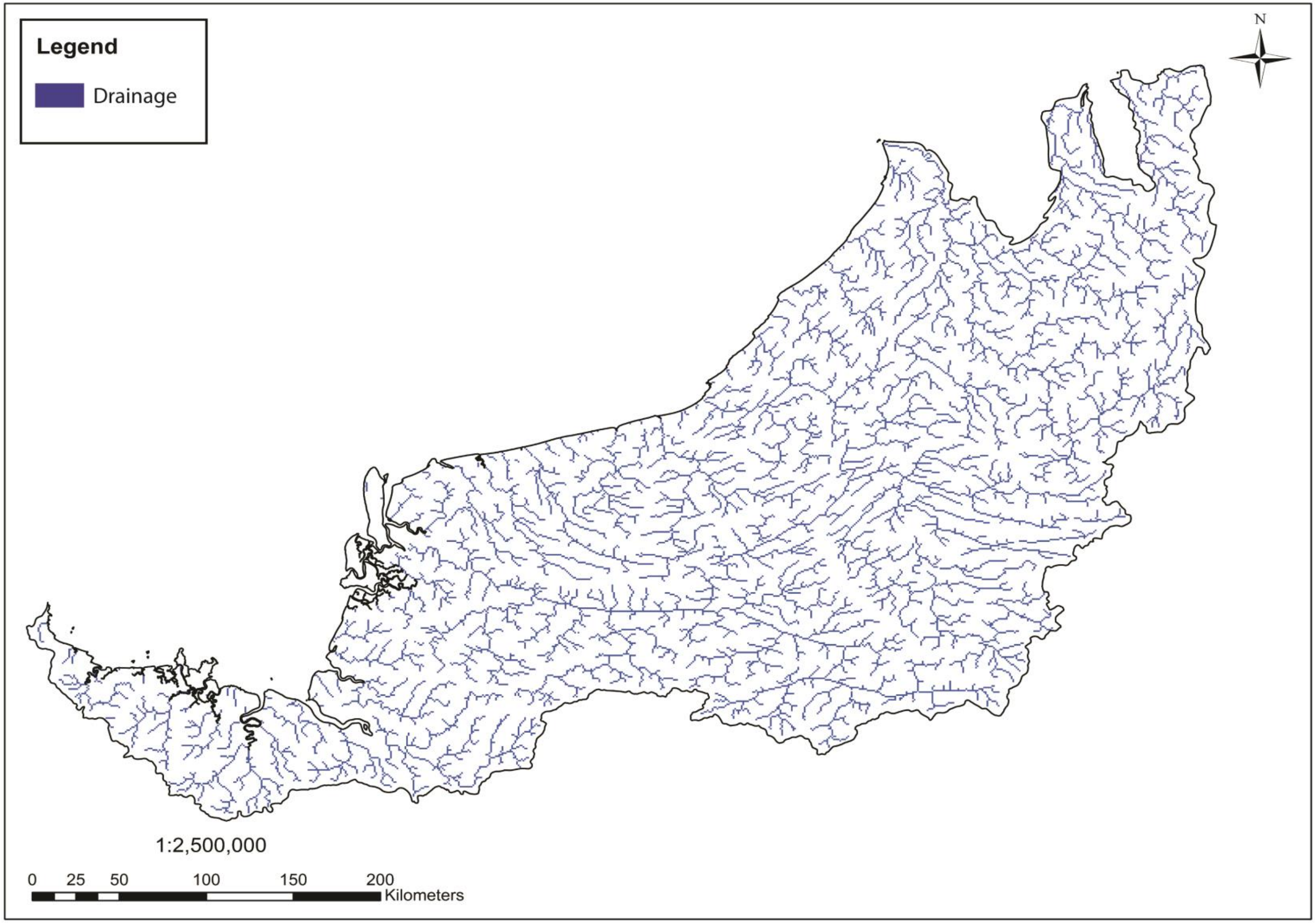


Figure 12: Map of delineated drainage networks in Sarawak.

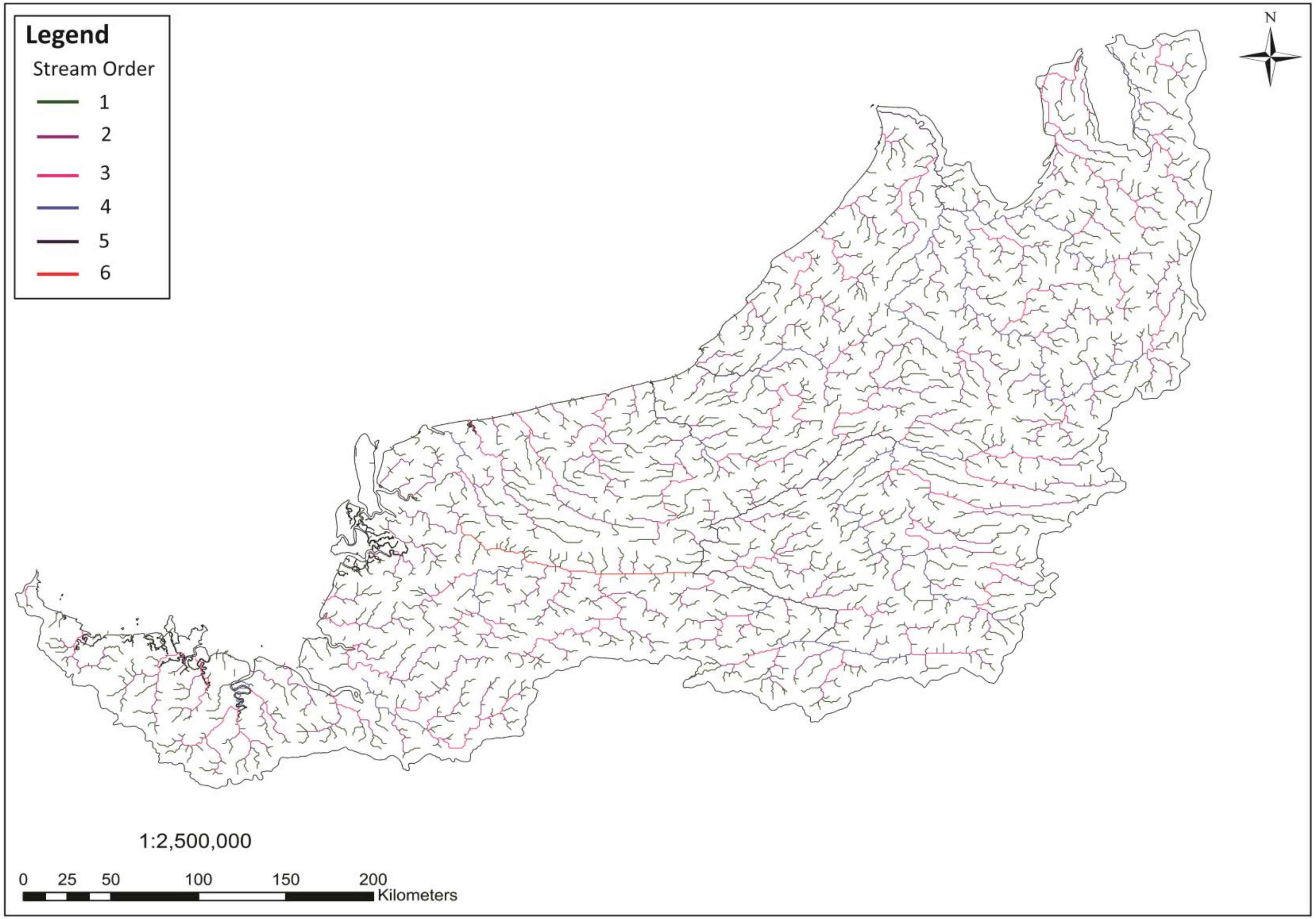


Figure 13: Map of drainage networks with stream order.

Table 1 shows the number of streams characterized into each order, from the lowest of first order to the highest of fourth order. From this analysis on the stream order, it can be observed that as the stream order increases from first to sixth, the number of streams that fall into each order decreases.

Table 1: Number of stream falls into each order.

Stream Order	Number of Stream
1	1280
2	253
3	64
4	17
5	5
6	1

Figure 14 shows the watersheds that have been characterized based on the delineated drainage network. For this project, only the first order watershed is delineated. Based on the result, the whole Sarawak is covered by 97 watersheds.

Calculation on the stream length is performed prior to calculation on drainage area and density. The total length of all streams in Sarawak is calculated to be 19185.7 km. The watersheds delineated is computed to cover a total area of 119664.04 km^2. The total density of all watersheds in Sarawak is calculated to be 119129.39 km^{-1}. These computed values area tabulated in Table 2. The density of each watershed is calculated based on these values of total stream length and drainage basin area. The result is tabulated in Table 4 in Appendix IV.

Table 2: Results on watershed delineation, drainage network length, and watershed basins area and density analysis.

Number of watershed	97
Total length of streams	19185.70 km
Total area of watershed	119664.04 km^2
Total density of watershed	119129.39 km^{-1}

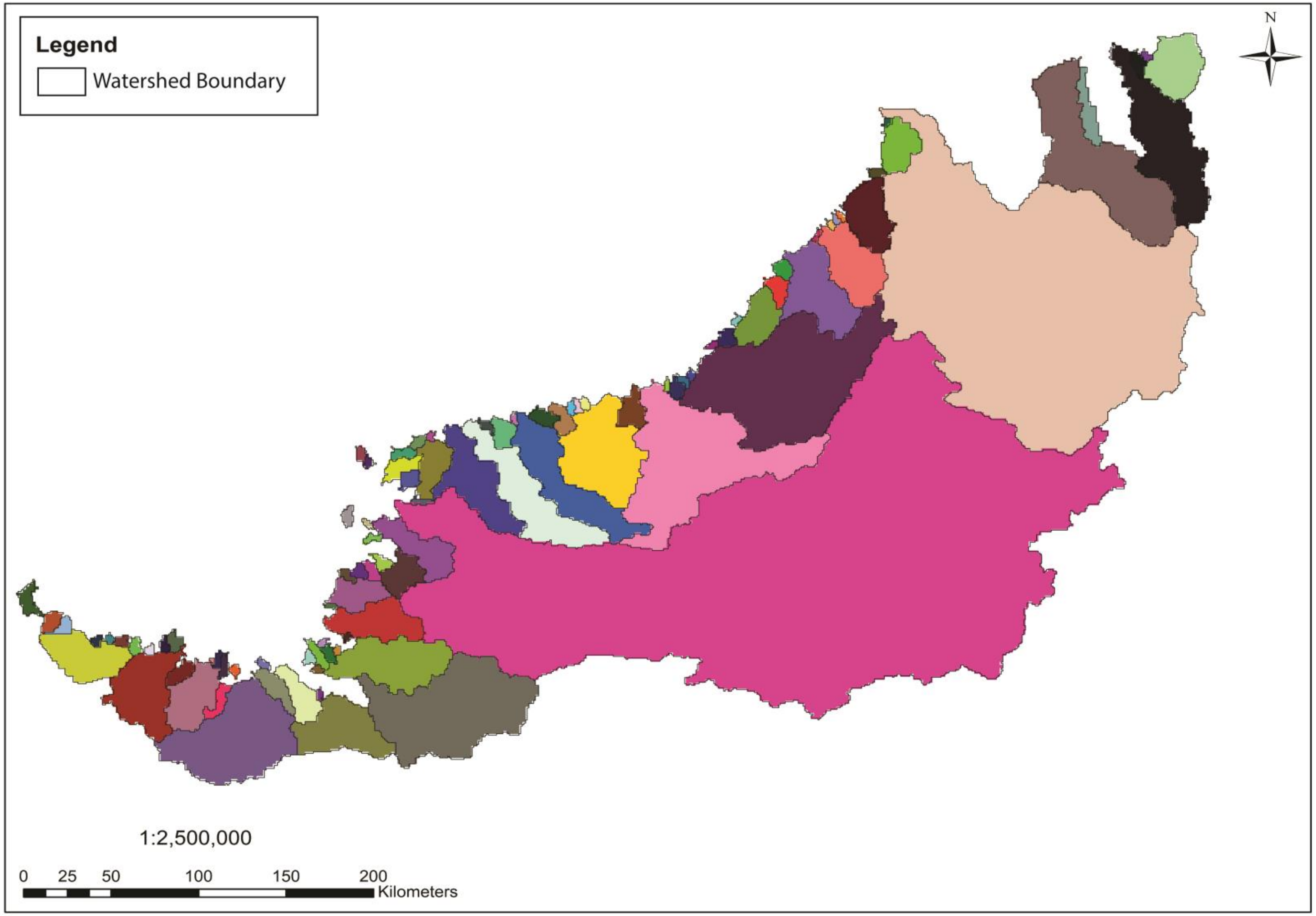


Figure 14: Map of delineated watershed basins in Sarawak.

In order to perform analysis on the drainage systems to study their relation to the tectonic processes in Sarawak, only four drainage networks have been chosen. These drainage networks are chosen based on information collected from field observation. Figure 15 shows the drainage networks that are used in analysing the relation between the drainage network and the tectonics and Figure 16 shows the location of these drainage networks on the map of Sarawak.

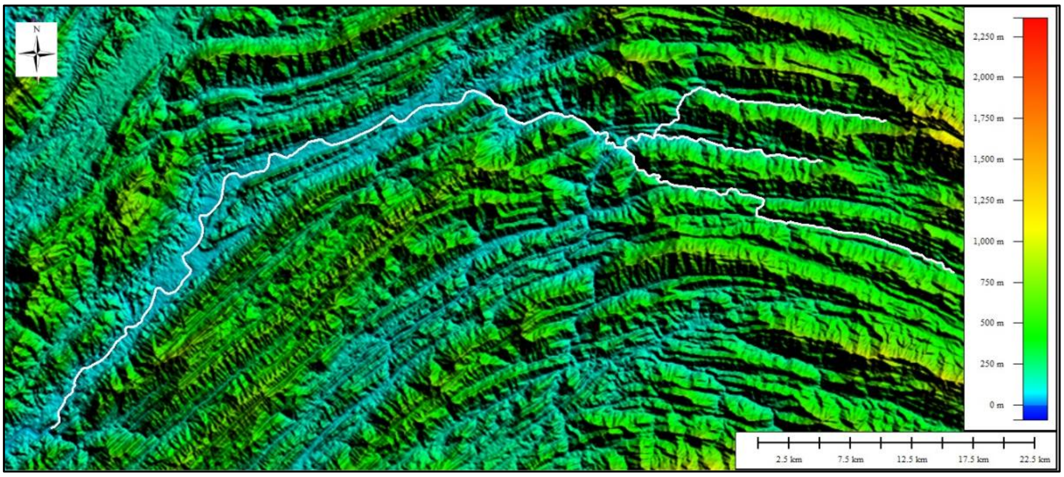


Figure 15: Selected drainage networks used for tectonic interpretation. Drainage networks are characterized by white lines.

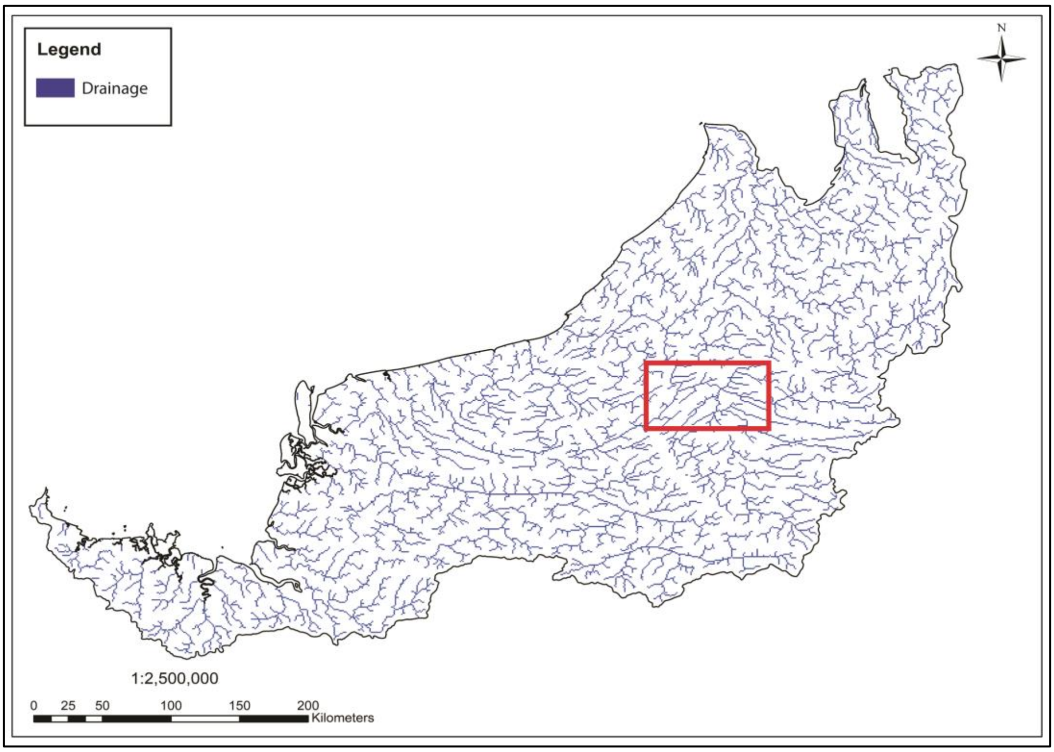


Figure 16: Location of the selected drainage networks, highlighted with the red rectangle on Sarawak's drainage networks map.

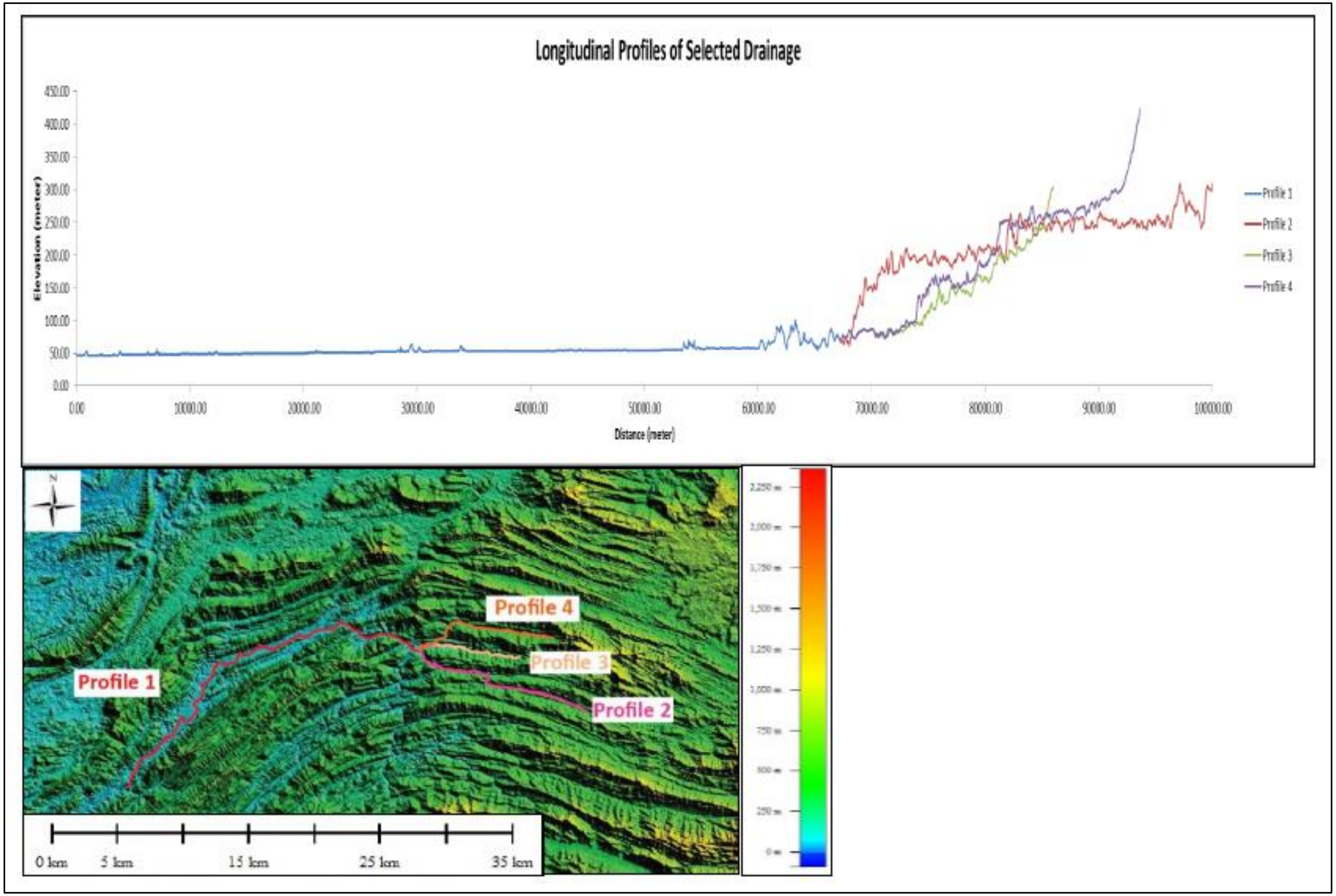


Figure 17: The longitudinal profiles of the selected drainage networks.

To analyse the drainage networks for the tectonic interpretation, longitudinal profiles of each of the drainage networks are generated. Figure 17 shows the longitudinal profiles that have been generated for all four drainage networks.

To further analyse the longitudinal profiles to relate the drainage networks to the tectonic processes that shaped the landforms of Sarawak, profile 4 as shown in Figure 17 is used. This profile is chosen after analysing each and every profile of the four drainage networks and drainage network with profile 4 produces the best longitudinal profile that can provide information about the tectonics.

From this profile 4, it can be observed that there are few anomalies or irregularities on the profile of the drainage network and these anomalies can be possibly related to the tectonic processes, particularly uplifting. The identified irregularities are circled both on the DEM and on the longitudinal profile as shown in Figure 18 (A) and Figure 18 (B) respectively.

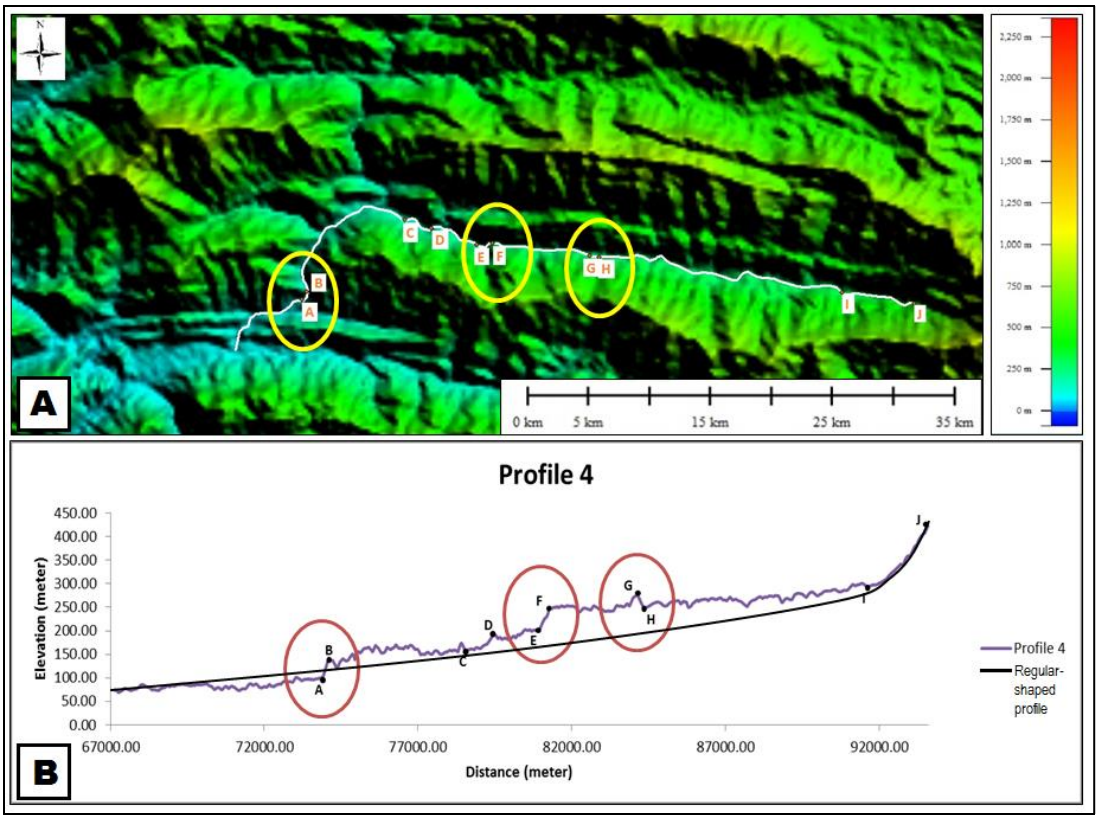


Figure 18: A. The identified irregularities on the drainage network as seen on DEM. B. The irregularities observed on the drainage network longitudinal profile. The irregularities are circled.

These irregularities on profile 4 not only qualitatively identified. Quantitative analysis on the differences in elevation at each irregularity is also performed as shown in Table 3.

Table 3: Difference in elevation at each irregularity on Profile 4

Point	Elevation (m)	Distance (m)	X-coordinate	Y-coordinate	Elevation Difference
A	98.47	73749.9	114.121342	2.766892	AB: 30.7 m
B	129.17	74037.7	114.122598	2.768918	
E	201.06	80779.5	114.164954	2.780578	EF: 40.51 m
F	241.57	81246.6	114.168900	2.780895	
G	270.98	84012.7	114.192964	2.777776	GH: 16.34 m
H	254.64	84294.3	114.195473	2.777499	

Cross section at every point of irregularities i.e. point A, B, E, F, G and H of the drainage network are generated. Figure 19 provides the images of the cross sections of the respective points.

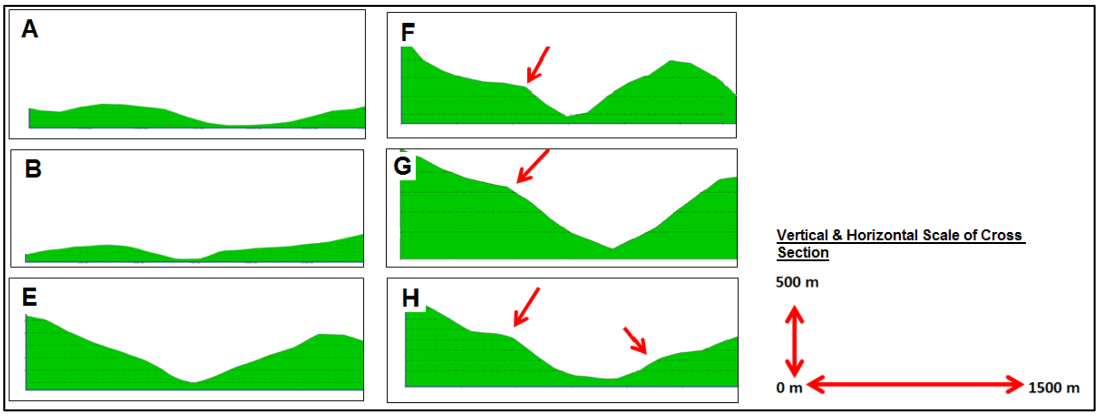


Figure 19: Cross sections generated across the points of irregularities on the drainage networks. Red arrows pointed the identified fluvial terraces.

From the cross section, analysis on the effect of possible tectonic process can be studied from the change in the valley shape from one point to the other. Apart from that, fluvial terraces observed from the cross section can also provide information on the possible tectonic process.

Based on the images of cross section, the valley shape at point A is very wide as it is located at a distance that is near to downstream course in the river or drainage profile. At point B, the valley is a relatively U-shaped but less wide compared to that of point A.

On the other hand, there are very distinctive differences between the cross sections of point E and point F. At point E, the valley shape follows a very clear V-shaped. However at point F, the valley is relatively U-shaped. Another difference that can be observed from the cross section of points E and F is that there is terrace identified at point F and none at point E. These differences can be contributed to the tectonic process in the area.

At points G and H, there are terraces observed from the cross sections. However, the valley shape at point G is a very distinct V-shape, while at point H, the valley shape is relatively wide. There is also possibility that, at this particular point along the drainage system, there have been tectonic process occurred that led to such difference.

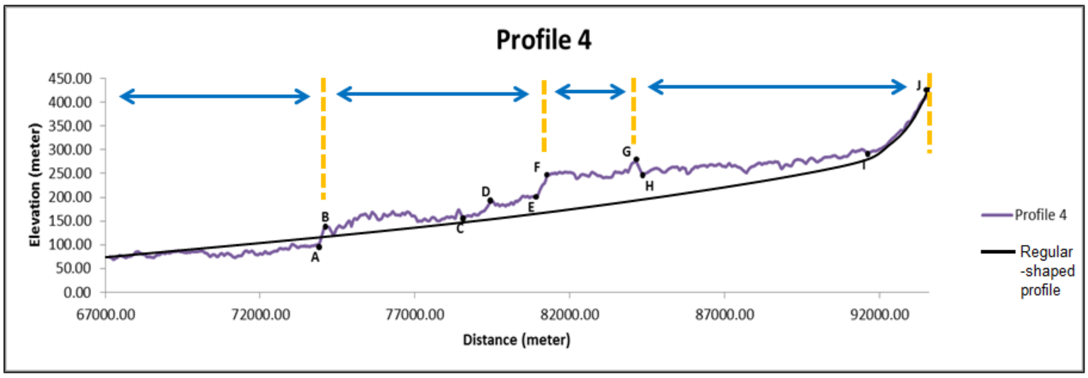


Figure 20: Sections that might be related to the tectonic processes, characterized along the longitudinal drainage profile.

Based on Figure 20 which shows the longitudinal profile 4, the profile can be segmented into four separate and clear sections. These sections are inferred from the distinctive different in elevation at the identified irregularities i.e. point A-B, E-F and G-H along the river profile. This can also be inferred to have been due to the tectonic process that causes the elevation along the drainage profile to change relatively.

Apart from that, from the DEM, faults can be observed that along the drainage system from which profile 4 is generated. Figure 21 shows the faults that have been characterized from DEM along this particular drainage system. The faults can be found along which the irregularities of point A-B, E-F and G-H are identified.

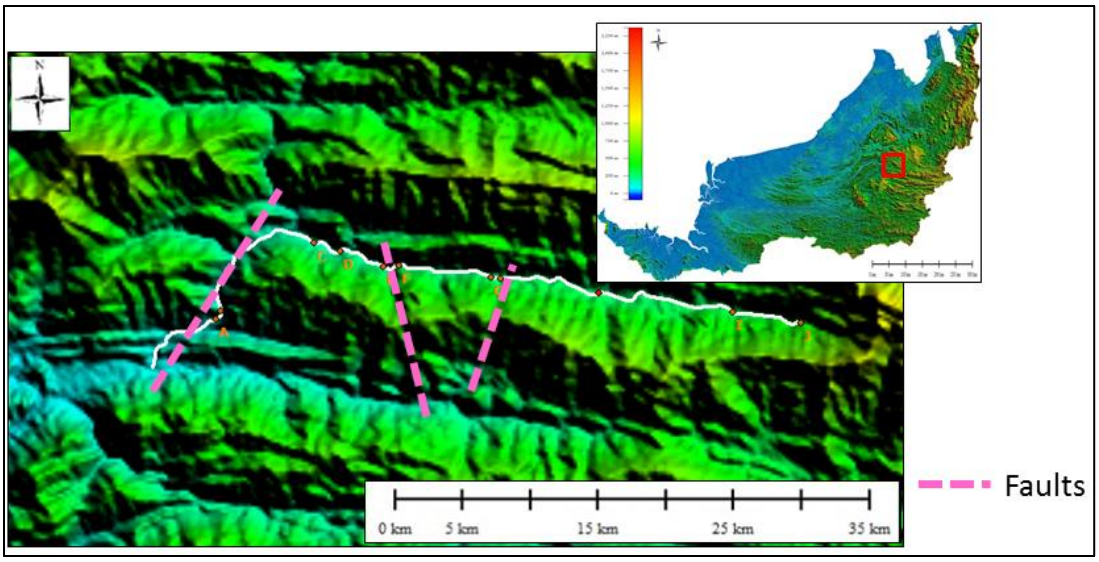


Figure 21: Faults identified on DEM along the drainage network.

From these analyses on drainage system, it can be proposed that there have been tectonic processes that have occurred along the drainage system from which profile 4 is generated. Figure 22 provides a schematic explanation on the possible tectonic processes.

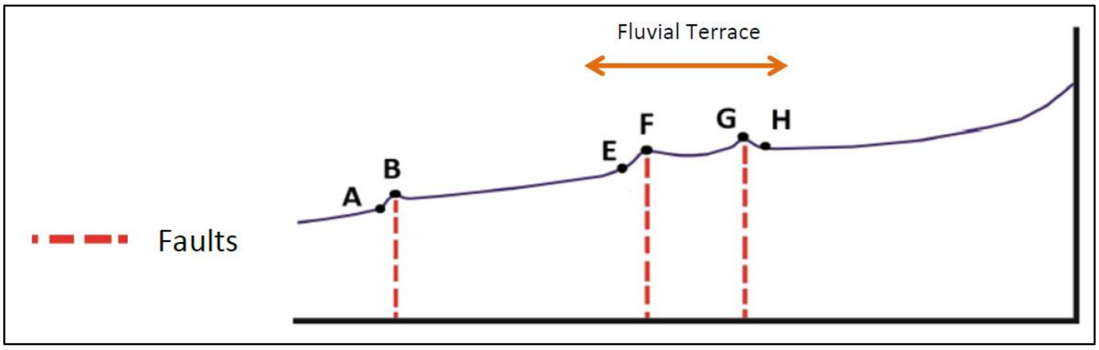


Figure 22: Schematic diagram to explain the possible tectonic processes occurred along the drainage network.

The drainage system along which profile 4 is generated has been subjected to tectonic processes i.e. uplifting. The uplifting is particularly faster between points E-F and G-H, causing the longitudinal profile to appear more elevated. This explains the sections shown in Figure 20. This also explains the existence of fluvial terraces at points F, G and H as shown in Figure 19. The faults that can be observed on DEM in Figure 21 provide more evidence on uplifting.

To further support the results obtained from the DEM, field observations have been conducted in the study area. Fluvial terraces that can be observed from the cross section of the drainage system can also be found in the field. Figure 22 shows the image of the fluvial terraces.

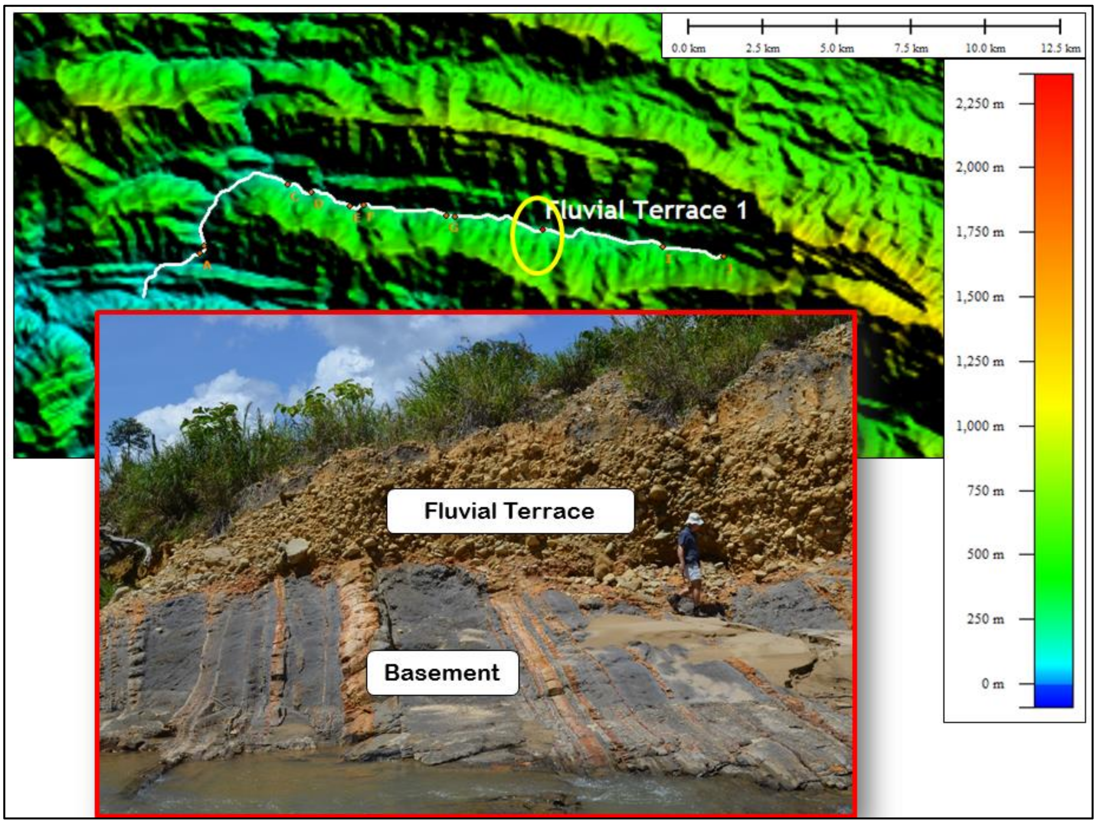


Figure 23: Basement and fluvial observed in the field along the drainage network. The location where the photo is taken is circled on DEM.

On top of that, based on Figure 23, the basement can be observed on the surface and thus provides more evidence that there have been uplifting occurred along the drainage system.

Figure 24 and Figure 25 also shows more evidences from the field to support the analysis performed using DEM. Figure 23 shows the photographic evidence of a V-shaped valley in the study area while Figure 24 shows the hills between which the drainage systems of profiles 2, 3 and 4 flow.

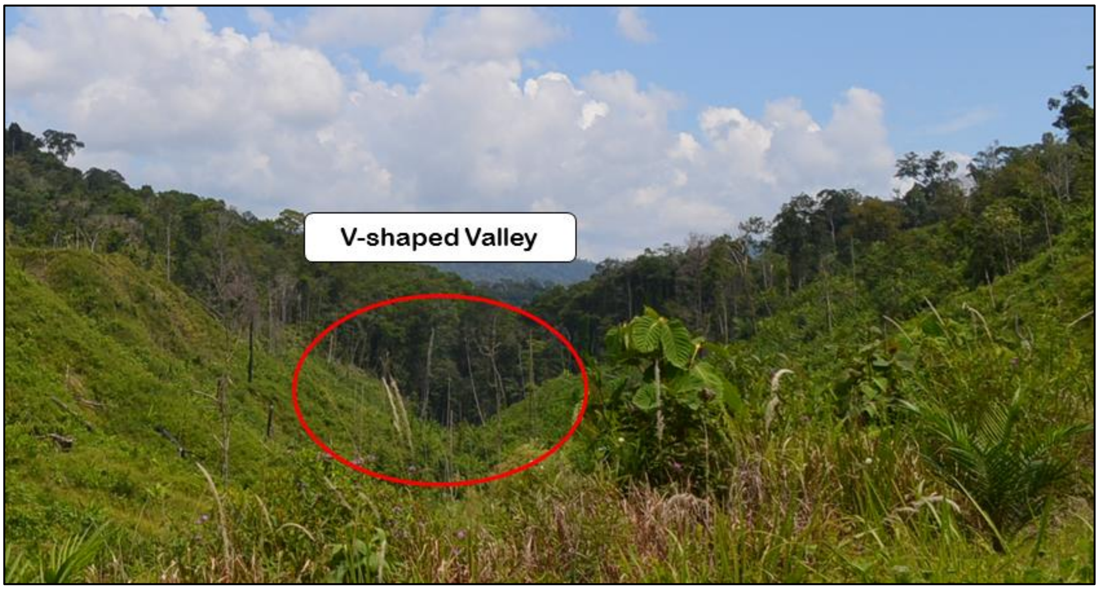


Figure 24: V-shaped valley observed in the field to support the V-shaped valley found from the cross section across the drainage network.

Figure 25: Hills between which the drainage systems of profiles 2, 3 and 4 flow, observed in the field.

CHAPTER 5

CONCLUSION & RECOMMENDATION

4.1 CONCLUSION

DEM data allows the drainage system to be studied and analysed in GIS environment. By using the DEM, drainage networks and watershed and their corresponding indices such as drainage density and area can be computed. Critical analysis on the drainage network could give us information on tectonics that has led to the formation of the geological features in the area. By analysing drainage network, the association between geomorphology and tectonics can be studied.

4.2 RECOMMENDATION

The interpretation on tectonic, especially, has been performed based on the longitudinal profile of a drainage network. Analysis on the longitudinal profile of more drainage networks in Sarawak would give more evidence on the tectonics and morphology in Sarawak.

Quantitative analysis on the delineated drainage networks and watershed basins can be performed in order to obtained more evidence on the tectonic processes that shaped the landforms in Sarawak. Analysis on uplift rate using DEM would provide information to support the finding of this project on the uplifting. Apart from that, there have been studies conducted to relate the drainage basins density directly to tectonics. Perhaps, more details analysis on the watershed basins density can also give more information on the tectonics in the area.

Besides tectonic processes, there are other several factors that also can affect the landforms, particularly the drainage networks of a certain area. These factors include climate changes with respect to the global sea level and lithology contrast. Further studies and analysis that focuses on these factors may provide more information and confirmation if there really are any tectonic processes that have influence the landforms in the study are, or there are other factors that have caused it.

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APPENDICES

Appendix I

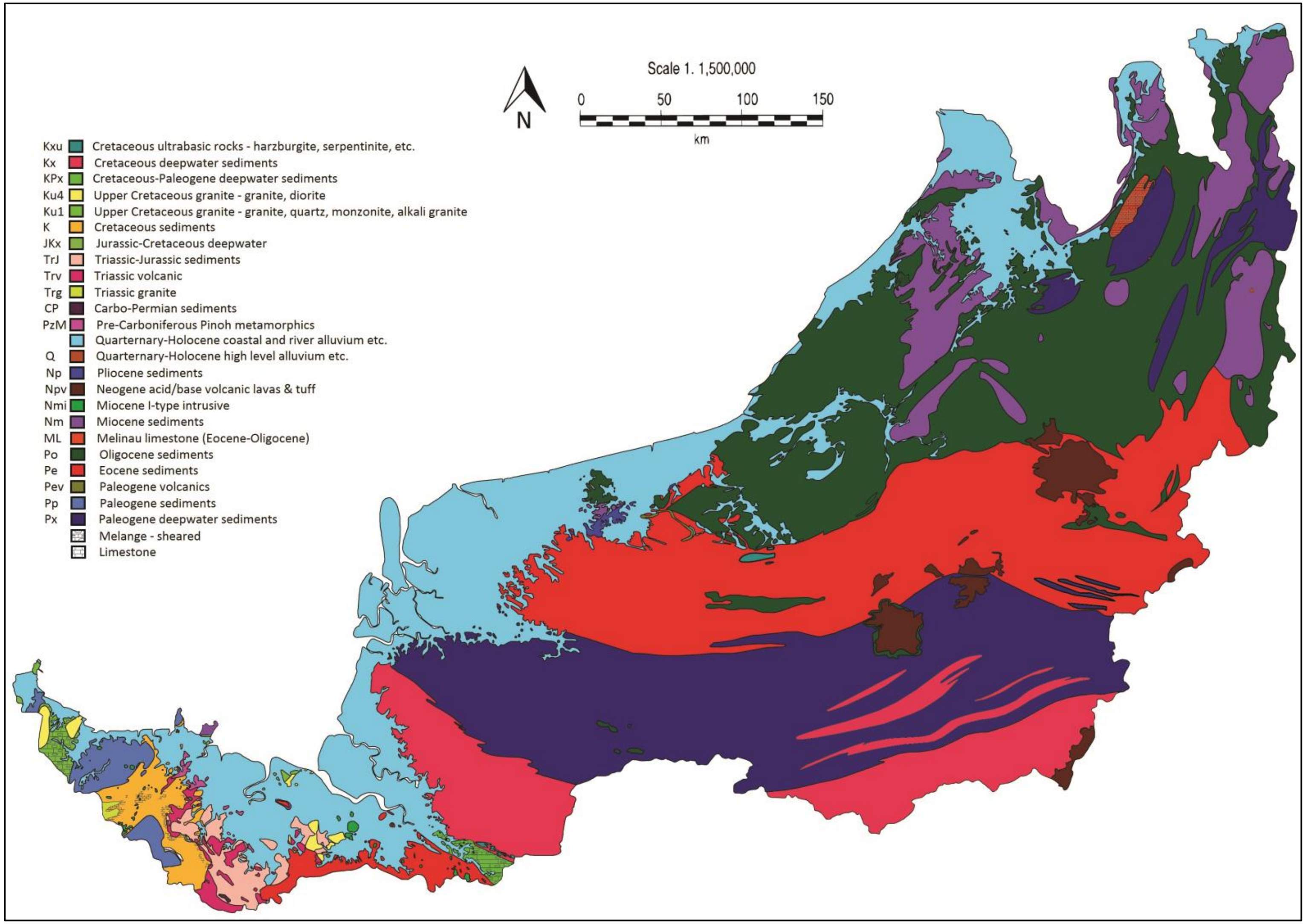

Figure 26: Geological map of Sarawak (Modified after Tate(2002))

Appendix II

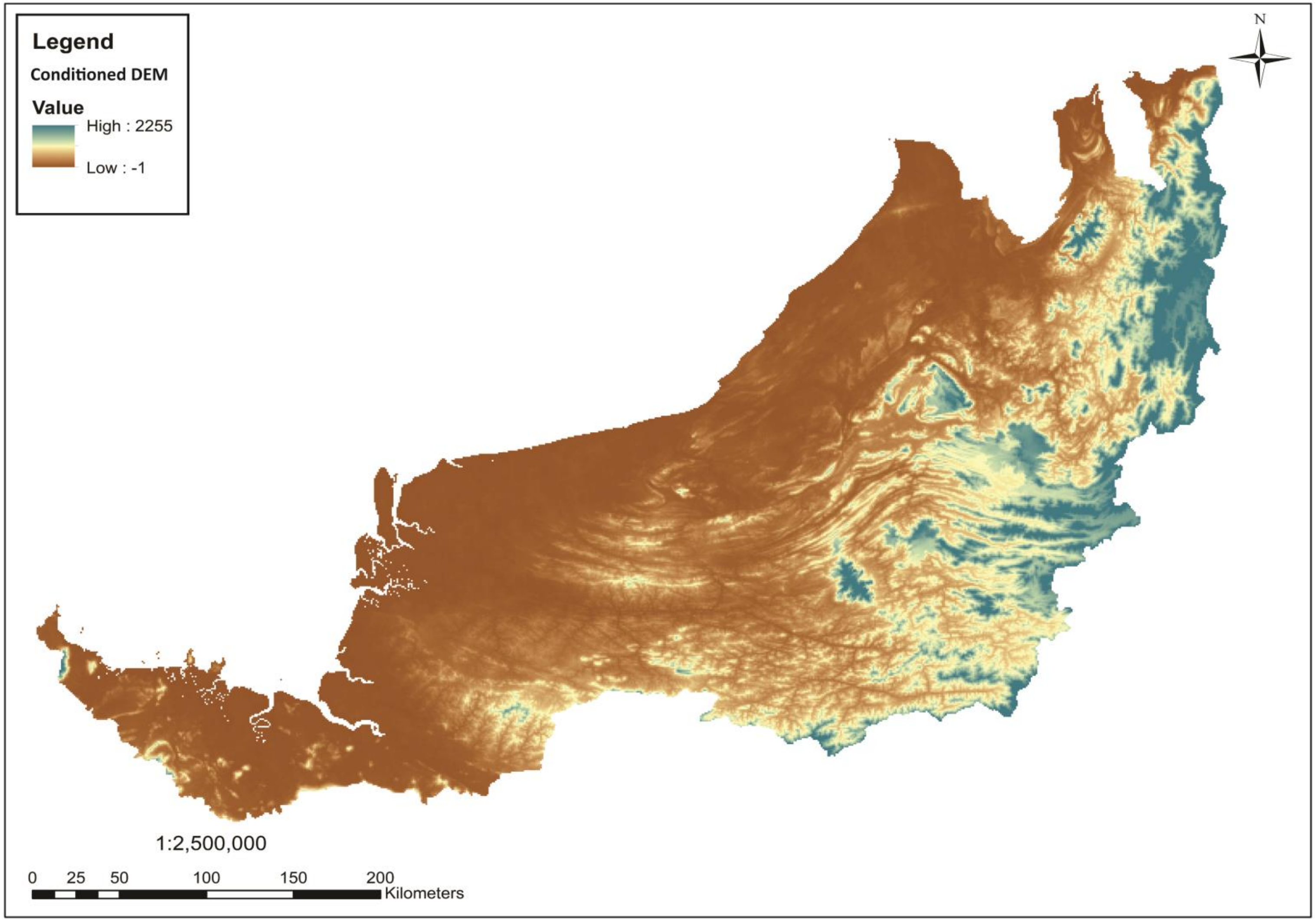

Figure 27: Conditioned DEM of 1 km resolution.

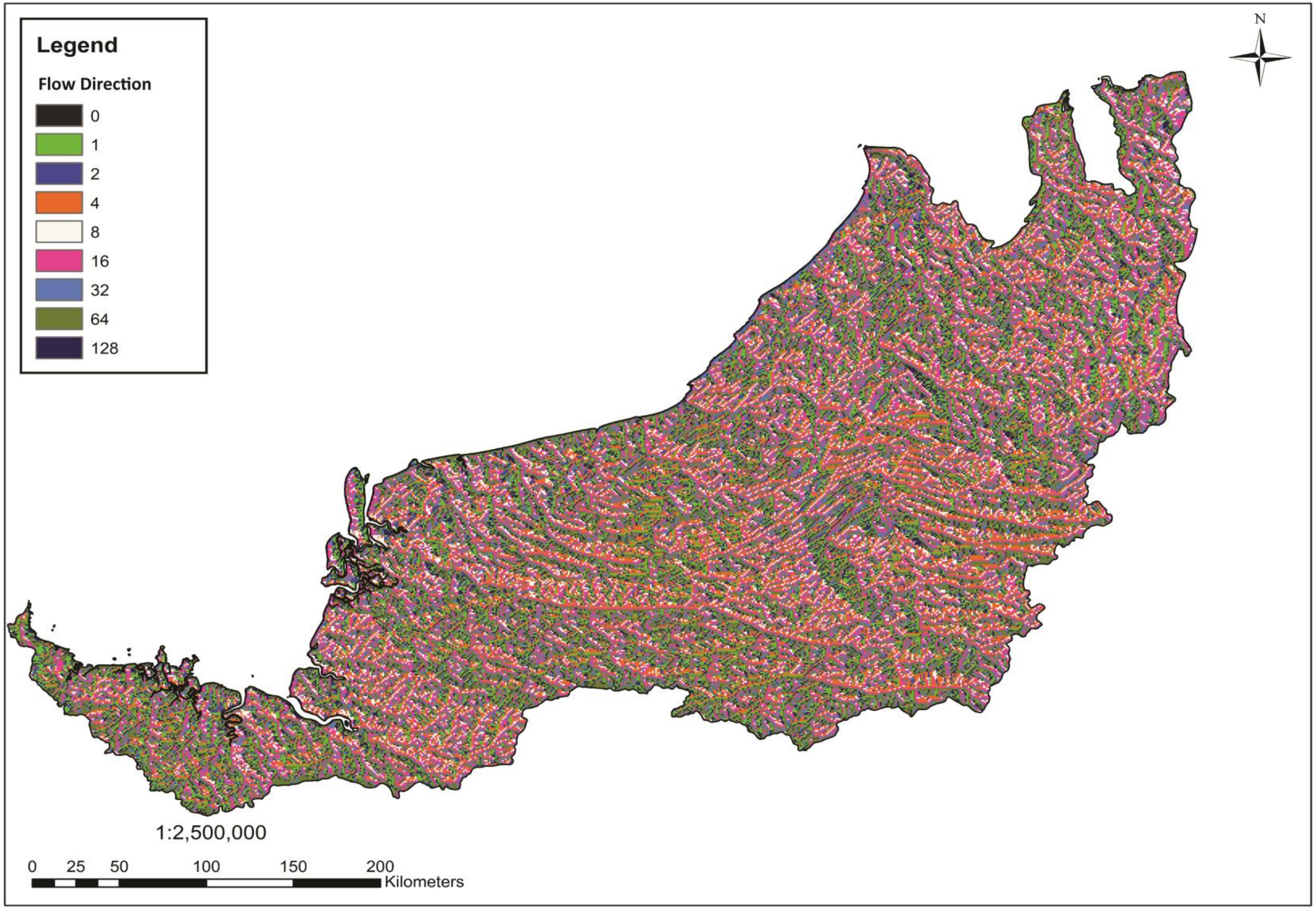

Figure 28: Flow direction of Sarawak derived from DEM of 1 km resolution.

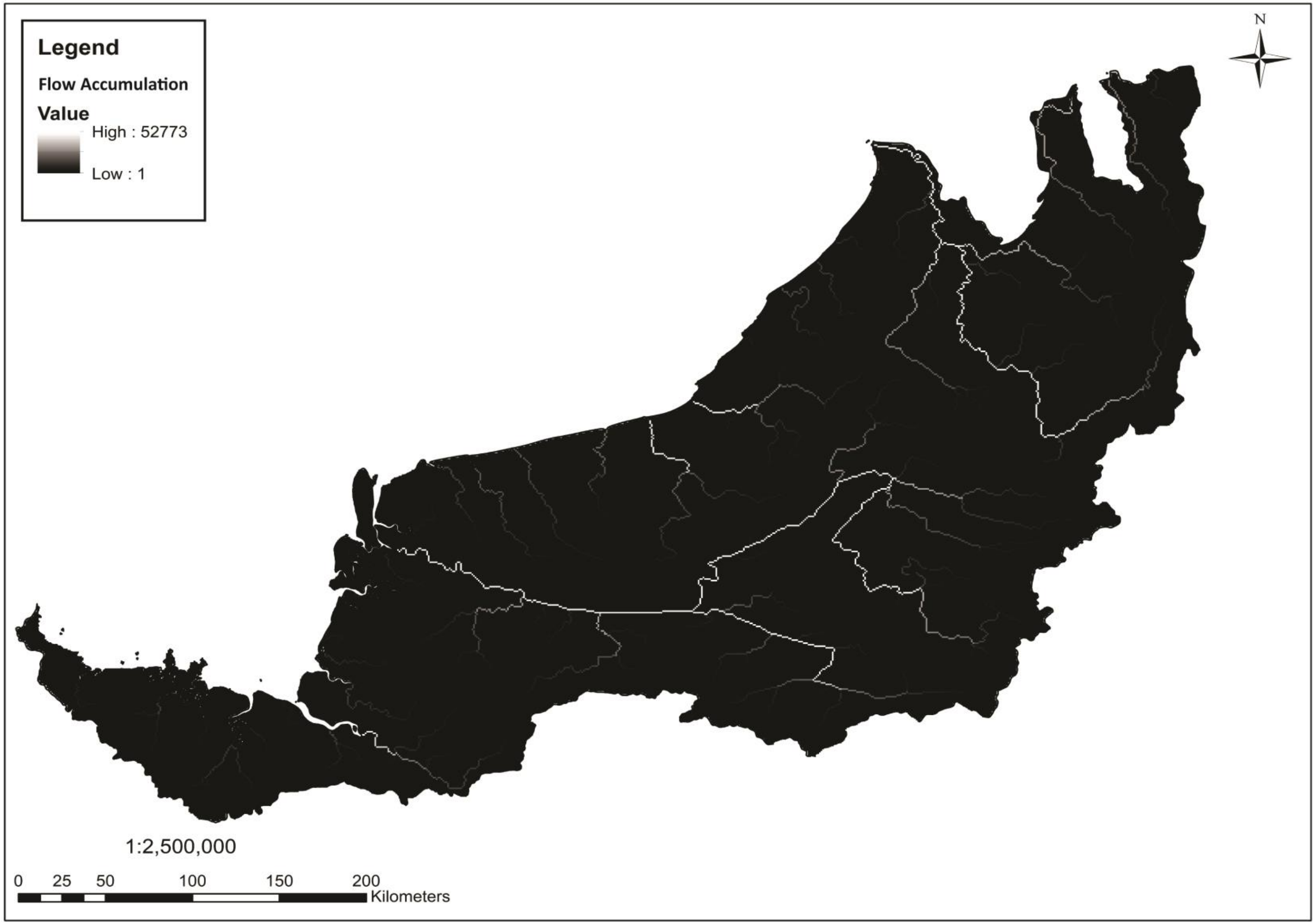

Figure 29: Flow accumulation of Sarawak derived from DEM of 1 km resolution.

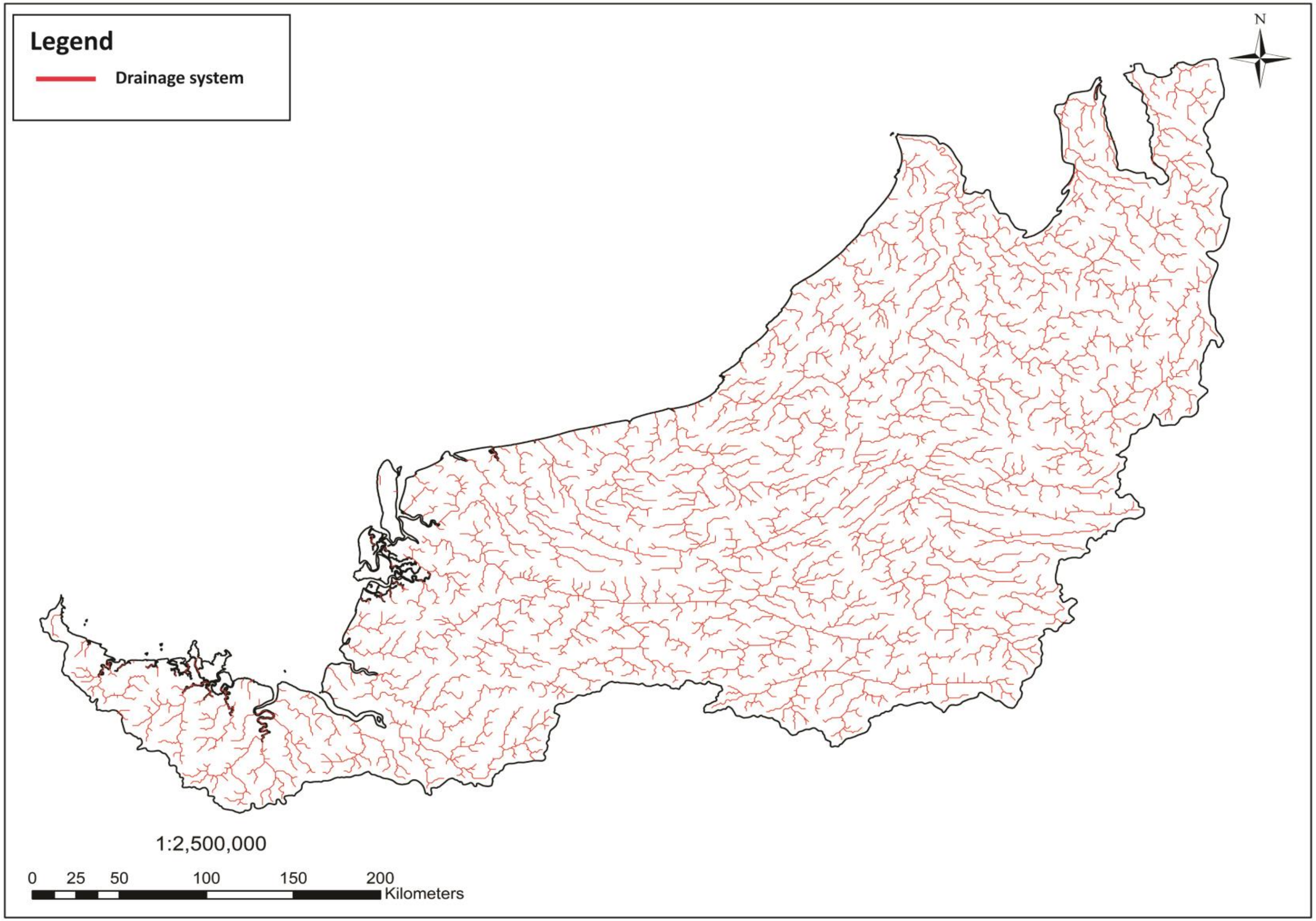

Figure 30: Drainage networks of Sarawak in vector format.

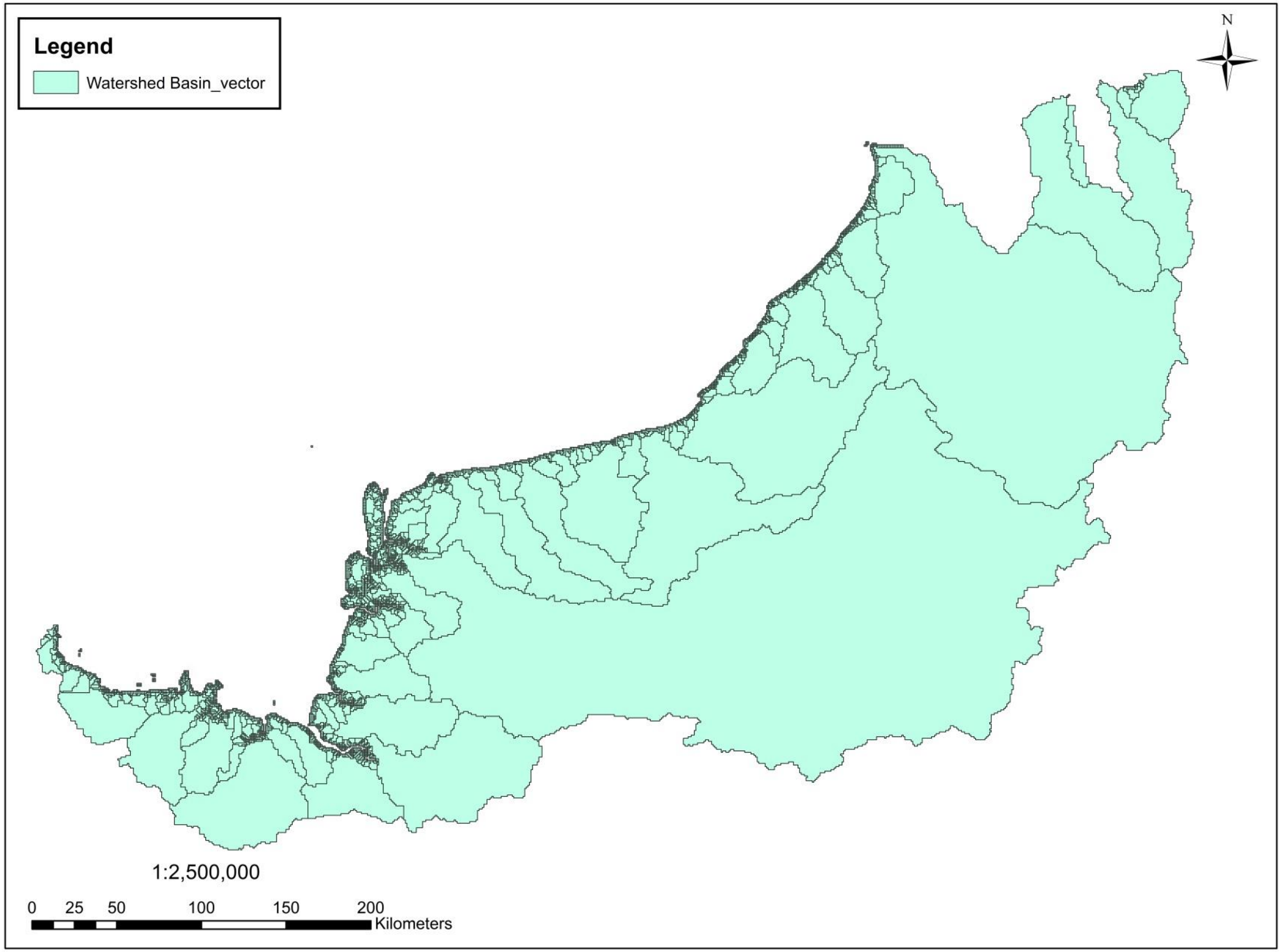

Figure 31: Watershed basins in vector format.

Appendix III

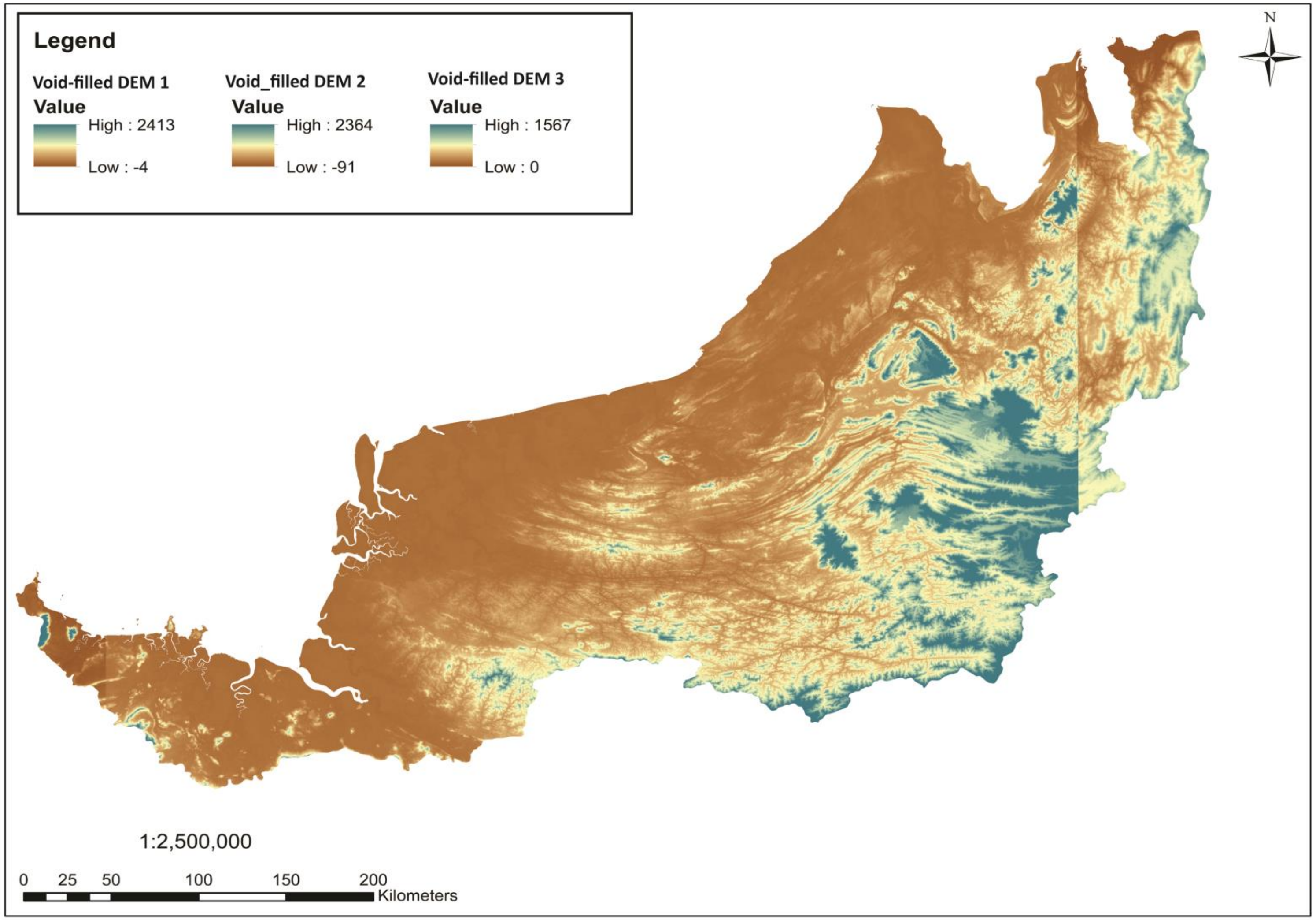

Figure 32: Void-filled DEM of 90 m resolution.

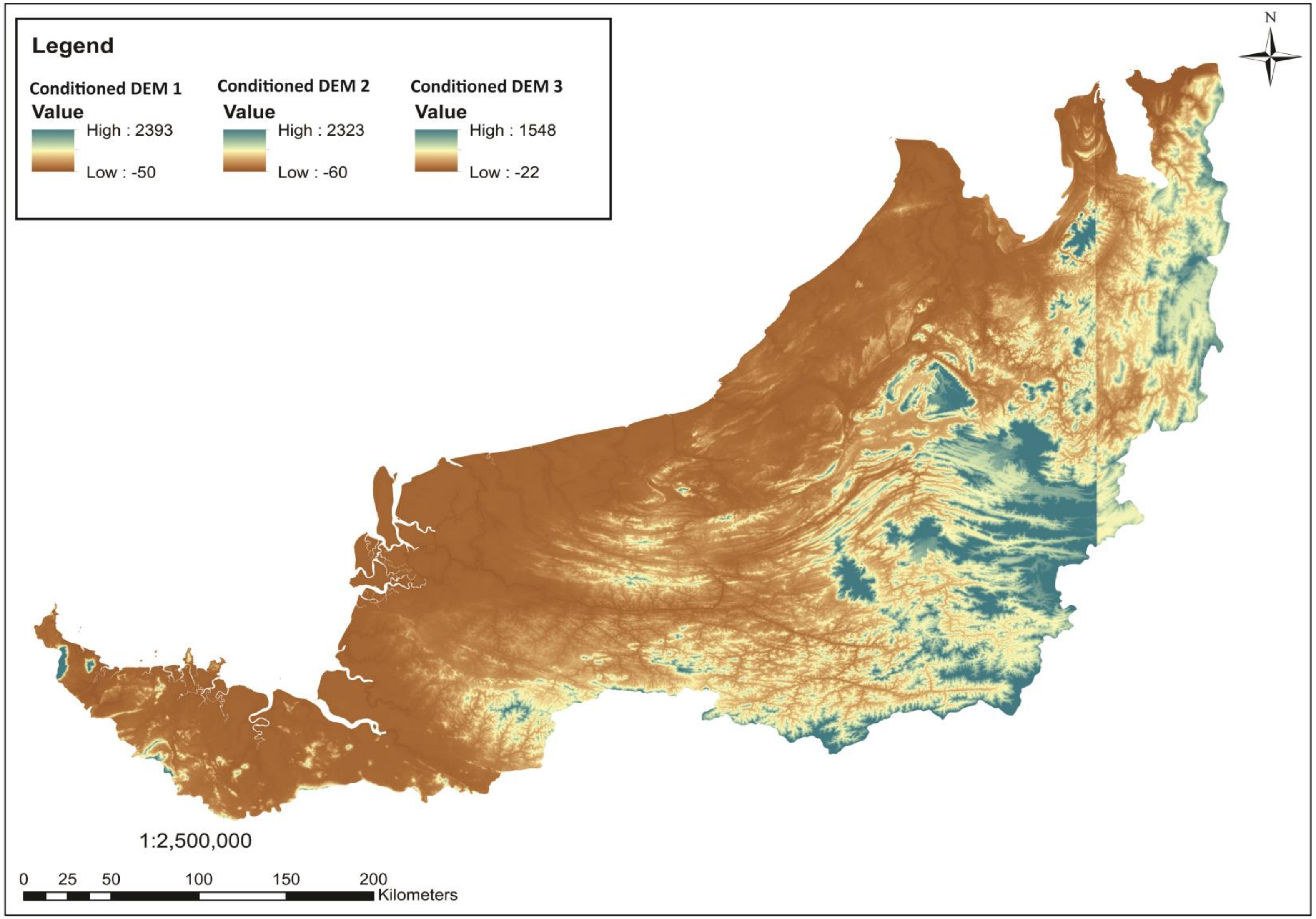

Figure 33: Conditioned DEM of 90 m resolution.

Appendix IV

Table 4: Calculated Stream Length, Drainage Basin Area and Drainage Basin Density for Individual Watershed

Basin Number	Stream Length (km)	Basin Area (km^2)	Drainage Density (km^{-1})
1	21.50	151.16	150.53
2	14.50	115.29	114.81
3	8.99	84.54	84.19
4	165.97	1045.23	1040.89
5	5.50	38.42	38.27
6	1.38	25.62	25.51
7	6.43	52.94	52.72
8	6.37	65.74	30.61
9	3.22	30.74	30.61
10	219.23	1437.06	1431.13
11	7.72	44.39	44.21
12	11.21	84.52	84.17
13	22.42	153.68	153.04
14	144.20	878.55	874.94
15	6.37	37.56	37.41
16	12.67	64.03	63.76
17	28.86	146.85	146.24
18	4.14	35.00	34.86
19	473.72	3000.30	2987.96
20	44.57	275.74	274.61
21	4.55	36.71	36.56
22	80.74	444.78	442.94
23	2.30	24.76	24.66

Basin Number	Stream Length (km)	Basin Area (km^2)	Drainage Density (km^{-1})
24	216.27	1350.68	1345.14
25	642.73	4124.33	4107.41
26	258.98	1658.75	1651.95
27	2.32	28.17	28.05
28	4.92	49.51	49.31
29	19.64	100.73	100.31
30	1.39	23.05	22.95
31	9.91	64.88	64.61
32	1.96	23.05	22.95
33	2.69	23.90	23.80
34	151.41	976.51	972.46
35	1.96	23.04	22.95
36	79.82	498.44	496.38
37	6.77	52.06	51.84
38	6.80	66.57	66.29
39	12.53	83.64	83.29
40	15.44	78.52	78.19
41	67.64	437.84	436.04
42	130.67	789.44	786.17
43	5.11	41.81	41.64
44	2.88	25.60	25.49
45	7.72	67.41	67.13
46	7226.99	45134.08	44931.38

Basin Number	Stream Length (km)	Basin Area (km^2)	Drainage Density (km^{-1})
47	5.85	43.52	43.34
48	80.36	496.56	494.50
49	15.81	106.65	106.21
51	2.32	31.56	31.43
50	35.92	200.49	199.66
52	6.37	44.36	44.18
53	12.00	84.46	84.11
54	9.58	58.01	57.77
55	1.96	23.03	22.94
56	236.90	1437.90	1431.98
57	303.72	1886.35	1878.56
58	7.35	49.48	49.28
59	34.25	202.22	201.38
60	290.96	1820.80	1813.22
61	16.37	129.70	129.17
62	27.22	174.94	174.22
63	6.22	37.55	37.39
64	4.92	32.43	32.29
65	1.96	39.26	39.09
66	389.49	2203.29	2194.16
67	45.88	283.40	282.23
68	845.53	4995.97	4975.54
69	1.38	22.20	22.10
70	12.14	91.35	90.97
71	4.92	33.30	33.16
72	4.00	27.32	27.21
73	961.04	5817.45	5792.78

Basin Number	Stream Length (km)	Basin Area (km^2)	Drainage Density (km^{-1})
74	3.62	26.47	26.36
75	9.84	96.48	96.08
76	4.00	26.47	26.36
77	99.87	608.84	606.32
78	26.00	168.22	167.52
79	12.20	106.73	106.29
80	243.18	1470.89	1464.78
81	1.96	23.91	23.81
85	2.69	25.62	25.51
86	127.58	857.58	854.03
87	6.40	50.38	50.18
88	96.75	561.07	558.76
89	1.39	23.05	22.96
90	3626.97	22521.56	22439.42
91	1.96	23.05	22.95
92	1.38	25.60	25.49
93	624.20	3764.86	3749.40
94	387.63	2564.89	2554.35
95	18.59	97.57	97.16
96	3.81	29.10	28.98
97	143.75	982.19	978.11
Total	19185.70	119664.04	119129.39