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Summary and Conclusion

The present river management scenario in India is marked by a distinct display of unsustainable interventions without much heed towards safeguarding the ecological, hydrological and socio-cultural integrity of the rivers and their watersheds. The situation becomes much more complicated in view of the mounting stress from escalating population growth, unsustainable development pattern and damaging land use practices. Under these circumstances, integrated and comprehensive approaches towards management of rivers are considered as the desperate need of the hour.

The Kolong River of Assam is a suitable illustration of a degraded river system. The river with a total length of 218.62 km, a basin area of 5218.75 sq km and spreading over parts of Nagaon, Morigaon, Kamrup and Karbi-Anglong districts of Assam, is a major distributary of the Brahmaputra River. The present day Kolong River, flowing sluggishly through the plains of Nagaon, Morigaon and Kamrup districts of Assam is a result of various detrimental effects of human interventions perpetuated on it over last five decades. An earthen embankment erected across the mouth of the river during the year 1964 as an ad-hoc solution to the intensified flood hazards (as an aftermath of the 1950 earthquake) is the key factor responsible for its current deplorable condition (flow starved and polluted). In the upstream portion, three major tributaries namely Missa River, Diju River and Haria River contribute some amount of water into the Kolong River thus giving it a touch of life which otherwise, in absence of adequate flow is merely a flow starved urban channel.

The Kolong River basin exhibits a stable geological setting with 91.3% of the geographical area under fluvial sediments of quaternary period. The major geomorphic units of the Kolong watershed are identified as (1) flood plain (2) younger alluvial plain (3) older alluvial plain (4) valley fill (5) denudational hills of Archaean gneissic complex (6) denudational hills of Precambrian granites and (7) piedmont plain of Shillong formation [192]. During the study, the longitudinal profile of the Kolong River is found to have a gradient of 0.122 m/km which is in accordance with most of the other rivers of the region. However, the gradient upto Jagibhakatgaon is comparatively less i.e. 0.067 m/km while downstream of Jagibhakatgaon a sudden increase in gradient was observed i.e. 0.3 m/km. The prominent increase in gradient after Jagibhakatgaon can be explained as due to addition of enormous volume of flow from Kopili River into the Kolong River thus causing scouring of the river bed.

Groundwater potential is significantly high in the valley areas of Assam including the Kolong basin. However, despite having good groundwater prospect, the Kolong basin, marked by good number of both confined and semi-confined aquifers, the areas at the immediate vicinity of the Kolong River in both its bank suffer intense groundwater scarcity during the dry season. This decrease in groundwater yield is because of the lowering of the water table in these areas as groundwater is being contributed as base flow to the flow deprived adjacent waterbodies mainly the Kolong

River. Moreover, less precipitation during dry season, in addition to absence of dense cover of vegetation further diminishes the infiltration capacity of the adjacent soils thus affecting groundwater replenishment.

The pollution level of the Kolong River is well illustrated by the water quality index (WQI) values calculated based on the water samples collected from seven sampling sites. Average WQI values for pre-monsoon, monsoon and post-monsoon seasons were estimated to be 85.73, 122.47 and 80.75 respectively accounting for poor to unsuitable quality of water. The highly polluted condition of the Kolong River is because of the river being used as a sewage and garbage sink of the urban centers mainly Nagaon town and encroachment from the riverside developments. The pollution level is further aggravated by the lack of aeration capacity of the river and absence of dilution of the pollutants, both resulting from the lack of adequate flow.

During the study it has been observed that forest and agriculture account for the main source of livelihood to the people of the basin, most of them belonging to different ethnic communities. However, historical records throw significant light on the fishing and other river related livelihood dependence of the riparian population which is presently adversely affected in absence of river flow and floodplain wetland degradation. Many of the fisher folk have lost their livelihood due to lack of fishes in the river and hence are bounded to practice some other occupations like agriculture, daily wage earning etc.

The landuse/landcover change analysis indicates that the areas under built-up category have expanded haphazardly from 20.11% in 1967/68 to 35.24% in 2014. A total of 704.97 sq km of agricultural land has been converted into built-up area during the study period. Furthermore, areas under wetland, agricultural land, forest cover and open space have decreased from 5.34%, 41.7%, 26.48% and 1.04% to 4.87%, 27.77%, 25.2% and 0.26% respectively. The remarkable decrease of agricultural land observed during the study period is a serious matter of concern. Although, a marginal reduction in total area under forest cover is observed during the study period, however, the forest cover of the Kolong basin constituting several reserve forests namely South-Diju Valley reserve forest, Swang reserve forest, Bamuni reserve forest, Dabaka resrve forest, Lutumai reserve forest, Borapani reserve forest, Lokota reserve forest, Sonai-Kuchi reserve forest, Kholahat reserve forest and Marakdola reserve forest is still little higher than that of the total forest cover percentage of Assam (24.58%) as per records of Ministry of Forests and Environment, Assam (2016). Moreover, vegetation health analysis based on NDVI calculation shows a strong positive correlation between vegetation health and growing season rainfall (i.e. r = 0.94) of the study area.

In view of the absence of any observed hydrological database on the river, considerable efforts has been made in the course of this study to develop a comprehensive hydrological database for the Kolong River and its tributaries. Field measurements of discharge data have been made for the period 2012 to 2016 during three different season viz. pre-monsoon (PRM), monsoon (MON) and post-monsoon season (POM). The results show that a flow-starved situation prevails in the upstream of the Kolong River especially upto Hariamukh due to lack of any major flow contributing source. Minimum discharge of 0 cumec was observed at Hatimura during pre-monsoon and post-monsoon seasons. Maximum seasonal average discharge of 718.75 cumec was observed at Kajalimukh during monsoon season. High seasonal fluctuations of flow regime is found to be a prominent characteristics of the Kolong River marked by very low flow during pre-monsoon and post-monsoon seasons, while considerably high flow during monsoon season contributed mainly by increased precipitation and surface runoff.

Regression equations were generated in order to obtain time-series discharge data at ungauged stations. The regression equations thus obtained allows the estimation of the dependent variable (Q at ungauged station) based on the known independent variable (Q at gauged site). Stage-discharge rating curves are also constructed for the Kolong River and some of its tributaries based on available data so that existing water level data can easily be converted into discharge data at the given locations.

After obtaining the requisite discharge data either from historical records or estimated based on the regression equations and the rating curves, flow regime analysis was carried out for two different time periods at four different sites. The first time frame was 1984 to 2000 at Missamukh, 1983 to 1995 at Nagaon, 1977 to 1988 at Jagibhakatgaon and 1986 to1995 at Kajalimukh while the second time frame was similar for all the four locations i.e. 2011 to 2016. From the obtained graphs inferences were drawn which show that the mean maximum water level of Kolong River at all the four sites records a considerable lowering during the study period. The reason behind the decrease in peak discharge may be because of reduction of lateral connectivity of the river with its floodplains thus restricting the entry of the surface runoff into the river channel. Maximum and minimum water levels of two specific sites viz. Kolong River at Nagaon and the Brahmaputra River at Hatimura pumping site were also examined. These water level data will play an important role in formulating river restoration model based on regulated flow release scheme.

Flood frequency analysis has been done based on availability of data, and 10 year, 25 year, 50 year and 100 year design floods were estimated following the *Log-Pearson Type III* method. Subsequently, 25 year and 100 year design discharge thus obtained was further used for flow simulations using HEC-RAS software. Water surface profiles so obtained during HEC-RAS hydrological modeling reveal 25 year design water surface elevation at Hatimura, Missamukh, Nagaon, Jagibhakatgaon and Kajalimukh to be 75.78 m, 75.38 m, 72.85 m, 67.58 m and 52.67 m respectively. Similarly, 100 year water surface elevation based on obtained water surface profiles for the above mentioned stations has been measured to be 76.54 m, 76.11 m, 73.36 m, 68.47 m and 53.08 m respectively. Moreover, bankfull discharge (*Qbf*), which is also known as channel forming discharge, has been calculated for the Kolong River based on field measurements. The Q_{bf} values thus obtained is very much essential for regulated flow release planning and is considered as the basis for optimum flow estimation based on channel morphological characters.

Hydraulic geometry analysis has been done for the Kolong River by representing discharge as power functions of channel width, mean depth and mean velocity both at individual stations as well as in the downstream direction. The results reveal that the average values of '*at-a-station*' hydraulic geometry exponents *b*, *f* and *m* are 0.22, 0.38 and 0.4 respectively; while the average values of downstream direction exponent *b*, *f* and *m* are found to be 0.32.0.23 and 0.44 respectively. These values compare well with those arrived at by pioneer workers in this field and considered useful in river restoration programs.

Basin runoff characteristics are also well documented in the present study. The SCS-CN method given by USDA was applied for estimating the rainfall-runoff characteristics of the Kolong basin. The results reveal that the Kolong basin has very good runoff potential. The three principal sub-basins viz. Missa sub-basin, Diju sub-basin and Haria sub-basin contribute 20.72 % of total surface runoff of the entire Kolong basin, with each sub-basin having a share of 2.66 %, 5.9 % and 12.16 % respectively. Remaining portion of the surface runoff (79.28 %) is supplied by the rest of the Kolong watershed. Calibration and validation of the results were performed using the *Nash-Sutcliffe coefficient of efficiency* (*E*).

Channel morphological parameters are well established in the present study. Analysis of channel morphological attributes shows that bankfull width for Kolong River ranges between 10.6 m to 280.34 m. The channel exhibits widening tendency towards the downstream with a maximum value of 280.34 m at the mouth i.e. at Kajalimukh against a minimum value of 10.6 m at the extreme upstream location i.e. at Hatimura. Mean bankfull depth exhibits an overall positive correlation to bankfull width with its values ranging between 0.27 m to 12.73 m. Floodplain is generally asymmetrical in nature throughout the river length, with a general trend of widening towards downstream. The entrenchment ratio shows moderate to highly entrenched stream channel of the Kolong River from Missamukh towards downstream. However, less entrenched river channel is observed at Hatimura with exposed riverbed. In case of an entrenched river channel, flood water is less likely to spill over its banks, than in less entrenched channel.

The Sinuosity index (SI) values of the Kolong River channel vary from 2.18 in 1912 to 2.1 in 2015. Thus with the SI values greater than 1.5, Kolong River is identified as an intensely meandering river based on the classification system suggested by Leopold and Wolman (1957) [132]. The meandering nature of the

Kolong River is clearly visible in spatial datasets like in satellite imageries. As a consequence of the restriction of entry of flow into the river channel, the total length of the river channel has decreased from 250.48 km during 1912 to 218.62 km during the year 2015, with a total loss of 31.86 km. The reduction in sinuosity of the Kolong River from 1912 to 2015 can be justified by the reduction of the total length of the river channel as a result of multiple factors like drying up of the river channel in the extreme upstream portion or reduction in sediment flushing due to lack of sufficient flow leading to chocking of the mender bends, thus cutting out of meander loops into abandoned oxbows etc.

A study determining the rate of erosion and deposition of Kolong River was carried out for two distinct time frames viz. 1912 to 1967/68 and 1967/68 to 2015. Interestingly, in comparison to other alluvial rivers of the region, the Kolong River represents negligible erosion and deposition during the 103 years of study period. It has been found that total area lost as a result of erosion is 9.7 sq km while total area gained as a result of sediment deposition along its bank is 16.12 sq km during the time period 1912 to 1967/68. On the other hand, the total area eroded and deposited during the time period 1967/68 to 2015 are found to be 6.25 sq km and 8.22 sq km respectively. The average rate of erosion and aggradation was estimated to be 0.17 sq km y^{-1} and 0.29 sq km y^{-1} respectively during the period 1912 to 1967/68, while during the second time frame i.e. 1967/68 to 2015, the annual rate of erosion and deposition were 0.136 sq km y^{-1} and 0.17 sq km y^{-1} respectively. In general, three types of channel shifts have been observed along the Kolong River channel viz. neck cut-off, chute cut-off and meander shifts with an estimated mean annual bankline migration rate of 0.11m y^{-1}.

Thus, based on the hydrological regime and water quality index results, it is clear that the Kolong River and its watershed need an appropriate and sustainable restoration strategy. Therefore suggestions towards framing a comprehensive restoration plan incorporating various problem areas and their probable solutions are advanced in the present research. Considering bankfull discharge (Q_{bf}) as the channel design discharge it is regarded as the optimum flow to be maintained while allowing design flow in the Kolong River channel by regulated opening of the link between the Kolong River and the Brahmaputra River. For such regulatory procedures, the provision of environmental flow needs to be strictly adhered in order to maintain the health of the river and to ensure sustainability of its various ecological services to the community. A highly efficient and operative sluice gate system designed with state-of-art engineering know-how for maintaining a design flow within the Q_{bf} based on a meticulously planned and properly executed schedule of operation will be the cornerstone for controlled flow release plan in the present case. Proper provisions of check-dams wherever necessary at the sub-basin level and improving the water holding capacity, inlet-outlet channel connectivity, and ecological health of the existing wetlands are some of the subsidiary activities suggested to be taken up under the proposed plan.

Since flood control was the main objective behind the construction of the Hatimura dyke, hence, the flow release plan should go in close association with proper measures keeping in mind the possibility of some high flow situations. Hence, the possible water surface elevations at two different magnitudes of flood viz. 25 year design flood and 100 year design flood were modeled using the HEC-RAS software. The water surface elevation values thus obtained for the entire river channel will be an essential tool for identifying areas where flood control levees need to be constructed or height estimation for designing new levees or rectifying the existing ones if necessary.

Besides releasing regulated flow from Brahmaputra River, a detailed earth work (dredging) involving technical expertise for reshaping the river channel and making it competent enough for holding the new flow is necessary. Hence, an in-depth elevation study is carried out at the Kolong River take-off point using high resolution UAV images. The elevation differences between bed levels of the two concerned rivers viz. the Kolong and the Brahmaputra are well portrayed in the Digital Surface Model (DSM) thus generated. Further, strategies for water quality improvement, sediment control, wetland connectivity, stakeholder involvement and post-project appraisal are suggested.

A scientific management paradigm like this, based on regional framework of planning with proper administrative and political decision making and stakeholder involvement, appears to be the prime need of the hour in restoring the degraded Kolong River. The necessity of adopting suitable river training works for stabilization of the channel in a desired way with provisions of dykes, guide bunds etc needs to be explored during proper implementation of the river restoration plan. Moreover, in respect to the Brahmaputra River at the takeoff point, a careful investigation should be carried out to map the spatio-temporal changes of the channel, its bankline shift, erosion and bed aggradation etc.

The need for restoration of the Kolong River has been reiterated throughout the present work based on analysis and observations carried out on different aspects of the river and its watershed. Therefore, the present study leads us to the conclusion that the Kolong River is a fit case for restoration and the possible pathways towards achieving this goal are suggested in this study.

Few photographs related to the study

Plate 7.1 The Hatimura dyke showing its A) Brahmaputra side B) Kolong side

Plate 7.2 Confluence point of Kolong River and Missa River during a) Pre-monsoon b) Monsoon

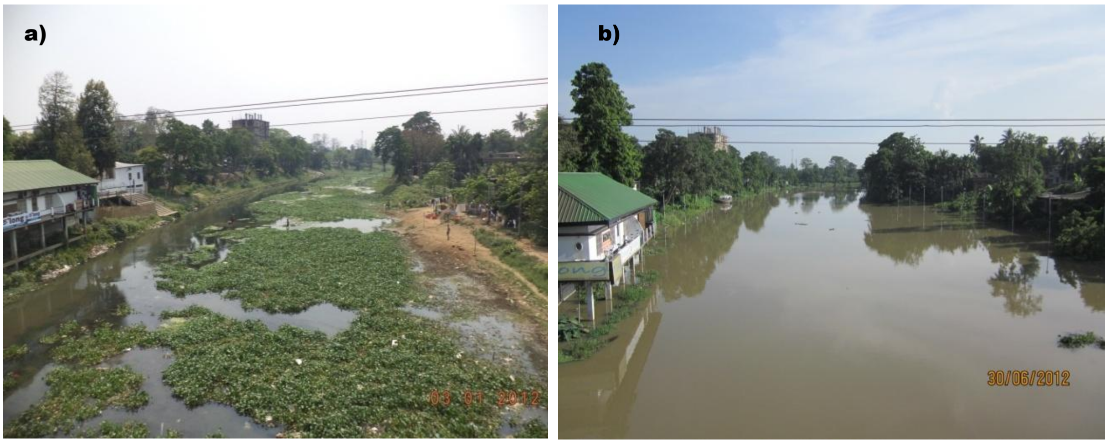

Plate 7.3 Kolong River at Nagaon Town during a) Pre-monsoon b) Monsoon

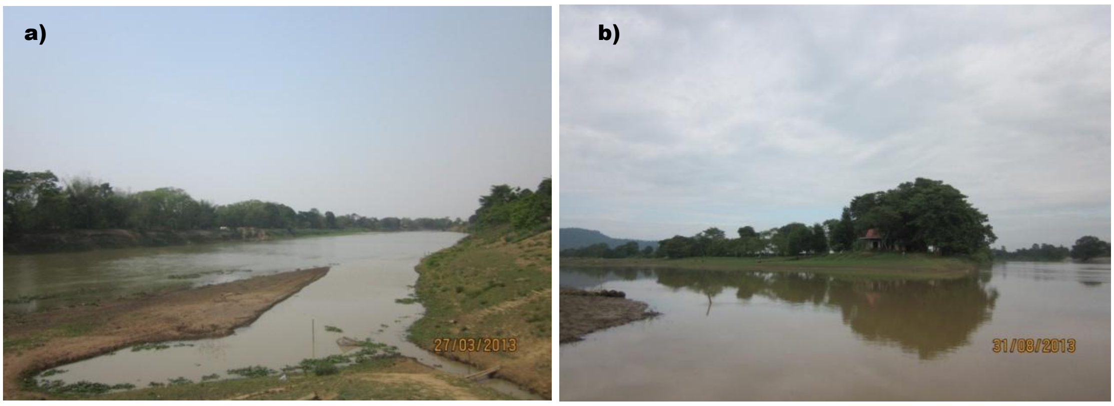

Plate 7.4 Confluence point of Kolong River and Kopili River during a) Pre-monsoon b) Monsoon

Plate 7.5 Kolong River at Kajalimukh during a) Pre-monsoon b) Monsoon

Plate 7.6 Brick-kilns near the Kolong River

Plate 7.7 Solid waste dumped on Kolong River near Nagaon Town

The author with her guide and Mr. G. Bora, a local engineer at the Kolong river takeoff point

The author with an employee on the floating barge used for lift irrigation at Hatimura

The author during socio-economic survey

The author during water sample collection

The author during historical data collection

The author with Late Mahim Bora, a litterateur of repute famous for his works on Kolong River

Plate 7.8 Snap during field visits and data collections