Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 11, Issue, 06, pp.5005-5017, June, 2019

DOI: https://doi.org/10.24941/ijcr.35476.06.2019

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

ANALYSIS OF RIVER LONG PROFILE AND HYDRAULIC GEOMETRY TO EVALUATE THE PRESENT SCENARIO OF KULIK RIVER, INDIA AND BANGLADESH

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ARTICLE INFO

Article History:
Received 25th March, 2019
Received in revised form
13th April, 2019
Accepted 18th May, 2019
Published online 30th June, 2019

Keywords:
Long Profile,
Hydraulic Geometry,
Regarded Profile, Thalweg.

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ABSTRACT

The river long profile analysis has been studied over the past several decades to decode the nature of river. The morphology of a river channel is the resultant effect of the interactions among a number of factors. Mainly lithology, slope, hydraulic characteristics like width, depth, velocity, sediment present in the fluid, *etc*. control the morphology of a river channel which in turn effect the mechanics of flow. Erosion, transportation and deposition shape the long profile as well as the cross profile. Meandering river in flood plain oscillates due to alternate erosion and deposition. Thalweg points shift over time and space. River energy gradient varies thought out the channel and finally the river tends to erosion or deposition prone or stable or unstable. The migration of meander is a common phenomenon of alluvial river and is capable to affect the long profile and hydraulic geometry which in turn controls the fold plain evolution. This paper presents a detail account of long profiles and hydraulic geometry to evaluate the present scenario of the Kulik River.

Citation: ***Dr. Rumki Sarkar, Biswajit Das and Ganesh Biswas,* 2019.** "Analysis of River Long Profile and Hydraulic Geometry to Evaluate the Present Scenario of Kulik River, India and Bangladesh", *International Journal of Current Research*, 11, (06), 5004-5017.

INTRODUCTION

A good number of valuable, innovative research was made by the fluvial geomorphologists, geologists and river engineers[2,3,6,10-12,15,16,18,19,23,24]. River long profiles are alaysed in several ways and their significance too. Basic equations on hydraulic geometry put forward the river research in various directions. The river long profile is capable to give clues on the climatic and lithological set up of a region, besides it express the evolutionary history of the river channel. River energy how does change over time can be assessed by analysing the long profile and hydraulic geometry. In this study how does the river long profile, adjusting by homeostasis principle to maintain its flow has been observed.

Geomorphic setting of Kulik river basin: The Kulik river basin covers parts of two nations: the northern part of West Bengal, India and western part of Bangladesh (Fig. 1). The length of the river is 131km out of which from the source to almost 50km falls in Bangladesh and the rest of the part in India. The river basin is located in Ganga-Kosi-Tista flood plain of Quaternary deposits, receives monsoon rainfall (Fig. 2, Table 1). Two third of the basin area comes under the state of West Bengal, India.

Objectives

The major objectives of the present work are as follows:

- To analyse the hydraulic geometry of the river
- To analyse the evolution of long profile
- To find out the Energy relation and head loss
- To identify present scenario of the river channel

Approach, Database and Limitations

River long profile and Hydraulic geometry analysis: an overview: Long profile is defined and analysed by a good number of authors. Long profile is used to analyse different types of channel like straight to meander[4,6,813,18,24]. In general, long profile is concave to the sky, but different shapes of long profiles are observed depending upon different climatic and physiographic location. It is clearly mentioned by Morisawa that 'aggradation in upstream in order to steepen its gradient and increase its velocity to become more competent' and such profile is named as 'Regraded profile'[5,7,19,20]. To evaluate the different scenarios that represent the present scenario of the river channel long profile for the last fifteen years has been considered. Hydraulic geometry like width, depth, velocity, To analyse the hydraulic relation among variable power law equations introduced by Knighton, Heede and Morisawa are applied[9,10,19,21]. Hydraulic geometry of the stream channel is analysed by using the equations proposed by Leopold and Maddock[1,14,19].

Equations used are as follows:

$$Q= wdv \quad (1)$$

$$w = aQ^b \quad (2)$$

$$d= cQ^f \quad (3)$$

$$v = kQ^m \quad (4)$$

Where Q is discharge, w is width, d is depth and v is velocity and

w d v = Q ; b+f+m = 1 ; a c k = 1

Besides these, width and velocity relation is also expressed

$$v=aQ^b \quad (5)$$

Bernoulli Energy equation has been adapted to compute the energy gradient..

$$H=d+z+v^2/(2g) \quad (6)$$

Heede and Morisawa during 1972 found strong reflection of bank material on *b, f* and *m* (Morisawa, p.76).

Database and limitations: The Google earth Landsat satellite images have been used to present the long profiles from the year of 2004 to 2019. The Water current meter has been used to measure the river water velocity. Velocity data are collected during pre-monsoon (January – February, 2019) season. The velocity has been recorded along the cross section and from the surface towards the bed. For a single station on an average 8 to 10 times data was acquired from the field. Flow cross-sectional data like depth, width are taken by using Auto level. The major limitation of this work is the velocity of the river was not taken in the upstream portion which falls in Bangladesh.

Calculation and Analysis: Calculated results derived from the equations are

From equation (2)

$w = 20.399Q^{0.293}$

From equation (3)

$d = 0.2733Q^{0.8104}$

From equation (4)

$v = 0.1794Q^{-0.103}$

since w d v = Q; relation among exponents b+f+m = 1 ; relation among threshold, a c k = 1. Hydraulic geometry exponents can distinguish the channel pattern[3,19]. The results reveal that an increase in discharge will lead both to an increase in width and depth, and decrease in velocity.

Higher *b* and lower *m* indicates the meandering nature of the river channel. The ratio of *b/f* , 0.3615 indicates the same. Lower *m* (-0.103) indicates that the river bank and bed are not resistant (lithology: sand and silt alternated layer). If *m* would large like 0.7 (Morisawa quoted Kninhton, where *m* ranges from 0.24 to 0.71*)* then calculated velocity would be 1.74 times more[19]. Therefore, calculated *m* depicts less resistant lithology and bank erosion enhances the oscillating nature of the channel. Higher *b* (0.293) indicates erodible nature of the bank. The result, *f>b* indicates form ratio (w/d) decreases with increasing discharge, and the bed is less resistant and eroded. As consequent channel becomes comparatively deeper with ability to transport the load. The changes in trend lines of long profiles show that the channel slope is slightly steeper than past (Fig. 22). Thus, the sequence of calculated exponents *i.e. f>b>m* reveals the less cohesiveness of bank material and bank retreat and shifting of the channel by an alternated thalweg and point bar in its planimetric profile. High SI values also are indicating that the meandering channel (Table 2). A series of cut-offs in the meander belt in the field also are the evidence of oscillating channel. The present channel shows *m<f*, which finally depicts decreasing trend of competence and capability. It is also to be mentioned that, *m<f/2*, indicates Froude number decreases with increasing discharge and flow remain subcritical with low sediment transport capability (Table 3).

It is observed that, *m* (-0.103) is very less than *b+f* ,(1.1), which indicates again the same, *i.e.* the channel materials are erodible or less resistant (due to sand- silt alternated layer in flood plain) and also indicates that with increasing discharge channel adjusting by changing channel size (width , depth ratio). To analyse the Kulik river hydraulic properties and the interrelation among variables a series of regression are calculated (Fig. 3-8). Discharge increases towards confluence and slope reduces in the same direction (Fig. 6 & 7).Generally the width increases faster than depth. If, Q is 2 m^3s^{-1}, then calculated w = 22.9739, d= 0.34822 and *w/d* will be 65.97 which indicate the rapid increase in width than depth which in turn reveals the non-cohesive lithology. Width and velocity inversely related and correlation is -0.61.

From equation (5),

$v = 9.8032w^{-1.276}$

The result indicates the inverse relation between width and velocity, *e.g.* if the maximum width *w*1, (34m) and minimum width *w*2, (20m) can be considered then expected *v1*and *v2* will be 0.11 ms-1 and 0.22ms-1 respectively (Fig.8).

Rate of change: ((v2-v1)/v2)*100 = 49%

Therefore, it can be stated that, due to the increase of width by 70% from source (51km from source) to confluence direction velocity falls by 49%. Width and amplitude show a positive relation (A=5.483 w+75.99) if minimum width (w1) is 13 and maximum width (w2) is 34 then the calculated amplitude will be 147.2 and 262.4 respectively. There for due to increase of width by 21, amplitude increase 115 in 2 metre, which means a 1 metre increase in width can enhance an increase by 5 metre.

Energy relation, head loss due to friction and long profile: Stream power is 84.3296 Wm^{-1}indicates that at this rate potential energy is converted to kinetic and heat energy along each metre of the channel length.

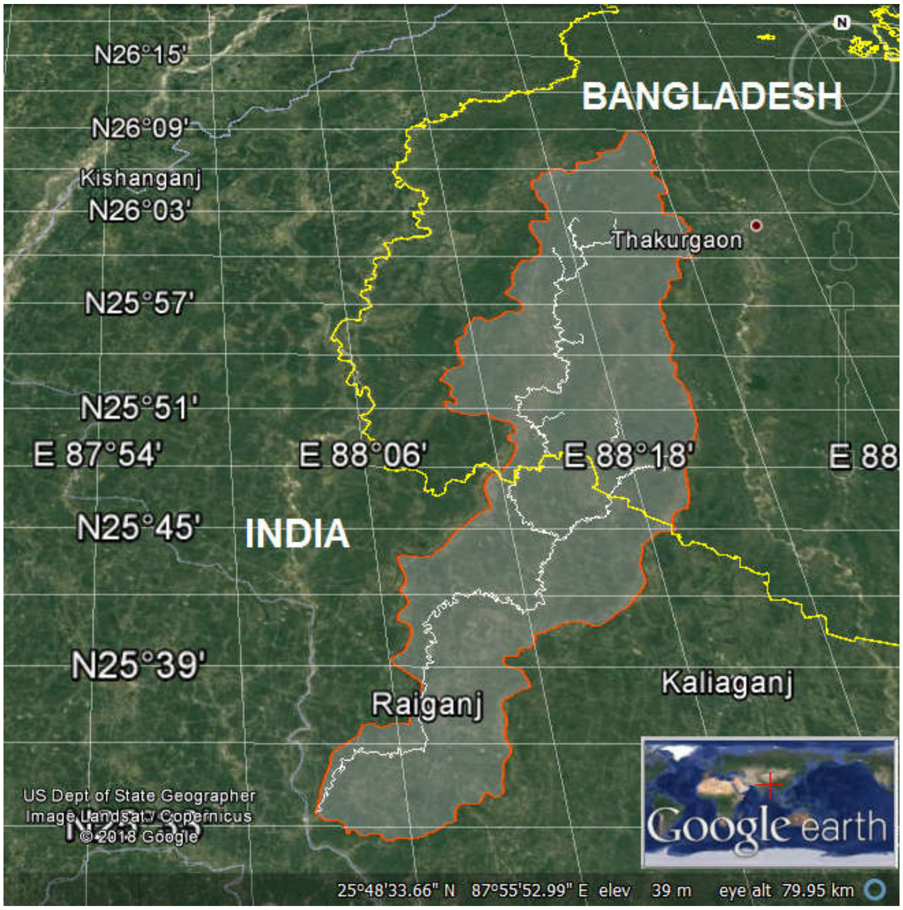

N26°15'
N26°09'
Kishanganj
N26°03'
N25°57'
N25°51'
E 87°54'
E 88°06'
E 88°18'
E 88
N25°45'
INDIA
N25°39'
BANGLADESH
Thakurgaon
Raiganj
Kaliaganj
US Dept of State Geographer
Image Landsat / Copernicus
© 2018 Google
Google earth
25°48'33.66" N 87°55'52.99" E elev 39 m eye alt 79.95 km

Fig. 1.

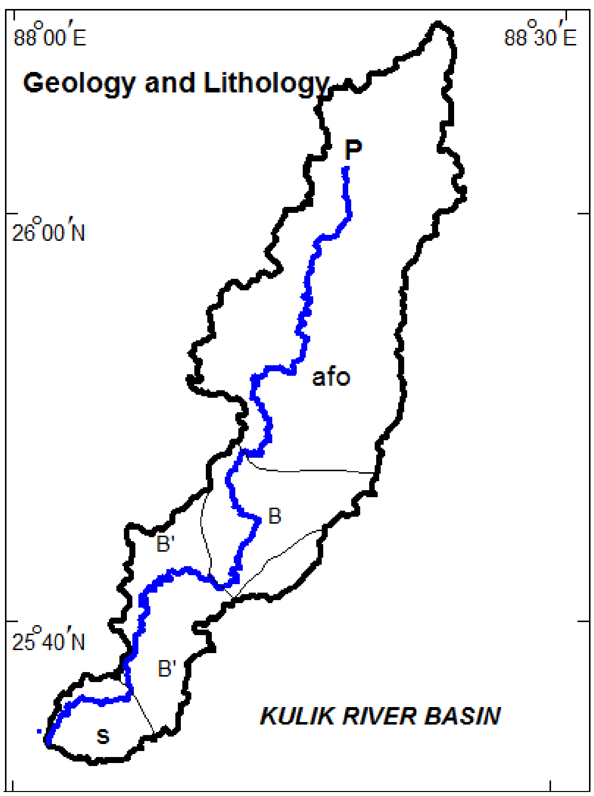

88°00′E
88°30′E
Geology and Lithology
P
26°00′N
afo
B
B'
B'
25°40′N
S
KULIK RIVER BASIN

Fig. 2.

Table 1.

Symbol	Lithology	Geological Unit	Geomorphological Unit	Soil	Age
P	Alternating sand, silt and clay	Present day deposition	Recent flood plain	Entisol	Holocene
S	Alternating sand, silt and clay	Shaugaon formation	Older flood plain(Fluvial facies)	Entisol	
B’	Alternating sand,silt and clay	Malda formation	Older flood plain(Fluvial facies)	Inceptisol	
B	Predominantly coarse to fine sand alternating with silty sand	Baikunthapur formation	Dissected piedmont	Black prairie soil	Late Pleistocene to early holocene
afo	Old gravelly sand	--	Alluvial fan deposits	--	Holocene

Source: Geological Survey of India, Kolkata & Geological Survey of Bangladesh, Bangladesh

Table 2. Relation among different hydraulic parameters

			Distance and Elevation				
Sl no.	Range of distance In km	Slope in Ratio	a	b	r	R^2	Remarks
1	0 to 10	0.005	55.55	-0.0005091	-0.94	0.89	Deposition
2	11 to 20	0.005	49.49	-0.0003758	-0.70	0.49	Deposition
3	21 to 30	0.005	47.02	-0.0004485	-0.80	0.64	Erosion
4	31 to 40	0.008	44.58	-0.0002848	-0.38	0.15	Deposition
5	41 to 50	0.002	40.51	-0.000091	-0.31	0.10	Erosion
6	51 to 60	0.004	38.65	-0.000012	-0.03	0.00	Balance
7	61 to 70	0.002	36.82	-0.0001818	-0.67	0.45	Balance
8	71 to 80	0.003	35.93	-0.0001394	-0.40	0.16	Balance
9	81 to 90	0.002	32.98	-0.00002	-0.06	0.00	Erosion
10	91 to 100	0.002	32.80	0.00000	0.00	0.00	Balance
11	101 to 110	0.006	35.13	-0.0005394	-0.79	0.63	Deposition
12	111 to 120	0.003	31.18	-0.0002848	-0.87	0.75	Erosion
13	121 to 132	0.002	29.50	-0.00003	-0.11	0.01	Erosion

Sl no.	Channel Width(W)/Amplitude	Width/Depth Ratio	Width/Wave length	Froude No	Average meander wavelength	SI	Remarks
1					231.17	1.388889	
2					257.69	1.474926	
3					297.87	1.72117	
4					293.85	1.77305	
5					339.77	1.858736	
6	0.3248896	116.50	0.3463544	0.15472	430.44	1.848429	Gravitational force dominant, Subcritical flow, meandering river. No erosion or deposition
7		46.10		0.141928	433.25	1.805054	Gravitational force dominant,
8		130.98		0.129491	450.49	1.953125	
9		36.46		0.082795	439.88	2.202643	
10		26.84		0.056759	373.99	2.227171	
11		42.04		0.049041	300.63	1.470588	
12		34.03		0.027954	310.42	1.633987	
13		50.34		0.042725	290.83	1.219512	

Table 3. Calculation of velocity, discharge and energy

Reference table for points				
Sl no.	Latitude	Longitude	Elevation from datum (m)	Distance from source in Km
1	25°44′30.93”N	88°13′53.45”E	34.7267	TRIBUTARY
2	25°47′4.93”N	88°12′25.06”E	36.7940	58.1
3	25°44′ 29.44”N	88°13′50.40”E	33.6700	68.1
4	25°44′31.73”N	88°13′51.82”E	33.7071	68
5	25°41′58.45”N	88°12′30.1”E	34.7744	75.9
6	25°42′03.39”N	88°10′27.84”E	32.7671	85
7	25°41′40.45”N	88°08′55.42”E	33.3856	89.8
8	25°40′32.09”N	88°07′52.51”E	31.1914	95.9
9	25°35′43.65”N	88°06′50.24”E	30.2817	109
10	25°34′38.77”N	88°03′18.27”E	29.1009	119
11	25°33′29.63”N	88°02′31.70”E	28.3167	132

Sl no.	Width in m	Average depth in m	Average Velocity (ms^{-1})			Discharge (Q) m^3s^{-1} Equation(1)
			Near Surface	Near bottom	Average	
1	5	0.273333333	0.777777778	0.466666667	0.622222223	0.85037
2	24	0.206	0.318253968	0	0.159126984	0.78672
3	19.7	0.33	0.59047619	0.2	0.395238095	2.56944
4	13.5	0.292857143	0.48	0.216559715	0.348279858	1.37695
5	21.8	0.225555556	0.452380952	0.193297279	0.322839116	1.58744
6	30.5	0.232862376	0.19047619	0.328100471	0.259288331	1.84154
7	22.4	0.614444444	0.154761905	0.097022513	0.125892209	1.73272
8	21.7	0.808571429	0.076190476	0.083666224	0.07992835	1.40242
9	30.2	0.71833333	0.1591	0.1013	0.1302	2.82452
10	30.6	0.899090909	0.098336386	0.069334652	0.083835519	2.30650
11	34.4	0.6833333	0.125462963	0.065135328	0.095299146	2.24017

sl no.	Elevation head (z)	Depth (d)	KE ($v^2/2g$)	Energy , TH (z +d + KE)	Energy gradient, Eq. (6)
1	Tributary	-	-	-	-
2	36.794	0.206	0.0013	37.00129	
3	33.67	0.33	0.0080	34.00796	8.8018
4	33.7071	0.292857	0.0062	34.00618	0.0052
5	34.7744	0.225556	0.0053	35.00531	-2.8542
6	32.7671	0.232862	0.0034	33.00343	6.0657
7	33.3856	0.614444	0.0008	34.00081	-2.9334
8	31.1914	0.808571	0.0003	32.00033	6.2514
9	30.2817	0.718333	0.0009	31.00086	3.2240
10	29.1009	0.899091	0.0004	30.00036	3.3350
11	28.3167	0.683333	0.0005	29.00046	3.4479

Table 4. Bernoulli Energy Equation

Sl No.	Distance zone	Elevation (z) in m	Depth (d) in m	KE = ($v^2/2g$)	Total Energy (TE)= $z+d+v^2/2g$	Segment-wise head loss due to friction
1	51-60	34.7267	0.2060	0.019732951	37.00129	-
2	61-70	36.7940	0.3300	0.001290591	34.00796	2.9933
3	61-70	33.6700	0.2929	0.007961934	34.00618	0.0018
4	71-80	33.7071	0.2256	0.006182409	35.00531	-0.9991
5	81-90	34.7744	0.2329	0.005312186	33.00343	2.0019
6	81-90	32.7671	0.6144	0.003426628	34.00081	-0.9974
7	101-110	33.3856	0.8086	0.00080779	32.00033	2.0005
8	111-120	31.1914	0.7183	0.000325614	31.00086	0.9995
9	111-120	30.2817	0.8991	0.000864018	30.00036	1.0005
10	121-131	29.1009	0.6833	0.000358226	29.00046	0.9999

total head loss = 8.0008 (distance 51 to 131km)

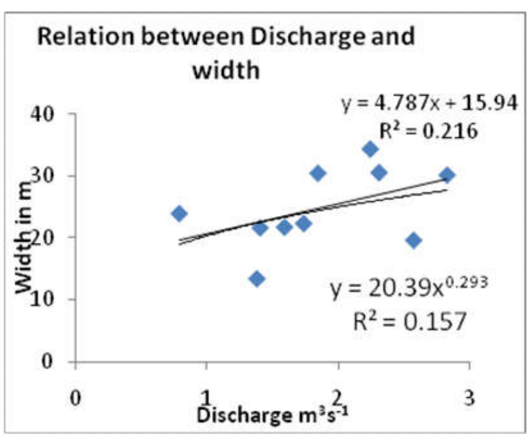


Fig. 3.

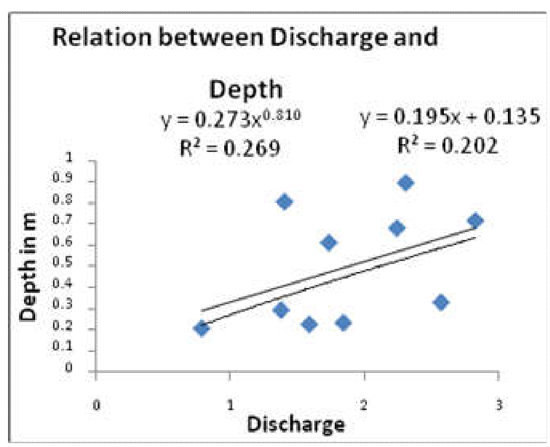


Fig. 4.

Stream power, $\Omega = \rho gQS$(after Charlton, 2007, p.94)

$= 1038.18\ kg\ m^{-3} \times 9.8\ ms^{-2} \times 2.2401 m^3s^{-1} \times 0.0037 mm^{-1}$
$= 84.3296\ Wm^{-1}$

River bed elevation increases, Indicates overall deposition within last 15 years

Flood plains change their morphology due to continuous shifting of river channels. Lateral migration of river channel and floods cause vertical and lateral accretion. Kulik river also changes the flood plain by its oscillating nature. Long profiles of the last 15 years show the dynamic nature of the river channel.

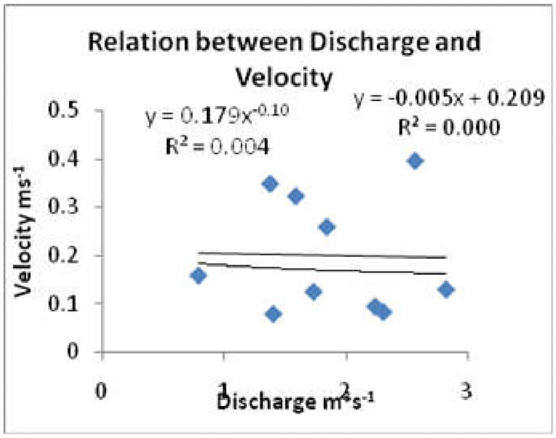


Fig. 5.

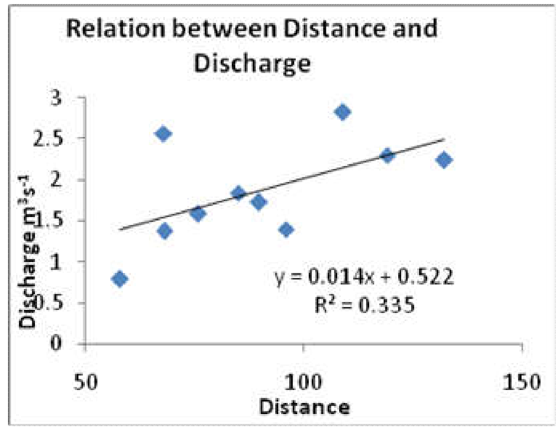
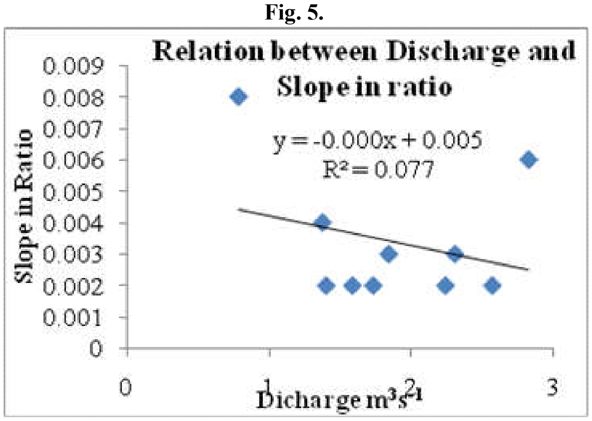


Fig. 6.



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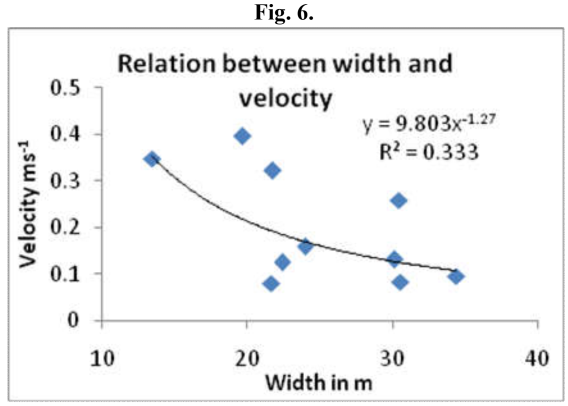


Fig. 8.

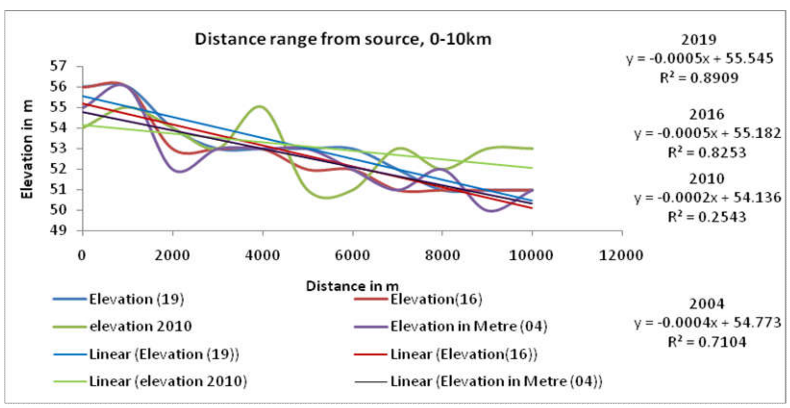


Fig. 9.

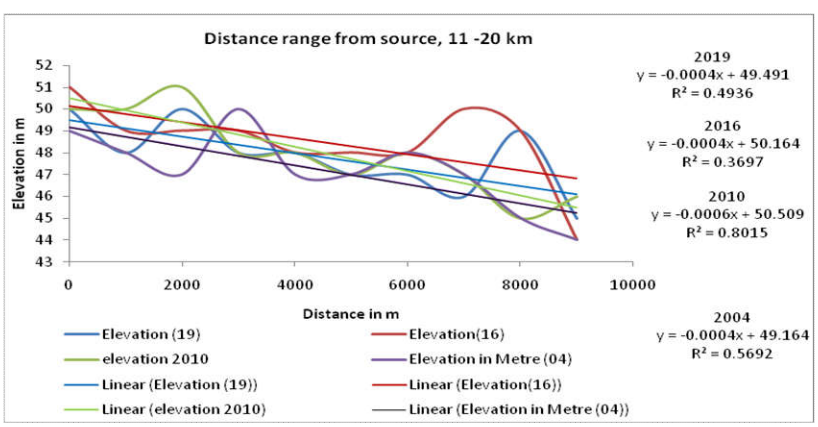


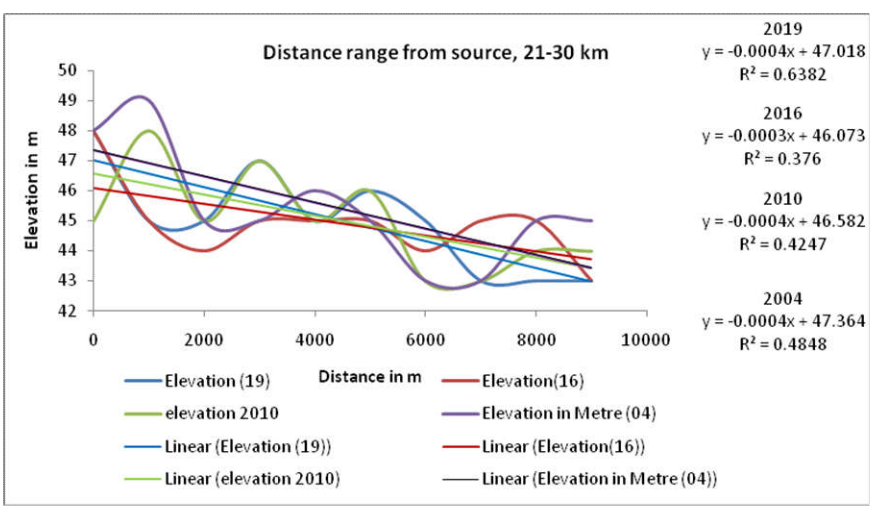
Fig. 10.

Table 5.Calculation for comparison of elevation of same point for the year of 2004 and 2019

Distance in m	Elevation (19), z_2	Elevation in Metre (04) , z_1	ele diff 2019 -2004
0	56	55	1
1000	56	56	0
2000	54	52	2
3000	53	53	0
4000	53	53	0
5000	53	53	0
6000	53	52	1
7000	52	51	1
8000	51	52	-1
9000	51	50	1
10000	51	51	0
11000	50	49	1
12000	48	48	0
13000	50	47	3
14000	48	50	-2
15000	48	47	1
16000	47	47	0
17000	47	48	-1
18000	46	47	-1
19000	49	45	4
20000	45	44	1
21000	48	48	0
22000	45	49	-4
23000	45	45	0
24000	47	45	2
25000	45	46	-1
26000	46	45	1
27000	45	43	2
28000	43	43	0
29000	43	45	-2
30000	43	45	-2
31000	44	42	2
32000	44	43	1
33000	49	44	5
34000	41	42	-1
35000	43	43	0
36000	42	45	-3
37000	42	42	0
38000	42	42	0
39000	42	42	0
40000	44	42	2
41000	40	42	-2
42000	40	43	-3
43000	41	40	1
44000	41	40	1
45000	39	40	-1
46000	40	41	-1
47000	41	39	2
48000	41	41	0
49000	39	38	1
50000	39	38	1
51000	39	38	1
52000	38	38	0
53000	38	36	2
54000	41	40	1
55000	37	40	-3
56000	39	39	0
63000	37	38	-1
64000	36	36	0
65000	37	35	2
66000	36	38	-2
67000	35	34	1
68000	35	36	-1
69000	35	35	0
70000	36	35	1
71000	36	35	1
72000	35	35	0
73000	37	39	-2
74000	34	35	-1
75000	37	35	2
76000	35	35	0
77000	35	33	2
78000	34	35	-1
79000	35	36	-1

80000	35	35	0
81000	34	33	1
82000	32	35	-3
83000	33	33	0
84000	32	32	0
85000	33	33	0
86000	33	33	0
87000	34	33	1
88000	32	34	-2
89000	34	34	0
90000	32	34	-2
91000	34	34	0
92000	33	35	-2
93000	32	33	-1
94000	32	32	0
95000	32	32	0
96000	33	33	0
97000	33	33	0
98000	33	32	1
99000	33	32	1
100000	33	32	1
101000	36	33	3
102000	33	33	0
103000	34	34	0
104000	36	34	2
105000	32	32	0
106000	31	31	0
107000	32	30	2
108000	31	31	0
109000	32	30	2
110000	30	29	1
111000	31	31	0
112000	31	32	-1
113000	31	31	0
114000	30	32	-2
115000	30	30	0
116000	30	31	-1
117000	29	30	-1
118000	29	29	0
119000	30	28	2
120000	28	29	-1
121000	30	29	1
122000	29	29	0
123000	30	30	0
124000	30	30	0
125000	30	31	-1
126000	28	31	-3
127000	28	31	-3
128000	29	31	-2
129000	29	29	0
130000	30	29	1
131000	30	29	1

$\sum(z_2 - z_1) = +7$



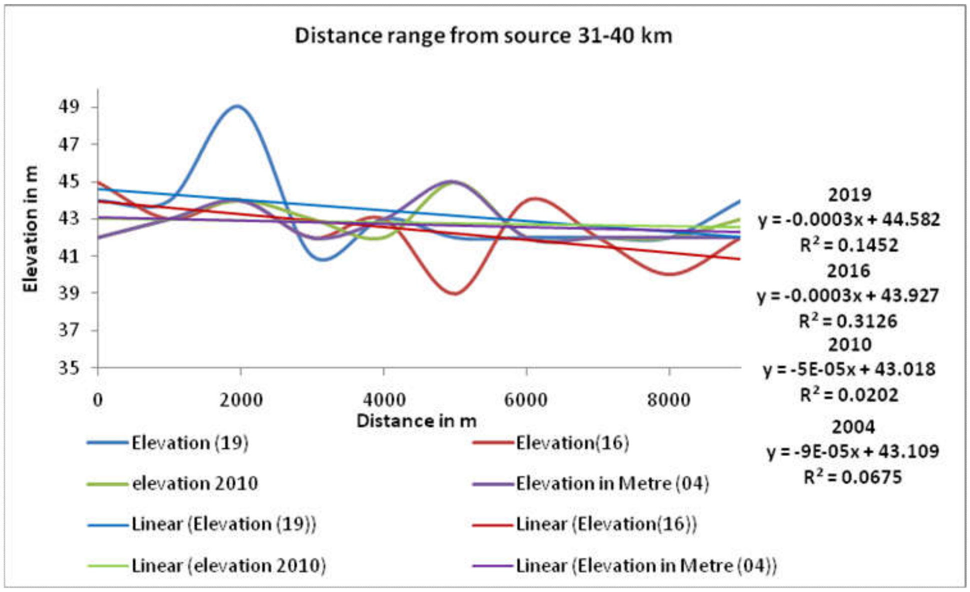


Fig. 11

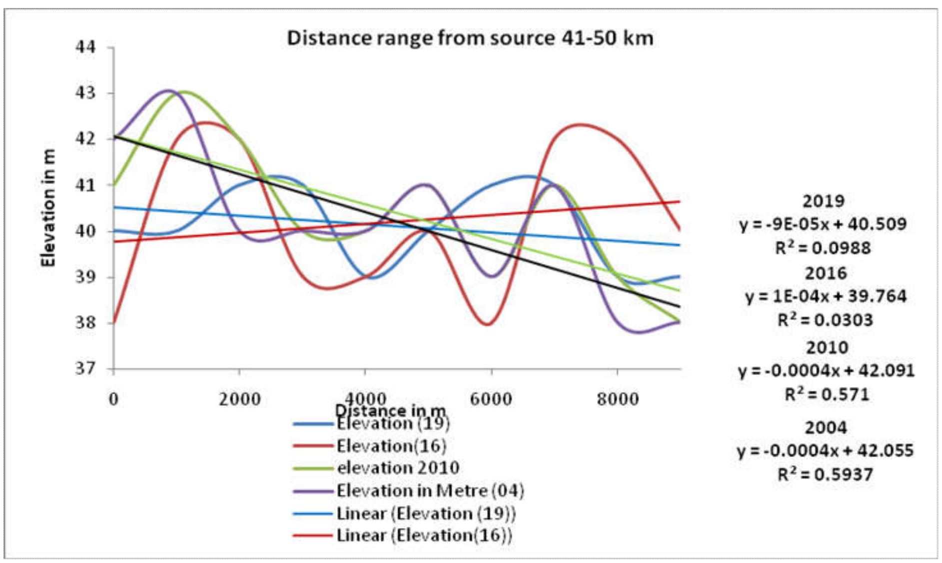


Fig. 12

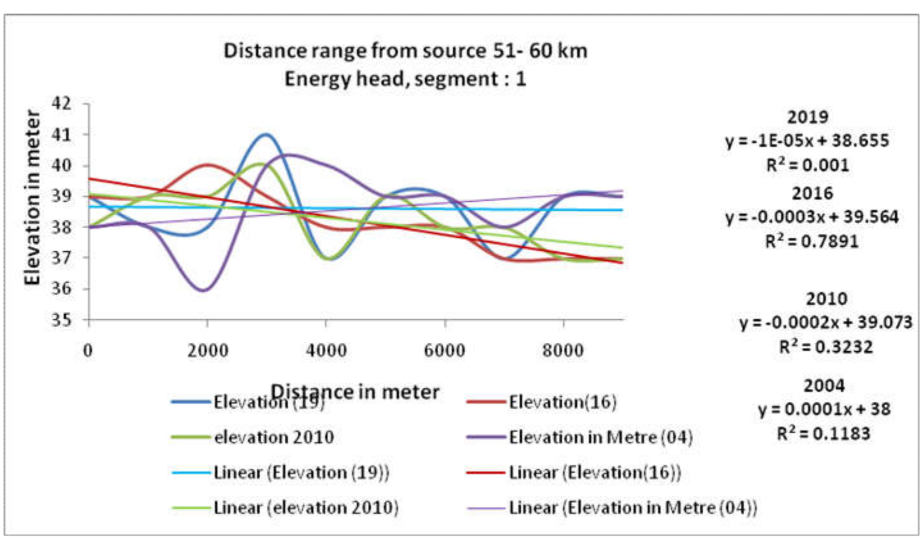


Fig. 13

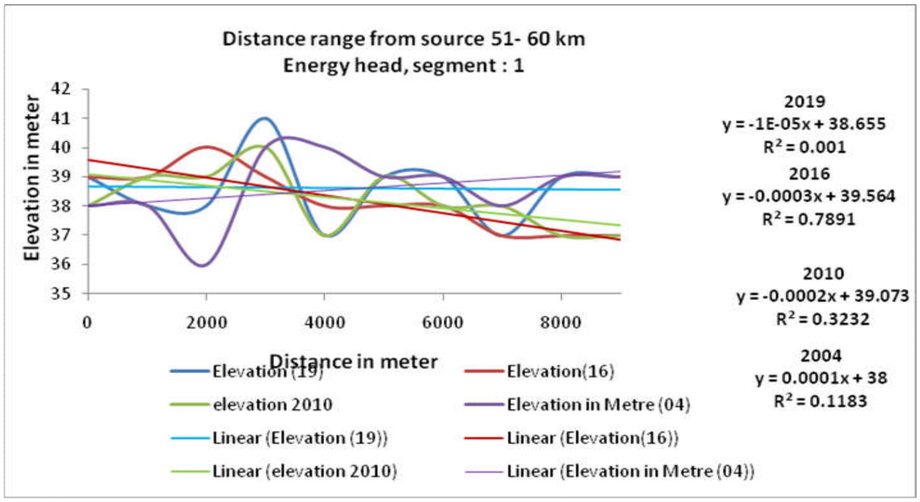

Distance range from source 51- 60 km
Energy head, segment : 1
Elevation in meter
Distance in meter
2019
y = -1E-05x + 38.655
R^2 = 0.001
2016
y = -0.0003x + 39.564
R^2 = 0.7891
2010
y = -0.0002x + 39.073
R^2 = 0.3232
2004
y = 0.0001x + 38
R^2 = 0.1183
Elevation (19)
Elevation(16)
elevation 2010
Elevation in Metre (04)
Linear (Elevation (19))
Linear (Elevation(16))
Linear (elevation 2010)
Linear (Elevation in Metre (04))

Fig. 14.

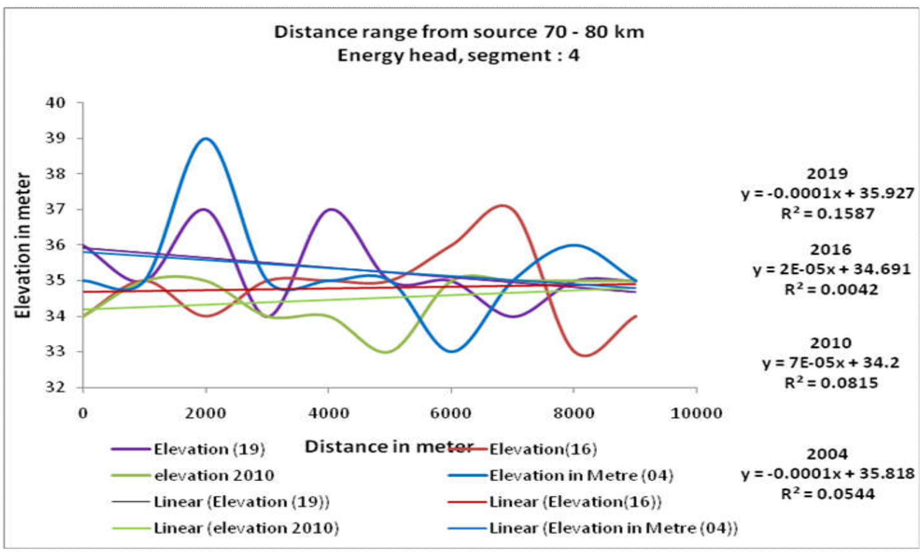
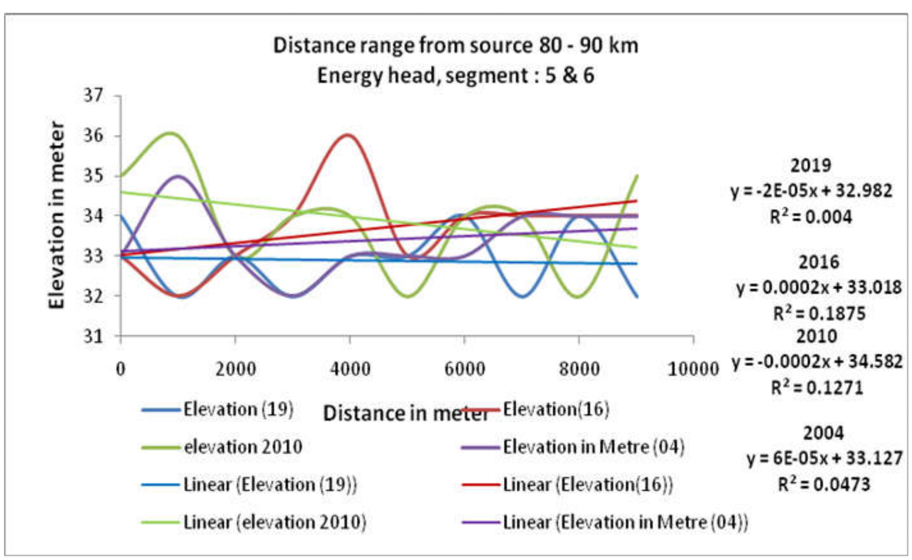

Distance range from source 70 - 80 km
Energy head, segment : 4
Elevation in meter
Distance in meter
2019
y = -0.0001x + 35.927
R^2 = 0.1587
2016
y = 2E-05x + 34.691
R^2 = 0.0042
2010
y = 7E-05x + 34.2
R^2 = 0.0815
2004
y = -0.0001x + 35.818
R^2 = 0.0544
Elevation (19)
Elevation(16)
elevation 2010
Elevation in Metre (04)
Linear (Elevation (19))
Linear (Elevation(16))
Linear (elevation 2010)
Linear (Elevation in Metre (04))

Fig. 15.


Distance range from source 80 - 90 km
Energy head, segment : 5 & 6
Elevation in meter
Distance in meter
2019
y = -2E-05x + 32.982
R^2 = 0.004
2016
y = 0.0002x + 33.018
R^2 = 0.1875
2010
y = -0.0002x + 34.582
R^2 = 0.1271
2004
y = 6E-05x + 33.127
R^2 = 0.0473
Elevation (19)
Elevation(16)
elevation 2010
Elevation in Metre (04)
Linear (Elevation (19))
Linear (Elevation(16))
Linear (elevation 2010)
Linear (Elevation in Metre (04))

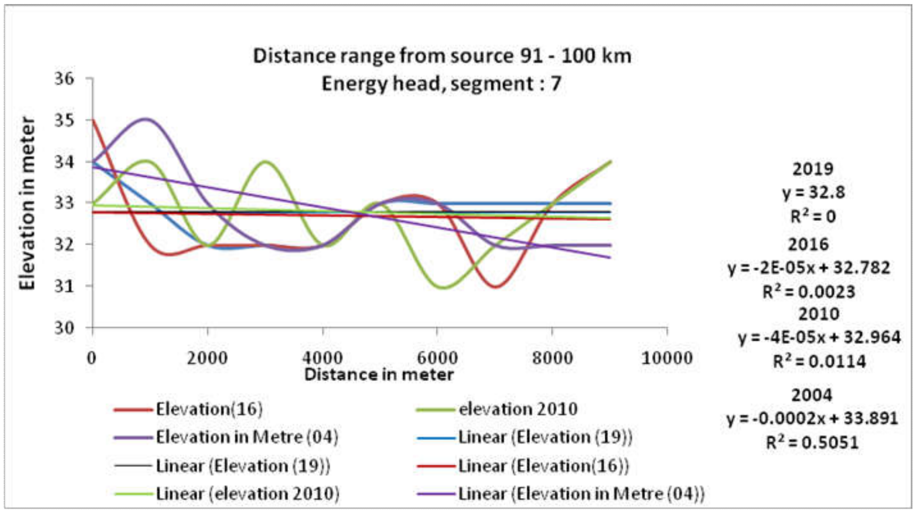


Fig. 17.

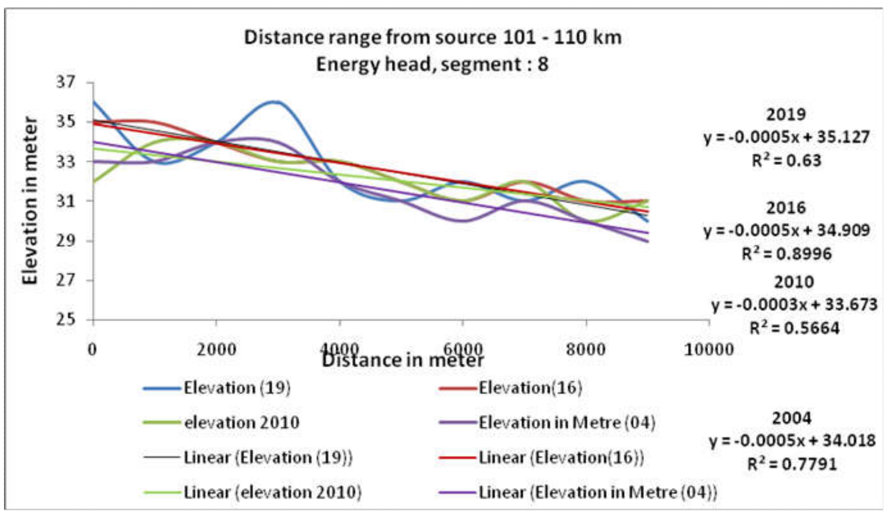


Fig. 18.

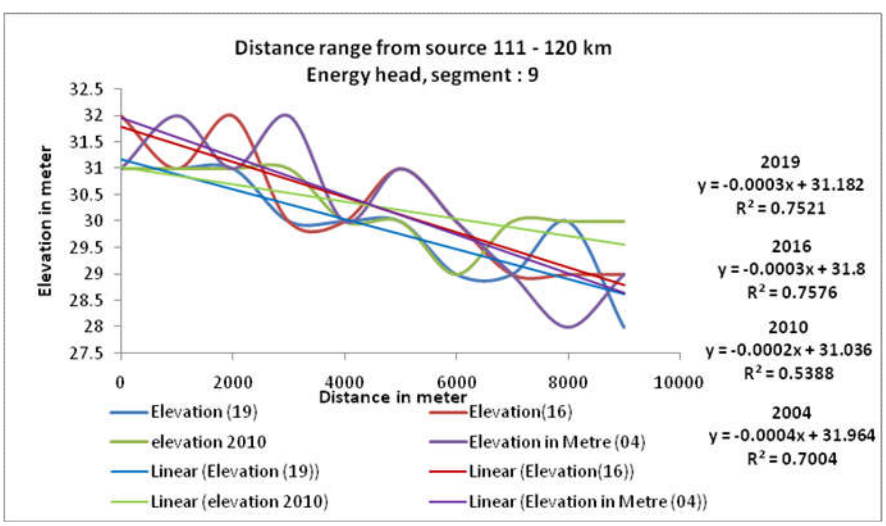


Fig. 19.

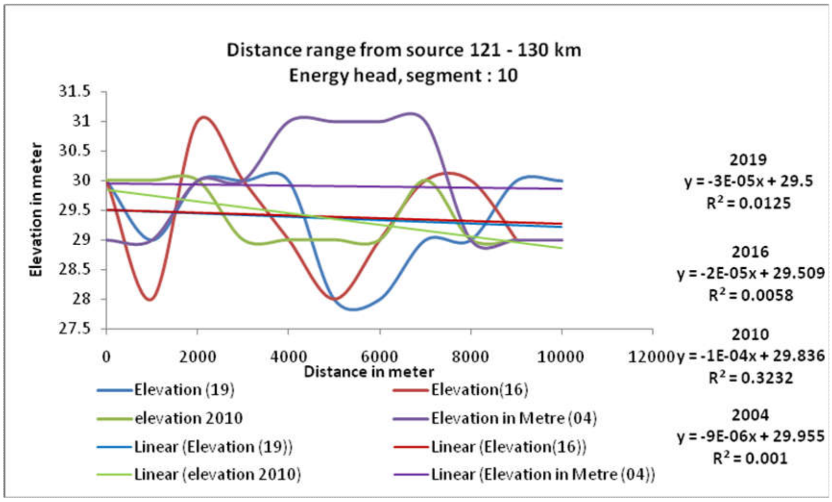


Fig. 20.

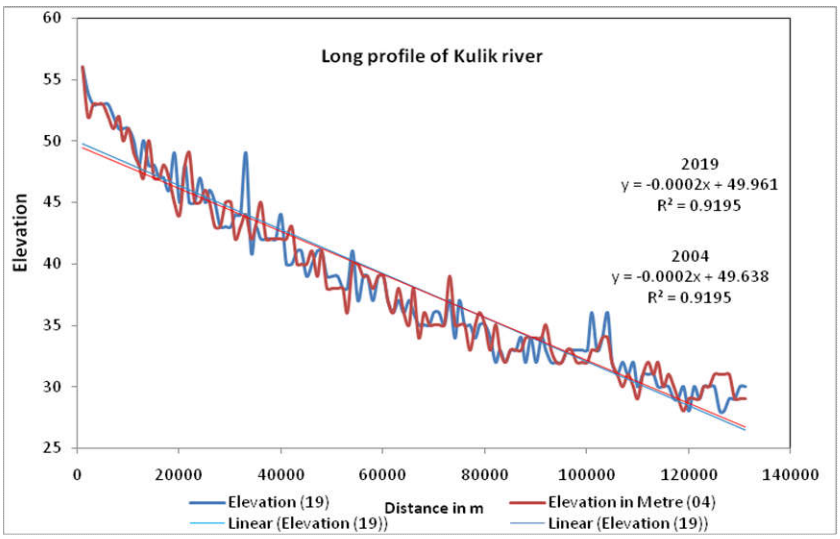


Fig. 21.

The source to almost 20km shows deposition and the river bed height increases from the datum since the last 15 years (Fig. 9-10, Table 5). From 21 km to 50km transportation process dominates as a consequence height decreases in the 1st half and in the 2nd half deposition occurs. This section of long profile finally tends towards gradation. Middle portion exhibits from 51 to 80 km is in steady state equilibrium. Due to the alternate erosion and deposition and consequent changes in thalweg, the deepest point in channel and pointbar the river bed height remains same since last 15 years (Fig.14-16, Table 5). Nagar river erodes its channel and consequently the river elevation falls by 1m from 2004 to 2019. Therefore, due to fall of base level (confluence) Kulik river continuously erodes its valley from 111 to 132 km zone (Fig.20-21, Table 5). According to Mackin deposition at any point on a river is controlled by factors upstream or downstream and models of control on aggradation in upstream and downstream is explained by Smith, 1974[19]. Trend lines of 2019 and 2004 clearly reveal that the river aggrade in the upstream direction and erode in downstream near confluence and form the regarded profile (Fig.22). River length is shortened due to such profile increases the gradient to maintain its flow. Bed configuration is maintained by the self-regulating mechanism to continue the flow by shifting thalweg and pointbar. Sand-silt dominated less resistant bed helps to reconfigure the long profile.

Finding and conclusion

Kulik River is trying to be more competent by modifying its long profile by homeostasis principle and negative feedback mechanisms to continue its flow. Long profiles or the energy profiles change over time and become steeper by depositing in the upstream direction and eroding in the downstream direction and made a Regraded profile. The river flows over a less resistant lithological composition of Holocene sand-silt alternated base as a consequence in the downstream direction the river deepen its valley rather than widening. The basic equations of hydraulic geometry demonstrate that the river energy losses by eroding the bed which in turn again depicts the formation of regarded profile. Further on this regarded long profile if deposition continued in the source region than the river will be in crisis of water as ground water cannot feed after a critical elevation. As a consequence the river may slowly dry. Human interferences like construction of embankment, settlement in meander belt enhances the deposition initially in the downstream direction. Meander belt should be free from adjustment and embankment enhances sedimentation which again causes aggradation in lower course and as a consequence profile gradient decreases. To maintain the gradient the river starts to aggrade in the source region and starts to erode in the downstream direction, but continuous aggradation and less removal of sediment from source region may cause of the water crisis, which in turn might convert the river dry.

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