Space Borne Technology in Assessing and Monitoring Bank Line Erosion of Busu River, Lae City, Papua New Guinea.

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Abstract

River is one of the natural features that can cause mass damage to the surrounding environment. River bank erosion is a common hydrographical issue that are experience around the world. Cities, infrastructures, communities that are located near or within the fast flowing rivers do always experience issue related to bank erosion. Continuous actions of such river issues can lead to reduction of economic stature of a region. The study was carried out to highlight and discuss specific hazard due to morphometric changes in the upper meander stream of Busu River, Lae city. The shift of river channel from time to time were analysed from 2006 high resolution Quickbird satellite image at 3.5 metre spatial resolution and 2012 Lidar image at 20cm spatial resolution coupling with 2000 base map. The analysis had shown quite major differences in each year time interval on how river shifted and caused related hazards. From the analysis it was found out that, bank line erosion or cutting was mainly because of presence of hard rock that induce high velocity and presence of lose and fine granular soil and rock structures. The analyses were all carried out in GIS and Remote Sensing environment. The study was furthered to highlight and discuss possible cause or areas of high rate of bank erosion within the study region. The study aims to undertake the river shift prediction analysis and to identify possible areas of installing embankment with fixed mitigation actions that are to be taken.

Key words: *River Shift, River Impact, Remote Sensing, Busu River, Change Detection*

1. Introduction

River has been one of the natural geomorphological agents that cuts, carry and deposits the materials from the surface. It is the agents that also do contribute to shape the earth surface where we currently live on (Aher S, 2012). Within different discipline of study, many researchers have carried out related study on river shift and bank line erosion with its related hazard. Das et al. (2012) have discussed about geomorphologic segments like river shifting, bank erosion that displays the chronic picture and associated problem regarding human society in terms of loss of property. His study was based on measuring temporal river shift and assesses the related hazard associated to such process. Milton et al. (1995) and Hickin (1983) also have discussed about the river channel migration through time and space that has a critical problem in river management system. Thus river shift and bank erosion do leads to problems like destruction of infrastructures like roads and bridges, evacuation of communities, reducing of land available for development purpose. It is obvious to our understanding that, such infrastructures, communities living there, informal or formal settlers and their land use, contributes to maintaining and improving the economy stature of a region. The concern lies here is the communities and infrastructures located within the riverine zone are more vulnerable to hazards caused by river. The effective monitoring and assessment of river bank line erosion can help, protect and secure available land and preserve the latter for development, protect the settlements area and infrastructures built along the river (Das et al.2012).

Lae being the largest industrial urban town in PNG has vast manufacturing, and various industries operating in the city including private and public business firms, institutions and settlements in every corner of the city. Currently the city is expanding, posing substantial pressure on the available land. That is industries and business firms are increasing including settlements and institution. However the city is located within three major rivers and these are Markham River, Bumbu River and Busu River and the concern here is; the rivers are slowly eroding the available landmass and decreasing the land availability of the city and forcing settlers to relocate or migrate away.

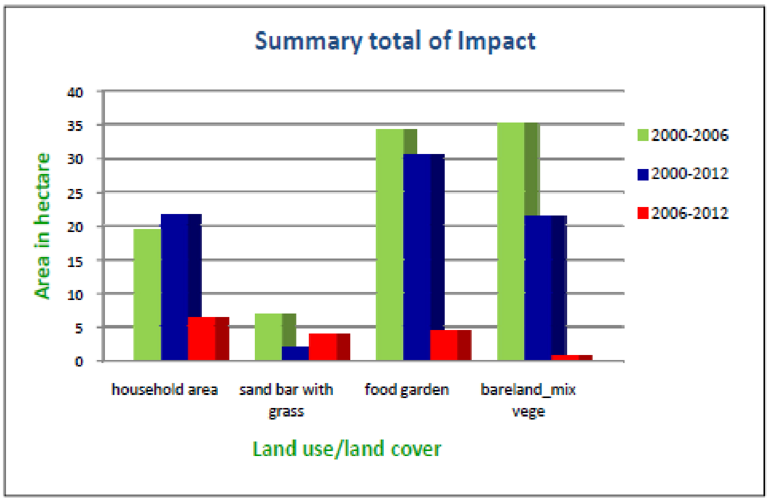
The current study is based on highlighting and discussing the specific sites at the upper meander stream of Busu River, where these sites are found to be more prone for bank line under-cutting causing severe attrition. From the past up to present, many communities have been evacuated due to bank line erosion within the study region. Furthermore the available lands, food gardens, roads have also been washed away or eroded (Sekac T, 2014). The study is trying to identify and quantify specific causes and source of bank cutting and erosion and furthermore to calculate and identify land area eroded between time to time, where these have assisted in predicting the future shift and location of Busu River through applying interpolation technique (Das et al. 2012).

For the current study, change detection study was mostly applied through utilizing time series remotely sense data coupling with base maps and field visit data. Change detection study is a study that utilized images or maps of different years for the same area (Moghadam et al, 2012). Through this study it is easy to find out the impact the River has caused, or is causing or will cause to the surrounding environment. The result of study can bring about better understanding of river flowing pattern, changing or shifting of river course and its impact. The study can assist in preparing better mitigation measure to achieve the 2050 development goal of the country.

1.1 Problem Statement

Busu River is a fast flowing river in PNG. It cuts, erodes and deposits at high rate. During the field visit, the velocity of Busu River was measured and calculated to be 4.44m/sec, which indicates that the river has high velocity. From the previous study done (Sekac, 2014), with change detection technique, it was found out that huge expanse of land and huge number of households have been eroded or removed from time to time. Figure 1 illustrates the impact caused by Busu River channel migration and shift from year 2000 to 2012. It was the overall assessment for whole Busu River, starting from Busu Bridge all the way down to the sea.

Within the current study area, it can be seen from the locality map (figure 2) that the Busu River is eroding and heading towards city zones where more infrastructure, households and available land are to be removed or eroded (affirmation from experience). It is from the experience that, there has been water ways created to divert or change the river course so that the river can’t head towards city zones, however due to existence or available of hard rock within the study region, it is practically impossible to divert the river in order to save the city zones from attrition. Hence currently the river is still eating away the bank line towards city zones.



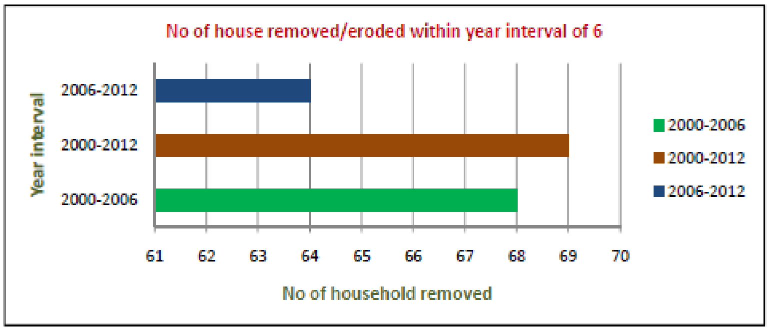


Figure 1: Summary total of impact of Busu River Course change (Source: Sekac, (2014))

1.2 Importance of the Study

1. The output of the study can lead to better upstanding of proper place to build embankments and prepare mitigation measures
2. Both communities, weather informal or formal settlers with available land and infrastructures, do contribute to build and maintain the economy of country. Such study might be helpful in protecting the socioeconomic status.
3. The study can help in understanding the future flow of Busu River, where proper development planning can be effectively done to achieve 2050 development goals.

1.3 Objective of the Study

(a)To demarcate and highlight the possible source, direction and area of bank erosion and river shift

(b)To calculate and measure the impact

(c)To predict the future position or future shift of Busu river

1.4 Study Area

The study area is located within Lae city, the second largest industrialized city in Papua New Guinea (PNG). As far as three major rivers are concerned that exist within Lae city, the study was only carried out at upper meander stream of Busu River that flows South-East direction and is about three (3) kilometres in length and hence located between 60 38’20 S, 6039’40S and 1470 0’40E, 1470 1’00E. The study was fully concentrated on these sites as mentioned because the sites are more vulnerable for erosion and bank cutting, where the researchers have previously experienced up to present. Also the sites have been selected for study because the gateway of direction of erosion and bank cutting, as it can be seen it figure 2, are towards or into city zones which is dangerous. Therefore the sites selected for study is important here. The study area has been again divided into indicating sites 1 and 2 or location 1(LC1) and location 2 (LC2) for precise analysis and assessment.

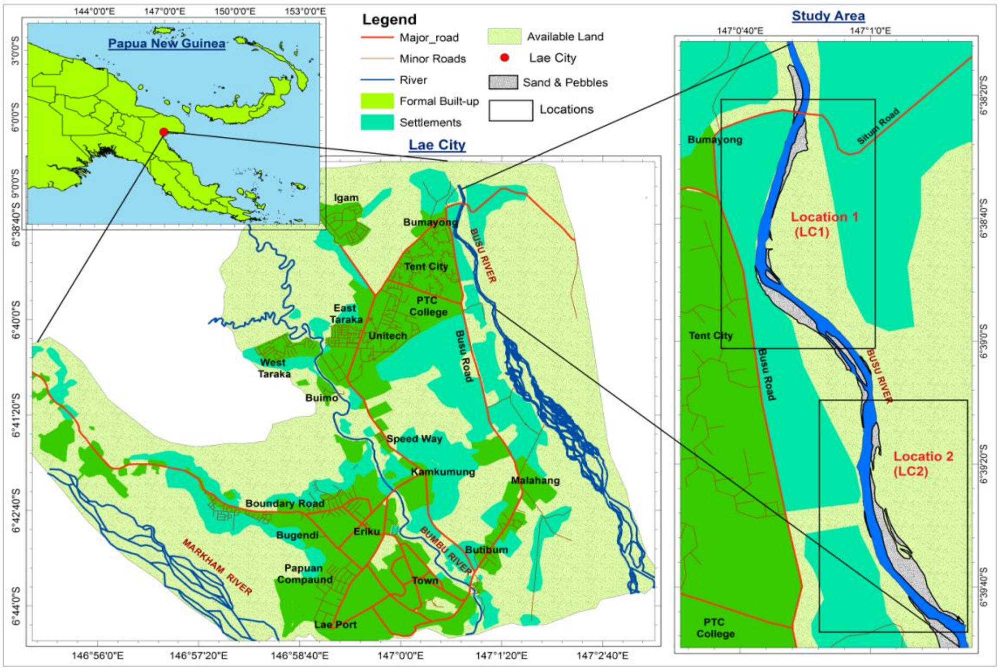


Figure 2: Study area locality map (source: Author, 2016)

2. Research Methodology & Data Used

For the present study several remote sensing images of the same area captured at different years were used. The data used were, base map of Lae and Environs, 2000 at a scale of 1: 10 000. The map was produced from 1:10 000 scale othorphoto, 1: 25 000 topographical map and 1:4000 scale cadastral plans and finally was updated from 1:10 000 scale aerial photos (flown Feb, 2000). The other data used was high resolution Quick bird satellite image at 3.9 meter spatial resolution of Lae city captured in 2006. The last and foremost data used for the study area was LIDAR image (othorphoto) of Lae city captured in 2012 at 20 cm spatial resolution. For each time series data, the study area was cropped and each and every individual layer of the study area was digitized and extracted using ArcGIS 10 software. The features are mainly river network of each year, formal built-up areas and settlements, road network, hard rock and unoccupied or available land area. These are the main features that were digitized and extracted. The three types of time series data collected and prepared for analysis are of years 2000, 2006, and 2012 that are of 6 years intervals. Furthermore the data were also acquired through Field visit and local interview with the questionnaires. One of the main data acquired during field visit was the velocity of Busu River. Hence the Velocity of Busu River was measured and calculated to be 4.44m/sec.

These data were purposely used for verification and help in area calculation and assist in estimating number of features, for example number of household in the study area that were removed or are still there. The field data was also used to verify the changes or shift of Busu River from time to time and to determine the river force applied at each bank line. The base data needed for analysis is tabulated in table 1.

All the data digitized and extracted were all assigned same projection system, i.e., all the data layers were projected to UTM projection system, WGS 84, southern hemisphere. This is because the data are to be overlaid and the differences are to be measured and calculated. Basically, proximity and overlay analysis were carried out. The evaluations were mostly carried out on the left lateral bank lines of LC 1 and LC 2, because these are the sites where the Busu River is trying to break into the city zones.

Table 1: Data layers used for the study

data type	**scale/resolution**	**source of data**
Base map of Lae and environs -2000	1: 10 000	Lae city council office
Quickbird satellite image-2006	3.9m spatial resolution	Lands and physical planning Department
Othorphoto(LIDAR) data-2012	20cm spatial resolution	Lae city council office
Field visit and local interview with the questionnaires		

To further the analysis part into measuring and calculating the river shift, bank lines erosion or cuttings, number of household, infrastructure or properties removed and to predict the future shift or position of Busu River, the number of 10 transect/cross-section line named from ‘A’ to ‘J’ were drawn across the river for both LC1 and LC 2 (figure 4). This technique was applied simply to calculate impact and rate of river shift or change between each cross-section (Thakur et al, 2011) where it can easily assist in doing prediction of future position of river (Das et al. 2012; Nguyen et al. 2010; Laha & Bandyapadhyay, 2013). Field visit and local interview data taken were also used to verify and help in calculation of impacts and finding out possible cause and source of bank line erosion. The calculation and findings were done location wise and cross-section wise.

Firstly the year 2000 and 2006 river vector data were overlaid and the river shift and properties or area eroded were evaluated between each cross-sections of each location. The same technique was applied to evaluate for year 2006 to 2012. Finally the combined impact or effect analysis was carried out for year 2000 up to year 2012. From the findings of the river shift and impact imposed, the data were used to do prediction between each cross-section for each location. The prediction technique employed was the interpolation techniques adopted from Das et al. (2012). Figure 3 illustrates the overlay analysis and the changes of river taken place between each year.

From the field visit, questionnaires and interview with the knowledge of actual experience, the source that diverts, direct and increase the river velocity which leads to bank line erosion at two sites were identified and mapped. Also with the help of change detection done with respect to remote sensing data, the possible sites of erosion and the direction of force applied were demarcated. The analysis and demarcation was done based on the idea and affirmation that the Busu River is to break into Lae city zones.

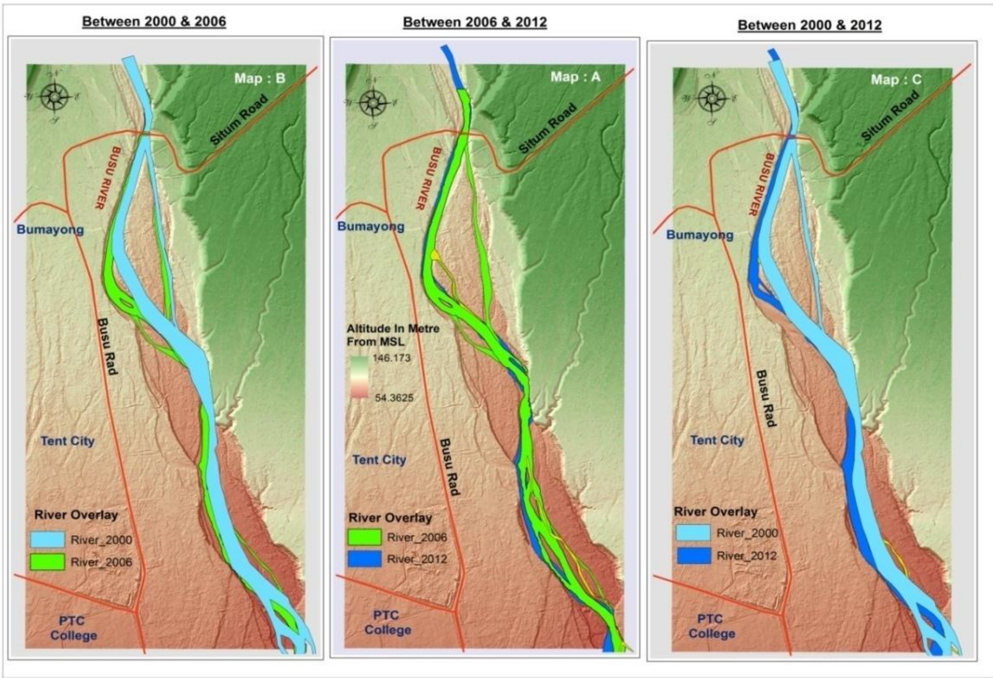


Figure 3: Busu River shift between years (source: Author, 2016)

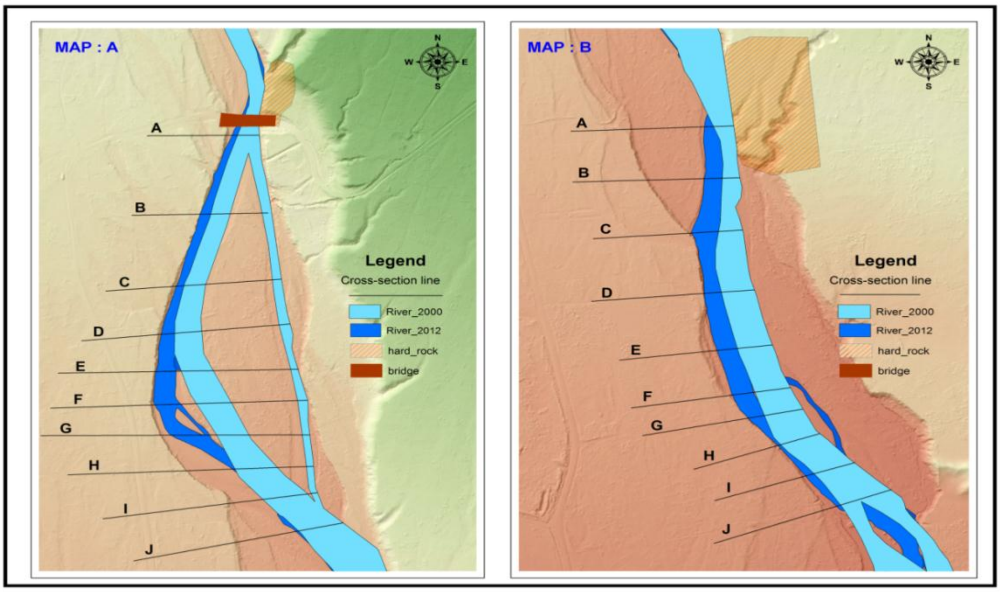


Figure 4: Cross-Section lines drawn to measure river shift and impact (Map A-LC 1 & Map B-LC 2) (source: Author, 2016)

3. Results and Discussion

The section here explains, illustrates and discusses all necessary findings or results from specific analyses that were carried out. The results and findings were all limited to the objectives of the study as stated above, field visit and field survey, time, data availability and cost of study. The study has been carried out with the help of remote sensing data with ArcGIS 10 software and MapInfo Professionals. All the data were individually processed and analysed in a GIS environment. After overlapping the prepared shape files with assumed cross-section line drawn, the changes of river course, the cause of high river velocity, bank erosion and its societal impact with future prediction were identified and analysed.

3.1 Investigation of Possible Source, Direction and Area of bank erosion and river shift

From the past to present, Buss River has cut/eroded huge amount of land masses, household and food gardens. One of the researchers, who is also a victim of Busu River bank line erosion, societal impact have been analysed and from his point of view for about 20 years' time period, have discovered significant knowledge and idea on behaviour and characteristics of Busu River flowing system. By involving the space borne technology within GIS environment, the changes of Busu River channel shift were identified from time to time (figure 3). For LC 1, it was found out from time to time that the river directions of force were always and possibly to the south-westerly direction, there the possible bank line erosion normally occurs exactly where the meandering patterns exist. For LC1, it was identified through field visit and also with remote sensing data, that there exists a huge hard rock in the north-east part of study area right at where another meandering river pattern exists above Busu bridge (figure 4&5). It was quantified that this is the hard rock where river hits and gain strength (increase velocity) that causes aggravated erosion at the backline south-westerly of LC 1 river bank.

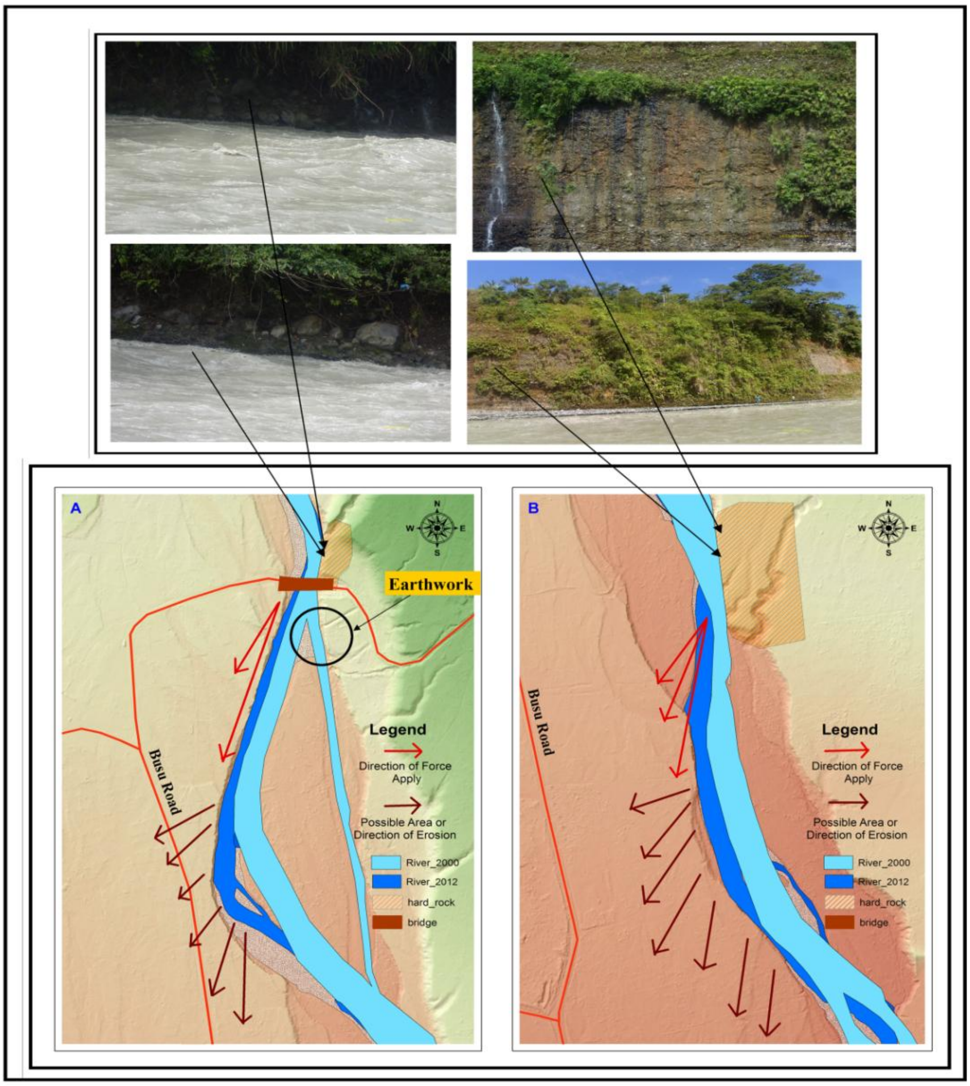


Figure 5: Possible direction of river force and erosion (Map A-LC1 & Map B-LC2) (Source: Author, 2016)

The climatic condition of PNG is wet and dry and during wet period with heavy down pour, the river floods. Every time as the river floods, the bank lines at LC 1 in the south-westerly direction to the meander sites (Figure 4&5), are always eroded and cut (from researcher point of view) approaching into the Lae city inter zones.

By taking this into consideration, there have been dredging or earth working took place between year 2005 and 2006 to change the course of Busu river to lead to the south-easterly direction (figure 6) where the paleo channel was found for year 2000 image. However due to the presence of hard rock, the result of work done was negative and currently the river is still flowing and eroding in the south-west part of LC 1 within and around the meander sites (figure 4& 5). Thus at the meander part where the river is currently exacting pressure, there is no existence of any hard rock. The soils out there are soft and loose mix with sand and pebbles that makes sites more prone for erosion. Figure 5 (A) illustrates the findings, quantification and affirmation of possible direction or force of present river flowing system including possible area of erosion. Also the figure illustrate where the hard rock was identified for LC1. Figure 6 illustrates the current river flowing pattern at LC1.

For LC2 there have been massive bank line erosion and cutting that have occurred from time to time up to present. Form the actual field visit and from researcher experience and point of view with the assist of remote sensing data, the possible areas and direction of erosion were identified and mapped. It was found out that, due to existence of hard rock in the north-eastern part of study region at LC 2 where the meander pattern exist, the river does hit and acquire pressure and force (increase velocity), where this result in high velocity that cuts and erodes and curve the bank line in the west and south-westerly direction thus leading into Lae city inter zones. Figure 5 (B) illustrates the findings, quantification and affirmation of possible direction of river force and erosion with demarcation of hard rock.

Figure 6: Flowing direction at Location-1(source: Author, 2016)

3.2 Impact Assessment

From the previous study, it has been found out that the flowing characteristics of Busu River have caused massive destruction towards surrounding community, infrastructures, food gardens and available lands. For the current study multi-temporal remote sensing images with base maps, were used to find out the changes of river course and upon those changes, the impacts that it have caused towards surrounding environment were evaluated.

From each cross-section line as were discussed earlier, the river shifts between each year were measured for both LC1 and LC2 and between each cross-section line, the amount of land masses removed and the number of household eroded or removed were measured. The main idea here in impact assessment is simply to find out how much in metre the river has shifted towards city zones from time to time and to find out how much in square metre the river have eroded the bank line from time to time. Also the task has been to find out the number of households that were removed or eroded from time to time. The analyses done and the findings/results are all presented in graphs and charts below. Figure 7 'A' and 'B' illustrate the actual map of river shift in metre and its impact. Figure 8 illustrates the graphs prepared to highlight shift in metre between each time interval for both locations (LC1 & LC2). It was measured with respect to each cross-section line. Figure 9 illustrates the findings of impact based on amount of landmass eroded/removed and number of household remove due to river shift between time to time. Figure 10 illustrates the actual current images taken to highlight the areas of impacts. The analysis and findings here were used for predicting the next shift or possible location of Busu River.

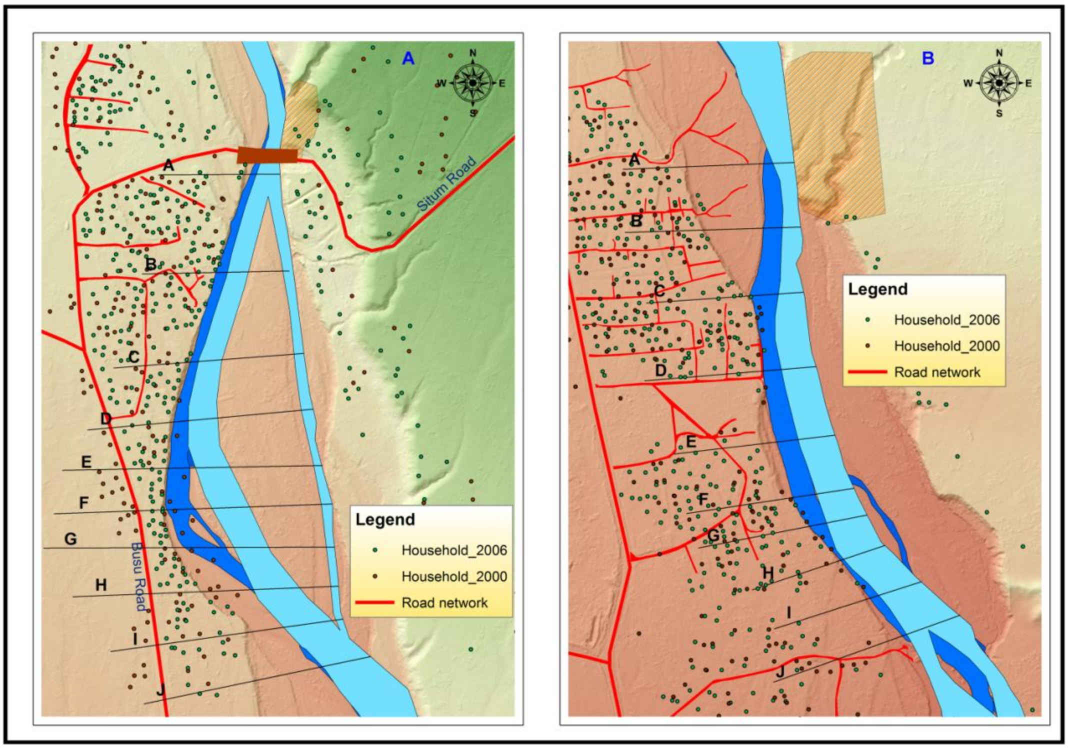


Figure 7: River Shift and impact between year 2000 & 2012(source: Author, 2016)

From the analysis and evaluation the results and findings were output. For location 1 (LC1) between year 2000 and 2006, the river has much shifted in between cross-section 'D' up to 'H' (figure 8) where huge amount of land mass with its features have been removed or eroded (figure 9). Between cross-sections 'A' to 'D', the river shifts have maintained at minimum steady rate as it can be seen in figure 8. The bank line or areas between cross-section lines 'D' and 'H' are said to be highly prone for erosion during flood. Consequently between 2006 and 2012 for LC1, beginning from cross-section ‘F’ all the way to ‘J’, there has been deposition taken place, where it is believed that currently the river force is directly applied at the bank line between cross-sections ‘C’ down to ‘E’. However from cross-section ‘A’ to ‘F’ the river shift maintain at minimum where erosion or bank cutting is minimum. From figure 8 and 9, it can be seen that the graphs highlights the negative values, thus this gives the idea that the river has shifted away from bank line and hence resulted in huge deposition (figure 7). For LC1 from year 2000 all the way to 2012, there has been quite a substantial number of households removed at the sites indicated between cross-section line ‘A’ to ‘B’ and ‘D’ to ‘H’.

For LC2 from year 2000 to 2006, the distance of river shift maintained below 50m and the changes across or between cross-section lines maintained no proper trend, thus it is changeable from cross-section to cross-section. The maximum amount of bank line erosion took place were from cross-section ‘B’ to ‘F’. From year 2006 to 2012, the river shift starts increasing from cross-section line A up to E and then again decreases down to I. The amount of erosion follows the trend of how river have shifted. It can be seen from figure 9 for LC2 that maximum erosion or bank cutting have occurred between year 2000 to 2006 where between year 2006 to 2012 the impacts were minimum. This was due to how intense were the flooding that have occurred from time to time. The bank erosion or bank cutting pattern at LC2 is curvilinear. Furthermore from year 2000 all the way to year 2012 at between cross-section line C and D there have been maximum numbers of household removed or eroded followed by loss of available land. Thus these areas are vulnerable areas of erosion.

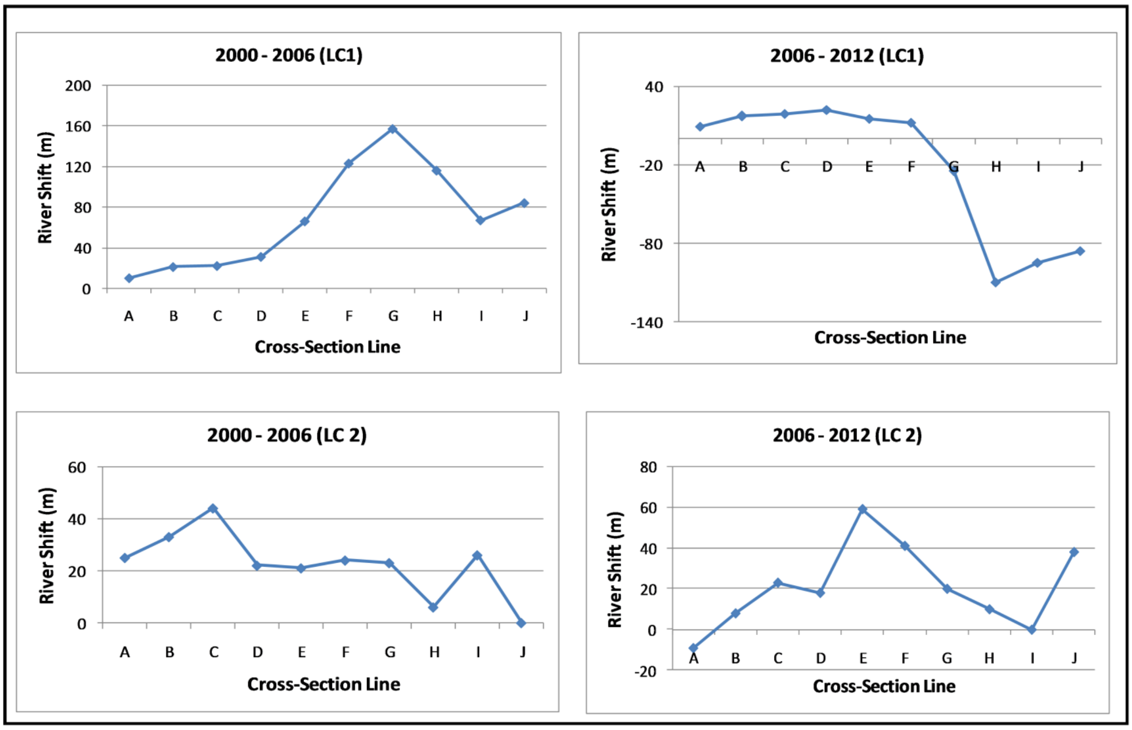


Figure 8: River shift measure in metre (m) at each cross-section line (source: Author, 2016)

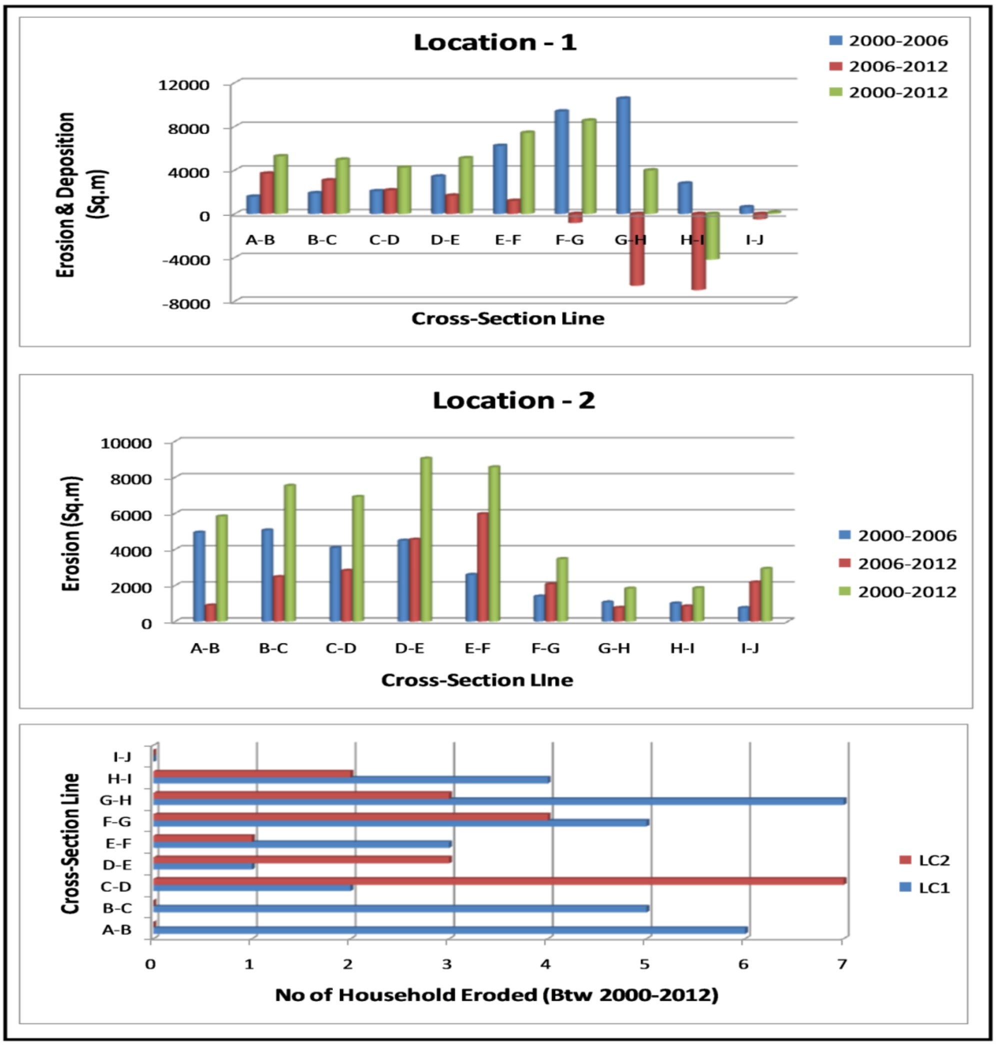


Figure 9: Impact findings between each cross-section line from time to time (source: Author, 2016)

Figure 10: Images taken by Author during field visit to highlight related impact of river shift

3.3 Predicting the Future River Shift

From the analysis and evaluation as discussed above, the necessary results were generated (figure 7, 8, 9). Hence the data were then used to carry out certain analysis and calculations to demarcate the future shift and location of Busu River. Also to point out amount of landmass and properties that can be possibly eroded and removed. Simply extrapolation method with intense calculation was applied to find out possible shift in metre of river. The river shift data for year 2000 was extracted and measured compared with 2006 and 2012; there the calculation was done collaboratively between each time interval to point out possible location of Busu River in 2030 through 2050 years of time period. According to Das et al. (2012); Nguyen et al. (2010); Lagasse et al. (2004b) &Heo et al. (2008), the future prediction of river shift can be evaluated or possibly done through utilizing and analysing the past related data of river shift between times to time (past year interval). For the present study the extrapolation technique was employed in GIS and remote sensing environment to calculate and find the distance in metre where river is to be shifted for year 2030 and 2050. From the survey and field visit, it was found out that at both locations, the river has a tendency to shift towards city zones. Thus the prediction was done to highlight the possible areas of future erosion and bank line cuttings and possible future location of river, that is to bring to the understanding of local community and governing bodies where mitigation and awareness measure can be possibly implemented at rightful location to minimize and avoid risk. Table 2 and 3 tabulate the possible data acquired with possible calculation done.

During calculation, some values were calculated to be negative. Thus this indicates the river shift is negative. The calculated values were then integrated in GIS environment using ArcGIS tool to demarcate the shift measure. Mainly the base data used was for year between 2000 and 2006. The subtraction was done between data for 2 years' time period and then was multiplied by year difference and again added to the base data to come up to the final output for year 2030 and 2050. The calculation done and value output were all demarcated on the map. Figure 11 illustrates the demarcation and extrapolation done for both location based on the calculated values.

Table 2: Linear extrapolation calculation to Measure River shift at LC1

Cross-section	2000 (no data)	2000 – 2006 (Shift in metres)	2006 - 2012 (shift in metres)	Predicted-2012 (shift in metres)	Predicted-2030 (shift in metres	Predicted-2050 (shift in metres)
A	0	10	19	(10-0)2/1+0=20	(19-10)4/3+10=22	(22 - 10)22/19+10=24
B	0	21	38	(21-0)2/1+0=42	(38-21)4/3+21=44	(44-21)22/19+21=48
C	0	22	41	(22-0)2/1+0=44	(41-22)4/3+22=47	(47-22)22/19+22=51
D	0	31	53	(31-0)2/1+0=62	(53-31)4/3+31=60	(60-31)22/19+31=65
E	0	66	81	(66-0)2/1+0=132	(81-66)4/3+66=86	(86-66)22/19+66=89
F	0	123	135	(123-0)2/1+0=246	(135-123)4/3+123=139	(139-123)22/19+123=142
G	0	157	132	(157-0)2/1+0=314	(132-157)4/3+157=124	(124-157)22/19+157=119
H	0	116	6	(116-0)2/1+0=232	(6-116)4/3+116=-30	(-30-116)22/19+116=-53
I	0	67	-28	(67-0)2/1+0=134	(-28-67)4/3+67=-60	(-60-67)22/19+67=-80
J	0	84	-2	(84-0)2/1+0=168	(-2-84)4/3+84=-31	(-31-84)22/19+84= - 49

Table 3: Linear extrapolation calculation to Measure River shift at LC2

Cross-section	2000 (no data)	2000 – 2006 (Shift in metres)	2006 - 2012 (shift in metres)	Predicted-2012 (shift in metres)	Predicted-2030 (shift in metres	Predicted-2050 (shift in metres)
A	0	25	16	(25 -0)2/1+0=50	(16-25)4/3+25=13	(13-25)22/19+25=11
B	0	33	41	(33-0)2/1+0=66	(41-33)4/3+33=44	(44-33)22/19+33=46
C	0	44	67	(44-0)2/1+0=88	(67-44)4/3+44=75	(75-44)22/19+44=80
D	0	22	40	(22-0)2/1+0=44	(40-22)4/3+22=46	(46-22)22/19+22=50
E	0	21	80	(21-0)2/1+0=42	(80-21)4/3+21=100	(100-21)22/19+21=112
F	0	24	65	(24-0)2/1+0=48	(65-24)4/3+24=79	(79-24)22/19+24=88
G	0	23	43	(23-0)2/1+0=46	(43-23)4/3+23=50	(50-23)22/19+23=54
H	0	6	16	(6-0)2/1+0=12	(16-6_4/3+6=19	(19-6)22/19+6=21
I	0	26	26	(26-0)2/1+0=52	(26-26)4/3+26=26	(26-26)22/19+26=26
J	0	0	38	(0-0)2/1+0=0	(38-0)4/3+0=51	(51-0)22/19+0=59

The map at figure 11 actually portrays the 2030 and 2050 bank line position or location of river shift; that is where it will be. It was assumed that due to high river velocity (4.44m/sec) and also due to presence of hard rocks, the river has a tendency to hit and erode the bank line towards city zones at South-West direction.

The extrapolation calculation was done to highlight future river bank line after erosion, however the erosion or bank cutting can be slow or fast depending upon amount of rain that can induce or contribute to flooding, rate of human activities along or near the river bank, levels of earthquake events where this can lead to landslide because the height of current river bank, which is measured to be roughly 10 -12 metre steeply high at LC 1 from cross-section line 'A' to 'G' and 4 -6 metre gently to steeply high at LC2 from cross-section 'B' to 'I'. Thus explained here are the medium or factor that can contribute to determine rate of bank line erosion or bank line cuttings for the next 20 to 30 years' time period.

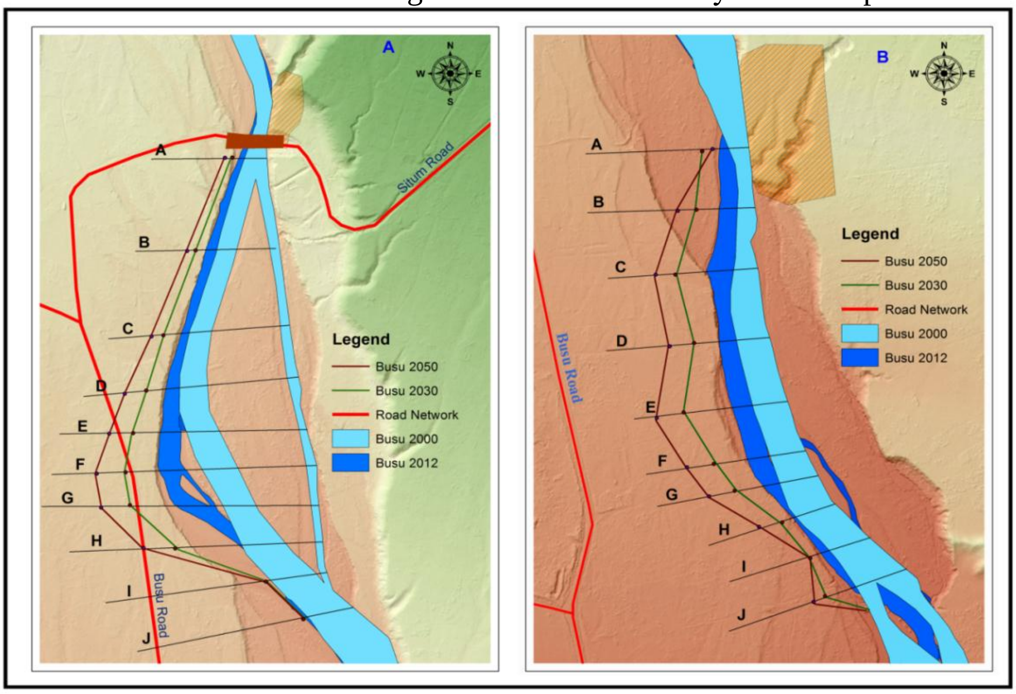


Figure 11: Prediction of River shift by 2030 and 2050 (Map A-LC1 &Map B-LC2) (source: Author, 2016)

4. Conclusions

The current study have mainly concentrated on the left lateral backlines due to idea that the bank lines are more erode-able where erosion and bank cutting can continue into city zones. The study shows that between years 2000 to 2012, Busu River shifted and hence several households, landmasses, infrastructures and properties have been removed or eroded within that time frame. It was found out that major impact of Busu river course change happened to be at the Left side. Presence and absence of hard rock in each sites within study region, high flow velocity and flowing pattern is the main causes of bank erosion and river course shifting. Changing river morphology and human activities have also contributed to higher river bank erosion and its societal impact. Local people have faced severe problem from bank erosion as they have lost residential and farm land, incurred loss of agricultural productivity and other valuable properties. From the study, based on river shift and measurement done, the predictions of future river location or bank lines location were demarcated. It was found out that the river has a tendency to move, shift and erode into city zones. The current research study has tried to identify the possible areas where governing bodies have to focus on minimizing the risk and hazard related to Busu River flowing pattern.

5. Mitigation Measure/Recommendation

From the results and discussion, the study has proven that the changing pattern and river shift had caused much destruction to its associated land use / land cover. The land availability has decreased and is continuously decreasing due to high rate of erosion and bank cutting. Furthermore many household have been removed and currently more household have seen to be removed or to be eroded. However, developments are also limited by presence of river network that do exist within the city, i.e., Busu, Markham and Bumbu River. These rivers have decreased and are decreasing the available land that could be preserved for development purpose. Furthermore every communities residing in Lae city weather in customary or government owned land, do in one way or the other contribute to build and maintain the economy of the city or country as a whole. To achieve the 2050 development goals, these are some of the implication that has to be solved or fixed. It is a must that the residing community and preserved available land or infrastructures are to be protected from river related issues. From the analysis, result and field visit, several mitigation ways or ideas were developed to be implemented to monitor the river system within the study region to protect and safeguard the communities, available land, food gardens and infrastructures like roads and bridges. The mitigation ways or measures identified and proposed are:

1. At LC1, construct the river embankment and or revetment (Brick wall/Iron steel wall) along the bank line beginning from cross-section ‘B’ all the way down to cross-section ‘G’.
2. At LC2 construct the river embankment and or revetment (Brick wall/Iron steel wall) along the bank line beginning from cross-section ‘B’ all the way down to cross-section ‘I’.
3. Scientific River training management, awareness generations in local people to save the food gardens or agricultural area near the river bank is required as well as to reduce the tendency of deforestation, imbibe sound agricultural practices in river bed etc.

These were the main solutions that were developed, which the researchers think and expect that these measures can help prevent the bank lines from eroding or down cutting, where communities, infrastructures and available land can be preserved and protected well. Furthermore the technique of creating walls can divert the river with its high velocity away from the city zone.

6. References

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