Ethiopian Journal of Science and Sustainable Development

e-ISSN 2663-3205 Volume 6 (1), 2019

Journal Home Page: www.ejssd.astu.edu.et

EJSSD
ETHIOPIAN JOURNAL OF SCIENCE AND SUSTAINABLE DEVELOPMENT
An Official International Journal of Adama Science and Technology University

Research Paper

Mapping Faults around Adama Town: Implication for Future Earthquake Triggering Potential

Asfaw Erbello*, Hassen Shube

Adama Science and Technology University, School of Applied Natural Sciences, Department of Applied Geology, Adama, Ethiopia

* *Corresponding author, e-mail:* asfaw.erbello@astu.edu.et

Abstract

Extensional tectonic environments mainly reflect normal fault induced geomorphological features. The study area (Adama and its surrounding) is located in the northern Main Ethiopian Rift (MER) where NNE-SSW striking extensional related normal fault features are common. Aim of this study is to integrate structural and geomorphological features of fault scarps of the area to infer their earthquake triggering potential. A combined method of fault plane analysis and stream profile index approach used to evaluate faults activity of the study area. Kinematics of five selected sites structural data analyzed and integrated with geomorphological results. All sites averaged fault plane analysis revealed N 112° E directed tectonic stress of the area. The result is statistically similar with the current stress inferred from geophysical monitoring (~ N 105° E). This geometrical coincidence in stress direction may result reactivation of previously formed major faults of the area. The result shows minor deflection to the south which could be resulted due to crustal strength heterogeneity and /or local stress change. Morphological analysis using stream profile index indicate active fault signatures such as knick points. These signatures are mainly common in the west of the study area. Integration of structural and geomorphological data mainly from the western side of the town further confirms active fault characteristics which may result rupture induced earthquake occurrence along these fault planes. Pilot study on ground cracks around the town shows a significant relationship with faults of the area. This correlation indicates the current tectonic stress of the area has a significant control on the frequently occurring ground cracks in the area.

Keywords: - *Fault kinematics, tectonic stress, paleo-stress, ground crack, knick point.*

1. Introduction

Surface manifestations of faults in tectonically active regions are common morphological expressions. Morphological expression of these active faults could be varied, mostly based on the faults activity, lithology affected by faulting and climatic condition of the area (Lifton & Ghane, 1999). The study area located in the northern MER which is part of the East African Rift System (EARS). The MER contains a series of active rift zones with associated effusive to explosive volcanic products concentrated along the general trend of the rift. The MER traditionally classified into three segments based on the relative intensity of Volcano-Tectonic activities and faults architecture (Agostini *et al.*, 2011). These are southern MER, middle (central) MER and northern MER. The boundary which divides each of them is delineated in different positions by different researchers. Petrologists and structural geologists classified the boundary based on the intensity of volcanic products, their petrographic characteristics and structural features (Agostini *et al.*, 2011) while geophysicists use geophysical anomalies to classify each of the sections (Keir *et al.*, 2006a). The whole

© 2019 Adama Science & Technology University. All rights reserved

MER which started to develop in Miocene time, is part of the EARS and comprises a series of rift zones extending over a distance of about a thousand kilometer from the Afar Triple Junction down to the south (Boccaletti *et al.,* 2000). A number of rift related episodic volcanic products distribute throughout the rift sector and rift shoulder in the region (Rooney *et al.,* 2018). Faulting in the region characterizes different geometrical features in the different sectors of the rift (Corti, 2009; Agostini *et al.,* 2011; Erbello *et al.,* 2016). The different geometrical features of the faults in the region developed due to a change in stress direction (Bonini *et al.,* 2005) or a constant continuous stress with the influence of pre-existing weak zones (Corti, 2009; Erbello *et al.,* 2016) or related northeast-southwest strike slip extension throughout the history of rifting in the region (Muluneh *et al.,* 2015). Geodetic and seismic data observations from the different segments of the MER which is assumed to be controlled by long term Nubia-Somalian plate motion constrain an average extension direction between ~N90^{0}E and ~ N 105^0 E (Keir *et al.*, 2006a; Stamps *et al.*, 2008; Saria *et al.*, 2014). Structural features developed due to either of the above stress orientations are classified in to marginal faults and axial faults (Corti, 2009). Majority of structures around the study area (axial faults) are characterized as Woniji Fault Belts (Abebe *et al*., 2007) with NNE-SSW general orientation.

The area is situated along one of the active right stepping en echelon arranged Gedemisa-Boset magmatic segment in the northern MER. Considering the area location within the MER specifically in the northern MER (Figure 1), it is believed that the region is both seismically and volcanically active. One of the most commonly known structural effects of earthquake is formation of fractures which will progress to faults. Repeated earthquakes along a fault plane will result a cumulative slip with a significant vertical displacement and well preserved fault scarps mark most recent earthquakes (Benedetti *et al.,* 2014). It is suggested that larger fault scarps such as the Adama fault scarp form through a long term continuous earthquake generations. In tectonically active regions; morphological features such as across fault scarp stream profiles reveal information about recent faults activity (Hack, 1973). Faults reactivation could be significantly influenced by geometrical relationship between their orientation and current kinematics of the region. Studying local faults kinematics and their morphological characteristics has a significant contribution to understand earthquake potential and earthquake induced geohazard in an area like Adama town and its surroundings where infrastructure development and population density is drastically increasing. This project aimed to study kinematic and morphological features of faults around Adama town to evaluate their future earthquake triggering potential through comparison with the current stress orientation of the region.

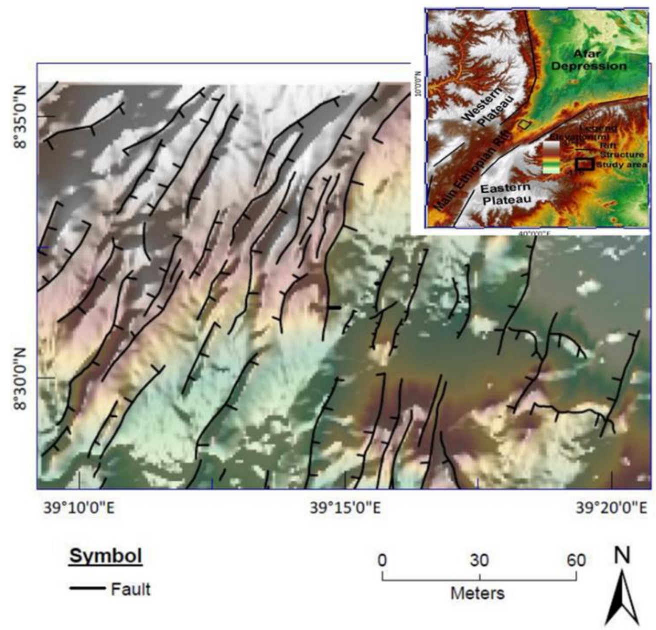

Figure 1: Location map of the study area.

2. Methods and Materials

Methods adopted for this study includes a morphological investigation of the area using high resolution Google earth images and satellite images using Arc GIS techniques. Stream network map of the area is generated from the Shuttle Radar Topographic Mission (SRTM, 30m resolution). Based on the characteristics of stream networks extracted from Digital Elevation Model (DEM), we choose stream profile networks flowing across the strike of faults to investigate their slope gradient variation. For this approach we used Hacker profile and SL index analysis of streams. The longitudinal river profile is a curve, which represents the variation of elevation with the downstream distance of a river (Hack, 1973).

SL= (ΔH/ΔL) L

Where ΔH/ΔL is the channel gradient for a particular segment (ΔH ¼ difference in elevation, ΔL ¼ length of segment); L is the total length of the channel from its source to the midpoint of the particular segment. Knick points are mostly associated with high values of SL index in comparison to the adjacent segments. In general, the segments with high SL index Correspond either to change in lithology or an active fault (Hack, 1973). In a profile, a graded river is approximated by a straight, inclined line (Hack & Young, 1957). However, ungraded river profiles are mostly marked by a concave or convex upwards segments, depending on the degree of erosion and rate of uplift. From this slope gradient along the stream, we evaluated the activities of some selected faults. In addition to these all, standard fault attitude measurement data from five sites distributed around Adama town (Figure 3) collected to compare with the current tectonic force of the region.

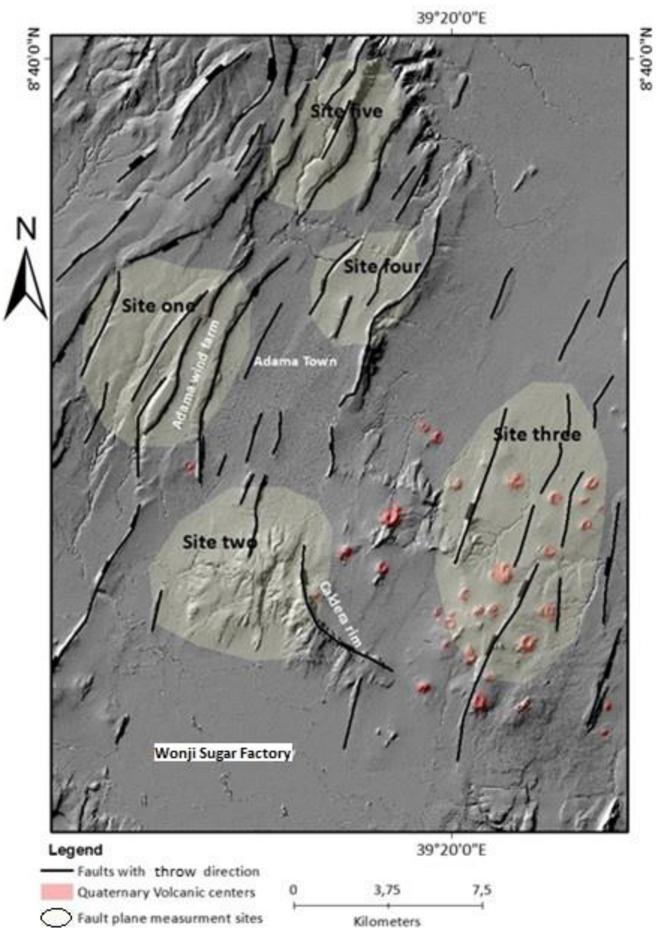

Figure 3: Distribution of fault plane measurement sites overlay on hill shaded image of a 30m resolution DEM.

3. Results and Discussion

3.1. Structural features of Adama area

Structures exposed in this area varied both in length and orientation. Most of structural features show closely related geometrical characteristics. The general orientation of structures range from N 10^0 W to N 25^0 E Strike. Dip of faults also varied from 65^0 -70^0 E. Most of structures dip to the west and east with the range of dip amount indicated above. Few east-west oriented structures identified in the south east of the study area. This east-west oriented structures mainly link larger NE-SW oriented structures. About 104 fault plane and fracture plane measurement data collected from five sites. The sites are geographically distributed to all directions of the study area where accessible fault plane measurements available. High displacement; longer faults are the characteristics of the western side of the study area. Orientation data of faults plotted on a stereographic projection (Figure 5). Overall strike of all the faults plotted show N 22^0 E orientation. The shorter faults are linked by some east-west oriented much shorter faults. Collapse of a ridge in the east of the Adama town follows the general orientation of faults in the area. The southern part of the town and its surroundings are characterized by closely spaced parallel faults. Scoria cones and volcanic ridges are systematically distributed in association with faults in this area (Figure 4). In addition to faults, there are smaller to larger ground cracks oriented parallel-subparallel with faults. As like the faults in the west of the town, the faults in this part forms narrow horst and graben structures. Further comparison of faults geometry, with the western side (site one), faults in this area are shorter both in length and vertical displacement. Some of the faults in the south and north of the town identified as propagating towards each other and closer to link within the town which could be a potential site for stress overlap. Faults in the north of the town are few in number, but longer in length. Some of the faults in this section are identified as propagating towards to the north of the town. An average extension direction of SE-NW or ~ N 112^0 E (Figure 6) inferred from kinematic analysis. Joints in the area are mostly two systems of joints where one is striking E-W and the second is perpendicular to the first and parallel to the strike of faults in the area.

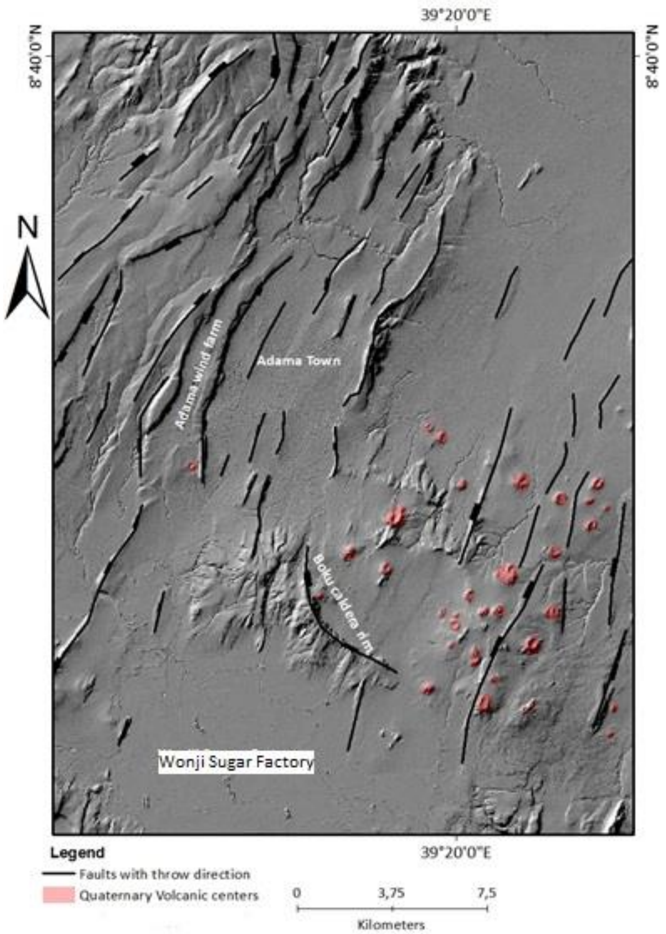

Figure 4: Structural map of the study area (Adama and its surroundings) overlay on a 30 m resolution DEM modified from (Abebe et al., 2007).

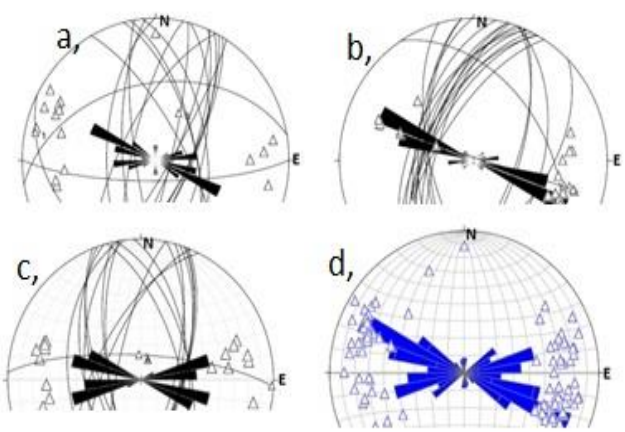

Figure 5: Calculated poles (triangles) plotted from strike and dip measurement data (great circles) from representative sites 1, 3 and 5 (a, b and c respectively). The last plot (d) shows overall calculated poles from all sites.

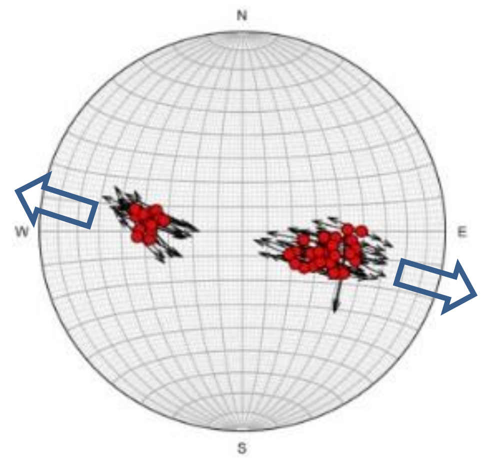

Figure 6: Calculated paleo stress direction on a stereographic projection. Small arrow emerging from red circles indicate paleo stress for each of measured fault data (outliers removed). The bigger arrow indicate an average paleo stress direction for all measured and analyzed fault data.

3.2. Morphological features of the study area

Geomorphological features of the study area resulted from fault morphology and volcanic product pileups (Figure 7). Stream network characteristics are significantly influenced by quaternary faulting activities of the area. Stream profile index SL is a powerful tool to investigate tectonic, climate and lithological impact on stream flow nature. Most of streams flow pattern in the region indicate strong relationship with the pattern of structures (Figure 9). Majority of streams are flowing parallel with the strike of faults. There are only little number of streams flowing across the strike of faults. The higher values of SL identified from each of across fault flowing streams and each of the points were also verified in the field. Majority of fresh fault scarps outcrop reveal immature stream profile signature. This is one of atypical characteristics of active fault features. Other common feature is fault overlap zones where two en echelon arranged faults are propagating towards each other. In active region like our study area; such feature zones are areas where stress overlap (Figure 8). A cumulative propagating stress could result an earthquake and associated earthquake hazard such as landslide because of the area contains highly fractured weak rock fragments.

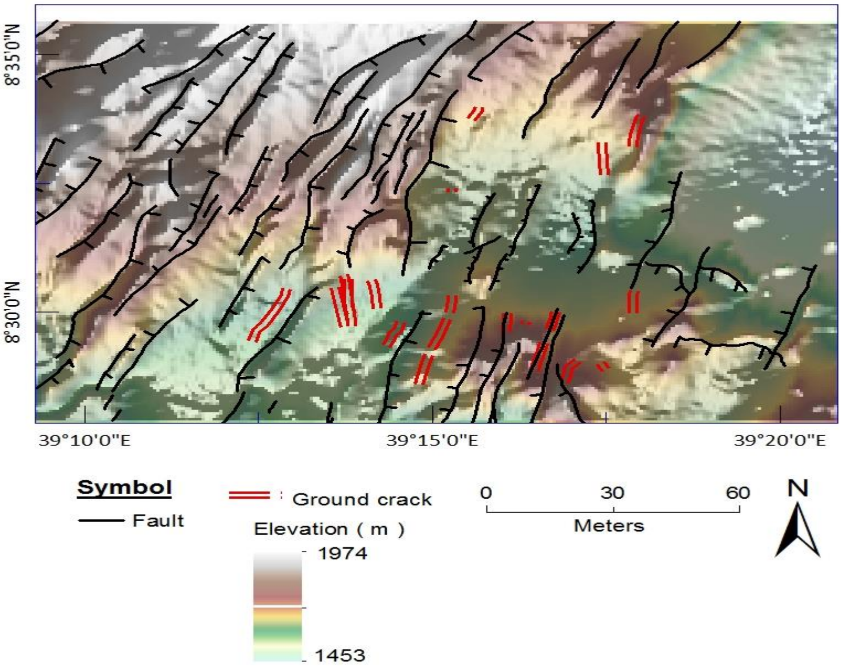

Figure 7: Morphological expression of fresh fault out crops (Inset figure).

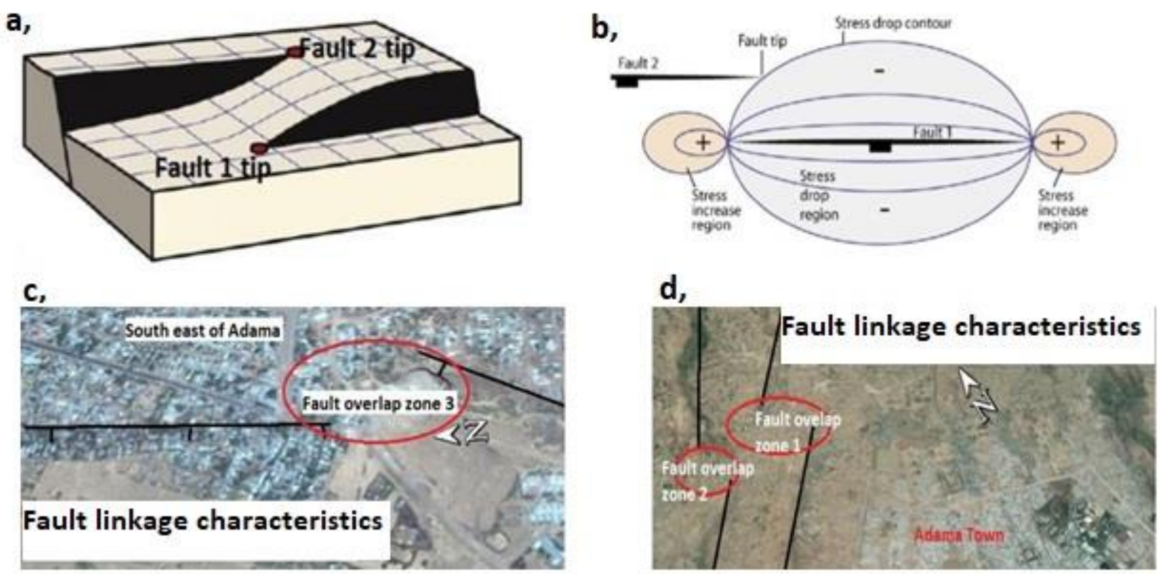

Figure 8: Overlapping fault characteristics: (a & b) fault overlap nature and stress drop envelop models modified from(Gupta A. & Scholz H, 2000) and (c & d) identified fault overlap zones and their characteristics in the study area mainly in Adama town.

3.3. Ground cracks and its tectonic relationship

Ground crack feature is a common ground failure characteristic in the rift valley of Ethiopia. Even though the cause of these ground cracks not yet identified in scientific reasoning, but it is becoming a critical problem in the rift valley regions of Ethiopia such as Adama area. Field work conducted to investigate these ground cracks in Adama and its surroundings to check their relationship with the structures of the area. Strike measurement of ground crack data performed using high resolution google earth image of the area. These ground cracks most commonly form in the rainy season. Intensity of their spatial distribution, their geometrical parameters such as crack width and crack length are also variable. Surface exposure of reworked volcanic and soil material thickness varies in the north and south directions of the town. This variation indicates cohesion variation in the area. This could be one of the reasons for the spatial distribution variability of ground cracks around Adama town. In addition to these, collected and analyzed ground crack orientation data from the different parts of the town reveal a significant contribution of tectonic activity of the area. The average orientation of ground crack measurement data obtained from stereo net plotting is N 13^0 E (Figure 10).

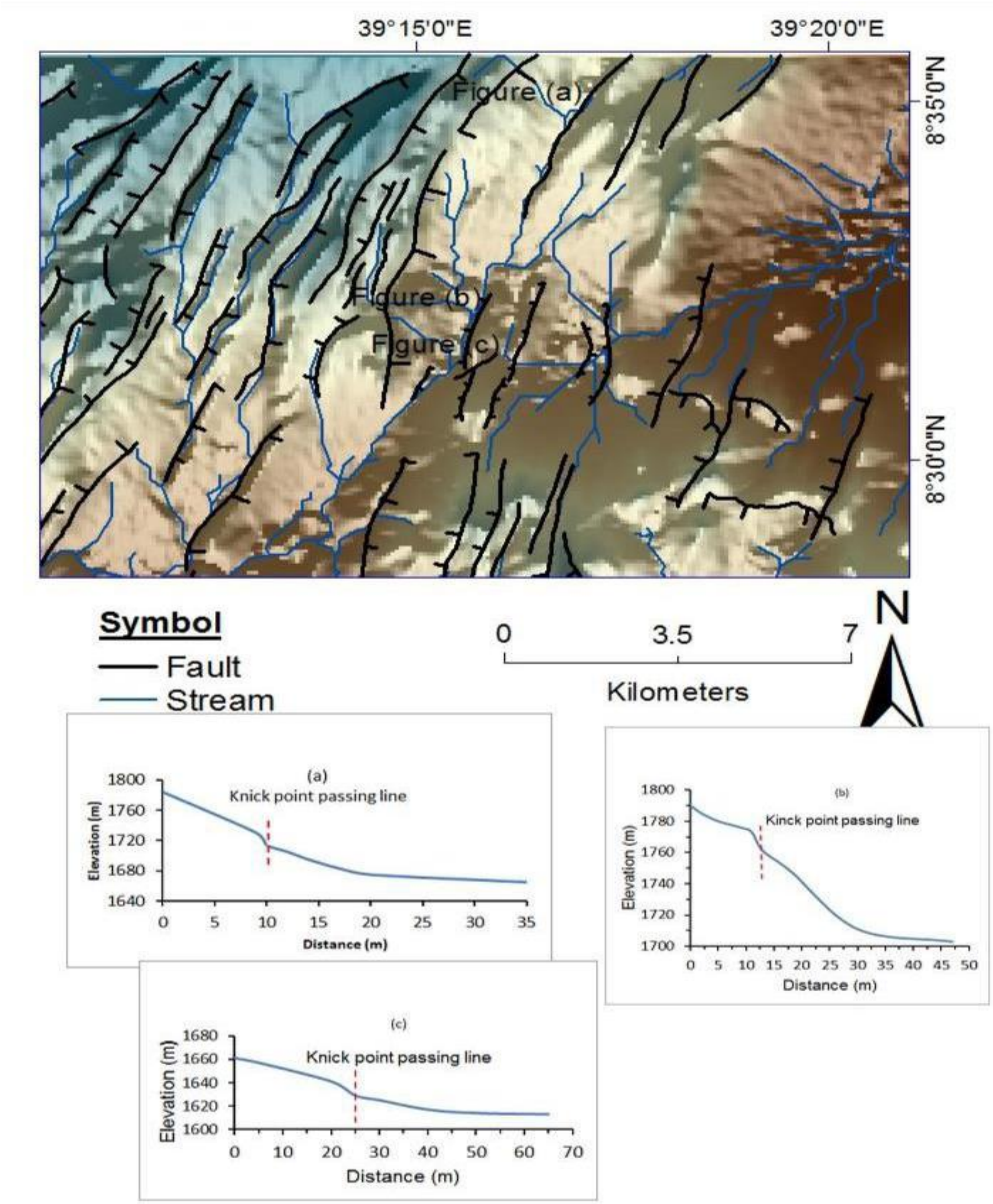

Figure 9: Fault controlled stream flow patterns and elevation versus distance profile of across fault flowing streams. Red dotted vertical lines (a, b, and c) indicate knick points which indicate active fault signatures.

Figure 10: Ground cracks orientation plot and an example of a 20 m wide ground crack between two parallel faults.

4. Conclusion

Along the strike of the MER, it has been recognized that seismic and volcanic activities are significantly variable. The northern MER is one of the most recognized volcanically and seismically active region. Our structural data analysis, comparison with geophysical data and integration with geomorphological feature suggest the following:

1. Overall paleo stress analysis of fault plane measurement data shows N112^0 E stress direction. It has a minor deflection with respect to the regional geophysical data N105^0 E (Stamps *et al* (2008). It is interpreted that the minor deflection could be due to local stress variation, local crustal heterogeneity and the area is an overlap zone between Central MER and northern MER. This close relationship with the current stress in the region can cause slip along the faults in the area to trigger an earthquake.
2. Geomorphic investigation through drainage analysis indicates, majority of streams are flowing parallel to the strike of the faults which indicate the scarp is still fresh for steam incision. Limited number of stream profile analysis indicate also fault scarps mainly the western margins are active. This agrees with the structural data.
3. Pilot major ground crack geometrical analysis reveal N 13^0 E strike direction. It clearly indicate close relation with the local and regional stress orientation. This suggests that local and regional tectonic stresses have significant contribution in ground crack formation in the region.

Acknowledgment

The authors would like to acknowledge Adama Science and Technology University Research Affairs for the financial support.

Reference

Abebe, B., Acocella V., Korme, T., Ayalew, D. (2007). Quaternary faulting and volcanism in the Main Ethiopian Rift. *Journal of African Earth Sciences*, *48*,115-124.

Agostini A., Bonini M., Corti G., Sani F., Mazzarini F. (2011).Fault architecture in the Main Ethiopian Rift and comparison with experimental models: implications for rift evolution and Nubia- Somalia kinematics. *Earth and Planetary Science Letters*, *301*, 479–492.

Benedeti Lucilla and Jermone van der Woerd. (2014).Cosmogenic Nuclide dating of earthquakes, faults and toppled blocks. *Elements*. DOI 10.2113/gselements.10.5.357

Boccaletti, M., Mazzuoli, R., Bonini, M., Trua, T., Abebe,B. (2000). Plio-Quaternary volcano-tectonic activity in the northern sector of the Main Ethiopian Rift (MER): relationships with oblique rifting. *Journal of African Earth Sciences*, *29*, 679–698.

Bonini, M., Corti, G., Innocenti,F., Manetti,P., Mazzanni,F.,Abebe,I., and Pecskay, Z. (2005). Evolution of the Main Ethiopian Rift in the frame of Afar and Kenya rifts propagation Tectonics. *Tectonics*, DOI 10, 1029/2004TC001680.

Corti G. 2009. Continental rift evolution: From rift initiation to incipient break-up in the Main Ethiopian Rift: East Africa. *Earth Science review*, *96*, 1-53.

Erbello, A., Corti,G., Agostini,A., Sani, F., Kidane, T. , Buccianti, A. (2016). Modeling along-axis variations in fault architecture in the Main Ethiopian Rift: Implications for Nubia-Somalia kinematics. *J. Geodynamics*, *102*, 24-38.

Gupta A. and Scholz H. (2000). A model of normal fault interaction based observation theory. *Journal of Structural Geology*, *22*, 865-879.

Hack, J.T. (1973). Stream-profile analysis and stream-gradient index. *U.S. Geol. Surv. J. Res*, *1*,421-429.

Hack, and Young. (1957). Studies of longitudinal stream profiles in Virginia and Maryland. *U.S. Geol. Surv*, *294* (B), 42-97.

Keir, D., Ebinger, C.J., Stuart, G.W., Daly, E., Ayele, A. (2006a). Strain accommodation by magmatism and faulting as rifting proceeds to breakup: seismicity of the northern Ethiopian rift. *Journal of Geophysical Research*, DOI 10.1029/ 2005JB003748.

Lifton, A. & Ghase, G. (1999).Tectonic, climatic and lithologic influences on landscape fractal dimension and hypsometry: implications for landscape evolution in the San Gabriel Mountains California. *Geomorphology*, *5*, 77-114.

Muluneh, A., Cuffaro, M., Doglioni, C. (2014).Left-lateral transtension along the Ethiopian Rift and constrains on the mantle reference plate motions. *Tectonophysics*, *632*, 21–31.

Rooney, T. (2018). The Cenozoic magmatism of East African: Part I- Flood basalts and pulsed magmatism. *Lithos*, *286-287*(2017), 264-301.

Saria, E., Calais, E., Stamps, D., Delvaux and Hartnady H. (2014). Present day kinematics of the East African rift. *Journal of Geophy Research*, DOI 10.1002/2013JB010901.

Stamps, D. S., E. Calais, E. Saria, C. Hartnady, J. M. Nocquet, C. J. Ebinger, and R. M. Fernandes. (2008). A kinematic model for the East African Rift. *Geophys. Res. Lett*, DOI 10.1029/2007GL032781.