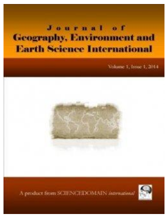

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Changing Fluvio-dynamic Scenario of the Adi Ganga River, Kolkata, West Bengal, India

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Author's contribution

The sole author designed, analszed, interpreted and prepared the manuscript.

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ABSTRACT

The Adi Ganga River is a paleodistributary of the Bhagirathi-Hugli River, and was once an important navigational channel according to Medieval Bengali literature. Many European merchants and travellers also travelled through the Adi Ganga by vessels to the port of Kolkata. Local people also carried various items from the Sundarban via Adi Ganga. Previously, earthen embankments and natural levees existed at different sites along the river. But now, due to unprecedented urban growth, the river is sandwiched on both sides. After the partition of Bengal, many refugees occupied the riverbanks and constructed huts. The river bed is converted into a built-up area in some places. Once it was lifeline of the people of the Bengal delta, but the lower stretch has been reclaimed. Previously the rainwater of Kolkata was discharged through different small outlets into Adi Ganga river. At present, the riverside land use patterns have been entirely modified. As a result, flooding has become a common problem during monsoon period. Several fluvial parameters are analysed to assess the present fluvio-dynamic status and the decay of the Adi Ganga River. The present study aims at the detection of the changing scenario of fluvial geometry of the Adi Ganga. The research work is mainly based on collected and thoroughly analysed primary data. The study on the fluvio-dynamics of the Adi Ganga River revealed that the fluvial geometry has been changing unto the fate of ultimate deterioration.

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1. INTRODUCTION

In the deltaic tract of the South Bengal, the river system is characterized by complex drainage network. The major channels have numerous distributaries and they ultimately drain into the Bay of Bengal. Like other deltaic rivers, the Adi Ganga is also oscillating in nature. The river is the heritage river of Kolkata, and a link to the historic Bengali culture and civilization. The typical problem is decaying of rivers in Bengal Delta. The Adi Ganga is also a lamentable state of decay. According to the Medieval Bengali literature, the Adi Ganga course of the Bhagirathi as a principal navigational waterway to the Bay of Bengal. The original course of the Adi Ganga is decaying condition and traceable only some places beyond Garia. But the river still retains its religiousness in the eyes of the Hindus, and they burn their dead along its banks. The Adi Ganga also carries millions of tons of domestic and market garbages and industrial waste from Kolkata and surrounding areas. The clay images or idols of Durga, and the other gods and goddesses, are immersed in the Adi Ganga river (consider as Holy River) after *Puja* (a religious ceremony) every year. It enhances the deposition of those soluble and insoluble materials. There is a dearth of studies on the changing fluvio-dynamics of the Adi Ganga River. This research work hopes to highlight the fluvial geometry as well as fluvio-hydrological parameters of the river.

2. LITERATURE REVIEW

In the 15th century, the Bengali verse of *ManasārBhāsān* or *Manasāmangal* wascomposed by Bipradas Pipilai. He has described the journey of Behula, wife of snake bitten merchant named Lakhindar through the Adi Ganga, crossing Chitpur, Betore, Kalighat, Churaghat, Baruipur, Chatrabhog, Badrikunda, Hathiagarh, Choumukhi, Satamukhi and Sagarsangam [1]. The description of Bipradas Pipilai to a large extent with Van den Brouke's map of the Adi Ganga in 1660. The Medeval Bengali literature, like the *Chandimangal* of Kabikangkan Mukundaram Chakrabarti (1594-1606), the *Rāymangal* of Krishnaram Das (1686), the *Chaitanyabhāgabat* or *Chaitanyamangal* of Brindabandas (1535-1536), the *Satyanārāyan Kathā* of Ayodhya Ram, the *Shitalāmangal* of Harideb and the *Kalu Rayer Geet* of Dwija Nityananda provide some information about the Adi Ganga during the 13th - 18th century. According to *Chaitanyabhāgabat* or *Chaitanyamangal* of Brindabandas Sri Chaitanyadeva, one of the major religious Clerics of eastern India, also travelled to Puri through this route [1]. Some works of Sherwill, W.S. [2], Reaks, H. G. [3], O'Malley, L. S. S. [4,5], Dutt, K. [6,7,8,9], Lahiri, A. C. [10], Hirst, F. C. [11], Mukherjee, R. K. [12], Mukherjee, K. N. [13,14,15], Bhattasali N. K. [16], Bagchi, K. [17], Rudra, K. [18,19,20], Bandyopadhyay, S. [21,22], and Mukhopadhyay, S.C. and Das Gupta, A. [23] provide information about the river. According to Hirst, F. C. [11], the stream (Adi Ganga) used to flow westwards from Surjyapur along the existing Surjyapur and Diamond Harbour tidal creeks to meet the Hugli at Diamond Harbour [21,22]. Reaks, H. G. [3] also agreed to Sherwill, W. S. [2] by stating that, before reaching the sea, the Adi Ganga used to 'split up into a number of branches one running into the lower Hugli at Diamond Harbour' [2,11,21,22]. Subsequently, the course of the Adi Ganga between Surjyapur and the Baratala was traced by Dutt, K. [6,7,8,9]. Lahiri, A. C. [10] elaborated that the Sagar island stretch of the Adi Ganga, beyond Kakdwip, followed parts of the existing tidal creeks of Shikarpur, Chemaguri, Manchkhali (may be Marichkhali), and Gangasagar (all N-S) and went through the present day localities of Rudranagar, Bishnupur, Narendrapur, Narayaniabad, Magra and Gangasagar [21,22,10]. Mukerjee, R. K. [12] was accepted the view of O'Malley, L. S. S. [4,5]. In another map Mukerjee, R. K. [12] showed the course of the Adi Ganga as slightly offset from the present day tidal channels all along. However, the basic path was identical to that of Lahiri, A. C. [10]. According to Mukerjee, R. K. [12], the suggested course was established on the basis of Mangalkavyas, toposheets and field evidences which were not specified [21,22,12]. According to Mukherjee, K. N. [13,14,15] the well-known 1552 sketch map of Jao de Barros also showed the Adi Ganga as flowing westwards a short distance after crossing Khari. Later, in a seemingly modified version of the above, the Palaeochannel was shown by Mukherjee, K. N. in [13] to approximately follow the existing railway track from near Bishnupur upto Laksmikantapur and then the Kulpi creek to join the Hugli near Kulpi [21,22]. Based on the positions of the five outlets of the Ganga Brahmaputra Delta compiled by Claudius Ptolemy in the 2nd century A. D., Bhattasali, N. K. [16] identified the present Hariyabhanga confluence of the India-Bangladesh border as the

‘Mega’ estuary of Ptolemy. According to him this was the ancient outlet of the Adi Ganga [21,22]. Based on modern photo interpretation studies by Babu, P. V. L. P. (1976), Das, D. K., Majumder, I. P. and Ganguly, A. (1985) detected that an approximately 5 kilometres wide and 50 kilometres long levee zone ‘representing an ancient channel’ extends from the south of Kolkata to the area around Khari which can closely be related with the course of the Adi Ganga [21,22]. According to Rudra, K. [18,19,20] from Khari onwards the river used to flow due south into the sea along the Gobadiya creek through the Saptamukhi estuary of today. This course coincides most accurately with the descriptions made in the Chaitanya-bhāgabat or Chaitanyamangal and Manasā-Bijay or Manasamangal. According to Bandyopadhyay, S. [21,22] the course of the lower Adi Ganga, downstream of Surjyapur, may be established with some confidence up to Gajmuri-Dighirpara through Multi, Hogla, Joynagar, Bishnupur, Chhatrabhog and Barashi, its position below that area may only be left undefined.

3. STUDY AREA

To study the causes and related problems for the decay of the Adi Ganga and its impact on the surrounding environment, the course of Adi Ganga from its Off-take (bounded by 22°27′12″N and 22°33′1″N latitudes, 88°18′53″E and 88°24′2″E longitudes, having an area of about 28.27 square kilometers in the Kolkata district of West Bengal) up to Garia has been selected for detailed fluvio-hydrological studies (Fig. 1). The river is continuous and traceable only for 12.78 kilometers downstream up to Garia [1]. The study area is located in the lower delta plains of the Bhagirathi-Hugli system. Few isolated traceable dry paths have also been noticed between Garia and Surjyapur (22°18′N, 88°28′E), which is seen 36 kilometers downstream of Kolkata [1]. The river was excavated by Major William Tolly (who was in service to the East India Company at Fort Williams) from 1775-1777, with a loan from the British Government, and it was leased to Major William Tolly for a period of 12 years. Actually, he started excavation work from the Off-take Point and went through Khidirpur, Alipur, Kalighat, Tollygunge, Kundghat, and Garia of Kolkata Municipality. But beyond Garia, he followed another path (leaving the original path towards Sonarpur, Baruipur and Surjyapur) and connected the river to the Bidyadhari River at Samukpota or at the port of Tarda [1]. Because he believed, this route could be more advantageous. At that time, Bidyadhari flowed southward and used to drain into Matla at Canning, South 24 Parganas, West Bengal, India. The elevation of the study area ranges between 1.50 meters and 6.10 meters above sea level. Hydrologically, the area is surrounded by the Adi Ganga levee formation, or older levee formations, confined by multiple aquifers, with transmissibility of approximately 2000 square meters per day [24,25]. As the area is located on the lower delta plain, it is covered by quaternary sediments, consisting of clay, silt, sand, gravel and the occasional pebble bed, etc., deposited by the river system flowing through the area [26]. The sub-surface geology is obscured by a blanket of recent sediments.

In the Calcutta Environmental Management Strategy and Action Plan (CEMSAP) survey (1997), the total number of residents (encroachers) along the Adi Ganga route was 22,000, which has risen from 6,200 in the year 1984, after the Unnayan survey. In 1984, according to Unnayan survey there was 6200 encroachers along the Adi Ganga [26]. In 1997, according to CEMSAP survey the total number of encroachers was 22,000 [27]. In 2011, the approximate number of residents or encroachers increased to 35,000 [28]. The resident uses the river water for domestic purposes like bathing of domestic animals and human being (32.82%), washing of clothes and utensils (23.82%), sanitation (25.47%) etc. The encroachers, resides in ward nos. 71, 73, 74, 75, 81, 82, 83 and 88 use river water for different purposes [29]. Based on satellite image - IRS P6 SENSOR = LISS IV, 2010 a land use and land cover map (by supervised classification) of Adi Ganga and its surrounding areas have been prepared (Fig. 6). Accordingly, large portion of the study area is dotted with settlements (coverage 52%) followed by vegetation (coverage 25%), water bodies (coverage 16%) and vacant land (coverage 7%). The eastern part is well covered by vegetation which continues across the river extending into the southern part and the extreme eastern segment of the area [1]. The region in its western section is occupied mostly by settlements and vegetation. Water bodies are found at different locations in central (ward no. 117) and southern part (ward no. 110, 111 and 114). Vacant areas exist in ward no. 74, 110 and 121. The area where the river takes a bend towards south-east direction is thickly vegetated marking the area under Tollygunge golf course. It is evident that the region is densely populated because of the presence of Adi Ganga [1].

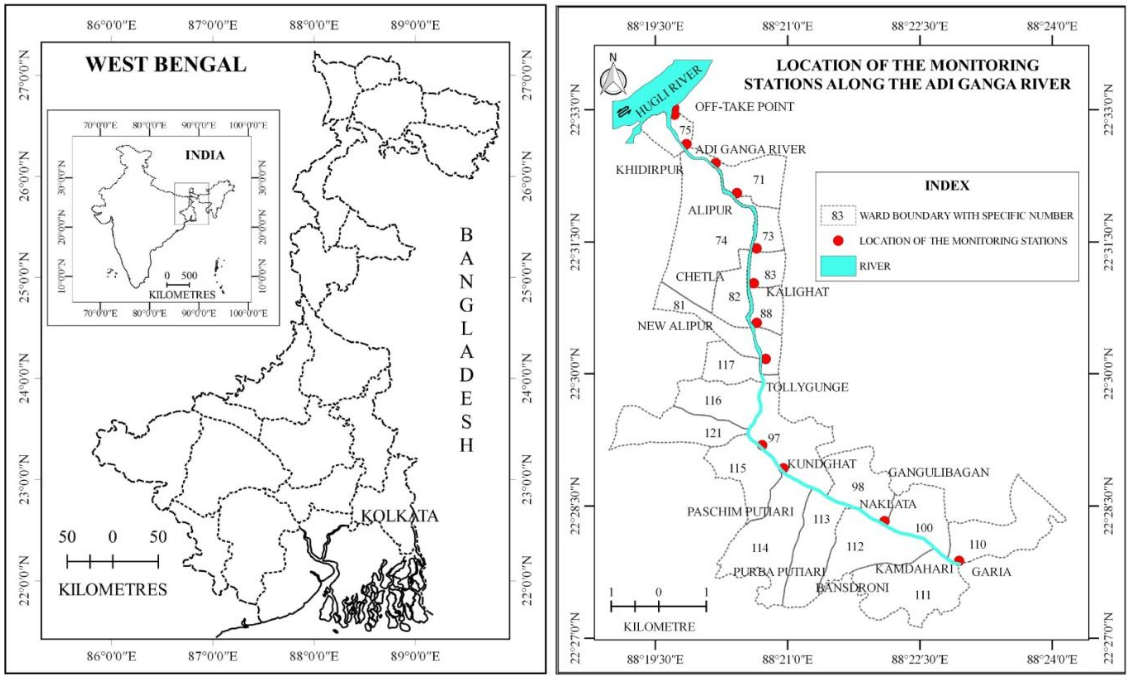

Fig. 1. Study area

4. STUDY OBJECTIVES

The objectives of this scientific study include the following:

- To highlight the fluvial as well as hydrological parameters of the Adi Ganga river.
- To find out the changing scenario of fluvial geometry.
- To determine the nature of siltation of the river.

5. DATABASE AND METHODOLOGY

For the present study, primary data on the fluvial geometry of the river was collected from the field using detailed field surveys and instrumentation. For the assessment of the deegenation of the Adi Ganga river, the few parameters have been taken into consideration: i) channel geometry such as channel width, channel depth, channel slope, channel cross-sectional area, wetted perimeter, hydraulic radius, ii) channel fluid dynamics such as velocity, discharge, and river energy. The study was accomplished in three phases which are as follows:

Pre-field method: The available secondary data also collected from various records, books, journals, and government publications. The historical background of the Adi Ganga river collected from existing literature and maps, which have published in different journals and books. References have collected on the different aspects of the study area. Information has been also collected from government and non-government institutions.

Field method: For the present study, the primary data on fluvial geometry of the river collected from the field by detailed survey work and instrumentation. Cross section of the river has been made by collecting the water depth and velocity data during three seasons (pre-monsoon, monsoon and post-monsoon) from 2008-2013, at various locations (Table 1) using Digital Current Meter. River depths in various locations were measured using rope and plum bob and verified with the tape measure. Widths at different places were measured by using measuring tape directly. The length of the river was measured by using the Survey of India Topographical map numbers 79 B/6 and 79 B/7 (1959-1960) with the R.F. 1:50000, and LANDSAT Satellite Images (IRS P6 SENSOR = LISS IV, 2010), as it was not approachable by vehicle or walking due to the inaccessibility of the interior portion of the channel.

Table 1. GPS locations of different river cross sections

Cross sections	Monitoring stations	Distance from the off-take point (in meters)	GPS locations	
			Left side	Right side
1	Off-take Point	0	E88°19′30″ / N22°33′03″	E88°19′28″ / N82°22′34″
2	Circular Rail Bridge	55. 6	E88°19′30″ / N22°33′01″	E88°19′29″ / N22°33′27″
3	Khidirpur Bridge	694.4	E88°19′41″ / N22°32′34″	E88°19′40″ / N22°32′33″
4	Zerut Bridge	1527.7	E88°20′03″ / N22°32′22″	E88°20′02″ / N22°32′20″
5	Alipur Bridge	2361.1	E88°20′15″ / N22°32′01″	E88°20′14″ / N22°32′00″
6	Kalighat Bridge	3730.0	E88°20′26″ / N22°31′25″	E88°20′25″ / N22°31′26″
7	Jatin Das Bridge	4444.4	E88°20′25″ / N22°31′01″	E88°20′24″ / N22°31′01″
8	Budge Budge Rail Bridge	5555.5	E88°20′26″ / N22°30′34″	E88°20′26″ / N22°30′34″
9	Tollygunge Bridge	6111.1	E88°20′32″ / N22°30′12″	E88°20′31″ / N22°30′12″
10	Karunamayee Bridge	8333.3	E88°20′27″ / N22°02′11″	E88°20′26″ / N22°02′11″
11	Kundghat Bridge	8888.8	E88°20′49″ / N22°28′04″	E88°20′48″ / N22°28′04″
12	Bansdroni Bridge	11111.1	E88°21′35″ / N22°28′28″	E88°21′34″ / N22°28′27″
13	Garia Bridge	12777.7	E88°22′46″ / N22°27′51″	E88°22′46″ / N22°27′50″

Source: Computed by the author from field survey data, 2008-2013. [1]

Post-field method: During this period, the author has analyzed the primary and secondary data. The collected data was analyzed using statistical techniques, and relevant cartographic representations, using QGIS (version 9.14), and MS Excel (2007).

6. RESULTS AND DISCUSSION

Various hydraulic data have been recorded regularly during high and low tide (also during new moon and full moon) at the monitoring stations from 2008 to 2013. There are thirteen permanent monitoring stations (Fig. 1, Table 1) which are Off-take Point,Circular Rail Bridge, Khidirpur Bridge,Zerut Bridge, Alipur Bridge, Kalighat Bridge, Jatin Das Bridge, Budge Budge Rail Bridge, Tollygunge Bridge, Karunamayee Bridge, Kundghat Bridge (near Netaji Metro Station), Bansdroni Bridge (near Surya Sen Metro Station) and Garia Bridge. The fluvio-hydrological parameters for the assessment of the degeneration of the Adi Ganga River discussed below.

6.1 Channel Width

Channel width at any given point along the river course represents a straight cross-sectional distance of the channel representing the stage of the river (i.e., level of water). It is, thus, apparent that channel width varies with changes in volume of water and discharge [30]. The bankfull stage of the river denotes the maximum channel width. Thus, channel width considerably changes in the river, having a seasonal regime of rainfall. If the cross-sectional shape of the channel is irregular, channel width increases with increasing discharge and volume of water. If the channel shape is rectangular, no appreciable change in channel width occurs despite the gradual increase in discharge and volume of water. The maximum channel width is associated with bankfull stage of discharge. In case of the Adi Ganga, the channel width changes due to tidal effects. The maximum channel width was measured as 63.3 meters at the Off-take Point in 2009. The minimum channel width was measured as 0.20 meters at the Garia Bridge in 2012 and 2013 (Fig. 2).

6.2 Channel Depth

The depth of channel denotes the vertical distance from the water level in the channel to the channel bed. Maximum channel depth is measured from the level of water at the bankfull stage of the river to the lowest point of the channel bed [1]. The lowest channel depth is found (0.1 meter) in the year 2013 at the Garia bridge (cross section 13). The maximum channel depth was measured as approximately 4.4 meters at the Circular Rail Bridge in 2012. Due to the construction of the Metro Railway pillars inside the river bed, the channel depth is lowest from Karunamayee to Garia (Fig. 3).

6.3 Channel Thalweg

The channel thalweg line represents the line that connects all the points of maximum depth of water from the source to the mouth of the river along the channel in the downstream direction. The channel thalweg represents the deepest point of cross-section of the river bed [1]. The lowest studied channel thalweg is found (0.3 meter) in the year 2013 at the Garia bridge. The maximum channel thalweg is measured as 5.6 meters at the Off-take Point in 2011 (Fig. 4). Here the thalweg line is not running along the midpoint of the channel width due to siltation and river side dumping. In the lower stretch, the thalweg line runs left-right, due to the construction of the Metro Railway pillars on the channel bed. The thalweg point has been shifted due to dumping of various materials as well as dredging at different stations along the cross section during the period 2008-2013.

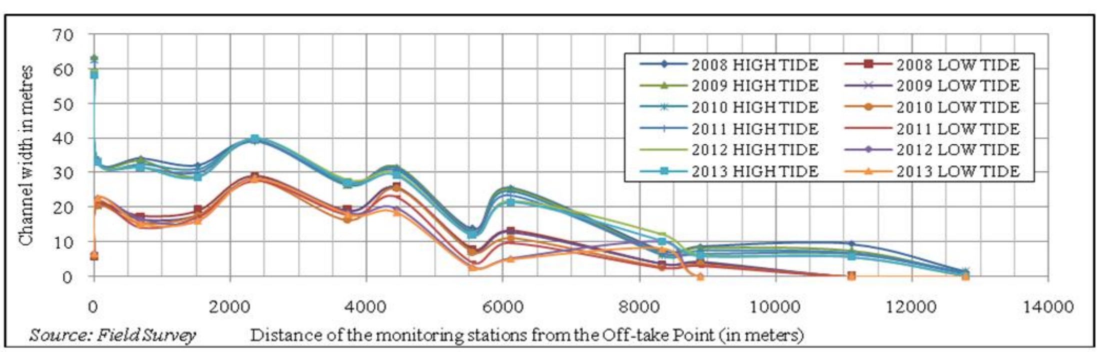

Fig. 2. Channel width

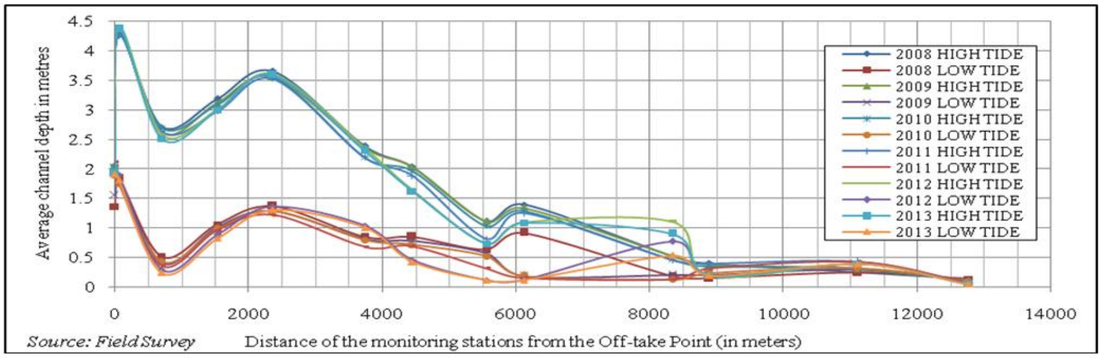

Fig. 3. Channel depth

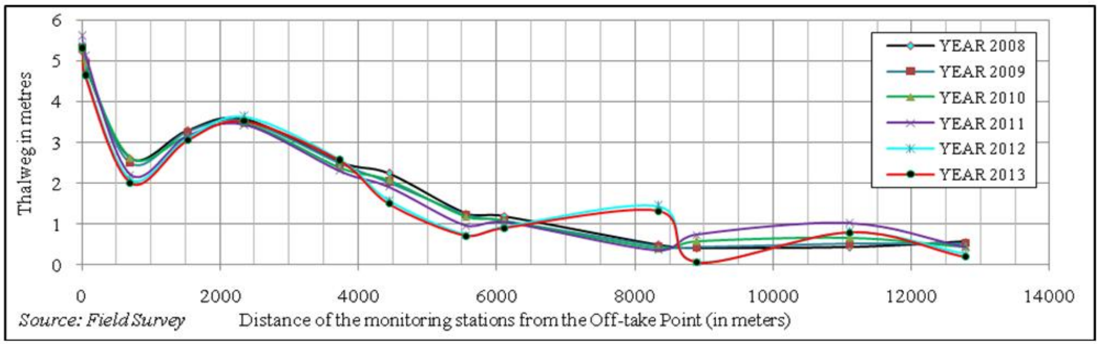

Fig. 4. Channel thalweg

6.4 Channel Slope

The channel downstream direction is known as the channel slope. Slope, $\theta = \tan^{-1}$ (r/d) where, d = ground distance between two points and r = elevational difference between them [31]. The maximum channel slope found is 0°44´25´´ (2012), between Off-take Point and Circular Rail Bridge and the slope direction is toward Off-take Point (Table 2). But, beyond the Karunamayee Bridge, there is no such variation of channel slope (the average channel slope is 0°00´45´´ towards the Karunamayee Bridge). That is the why water here is stagnant throughout the year (except the monsoon period). The middle portion the channel slope varies due to dumping of materials and the dredging of the channel bed.

6.5 Channel Cross-Sectional Area

The channel cross-sectional area is measured by multiplying the channel width by the channel depth [30]. The maximum cross-sectional area was 145.42 m^2during high tide in the year 2013 at the Circular Rail Bridge. Dry channel bed found near the Garia Bridge, but during the monsoon months the cross-sectional area increased. The average cross-sectional area during 2008-2013 shows a gradually decreasing trend. The yearly graph of cross-sectional area is shown in Fig. 5. In the year 2008, the cross-sectional area at the Off-take Point was 131.15 m^2, but it has slightly decreased (112.72 m^2) in 2013. An interesting result is also found at the Karunamayee Bridge. In 2008, the cross sectional area was 3.56 m^2, and it was gradually decreasing up to 2011, but in 2012, it suddenly increased (13.47 m^2) due to dredging [1].

6.6 Wetted Perimeter

Wetted perimeter denotes the cross-sectional distance of the wetted portion of the river valley [30]. The maximum wetted perimeter (65 meters) was measured in 2008 during the monsoon high tide. In 2013, it dropped by 51.25 meters at the Off-take Point (Fig. 6). Due to dredging the wetted perimeter increased at the. During the dry season, the channel bed is exposed on the surface near the Garia Bridge. Previously, the water was slowly flowing throughout the year. The channel flow is being restricted from Karunamayee Bridge to Garia Bridge, due to the construction of the Metro Railway pillars inside the Adi Ganga channel bed and construction of concrete embankment.

Table 2. Year wise variation of channel slope at surveyed sites

Stretch	Channel slope (in degrees)					
	2008	2009	2010	2011	2012	2013
Off-take Point to Circular Rail Bridge	0°21´06´´	0°24´19´´	0°24´19´´	0°28´16´´	0°44´25´´	0°41´16´´
Circular Rail Bridge to Khidirpur Bridge	0°12´06´´	0°13´06´´	0°12´28´´	0°15´47´´	0°13´52´´	0°14´06´´
Khidirpur Bridge to Zerut Bridge	0°02´50´´	0°03´05´´	0°02´09´´	0°03´51´´	0°04´07´´	0°04´20´´
Zerut Bridge to Alipur Bridge	0°01´04´´	0°01´07´´	0°01´22´´	0°01´09´´	0°02´14´´	0°01´56´´
Alipur Bridge to Kalighat Bridge	0°02´37´´	0°02´38´´	0°02´43´´	0°02´49´´	0°02´40´´	0°02´27´´
Kalighat Bridge to Jatin Das Bridge	0°01´21´´	0°02´11´´	0°01´30´´	0°01´51´´	0°04´43´´	0°05´02´´
Jatin Das Bridge to Budge Budge Rail Bridge	0°03´02´´	0°02´27´´	0°02´47´´	0°02´57´´	0°02´38´´	0°02´27´´
Budge Budge Rail Bridge to Tollygunge Bridge	0°00´24´´	0°00´52´´	0°00´32´´	0°00´28´´	0°01´12´´	0°01´10´´
Tollygunge Bridge to Karunamayee Bridge	0°01´04´´	0°00´58´´	0°01´03´´	0°01´03´´	0°00´47´´	0°00´39´´
Karunamayee Bridge to Kundghat Bridge	0°00´34´´	0°00´11´´	0°01´04´´	0°02´19´´	0°08´26´´	0°07´45´´
Kundghat Bridge to Bansdroni Bridge	0°00´02´´	0°00´07´´	0°00´08´´	0°00´27´´	0°01´07´´	0°01´08´´
Bansdroni Bridge to Garia Bridge	0°00´16´´	0°00´03´´	0°00´27´´	0°01´12´´	0°01´06´´	0°01´14´´

Source: Computed by the author from field survey data, 2008-2013

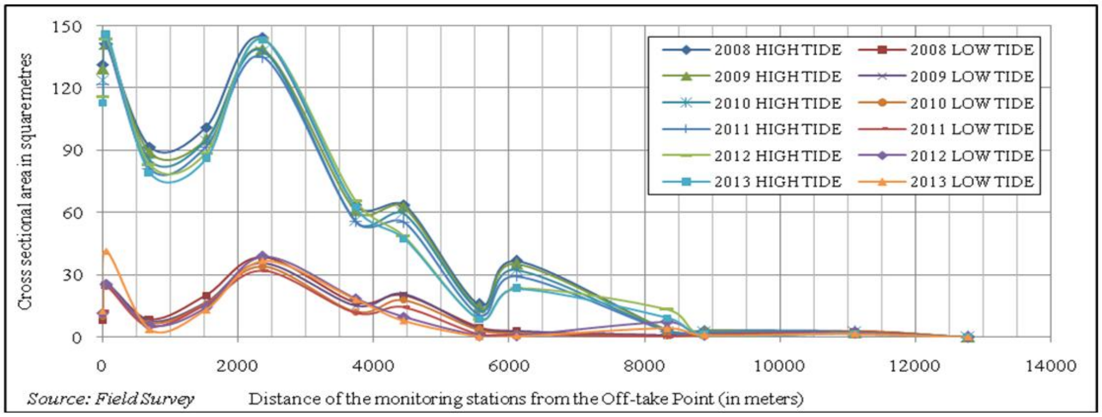

Fig. 5. Channel cross-section

6.7 Hydraulic Radius

River hydraulic radius is the ratio between the cross sectional area and the wetted perimeter of the channel [30]. It is shown as HR = A/WP, where HR is hydraulic radius, A is the cross-sectional area of flow, and WP is the wetted perimeter [32]. The maximum hydraulic radius found is 5.145 meters at the Circular Rail Bridge in 2011, and the minimum was 0.033 meter at the Garia Bridge in the year 2013. From Fig. 7, it is found that the hydraulic radius value is less than 1.0 meter beyond the Karunamayee Bridge and towards upstream it is above 1.0 meter. It is an important hydraulic parameter for the assessment of the degeneration of rivers like the Adi Ganga. The downstream beyond the Karunamayee Bridge is already decayed and towards Off-take Point it is in a decaying situation. Due to the tidal effect, the fluvial dynamics are partially maintained from Off-take Point to the Karunamayee Bridge [1].

6.8 Velocity

In the open channel, water is subjected to the acceleration of gravity and the resistance forces generated by the friction between the water and the channel boundaries (channel bed and channel wall). In case of the Adi Ganga the flow is restricted between the Karunamayee Bridge and Off-take Point [1]. Due to tidal effects, the velocity is measured by digital current meter during high tide and low tide. The maximum velocity (0.66 m/s in 2008) is found at the Off-take Point during low tide, due to the high channel gradient, but there is no change of average velocity in the different years at the same stations (Fig. 8). Generally, maximum average velocity is observed during the monsoon period due to the addition of excessive monsoon rainfall from the proximity area. At a cross-section, the mean velocity in a river channel increases with increasing distance from the channel beds and banks. At the bed, the velocity is zero, and increases vertically. Velocity is also affected by channel roughness. The roughness of the channel is determined by the shape and size of the bed sediment, the number of bends in the channel, the type of obstructions and irregularities in the channel, as well as the depth and velocity of the water. According to sinuosity index, the Adi Ganga is a wandering channel (Sinuosity Index = 1.16). Due to the construction of several bridges across the river and bridge supporting pillars on the river bed, the river velocity is disrupted [1].

6.9 Discharge

The product of mean velocity and the cross-sectional area defines the discharge of a stream [30]. Discharge is the volume of water passing a cross-section during a fixed period of time, and is expressed in cubic meter per second (m^3/s). Q = WDV, where, Q is the discharge, W is the channel width, D is the channel depth and V is the channel velocity [30,33,34]. Fluctuation of river discharge is regulated by different factors such as water supply, cross-sectional area of a channel, and the velocity of a channel. According to Figure 9, the maximum discharge is found (82.16 m^3/s) at the Circular Rail Bridge during the monsoonal months of 2013 (high tide). Beyond the Karunamayee Bridge towards Garia, there is very low water discharge throughout the year, but during monsoons, small volumes of water pass through the confined, narrow channel bed [1].

6.10 Kinetic Energy

River energy is the capacity or ability to do work. Numerous studies show that the geomorphic work, erosion, and transportation performed by a stream depend on the available fluvial energy, which is controlled by the discharge, the flow velocity, and degree of turbulence [30]. The ability of a stream to erode and transport is related to the force exerted by flowing water on the channel beds and walls. To study the energy of the Adi Ganga, the *Bernoulli Equation*is applied [1].

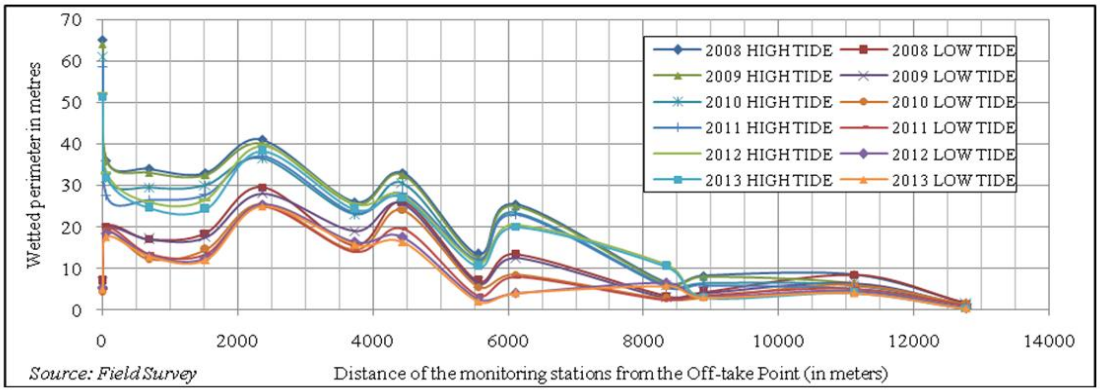

Fig. 6. Channel wetted perimeter

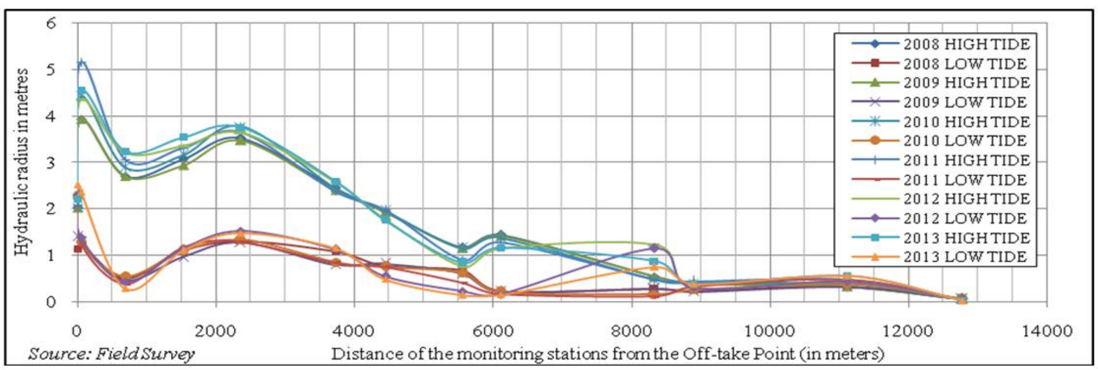

Fig. 7. Channel hydraulic radius

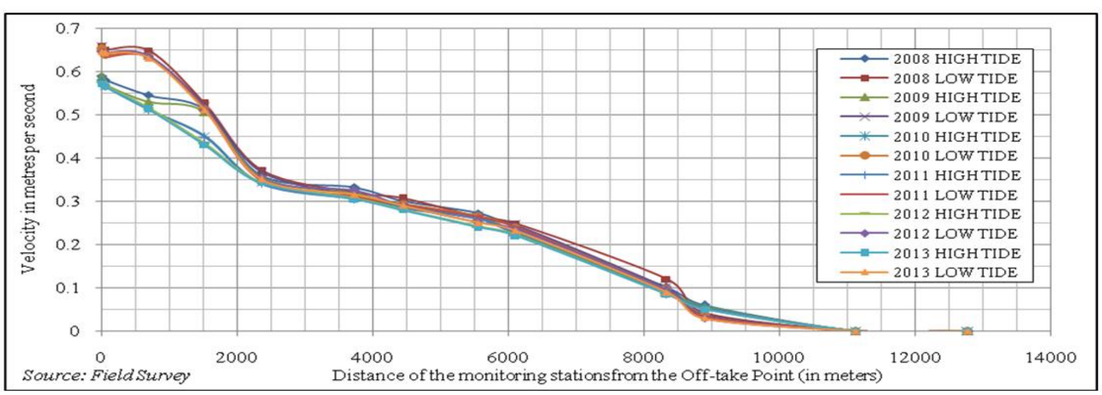

Fig. 8. Channel velocity

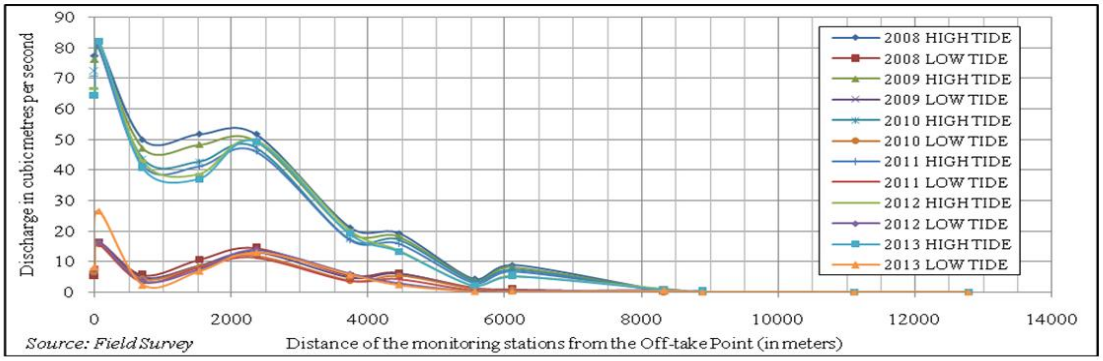

Fig. 9. Channel discharge

Kinetic energy is implemented through moving objects. The kinetic, or velocity head, can be derived by dividing the kinetic energy by the weight of water to give a head in meters [34]. From the graph (Fig. 10), it is seen that the river Adi Ganga has lost its ability to flow, because the value of kinetic energy at all the stations are less than 0.02 joule. Beyond Karunamayee, due to the construction of the Metro Railway pillars on the channel bed, the channel bathymetry has been modified, and except during the monsoon months, the river is unable to flow.

6.11 Total Energy

At any point in the channel, the total energy 'possessed' by the water is the sum of potential energy, kinetic energy, and pressure energy. This can be written as an equation – the *Bernoulli Equation*. This was derived by the eighteenth century Swiss mathematician Daniel Bernoulli, and is widely used in hydraulics. For flow in open channels the equation states that:

$TE = d + v^2 / 2g + z$ (Total energy head = Pressure head + Velocity head + Elevation head) Total energy head

Where TE is total energy head (m), d is water depth (m), v is flow velocity (ms^{-1}), g is the gravitational constant (9.81 ms^{-2}), and z is elevation head (m), [35].

The maximum value was 10.51184 joule at the Circular Rail Bridge during high tide in 2012, and the minimum value of total energy (3.12000 joule) was found at Garia in 2013. From the six year average, the value of total energy of the Adi Ganga is insignificant (Fig. 11).

6.12 Rate of Siltation

Siltation is a common problem of the deltaic rivers or flood plain alluvial rivers. The rivers, which originate from the Himalaya and Chhotanagpur plateau, carrying millions of tons of sediment and these are deposited (in the down stretch) because of the sudden loss of gradient and low energy [1]. There are several factors which are responsible for the siltation or sedimentation in the channel bed. Studies have been conducted since 2008. During 2008-2009, siltation was prominent near the Tollygunge Bridge (39.40 cm), Khidirpur Bridge 10.45 cm, Off-take Point (9.40 cm), and the Alipur Bridge (9.50 cm). The average rate of siltation was 7.40 cm between 2008 and 2009. In 2009-2010, maximum siltation was 15.00 cm, recorded near the Off-take Point and near the Kalighat Bridge it was 9.05 cm. But in all stations the rate of siltation was below 7.5 cm. The average rate of siltation was 4.81 cm in between 2009 and 2010. During 2010-2011, the maximum (21.15 cm) rate of siltation was recorded near the Budge Budge Rail Bridge. The average rate of siltation was 6.66 cm in between 2010 and 2011. In 2011-2012 periods, due to dredging near Karunamayee Bridge the depth of the channel bed is decreasing (-64.70 cm) in trend. The siltation was very different near the Kalighat Bridge (25.70 cm) and Budge Budge Rail Bridge (24.10 cm). The average rate of siltation was 5.49 cm in between 2011 and 2012. From 2011 to 2012, the average rate of siltation was 6.09 cm per year. The average rate of siltation was 9.47 cm in between 2012 and 2013 (Fig. 12). To rejuvenate the Adi Ganga, the Kolkata Municipal Corporation and the Department of Irrigation and Waterways, and the Government of West Bengal dredged in different years. Due to dredging, the channel bathymetry modified and has also been increased at some stations [1].

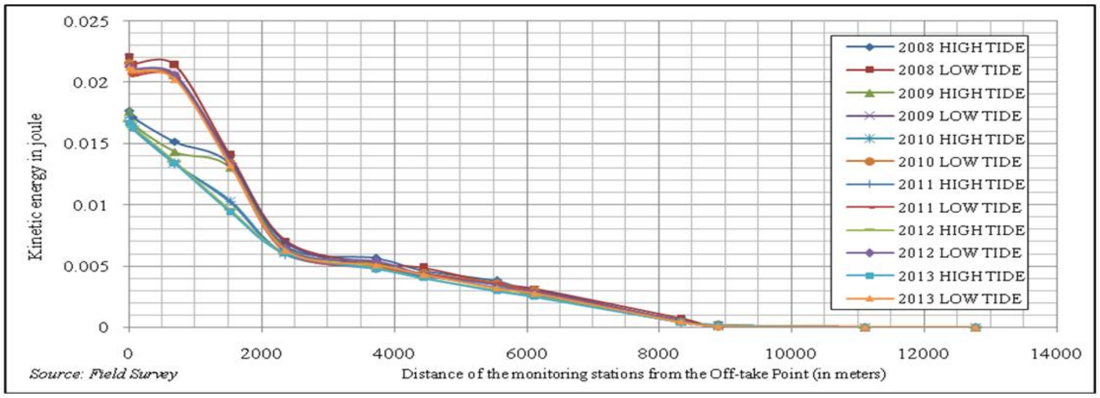

Fig. 10. Channel kinetic energy

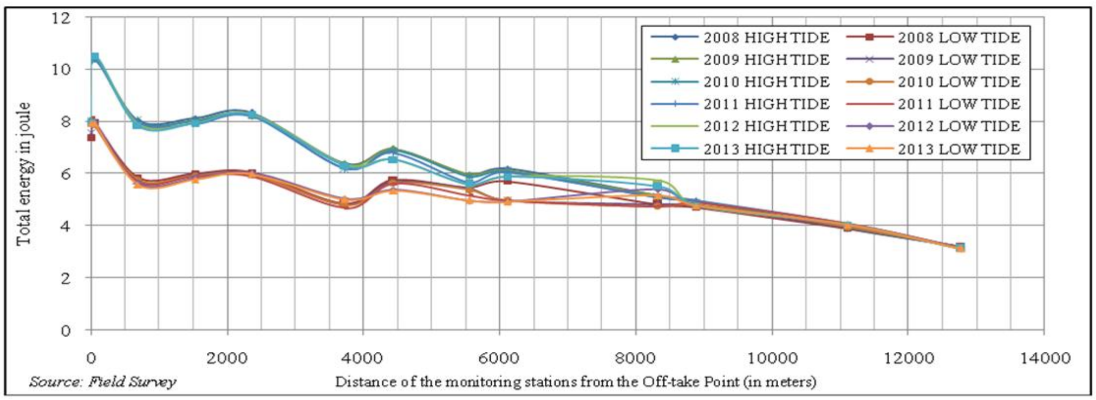

Fig. 11. Channel total energy

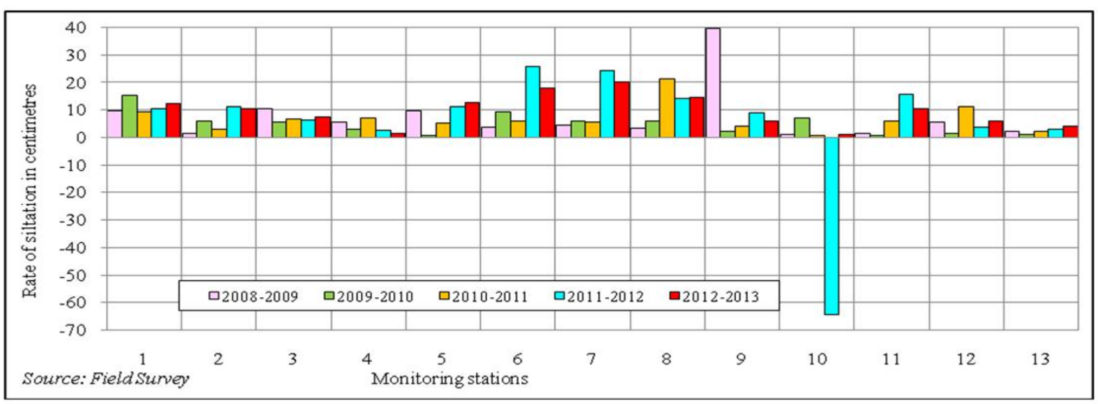

Fig. 12. Rate of siltation

7. CONCLUSION

In case of the active deltaic plains, decaying of rivers are common fluvial phenomena, and the Adi Ganga is no exception. Multiple parameters have been considered to evaluate the decay of the Adi Ganga. Statistical techniques have been adopted to correlate the variables. Tremendous efforts have been given to determine the actual scenario of the river. Various layers (channel aspects) are superimposed on one another. Due to high metropolitan growth and encroachment on both sides of the river, the river flow has been confined and converted into a narrow channel path. From the field data and various graphs, it is noted that, channel depth, channel cross-sectional area, channel width, and energy has been dropped drastically. The hydraulic radius value shows that, the river has lost its capacity to flow. Channel bathymetry also shows an unexpected shifting of the thalweg line, in different years, due to continuous dumping of residential and industrial wastes inside the channel bed. In the Tollygunge-Garia Section (8.5 kilometers), the Metro Railway Authority constructed five (Netaji, Masterda Surya Sen, Gitanjali, Kavi Nazrul, Sahid Khudiram) out of six stations (except Kavi Subhash station) on the bed of the Adi Ganga. The railway track supported by a row of 300 concrete pillars (which are 2 meters in diameter and 20 meters in distance) built inside the Adi Ganga. Kolkata Port Trust, Kolkata Corporation, and the Department of Irrigation, the Government of West Bengal dredged in few stretch to rejuvenate the river. Fluvial parameters are very much important to assess the present fluvio-dynamic status of the Adi Ganga. Natural deltaic process and anthropogenic activities are responsible for the deterioration of the Adi Ganga river.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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