JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 17 2009

THE EVOLUTION OF THE RIVER GASH BASIN, EASTERN SUDAN

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The study area covers the River Gash Basin located in the eastern part of the Sudan. The river is considered an intermittent stream originating in the highlands of Eritrea. It flows northwest across a flat plain and ends in the Gash delta, an important agricultural region. Remote sensing methods are used with structural analysis and geophysics to detect river course changes and delta migration. The River Gash historically was part of the Nile River system. Dramatic river course changes have occurred due to tectonic activities, sedimentation, and climatic changes. The subsurface geometry and structural pattern of the basin have a strong influence on river course changes and delta migration. This study shows two paleodeltas of alluvial sediments towards the River Atbara. Structural analysis reveals four dominant fracture systems which are the main factors that control the river course. Geophysical investigations using electrical resistivity confirmed the existence of the paleodeltas and fracture systems. The geophysical survey identified a step faulting system caused by an E-W fracture trend, in which the depth of the basin increases toward the north.

BACKGROUND

The problem of flooding and river bed rise due to sedimentation is the most chronic problem in Kassala town, eastern Sudan, and its surroundings. The River Gash delta is in continuous migration toward the town to the south. Although many engineering solutions have been carried out to protect the town from flooding including earth protection walls and dikes, the town remains very vulnerable. All the engineering solutions are mainly based on the surface morphology of the river without consideration of the subsurface geometry of the basin. This study represents a new approach to look for other elements that may effect the development of the basin configuration.

STUDY AREA

The Gash river basin is considered to be one of the most famous alluvial basins in Sudan. The Gash river is an intermittent stream originating in the highlands of Eritrea. It flows northwest across a flat plain and ends as an inland fan delta (Figure 1). It is the most important agricultural land in the area (Saeed, 1969).

The region is characterized by semiarid climatic conditions. Two main seasons can be distinguished: summer and winter. The rainy period starts in July and continues to the end of September with an average annual rainfall of 340 mm. The vegetation cover is governed by the intensity of the seasonal rains and it increases after the flood periods of the Gash River (Alobeid, 2007).

The topography of the River Gash Basin is generally flat to slightly rolling with a gentle slope towards the northwestern part of the study area. The elevation ranges from 500 m in the southeast to 450 m in the northwest (Figure 2).

The total length of the river from its source in Eritrea to the apex of the fan north of Kassala is about 280 km (Abdul Latif, 1989). When entering Sudan, the flow direction of the river changes from west to the north and the river attains its characteristic appearance of a wide shallow stream with a sandy bed bordered on either side by extensive flood plains. The drainage pattern is characterized by several minor khors flowing from the east to the northwest joining the River Gash (Figure 2).

DATA TYPES

1. Enhanced Thematic Mapper ETM+ Landsat satellite data (scene p171/r49)
2. Shuttle Radar Topography Mission (SRTM) data
3. Radar imagery
4. Geological Research Authority of Sudan (GRAS), RRI project geological maps
5. Russian Topographic maps of scale 1 : 500,000
6. 1 : 100,000 Sudan survey topographic maps
7. 1 :250,000 Sudan survey topographic maps

IMAGE ANALYSIS

Remote sensing and GIS are known to be powerful techniques used in river development studies. To obtain a full coverage of the area under investigation, a mosaic was prepared from the original

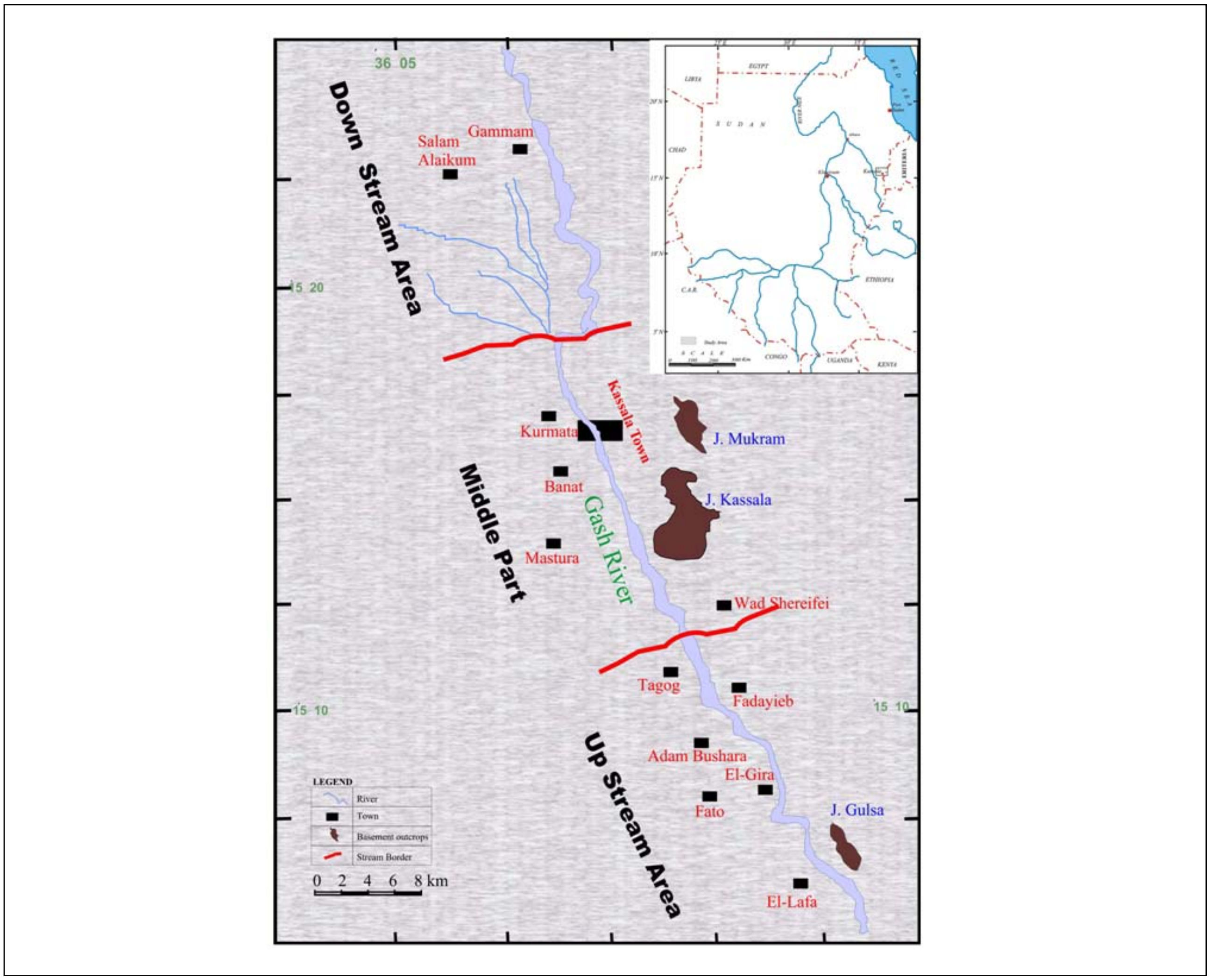

Figure 1. Location map of the River Gash Basin.

raw data. Preprocessing of raw data and different enhancements were applied to increase the interpretability of satellite images.

Color composite of bands 7,4,1 and 7,5,2 displayed in R,G,B respectively (Figures 3 and 4) aided the geological, topographical, and geomorphological interpretations of the basin.

Moreover, high–pass and directional filtering were carried out to reveal the lineaments occurring in the study area. Image sharpening using the panchromatic band, with the most suitable color composites, enhances the drainage pattern of the area as well as the lineaments.

Canadian RADARSAT SAR-1 image of spatial resolution of 20x20m was used by ParBleu Technologies Inc. (2003) for River Gash flood assessment. Reinterpretation of these images shows the existence of old deltas and buried channels in addition to the most vulnerable areas for flooding. The Shuttle Radar Topography Mission data (SRTM) with 90m spatial resolution has been used to generate a digital elevation model to increase the breadth of geomorphologic information (Figure 2).

FRACTURE ANALYSIS

The goal of structural analysis methods used here after the remote sensing investigations, is to classify fracture patterns that control the river course. Generally, fractures can be classified

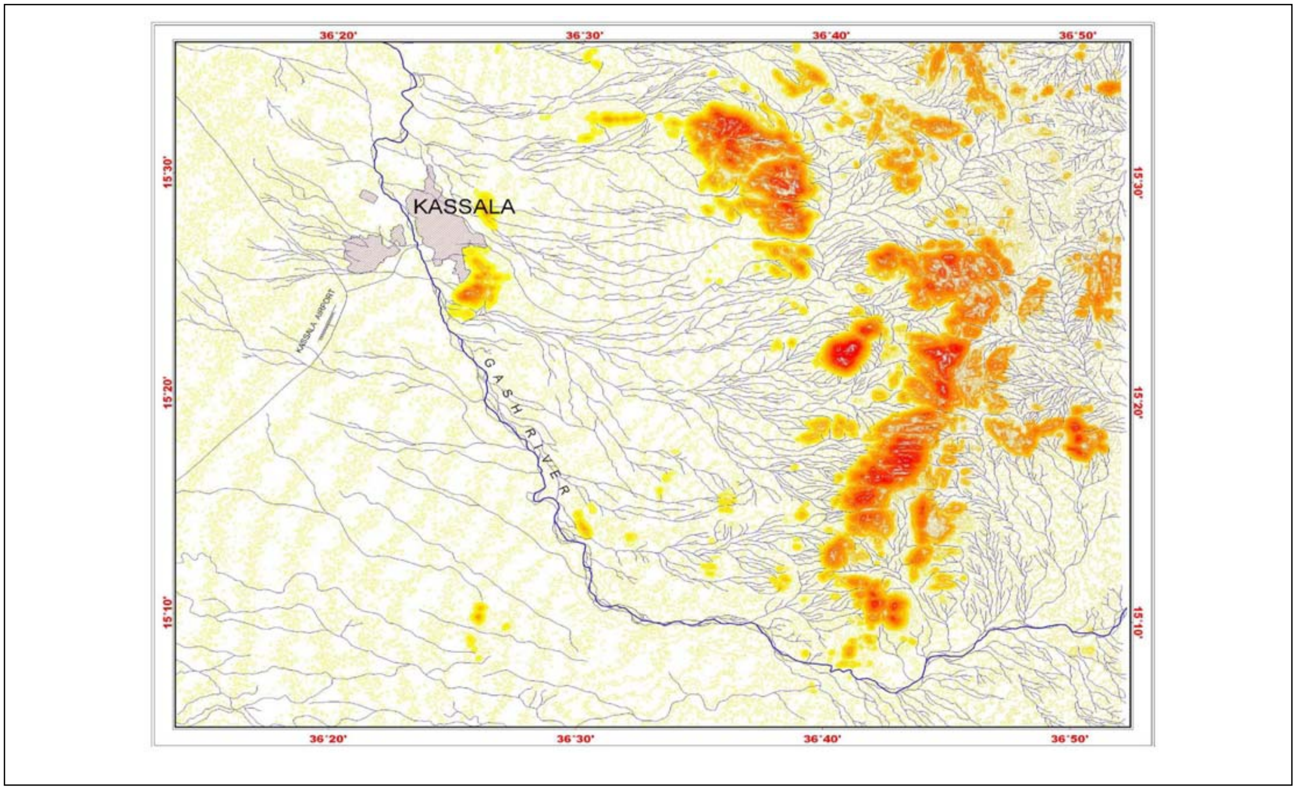

Figure 2. Elevation and drainage map of the River Gash Basin.

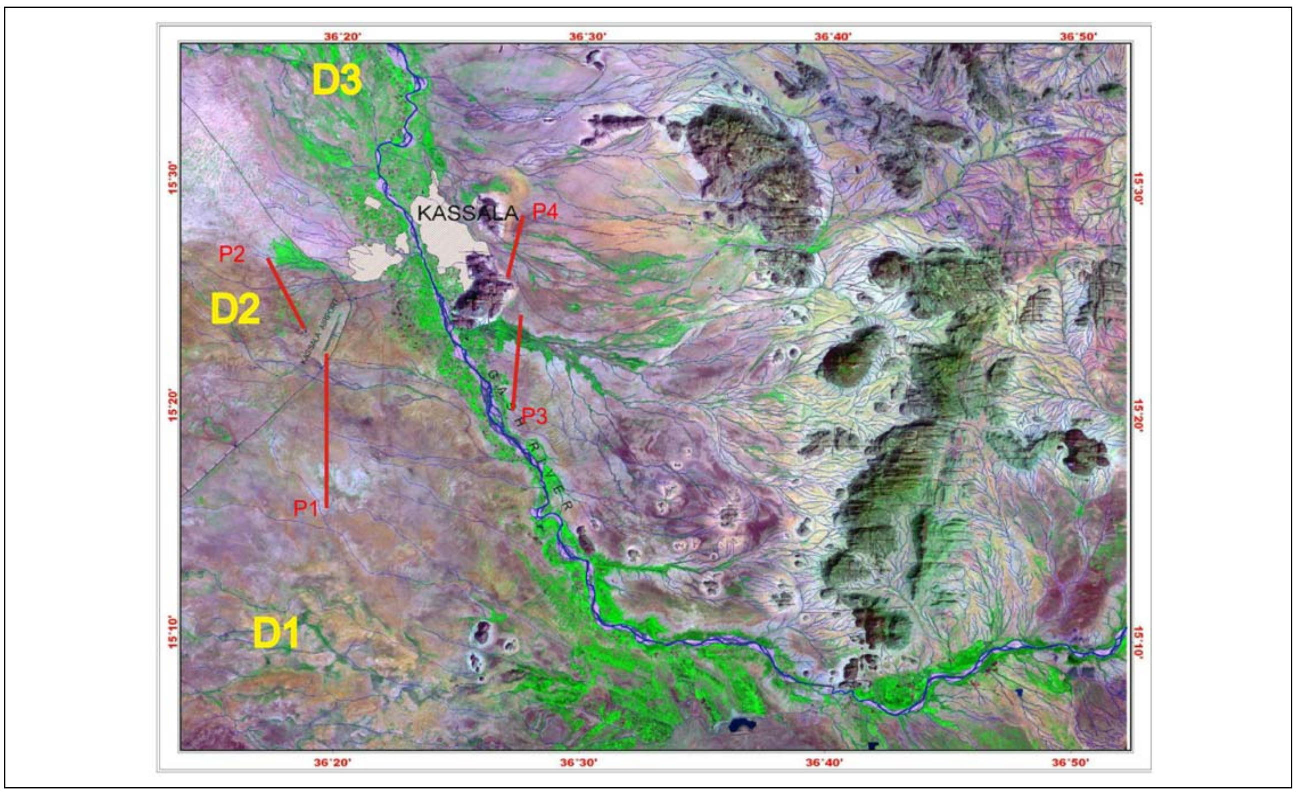

Figure 3. Landsat ETM+ 7 color composite image of bands 7, 4, 1 represented in R, G, B, respectively for River Gash Basin.

according to their genesis and origin into four main types: Tensional, Extensional, Shear and Release fractures. The different types of fractures have important impacts in controlling river courses.

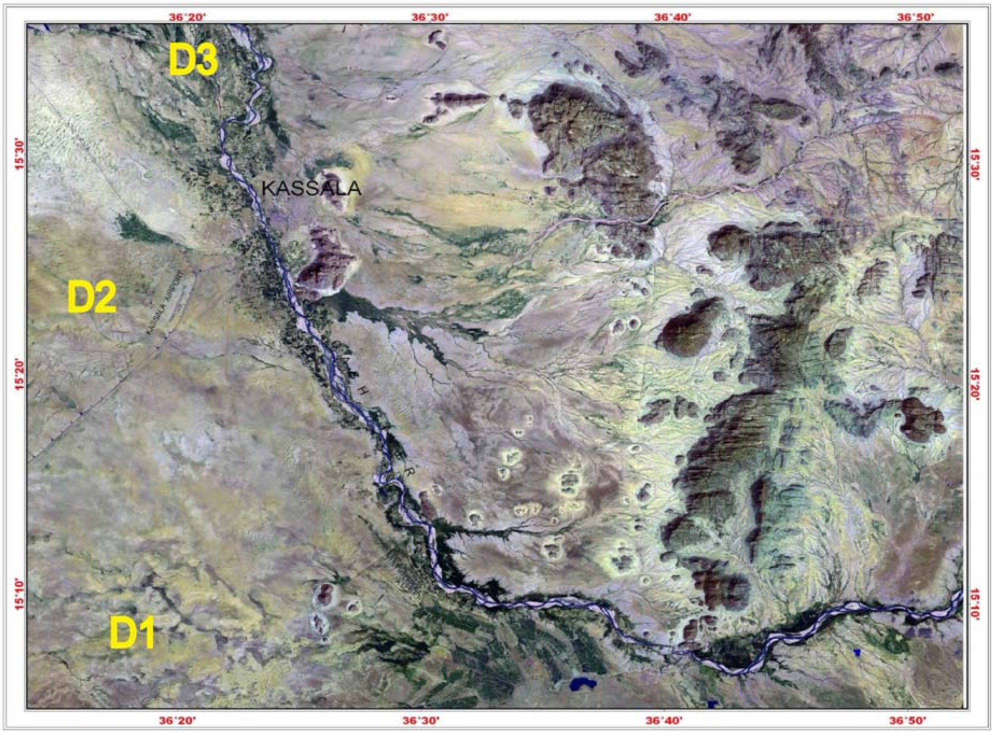

Figure 4. Landsat ETM+ 7 color composite image of bands 7, 5, 2 represented in R, G, B, respectively for River Gash Basin.

The stress and strain ellipsoids were used to study the force directions, paleo-stress, and then to detect and classify the fracture types. The Stress ellipsoid is composed of three main stress axes, (Park, 1997; Twiss and Moores, 1992): the greatest stress axis (σ_1), the medium stress axis (σ_2) and the smallest stress axis (σ_3), as in Figure 5 below.

In other way, the Strain ellipsoid is the reflection of Stress ellipsoid in which the main Strain axis (θ_1) is consigned to the smallest Stress axis (σ_3), the medium Stress and Strain axes (σ_2 & θ_2) are in the same plain and the smallest Strain axis (θ_3) is consigned to the greatest Stress axis (σ_1) (Figure 5).

Satellite images of Landsat ETM+7 were digitally enhanced using different processing techniques. Special emphasis was given to spatial filtering, by which linear features were detected, thus facilitating the production of the lineament map presented in Figure 6. The eastern part of the River Gash Basin is dominated by hard rocks, where delineation of fractures is more successful than in the unconsolidated sediments of the western part of the basin.

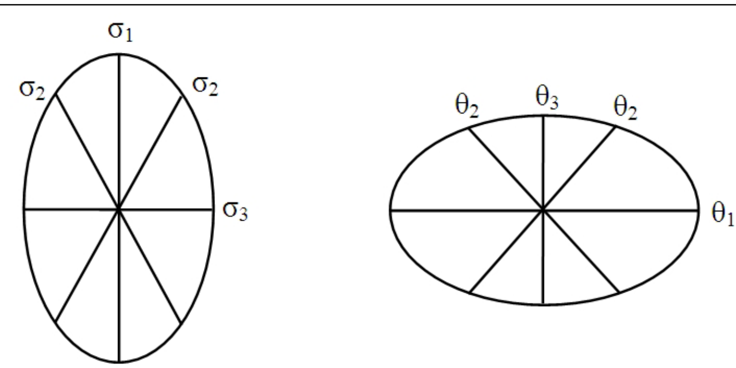

Figure 5. Stress-Strain ellipsoids used for fractures analysis.

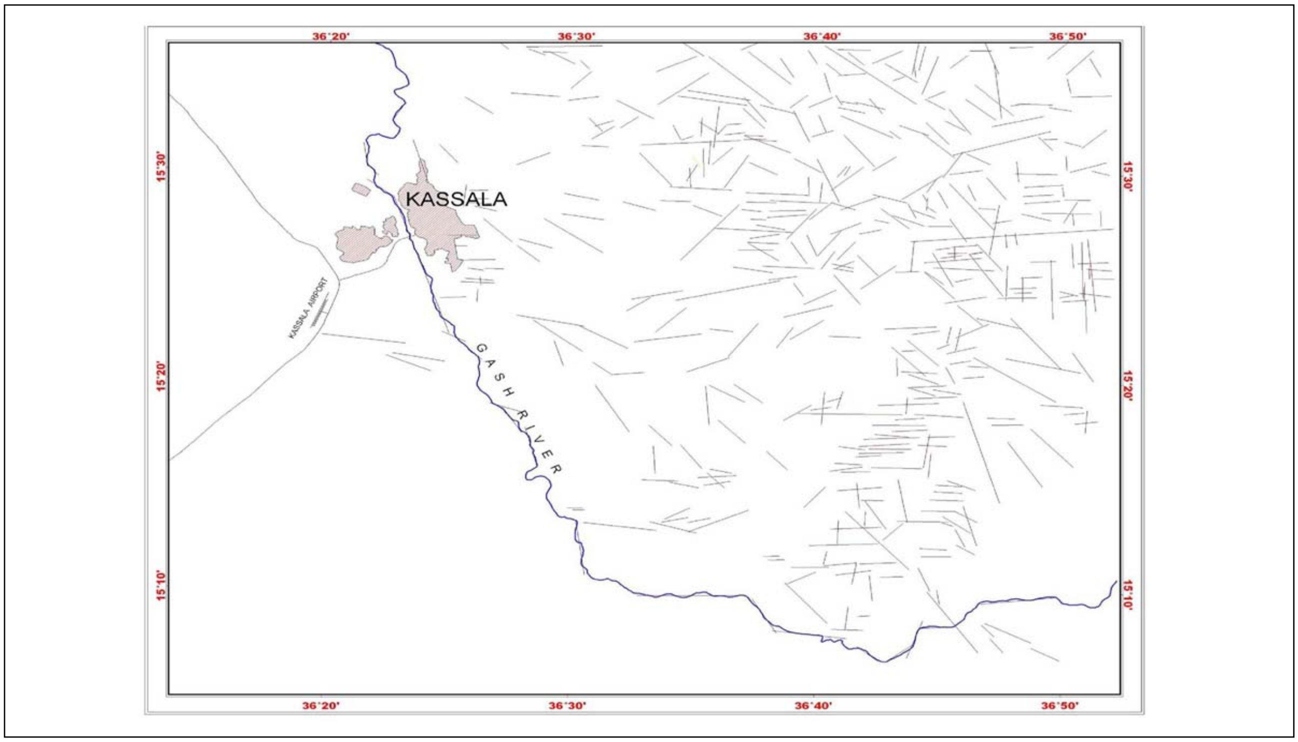

Figure 6. Lineament map of the River Gash Basin obtained from the interpretation of satellite images.

From this map, the main trends of lineaments can be classified into:

- N-S direction fractures
- NE-SW direction fractures
- NW-SE direction fractures, and
- W-E direction fractures

From the general tectonics of Sudan, the generation of the Pan-African Orogenic Belt developed due to the collision of the Island Arcs east of the old continent to the west (Kröner, 1987). The force directions are suggested to be from E to W. Accordingly, the W-E fractures were classified as extensional fractures, parallel to the greatest Stress axis (σ_1), and the smallest strain axis (θ_3). The NE-SW and the NW-SE fractures were classified as shear fractures parallel to the shear stress and strain axes (σ_2 and θ_2). The N-S direction fractures are classified as release fractures parallel to the smallest stress axis (σ_3) and the greatest strain axis (θ_1). The Tertiary tectonic events represented by the East African Rifting (EAR) also affect the area, and it is considered an active tectonic zone. The tectonic activity along the EAR and the Red Sea floor spreading may affect the river basin development in the region.

GEOPHYSICAL INVESTIGATION

The electrical resistivity methods are based on the principle of applying electric current to the earth through two electrodes and measuring their potential difference. The distance between the electrodes and the measured potential difference are the data used to interpret subsurface conditions (Telford et al., 1990). The Wenner array was applied to detect lateral variations, by which four profiles (Figures 7 to 10) were conducted. For the location of geophysical survey, see Figure 3. A current electrode separation of 120 m was used to reach a constant estimated depth ranging from 30 to 40 m below the earth surface, with station separation intervals of 60 m.

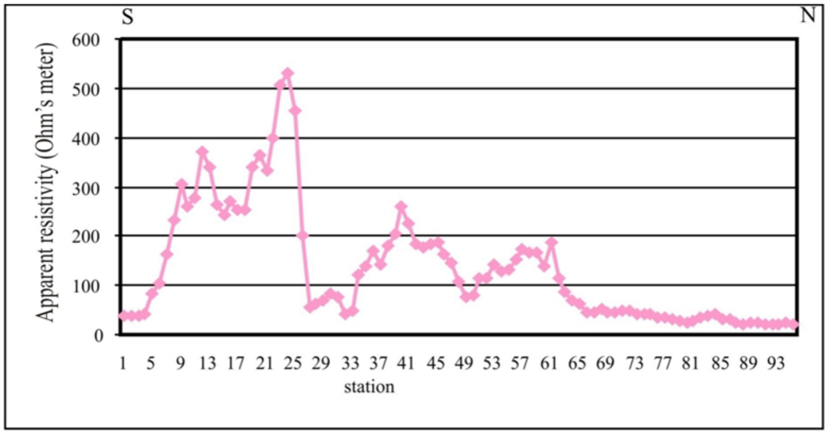

Figure 7. Electrical profile P1.

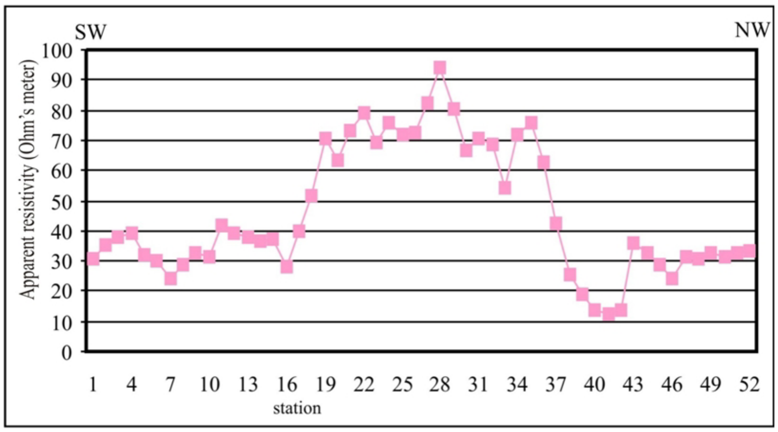

Figure 8. Electrical profile P2.

Interpretation of geophysical data

The geo-electrical profiles were conducted generally in a N-S direction crossing the E-W trend Extension fractures, which are expected to be the main fractures affecting basin development.

The electrical values change along profile P1 from south to north. They reflect high resistivity values from 300 to 500 ohm meters (Ωm) that indicates the existence of the basement rocks near the surface up to station 25. The sudden drop of the electrical values near station 29 indicates a fracture zone with vertical movement and subsidence toward the north. The lowest resistivity values along the profile after station 65 also indicate another fault plane with vertical movement and subsidence toward the north. This part of profile P1 is characterized by the deposition of the alluvial sediments, in which resistivity values are less than 50 Ωm.

For profile P2, the relatively low resistivity values from station 1 to station 16 and after station 40 represent subsurface alluvial sediments of silty-clay or fine sand, while the relatively higher resistivity values indicate coarse sand deposits. The variations of the sediments type clearly reflect a braided river and delta depositional environment that coincides with the appearance of the second paleo-delta that was detected through the interpretation of remote sensing images.

Profiles P3 and P4 are conducted at the eastern parts of the river in a N-S direction parallel to profiles P1 and P2 crossing the most effective extension fractures. The E-W fractures clearly show the low resistivity values of alluvial sediments alternating with the relatively higher resistivity values of weathered basements.

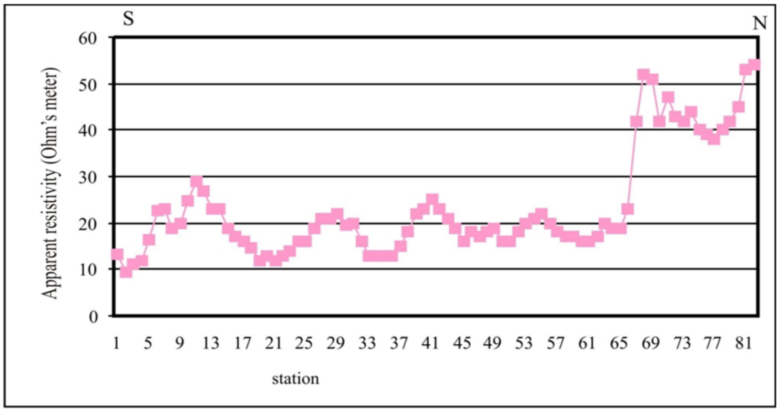

Figure 9. Electrical profile P3.

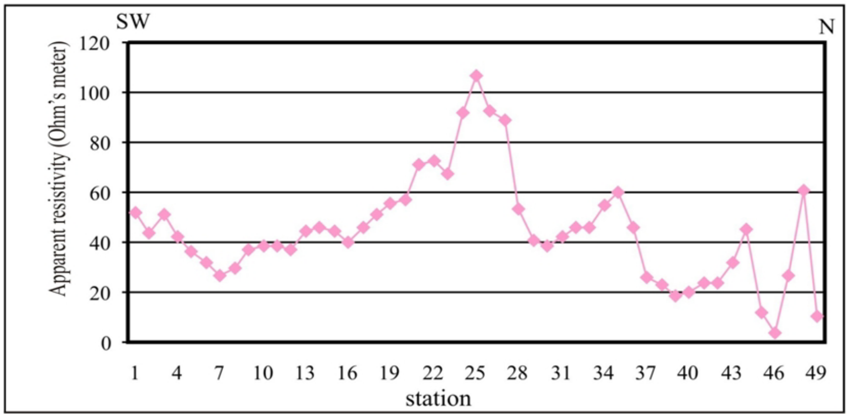

Figure 10. Electrical profile P4.

The geophysical profiles indicate a faulting system trending E-W parallel to the extension fracture pattern accompanied by vertical movements with subsidence toward the north. The E-W and N-S structural features strongly govern the drainage system and the river course geometry.

CONCLUSIONS

In the last few decades a chronic problem of flooding and river bed rise due to siltation has negatively affected Kassala town and the nearby territories. This study focuses on the subsurface geometry of the basin using remote sensing data, structural analysis, and geophysical surveys.

Interpretation of Landsat images shows two paleo-deltas towards the River Atbara in addition to the current Gash delta. These findings were supplemented by interpretation of Canadian RADARSAT SAR-1 image, which confirmed the existence of the above-mentioned paleo-deltas and buried rivers. We conclude that the River Gash has undergone a clockwise delta migration and river course change through time.

Further structural analysis indicates that the river geometry and morphology is controlled by four main fracture systems trending in N-S, E-W, NE-SW and NW-SE directions. The most dominant fracture systems are E-W, which are interpreted as an extensional fracture system, and N-S which are interpreted as release fractures.

Correlation of drainage maps, lineament maps and the results of structural analysis indicate that the paleo-river courses are parallel to the E-W fractures trend, while the current river course is parallel to the N-S fractures trend.

Geophysical survey supports the interpretation of remote sensing data and structural analysis. From this study it is evident that the River Gash Basin is structurally controlled showing step faulting of vertical movement with gradual subsidence towards the north. Therefore, neotectonics, in addition to sedimentation, may have a great role in the future morphology of the River Gash Basin.

ACKNOWLEDGMENT

The support and comments from the internal review from our university by Prof. Elsheikh M. Elamin from the School of Applied Earth Sciences, and Dr. Abdalla E. Ibrahim, the Director of the Nile Basin Research Center-Al Neelain University, are gratefully acknowledged. The acknowledgment is extended to WES, GWWD, and UNICEF offices in Kassala State.

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