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ORIGINAL PAPER

Evaluation of engineering properties of KBH and KCH Kaimur Sandstone based on petrological analyses

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Abstract

The Vindhyan sedimentary rocks are well exposed near Son valley due to Markundi-Jamwal fault. A relationship among textural, petrographic, and mineralogical characteristics with mechanical properties of sandstone has been established for Kaimur Bhagwanpur village Hill (KBH) and Kaimur Chainpur village Hill (KCH) which falls under Kaimur group. A comparative study between KBH and KCH has been performed to understand the textural behavior of minerals. The petrographic study reveals that the rock is characterized by rich sources of quartz, feldspar, mica, clay-rich minerals, and some accessory minerals. Based on petrographic data, the relationship of K-feldspar with moisture content (MC), grain area ratio (GAR), packing density (PD), shear strength (SS), proto-dykonova values (PdT), slake durability index (SDI), impact strength index (ISI), and Young Modulus (E) of sandstone rock collected from 5 different locations from both KBH and KCH sandstone were evaluated. It was found that all parameters show the linear incremental relationship with K-feldspar except Young Modulus in KCH sandstone. In addition, K-feldspar shows linear incremental relationship with packing density, shear strength, proto-dykonova values and Young Modulus whereas linear decremented relationship was observed with moisture content, grain area ratio, slake durability index and impact strength index.

Keywords Petrographic study · Mechanical properties · Grain area ratio · Kaimur Sandstone

Introduction

Stability of slope is significantly affected by engineering properties of rock (Kainthola et al. 2012; Pain et al. 2014). Compressive and shear strength which are also strongly dependent on the petrographic properties of the rock. The physical and mechanical properties of the rocks are greatly influenced by the petrographic characteristics viz. texture, fabric, and degree of interlocking of grains, nature of contacts, mineralogical composition, and the weathering state (Irfan 1996).

The rocks under vindhyan super group are well matured due to long term deposition history. Vindhyan supergroup is characterized by the deposition of calcareous, arenaceous, and argillaceous sediments of different gran size. The sandstone is most abundant sedimentary rock under Kaimur group in northern Indian continent. The rock is mainly composed of Quartz and Felspar. In Vindhyan, exposer expansion of sedimentary rock as Kaimur group sedimentary basin. The samples of sandstone show the variation in the mineralogy, petrographic characteristics, and engineering properties (Chaudhary et. al., 2021a, b). In the study area, sedimentary rock is very strong, stable, and has a higher abrasion value; therefore, it is suitable for building construction material.

Geotechnical parameters of sandstones such as density, specific gravity, shear strength, Protodykanova test, impact strength, and Young Modulus are validated by petrographic analysis. The properties of rock like discontinuities, inhomogeneity, anisotropic non-elastic, and non-linear behavior are studied (Shalabi et al. 2007). Hence it is understood that the properties of rock mass largely depend upon the behavior of these discontinuities under various natural and induced stresses.

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According to engineering viewpoint, most of the engineering properties depend on quality of sedimentary rocks. The sedimentary rock has high density and is mostly used in building construction. The density of sedimentary rocks may vary with the variation in mineral composition. However, it is generally greater than 2.55. The geotechnical parameters have been classified as suggested by Griffith (Gupta and Rao 2000). According to the classification, the relationship between unconfined compressive strength of different rock types with their respective compactness has been established. Similarly, the relationship between simple linear equations is also generated with shear strength and hardness (Wuerker (1953). Most of the engineering properties are directly related to the shear strength of rock. Minerology also plays an important role in assessing the strength of the rock. The texture structure and grain size variations also affect the anisotropic rock (Deere and Miller 1966). Several researchers have also utilized mineralogical properties to better understand the engineering properties of rock using geotechnical parameters for example, unconfined compressive strength (UCS), hardness, Impact strength index (ISI) (Aufmuth 1974; Katz et al. 2000; O'Rourke 1989; Sachpazis 1990; Singh et al. 1983; Tugrul and Zarif 1999). The mineralogy and texture together are responsible for the strength and elastic deformational characteristics of different rock types (Johnson and De Graff 1988). Earlier studies (Brace 1961; Srivastava and Sahay 2003) indicate that the finer grains size results in higher compressive strength of rock and vise-versa (Onodera 1980). Further, the strength of the quartz and its percentage in rock have a direct and significant relationship (Merriam et al. 1970). For example, the higher percentage of quartz increases the strength of the rock. In contrast, the strength of rock decreases due to the presence of feldspar and clay minerals. Similarly studies also indicate that the texture and microstructures added with the type of minerals present and petrographic characteristic have a strong correlation with the physical and mechanical properties of rock (Deere and Miller 1966; Irfan 1996; Mendes et al. 1966). Figure 1

Study area

In the Vindhyan basin, the thickest Proterozoic succession lies over the stable Bundelkhand craton of Archean-Early Proterozoic age in India (Bhattacharyya 1996; Bose et al. 2001; Pascoe 1959). It has derived its name from the Kaimur range in Central India which divides the Son from the Tons valley. Vindhyan Supergroup is comprised of Bhander, Rewa, Kaimur and Semri groups from top to bottom (Kumar et al. 2019). The well-exposed outcrops of Semri and Kaimur Groups in the Son valley area are bounded by the Bundelkhand Granitic Complex (BGC), Mahakoshal Group and Chotanagpur Gneissic Complex in the north and southern margin respectively. Son Valley covers the state of Bihar, Uttar Pradesh, and Madhya Pradesh (Kumar and Pandey 2021). The study area under investigation is the eastern part of Son valley in Kaimur District of Bihar. The rocks of the Kaimur group (lowest unit of the upper part of Vindhyan super group overlying Semri Group) are well exposed in the study area. The Kaimur outcrops extend from Chittaur in the west to Saramam in the east (Ramakrishnan and Vaidyanathan 2008) (Fig. 2).

In this study, the representative samples were taken from five different locations from Bhagwanpur village hill (KBH) situated 24°57’65” north and 83°36’1” east and Chainpur village hill (KCH) situated 24°05’42” north and 83°28’07” east falls under kaimur group in the Son valley. The Upper Kaimur Group (Dhandraul Sandstone, Scarp Sandstone) is

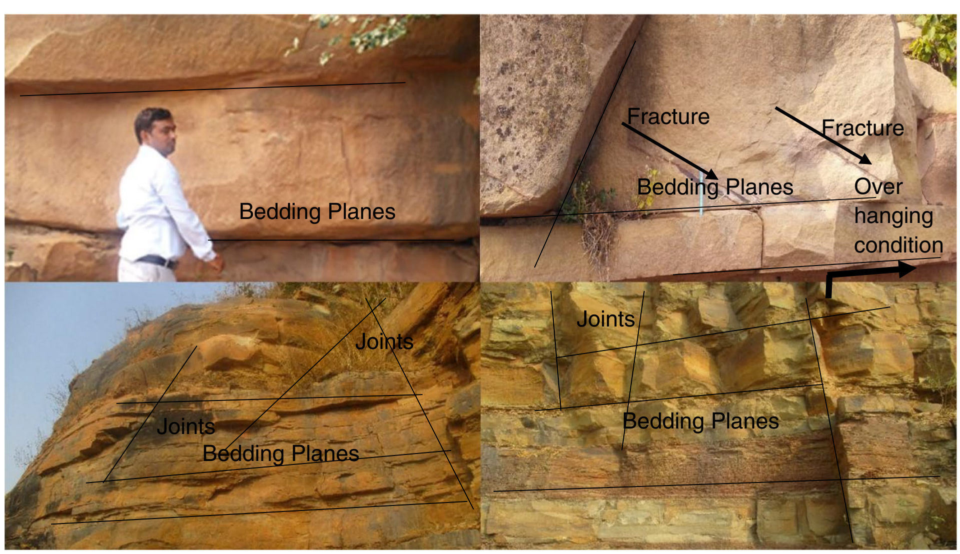


Fig. 1 Physical condition of the rock cut slope belong to KBH and KCH at different locations

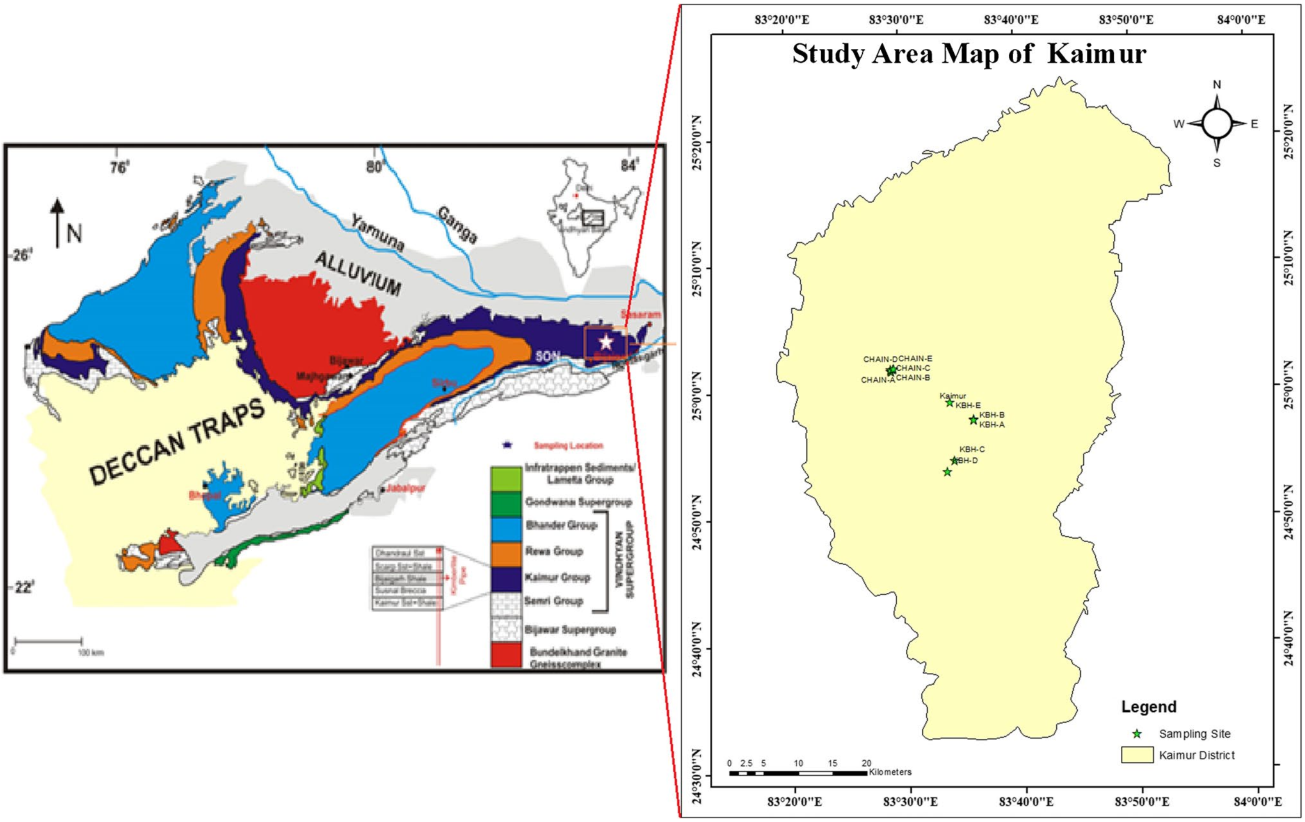


Fig. 2 Geological and Location map of Vindhyan Super Group (Modified after Azmi et al. 2008)

very well exposed in this section (Fig. 1). The general stratigraphy of the Kaimur Group is presented in Table 1.

The geological map (Fig. 2) shows the lithological variations in the Vindhyan supergroup of the exposed rock succession in Son valley in the east. The Bhagwanpur village hill (KBH) is situated 15 km from Chainpur village hill (KCH) in the north. Generally, the Vindhyan rocks are un-metamorphosed and un-deformed. However, there are

Table 1 Stratigraphy of the Kaimur Group (Ramakrishnan and Vaidyanathan 2008)

	Group	Formation	Alternative Names
VINDHYAN SUPERGROUP (Meso-Neoproterozoic)	Rewa Group (100-300 m)	Govindgarh Sandstone	Upper Rewa Sst.
		Drummondganj Sandstone	
		Jhiri Shale	Variegated Shale
		Asan Sandstone	Upper Rewa Sst.
		Panna Shale	
	--------Normal contact/ Facies change---------		
	Kaimur Group (400 m)	Dhandraul Quartzite	Upper Kaimur Sst.
		Mangesar Formation	Scrap Sandstone
		Bijaigarh Shale	
		Markundi Sandstone	Ghaghar Sandstone
		Ghurma Shale	Susnai Breccia
		Sasaram Sandstone	Lower Kaimur Sst.
	------Unconformity/ Normal contact--------		
	Semri Group (3000-4000 m)	Suket Shale	Baghwar Shale
		Rohtas limestone	Nimbhahera Lst.
		Chorhat Sandstone	Glauconitic bed, Rampur Sst.

significant numbers of folds in the Son valley (Srivastava and Sahay 2003; Verma 1996). The Vindhyan Super group is comprised mainly of sandstone, shale, and carbonate with some conglomerate and volcanoclastic rocks separated by major regional and numerous local-level unconformities (Bhattacharyya 1996; Ismail and Ateiza 1991; Rogers 1986).

Methodologies

The objective of the present study was to determine the petrographic properties and geotechnical properties of the rock mass belonging to the study area and establish the correlation among them. Rock samples were collected from 10 different locations from the study area and prepared as per IS code for different tests.

Petrographic description

The thin sections were prepared and examined under a high-resolution petrographic microscope to understand the textures and mineralogy (grain fabric and grain shape) of the sandstone falling under Kaimur group. The samples have been collected from ten different locations at Bhagwanpur and Chainpur in the Kaimur district of Bihar.

The inter-granular space may be partially or filled up either with Fe-oxide, Silica and Calcium Carbonate or a fine-grained matrix composed of silt and clay particle (Pettijohn 2002). The sand is consolidated during burial and a binding agent viz. quartz, calcite, or Fe-oxide is precipitated from groundwater that passes through passages among the grains. The petrographic description of two types of Sandstone is tabulated below (Table 2).

Geotechnical properties

The geotechnical properties viz: Shear Strength, Protodykonova Test, Slake Durability Test, Young Modulus, Impact Strength Index, Density and Specific Gravity of the sandstone are determined as per the guidelines and procedures mentioned in ASTM 2005 and ISRM 1981. These parameters provide critical information about the bearing capacity and resistive energy that can be sustained before rock mass failure (Adebayo and Umeh 2007; Kahraman et al. 2003). Ersoy (1995) suggested that texture is the major and important factor which determines rock behavior. The strength of rocks, however, not only varies with rock type but also within the same rock under different geological conditions. It has been attempted to establish the relationship between mineralogical characteristics and mechanical properties of the sandstone which has also been correlated using statistical analysis tools and techniques. Furthermore, mineralogical characteristics and mechanical properties of the sandstone rock were also correlated using statistical analysis and techniques to establish their interdependence.

Results

Petrographic description

The petrographic studies reveal that the general texture of sandstone can be represented as sub-hedral, angular, sub-angular and sub-rounded (Fig. 3a–d). It was observed that quartz (with undulose extinction), feldspar and mica are the important minerals in the sandstone in decreasing order. Feldspar is expressed in the form of common mineral viz. Potassium (K)-feldspar (Orthoclase) or alkali feldspar commonly present in the samples. In addition, it was found that the most common mica minerals are muscovite (abundant and show

Table 2 Petrographic details of Vindhyan Sandstone, Kaimur Group

Sample	Petrographic Description
KBH-A	Sub-hedral quartz, sub-hedral feldspar, euhedral to subhedral biotite, muscovite, iron oxide as cement, accessory minerals – Zircon and tourmaline
KBH-B	Sub-hedral quartz, feldspar and biotite. Feldspar is slightly altered, iron oxide as cement
KBH-C	Sub-hedral quartz, sub-hedral to anhedral feldspar, sub-hedral biotite, muscovite and Feldspar slightly altered
KBH-D	Sub-hedral quartz dominant, sub-hedral feldspar, sub-hedral to eu-hedral biotite, Biotite flakes with dark brown to black pleochroic haloes. Feldspar slightly altered, rock fragments. Matrix dominant
KBH-E	Sub-hedral quartz and feldspar (orthoclase), platy sub-hedral biotite. Biotite with dark brown to black pleochroic haloes. Feldspar altered, Rock fragments with matrix dominant
KCH-A	Medium grain sub-hedral quartz, sub-hedral feldspar. Feldspar slightly altered.
KCH-B	Sub-hedral quartz, sub-hedral biotite, sub-hedral orthoclase, numerous flakes of biotite and muscovite, iron oxide cement.
KCH-C	Sub-hedral quartz, sub-hedral feldspar and biotite. Feldspar slightly altered, also muscovite, rock fragment and matrix present
KCH-D	Sub-hedral quartz, feldspar and biotite, Feldspar altered to clay minerals
KCH-E	Sub-hedral quartz, feldspar and biotite and muscovite, iron oxide cement, Rock fragments with matrix dominant

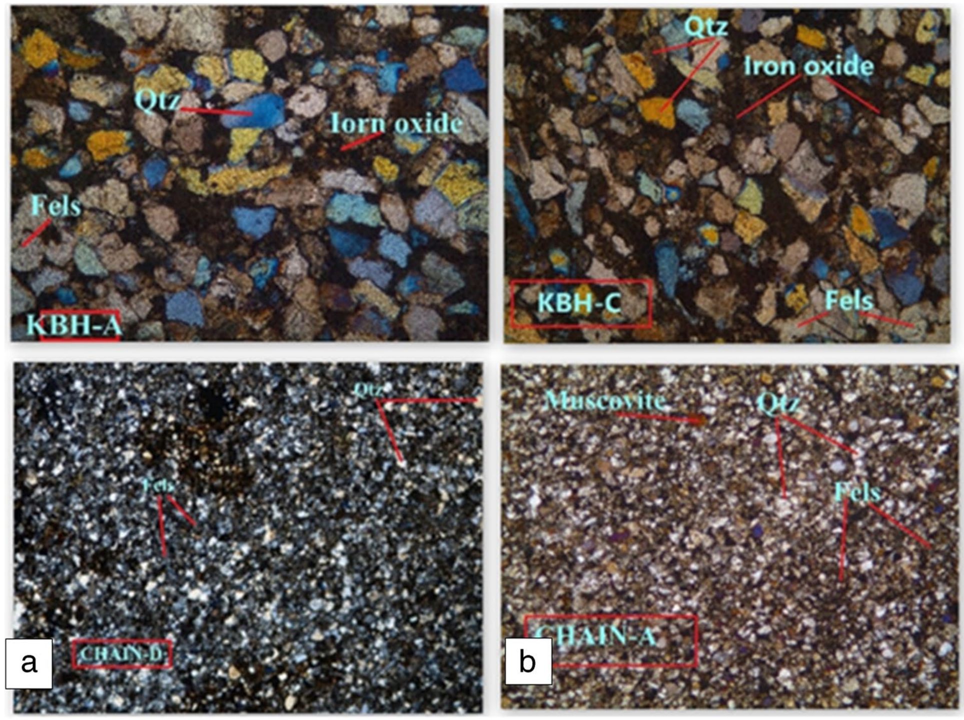


Fig. 3 (**a**–**d**) Microphotographs of Vindhyan Sandstone, Kaimur, Bihar

preferred alignment occasionally altered to clay mineral) and biotite. Other accessory minerals like zircon, tourmaline and leucoxene are present in subordinate amounts. The quartz grain shows zircon, tourmaline, and muscovite. Among feldspars, orthoclase was found to be dominant while microcline present in minor amounts. Further, the dissolution of orthoclase was also evident from petrography. The clay mineral has developed along cleavages, and cracks. Iron oxide along with siliceous cement is also present as cementing material. The sandstone in the study area belongs to Quartz -Arenite type.

The X-ray diffraction (XRD) test was conducted to understand the mineral content of four rock samples collected from different Locations (KBH-A, KBH-B, KCH-A and KCH-D) in the study area (Fig. 4). The XRD graph reveals that the major mineral is quartz in all the samples (Fig. 8.7 (a), (b), (c) and (d)).

The sandstone of Mangeser formation is medium to fine-grained, moderately to poorly sorted with angular to sub-angular detrital framework grains. The study indicates that Quartz constitutes about 72.6%. Further, the Q/F ratio is higher in KBH as compared to KCH location. The results of the petrographic analysis are summarized in Table 3.

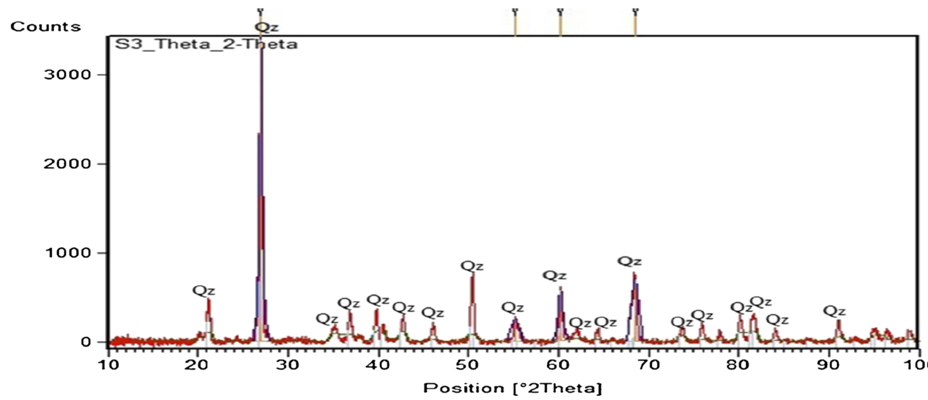
The petrographic study (Fig. 2) and XRD analysis (Fig. 3) show that KBH pure Quartz in significant amount with bigger grain size as compared to KCH. Mineral composition (Table 3) validates that the KCH has higher feldspar, fine grained rock fragment and cement content as compared to KBH. The petrographic study also shows that the grain size in KBH is much bigger than KCH.

Geo-mechanical study

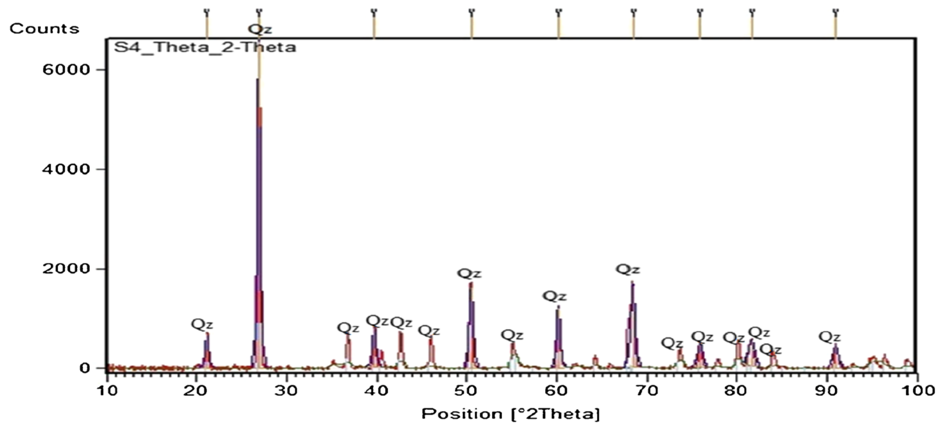
The Grain Area Ratio (GAR) varies from minimum (60) at location KCH-E and maximum (84) at location KCH-A while PD is minimum (63) at location KCH-D and maximum (84) at location KCH-A. The average GAR is 69 and PD is 73.2. The Moisture content (MC) varies between 0.12% and 0.60% and the average being 0.255%. The average specific gravity of the rock sample is 2.57 which shows that the rock is sandstone. The sandstones having specific gravity (SG) ≥ 2.55, are suitable for major construction work. The observed values of SG vary between 2.54 and 2.67. In the present study, the observed value of density (ρ) varies between 2.45 and 2.57 g/cm^3, the average being 2.54 g/cm^3. The above properties of the rock samples from different locations are listed below in Table 4.

Table 4 shows the index and strength properties of the rock samples collected from the study area. It was interesting to note that the specific gravity and density of samples from both locations are almost similar, yet other parameters were found to vary significantly. For example, the GAR, PD and MC for KBH samples were found to be higher than KCH samples. In fact, MC of KBH samples were found to be nearly 62% higher than KCH samples which may influence the shear strength of the rock. Evidently, the shear strength of the KBH samples (17.66 MPa) was found to be less than KCH samples (19.66 MPa) (Table 4). The reduction in strength was also validated using Protodykonov value. The Protodykonov value of KBH samples (29.67) was found to be 39% less than KCH samples (48.47). Similarly, the SDI and ISI of KBH samples were found slightly less than KCH samples.

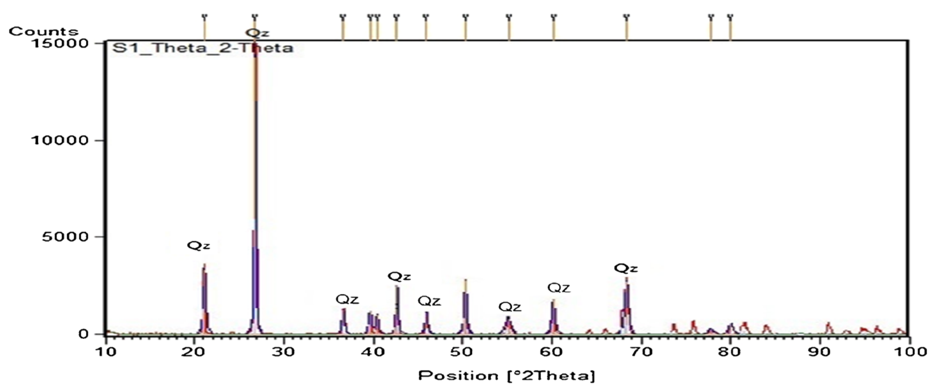
Fig. 4 **a**) Shows the X-ray diffraction of rock samples belongs to locations KBH-A. **b**) Shows the X-ray diffraction of rock samples belongs to locations KBH-B. **c**) Shows the X-ray diffraction of rock samples belongs to locations KCH-A. **d**) Shows the X-ray diffraction of rock samples belongs to locations KCH-D



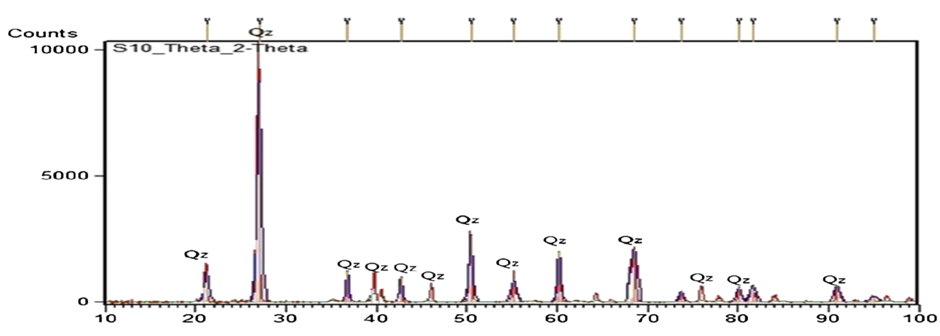
(a) *Shows the X-Ray diffraction of rock samples belongs to locations KBH-A*



(b) *Shows the X-Ray diffraction of rock samples belongs to locations KBH-B*



(c) *Shows the X-Ray diffraction of rock samples belongs to locations KCH-A*



(d) *Shows the X-Ray diffraction of rock samples belongs to locations KCH-D*

Table 3 Mineral composition (Quartz and K-feldspar) of the sandstone rocks

Location	Quartz	Feldspar	Rock Fragments	Matrix	Cement	Q/F
KBH-A	82	6	4	5	6	13.67
KBH-B	84	4	5	2	5	21
KBH-C	80	3	8	6	9	26.6
KBH-D	81	2	5	6	7	40.5
KBH-E	78	2	5	5	9	39
KCH-A	63	12	16	9	21	5.25
KCH-B	69	14	12	6	9	4.92
KCH-C	65	18	9	8	14	3.61
KCH-D	60	17	13	10	18	3.52
KCH-E	64	19	12	8	15	3.36
Average	72.6	9.7	8.9	6.5	11.3	16.14

Table 4 Index properties and strength properties of rock samples

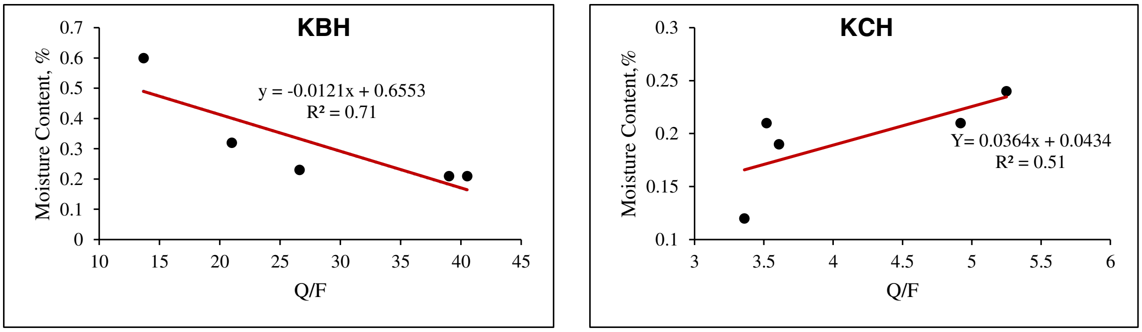
Location	GAR (%)	PD (%)	MC (%)	SG	ρ (g/cm3)	SS (MPa)	PdT (Pi =20n/l)	SDI (%)	E (GPa)	ISI (%)
KBH-A	74	69	0.6	2.57	2.57	12.8	27.41	98.84	4.11	75
KBH-B	83	78	0.32	2.58	2.53	11.7	30.71	99	4.06	74
KBH-C	68	81	0.23	2.54	2.53	21.5	27.5	98.74	7.21	73
KBH-D	65	75	0.21	2.6	2.56	24.3	33.33	98.43	8.5	73
KBH-E	60	85	0.21	2.67	2.55	18	29.41	98.77	6.6	72
Average	70.00	77.60	0.31	2.59	2.55	17.66	29.67	98.76	6.10	73.40
KCH-A	84	84	0.24	2.56	2.56	22.5	66.66	97.89	6.69	80
KCH-B	62	77	0.21	2.54	2.56	18.7	66.66	98.41	5.67	82
KCH-C	69	73	0.19	2.56	2.45	20	31.25	98.98	6.08	71
KCH-D	71	63	0.21	2.55	2.54	18.1	50	98.66	5.86	76
KCH-E	54	69	0.12	2.61	2.56	19	27.77	99.21	3.92	72
Average	68.00	73.20	0.19	2.56	2.53	19.66	48.47	98.63	5.64	76.20

**GAR* grain area ratio, *PD* packing density, *MC* moisture content, *SG* specific gravity, *ρ* density, *SS* shear strength, *PdT* Protodykonov test, *SDI* Slake durability index, *E* Elastic Modulus, *ISI* Impact Strength Index

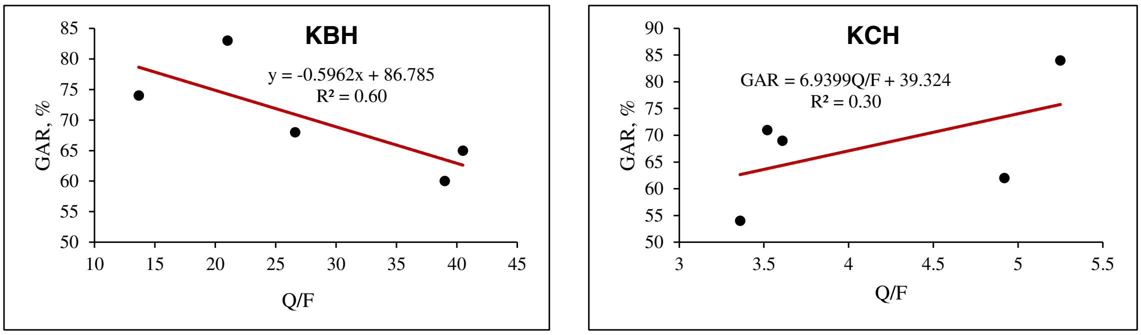
Further, mathematical models have been established for all the engineering parameters. The observed results as shown in Table 4 are analyzed using least-square regression analysis. The relationship between petrographic characteristics and mechanical properties of Kaimur group (Vindhayan sandstone) samples collected from the study area has been developed to understand, predict, and estimate the correlation among different parameters. The detailed discussion on the petrographic characteristics and engineering properties of the rock samples from different locations is discussed in the following section.

Correlation between the petrographic characteristics and engineering properties

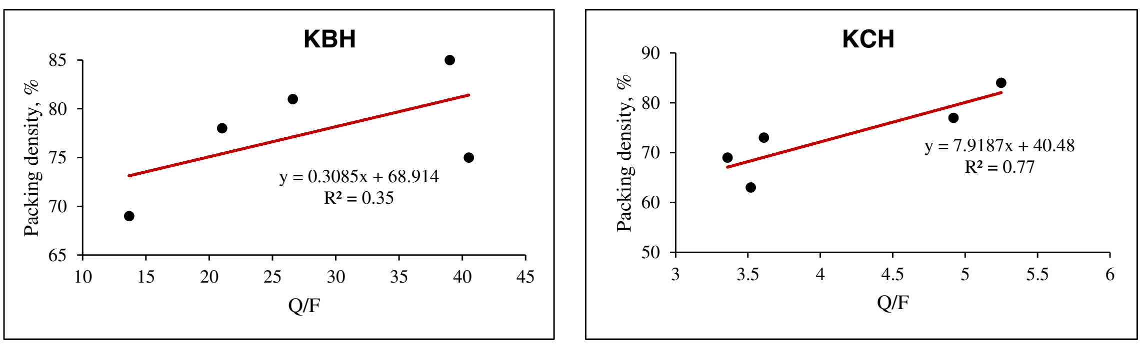
The petrological characteristics greatly influence the engineering properties. The linear regression relationship analysis has been carried out for both KBH and KCB. The petrographic study reveals that the rock belongs to the study area is rich source of quartz, feldspar, mica, clay-rich minerals, and some accessory minerals. Based on that, the relationship between K-feldspar with moisture content, grain area ratio, packing density, shear strength, protodykonov values, slake durability index, impact strength index and Young Modulus of sandstone rock collected from 5 different locations from both KBH and KCH has been evolved. This indicates that all parameters show the linear incremental relationship with K-feldspar except Young Modulus in KCH. While K-feldspar shows the linear incremental relationship with packing density, shear strength, protodykonov values and Young Modulus and linear decremental relationship with moisture content, grain area ratio, slake durability index and impact strength index (Fig. 5).



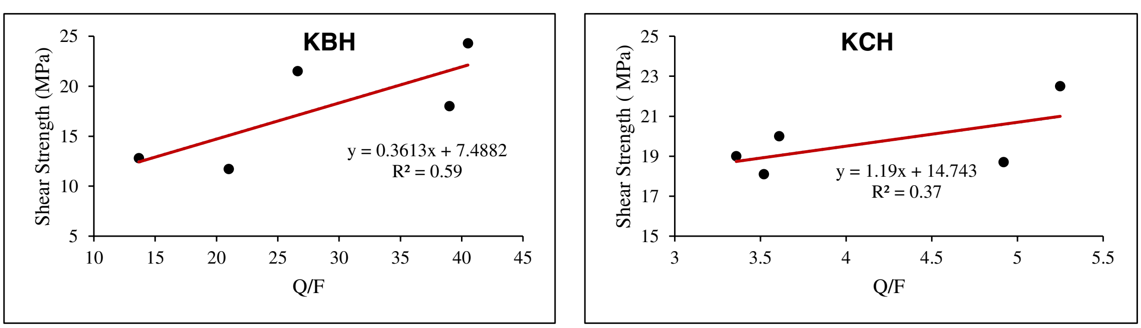
(a) Shows the linear relationship of Moisture Content and Q/F relationship for KBH and KCH Locations



(b) Shows the linear relationship of GAR and Q/F relationship for KBH and KCH Locations

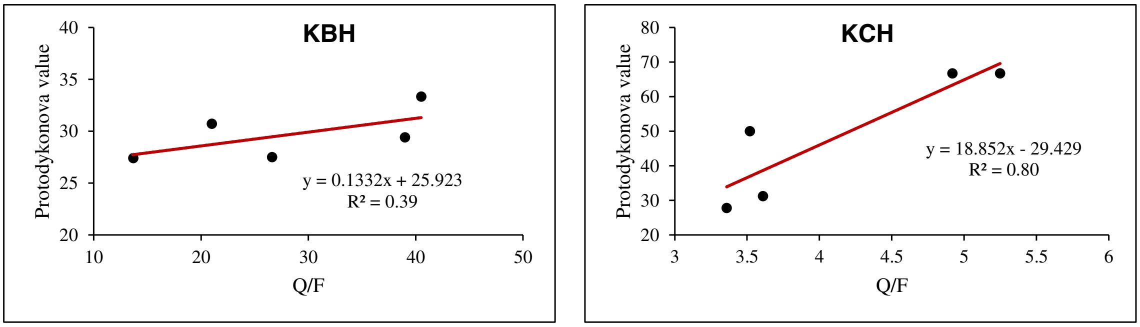


(c) Shows the linear relationship of Packing density and Q/F relationship for KBH and KCH Locations

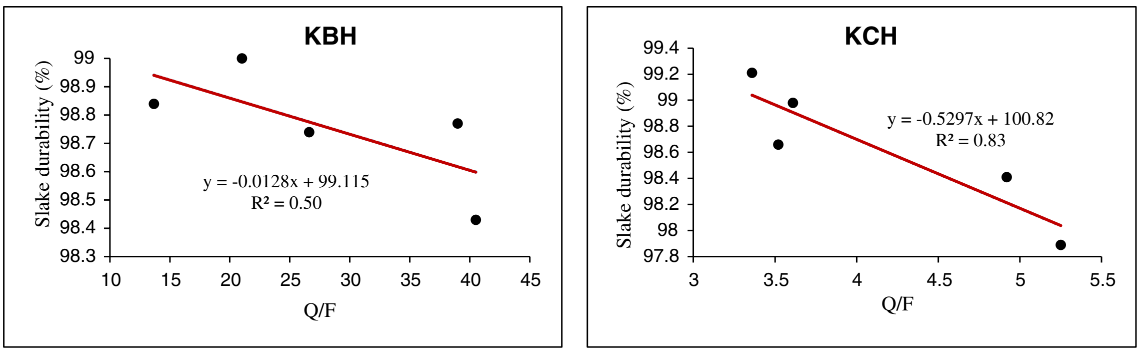


(d) Shows the linear relationship of Shear Strength and Q/F relationship for KBH and KCH Locations

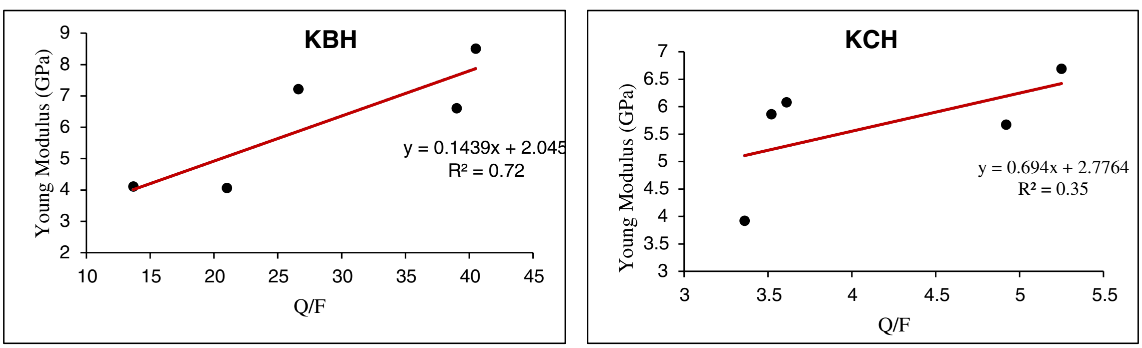
Fig. 5 (**a**) Shows the linear relationship of Moisture Content and Q/F relationship for KBH and KCH Locations. (**b**) Shows the linear relationship of GAR and Q/F relationship for KBH and KCH Locations. (**c**) Shows the linear relationship of Packing density and Q/F relationship for KBH and KCH Locations. (**d**) Shows the linear relationship of Shear Strength and Q/F relationship for KBH and KCH Locations. (**e**) Shows the linear relationship of Protodykanova and Q/F relationship for KBH and KCH Locations. (**f**) Shows the linear relationship of Slake durability Index and Q/F relationship for KBH and KCH Locations. (**g**) Shows the linear relationship of Young Modulus and Q/F relationship for KBH and KCH Locations. (**h**) Shows the linear relationship of Impact Strength Index and Q/F relationship for KBH and KCH Locations



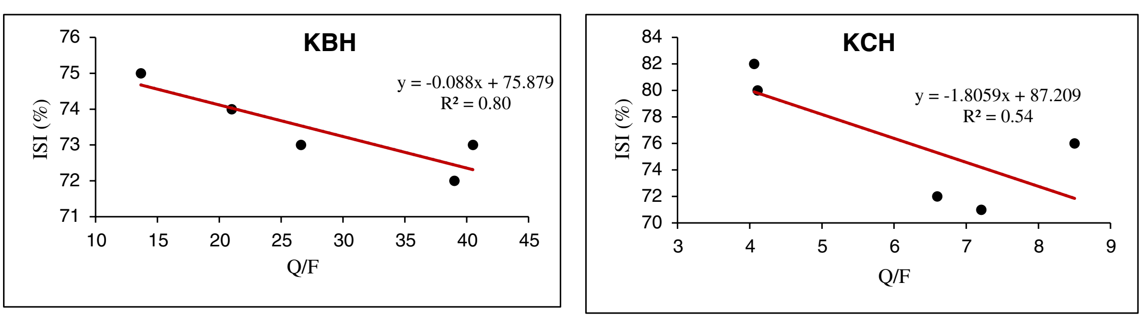
(e) Shows the linear relationship of Protodykanova and Q/F relationship for KBH and KCH Locations



(f) Shows the linear relationship of Slake durability Index and Q/F relationship for KBH and KCH Locations



(g) Shows the linear relationship of Young Modulus and Q/F relationship for KBH and KCH Locations



(h) Shows the linear relationship of Impact Strength Index and Q/F relationship for KBH and KCH Locations

Fig. 5 (continued)

Based on the goodness of fit criteria for subjective classification, relations were classified as "Good" for R^2>0.70, "Fair" for 0.40 < R^2 <0.69, and "Poor" for R^2<0.39 (Singh and Mishra 2018). Figure 5(a) indicates that the relationship between Q/F and moisture content shows good correlation (R^2=0.71), in KBH whereas Q/F and moisture content show

Fair correlation (R^2=0.51) in KCH. Figure 5(b) indicates that the relationship between Q/F and GAR is good correlation (R^2=0.71), In KBH while Q/F and moisture content show Fair correlation (R^2=0.30) in KCH. Figure 5(c and e) shows the relation of Packing density and Protodykonov value with Q/F for show Fair correlation (R^2=0.35 and R^2=0.39), In KCH, show good correlation (R^2= 0.77 and R^2= 0.80). In Fig. 5(d), the Q/F and shear strength linear but due to the degree of alteration affects this ratio, so that the correlation between the Q/F and shear strength is not significant either KBH and KCH (R^2= 0.59 and R^2= 0.37). The correlation between the Young Modulus and Q/F content shows good correlation for KBH (R^2= 0.72) and Fair correlation for KCH (R^2= 0.35) (Fig. 5(g)). The weathering phenomenon also affects the strength of rock as it altered some minerals such as feldspar and mica to clay minerals. Due to the alteration of minerals pores are created in the rock which is responsible for the loss of strength (Goodman 1989; Gupta and Rao 2000). In Fig. 5 (f and h), the correlation between Q/F with Slake Durability Index and Impact strength index values show inverse linear correlation for both KBH and KCH. The SDI of KCH shows good correlation (R^2= 0.83) to Q/F shows that the degradation rate is higher in KCH as compared to KBH. So that the shear strength is also less in KCH as compared to KBH. Since shear strength of a rock is one of the important parameters for designing structures therefore, its determination is an essential aspect in designing structures such as rock slope, dam foundation, tunnel, shaft, waste repositories, caverns for storage and other purposes (Muralha 2007). The in-situ tests are the only option available for weak, fractured, or sheared rock mass (Dev 2017). The mechanical properties and mineralogical characteristics of rock are important to determine the strength, quarrying operation, strength, stability, durability of rocks and the use of rock as a building material and its capability from various types of failures (Srivastava and Sahay 2003).

The above results show that quartz, feldspar, and quartz-feldspar ratio (Q/F) have a significant influence on the strength of rock. As the percentage of quartz feldspar ratio (Q/F) increases, the rock strength increases. Some samples show the low strength values due to low packing density (Gupta and Rao 2000). Feldspar plays a significant role in strength reduction. The presence of mineral cleavage, cracks, micro-fissures in quartz, feldspar and other minerals also reduces the shear strength, SDI, and ISI value (Onodera 1980).

Conclusion

On this basis of present research, the authors find out the following conclusions are drawn:

1. The Kaimur rock group shows a significant presence of quartz, indicating that the dominant rock type in both KBH and KCH is sandstone. *The study reveals that the mineral grains in KBH are larger compared to those in KCH.* The difference in grain size suggests varying degrees of degradation and alteration of mineral grains at KBH and KCH.
2. *The strength of the rock is affected by the quantity and characteristics of quartz and feldspar.* A higher content of quartz has contributed to greater strength, whereas the presence of other minerals like feldspar and mica have reduced the rock's strength. Alteration of feldspars to clay minerals can lead to a significant reduction in rock strength.
3. *The study also notes that higher content of mica minerals has lowered the strength of the rocks*. Additionally, weathering even in rocks with smaller grain size has affected their strength. It implies that weathering processes have played a role in the strength variations.
4. The shear strength of the rock is higher in KBH while KCH exhibits normal shear strength with a higher value of SDI. This indicates that the rock in KBH is more stable compared to KCH due to differences in mineral deformation and the geological formation of the sandstone at different locations.

The study suggests that the Kaimur Group rocks consists mainly of sandstone with a dominant quartz component. The strength of the rock is influenced by the quantity and proportion of quartz and feldspar, as well as the presence of other minerals like mica. The variation in strength observed between KBH and KCH can be attributed to differences in mineral deformation and the geological formation of the sedimentary rock.

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Declarations

Conflict of interest The authors declare no competing interests.

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