CHAPTER - V

SUMMARY AND CONCLUSION

Mars has attracted several planetary scientist to understand its origin, early climatic condition, present climate conditions, atmospheric composition, fluvial activity, presence of water, crustal dichotomy, volcanism, present dynamic geomorphic processes, evidence for past life and human colonization. The interest on Mars was started much earlier around 6th century, the scientist started thinking existences of channels, presence of life and the reduction of atmosphere, due to loss of magnetosphere. Mars has created special attention due to its crustal dichotomy. The surface is divided into heavily cratered elevated southern hemisphere and northern lowlands.

About 2/3 of Martian surface is cratered due to heavy bombardment of meteorites. The geological time scale of Mars divided into three periods as Noachian (4.5-3.7 Ga), Hesperian (3.7-3.0 Ga) and Amazonian epoch (3.0 - present). The surface of the Mars is covered by craters, volcanos, channels and large canyons. Geologically the Martian surface covered by volcanic rocks of basaltic and andesite composition. In addition, sedimentary rocks like clay minerals and evaporites deposits covered significant areas on Martian surface.

The Martian surface has explored through various unmanned space missions like orbiters, landers and rovers. The USA, South Union, Europen Space Agency and Indian Space Research Organization were successfully launched mission to Mars for exploration. Among various missions, currently Mars Global Surveyor (MGS), Mars Odyssey, Mars Express (MEX), Mars Reconnaissance Orbiter (MRO), Mars Atmosphere and Volatile EvolutionN Mission (MAVEN) and Mars Orbiter Mission (MOM) are providing valuable information on Martian surface.
In the case of formation of valley network on Martian surface, remains divisive and need in depth study and further evidences which support hydrological activity on the Mars. There are several theories proposed for origin of valley networks on Martian surface. In this context, there is a scope for further detailed studies on fluvial morphological studies on Martian surface. In this context, we have identified two channel systems namely Cusus and Columbia Valles for detailed fluvial morphological studies. The main objective of the present study is to understand the fluvial processes, early climatic conditions and dynamics of flow discharge. For this study, THEMIS, MOLA and MCC remote sensing data were analyzed through ArcGIS 10.4, ENVI 5.4 and JMARS software.

The Martian valley networks at few locations resemble terrestrial fluvial system, which creates curiosity to study the origin and source of such valles system. The Cusus Valles located SE of Cassani crater is identified to study in detail to infer the geomorphic processes behind the development of valley network. The THEMIS image with 100m resolution is useful to digitize the craters in the Cusus Valles. The number of craters along with size is the input for estimation of absolute age of valles through crater-size frequency distribution method. Through this method the age of Cusus Valles is estimated as 3.9 Ga which fall in late Noachian time period.

The Martian surface mostly covered by basaltic composition however, direct mapping of rock types through remotely sensed data is difficult because of rare exposers of outcrops and mostly covered by regolith and dust mantle. However, based on global geological mapping (Tanaka et al, 2014) the Cusus Valles classified into three categories as channel materials, cratered materials and plains and plateau materials. These materials further classified into subgroups based on the landforms it associated in the Valles. The geological mapping was done with help of THEMIS image.
The Cusus Valles is bounded by two major wrinkle ridges, which may be controlled by fault and graben structure. In addition, at few locations the drainage system controlled by EW running linear fault. The channel system in the Cusus Valles regions geomorphically classified into grooved valley floor, former lobate debris aprons, craters, craters ejecta materials and flow materials.

Detailed morphometeric analyses of Cusus Valles were carried out using THEMIS image and MOLA data. The analysis was done with help of hydrological modeling tool in ArcGIS 10.4 software. The linear morphometric parameters include stream order, stream number, stream length, bifurcation ratio, stream sinuosity indices were drawn. In the aerial morphometric analysis, drainage density, drainage frequency, drainage texture, elongation ratio and circularity ratio were estimated. Similarly few parameters were derived under relief morphometry. All these morphometric parameters were interpreted in detailed for understanding the Cusus Valles development terrain conditions, geomorphic processes and climatic conditions.

The Columbia Valles located in the east of Valles Marineris region is another fluvial system taken in this study. Columbia Valles typically fill in the category of outflow channels developed by catastrophic flooding. The study has conducted to understand the morphological features associated with the catastrophic flooding, the origin of outflow channels and flow dynamics during catastrophic flooding and channel initiation time. In contrary to Cusus Valles, the outflow channel of Columbia Valles in the southern hemisphere is younger. Through CSFD method, the absolute age of the Cusus Valles is estimated as 3.58 Ga, which fall in early Hesperian time period. During this time, the climatic conditions might have shifted from warm and wet climate conditions to cold and dry conditions. The Columbia Valles channel system spread over about 70km width from Aurore planum to Eos Mensa. There are six outflow channels developed in the Columbia Valles which categorically linked Capri chasma and
Ganges chasma. The MGS MOLA data along with THEMIS and MCC data were extensively used for plotting the longitudinal and cross sectional profile of Chasma, overland valles region and channels. The morphological features associated with outflow channels include grooved terrain, streamlined uplands, mensa, cataracts, cliffs, butte and basin topography and hummokey terrain. These features indicate the evidences of catastrophic flooding in the Columbia Valles. An attempt has made to derive flow morphometry parameters in the Columbia Valles, which are entirely different from the Cusus Valles, developed through precipitation and surface runoff. An attempt has been made to estimate the volume of discharge of water in the Columbia Valles. The volume of discharge is estimated at two stages as initial overland flow before channel incision and late stage flow estimation. The discharges for individual channel were estimated. The peak flow flux in the Columbia Valles is estimated at 23.61 m$^3$.

In the present fluvial morphological study of Cusus and Columbia Valles, the following conclusions were drawn:

- The systematic ordering of streams, narrow valley, dendritic drainage pattern and concave profile of major drainage indicates the atmospheric precipitation, surface runoff, erosion and infiltration processes are responsible for the origin of valley networks in Cusus Valles.

- The absence of theatre-like termination in the catchment areas of Cusus Valles suggested that the development of valley network through ground water sapping is ruled out.

- The wrinkle ridges interpreted from THEMIS image and DEM profile created from MOLA data clearly show the Cusus Valles developed in a graben structure.
Chapter 5 Conclusion

- The comparison of Cusus Valles stream order to terrestrial environment indicates that the Valles region is not attained the maturity level in the fluvial cycle. The immature developments of fluvial system indicate the cessation of fluvial activity, due to interpretation in the hydrological cycle by changes in climatic conditions.

- The low drainage density and bifurcation ratios in the Cusus Valles indicated that the terrain is covered by high permeable material. Terrain might have stored large quantity of water in subsurface during active fluvial systems.

- Our study reveals that the development of Cusus Valles through atmospheric precipitation, surface runoff and erosion. These could be happened by presence of warm and wet climatic conditions. The late Noachian time period (3.9 Ga) of Cusus Valles also suggested these phenomena. Most of the earlier studies are also favor that the warm and wet climate prevailed during late Noachian to early Hesperian time period.

- We concluded that the rupturing of cryosphere associated with Aurore Planum and large volume of catastrophic flooded water from Valles Marineries regions are the major causes for development of outflow channels in the Columbia Valles.

- The hummocky terrain, cataracts and cliffs in the margins of Aurore Planum clearly indicates rupturing of cryosphere and development of outflow channels.

- Capri chasma with aerial coverage of 29,177sq.km is acted as major reservoir and stored millions of cubic meter of catastrophic flooded
water in the chasma region before development of outflow channels.

- Through MOLA data we infer that the channel initiation was taken at the elevation of 1150m.

- The morphological features associated with Columbia Valles clearly indicate the catastrophic flooding originated due to collapse of groundwater aquifers.

- The development of outflow channels in the Columbia Valles is approximately during early Hesperian period when climatic conditions also change from warm to cold conditions.

- The estimated overland flow of discharge in the Columbia Valles is 3.62 m$^3$ s$^{-1}$ over the width of 60km just before the development of channels. The maximum quantity of water discharged through channel 5 with 7.67 m$^3$ s$^{-1}$ of water.