Morphometric and Geophysical Studies from a Part of Aravalli-Delhi Fold Belt, Rajasthan, India

Kutubuddin Ansari, Mery Biswas, Suvashree Das, and Soumyajit Mukherjee

Abstract The study investigates bathymetry (topographic) height and gravity studies over the region of Aravalli-Delhi Fold Belt (ADFB). The general topography trend is low at the NW portion and increases toward SE. Gravity trend varies from − 20 to 100 mGal. A significant change in the trend of gravity contour pattern is probably due to the subsurface deflection of ADFB due to rotation related to plate collision. The bathymetry elevation height and gravity anomaly correlation in the ADFB region has been checked by using principal component analysis (PCA). The first four principal components (PCs) of bathymetry elevation and gravity are evaluated, and their comparison analysis is carried out. The results showed that correlation coefficient values are 0.9908 and 0.8938 for PC1 and PC3, respectively. These high values indicate strong positive correlations between gravity and elevation. The correlation coefficient values of PC2 and PC4 are − 0.9186 and − 0.9270, respectively. Such high negative values indicate a strong inverse relationship. The study concludes that only odd PCs follow the positive trend while even PCs have negative trends in the study area. Morphometric studies through various pinpointed watersheds that are active and also deciphered direction of tilting of different watersheds.

Keywords Geomorphology · Tectonics · Recent tectonics · Indian plate · Subsurface geophysics

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1 Introduction and Geology

Academicians and industry experts have been working intensely on Rajasthan basins with enormous interest (e.g., Ansari et al. 2025a, b; Dasgupta and Mukherjee 2017; Biswas et al. 2022a, b, 2024, 2025; Kar et al. 2022, 2025; Dasgupta 2023; Dasgupta et al. 2023, 2024; Mishra et al. 2023; Puniya et al. 2023a, b; Raha et al. 2025). The Aravalli-Delhi fold belt (ADFB) is an early- to middle-Proterozoic geologic unit (Chattopadhyay et al. 2012; Biswal et al. 2022). This part of the fold belt, adjoining Pali area, is dissected by a number of westward flowing drainage lines being followed by structural controls. ADFB as a range extends for hundreds of km. This range is characterized by deformed rocks.

Morphometric studies have been an efficient way to comment on active tectonics of a region where drainages are available (e.g., Biswas et al. 2022a, b). See Shekar and Mathew (2024) for morphometric parameters and their use in basin/watershed studies.

Precise measurements of time-variable gravity are essential for comprehending the dynamic nature of the Earth. Since the early twenty-first century, advancements in gravimetric technology and the establishment of extensive gravity survey networks have made repeated gravity measurements a crucial method for monitoring various natural phenomena, such as volcanic magma activity, flood detection, postglacial rebound, surface deformation, and seismic events (Carbone et al. 2019; Yang et al. 2021). Gravity data collected across diverse temporal and spatial dimensions have been extensively utilized to explore earthquake precursor signals and to observe mass transport processes. The gravity anomaly exhibits a clear direct correlation with surface elevation, which is influenced by the distribution of subsurface densities and the density contrast between the crust and mantle (Ganguli and Pal 2023). Several studies have been carried out to find the relationship between gravity and elevation, which displays an inverse relationship (Chatterjee et al. 2024).

In this study, free-air gravity (FAG) anomaly data has been accessed from EGM2008 (Internet Ref-1) along ADFB region. The gravity anomaly exhibits a clear direct correlation with surface elevation, which is influenced by the distribution of subsurface densities and the density contrast between the crust and mantle (Ganguli and Pal 2023). Several studies have been carried out to find the relationship between gravity and elevation, which displays an inverse relationship (Chatterjee et al 2024). The bathymetry elevation height data has been collected from the General Bathymetric Chart of the Oceans (GEBCO) (Internet Ref-2) in the same region (ADFB region), and their correlations with FAG are checked by using principal component analysis (PCA).

2 Principal Component Analysis

Consider gravity observation matrix (g) for an area is arranged in the order latitude × longitude form. Take the matrix of these gravity observations (G) as follows (Ansari et al 2020):

$$G = g \times g'. \tag{1}$$

By taking singular value decomposition (SVD) of matrix (G), we can get its eigen value (λ_g) and eigen vector (V_g). Now, arrange all eigen values in decreasing order like this:

$\lambda_{g1} < \lambda_{g2} < \lambda_{g3} < \cdots < \lambda_{gn}$ with their corresponding eigen vectors (V_{gn}), where n is rank of matrix G.

Calculate their principal component with obtained order of eigen vectors:

$$PC_g = g' \times V_{gn}. \tag{2}$$

Similarly, in case of Bathymetry (topographic) data set, consider the elevation height matrix (h) area to be arranged in the order latitude × longitude form. Their PC can be estimated as follows (Ansari et al 2020):

$$\mathrm{PC}_h = h' \times V_{hn}. \tag{3}$$

In this study, we used first four PCs of gravity and bathymetry (topography) and their correlations with each other are studied.

3 Results and Discussions

3.1 Geomorphological Aspects

We studied active tectonics considering watershed-scale indicators mountain front sinuosity (S_{mf}), drainage basin asymmetry (AF) and in linear morphometry, long profile analysis with R^2 model (Bull and McFadden 1977; Bull 2007; Dhawale et al. 2023; Raha et al. 2023; Mondal et al. 2024). We used the Copernicus Global Digital Elevation Model (European Space Agency), Sinergise (2021) distributed by Open Topography (Internet Ref-1) and processed in ArcGIS 10.8 platform (2020).

The study area (Fig. 1) covers a part of SW section of the ADFB where the westward drainage lines carry significant role to assess the active tectonics. We delineated seven watersheds. The aspect slope direction map (Fig. 2) indicates multidirectional slope facets that control the drainage orientation. The river network closely indicates the tectonic imprint where these are sub-parallel almost straight ruining in the hilly portions (Fig. 1).

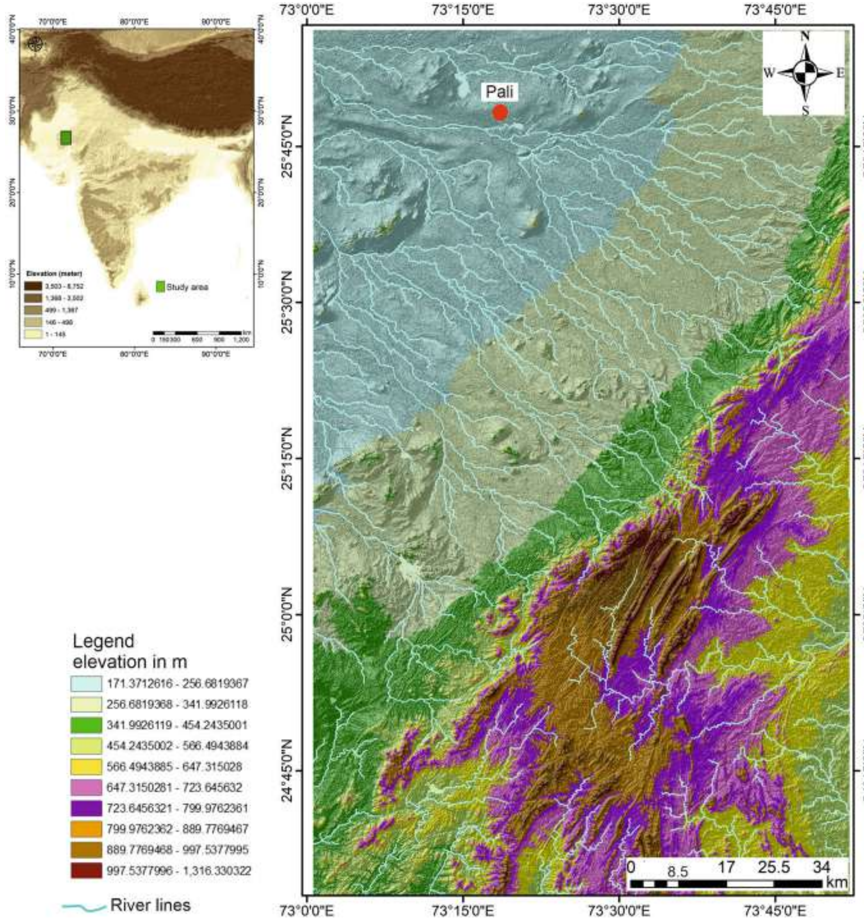

Fig. 1 Location of study area along with drainage lines

S_{mf} (Fig. 3) defines degree of irregularity or sinuosity along the base of a topographic escarpment as the active structures tend to maintain straight or curved profiles (Fountoulis et. al. 2015). The lowest value of S_{mf} in mountain front MF 7 is 0.47. It indicates most active front of the studied belt, and it is followed by MF 6 (S_{mf} = 1.5), MF 4 (S_{mf} = 1.72), MF 2 (S_{mf} = 2.02), MF 5 (S_{mf} = 3.53), MF 2 (S_{mf} = 4.02), and MF 3 (S_{mf} = 6.33) (Fig. 3). So, MF 3 is less active than the other fronts.

AF constrains the amount of tilting of the delineated watersheds. Watersheds 1, 4, 5, 6, and 7 tilted toward NW, and watersheds 2 and 3 tilted toward SW (Fig. 4). There can be a tectonic imprint on watersheds that justify this tilting. The master streams (MS) of each watershed have been considered for long profile best fit curve analysis. R^2 model signifies that MS 6 and 7 are tectonically very active as the linear R^2 values are highest (0.9503, 0.9799) (Table 1). For MS 1–5, R^2 values are

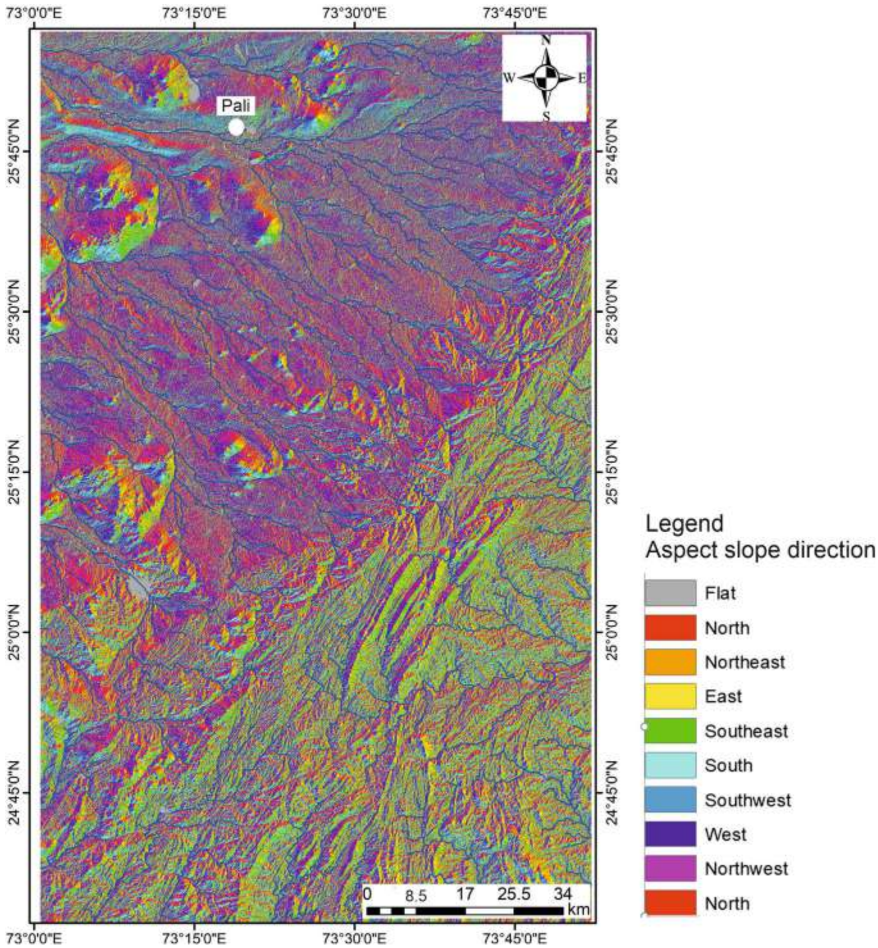

Fig. 2 Aspect slope map with drainage network showing slope directions and drainage orientation

0.9051, 0.8183, 0.7922, 0.9656, and 0.8054, respectively. R^2 value is highest for the exponential curve MS 1–5 that justifies the master stream to be highly active. The Kernel spatial lineament density map and line density map also disclose that the catchment area of northernmost rivers is mostly structure-controlled (Figs. 5a, b). The entire area discloses that the ADFB is active tectonically. River channels indicate the activeness. Yadav et al. (2022) mentioned that the GPS study of the area shows present-day reactivation.

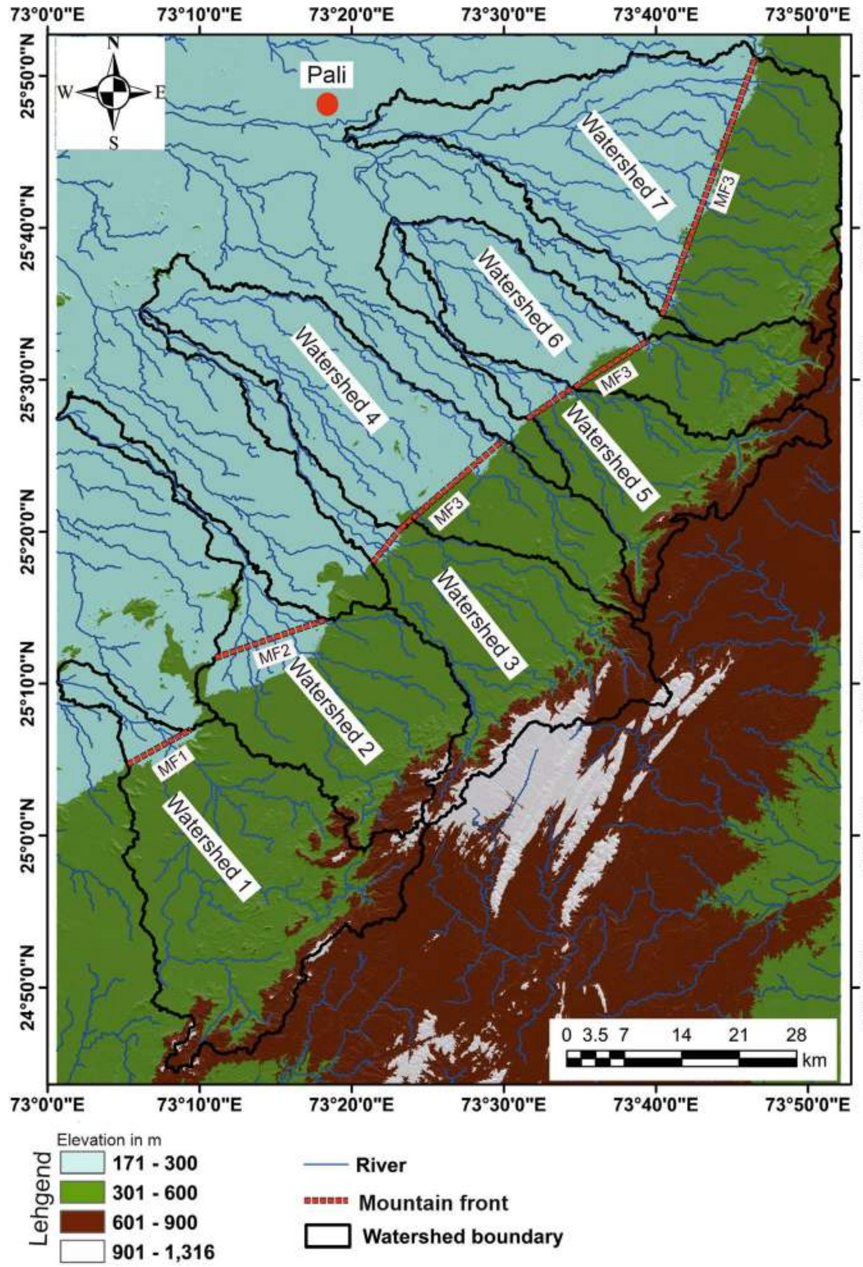

Fig. 3 Seven delineated watersheds with marking of considered mountain fronts (MFs)

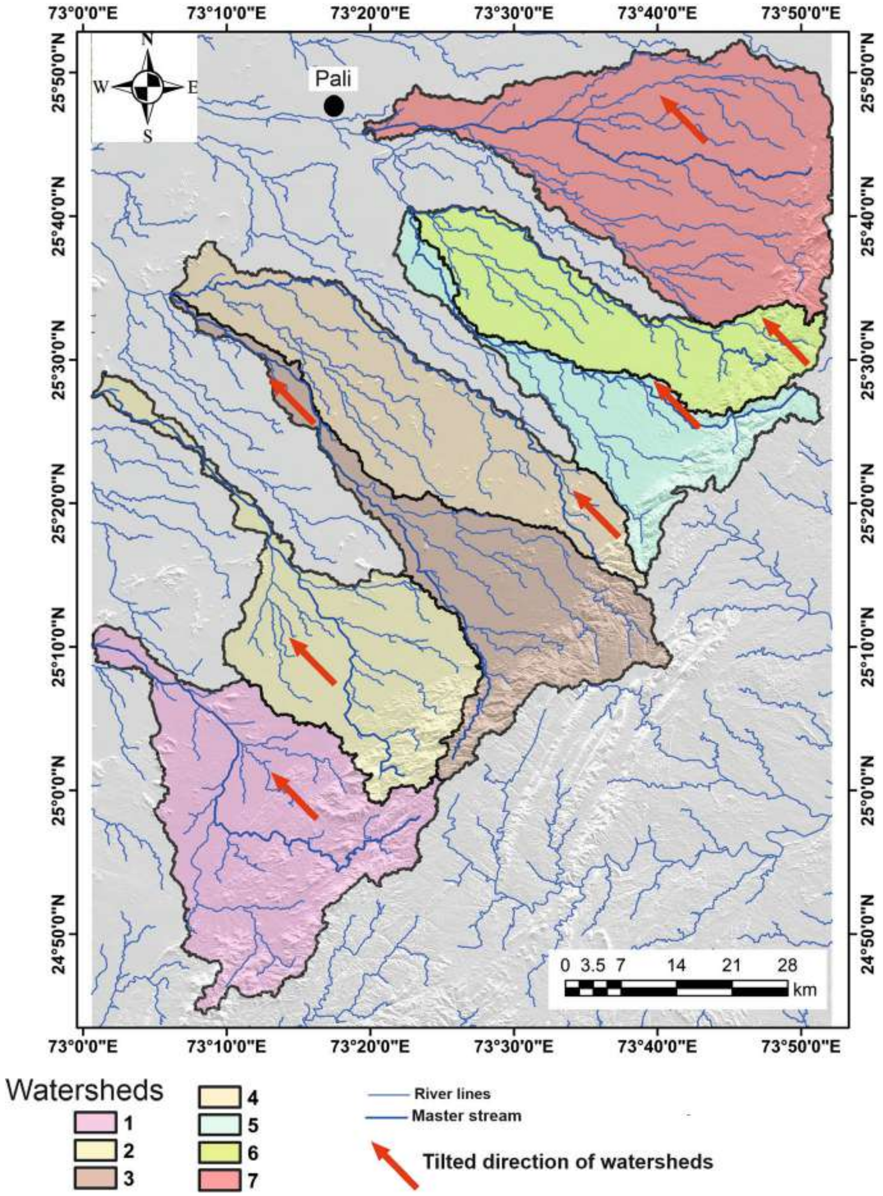

Fig. 4 Basin asymmetry factor showing tilting direction of watersheds. Master streams are marked

Table 1 Calculations of R^2 values for master streams of seven delineated watersheds

Watersheds	Linear	Exponential	Logarithmic	Power
1	0.8204	*0.9051*	0.9205	0.6559
2	0.7682	*0.8183*	0.9531	0.6684
3	0.6994	*0.7922*	0.8954	0.3146
4	0.9335	*0.9656*	0.8865	0.6537
5	0.7289	*0.8054*	0.3847	0.3847
6	*0.9503*	0.9314	0.8795	0.7161
7	*0.9799*	0.9758	0.7906	0.5325

Highest R^2 values are marked by italic emphasis

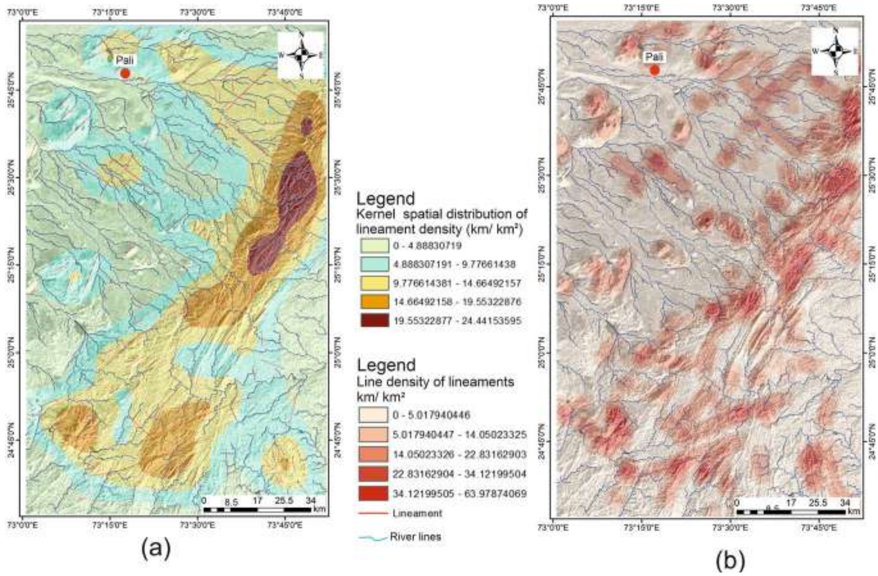

Fig. 5 **a** Kernel spatial lineament density map extracted from DEM hill shade analysis. **b** Line density map of lineaments

3.2 Geophysical Aspects

The bathymetry (topographic) data has been accessed from Internet Ref-1. Contour plot has been plotted using MATBALB 2017b version, which includes seven watersheds (W) (Fig. 6). It is prepared for the different heights to get a clear regional picture of the study area. On analysis of upward continuation maps at different heights, it is found that the 1000 m upward continuation map is the smoothest, and the regional picture is visible, so it is taken as a reference for the regional elevation map. The elevation height varies within 200–1200 m with their changing topography. The general topography trend is low at NW and increases toward SE. Still, in the southern side, different trends are identified, such as it has high topography vertical in skyward direction to the 73°30′ E, which makes it different from the general trend. This kind of variation is possible because of the regional subsurface tectonic deformation of ADFB. Mostly, the watershed (W) area lies in the northeast with low elevations.

The gravity contour plot in the ADFB region has been plotted using the MATLAB 2017b environment (Fig. 7). The plot shows that the gravity trend varies from − 20 to 100 mGal. A significant change in the trend of gravity contour pattern is observed. In the southern portion of the study area, the general trend of the gravity anomaly contour is in NNE–SSW, which conforms to the regional strike of ADFB whereas in

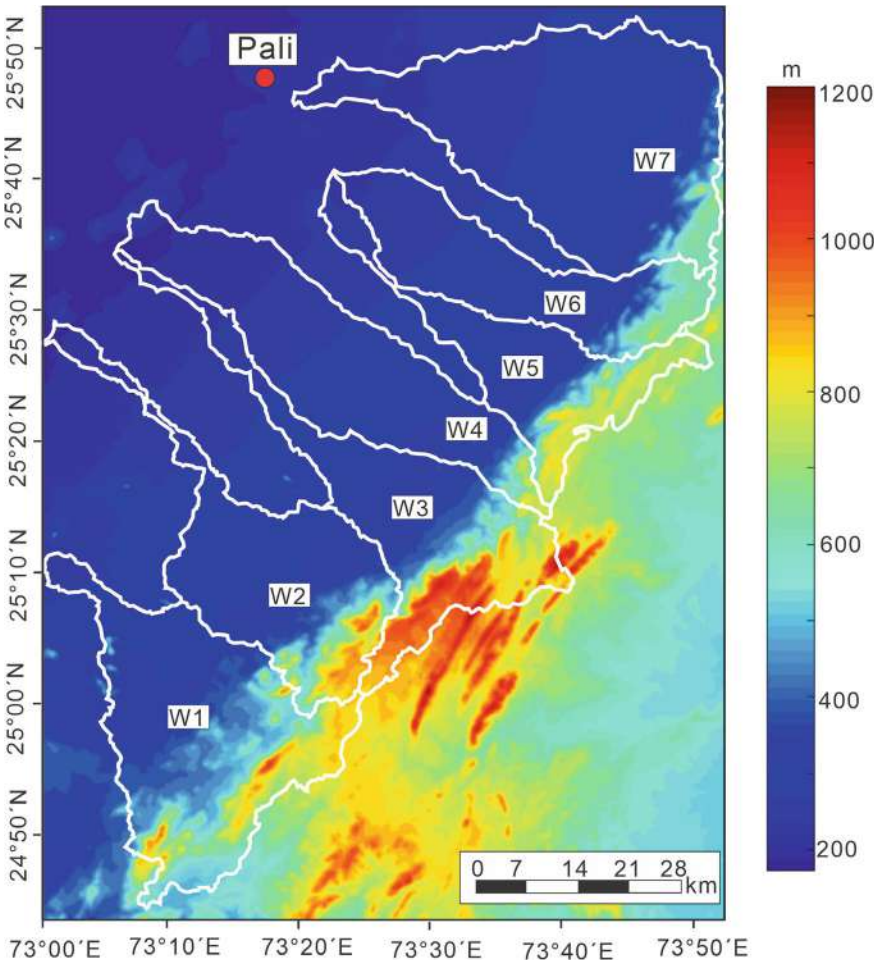

Fig. 6 Regional map of Aravalli-Delhi Fold Belt (ADFB) with plot of bathymetry (elevation) data. Color bar: height in km with respect to the mean sea level (MSL)

the central part, the contour trend changes to NW–SE direction. The study includes seven watersheds (W) which show different gravity variations. The SE corner of each watershed has high gravity values of ~ 100 mGal, while their NW parts show lower values of ~ 0 mGal. This gravity trend is almost the same as the regional gravity trend. Additionally, a moderate regional gravity anomaly is noted over Sohna.

Now, we evaluated the first four Principal components (PCs) of bathymetry (elevation) and gravity and plotted them in Fig. 8 for comparison. The bathymetry (elevation) has been plotted with orange color, and their magnitude have been shown with the *y*-axis. The gravity anomaly PCs are plotted with cyan color. Their magnitude has been shown on the left side of the *y*-axis. At first glance, PC1 and PC3 trends match for both data while those for the PC2 and the PC4 are opposite (inverse relation).

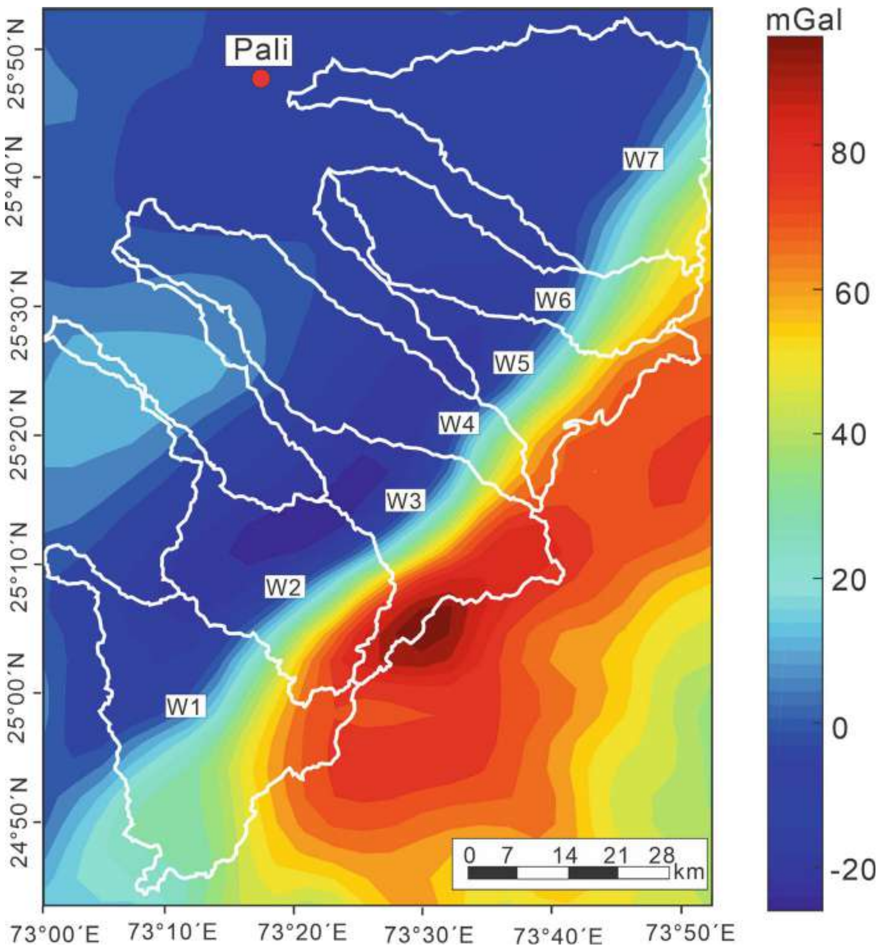

Fig. 7 Regional FAG map of Aravalli-Delhi Fold Belt (ADFB). Color bar: gravity tend (mGal)

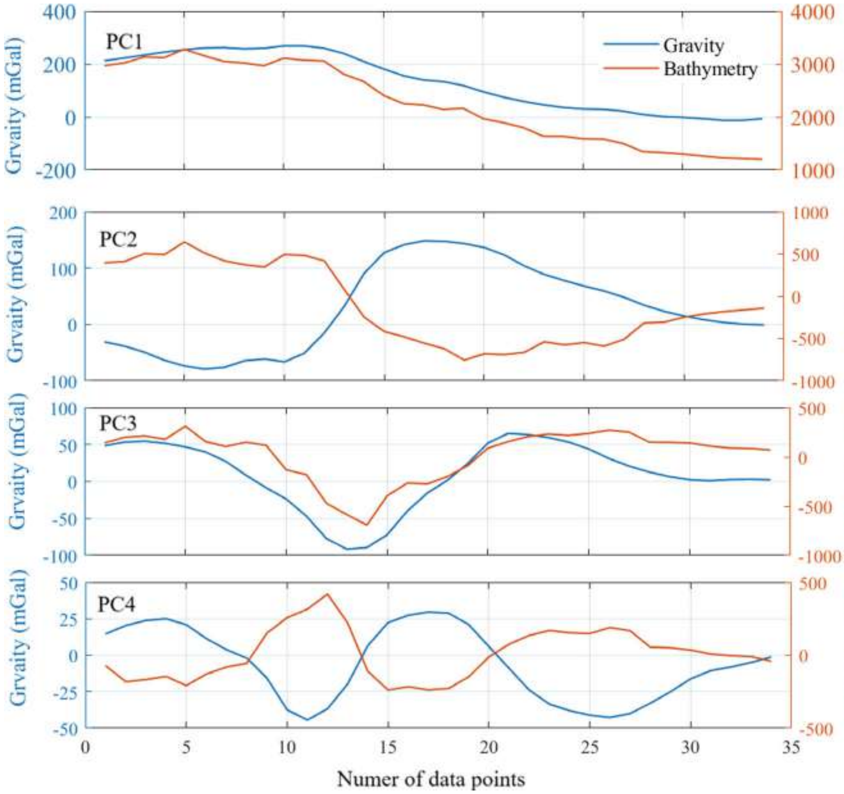

Fig. 8 First four Principal component (PC) of bathymetry elevation (orange color) and gravity anomaly (cyan color)

In this study, we can conclude that only odd PCs follow this trend while even are opposite with them.

We also studied correlation coefficients (R) and linear trend of all first four as shown in Fig. 9. This is clear from the figure that PC1 and PC3 have positive trends with their linear coefficient of 6.8453 and 5.1452 values, respectively. The correlation coefficient (R) values are 0.9908 and 0.8938 for PC1 and PC3, respectively. These correlation coefficient values are very high and point out strong positive correlations. PC2 and PC4 have a negative trend with linear coefficients of − 5.5585 and − 6.4582, respectively. The correlation coefficient values for PC2 and PC4 are − 0.9186 and − 0.9270, respectively. Negative yet high coefficients indicate their strong inverse relationship. Bathymetry (elevation) and gravity odd PCS are positively related to each other, and even PC2 are negatively related to each other.

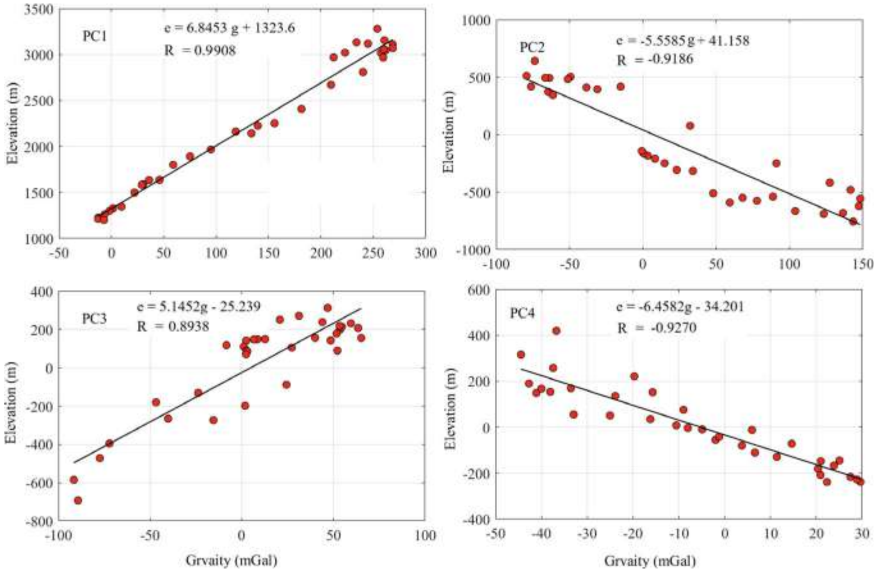

Fig. 9 Correlation coefficients (R) and linear trend of all first four PCs

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Abbreviations

ADFB	Aravalli-Delhi Fold Belt
FAG	Free-air Gravity
GEBCO	General Bathymetric Chart of the Oceans
MSL	Mean Sea Level
PCs	Principal components
PCA	Principal Component Analysis
R	Correlation coefficient
W	Watershed

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