Global Journal of Engineering Science and Research Management

LITHOLOGICAL CONTROL ON CHANNEL MORPHOLOGY: A STUDY OF KAS RIVER GORGE IN AHMEDNAGAR DISTRICT, MAHARASHTRA, INDIA

Babaji B. Maskare*1 Sudhakar D. Pardeshi[2]
Department of Geography, University of Pune. Pune 411007, India.
*Correspondence Author: **Babaji B. Maskare**

Keywords: Bedrock Channel, Fluvial Geomorphology, Gorge, Lithology (Basalt), longitudinal profile.

Abstract

Gorges and bedrock channels are always the sites of interest for studying fluvial processes. The response and adjustment of the flow to lithological and structural control are also the causes of the several focused studies of bedrock channel. The bedrock channel in the present study also reveals the response to bedrock lithology. The bedrock channel incision affects the evolution of the channel forms while the shapes, size, gradient and plan form of the rocky channels are largely determined by the physical characteristics of bedrock (structure, jointing, resistance to erosion, etc.) rather than the hydraulics and sediment transport characteristics. Since the width and depth of the Kas River George are almost constant therefore the velocity of discharge increases. Hence, the energy available for stream work will be greater in the segments of gorge even at normal flow discharge. Increased velocity helps to maintain the material transportation and/or increases the intensity of erosion processes in the gorge. Kas river also shows variation in the channel width from 40 to 150 meters, channel depth varies unusually from knick towards the confluence. On the basis of channel morphometshows lots of variations in the width and depth in the lower reaches of the stream, which may be the effect of the local controls like bedrock lithology and structure.

Introduction

Bedrock channels are always the sites of interest for the study of fluvial processes. The response and adjustment of the flow to the lithology and structure are also the causes of the several focused studies of bedrock channel. Recent interest in feedback between erosion and rock uplift, such as that between the rate of river incision into bedrock, relief development and hill stability (Montgomery et al., 1995), has focused attention on the processes of bedrock river incision. In bedrock channel the rate of erosion would be very high and in alluvial channel the rate of erosion would be low. In the bedrock channel system some beds of the channel consist of hard rock while others are soft rock such as alluvium. Bedrock channel has a deeper flow than the alluvial channel because bedrock channels are narrower. The bedrock channel incision affects the evolution of the mountain topography and therefore bedrock channel incision has become an important concept in geomorphology (Finnegan et al., 2005).The shape, size, gradient and plan form of the rocky channels are largely determined by the physical characteristics of bedrock (structure, jointing, resistance etc.) rather than the hydraulics and sediment transport characteristics (Kale, 2001).

Bedrock channel

Broadly two main types of bedrock channels have been identified in the geomorphological literature. Bedrock channel is developed in the mountain region in which an incision is required to maintain gradient of the channel and if the channel has a bed of alluvial then they are exposed and eroded at the time of high discharge event. At some places the channel bed contains alternating bedrock and alluvial beds (Montgomery et al., 2001).

The channel could become increasingly wide, keeping its depth and velocity constant or it could increase its velocity, keeping its depth and width constant (Leopold et al, .1964).The bedrock channels in high discharge or flood condition having a high depth and also the width and velocity. During the time of high discharge large boulders, gravel, pebbles suspended load is carried away. The coarser materials settle down on the bed and the finer material like fine sand and silt is deposited on the banks. This fine deposited material marks flood boundary.

Study area

Bedrock channel studies have been carried out in the Deccan plateau region because most of the rivers flow through the basaltic bedrock of lava flows belonging to the Deccan Traps. The rivers rise in Western Ghat and flow towards the East during which they dissect the plateau extensively.

In these bedrock channels, many small and large erosional as well as depositional features are identified. The formation of such features is related to different factors that affect the channel such as base- level change, tectonic activity, variation in lithology, channel width, flow velocity etc. For the present study the area of the lower reaches of Kas River has been selected (Fig:1). The gorge of Kas River is very narrow and long and contains a waterfall (knick) of 15 m height at the headward end of gorge. The objective of this paper is to document the geomorphology of the Kas River gorge, Therefore the study of such streams and the processes that affecting on the formation of the features like gorge, waterfall, preconditions of gorge elongation, widening, material

Global Journal of Engineering Science and Research Management

of gorge and their relationship is undertaken. Besides interesting geomorphic set up, exploration of such site is also important for better understanding of the fluvial processes and related features.

The lower reaches of the stream before confluence such as occurrence of alluvial deposits on one bank and presence of rocky bank on the other has attracted the attention towards the geomorphic analysis of bedrock channel of Kas River.

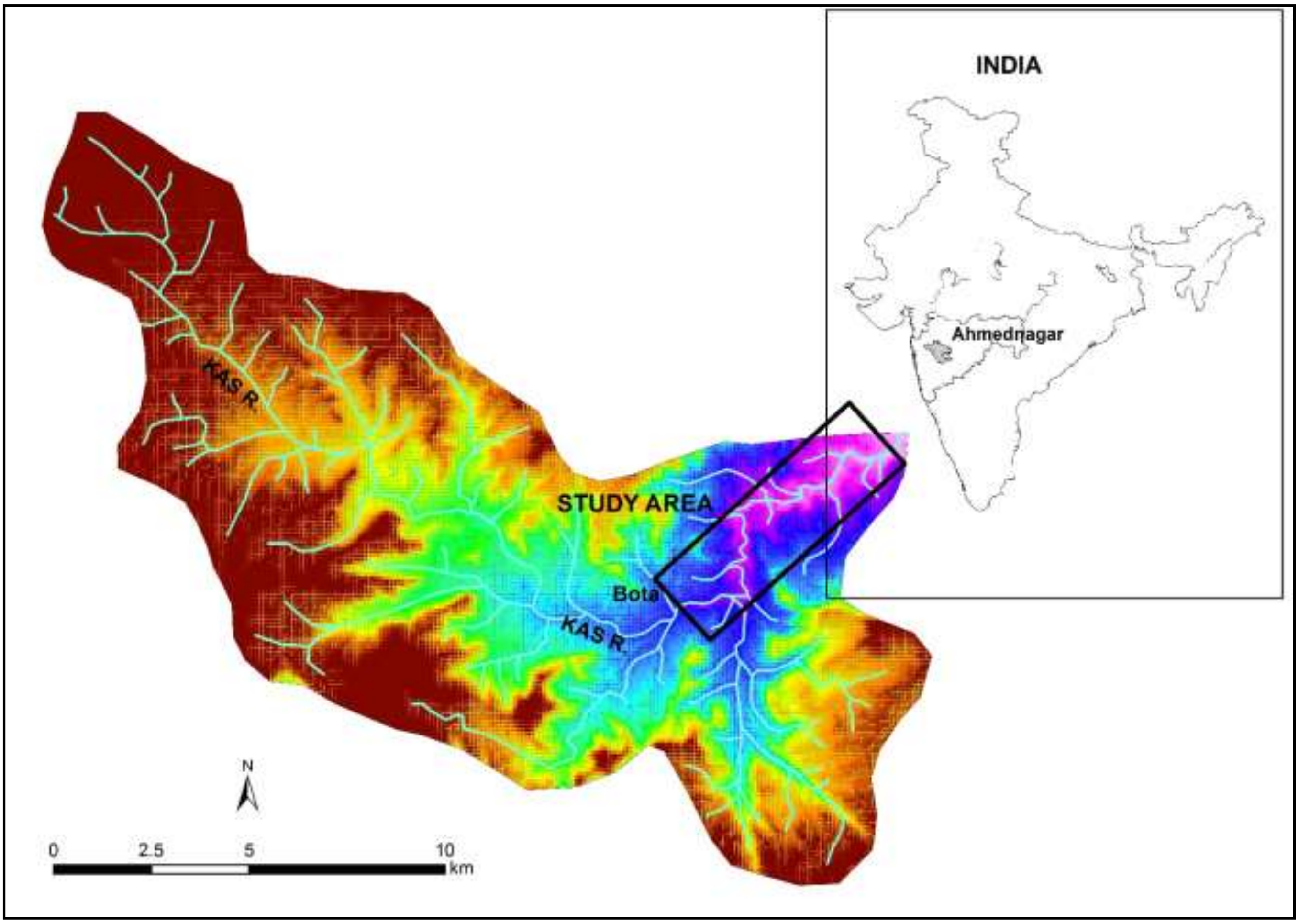


Figure 1. Location map of the study area

Physical set up of study area

The WesternGhat is a major water divide in western Maharashtra and sepeartes the eastward flowing rivers (Plateau rivers) from the westward flowing rivers (Konkan rivers). The Kas River is a six order tributary of Godavari River. Its source is near the Karandi village in Ahmednagar district in Western Ghat and crest area. It flows in upper reaches eastward and in lower reaches it turns to north direction and again it flows in eastward direction. The total length of Kas River is 35.25km (from source to confluence). The study area lies near to village Bota and on the administrative boundaries of Ahmednagar and Pune district. The study area falls in rain shadow zone of Western Ghat and it experiences semiarid climate conditions.

Geology

The study area is a part of upland Maharashtra which is part of Deccan Traps. On the basis of their physical characteristics the lava flows may be classified as massive compact basalt and amygdoloidal vesicular basalt. The massive basalt is black, bluish-black, brownish black or dark gray in colour. They are characteristically medium to fine grained with porphyritic texture (Uddin, 1984). Amygdoloidal basalt is vesicular in nature with or without minerals and quartz vesicles. In the lower reaches of Kas river, near the knick and in the gorge both compact and amygdoloidal basalt types are observed.

Lithology

Global Journal of Engineering Science and Research Management

The term lineament was first proposed by Hobb (1904) for the rectilinear features of the earth surface such as crest, ridges or boundaries of the elevated area, drainage lines and boundary lines of the petrographic rock types. Some of the lineaments in the western Maharashtra are also found in the Kas river basin.

The Deccan Traps consists predominantly of tholeiite lava flows intruded by dolerite dykes. The ~3.4 km thick volcanic pile exposed in the Western Ghats consists of lava -flows are of compound pahoehoe (Duraiswami et al. 2001, Bondre et al. 2004), slabby pahoehoe (Duraiswami et al. 2002), rubbly pahoehoe (Duraiswami et al. 2008) and aa types (Brown et al. 2011). The lava flows from the Kas River consists of compound pahoehoe flows and are intruded by numerous dykes. The dykes belong to the West Coast dyke swarms. Most dykes are hypabyssal (Auden 1949) but, recent interpretations consider that many of the dykes fed the flows (e.g. Bondre et al. 2006, Hooper and Widdowson, 2010, Vanderkluysen et al. 2011).The pahoehoe lava flows consists of lobes and sheets that consists of a basal pipe amygdale zone, a massive central core and a vesicular upper crust. The various units are exposed in the bed rock of the Kas River gorge.

Drainage

The Kas River is a 6 th order stream with a catchment area of about 185.28km2 and drainage density is 2.98, bifurcation ratio is 4.14 (Table 1). All these values suggest that the stream is draining over a uniform rock and there is no strong control of geology and structure.

Climate

This region falls in the semi-arid region of west central Maharashtra. The annual average rainfall in this area is 530 mm (Joshi, 1992).The temperature ranges from 10° C to 40°C during winter to summer season, generally the lowest temperature occur in month of November, December and April to June annual maximum temperatures are recorded (Uddin, 1984).

Table 1. Drainage basin and network morphometry in Kas River

Sr.No.	Drainage basin parameters	Values obtained
1.	Basin area (km) ^{2}	185.28
2.	Absolute relief (m)	1060
3.	Relative relief (m)	469
4.	Channel length (km)	35.25
5.	Dissection index (%)	55.75
6.	Order	6
7.	Drainage density km/km^2	2.98
8.	Bifurcation ratio	4.14
9.	Stream frequency No./km^2	5.48

Longitudinal profile

The longitudinal profile of a river channel extends from its source to its mouth/confluence. Ideally the longitudinal profile is smooth concave curve. According to Smith (1984), it is usually broken by knick points (as a result of past base level changes) at stretches of rapids, lakes, hard rock, bands etc. A smooth profile from source to mouth may indicate that the river has reached a state of grade, in which there is a balance between erosion and deposition. The river is then said to possess a graded long profile. In an area of hard bedrock vertical erosion may predominant, producing a steep sided narrow gorge and a lower value of hydraulic radius. The convexity of long profile can therefore be expected in an area where the river crosses hard bedrock. Convexity usually marks the site of knick i.e. rapids and waterfalls. The ultimate profile is a function of a number of factors, such as the lithology of the area through which the stream flows, discharge amount and texture of the channel load, flow resistance, flow velocity, width, depth of channel and regional slope (Kale, 1997). When in the downstream of the channel abrupt change or break in gradient occurs the break is associated with the waterfall, rapids, knick point and gorge.

The data for the longitudinal profile extracted from the SOI topographical map number 47 I/3 at 1:50000 scale. The distance from the source of stream up to the confluence is taken against the elevation. The profile has been prepared for main stream up to the confluence for the distance of 35.25 km. where Kas River meets to Mula River.

The basic data for elevation for the preparation of longitudinal profile is the contours. The contour interval at the scale of 1:50000 is 20 m. After that the channel bed, elevation plotted against the distance from source to confluence on the arithmetic graph paper. But it dose not indicate the much variation in the channel gradient. The curve indicates the very low gradient. Therefore, same as to earlier workers who have plotted data on semi- logarithmic scale, with distance on the logarithmic scale and elevation on arithmetic scale (fig: 2). this profile gives better detailed information about the channel gradient.

Global Journal of Engineering Science and Research Management

Hack (1957) defined the stream gradient index (SL), which has been widely used for the gradient over a distance. According to Hack wherever there is break on long profile, the stream gradient index is more that means there is a more commonly lithological or tectonic controls on the channel slope. For the Kas River the steam gradient index (SL) has been calculate to given by Hack (1957) following formula.

$$SL=h_1-h_2/\ (InL_2-InL_1)$$

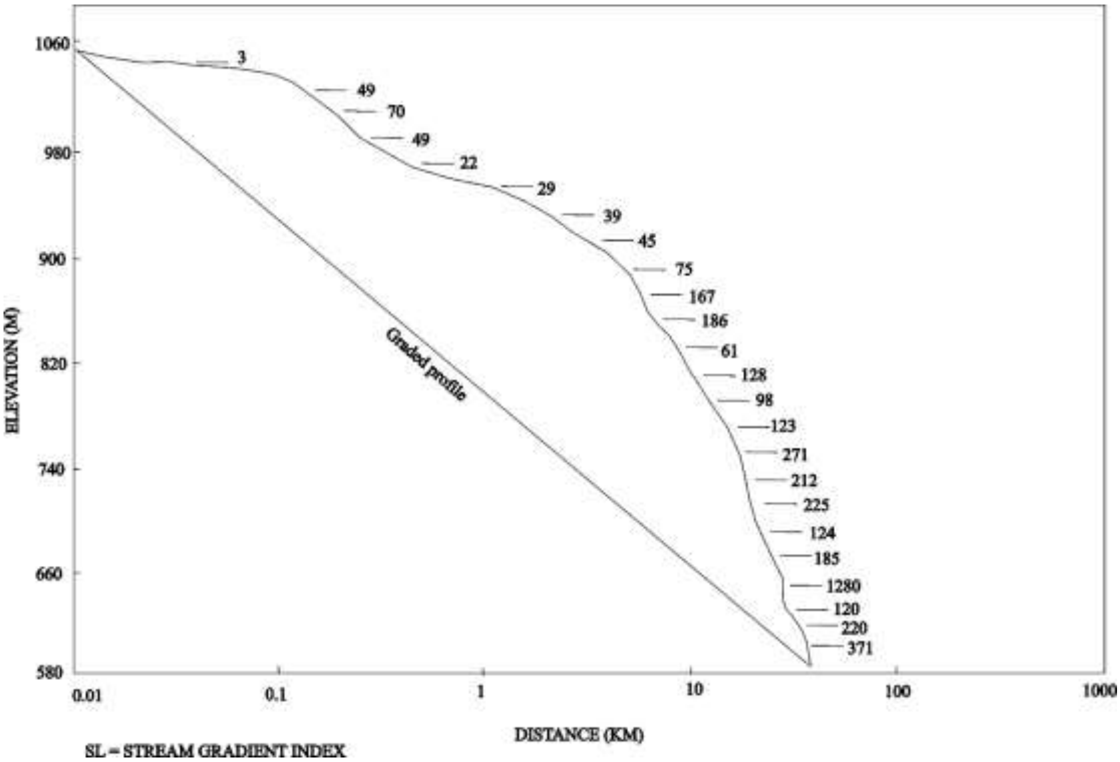
Where,

SL=Stream Gradient Index
h_1=Elevation of first point
h_2=Elevation of second point
L_1=Distance of first point from the source
L_2=Distance from the source of second point

The profile on semi-logarithmic graph shows overall convexity; indicating increase in the channel gradient in downstream and that implying the river is in the above-grade condition. Graded stream as one in which, over a period of years, slope is delicately adjusted to provide, with available discharge and with prevailing channel characteristics, just the velocity required for the transportation of the load supplied from the drainage basin.

The SL Index values range between 3 to 1280. The plot in (fig: 2) also shows the variation between the SL values by number of segments. From source to mouth SL Index values do not decrease downstream but showing variation with distance. In the source area the SL Index values are lower but in the middle and lower reaches SL Index values suddenly increase from 185 to 1280 (fig: 2).

This means that there is major break in the profile or steepning of the profile further downstream. In the lower reach the SL values increases 120 to 371. This indicates steepning of channel gradient is close to the confluence, SL value is 371. This profile clearly shows the disequilibria and erosion is the main process. The changed gradient studied from SL index has been confirmed after doing actual field survey. Change in level of thalweg before and after knick is 15m. This confirms the major break and it also indicates the lithological control on the bedrock channel.



Global Journal of Engineering Science and Research Management

Figure 2. Longitudinal Profile of the Kas River

Channel width

Channel width is an important parameter to understand the channel characteristics behavior of flow and the process operating. To understand the variations in channel width, cross sections were taken with the help of Theodolite survey in the lower reaches of Kas River gorge. For the detail information about the gorge and channel morphology, relation between litho logy and characteristics of bedrock channel, a detailed study of cross section was undertaken.

Throughout the study area mostly compact basalt and amygdaloidal vesicular basalt occurs. After the channel cross-section survey, the analysis of cross section plots were carried out. With the help of analysis it is confirmed that channel bed width is more in study area just before upstream the knick. After the knick in the downstream reaches channel bed becomes narrow. In this section channel width is bounded by gorge walls. When the cross-sections of upstream from the knick and lower stream from the knick are compared, it is found that the channel before knick is wider than the channel bed in the gorge (Table 2). The cross-sections for gorge reaches are also analyzed and compared to understand variation in channel width. After analysis it is found that the gorge has become wider in downstream areas. The gorge walls are of alluvium which may be one of the causes of gorge widening.

With the help of cross section that were taken in the gorge it is evident that the shape of the gorge is box type. This means that there was both vertical and lateral erosion. Vertical erosion is also dominated in the channel, implies that there is some control on lateral erosion. As we to lower reaches the channel becomes wider and wider. This is confirmed from the cross section. This means that there is also change in the litho logy that changes from basalt to alluvial material. It is observed that were the channel bed becomes wider depositional features like boulder bar, points bars occur. It may be due to the fall in the stream power. It means stream power decreased because of channel widening.

Table 2. Cross- sectional parameters along the Kas River

Cross-section No.	Distance from the source (km)	Channel Floor width (w)(meters.)	Channel depth (d) [b] (meters)	Form ratio (w/d)
C1	25.286	78	6.5	12
C2	25.294	53	5.7	9
C3	25.400	118	11.5	10
C4	25.410	36	15	2
C5	25.494	53	16.5	3
C6	25.566	71	9.5	7
C7	25.740	59	11.9	5
C8	25.899	58	15.3	4
C9	25.931	73	15	5
C10	26.137	97	14	7
C11	26.225	64	17	4
C12	26.560	150	17.2	9
C13	26.947	105	6.8	15
C14	27.577	140	13.5	10
C15	29.150	102	18.2	6
C16	29.900	55	14.3	4

[b] on the basis of actual survey

Channel parameters and their relationship

With the help of channel parameters and their relationship we can understand various aspects such as shape of the channel, channel depth, width and length. The relationship such as between channel aspects such as width and depth, distance and elevation, relation between distance and width, relation between distance and depth etc. (Fig. 3).

Fig No 4. Shows the relation between the distance and from ratio (width/depth). Form ratio means the ratio between channel width and channel depth. It shows that at the starting or close to gorge head, channel depth is increased. That means form ratio is more. As distance from knick has increase form ratio decreased. This indicates that with increasing distances the rate of increases in depth is more than rate of increase in width. This is due to the fact that there is change in litho logy in the lower reaches. It changes from basalt to alluvium. A significant variation in elevation is also observed in the field and it is confirmed after getting positive correlation that is 0.2389 means width increases as distance increases in lower reaches.

Global Journal of Engineering Science and Research Management

In other correlation matrix between increasing distance and the channel depth also correlation is positive. This means that as the distance is increases depth also increase.

There is positive correlation between the distance from the source and the width, which is r = 0.2389.

Where,

$$y = -70.364 + 5.7698x$$

This correlation shows that as a distance from the source increases the width also increases (fig.5 A)

There is positive correlation between the distance from the source and the depth, which is r = 0.3512.

Where,

$$y = -13.864 + 1.071x$$

This correlation shows that as the distance from the source increase, the depth in the lower reaches also increases (fig.5 B)

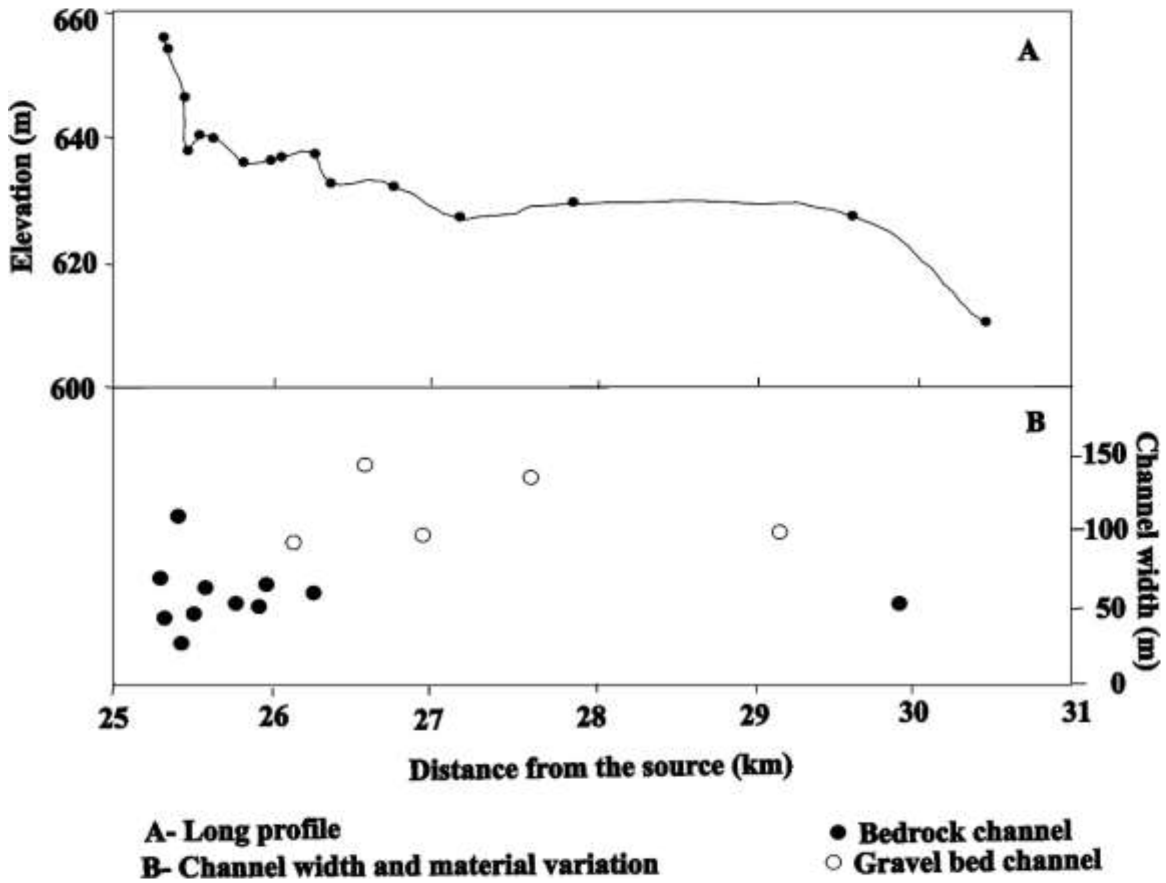


Figure 3. Long profile, channel width and material variation

Global Journal of Engineering Science and Research Management

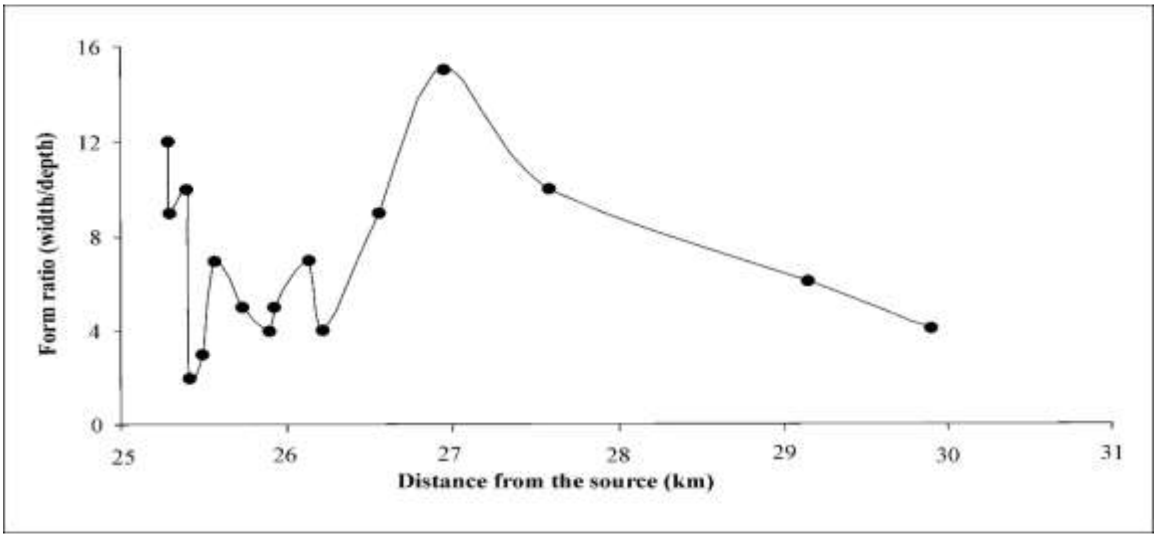


Figure 4. Form ratio of the Kas River channel in the study area.

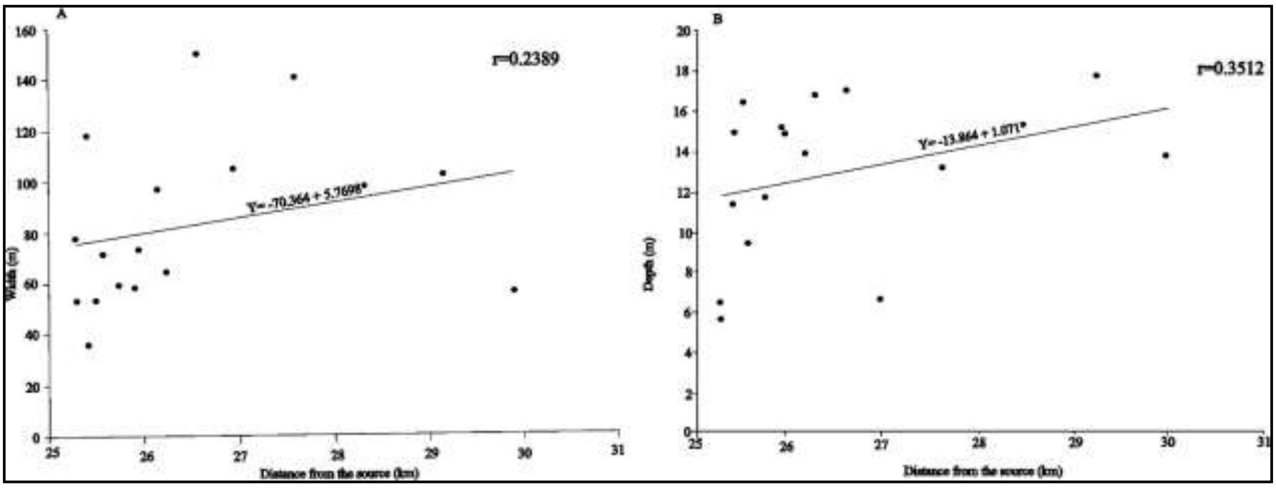


Figure 5. Correlation between the distance from the source and width and depth

Geomorphic mapping

"Geomorphic mapping means by which geomorphological characteristics and features of any area are recorded on a map". For the detail study of bed rock channel it is necessary to study the geomorphic feature present in study area. For the study area of Kas river gorge and channel in lower reaches by the using standard geomorphic symbol a geomorphic maps were prepared. Number of cross-sections are taken in the lower reaches these are used to know the shape of the channel and gorge.

From these cross-sections it is clear that the channel in basalt is wider above the knick (fig: 6). beside wider channel, scabland topography is also observed. The scabland topography shows grooves, potholes, and inner channel. Potholes are merged. Deep gorge starts after cross section 3 that is cross-section at knick. Gorge walls are vertical and well developed these are carved in basalt. In the longitudinal profile major break represents the location of water fall (15 m) and below this deep plunge pool occurs. The shape of the gorge is a box type. In gorge the bed material is of depositional in nature. Fig. 6 shows features like point bar, bolder berm, pot holes, sand deposit, calcareous rock, pools are present in the gorge bed, and gorge bed is flat and less gradient. Bedrock is exposed in patches on the channel floor, particularly in the vicinity of large pools, some time deposits of gravel are observed in the channel (Table: 3).In the study area after the narrow gorge, channel width increases because lithology changes in lower reaches. In downward segments on either bank alluvial deposits are observed. Lower reaches channel is meandering (Fig: 7) and there are two tight meanders before the confluence.

Global Journal of Engineering Science and Research Management

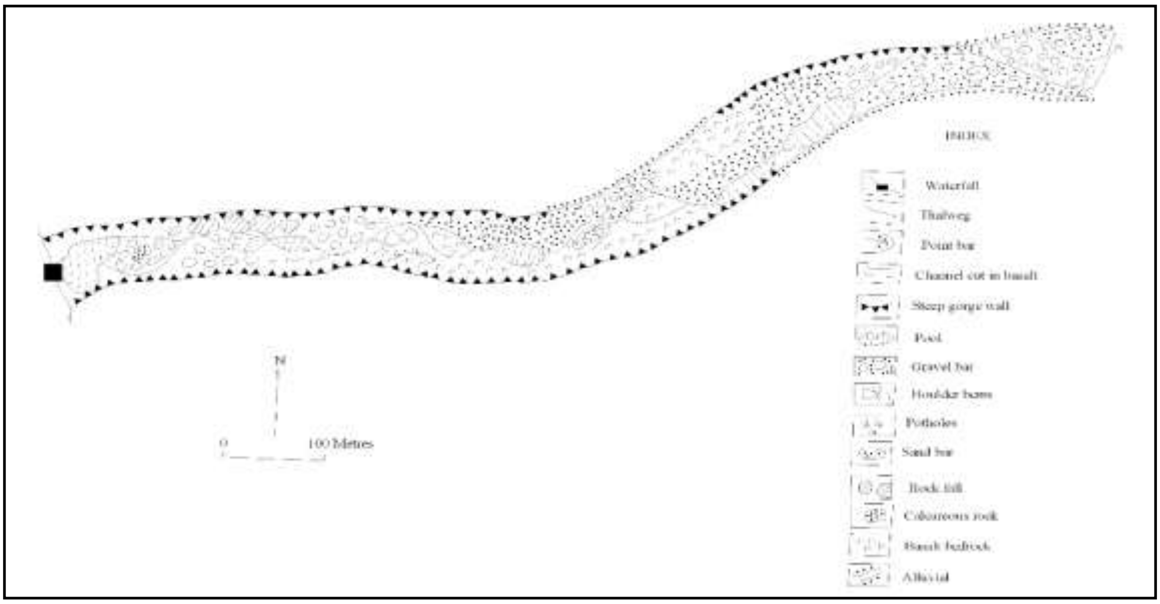


Figure: 6 geomorphic map of the Kas River channel.

Global Journal of Engineering Science and Research Management

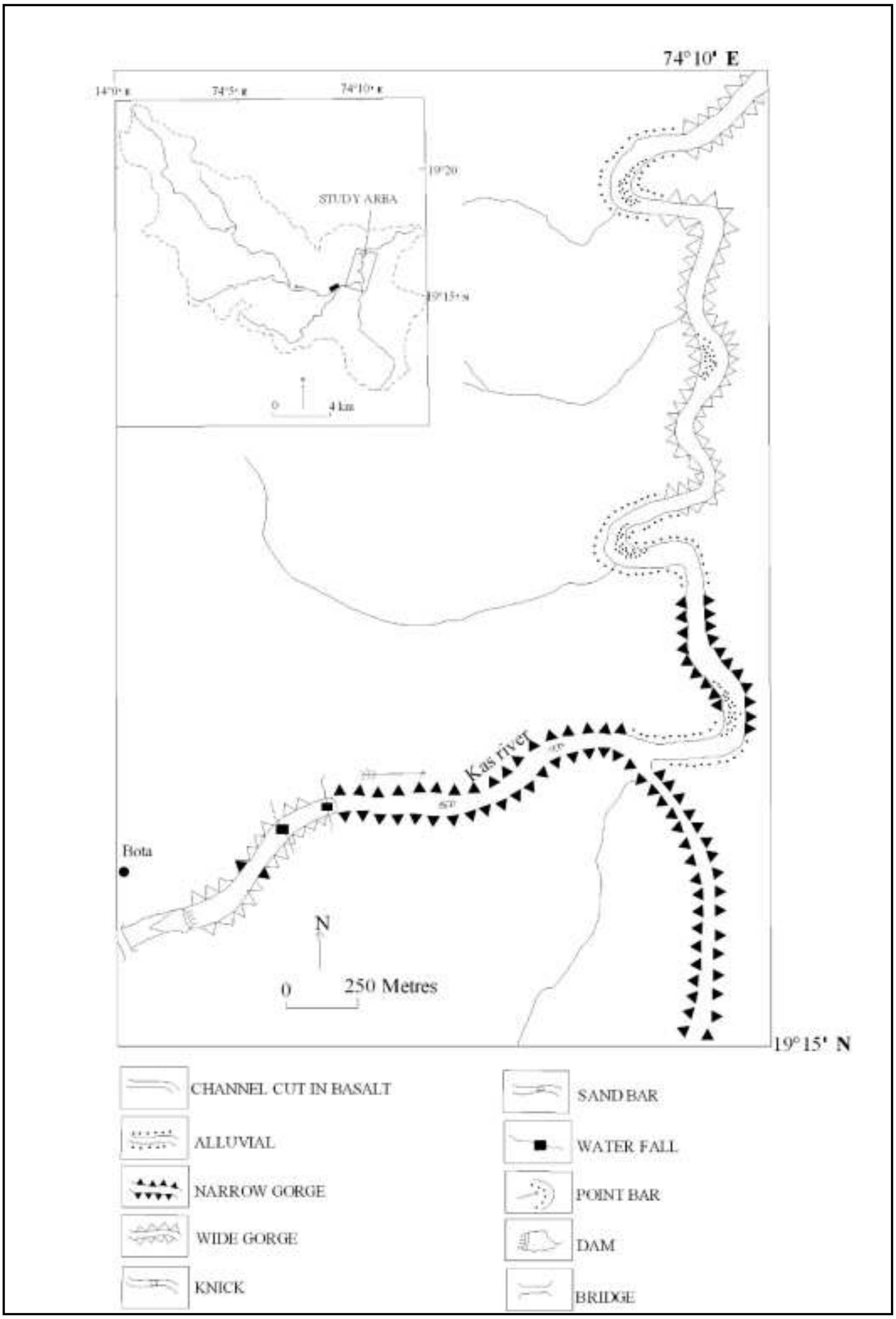


Figure 7. Geomorphic map of the Kas River Gorge

Table 3. Nature of channel bed and geomorphic features at cross-sections

Global Journal of Engineering Science and Research Management

Cross-section no.	Dominant channel bed characteristic	Geomorphic features
C1	Bedrock	Wide gorge, terrace, grooves
C2	Bedrock	Wide gorge, plunge pool, waterfall, potholes
C3	Bedrock	Waterfall, potholes, grooves, inner channel
C4	Bedrock	Narrow gorge, plunge pool
C5	Bedrock	Narrow gorge
C6	Bedrock	Narrow gorge, terrace
C7	Bedrock	Narrow gorge, sand bar
C8	Bedrock	Narrow gorge
C9	Bedrock	Narrow gorge
C10	Coarse gravel	Wide gorge
C11	Bedrock	Narrow gorge
C12	Coarse gravel	Boulder bar, sand bar
C13	Coarse gravel	Gravel bar
C14	Coarse gravel	Tight meander channel, point bar
C15	Coarse gravel	Gravel bar
C16	Bedrock	Tight meander channel, point bar

Knick point

The long profiles of the river indicate smooth curve that of elevation and gradient this trend is interrupted and an abrupt change in gradient is observed. This break, known as a knick or nick point this develop because of the appearance of resistant bedrock or may be created lowering of base level or uplift of land (Kale, 2001).

In the lower reaches river adjust to new conditions caused by knick. In this portion of adjustment the river erodes very slowly headwards due to those rapids and waterfalls are also found in lower reaches of river.

In case of Kas River the knick point is present in the lower reaches, river channel has eroded the bedrock as well as alluvium. The evidence of headward erosion is presence of the knick point. The Kas River gradient suddenly changes near the Bota village. This knick point is of the 15 meter waterfall. Other features near the knick are number of potholes, inner channel and polished surface, merged potholes. Rapid/ faster potholes formation the collapse and merging of walls of potholes leads to elongation and groove formation. Near the knick these erosional processes are dominant. It may be because at one point of time in the past, there must have been sudden increase in the energy level of stream. It would have increase the intensity of erosional processes.

In the vicinity of waterfall or knick in upstream part, number of cracks and joints are observed in the rocks. These joints and cracks are weaker. Slight increase in stream energy may cause widening of cracks and joints and collapse of boulder in the channels, and finally in the plunge pool through waterfall.

Gorge morphology

If the rate of incision exceeds the rate of slope denudation, gorges are produced. The width of gorge is equal to the width of the channel. Due to the vertical incision in the bedrock and also the contribution of potholes and grooves in the incision processes, the formation of inner channel continues and ultimately developed in a deep narrow gorge. Erosional behavior of the jointed basalt induced many differences in the details of the erosional forms. The observed Kas River gorge has parallel bank walls and it also has box shape. The gorge is narrow and deep.

The study of gorge of Kas River was carried out to understand morphology and various related processes. The lithology in present area is mainly of amygdoloidal vesicular basalt, compact basalt and occasionally of soft rocks. These soft rocks are mainly formed due to the accumulation of calcium carbonate due to seepage in the gaps between two strata. There are different strata identified in the gorge wall. The topmost strata are amygdaloidal vesicular basalt (Uddin, 1984). Beneath those middle strata is of gray colored compact basalt. The lower most strata are of softer calcareous rock. The gorge widening also take place because of removal of this softer rock and collapse of overlying hard basalt rocks. These rocks are separated along weaker zone of cracks and joints. Spring sapping is another process observed along the base of gorge wall. Besides lateral erosion these processes also lead to gorge widening.

Elongation of gorge takes place due to headward recession of the knick. This action is triggered by the undermining of softer rock present at the base/ foot of knick. Other minor features like rapids, inner channel, grooves, potholes, merging of potholes and formation of natural bridges, flute marks etc. are present in upstream area of the knick. In gorge bed embryo potholes and deposition of alluvium, debris depositions of gorge wall collapse etc. features are observed.

Global Journal of Engineering Science and Research Management

The incised tight meanders

Low to moderate sinuosity, the increase in sediment load caused by the deposition on the point bar on the inner bank and thus the meander channel has to increase its meander length for uniform distribution of energy (Leopold et al., 1964: Kale and Gupta, 2001).

If a river has meander and its bank are highly resistant to erosion, down cutting would predominate and the meanders may become incised. The river may be approaching to a graded state, vertical erosion is limited. The available energy is used to do lateral erosion in the channel. It means river had very little time to straighten its channel. The incised meander is, thus an evidence of rejuvenation (Thornbury, 1984). Other evidence is the higher elevation of the outer bank and this is resulted because of angular momentum and centrifugal force that is generated because of the moving water and level of water is high on concave bank. When water moves through it along the outer bank, because of centrifugal force river experiences rise in water level. This causes more erosion along the outer bank and channel sinuosity increases (fig: 6).

Discussion

The characteristics of the longitudinal profile of the Kas River and various type of features in the lower reaches and in the gorge are discussed.

The stream gradient of the Kas River is not smooth and typically concave but it is convex in shape the upper segment of river is with low gradient but in downstream reaches steepness is high because of the major breaks or Knicks. The change in stream gradient index (SL) calculated for the entire river channel shows the enormous changes in the (SL values) for downstream reaches of the river. The stream gradient index of the river increases to the downstream but it decreases after knick location. This value is extremely low in the upper segment but in the downstream reaches especially in middle reach this is high. It indicates the control of tectonics or the lithology on channel gradient. The SL values characterize the river 'above grade condition' and erosion is the dominant process. The cross-section above the upstream knick shows very wide channel and in the gorge means downstream to the knick, width suddenly decreases and depth increases. Further downstream lower reaches width also increases due to the change in lithology that is from hard bedrock to alluvium. The alluvium is partially consolidated at some places. The litho section in the gorge is indicating that the high-energy deposits are there along the banks that means there were high discharges and available energy was more. Different type of geomorphic features (erosional and depositional) are observed and mapped, which indicate that the velocity of discharge is higher in the upstream gorge section and it is decreased in downstream gorge section. The tight meanders are remarkable features in the lower reaches of the Kas River. Which indicates that on the outer bank of meander the stream energy is concentrated and incision is observed.

In the downstream reaches the process of channel incision is associated with formation and deepening of gorge. It is also responsible for development of knick in the form of waterfall. In the vicinity of the waterfall on upstream side grooves, potholes and inner channel are formed. These grooves and widened potholes caused widening of inner channel this leads to headword elongation of gorge. Rock types are varying vertically like amygdaloidal vesicular basalt is overlying compact basalt. These strata are underlain by soft calcareous rock. This change in rock strata promotes deepening and widening of gorge. The weaker zones across channel and in the rocks promote bed rock channel incision, and widening of gorge.

Acknowledgements

The authors are thankful to Dr. Suchitra Pardeshi supporting during this research. Authors are also thankful Mr. Hemant Sabale, Mr. Mahendra Korade and Mr. Samir Lende for the carring the survey during fieldwork.

References

1. *Auden JB (1949) Dykes in western India: a discussion of their relationship with the Deccan Traps. Trans Nat Inst Sci Ind 3:123-157*
2. *Bondre NR, Duraiswami RA, Dole G (2004) Morphology and emplacement of flows from the Deccan Volcanic Province, India. Bull Volcanol 66:29-45*
3. *Bondre NR, Hart WK, Sheth HC (2006) Geology and geochemistry of the Sangamner mafic dike swarm, western Deccan volcanic province, India: Implications for regional stratigraphy. J Geol. 114:155-170*
4. *Brown RJ, Blake S, Bondre NR, Phadnis VM, Self S (2011) 'A'a Lavas in the Deccan Volcanic Province, India and their significance for the nature of Continental Flood Basalt Eruptions. Bull Volcanol 73:737-752*
5. *Duraiswami RA, Bondre NR, Dole G, Phadnis VM, Kale VS (2001) Tumuli and associated features from the western Deccan Volcanic Province, India. Bull Volcanol 63:435-442*
6. *Duraiswami RA, Bondre NR, Managave S (2008) Morphology of rubbly pahoehoe (simple) flows from the Deccan Volcanic Province: implications for style of emplacement. J Volcanol Geotherm Res 177:822-836*
7. *Duraiswami RA, Dole G, Bondre NR (2002) Slabby pahoehoe from the western Deccan volcanic province: evidence for incipient pahoehoe-aa transitions. J Volcanol Geotherm Res 121:195-217*

Global Journal of Engineering Science and Research Management

8. *Finnegan N. J. and Montgomery R. D. (2005): Controls on the channel width of rivers: Implication for modeling fluvial incision of bedrock, Geological society of America, v.33; pp.229-232.*
9. *Hack JT. (1957). Studies of longitudinal stream profiles in Virginia and Maryland. U.S. Geological Survey Professional Paper 294-B: 45–97.*
10. *Hooper PR, Widdowson M (2010) West Coast dike-flow correlation and the timing of the final phases of the Deccan Flood Basalt Province, India. In: Origin and evolution of the Deep Continental Crust (eds.) NR Karmalkar, RA Duraiswami, NJ Pawar and Ch Sivaji, Narosa Publishing House, New Delhi, 173-186*
11. *Joshi V. (1992): Late quaternary colluvial stratigraphy, morphology and associated geomorphic features, in the foothill zones of western upland Maharashtra, unpublished Ph.D. thesis, University of Pune.*
12. *Kale V. S. and Nagarale V. (1997): Lithological control on the channel morphology of the upper Tapi River, Madhypradesh, Indian journal of Geomorphology, v.2; pp.159-167.*
13. *Kale V.S. and Gupta A. (2001): Introduction to Geomorphology, Orient Longman, Kolkata.pp. 98,122.*
14. *Leopold L.B. Wolman M.G. and Miller J. P. (1964): Fluvial process in Geomorphology, W. H. Freeman and co. San Francisco, pp. 250-258.*
15. *Montgomery R. D. and Gran K. B. (2001): Downstream variations in the width of bedrock channels. Water resources research, v.37; pp. 1841-1846.*
16. *Richerds K. (1987): River Channels Environment and Processes, Basil Blackwell Ltd. Oxford, pp. 69-72.*
17. *Smith J. (1984): Dictionary of Geography, Arnold publications, New Delhi; pp.146.*
18. *Thornbury W. D. (1984): Principles of Geomorphology, Wiley eastern Limited, pp.110.*
19. *Uddin M. R. (1984): The natural environment of Pravara river basin and its impact on land utilization. Unpublished Ph.D. thesis, University of Pune, pp. 8, 18, 47.*
20. *Vanderkluysen L, Mahoney JJ, Hooper PR, Sheth HC, Ray R (2011) the feeder system of the Deccan Traps (India): Insights from dike geochemistry. J Petrol 52:315-343*