



ARTICLE

Morphologic Response of a River Channel to Sand Mining in River Tyaa, Kitui County, Kenya

Philip Gathogo Muiruri* Joy A. Obando Ishmail O. Mahiri

Department of Geography, Kenyatta University, Kenya, 43844, Nairobi

ARTICLE INFO

Article history

Received: 29 May 2020

Accepted: 22 June 2020

Published Online: 31 October 2020

Keywords:

Channel incision

Ephemeral stream

Morphologic response

Sand mining

Sustainable development

ABSTRACT

Over 40 billion tons of sand is mined worldwide every year which is estimated to be higher than the natural replacement rates. In Kenya, the rate of sand mining is raising concerns over its environmental effects since it is not regulated. This paper presents findings on the geomorphic effects of sand mining in the ephemeral River Tyaa channel in Kitui County. The study adopts the concept of feedback response mechanism of a natural geomorphic system. Through purposive sampling River Tyaa was selected for the study, where rampant sand mining was reportedly taking place. Random sampling on the five sand mining sites identified came up with a representative site namely Kanginga on which systematic sampling was applied while collecting data at both the active and control sites. Data on channel width, depth and slope angles was obtained through physical measurements while data on quantity of sand mined was obtained from Mwingi Sand Mining Cooperative. Multiple logistic regression analysis was used to analyse data whereby the model compared active and control sites. Test results indicated that sand mining had significantly increased river channel's width (O.R. =1.531), depth (O.R. =1.527) and slope angles (O.R. =1.634) at active mining sites compared to control sites as deduced from the respective Odds Ratios. It concluded that sand mining had altered channel's morphology resulting to adverse environmental effects such as loss of riparian vegetation and channel incision. It recommended curbing of illegal sand mining through licencing operators and reducing quantity of sand mined by closing some mines. Further, it recommended monitoring through regular Environmental Impact Assessment (E.I.A) and Audit (E.A) to inform protection of the river system from degrading.

1. Introduction

River sand mining is an activity that have been ongoing over centuries, with increasing frequency and intensity rising over time^[1]. The activity has been exacerbated by the rising need for grade sand in the rapidly growing construction industry across the world.

According to^[2], sand mining from river channels in the world at the moment is unsustainable as it is estimated to exceed the natural replacement rates. The current annual global sand consumption rate slightly exceed 40 billion tonnes^[2], which is estimated to be twice as much as the annual total amount of sand transported by rivers of the world as calculated by^[3]. In line with that,^[4] posits that

*Corresponding Author:

Philip Gathogo Muiruri,

Department of Geography, Kenyatta University, Kenya, 43844, Nairobi;

Email: philipogathogo@gmail.com

sand extraction rates from river channels exceeding the natural replenishment lead to adverse environmental effects. Sand mining, just like bank protection and damming of the river intercepts sediments flow in a river channel which creates a sediment deficit downstream^[5].

In some instances, instream sand mining may be important to some human activities such as river transport because it modifies the channel geometry to accommodate water vessels. Further, sand mining activities attracts income to the sand miners and transporters and also promotes the construction industry across the world^[6,7]. However, studies have indicated that sand mining often yield negative environmental effects, with extent dependent on the method of mining adopted as well as the intensity at which it is carried out^[8,9]. On ephemeral rivers, one of which is focused on in this study, two main methods may be applied namely dry-pit and bar skimming mining methods. Dry-pit mining method may result into environmental effects such as lowering of the alluvial water table, contamination of water impounded in the alluvial aquifer as well as alteration of river channel dimensions. On the other hand, bar skimming yields least negative environmental effects if done in a controlled way^[10].

The river channel morphology is a factor of its cumulative seasonal or annual discharge and amount and nature of load supplied from the drainage basin over time^[11]. Anthropogenic interventions such as sand mining in such natural and stable channels creates pits which tampers with the dynamic equilibrium of a river channel.^[4] explains that sand mining causes increased gradient of the channel on the upper side of the mine, which in turn induces channel incision on the upstream stretch. On the other hand, the in-channel pits created filters sediments from the channel flow thus releasing sediment deficient water (hungry water) which causes erosion leading to channel incision downstream.

In most countries in Africa, sand mining is taking place uncontrolled. For instance^[12,13] indicate that rampant sand mining is taking place in most river channels in Nigeria. More precisely,^[14] reported that unregulated sand mining in river Kano in Nigeria had resulted into modification of the river channel dimensions. In Botswana,^[15] documented widespread illegal sand mining thriving in most river channels resulting to negative environmental effects. Elsewhere in Kenya,^[16-19] unanimously point out that sand mining is proceeding in Kenyan rivers unregulated mainly to supply the rising sand demand in the rapidly growing construction industry.

As^[14] points out, sand mining results obtained in one site lack application in another due to variation in many local and regional factors, and this necessitated a local

study in River Tyaa. Additionally, need to achieve sustainable development dictates environmental friendly exploitation of natural resources at our disposal to ensure constant supply both for current and posterity needs as well as minimal disruption of the ecosystem. In line with that and in light of the rampant nature in which sand mining is taking place in Kenyan rivers, this study set out to establish the geomorphic effects of sand mining in River Tyaa in Kitui County. This was significant because it informed development of sound site-specific proactive rather than reactive sand mining strategies which captures the spirit of the Sustainable Development Goals (SDGs), particularly the one emphasizing need for sustainable production and consumption, hence prioritization of ecological conservation while exploiting natural resources^[20].

Conceptual Model of the Study

The conceptual model of this study is anchored on the feedback response mechanism of geomorphic systems. In a geomorphic system such as a river channel, various elements interact in a complex and interdependent manner. When a change is introduced in one element of a system, it may trigger either a positive or a negative feedback response. According to^[21], negative feedback occurs when the effect of the change introduced in a geomorphic system triggers a series of responses that cause it to progressively diminish thus sending the system back to a state of stable equilibrium. On the other hand, positive feedback occurs when a change introduced in a geomorphic system triggers responses that progressively magnify it leading to a great extent of instability in the system.

As illustrated in Figure 1, sand mining is the change that has been introduced to the stable natural system of ephemeral River Tyaa channel. If high rates of sand mining which exceed the natural replacement rate is carried out, a positive feedback occurs leading to increased width, depth and slope angles of the channel. As a result, the river channel will experience faster flows during the rainy season which will in turn cause more erosion in the channel thus making it even more unstable. More bank erosion will lead to loss of the riparian vegetation while channel bed erosion will lead to river incision, hence a degraded channel.

On the other hand, if sustainable rates of sand mining is exercised, negative feedback results whereby the channel dimensions of slope angles, width and depth will be sustained thus ensuring a self-regulating channel. Since sand is a crucial resource in the construction industry, there is need to harness it in a sustainable way to promote sustainable development. In order to ensure Stable River channels are sustained, there is need for intervention through policy formulation and implementation to control rampant

sand mining.

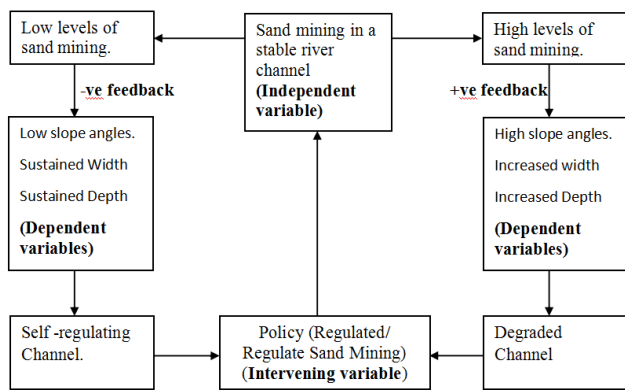


Figure 1. A Conceptual Model of River Channel's Response to Sand Mining

Source: Modified from Huggett (2007)

2. Methodology

2.1 Study Area

River Tyaa which is a tributary of River Tana and in which this study was carried out lies in Kitui County, Mwingi Sub-County, Kenya. Kitui County forms part of the Central Eastern Mozambique belt in Kenya [22]. As illustrated in Figure 2, its sub-catchment is bound by longitude 37°55'E and 38°05'E and latitude 01°05'S and 04°45'S. The area experiences hot and dry climate, with temperature ranging between 24-26°C and rainfall ranging between 400-800 mm per annum [23]. Owing to the little seasonal rainfall and the high temperature experienced in the area, most rivers are seasonal in nature, including River Tyaa.

Geologically the area is characterized by metamorphic rocks such as leucocratic gneisses, biotite gneisses and granulite's [24]. Over the years, these rocks have weathered through chemical and physical processes leading to development of a thick crust of loose highly drained sediments lying over the bedrock. The area's main economic activity is dry-land agriculture mainly goat rearing, fruit farming (Mangoes) and selected grain cultivation such as millet and sorghum. Following presence of limited economic options in the area, the poverty index is high averaging at 61% [25]. As a matter of necessity, the inhabitants have turned their focus on the natural resource available in the area to complement their low income. As a result, river sand mining activities have been established in the seasonal streams in Mwingi-Sub County, remarkably so in River Tyaa due to its ease of accessibility.

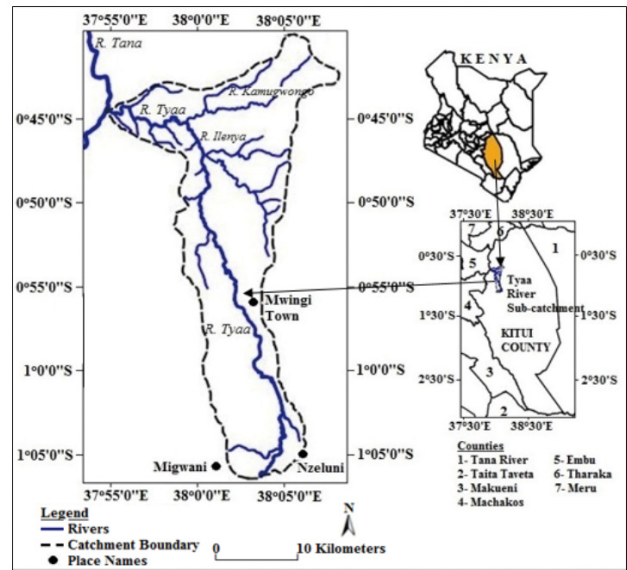


Figure 2. Study Area Showing River Tyaa in Kitui County, Kenya

Source: Cartographic Unit, Department of Geography, Kenyatta University, 2019

2.2 Sampling Design

The study adopted a multistage sampling technique whereby purposive sampling helped come-up with River Tyaa in which unregulated sand mining activities were reportedly taking place. From the five active sand mining sites identified along River Tyaa as illustrated in Figure 3, random sampling was used to come up with one representative site namely Kanginga which measured 500 meters.

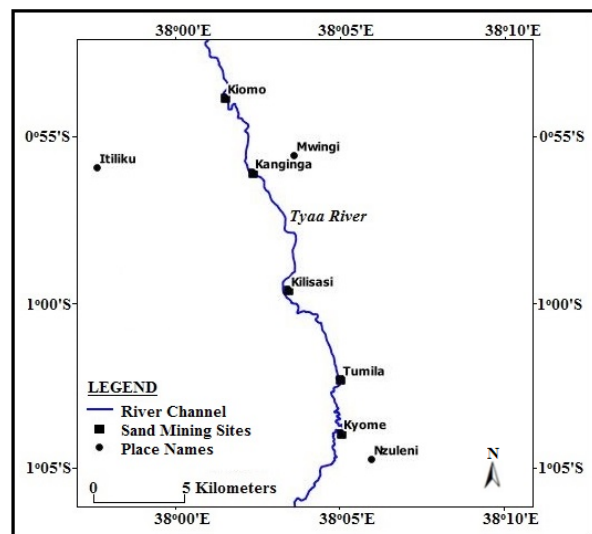


Figure 3. Active Sand Mining Sites along River Tyaa

Source: Author, (2019)

Systematic sampling was used to collect data on vari-

ables of interest at predetermined intervals of 10 meters on the active site and on the control sites as illustrated in Figure 4. The control sites comprise the upper and lower stretches of Kanginga site, each measuring 500 meters respectively. This enabled adequate coverage and a detailed study of the river channel and comparison of the active and control sites, a concept that was employed by [26] to determine the morphometric response of the river channel to sand mining.

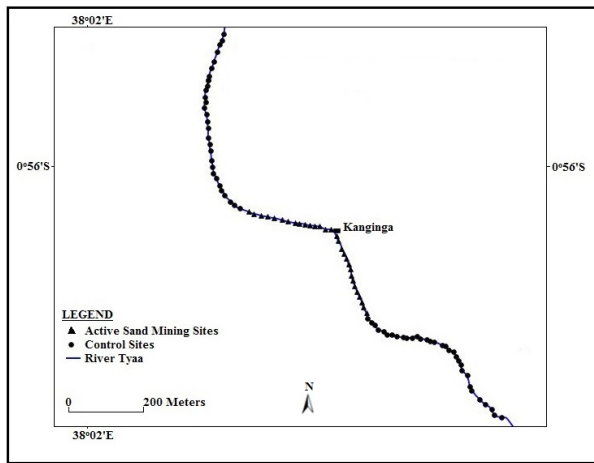


Figure 4. Active Sand Mining Site and the Control Sites

Source: Author, (2019)

2.3 Data Collection

Data collection involved both quantitative and qualitative methods which entailed undertaking physical measurements, a desktop survey and taking photographs. Data on variables namely the river channels depth and width was obtained through physical measurements by use of a G.P.S and a tape measure respectively while the channel bank slope angles were obtained by use of an Abney Level. Measurements were undertaken fortnightly just after the rains for a duration of two months. This enabled measurements to be taken when sand reserves have been replenished by the seasonal stream flow, and later monitor the alterations inflicted by mining at the said time intervals for the whole period of time. Data on the quantity of sand mined on the site fortnightly for a period of two months was obtained from Mwingi sand mining cooperative.

2.4 Data Analysis

The multiple logistic regression analysis was carried out to establish the geomorphic effects of sand mining to the River Tyaa channel. This technique categorizes subjects based on a set of predictor variables. See equation 1 showing the multiple logistic regression model.

$$Y = \frac{e^{[(\alpha^1 - (\beta_0 + \beta_1 X_1 + \dots + \beta_n X_n))]}{1 + e^{[(\alpha^1 - (\beta_0 + \beta_1 X_1 + \dots + \beta_n X_n))]} \tag{1}$$

In the equation, *Y* is the river morphology, *e* is the exponential value, α is the intercept value in the normal linear regression model, β_1 is the gradient for an independent variable X_1 while $\beta_n X_n$ represents the gradient values multiplied by the respective independent variables considered in this case, up to the last variable.

A data set with dependent variable namely the river morphology and the independent variables namely the altitudes, sand volume in tonnes leaving the site fortnightly for two months duration, the river channels depth and width, and channel slope angles was used. The data was imported into R-geostatistical software whereby it got divided into model training data (70%) and model testing data (30%) as guided by [27]. Training data was used to develop a Multiple Logistic Regression model as well as optimizing its accuracy, while the testing data was used to test the accuracy of the model. The model testing results indicated that the model was able to predict the categorical placements of the data with an accuracy of 87%. The results from the analysis clustered the effects of the independent variables of the river morphology into three categories denoted 1, 2 and 3 which implies normal, moderately modified and highly modified as well as their respective odds ratios.

3. Results and Discussions

The model compared data from the active sand mining site with that of the control sites. It gave out odds ratios which indicated the level of significance of each variable in influencing morphology of the River Tyaa channel. The results pointed out that sand mining had significantly affected the river channel's width, depth and slope angles. Table 1 shows the logistic regression outputs for individual variables as predicted by the model.

Table 1. The Multiple Logistic Regression Model Output

| Variables | Model Coefficients | Odds Ratio | Confidence Interval | |
|----------------------|--------------------|------------|---------------------|---------------|
| | | | 2.5 % | 97.5 % |
| Channel Width | 0.2078 | 1.531 | 0.012457e-05 | 1.235645e-02 |
| Channel Depth | 0.3556 | 1.527 | 0.0025456e-03 | 0.1255678e-02 |
| Channel Slope Angles | 0.4910 | 1.634 | 0.2651254e-06 | 0.2154579e-03 |

3.1 The Effect of Sand Mining on the Channel Width

Sand mining was established to cause increased width of

the river channel as inferred from the odds ratio obtained as seen in Table 1. As deduced from the odds ratio, a unit increase in sand mined led to an increase in odds ratio for increased width of the river channel by 53.1% compared to the control stretches of the river channel. The findings corroborated with those of ^[14,16] who unanimously determined that sand mining had caused statistically significant alteration of the river channel's width. In a study by ^[1] sand mining rates that exceed the natural replacement rates lead to instability of the river channel. In this case, undercutting of the river banks curtesy of sand mining has made the banks unstable causing them to collapse as illustrated in Plate 1. In turn, this has caused widening of the river channel hence loss of riparian vegetation which progressively lead to environmental degradation. Presence of these effects is a clear indicator that sand mining is taking place at high and unsustainable rates in River Tyaa.



Plate 1. Effects of Sand Mining on Channel Width

Source: Author, February (2019)

3.2 The Contribution of Sand Mining to the Channels Depth

The results indicate that sand mining had caused a statistically significant increase in channels depth as shown by the odds ratio in Table 1. Compared to the control sites, it is clear that a unit increase in sand mined at the active site led to 52.7% increase in odds ratio for increased depth of the channel compared to the control sites. Similar findings were arrived at by ^[28] who established that uncontrolled sand mining led to depletion of sand deposits on the river bed hence increased depth. Further, ^[14] remarked that alteration of river channels depth comes about where the sand mining rates exceed the natural replacement rates. As depicted in Plate 2, sand mining in River Tyaa has caused increase in depth of the channel, a factor that indicates that sand mining is taking place at a higher rate compared to the natural replacement. As explained by ^[29,9],

high rates of sand mining distorts the alluvial aquifer on the river beds and flood plains thus causing a downshift of the water table hydrologically connected to the river. The implication of this is drying up of the riparian vegetation which may no longer access underground water which in turn exposes the river banks to more erosion and instability leading to further distortion of the channel geometry.



Plate 2. Influence of Sand Mining on River Channel's Depth and Slope Angles

Source: Author, February (2019)

3.3 Influence of Sand Mining on the Channel's Slope Angles

The test results indicated that sand mining had contributed to increased channel slope angles as shown in table 1. This imply that a unit increase in sand mined led to 63.4 % increase in odds ratios of channel slope angles at the active site compared to the control sites. Following that, it is inferable that high rates of instream dry pit sand mining as practiced in River Tyaa may distort the stable equilibrium profile of the stream channel. ^[30, 31] argues that dry pit excavation creates a steep gradient on the river bed on the upper end of the pit, which increases the flow velocity thus exacerbating head ward erosion upstream. According to ^[5, 10], this results to channel incision which may extend upstream for several kilometres. On the other hand, pits left on the river bed traps sand from the stream flow thus releasing sediment deficient water downstream. ^[4] refers to such waters as hungry water which erodes the river bed to regain some load leading to river incision on the lower stretches of the active site of mining for several kilometres.

Channel incision leads to induced lowering of the stream channel hence establishment of a new base level which is consequently transferred to the tributaries of

the river in the drainage basin. The net effect of channel incision is lowering of the water table in the alluvial aquifers which is hydrologically connected to the river which consequently adversely affect the riparian vegetation and the river banks. As seen on Plate 2 and deduced from the Odds Ratio (1.634), it is clear that sand mining has caused an increase in channel slope angles and this may lead to channel incision on both upper and lower stretches of the active mining sites.

4. Conclusions and Recommendations

From the study findings, it is noted that sand mining has caused modification of river Tyaa channel morphology by increasing channel's width, depth and slope angles. Alteration of river channel width has resulted into loss of riparian vegetation which in turn result to more bank erosion leading to a degraded channel. An increase in the river channel's depth and slope angles may result into channel incision which lowers the alluvial water table which may adversely affect the riparian vegetation thus disrupting some ecosystems.

The study recommends that the regulatory environmental authorities such as NEMA and country government to regulate sand mining through licencing of the operators and implementation of existing regulations so as to help curb illegal/ rampant sand mining. Further, the said authorities should also regulate the quantity of sand mined from River Tyaa through closing some of the active sand mines, which should be informed by an Environmental Impact Assessment (E.I.A.) report on all the sites. Finally, the study recommends monitoring of sand mining through undertaking regular E.I.A. and Environmental Audit (EA) by NEMA so as to detect early signs of high rates of sand mining such as increased channel slope angles, width and depth in order to protect the river system from eventual degradation thus promoting sustainable exploitation of sand resource. Further studies are also required to enhance understanding of the effects of sand mining on the river channels, particularly in drylands.

References

- [1] Rinaldi, M., Wyżga, B., Surian, N. Sediment mining in alluvial channels: physical effects and management perspectives. *River Research and Applications*, 2005, 21(7): 805-828.
<https://doi.org/10.1002/trr.884>
- [2] United Nations Environment Programme (UNEP). Sand, Rarer Than One Thinks. 2014. Available online: http://www.unep.org/pdf/UNEP_GEAS_March_2014.pdf (accessed on 24 May 2016).
- [3] Milliman, D., Syvitski, M. Geomorphic/Tectonic Control of Sediment Discharge to the Ocean: The Importance of Small Mountainous Rivers. *J. Geol.*, 1992, 100(5): 525-544.
- [4] Kondolf, G.M. Hungry water: effects of dams and gravel mining on river channels. *Environmental Management*, 1997, 21(4): 533-551.
- [5] Kondolf, G.M., M.L. Swanson. Channel adjustments to reservoir construction and Instream gravel mining, Stony Creek, California. *Environmental Geology and Water Science*, 1993, 21: 256-269.
- [6] Rajesh, S., Anushiya, S. Report on state of Sand mining at Peri-Urban Kathmandu Case of Jhaukhel VDC.pdf. Nepal Engineering College, 2013.
- [7] Khan S., Sugie A. Sand Mining and Its Social Impacts on Local Society in Rural Bangladesh: A Case Study of a Village in Tangail District. *Journal of Urban and Regional Studies on Contemporary Issues*. The Center for Contemporary India Studies, Hiroshima University, 2015.
- [8] Collins, B., Dunne, T. Fluvial geomorphology and river gravel mining: a guide for planners, case studies included. California Division of Mines and Geology Special Publication 98, Sacramento, California.
- [9] Kondolf, G.M. Geomorphic and environmental effects of instream gravel mining. *Landscape and Urban Planning*, 1990, 28: 225-243.
- [10] Kondolf, G.M. Environmental effects of aggregate extraction from river channels and Floodplains. Rotterdam, 1998: 113-129.
- [11] Leopold, L.B., M.G. Wolman, J.P. Miller. *Fluvial Processes in Geomorphology*. Freeman, San Francisco, CA, 1964.
- [12] Akot T., Onoduku U., Oke S., Essien B., Idris F., Umar A., Ahmed A. Environmental Effects of Sand Mining and Grvel Mining on Land and Soil in Luku, Minna, Niger State, North Central Nigeria. *Journa of Geosciences and Geomatics*, 2014, 2(2): 42-49.
- [13] Atejiroye A.A. Odeyemi C.A. Analysing Impact of Sand Mining in Ekiti State, Nigeria using GIS for Sustainable Development. *World journal and of Research and Review (WJRR)*, ISSN: 2455-3956. 2018, 6(2): 26-31.
- [14] Nabegu, A. B. Morphologic Response of a Stream Channel to Extensive Sand Mining. *Research Journal of Environmental and Earth Sciences*, 2014, 6(2): 96-101.
- [15] Madyise, T. Case studies of environmental impacts of sand mining and gravel extraction for urban development in Gaborone, 2013. Retrieved from: <http://umkn-dsp01.unisa.ac.za/handle/10500/13896>

- [16] Muiruri P.G. Amimo M.O. Social-Environmental Effects of River Sand Mining: Case Study of Ephemeral River Kivou in Kitui County, Kenya. *International Organization of Scientific Research, Journal of Humanities and Social (IOSRJHSS)*, 2017, 22: 31-37.
- [17] Mwaura, S. K. The Effects of Sand Harvesting on Economic Growth in Kenya with case study of Machakos County. *International Journal of Social Sciences and Entrepreneurship*, 2013(5): 342-350.
- [18] Wambua M. P. Environmental and socio-economic impacts of sand Harvesting on the community in river Kivou catchment, Mwingi Sub-County, Kitui County, Kenya. Unpublished M.A. Thesis. Kenyatta University, 2015.
- [19] Mutisya, D. N. Sand harvesting and its environmental and socioeconomic Effects in arid and semi-arid Kenya. *P. World Assoc. Soil Water Conserve.* 2006, PI: 82-90
- [20] Huggett, R. J. *Fundamentals of Geomorphology* (2. ed). London: Routledge, 2007.
- [21] United Nations. Consensus Reached on New Sustainable Development Agenda to Be Adopted by the World Leaders in September. 2 august 2015 [online]. Available at: <http://www.un.org/sustainabledevelopment/blog/2015/08/transforming-our-world-document-adoption/> [accessed 20 may 2016].
- [22] Nyamai, C. M., Mathu, E. M., Opiyo-Akech. N., Wallbrecher. E. A Re-appraisal of the Geology, Geochemistry, Structures, and Tectonics of the Mozambique belt in Kenya, East of the Rift System. *African Journal of Science and Technology (AJST)*, 2003, 4: 51-71.
- [23] Nissen, P. *Rain catchment and water supply in rural Africa*. London: Hodder and Stoughton, 1982.
- [24] Pulfrey W. *Geological Survey Report of Kenya*, Nairobi, 1954.
- [25] GOK. Government of Kenya. *The 2009 Kenya National Census Results*. Ministry of Home Affairs, Nairobi, Kenya, 2010.
- [26] Brown, A.V., M.M. Lytte and K.B. Brown. Impacts of gravel mining on gravel bed streams. *T. Am. Fish. Soc.*, 1998, 127: 979-994.
- [27] Kim, A., Song, Y., Kim, M., Lee, K., Cheon, J.H. Logistic regression model training based on the approximate homomorphic encryption. *IACR Cryptology. ePrint archive*, 2018.
- [28] AMPONSAH-Dacosta, F., Mathada, H. Study of Sand Mining and Related Environmental Problems along the Nzhelele River in Limpopo Province of South Africa. *Journal of Mine Water and Circular Economy*, 2017.
- [29] Nabegu, A. B. The effect of sand mining on ground water in Kano river catchment *Journal of Environment and Earth Science*, 2013, 3(2): 2224-3216.
- [30] Surian N, Rinaldi M. Morphological response to river engineering and management in alluvial channels in Italy. *Geomorphology*, 2003, 50: 307-326.
- [31] Marston R. A, Bravard J-P, Green T. Impacts of reforestation and gravel mining on the Malnant River, Haute-Savoie, French Alps. *Geomorphology*, 2003, 55: 65-74.