5 Geophysical Control on the Channel Pattern Adjustment in the Kunur River Basin of Western Part of Lower Ganga Basin

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Abstract

Surface gravity anomaly is important to know the underlying rock density and basement structure since they are playing dominant role in the channel pattern adjustment. Over the Western Bengal Basin (WBB), EW-tending and NS-tending garbens are actively controlled the gravity anomaly and adjacent variation in basement structure and lithology. The streamlines of Kunur River Basin (KRB) and rivers in surrounding are sharply controlled by the variation in underlying rock density, alignment of the lineaments and subsurface faults. Medinipur–Farakka Fault (MFF) and Garhmayna–Khandaghosh Fault (GKF) lines make prominent deformation in longitudinal profile, planform index, channel geometry and other fluvial forms of Kunur River. High Transverse Topographic Symmetry Factor (TTSF) values (>0.40) around the fault lines and high Drainage Basin Asymmetry (AF-index) values (64.40) also positively reveal the neotectonic sensitivity over the basin.

Keywords

Channel pattern · Bouguer gravity anomaly MFF line · TTSF · AF-Index · Neotectonic

5.1 Introduction

The term ‘gravity’ deals with the force that attracts a body towards the centre of the Earth (Mallick et al. 1999, 2012). The departure (anomalies) of uniform gravitational field is expressing the anomalous of density distribution over the outer part of Earth’s surface, i.e. lithosphere (VijayaRao et al. 2006; Mandal et al. 2015). Bouguer gravity anomalies alternatively may call density anomalies below the Earth’s surface (Marotta et al. 2006). The gravity directly controls the rate of mass wasting and related erosional processes. Among the obtained gravity data from geophysical estimations, Bouguer gravity data have appeared to be more accurate and aid to maintain the standard in geologic interpretation of land (USGS 1997). According to Verma (1985), an area underlying by masses with relatively higher

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density, Bouguer anomalies are reflected by higher gravity and vice versa. Bouguer anomalies are negative over the elevated region and it shows an inverse relationship with topography (Mandal et al. 2015). The most important unknown source of gravitational anomaly is the effect of the irregular underground distribution of different density rocks (USGS 1997). According to McKenzie (1977), if the gravity anomaly is well defined, the excess or missing mass can be computed directly from the gravity data. The exercise would be helpful for river science also to interpret the asymmetry in channel planform due to underlying litho-stratigraphy.

The Bengal Basin (BB) is always a complex region for geoscientists, in terms of its typical underlying structural geology, stratigraphy and alignment of surface river lines (Bagchi and Mukherjee 1979; Singh et al. 1998). Although the explanation of underlying geology is satisfactory (Alam et al. 2003; Goodbred et al. 2003; Mukherjee et al. 2009; Mallick and Mukhopadhyay 2011; Nath et al. 2014), the scientific explanation of typical arrangement of river lines are still not clear properly. Bhattasali (1941), Bhattacharya (1959), Banerjee and Chakraborty (1983), Bandyopadhyay (1996), Bandyopadhyay and Bandyopadhyay (1996), Bandyopadhyay et al. (2014, 2015) and Rudra (1987, 2010, 2014) all have explained well about the temporal shifting history of some rivers using historical maps and recodes, field observation and remote sensing images. However, introduction of the geophysical causes behind these channel shifting can increase the level of precision in the reconstruction palaeo-fluvio landscape. The present work has focused on the role of such geophysical parameters (gravity anomaly, active tectonic) on channel pattern adjustment over a small catchment (i.e. Kunur River Basin) in Lower Gangetic Plain.

5.2 Methods and Materials

5.2.1 Study Site

A 30 km long channel reach has been selected for the special focus within the Kunur River Basin (KRB) (Fig. 5.1). KRB is a major right bank tributary basin of the Ajay River and covers about 916.40 km^2 of area. The river originates near Jhanjira village of Ukhra Gram Panchayat on the western upland of the Barddhaman District at an altitude of 125 m. It runs for a distance of 114 km towards east direction. The elevation ranges from 20 to 131 m throughout the basin coverage. Over the region, annual average rainfall observed is 1380 mm and mean temperature is 25.8 °C during last 100 years (IMD 2014). The basin may discharge ~200 m^3/s of water during its peak flood season (Roy and Mistri 2013). Average width of the study reached is ~30 m.

Geologically, the entire reach is flowing over the Quaternary series of formation, where the Sijua formation (late Pleistocene to middle Holocene) has covered the downstream area and represents the oldest alluvial formation covering the floodplain of Kunur River (Bhattacharya and Dhar 2005). The exposed surface layers of this formation comprise a top soil of brown silty loam underlain by compact sticky clay in khaki or grey colour with greenish tinge impregnated with caliches nodules varying in size from 0.5 to 3.0 cm (Roy and Banerjee 1990). The reach has been selected for its typical pattern of channel planform in corresponding to the abrupt change in the Bouguer Gravity values (Fig. 5.1).

5.2.2 Geophysical and Geomorphological Data Acquisition

The present study has followed an integrated approach based on fluvial geomorphology, morphotectonics, geophysical parameters and digital topography, i.e. ASTER GDEM (30 m), multispectral imagery (Landsat 8and LISS IV) and field mapping. The regional gravity anomaly reading (Bouguer Gravity Anomaly) has been mapped by the National Geophysical Research Institute or NGRI (1978), Hyderabad, India composed with the interval of 5 mGal isolines. The map has been used here after converting into raster database using Q-GIS to extract gravity

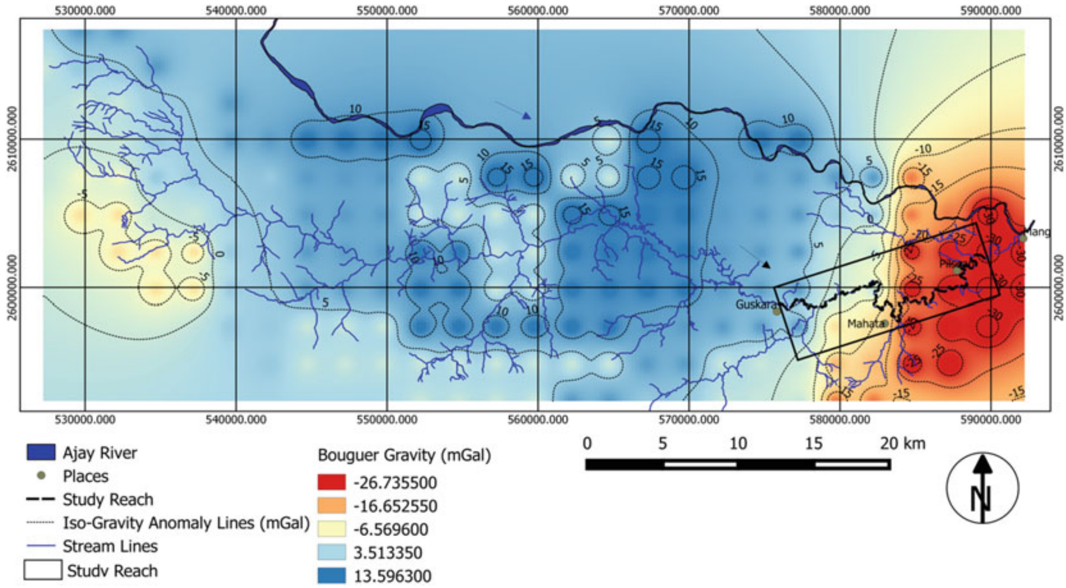

Fig. 5.1 Location map of the study reach (in Black Rectangle Box) within the Kunur River Basin. The background corresponds to the Bouguer Gravity Anomaly Map including gravity contours at 5 mGal interval

anomalies in the study. The basin boundary and river lines have been delineated using topographical maps of Survey of India (SoI) (73 M/6, M/7, M/10, M/11, M/14 and M/15 of 1:50,000) and LISS IV images. The geomorphological features related to morphometric indices have been digitized from topographical maps. In addition, online mapping using 'Plug-in layer tool in Q-GIS software' with 'Google Satellite Image' becomes a useful technique in extraction and upgrading of linear features related to relief and linear geomorphology. Online enable mapping technique has been followed using the 'Layer from WM(T)S server' mapping tools in Q-GIS to get the arrangement of lineaments from the recently updated web enable data (http://bhuvan5.nrsc.gov.in/bhuvan/wms) in thematic map services of National Remote Sensing Centre (NRSC), India. The lithological condition has been investigated through borehole data collected from secondary sources.

5.2.3 Morphotectonic Indices

Transverse Topographic Symmetry Factor (TTSF or T-index) and Drainage Basin Asymmetry Factor (AF-index) have been applied to the Kunur River Basin (KRB) to explain the neotectonic influence on the deformation of channel planform (Cox 1994; Jacques et al. 2014; Kale et al. 2014) and the assessment of the stream asymmetry, and identification of tilted drainage basin (Siddiqui 2014; Jacques et al. 2014). TTSF values range from 0 to 1. The value near to '0' means symmetric basin and value more than or far from '0' indicates asymmetric basin (Cox 1994). T-index has been computed for 35 reaches of the trunk Kunur River with equal interval of 2 km by using Eq. (5.1).

$$\mathrm{TTSF} = D_a / D_d, \tag{5.1}$$

where D_a is the distance from the longest channel to the basin midline (measured perpendicular to a straight line segment fit to the channel) and D_d is the distance from the basin boundary.

AF-index evaluates the active tectonic tilting within the drainage basin and to determine the direction of tilting (Cox 1994; Sarma et al. 2013; Siddiqui 2014; Kale et al. 2014). It is suitable for large extended area and is sensitive to tilting perpendicular to the direction of the trunk stream (Keller and Pinter 1996). AF for the Kunur basin is defined by the Eq. (5.2).

$$\mathrm{AF} = A_r / A_t, \tag{5.2}$$

where A_r is the area of the basin to the right of the trunk stream, A_t is the total area of the drainage basin. AF-index value close to 50 indicates none or a slight tilting and value above or below 50 suggests a significant tilting of the drainage basin.

5.3 Result

5.3.1 Adjustment of Channel Attributes with the Fall of Bouguer Gravity

The Bouguer gravity anomaly varies from −35 to +15 mGal over the KRB (Fig. 5.1). The minimum gravity (−35 mGal) has been observed over the extreme eastern part of the basin with a concentrated elliptical depression near the confluence zone with Ajay River. The downstream reach of the Kunur River faces a certain fall in Bouguer gravity values, i.e. within ten kilometres gravity has fallen from −30 to +10 mGal. The result implies a huge change in the underlying rock density and mass. To adjust such geophysical condition, the channel of Kunur River has also changed its geometry (Fig. 5.2). As per the Fig. 5.2, the certain fall in the gravity value starts near the distance of 10,000 m and continue up to 20,000 m, where the distance value indicates a cumulative increase towards the confluence of KRB. Significant fluctuation in slope value has been observed within this definite zone (10,000–20,000 m), which varies from ~1.2° to ~3.6°. The increasing slope may also correspondingly increase the flow velocity and Kunur River follows a straight pattern with low sinuosity index (<1.1). However, the value of sinuosity index has rapidly increased (>1.35) just immediately after the definite zone of gravity anomaly (10,000–20,000 m). However, no typical change has been observed in the river bank elevation, although this map may be affected by coarse resolution digital elevation data (ASTER, 30 m). Nevertheless, the longitudinal profile of entire Kunur River (~114-km) shows two certain falls in the bed elevation (i.e. Knick Point) at ~98 and ~74 km, respectively from the confluence point (Fig. 5.3). Near the second knick point, i.e. ~74 km from confluence, the Kunur River faces about 5–7 m fall in bed elevation and bankfull channel width (Fig. 5.3).

For further knowledge of geophysical control on channel pattern adjustment at different sub-basin levels, one may go through Chap. 6 of this present volume with title ‘imprints of neo-tectonism on the evolutionary record along the course of Khari river in Damodar fan delta of lower Ganga basin’.

5.3.2 Lithological Adjustment with the Changing Pattern of Bouguer Gravity

The panel diagram using 12 boreholes data has fairly defined the lithological adjustment of the region with the spatial variation in Bouguer gravity and associated distribution of underlying rock density and thickness (Fig. 5.4a). In reference to the higher positive anomaly in the western part (near Kuldihi, Daradanga borehole point), the lithology consists of high-density rock, e.g. sandstone, calcareous shale and limestone with less amount of granular materials

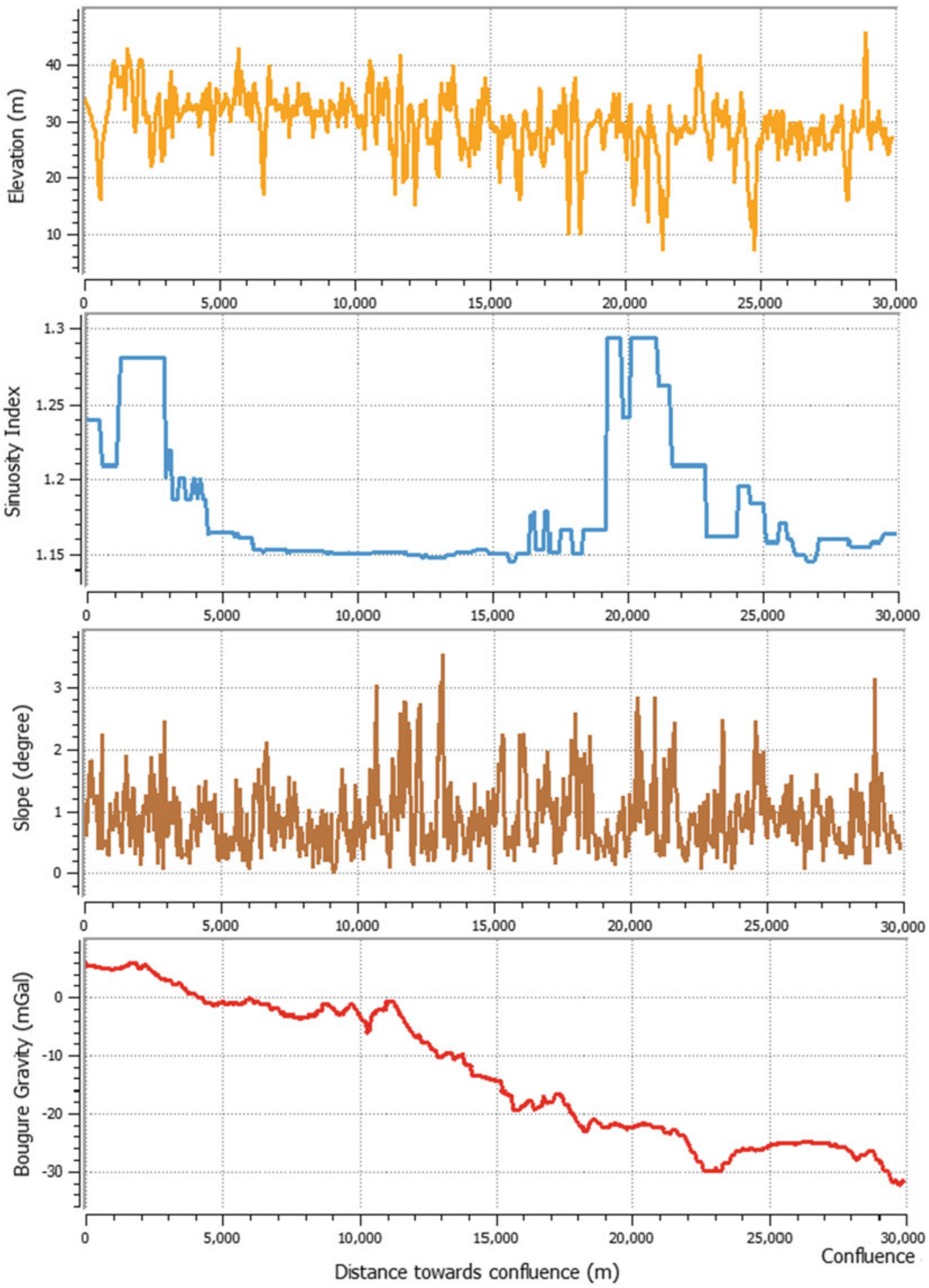

Fig. 5.2 Adjustment of channel attributes (Slope, Sinuosity Index, and Bed Elevation) with the certain fall of Bouguer gravity values (10,000–20,000 m) in the downstream of Kunur River

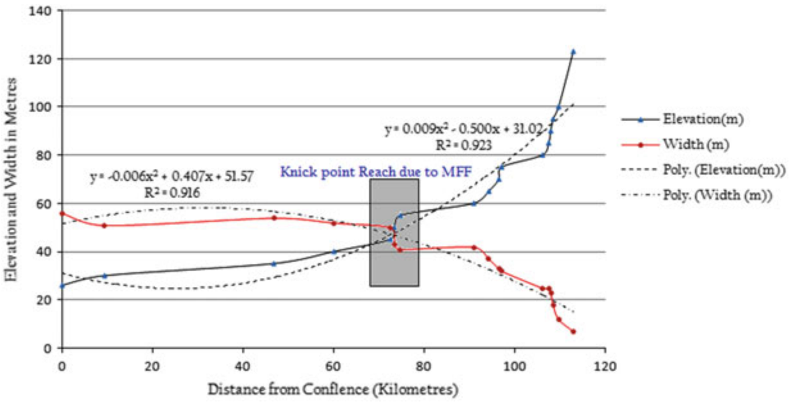

Fig. 5.3 Longitudinal profile of the entire Kunur River and associated bank full channel width

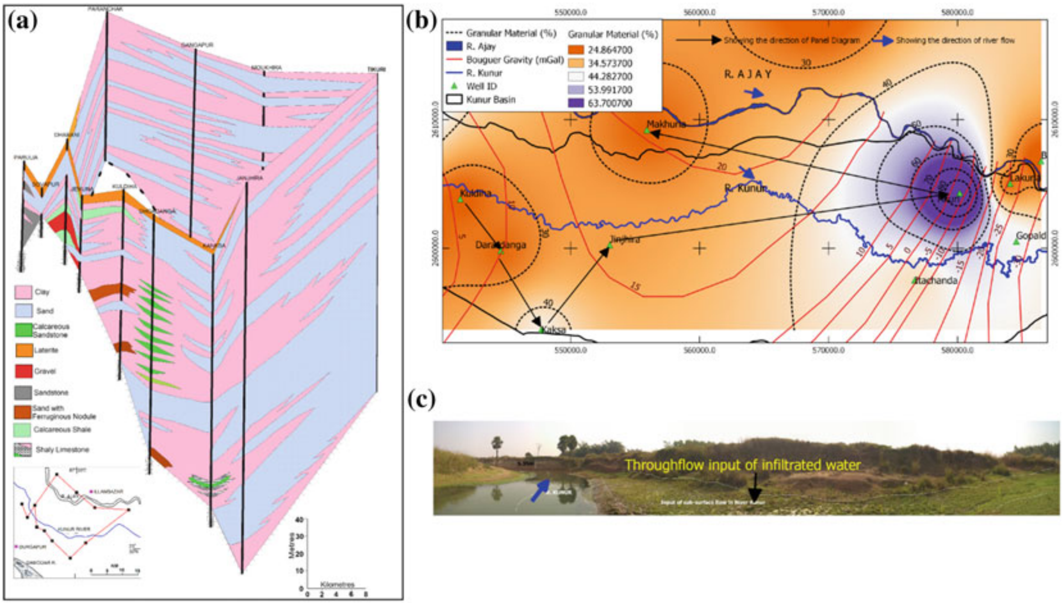

Fig. 5.4 **a** Panel diagram showing the lithological condition in the interfluve region of Ajay and Kunur Rivers (modified of Niyogi 1985); **b** distribution of underlying granular material in the downstream of Kunur Basin; **c** lithological influence on subsurface flow condition and steep bank indicates the active stream flow

or sandy layer (<20%). However, the eastern part consists of more than 60–80% of granular materials or sandy layer (at Tikuri 85.50%) and suggests major cause behind the high negative anomaly over here (Fig. 5.4b). The panoramic view of Kunur River, captured from this negative anomaly zone, also shows that the layer of granular materials works as a permeable layer (Fig. 5.4c). As a result, the infiltrated water from the upland area effluents in the channel of Kunur and maintain its base flow near Mahata village.

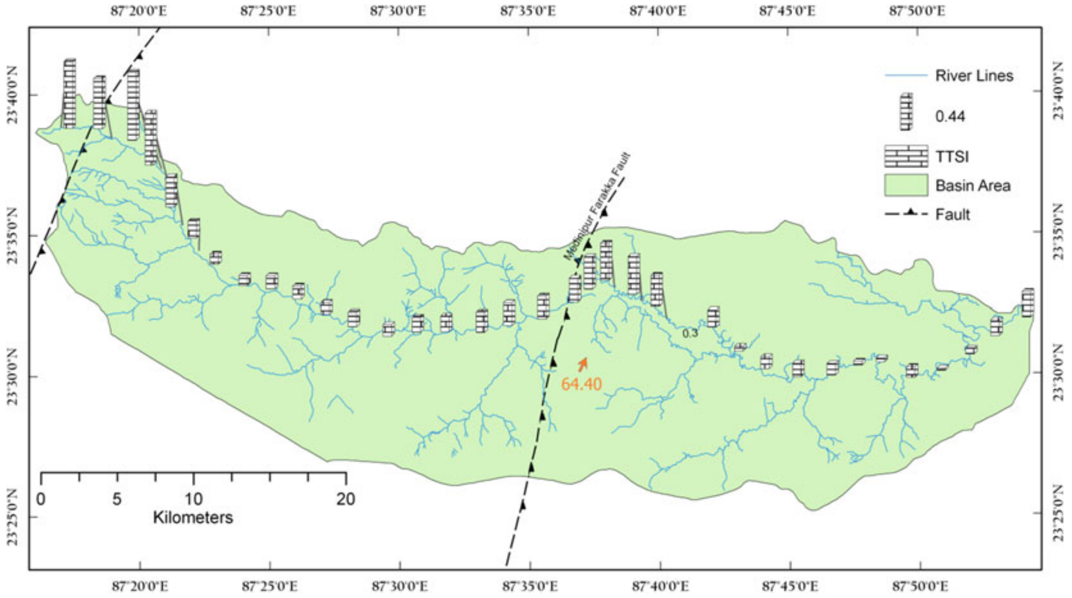

Fig. 5.5 Reach scale (~2 km) variation of TTSF index along the Trunk River of Kunur River inclosing the alignment of two major subsurface faults

5.3.3 Basin Asymmetry and Channel Planform Adjustment

There is a prominent northward tilting of the KRB with high AF-index (64.40), whereas reach wise (~2 km) TTSF values of the basin are ranging from 0.02 (purely symmetrical) to 0.93 (very highly asymmetrical). Therefore, Kunur River migrates towards north-east; however, the migration rate is not uniform in this direction along its all segments. Maximum rate of migration has been observed in the surrounding of predefined subsurface fault zones (Fig. 5.5). Hence, low TTSF values in the focused reach reveal the lower rate of migration, whereas the channel makes steep vertical erosion and configured an incised meandering planform due to steep slope and low density of underlying materials (Fig. 5.4c).

5.4 Discussion

Being an oldest tectonic block Western Bengal Basin (WBB) is still marked as active tectonic region since its beginning because of the marginal areas are still sinking as oblique manner and subsidence of the Central Bengal Basin (Steckler et al. 2016). The formation of WBB has begun as an intercratonic rift basin of the Gondwanaland during the late Carboniferous period before the apparent splitting of Gondwana in the Jurassic and early Cretaceous period (Krishnan 1982). The underwater sedimentation in the basin started during late Mesozoic Era (~205 Ma) as fluvio-deltaic formation with the opening of Bengal Basin through the splitting of Gondwanaland (Valdia 2001) when the Australia and India were separated and slipped along 90° east longitude (Alam 1989). At the same time, crystalline basement of Archean gneissic complex is also underlined by the Singhbhume group of metavolcanic rock and the Deep Seismic Sound (DSS) profile from north to south (CD) shows the depth of the basement varies from ~4.9, ~6.8 and ~6.3 km at Kandi, Kusumgramand Palashi, respectively (Figs. 5.6 and 5.7a) (Murty et al. 2008). In addition, another DSS profile in the west to east (AB) direction also shows the depth of Singhbhume basement that also varies significantly and the maximum depth (~6.3 km) of basement has been encountered in the middle of the profile, which also coincides with the deepest part at

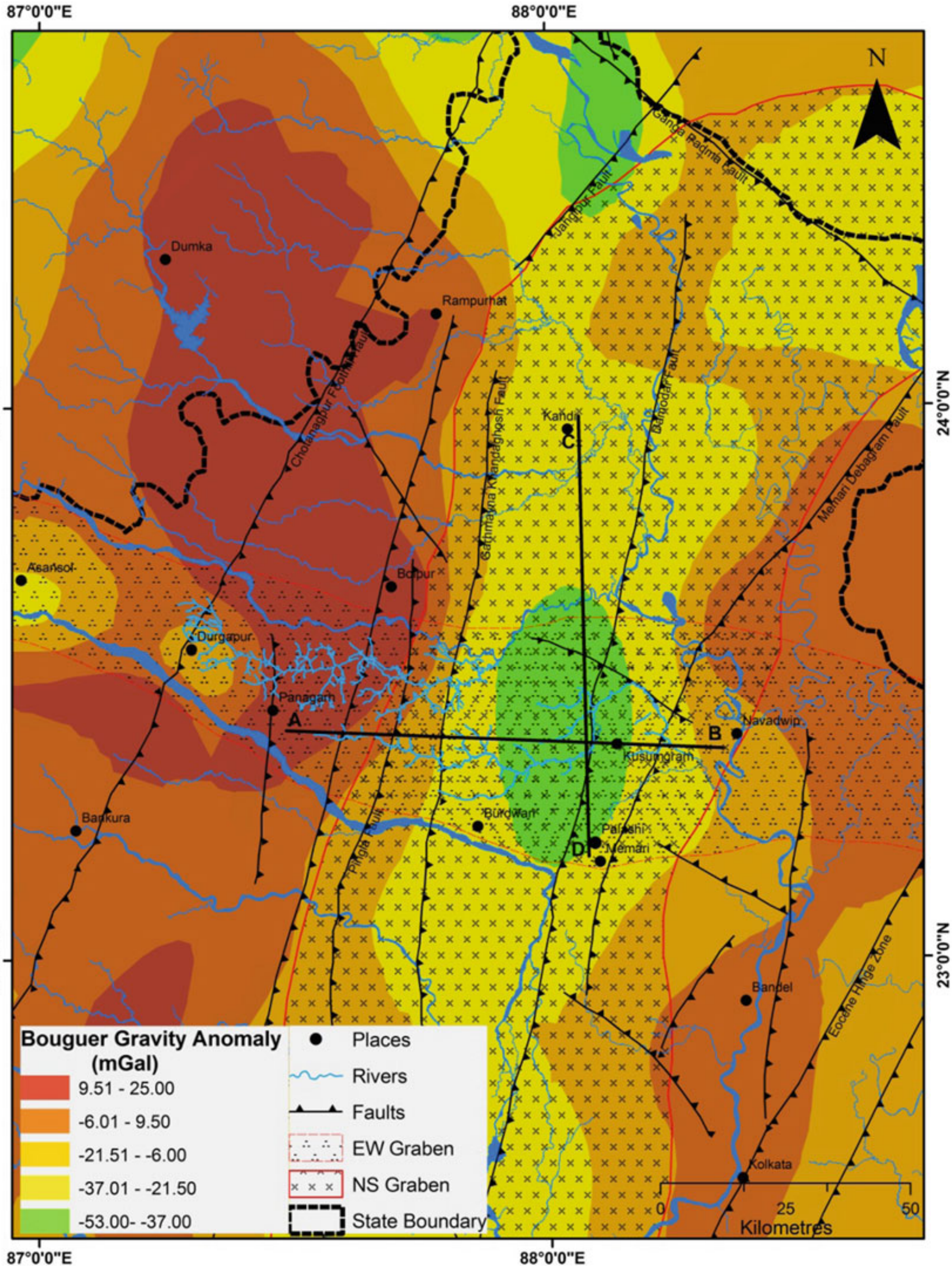

Fig. 5.6 Neotectonic map of the Western Bengal Basin (WBB) has been superimposed over the observed Bouguer gravity data (NGRI 1978), where two important Gondwana grabens (EW-tending and NS-tending) have been delineated with the mark of two DSS profiles. *Source* Based on Choudhury and Datta (1973), Verma and Mukhopadhyay (1977), Reddy et al. (1993), Murty et al. (2008), Rajasekhar and Mishra (2008), Roy et al. (2010), Banerjee et al. (2013)

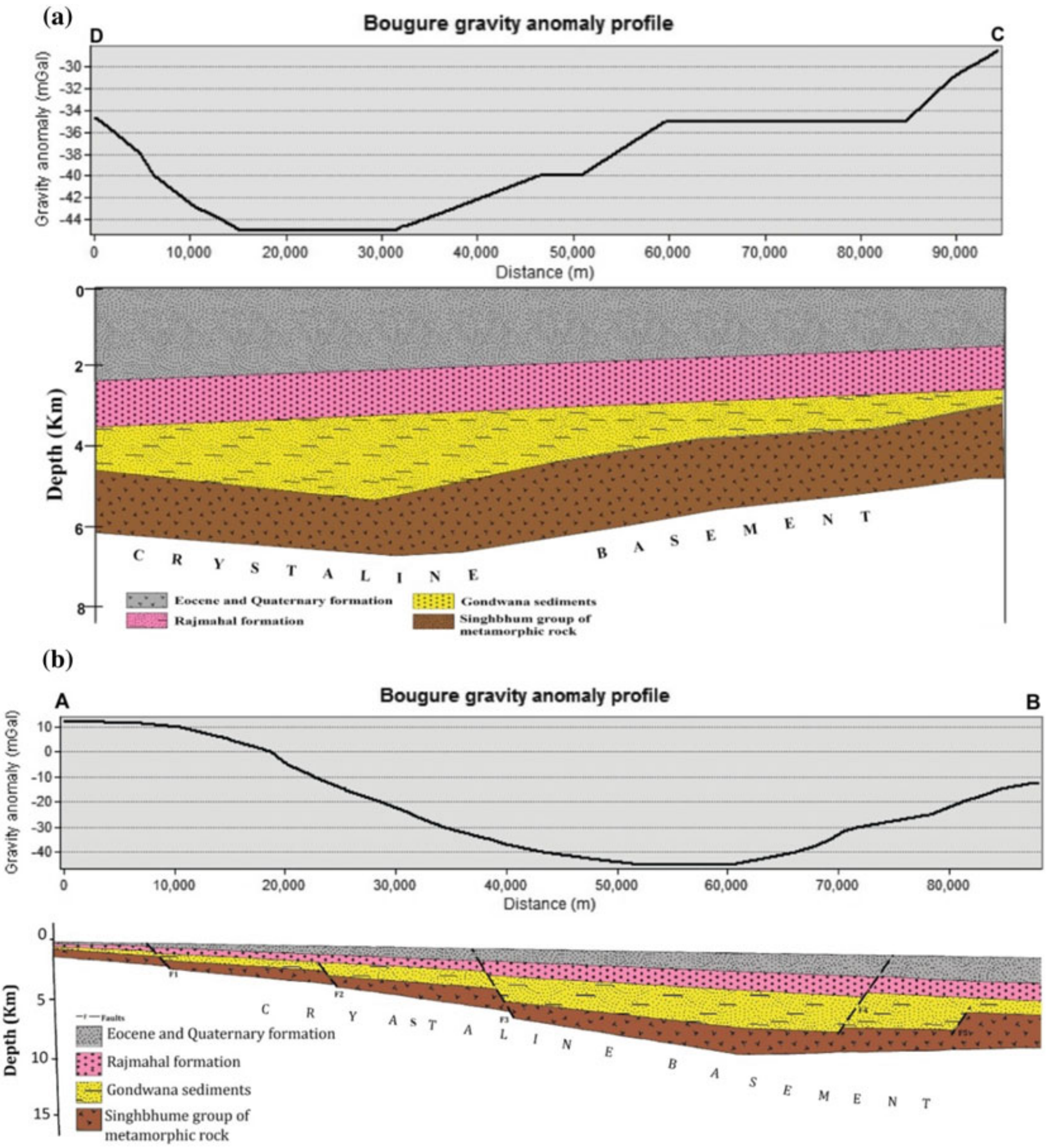

Fig. 5.7 Basement configuration and subsurface structure has been delineated through integrated interpretation of travel-time inversion of wide-angle seismic sounding reflection data and gravity data. **a**, In particular, profile CD shows north–south depression in Bouguer gravity values, where maximum depression has been observed over the interfluve of Ajay and Damodar Rivers (lower part); **b** and profile AB shows variation in gravity value and basement depth with successive formation and different fault lines (F_n): F1 = Mednipur–Farraka Fault or Basin-Margin Fault, F2 = Pingla Fault, F3 = Garhmayna–Khandaghosh Fault, F4 = Damodar Fault and F5 = Memari–Debagram Fault. *Source* Modified after Choudhury and Datta (1973), Verma and Mukhopadhyay (1977), Reddy et al. (1993), Murty et al. (2008), Rajasekhar and Mishra (2008), Roy et al. (2010), Banerjee et al. (2013)

Kusumgram in the north–south profile (Figs. 5.6 and 5.7b).

Both tectonic troughs are termed as EW-tending Gondwanagraben and NS-tending Gondwanagraben (McDougall and McElhinny 1970; Murty et al. 2008; Banerjee et al. 2013). The variation in basement depth of both grabens have also been influenced to make different depths of Gondwana sedimentation. The EW-tending graben, identified as 'Damodar Graben' (DG) in eastern Peninsula, was subsequently filled with thick Gondwana sedimentation during early Carboniferous to Triassic period (359–201 Ma) (McDougall and McElhinny 1970; Murty et al. 2008; Banerjee et al. 2013). The DG has been extended eastward up to the Bengal shelf zone, which is revealed by the presence of coal-bearing strata cover by several kilometres thick Quaternary alluviums (Krishnan 1982). Another graben in the north–south direction is bounded by the Basin Margin Fault (BMF) or Medinipur–Farakka Fault (MFF) to the west and Memari–Debagram fault on the east and filled by very thick depositions (Choudhury and Datta 1973; Reddy et al. 1993; Banerjee et al. 2013). The intersection zone of these two grabens can be marked as a deepest Gondwana structural depression in the WBB with thick column of sedimentation and called as sink zone.

In the regional Bouguer gravity maps, both grabens are also prominent with deep elliptical depression in gravity values (Fig. 5.6). Maximum negative anomaly (−45 mGal) has been identified at the intersection zone near Kusumgram. The spatial variation in the depth of basement rock (i.e. Singhbhume group) and associated thickness of Gondwana sedimentary layer is the major cause behind the typical gravity anomaly over the region. The Kunur River is also running through the northern boundary of this sink zone, where the graben is sedimented by Talchir formation (boulder bed succeeded by shales and sandstone) overlie by Barakar formation (sandstone and grits with occasional conglomerates), Raniganj formation (sandstone and shale with coal seams) and Panchet formation/Super-Pachet formation (micaceous and feldspathic sandstone shales) of Gondwana sediments which are sequentially exposed over surface at the western side of KRB (Krishnan 1982). Subsequently, this formation is roofed by Triassic Rajmahal Trap formation, which is also overlain by thick layer of Tertiary and Quaternary alluvium formation. Nature of this alluvium is soft and unconsolidated oxidized sand, silt and clay with caliche concretion (Table 5.1 and Fig. 5.7b) (GSI 2001). Hence, there is no significant variation in the thickness of Rajmahal Trap and Quaternary deposition (Fig. 5.7b). However, the basement complex and overlie sediments have been warped by strike-slip faulting during late Paleozoic and late Mesozoic Era which was tectonically reactivated during late Eocene (Alam et al. 2003).

Previous studies have delineated two strike-slip faults across this region, e.g. Chhotanagpur Foothill Fault (CFF) and Medinipur–Farakka Fault (MFF), which are the key controller of channel geomorphology of this region (Singh et al. 1998; Roy and Sahu 2015a, b, 2016). The two defined knick points in the Kunur River are also directly corresponding with these two fault lines. According to Roy and Sahu (2015a, b), the identified palaeo-channels within the interfluve of Ajay and Kunur (AKI) Rivers were also developed due to north-eastward shifting of Ajay River induced by neotectonic actions and the present lower reach of Kunur is basically a palaeo-path of Ajay River. Therefore, a direct control of underlying rock density has been observed on the planform of lower Kunur River. Roy and Sahu (2015a) have also identified the changes of sinuosity index along with the planform of Kunur and Khari Rivers (Fig. 5.8). It is clear to see that how the straight reach of both rivers become meandering and incised immediately after the MFF line. Inserted field photos (P1–P4) are also showing reach scale changing shape of Kunur River channel. A huge deformation near Mahata has been also marked in the same figure (Fig. 5.8).

Table 5.1 Generalized litho-stratigraphic chart of the Western Bengal Basin (WBB) along the AB profile in Fig. 5.6

Formation	Age	Average density (g/cc)	Depth of base from surface (km)	Velocity of seismic sound (kms^{-1})	Lithological description	Environment
Alluvium deposits	Quaternary (2.6 Ma–Resent)	2	0.30–0.75	1.95	Clay alternating with silt and sand, clay with caliche concretion and laterite patch	Fluvial and fluvio-marine
Shale	Pliocene (5.3–2.6 Ma)	2.31	0.50–1.70	2.86		
Sylhet limestone	Late Cretaceous to Eocene (100–33.9 Ma)	2.37	1.70–1.90	3.7		
Unconformity						
Rajmahal trap	Jurassic to Early Cretaceous (201–100 Ma)	2.8	1.70–2.40	4.6	Basalt (continental tholeiites) trap wash with intertrapen	Fissure type volcanic eruption
Unconformity						
Gondwana sediments	Carboniferous to Triassic (359–201 Ma)	2.4	2.40–5.80	4	Greenish sandy shale with boulders at base, very coarse to medium-grained dark grey to white sandstone, soft feldspathic sandstone and coal seam	Fluvial and glacio-fluvial
Unconformity						
Singhbhume group of metavolcanic rock	Proterozoic (2500–541 Ma)	2.61	5.80–6.80	5.5	Granite, Granodiorite	–
Crystalline basement	Archean (>2500 Ma)	2.71	Undefined	6.1		

Source Modified after Choudhury and Datta (1973), Verma and Mukhopadhyay (1977), Reddy et al. (1993), Murty et al. (2008), Rajasekhar and Mishra (2008), Roy et al. (2010), Banerjee et al. (2013)

The high negative gravity values have indicated the presence of low-density materials with higher thickness of basement sediment below the AKI region. This gravitational depression might be the result of underneath sandy or unconsolidated sediment with higher percentage of granular material (Sahu and Saha 2014). Underlying heavy dense rock and lower depth of basement have been perceived in the middle of the basin from the maximum positive gravity anomaly. Lithological condition of this region has been revealed by the panel diagram (Fig. 5.4a). Roy and Chatterjee (2015) have also delineated the western margin fault of Bengal Basin based on the zone of crowding of gravity contours; where the fault line marked along the neutral gravity value, i.e. 0 mGal. Similar crowding of gravity contours including 0 mGal have been also observed in the focused study region, where the Garhmayna–Khandaghosh Fault (GKF) has been

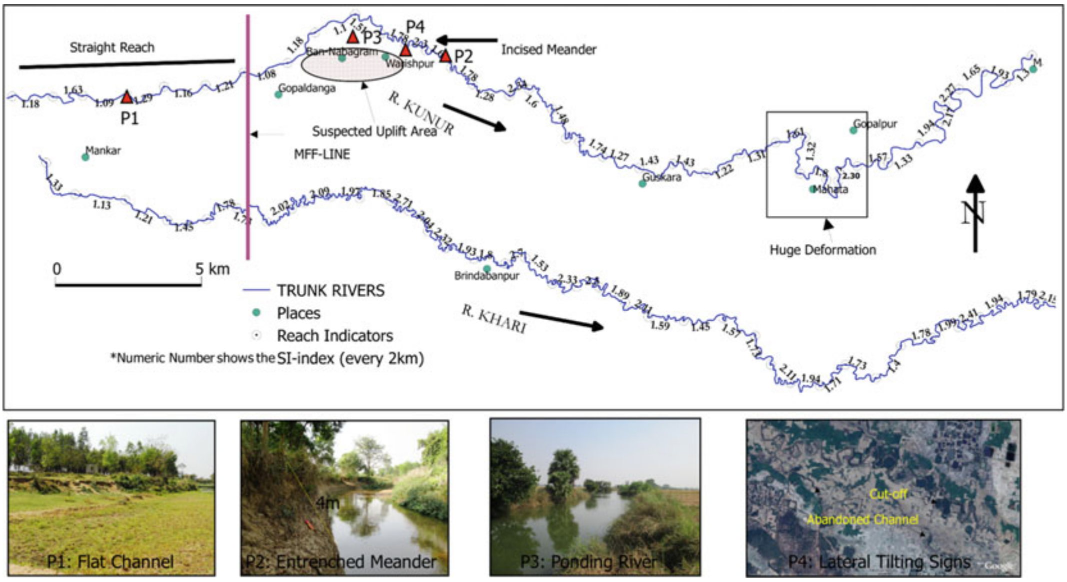

Fig. 5.8 Adjustment of channel sinuosity index and local fluvial features of Kunur and Khari rivers with tectonic controls (after Roy and Sahu 2015a)

marked by Geological Society of India in their 'Seismotectonic Atlas' (Fig. 5.6). The GKF is the major cause of the typical channel pattern in the study reach formed by the certain change in underlying structure. In the perpendicular direction of study reach, similar asymmetric in channel pattern has been observed for the Khari River also, where GKF also crosses the river Khari (Fig. 5.6). In addition, at the intersection part of both graben with maximum gravity anomaly (in negative), Khari River also takes a sharp right angle turn towards north near Kusumgram and runs almost 21 km with steep sidewall and developed extended mushy land over its floodplain (Roy and Sahu 2015a).

Channel side exposed strata also carry the evidences of active hydraulic actions in past due to active tectonic and geophysical actions around the focused channel reach. The buried soil layer of Sijua formation contents upward coarser materials (from coarse sand to gravel), which explains the presence of higher flow action during the late Pleistocene to middle Holocene (Fig. 5.9). According to Singh et al. (1998), the western part of lower Gangetic plain has number of subsurface faults which are reactivated during the early Pleistocene epoch. In connection with this, it may conclude that this part of Kunur Basin also experienced by the reactivation of GKF and tilting during this period. The factors related to asymmetry indices also allow the determination of general tilt of the basin landscape irrespective of the whether the tilt is local or regional. The unpaired terraces around the MFF line again exemplify the role of geotectonic control over the Kunur Basin (see Fig. 6a in Roy and Sahu 2015a).

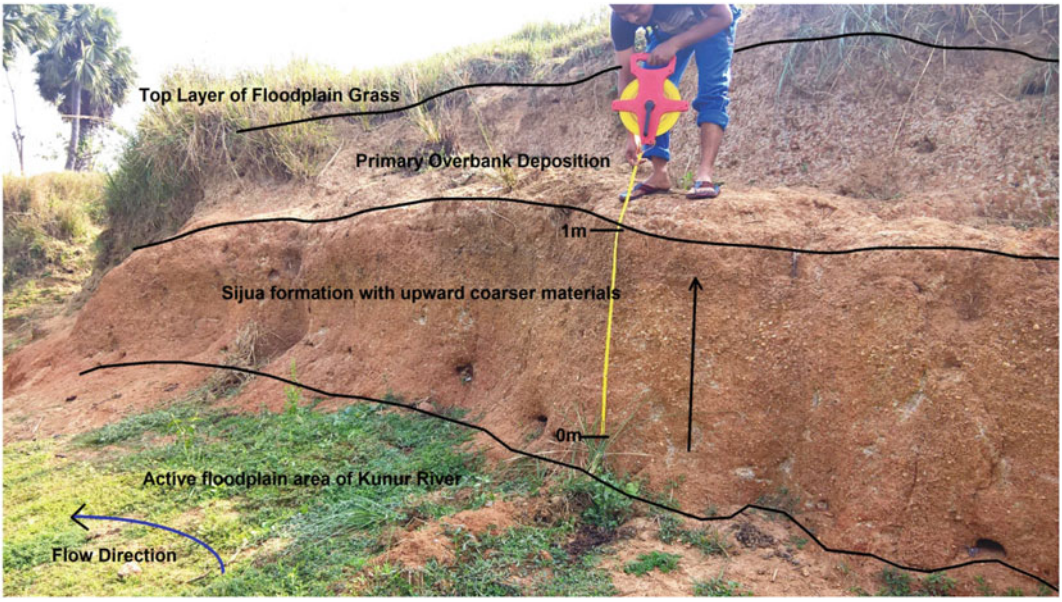

Fig. 5.9 Lithological evidence of high hydraulic action during early Pleistocene epoch, upward coarser layer of Sijua formation indicates the presence of high flow action over here

5.5 Conclusion

The overall attempt has been made to correlate the role of subsurface lithology, defined by gravity anomaly, on the explanation of anomalous drainage behaviour and drainage patterns of Kunur Basin and rivers in surroundings. The study has confirmed that the typical pattern of Kunur River, in its downstream area, is a combined result of underlying geology, i.e. variation of density and thickness of sedimentation and neotectonic movements. Tectonically formed grabens are the major sources of gravity anomaly over the WBB and the intersection zone featured with maximum negative anomaly and typical arrangements of surface river lines and their geometry. However, the resolution of Bouguer gravity anomaly is coarse but the data have played a valuable role in the combined interpretation of channel geomorphology and help to uncover the underlying causes behind the channel pattern adjustment. The subsurface lithological configuration helps to discriminate the variation of Bouguer gravity values and associated geology of this region. TTSF and AF indices also assist to define the presence neotectonic actions within the basin and field photographs provide valuable support in this interpretation.

N.B. for special understanding on influence of faulting on the extra-channel geomorphology, readers may go through Chap. 4 of this volume

References

Alam M (1989) Geology and depositional history of Cenozoic sediments of the Bengal Basin of Bangladesh. Palaeogeogr Palaeoclimatol Palaeoecol 69:125–139

Alam M, Alam MM, Curray RJ, Chowdhury MLR, Gani MR (2003) An overview of the sedimentary geology of the Bengal Basin in relation to the regional tectonic framework and basin-fill history. Sed Geol 155:179–208

Bagchi K, Mukherjee KN (1979) Diagnostic survey of Rarh Bengal, Part–I, morphology, drainage and flood: 1978. Department of Geography, University of Calcutta, Calcutta

Bandyopadhyay S (1996) Location of the adi ganga palaeochannel, S. 24 Parganas, West Bengal: a review. Geogr Rev India 58(2):93–109

Bandyopadhyay S, Bandyopadhyay MK (1996) Retrogradation of Western Ganga—Brahmaputra—Delta: possible reason. Nat Geogr 31(2):105–128

Bandyopadhyay S, Das S, Kar NK (2015) Discussion: 'Changing river courses in the Western part of the Ganga-Brahmaputra Delta' by Kalyan Rudra (2014). Geomorphology 227:87–100. Geomorphology 250:442–453. https://doi.org/10.1016/j.geomorph.2015.02.037

Bandyopadhyay S, Kar NK, Das S, Sen J (2014) River systems and water resources of West Bengal: a review. Geol Soc India (Spec Publ) 3:63–84

Banerjee B, Mara IA, Biswas AK (2013) Subcrop Gondwana of Bengal basin and their reservoir characteristics. J Geogr Soc India 81:741–754

Banerjee SN, Chakraborty P (1983) Some observation on recent trends of shifting pattern of the ganga between Rajmahal and Ganga. J Geol Soc India 24:318–320

Bhattacharya AK, Dhar N (2005) A report geo-environmental appraisal in Barddhaman Urban agglomeration area and its environment for sustainable developmental activities. Geological Survey of India, Kolkata Eastern Region, pp 1–43

Bhattacharya K (1959) Bangladesher Nad-Nadio Parikalpana (in Bengali). Bidyadoya Library Ltd., Calcutta

Bhattasali NK (1941) Antiquity of the Lower Ganges and its courses. Sci Cult 233–239

Choudhury SK, Datta AN (1973) Bouguer gravity and its geological evolution in the Western part of the Bengal Basin and adjoining area, India. Geophysics 38 (4):691–700

Cox RT (1994) Analysis of drainage-basin symmetry as a rapid technique to identify areas of possible quaternary tilt-block tectonics: an example from the mississippi embayment. Geol Soc Am Bull 106:571–581

Goodbred SL, Kuehl SA, Steckler MS, Sarkar MH (2003) Controls on facies distribution and stratigraphic preservation in the Ganges-Brahmaputra delta sequence. Sed Geol 155:301–316

GSI (Geological Society of India) (2001) District resource map: Barddhman. Eastern Region, Kolkata

IMD (2014) District wise normals. Indian Meteorological Department, Govt. of India, Barddhaman

Jacques PD, Salvador ED, Machado R, Grohmann CH, Nummer AR (2014) Application of morphometry in neotectonic studies at the eastern edge of the Paraná Basin, Santa Catarina State, Brazil. Geomorphology 213:13–23. https://doi.org/10.1016/j.geomorph.2013.12.037

Kale VS, Sengupta S, Achyuthan H, Jaiswal MK (2014) Tectonic controls upon Kaveri River drainage, cratonic Peninsular India: inferences from longitudinal profiles, morphotectonic indices, hanging valleys and fluvial records. Geomorphology 227:153–165. https://doi.org/10.1016/j.geomorph.2013.07.027

Keller EA, Pinter N (1996) Active tectonics: earthquakes, uplift and landscape. Prentice Hall, New Jersey

Krishnan MS (1982) Geology of India and Barma. CBS Publishers & Distributors, India

Mallick K, Sharma KK, Rao VK (1999) A new gravity interpretation: a case study from Pahute Mesa, Nevada test site. Current Sci 76:1495–1498

Mallick K, Vasanthi A, Sharma KK (2012) Bouguer gravity regional and residual separation: application to geology and environment. Springer Publication, Netherlands

Mallick M, Mukhopadhyay D (2011) An analysis of GPS-derived velocities in the Bengal basin and the neighbouring active deformation zones. Current Sci 101(3):1–4

Mandal A, Gupta S, Mohanty WK, Misra S (2015) Sub-surface structure of a craton—mobile belt interface: evidence from geological and gravity studies across the Rengali Province—Eastern Ghats Belt boundary, eastern India. Tectonophysics 1–13. http://dx.doi.org/10.1016/j.tecto.2015.01.016

Marotta AM, Spelta E, Rizzetto C (2006) Gravity signature of crustal subduction inferred from numerical modelling. Geophys J Int 166:923–938. https://doi.org/10.1111/j.1365-246X.2006.03058.x

McDougal I, McElhinny MW (1970) The Rajmahal trap of India, K-Ar ages and palaeomagnetism. Earth Planet Sci Lett 9:372–378

McKenzie D (1977) Surface deformation, gravity anomalies and convection. Geophys J R Astr Soc 48: 211–238

Mukherjee A, Fryar AE, Thomas WA (2009) Geologic, geomorphic and hydrologic framework and evolution of the Bengal basin, India and Bangladesh. J Asian Earth Sci 34:227–244

Murty ASN, Sain K, Prasad BR (2008) Velocity structure of West-Bengal Basin, India along the Palashi-Kandi profile using a travel-time inversion of wide-angle seismic data and gravity modeling—an update. Pure Appl Geophys 165:1733–1750

Nath SK, Adhikari MD, MaitiSK DevarajN, SrivastavaN MohapatraLD (2014) Earthquake scenario in West Bengal with emphasis on seismichazard micro zonation of the city of Kolkata, India. Nat Hazards Earth Syst Sci 14:2549–2575. https://doi.org/10.5194/nhess-14-2549-2014

NGRI (1978) NGRI/GPH-1 to 5: gravity maps of India scale 1: 5,000,000. National Geophysical Research Institute, Hyderabad, India

Niyogi M (1985) Groundwater resource of the Ajay Basin. In: Chatterjee SP (ed) Geographical mosaic–Professor K. G. Bagechi Felicitation. Manasi Press, Calcutta, pp 165–182

Rajasekhar RP, Mishra DC (2008) Crustal structure of Bengal Basin and Shillong plateau: extension of Eastern Ghat and Satpura mobile belts to Himalayans fronts and seismotectonics. Gondwana Res 14: 523–534

Reddy PR, Venkateswarlu N, Prasad ASSSRS, Rao PK (1993) Crustal density model across West Bengal basin, India: an integrated interpretation of seismic and gravity data. Proc India Acad Sci (Earth Planet Sci) 102(3):487–505

Roy AB, Chatterjee A (2015) Tectonic framework and evolutionary history of the Bengal Basin in the Indian subcontinent. Curr Sci 109(2):271–279

Roy BC, Banerjee K (1990) Quaternary geological and geomorphological mapping in Parts of Barddhaman and Bankura Districts (And preliminary assessment of sand deposits suitable for construction and other allied purposes). Published Report. Geological Survey of India, Eastern Region, Calcutta

Roy DK, Ray GK, Biswas AK (2010) Overview of overpressure in Bengal Basin, India. Geol Soc India 75:644–660

Roy S, Sahu AS (2015a) Quaternary tectonic control on channel morphology over sedimentary lowland: a case study in the Ajay-Damodar interfluve of Eastern India. Geosci Front 6(6):927–946. https://doi.org/10.1016/j.gsf.2015.04.01

Roy S, Sahu AS (2015b) Palaeo-path investigation of the lower Ajay River (India) using archaeological evidence and applied remote sensing. Geocarto Int. https://doi.org/10.1080/10106049.2015.1094526

Roy S, Sahu AS (2016) Morphotectonic map generation using geo-informatics technology: case study over the Ajay-Damodar Interfluve, West Bengal, India. Arabian J Geosci. https://doi.org/10.1007/s12517-015-2247-z

Roy S, Mistri B (2013) Estimation of peak flood discharge for an ungauged river: a case study of the Kunur River, West Bengal. Geogr J 2013(214140):1–11. https://doi.org/10.1155/2013/214140

Rudra K (1987) Quaternary history of the lower Ganga distributaries. Geogr Rev India 49(3):37–38

Rudra K (2010) Banglar Nadikath (in Bengali). Shahitto-Sangsad, Kolkata

Rudra K (2014) Changing river courses in the Western part of the Ganga-Brahmaputra Delta. Geomorphology 227:87–100. https://doi.org/10.1016/j.geomorph.2014.05.013

Sahu S, Saha D (2014) Geomorphologic, stratigraphic and sedimentologic evidences of tectonic activity in Sone-Ganga alluvial tract in Middle Ganga Plain, India. J Earth Syst Sci. 123:1335–1347

Sarma JN, Acharjee S, Murgante G (2013) Morphotectonic study of the Brahmaputra basin using geoinformatics. Geophys Res Abs 15: EGU2013-14001

Siddiqui S (2014) Appraisal of active deformation using DEM-based morphometric indices analysis in Emilia-Romagna Apennines, Northern Italy. Geodyn Res Int Bull 1(3):34–42

Singh LP, Parkash B, Singhvi AK (1998) Evolution of the lower Gangetic plain landforms and soils in West Bengal, India. Catena 33:75–104

Steckler MS, Mondal DR, Akhter SH, Seeber L, Feng L, Gale J, Hill EM, Howe M (2016) Locked and loading megathrust linked to active subduction beneath the Indo-Burman Ranges. Nat Geosci. https://doi.org/10.1038/NGE02760

United State Geological Society (1997) Introduction to potential fields: gravity. FS-239–95.http://pubs.usgs.gov/fs/fs-0239-95/fs-0239-95.pdf. Accessed 13th Dec 2014

Valdia KS (2001) HIMALAYA emergencce and evolution. University Press Limited, India

Verma RK (1985) Gravity field, seismicity, and tectonics of the Indian peninsula and the Himalayas (Solid earth sciences library). D. Reidel Publishing Company, Holland. https://doi.org/10.1007/978-94-009-5259-1

Verma RK, Mukhopadhyay M (1977) An analysis of the gravity field in northeastern India. Techtonophysics 42:283–317

VijayaRao V, Kalachand S, Reddy PR, Mooney WD (2006) Crustal structure and tectonics of the northern part of the Southern Granulite Terrane, India. Earth Planet Sci Lett 251:90–103. https://doi.org/10.1016/j.epsl.2006.08.029