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# Challenges Associated with Incomplete Assessment of Stream Ecosystem Health and Land use Interaction Studies in East and Southern Africa – A Review

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**ABSTRACT**

The review aimed at identifying the gaps left out in the studies on how landuse influences ecosystem health of adjacent rivers in East and Southern Africa. These gaps left have affected both interpretation of results and rendered the studies incomplete. The gaps of interest here were three including; sampling procedure, relationship between river size and land use size as well as limited full ecosystem health components consideration. In our discussion, we have highlighted what the researchers should have done to seal the gaps and complete the ecosystem health assessment. The works reviewed in this paper include 22 peer reviewed papers in various journals, 3 technical ecological reports and 6 academic theses. The time frame of the works reviewed range between 2001 – 2019. It was concluded that a standard protocol be set for all researchers about the elements that must constitute a complete ecological health study such that if an element is left out, the study is not recognized as a complete ecological study. Sampling procedure should follow the before, in and after a stressor or landuse.



## Introduction

Biomonitoring of river ecosystem health is important for sustainability of fresh water resources throughout the world. This is because increase in human population continues exerting pressure on land adjacent to rivers leading to degradation and loss of aquatic biodiversity as has been revealed by many studies (Van Butsel *et al*., 2017, Raburu *etal*., 2002, Ratemo *et al*.,2018).Most studies in east and southern African regions have tried to evaluate the effect of landuse on ecosystem health by considering various components of ecosystem health each one choosing what he wants to consider from limno-chemical, macroinvertebrate, fish, nutrients and habitat quality (Raburu *et al*., 2002, Ratemo et al,2018, Kasangaki *et al*., 2007,2008, Shivoga *et al*., 2001,2007). Considering the aims of researchers in each of the above cases, very few or no researcher has assessed at greater depth a complete ecosystem health. Whoever uses any of the above indicators leaves it incomplete but hurries to make conclusions based on their findings.

Hardly do you find any researcher who has arranged his sampling procedure in the order of 'before, in and after' each landuse of consideration to cater for ecological edge effects as opposed to core data. Ecological edge data helps to draw conclusions on whether the effect found in the landuse is actually generated from that landuse and not to have come from landuses before the one under study (Vallejo 2018). This means that studies about the influence of landuse on ecological health of a river should target a landuse identified such as urban, agriculture or forest, study the ecological health conditions of the river before it enters the landuse, as it is inside the land use and as it leaves the landuse such that the difference between before and after compared to inside gives a pattern of effect of a particular landuse on health of river ecosystem.

In the set of the literature reviewed in this paper, some researchers did not even consider landuses (matshakeni, 2016, Ollis, 2005) while those who considered landuses did not indicate the size of the landuse and the size of the rivers affected by these landuses (wolmarans *et al*.,,2014 *et al*., Shivoga *et al*.,2007). It is important to compare landuse size (can be obtained using G.I.S technology) with the size of the river (as can be indicated by river order, discharge or indicators of discharge like width, depth and velocity) (Shivoga, *et al*., 2001). This is because anthropogenic effects on river ecosystem health are not an abrupt phenomenon, it is a collection of contributions from different river orders and different landuses affect ecosystem health of different river sizes or orders differently. For example, if the same magnitude of a landuse on a 5$^{th}$ order river is exerted on a 1$^{st}$ order river, this first order can become an effluent while if the effects of a 1$^{st}$ order is exerted on a 5$^{th}$ order, the impact may not be felt. So the size of the river and the size or magnitude of the landuse matter a lot as far as ecological health is concerned.

This paper reviewed literature on research carried out in east and southern African regions about effect of land use on ecosystem health of rivers pointing out gaps that have not been filled mainly on three aspects that matter for a complete

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ecosystem health of rivers and streams ie, i) full ecosystem health components including; living organisms like macro invertebrates or fish, Physico-chemical water quality parameters, nutrients, fecal coliforms, physical habitat quality, ii) sampling procedure should follow the order of before, in and after each landuse and iii) relationship between landuse size and size of the river (river order, discharge or indicators of discharge like width, depth and velocity).

We discussed possible ways of how these gaps could have been closed and how these gaps affected results obtained by respective authors and finally we suggested what the next researchers should avoid and what they should do to make their ecological studies complete and comprehensive.

**Discussion**

While assessing the influence of land use/land cover on aquatic health of the upper and middle reaches of River Njoro in Kenya, Shivoga *et al*., (2007) considered nutrients of carbon, phosphates and nitrogen. The study labored to compare the proportion of landuse impacting on water quality of the river which gives an explanation of magnitude of effects. It is the only study that has measured size of landuse under study which when compared with the size of the river under study gives a clear picture of the impact. This study however left out the size of the river that was affected which influences concentration of these nutrients. The discharge indicated in here is the historical annual one for the whole river not specific tributaries covered as had been done earlier by Shivoga *et al*.,(2001) on R. Baharini and Njoro.

Although Shivoga *et al*.,(2007) indicates that nutrients were found increasing in mid stream but decreasing downstream which is possible due to natural filtration by substrates, there was need to measure the concentration of these nutrients before the water entered a particular landuse under study. This is because the concentration of these nutrients from landuse before the one under study could have been more or less than the concentration from the landuse under study and so all this effect was attributed to the landuse understudy. This result therefore remained omnibus and not specific to the landuse sampled. The mixture of small scale agriculture needed to be described since different crops contribute different amount and type of nutrients to runoff.

Shivoga *et al*., (2001) sampled water quality following the ideal guideline of before, in and after landuse which gives a better picture of the pattern of pollution. He compared the influence of hydrology on macroinvertebrate structure on two rivers of Njoro (intermittent) and baharin Springbrook(perennial). While it is possible that the rapid colonisation of macroinvertebrates of the intermittent Njoro could have come from upstream perennial parts, it was important to assess and quantify the habitat quality before, during and after wet season since this habitat quality changes with change in season to influence change in macroinvertebrate assemblages.

The recovery of macroinvertebrates after 27 days of bigger spates could have come as a result of a change in physical habitat like stone out of current getting into stone in current which could have improved the habitat quality and not only hydrology as stated. In addition, since some macroinvertebrates live both in water and land with associated land cover, runoff from these riparian vegetation could have drifted them back to study sites and they found stone out of current had become stone in current. This means that before a conclusion was made about the source of macroinvertebrate during heavy spates, there was need to assess physical habitat quality.

As Danha *et al*., (2014)was investigating potential impact of washbay on water quality on R. Nyahode of Zimbabwe, he only measured Physico-chemical water quality parameters of which when compared with WHO (2008) were below standards, a finding that is crystal clear because washbay effluent discharged in the river would not leave its quality the same. This result is omnibus in that the researcher did not include ecological edge data. The sampling needed to cater for before, in and after the washbay because the accumulation of these Physico-chemical parameters could have come from land uses earlier than the washbay since washbay is not the only cause of change in water quality neither was it the only landuse in the area.

The size of the river against which we would compare the size of washbay to draw a clear picture about the intensity of the effect was ignored yet these influence the concentration of the parameters being studied. The limno-chemical parameters used are highly dynamic (just a 'snap shot'), since the aim of monitoring R. Nyahode water quality was ecological monitoring, this study should have considered living organisms too like macroinvertebrates or fish since they have been proven to be the most reliable and usefull indicators of freshwater ecosystem health because they i)respond very rapidly to pollution, ii)are abundant and easy to collect, iii) represent local conditions due to their sedentary behavior and iv) have a long life span which provides an integrated record of water quality.

Niels *et al*., (2016) unlike Danha *et al*., (2014) assessed the impact of landuse on water quality of two rivers of Awetu bisecting Jimma city and Kito that flows west of the same city in Ethiopia using macroinvertebrates, Physico-chemical and nutrients parameters. Niels sampled ecological edge effect of before and after each landuse to ensure specificity of the effect of a given landuse on ecosystem of the two rivers but left out the inside of landuse which would have given apattern of effect by a particular landuse. This is however not as omnibus as Danha *et al's*., (2014). He also lacked approximation of size of land use while the size of the affected river was inadequately indicated by only velocity.

In this study, Niels *et al*., (2016) considered macroinvetebrates ETHbios, ASPT and Physico-chemical to assess the quality of ecological health which was not complete without physical habitat consideration where these macroinvertebrates live. This is because, even if limno chemical parameters are good but with poor physical habitat quality, macroinvertebrate have no residence. So to complete this ecological health assessment, there was need to measure physical habitat. For example, from figure1 and photos in the study, site 3 seems to have poor physical habitat, so poverty in ecological health might have not been necessarily due to agro-pastoralism practiced there, but habitat quality. Even if the landuse is good but with poor physical habitat you get low scores of macroinvertebrates and vice-versa.

Van Butsel *et al*., (2017) is the only research we found to have assessed ecological state of R.mpanga in western Uganda using all parameters of ecological health quality including macroinvertebrates, Physico-chemical and habitat quality, but he forgot to consider ecological edge effect. Like Danha *et al*., (2014) and Shivoga *et al*., (2007), these results remained omnibus. In this study the size of the landuse (stressor) was not considered but at least this unlike many researches considered the size of the river affected as represented by measurements of velocity, depth and width that indicate discharge.

The most important Physico-chemical parameters were studied in relation to aquatic life but when he stated that chemical and biological water quality are lowered by certain pressures like waste disposal yet in Fort portal town people abstract water for domestic use, we realized that the measure of fecal coliforms that was ignored by the researcher needed to have been measured.

To evaluate ecosystem health of R. Olifants in south Africa, Wolmarans *et al*.,(2014) did not only base on Physico-chemical parameters but also based on macroinvertebrates on selected sites by adopting South African Scoring System and Average Score Per Taxon to conclude that the water of the river was in a poor state. This was a confirmation of earlier studies about south African rivers. The dominant families found (chironomidae, baetidae, caenogrinidae etc) were indicators of very poor ecosystem health which must have come from undesired land uses that needs regulation or monitoring, but unfortunately, no landuse here was quoted/ implicated to be involved. The effects are omnibus. The size of the river or its indicators was ignored.

Also, only three physico-chemical parameters (pH, conductivity and Temperature) considered were insufficient. More important ones as far as macro invertebrates' wellbeing are concerned for this study such as DO, BOD, Turbidity and nutrients were ignored and the few parameters that were considered did not even take the sampling procedure of before, in and after. Because macroinvertebrates were involved in this study, physical habitat quality should have been assessed as this also determines macroinvertebrate assemblages in rivers. In short, explanation for distribution of macroinvertebrates remained wanting.

While assessing Physico-chemical parameters in relation to fish ecology in the lower parts of R. Ishasha (a boarder river between Uganda and DRC), Mbalassa *et al*., (2014) found that water was well oxygenated and alkaline upstream favorable for fish survival. Because this is a general theoretical statement by Marshall (1998), Mbalassa should have gone ahead to catch fish in this zone, but no attempt to catch fish was made. Since the interest of this research was to study fish ecology, fish habitat quality should have been scored and classified to be sure whether fish can live in this habitat or not. The Physico-chemical parameters should have been studied along with the nutrients like phosphorous and nitrates since these nutrients influence growth of planktons for fish to feed, but no single nutrient was studied. In the downstream where TDS and EC remained high due to agriculture and deforestation impact, there was need to measure or estimate the size of these landuses viz-avis the size of the streams affected which would have given a clear picture of the impact.

Raburu *et al*., (2002) considered the water quality above and below coffee, tea and sugarcane plantations which is a good consideration of ecological edge effect that specifies effect of landuse on ecological health, but he forgot to sample inside these landuses where the effect might have been at its peak. Although he indicated that in R. Nyando water quality values in sugarcane zone were higher than out of the landuse while below muhoroni in agro-chemical the quality was poor, he need to estimate the size of each landuse of interest crossed by the river which should have been compared with the size of the river or its indicators. Also unique to this researcher is, the study compared Physico-chemical parameters with Index of Biotic Integrity and Nyando Habitat Evaluation Index which somehow brought out a rough picture of the ecosystem integrity.

Much as Matshakeni (2016) found out that nitrate concentrations in R. Erste of South Africa were ranging between 0-9mg/l hence below South African standards, no landuse in this study was implicated to be the cause of this situation.

Having noted that Physico-chemical parameters in R. Msimbazi catchment was higher at Vinguguti hence below permissible levels by the Tanzanian Bureau Of Standards (TBOs) and World Health Organisation (2008), Mwenda (2014) should have gone ahead to estimate the areal coverage of the different industries studied and river sizes affected. This together with the ecological edge effect data that he obtained would clearly show the contribution of each industry under study for easy regulation and monitoring.

Ratemo *et al.*, (2018) indicated that pollution in R. Athi decreases as the river flows down stream of industries. Unlike Raburu *et al*., (2002), Ratemo sampled inside and on edges of the industries thereby making a complete sampling procedure of before, in and after landuse. Ratemo too did not estimate the size of the industries and river tributaries under study.

This review found M'Erimba *et al*., (2014) as one of the very few researchers in east Africa that has tried to measure a complete ecosystem health elements. This is because he assessed habitat quality where R.Naromoru in Aberdare catchment was classed under class B, aspects of size of river like discharge, depth, width and length were considered, and macroinvertebrate (South African score system and Average Score Per Taxon) which are reliable and Physico-chemical parameters were measured. The only loophole in this study was no land use was implicated and there was lack of ecological edge effect that rendered the results remain omnibus.

The study of mucheke and Shagashe rivers in Masvingo town of Zimbabwe using macroinvertebrates and Physico-chemical by Chikodzi *et al*., (2017) considered ecological edge data to specify the urban effects on ecosystem health but this would have been made better if inside of the town was sampled where concentration of pollution may be at its maximum. This would give a pattern of pollution on the river hence aid monitoring.

Although water quality at mucheke before the city basing on SASS indicated moderate pollution and Physico-chemical parameters are in acceptable limits of WHO(2008), the direct negative opposite of the same after the city indicate the need to measure the size of the city that causes this alarming pollution and the size of this river should have been estimated. Also since macroinvertebrates were involved, their physical habitat quality needed to be measured since these change with change in habitat quality.

Because Ollies (2005) bio assessed ecological integrity of three rivers using macroinvertebrates, like many east African researchers, Olliies used Physico-chemical, macroinvertebrates, habitat quality but forgot ecological edge effect sampling. He also needed to estimate the size of the river and landuse studied. The recommendation of this study that other researchers should emphasize assessment of habitat using Integrated Habitat Assessment Scores (SASS) alongside Average Score Per Taxon does not differ from what Dallas *et al*.,(1997, 2004) stated that there is a positive relationship between SASS scores and Integrated Habitat

Assessment Score totals where higher total SASS scores encourage macroinvertebrate habitation.

It is important to note that much as Dallas *et al*.,(2000 and 2002) noted that higher IHAS totals would mean higher SASS scores hence better quality, Nieman *et al*., (2013) later found that sensitive species were associated with lower IHAS scores in the Pullenshope town of south Africa. This results re-affirms the need for implementation of Ollies' (2005) recommendation of having more than one parameter of ecosystem health measurement. In this study by Nieman *et al*., (2013), habitat quality was well covered, Physico-chemical and macroinvertebrate but the urban ecological edge data was ignored as well as size of the river and town itself. The overflowing dam at KFBMZ site where Physico-chemical water quality was measured indicates that water is abstracted for domestic use in this town, so fecal coliforms should have been determined but this study ignored it.

Odume (2011) applied macroinvertebrates to monitor anthropogenic impacts on the Swartkops River in South Africa but considered no specific landuse yet contributions come from individual landuses. The study successfully sampled macroinvertebrates, habitat quality and Physico-chemical parameters but ecological edge data was ignored. The three replicates he did here should have covered ecological edge data too to avoid omnibus assessment. The study also never estimated the river size and landuse size.

Sanja *et al.*, (2014) is one of the South African researchers who almost completed the whole ecosystem health assessment elements. He used Physico-chemical parameters, macroinvertebrates and fish, assessed habitat quality and vegetation integrity and river size was measured only that, he collected only ecological edge data and left out the inside landuse data but at least here the data is not omnibus. Whereas the fish habitat was assessed using Index of Habitat Integrity Assessment (IHIA) and concluded that the ecosystem had been severely modified, no fish was caught (fishing was not done) yet habitat may not be adequate but you find resilient/tolerant fish species.

In Uganda, Kasangaki *et al*., (2007) was thorough on sampling of both ecological edge data and inside forest using limno-chemical parameters and fish where he found that the majority of the fish (Amphilius Jacksonii) were insectivorous followed by herbivorous clarias in the Bwindi impenetrable forest. This study however needed to examine the complete fish habitat quality which would aid the interpretation of fish scores as suggested by chutter (1998,1994,Dallas 1997,Mcmillan1998 and Dickens and Graham 2002) who recommended that habitat should be undertaken together with all bio-assessments. The size of the forest and rivers studied need estimation of their sizes which was not done.

Muyodi *et al*.,(2011) did better than Mbalassa *et al*.,(2014) and Sanja *et al*., (2014) when he did not only measure Physico-chemical visa-avis fish but went ahead to catch fish using gillnets to study ecological health of R. Kisat and Yala catchment as one of L. Victoria catchments. He used ecological edge data and core (inside landuse) data of wetlands at these river mouths. Physical habitat of fish was not measured hence ignoring the recommendation by Fryer (19730 and Greenwood (1966), Kleynhans(1999). River size and wet land sizes were not estimated. Since fish were caught, a fish - based integrity of biotic index would have been calculated to quantify ecological integrity of sites chosen.

Like Sanja *et al*.,(2014), Mulders (2015) considered ecological edge data of landuse effects on ecological health (Physico-chemical, macroinvertebrates). Macroinvertebrate sampling needed to be followed by physical habitat assessment for better interpretation,ie, there was need for a complete habitat quality assessment. The study was also silent about the river size and landuse size estimations.

Whereas Isabel *et al.*, (2015) indicated that they sampled medium sized rivers in Lungwa National Park of Zambia, she only sampled inside landuse, leaving out ecological edge effect. Also a complete habitat quality would have been assessed since macroinvertebrates depend on habitat quality and availability. Two national parks were considered here and their respective sizes alongside their effects would have made interpretations easier but was ignored leaving the study incomplete.

Although they did not consider landuses that influenced macroinvertebrate assemblage and their respective river sizes, Molefi (2004) gives a complete sampling procedure of before, in and after landuse. South African Scoring System that was used would have best been completed with Invertebrate Habitat Assessment System as recommended by Dallas *et al*., (2002) and Mcmillan (1998) and used by Nieman *et al*.,(2013).

The conclusion by Dobson Michael *et al*., (2007) that the relationship between habitat and average body size of crabs suggests that crabs are more productive in forest habitats required that a complete physical habitat should have been assessed and quantified in this study but was ignored. He indicates the size of the rivers considered were only 5m wide and above, but crabs can inhabit any size of the river as long as water quality and physical habitat permit, so he should not have restricted to only above 5m width but even less as long as he measured the habitat quality.

During the assessment of pollution impacts on ecological integrity of Kisat and Kisian rivers of Kenya, Kobingi *et al*., (2009) did well the sampling procedure when he sampled 0.5km before town in minimum human activity, inside the slum at Obunga where domestic effluents and other wastes were deposited and after the industrial and municipal waste discharges. This however was not followed on Kisian where he sampled inside forest, inside agriculture and after swamp yet his aim was agriculture so he should have sample before, in and after agriculture. Because he employed BioMonitoringWorkingParty (BMWP) for macroinvertebrate assessment, he needed to accompany this with physical habitat assessment because a poor habitat is not expected to have rich and diverse macroinvertebrates even if the landuse is harmless. Also the magnitude of landuse effects depends on the size of the landuse and the affected river size all of which were ignored in this study.

Consideration of forest and forest edge before river enters agriculture by Kasangaki *et al*., (2008) is an indicator that the sampling followed the procedure of before, in and after landuse, but the size of agricultural land and forest sampled were not estimated. Because macroinvertebrates were considered here on pristine (usually small sized) rivers, there was need for assessment of physical habitat for macroinvetebrates.

A study on the influence of landuse on nutrient regime of R. Isiukhu, Kakamega by Onyando *et al*., (2013) obtained results that were omnibus (not particular to a landuse). The sample selection procedures needed to follow the before, in and after a landuse to be sure that the effects were particular to a specific landuse. The size of the agriculture, urban, forest and sugarcane plantation as well as river size needed estimation because concentration of nutrients is affected by discharge, all of which were ignored. This weakness however does not overshadow the right fact that the study found out that the type of landuse cover influences nutrient concentrations in a water body.

Raburu *et al*., (2009) is one of the researchers who satisfied ecosystem health assessment elements of R.Nyando. He studied Physico-chemical parameters, assessed habitat quality and macroinvertebrates were sampled, river size (orders from 1,2,3 and 4) was estimated. It is his sampling procedure that left out ecological edge data and he never quantified the size of the landuses considered.

Like many east African researchers, Elias *et al*., (2014) in his study of fresh water macroinvertebrates in Tanzania's pangani River basin did not consider any landuse, neither did he exhaust physical habitat assessment although he obtained 12,527 macroinvertebrates in 48 families. The sampling procedure was only inside landuse hence ecological edge data was ignored.

Gichaba *et al*., (2015) studied effects of human activities on macroinvertebrates and water quality of Nyangores River but the size of the river and landuse were not estimated. Although Canonical Corespondence Analysis showed a relationship between macroinvertebrates and Physico-chemical variables, no ecological edge data was obtained and the physical habitat quality in totality was not measured. This same approach was adopted by Tumwesigye *et al*., (2001) only that Tumwesigye indicated discharge (indicator of size) of the river.

While assessing ecosystem integrity and macro invertebrate community structure in the small streams in Tanzania, ojija *et al*., (2017) used BMWP and ASPT to determine the ecological health of R. Nzovwe in Mbeya, which only needed to be accompanied by habitat quality assessment. No landuse was implicated here to be responsible for the moderate water quality found by the study. Ecological edge data and river size were ignored. Worst of all, no single physical-chemical was measured yet measurement of Physico-chemical parameters is primary in ecological studies. This study is therefore the first of its kind to assess ecological integrity without considering any Physico- chemical parameter and therefore incomplete.

**Conclusions**

The review paper came up with some conclusions which also serve as recommendations and they include the following;

- A standard protocol should be set for a research about elements that must constitute a complete ecological integrity study without which any element missing renders the study rejected as an incomplete study otherwise everybody will keep picking what he wants and rashes to produce conclusions on basis of incomplete information.
- Ecological studies should cover enough time (more than once or more than one climatic season) of sampling since environmental parameters change over time or seasonally.
- Studies that aim at only Physico-chemical parameters should exhaust all or at least a minimum of ten parameters including fecal coliforms, and nutrients since they are just 'snap shots'.
- Studies involving macroinvertebrates or and fish should also accompany this with both Physico-chemical and physical habitat quality assessment.
- Landuse size and size of stream being studied should be estimated or can be calculated based on G.I.S technology. Sampling procedure should follow the before, in and after landuse being studied.
- All studies should be targeting a specific landuse predicted to be impacting on the ecosystem health. No study should be left omnibus without a landuse/cover targeted for assessment.

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